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NON-METALLIC TOOLING FOR HIGH TEMPERATURE APPLICATIONS

G.E. CONNELL
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MANUFACTURING RESEARCH
LOCKHEED AIRCRAFT CORPORATION
GEORGIA DIVISION
CONTRACT AF33(600)36888
AMC PROJECT 7-669

FINAL TECHNICAL ENGINEERING REPORT
5 JUNE 1958 - 31 DECEMBER 1960

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Commercial castable refractory ceramics can be economically fabricated into tools for hydroform blocks, draw dies, braze and heat treatment fixtures, stress relief fixtures, and stretch form dies that will withstand operating temperatures in the 1500° -2000° F range for use in the fabrication of the newer high-temperature alloys.

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AMC AERONAUTICAL SYSTEMS CENTER
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

"Barry R. Emrich"

ABSTRACT - SUMMARY
Final Technical Engineering Report

AMC TECHNICAL REPORT 61-7-669
March 1961

NON-METALLIC TOOLING FOR HIGH TEMPERATURE APPLICATIONS

G. E. Connell
et al
Lockheed Aircraft Corporation

Commercial castable refractory ceramics can now be economically fabricated into tools for hydroform blocks, draw dies, braze and heat treatment fixtures, stress relief fixtures, and stretchform dies that will withstand operating temperatures in the 1500°- 2000°F range for use in fabrication of the newer high-temperature alloys.

Many of the newer high strength - high temperature alloys require hot forming and thermal treatment tooling capable of operation at temperatures up to 2000°F, above the usefullness of plastics, kirksite, lead, etc. While hard metallic tooling such as meehanite and high nickel alloys which require machining to final dimensions, might suffice, it was felt that cast to dimension ceramic tooling would be more economical.

A world wide search for potential formulations was made, resulting in the evaluation of 153 ceramic compositions. Of these, 9 have been found satisfactory for the high temperature tooling applications.

Laboratory and production size tooling have been proven for up to 2000°F hydroforming and stretchforming, stress relieving, heat treating, and brazing.

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United States Air Force
Wright-Patterson Air Force Base, Ohio

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This Final Technical Engineering Report covers all work performed under Contract AF33(600)-36888 from 5 June 1958 to 31 December 1960. The manuscript was released by the Contractor 30 December 1960 for publication as an AMC Technical Report.

This contract with Manufacturing Research, Georgia Division of Lockheed Aircraft Corporation was initiated under AMC Manufacturing Methods Project 7-669, "Non-Metallic Tooling for High Temperature Applications". It was administered under the direction of Mr. Bert E. Price, Jr., of the Fabrication and Components Branch (LMBMF), Manufacturing and Materials Technology Division (LMBM), AMC Aeronautical Systems Center, Wright-Patterson Air Force Base, Ohio.

Mr. G. E. Connell was the Unit Engineer in charge. Others who cooperated in the research and in the preparation of the report were:

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Mr. R. B. Cantley, Supervisor
Mr. J. L. Peters, Asst. Unit Engineer
Mr. W. K. Fossett, Metallurgist and Editor

This report has the Lockheed designation GMRI: 434.00.

The Contractor wishes to express his appreciation to the ceramic industry, to the colleges and universities and to the aircraft and missile industry for furnishing raw materials and technical information and assistance. The Contractor wants especially to acknowledge its indebtedness to the Battelle Memorial Institute and to the Georgia Institute of Technology.

The primary objective of the Air Force Manufacturing Methods Program is to increase producibility, and improve the quality and efficiency of fabrication of aircraft, missiles, and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing costs and giving "MORE AIR FORCE PER DOLLAR".

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

****

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK R. MARSH
Deputy Chief
Manufacturing and Materials
Technology Division

LOCKHEED AIRCRAFT CORPORATION
GEORGIA DIVISION
MANUFACTURING RESEARCH DEPARTMENT

REPORT NO. 7 (FINAL REPORT)

(GMRI 434.00)

NON-METALLIC TOOLING
FOR
HIGH TEMPERATURE APPLICATIONS

CONTRACT NO. AF 33(600)36888

PHASE I-VI

March 1961

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GENERAL INTRODUCTION

BACKGROUND

This report covers work which had its inception in October, 1957, when the Contractor responded to a request[1]* for proposal from the Production Planning and Materials Section, Research and Development Branch, Specialized Procurement Division, Air Materiel Command of the United States Air Force. The RFP asked for a proposal:

> "Covering the procurement of investigation and evaluation of available high-temperature, high-strength ceramic formulate and techniques as a background for developing and designing various types of ceramic tooling for use in fabrication of the newer high-temperature alloys, in accordance with Exhibit "A" attached hereto. Such tooling will withstand operating temperatures in the 600°F - 1500°F range."

The Exhibit "A" mentioned above has as its objective:

> "To develop low temperature curing castable refractories and/or ceramics for use as tooling for the fabrication of the newer high-temperature alloys. The applications under consideration are those wherein the greater portion of the stresses imposed are compressive. The types of tooling investigated and developed should include, but not be limited to, hydroform blocks, draw dies, braze fixtures, stress relief fixtures and stretchform blocks (dies)."

The Contractor's reply to the RFP, a proposal[2] ("Development of Non-Metallic Tooling for High Temperature Applications"), resulted in the award of Contract No. AF 33(600)36888 on May 5, 1958. The Work Statement of the contract is Exhibit 1 of this report.

The Contract Work Statement calls for the conduct of this investigation in six phases:

I - Background Investigation
II - Materials Development
III - Tooling and Reinforcement Development
IV - Tooling Evaluation
V - Standardization of Tool Design
VI - Final Report

Table 1 gives the time span for the accomplishment of this investigation, for which this report is the Final Report, Phase VI, of the Work Statement.

*Note: The numerical superscripts refer to references given in the Reference Section, Page 473.

EXPLANATION

In general, the reporting is done chronologically, step-by-step, through the first five phases. However, as the Contractor continually reviewed his data, in view of subsequent findings, he sometimes found occasion to retest. The results of the retesting were frequently "brought back" and reported along with the analogous initial data. As a matter of interest, the retesting was still being done during the December completion of Phase V.

The nine bar graphs, Figures 77 thru 85, which reduce the basic evaluation data of Table 15 to more useable form, reflect test data gathered during the last month of the investigation, although the bulk of the work was done prior to July, 1959.

A note of explanation about the coding used to identify the hundreds of specimens shown in Figure 1, Page 13, and mentioned throughout the report is given for the reader's benefit. A typical code number is:

3.1.5A.1-6

Where "3.1." is a prefix tying ceramic tooling into the Contractor's filing system. This prefix was dropped during the investigation.

"5" is representative of any number and indicates a particular supplier of refractory ceramic castables.

"A" is representative of any letter and indicates a particular product of the supplier whose code number precedes it.

"1" is any number and indicates a division of a company supplying products. (Actually this designation was employed on only one occasion - to differentiate among the divisions of The Carborundum Company.)

"-6" is representative of any number and indicates a specific specimen.

For simplicity's sake code numbers have, at times, been abbreviated to "5A" instead of "3.1.5A.1" or "5A.1". The code key is presented as Table 45, Page 10.

SUMMARY

The Contractor decided early to evaluate the castable refractories for three main purposes.

1. Unfired tools used at room temperature (with resistance heating)
2. Fired tools used at room temperature (with resistance heating)
3. Fired tools used at temperatures up to 2000 F

In performing the evaluation, first consideration was given to the following measureable properties:

1. Modulus of rupture, room temperature and 2000 F
2. Drying or firing size change
3. Surface finish

A linear measurement method was devised for depicting the worth of a promising material, giving thought to strength (modulus of rupture) from which penalties were made for surface finish and drying or firing size change.

Perhaps one of the greatest contributions of this report is the series of three tables (16, 17, and 18 on Pages 135, 138 and 141) and nine bar graphs (Figures 77 thru 85 on Pages 188 thru 196) which reduce the evaluation data from 114 commercial refractory ceramic castables to conveniently usable form. Depending upon the anticipated use of a tool, a material (or choice of several) may be readily found from the appropriate bar graph. These graphs rank the better materials in regard to:

1. Surface finish
2. Drying size change
3. Firing size change
4. Unfired strength
5. Fired strength at room temperature
6. Fired strength at 2000 F
7. Composite of unfired strength, drying size change and surface finish
8. Composite of fired strength at room temperature, firing size change and surface finish
9. Composite of fired strength at 2000 F, firing size change and surface finish

For hydraulic setting castables, this initial evaluation resulted in the closer definition of two variables of placement - vibration and amount of added water. Phase II reports the preliminary effort to standardize the vague word "vibrate" found in so many instruction sheets. Phase II also describes the care with which experimentation was done to arrive at the minimum amount of accurately measured water required for placement of the hydraulic setting type.

These two variables, when subject to close control, enable the placement of castings with higher density, strength and better surface finish. This situation is more apparent from the data of Tables 16, 17 and 18, which in many cases show the modulus determined in this investigation to be greater than that reported by the supplier.

The determination of the hot modulus of rupture provides an almost unique contribution to the literature of castable refractories as very few suppliers had such information on their products.

An investigation, reported in Phase III, was made to determine the feasibility of reinforcing castable refractories and the effect of weathering on them. Two reinforcements, expanded mild steel and Kovar rods, are useful, but their benefit in a fired castable is a function of the coefficient of thermal expansion of the castable. Although the weathering tests were not exhaustive, it does not appear advisable to store ceramic tooling outdoors in cold, wet weather.

Phase III also reports the results of a thermal shock test of several materials of low coefficient of thermal expansion. The fused silica material, Code 25A.1, is shown to be uniquely superior in this regard.

The transition between standard brick test specimens and production size tools was bridged with laboratory size tools. For these, nine materials from among the leading contenders of Tables 16, 17 and 18 were used.

Production size tools, some of which weigh nearly a ton, have been made in both solid and cap types. These tools represent hydroform blocks, stretchform blocks, heat treat draw (temper) fixtures, heat treat fixtures and draw dies. All tools have performed satisfactorily except the draw dies which require a continued investigation.

During the time of the "state of the art" survey, the ceramics industry frequently gave the impression that castable refractories were impractical for making large tools. Several reasons were given: drying, with its attendant long-time and elaborate humidity control and firing difficulty were the primary reasons. Others were anticipated placement difficulties, rough surface finish, low strength and low thermal shock resistance.

This investigation has dispensed with some of these fears. It has not been necessary to pack the tools in wet sawdust for a month at a time prior to being put in an oven for similar time periods. By using plastic films and wet burlap wraps, to retard too-fast initial evaporation, together with 150 F and/or 220 F ovens the entire drying cycle, prior to firing, has been reduced to about three weeks.

Placement has not proved to be a problem with the vibration cast materials: it has, however, with the ram cast materials. (This is described in Phase IV.) Placement problems with the production size tools have been minimized by using the knowledge and the skill of the placement art acquired during the initial investigation making standard size brick specimens.

This investigation has proven commercial refractory ceramic castables to be -

- practical,
- economical
- *reliable and
- reproducible

when used as high temperature (up to 2000 F) tooling for -

- hydroform blocks,
- stretchform blocks,
- draw heat treat fixtures,
- brazing fixtures,
- stress relief fixtures and
- heat treat fixtures.

*Forming tools have short life, 8 parts maximum in some applications.

In particular, this investigation has shown commercial refractory ceramic castables to be suitable for the high temperature hydropress forming of -

AISI 420 martensitic stainless steel,
HM21A magnesium-thorium alloy,
Rene' 41 nickel alloy,
B-120 VCA titanium alloy,
HS25 (L-605) cobalt alloy,
VascoJet 1000 5% chromium ferritic steel,
N-155 austenitic steel, and
PH15-7Mo precipitation hardening stainless steel.

Finally, this investigation has shown that for the described uses, the commercial refractory ceramic castable are -

cast to dimensions,
inexpensive,
cureable in short times at relatively low temperatures,
high in strength at elevated temperatures,
dimensionally stable at operating temperatures,
highly resistant to repeated thermal shock,
capable of economical quick repair or replacement, and
adaptable to either cap or solid core types.

Toward the end of the contract (late October 1960) the Contractor solicited certain castable refractory suppliers for price and delivery information on their products. This information, given in Table 44, Page 9, pertains to the final selection of materials and gives costs as of November 1960.

CONCLUSIONS

Low temperature curing castable ceramics can be used for tooling for fabrication of the newer high temperature alloys, such as:

1. HM21A, magnesium-thorium
2. Rene' 41, nickel base
3. B-120 VCA, titanium
4. HS25, cobalt base
5. VascoJet 1000 (H-11), 5% chromium-ferritic
6. N-155, chromium, nickel, cobalt-austenitic
7. PH15-7Mo, chromium, nickel, molybdenum precipitation hardening stainless steel.

Specific conclusions for each type of fabrication tool follows.

Hydroform Blocks (Rubber Forming)

1. Hydroform blocks for forming high temperature alloys should be cast from material Code 8B.1, Norton Company's 33-HD, unfired.

2. Molds should be constructed of dense plaster and sealed or of plastic.

3. A suitable parting agent is peanut oil.

4. Castings should be monolithic and have a minimum thickness of 3 inches, and radii as large as part configuration will permit.

5. Either external or internal vibration should be used to aid placement.

6. Moisture should be used during the drying period, covering with wet burlap being adequate.

7. Oven drying at temperatures up to 250 F should be used.

8. A flat base of Furane Epocast plastic or similar product should be applied - 70 to 80 durometer.

9. Rigid and flat machine mounting should be provided.

10. A ceramic fiber bat should be used to protect rubber during forming with resistance heating.

11. For utilizing hot platens, a conductive ceramic tooling material such as 8D.1, Norton Company's Silicon Carbide, L.M. Cement #1615-1A-246 (Experimental), may be used.

Draw Dies

Draw dies are not considered practical under the present "state of the art".

Braze Fixtures

1. For furnaceless brazing, tooling made of fused silica, Material Codes 25A.1 thru 25E.1, should be used. These materials are available from Glasrock Products, Incorporated, Atlanta, Georgia. Either 25A.1 or the 25D.1 cement cap with 25E.1 foam block backup can be used, but the latter is more practical for large tools.

   Special and non-commercial formulation, Material Code 122B.1, should be considered as an alternate.

   Material Code 71B.1, Special High Alumina Castable by General Refractories Company and 108A.1, AA22, by Resco Products, should also be considered. (Refer to Table 44, Page 9.)

2. For furnace type brazing where high conductivity and good thermal shock resistance are needed, Material Codes 8D.1, and 71B.1 should be considered.

Stress Relief Fixtures

1. For furnaceless stress relief tooling, such as with resistance heating of part or the electric blanket concept, Item Number One listed above under Braze Fixtures applies.

2. For furnace type tooling or hot sizing press tooling, Item Number Two listed above under Braze Fixtures applies.

Stretchform Blocks

Materials, Code No. 8B.1 or 71B.1 should be used for stretchform tooling. Conclusions Numbers Two thru Ten listed under Hydroform Block apply.

Other Tools

Table 44, Page 9, and Figures 77 thru 85, Pages 188 thru 196, should be used to aid selection of materials for tooling types not investigated under the contract.

RECOMMENDATIONS

1. It is recommended that draw die development be continued to further improve surface finish, such as by glazing, and to find a suitable high temperature lubricant.

2. Additional work should be performed to minimize quenching effects during forming. Imbedded element forming tooling should be fully exploited.

3. Induction heating and polyphase resistance heating should be investigated for use with ceramic tooling. Imbedded induction coils or the use of polyphase resistance heating of part should permit blanks to be trimmed to optimum shape, yet be uniformly heated.

4. Plastic-ceramic formulations should be investigated for they should be less fragile than the pure ceramic varieties.

5. Other applications which should be investigated are:

   a. Ceramic weld jigs

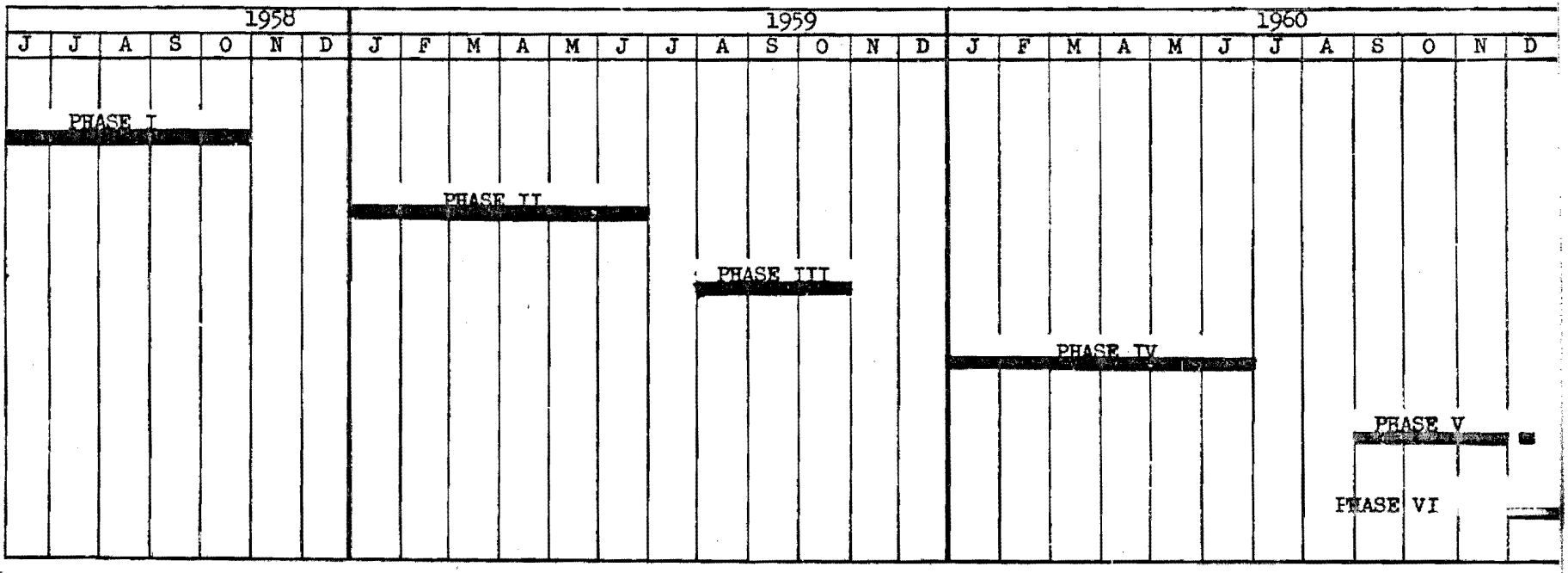
   b. Spin blocks

   c. Brake dies

   d. Forging and extrusion dies

"STATE OF THE ART" SURVEY

Exhibit 7, Pages 441 thru 472, gives the current industry posture on ceramic tooling development.



PHASE I	-	BACKGROUND INVESTIGATION	- 5 Months	PHASE IV	-	TOOLING EVALUATION	- 6 Months
PHASE II	-	MATERIALS DEVELOPMENT	- 6 Months	PHASE V	-	STANDARDIZATION	- 3 Months
PHASE III	-	REINFORCEMENT DEVELOPMENT	- 3 Months	PHASE VI	-	FINAL REPORT	- 1 Month

TABLE I
SPAN CHART
FOR
INVESTIGATION
OF
NON-METALLIC TOOLING
FOR
HIGH TEMPERATURE APPLICATIONS

TABLE 44 - PURCHASING INFORMATION ON RECOMMENDED MATERIALS

CODE	NAME	SUPPLIER	AGGREGATE AND BINDER	DENSITY LBS/CU. FT.	PURCHASING INFORMATION														
					CONTAINER	CONSISTENCY		PRICE - DOLLARS PER 100 LBS. FOR QUANTITIES OF									DELIVERY	F.O.B.	
						WET	DRY	100 lbs.	300 lbs.	500 lbs.	1000 lbs.	2000 lbs.	5000 lbs.	10,000 lbs.	20,000 lbs.	25,000 lbs.	Carload		LCL	CARLOAD
5A	Purotab	Mexico Refractories Company	Tabular alumina plus calcium aluminate	161	100 lb. water-proof cloth bag		X	20.50			20.50			20.50			18.00	Prompt	Chattanooga, Tennessee	Point of manufacture
8B	33-HD	Norton Company	Alumina plus calcium aluminate	165	100 lb. paper bag		X	32.25	29.50			26.50				24.00	24.00	Prompt on all but 25,000 which is 1-2 weeks	Point of shipment	Point of shipment
12E	Plicast HA	Plibrico Company	Tabular alumina plus calcium aluminate	153	100 lb. multi-wall paper bag		X	19.80		19.40		19.00					18.00	5 days on LCL 10 days on carload	Firebrick, Ohio	Firebrick, Ohio
12F	Plicast SF	Plibrico Company	High grade calcined clay plus calcium aluminate	131	100 lb. multi-wall paper bag		X	11.80		11.40		11.00					9.55	5 days on LCL 10 days on carload	Firebrick, Ohio	Firebrick, Ohio
20A	X-10326-C	The Charles Taylor Sons Company	Corundum plus sodium fluosilicate	167	100 lb. bag		X	25.90			25.90	25.10		25.10	24.40		24.40	1-2 weeks	Cincinnati, Ohio	Cincinnati, Ohio
20B	X-11509-E	The Charles Taylor Sons Company	Corundum plus calcium aluminate	157	100 lb. bag		X	20.00			20.00	19.20		19.20	18.50		18.50	1-2 weeks	Cincinnati, Ohio	Cincinnati, Ohio
25A	Masrock*	Glasrock Corporation	Fused silica plus unknown	111	50 lb. paper bag of Glasgrain		X	32.68	32.68	32.68	32.68	32.68	32.68	32.68	32.68	32.68	32.68	1 week on LCL 2 weeks on carload	Atlanta, Georgia	Atlanta, Georgia
					Steel drum holding 80 lbs. slip	X														
71B	Special Hi Alumina Castable	General Refractories Company	Hi alumina plus calcium aluminate	165	100 lb. multi-wall paper bag		X	15.25	15.25	15.25	15.25	15.25	15.25	15.25	14.50	14.50	14.50	7-10 days	St. Louis, Missouri	St. Louis, Missouri
103A	AA-22	Resco Products	Alumina plus phosphoric acid	167	Steel drum holding 100 lbs.	60 lbs	40 lbs	23.00	23.00	23.00	23.00	23.00	over 4000 lbs. 22.00	22.00	22.00	22.00	22.00	Prompt	Norristown, Pennsylvania	Norristown, Pennsylvania

*Use 40 lbs. slip (which contains 17% moisture) and 60 lbs. Glasgrain to make 100 lbs.

TABLE 45

CODE KEY FOR CERAMIC PRODUCTS

Code No.	Trade Name	Company
3.1.1A.1	JM 2000 Concrete	Johns-Manville
3.1.1B.1	C-3 Concrete Silocel	Johns-Manville
3.1.1C.1	C-2 Cement	Johns-Manville
3.1.1D.1	L. W. Firecrete	Johns-Manville
3.1.1E.1	H. T. Firecrete	Johns-Manville
3.1.1F.1	3X Firecrete	Johns-Manville
3.1.1G.1	Std. Firecrete	Johns-Manville
3.1.1H.1	#20 Firecrete	Johns-Manville
3.1.1J.1	3X Blazecrete	Johns-Manville
3.1.1K.1	Std. Blazecrete	Johns-Manville
3.1.1L.1	L. W. Blazecrete	Johns-Manville
3.1.1M.1	C-31M	Johns-Manville
3.1.1N.1	C. A. Firecrete	Johns-Manville
3.1.1P.1	MX1187 Castable	Johns-Manville
3.1.2A.1	MC 22	A. P. Green Fire Brick Co.
3.1.2B.1	Kast-Set	A. P. Green Fire Brick Co.
3.1.2C.1	Kast-O-Lite	A. P. Green Fire Brick Co.
3.1.2D.1	Greencast 12	A. P. Green Fire Brick Co.
3.1.2E.1	Castable Block Mix	A. P. Green Fire Brick Co.
3.1.2F.1	Castable Ins. #20	A. P. Green Fire Brick Co.
3.1.2G.1	KS 4	A. P. Green Fire Brick Co.
3.1.2J.1	L-2429 (Cap Material)	A. P. Green Fire Brick Co.
3.1.3A.1	Kaolite 20	Babcock & Wilcox Co.
3.1.3B.1	Kaolite 22	Babcock & Wilcox Co.
3.1.3C.1	Kaocrete D	Babcock & Wilcox Co.
3.1.3D.1	Kaocrete B	Babcock & Wilcox Co.
3.1.3E.1	Kaocrete A	Babcock & Wilcox Co.
3.1.3F.1	Kaocast	Babcock & Wilcox Co.
3.1.3G.1	Kromecast	Babcock & Wilcox Co.
3.1.3H.1	Mulram	Babcock & Wilcox Co.
3.1.3J.1	Mix 1921-1	Babcock & Wilcox Co.
3.1.3K.1	Mix 1921-2	Babcock & Wilcox Co.
3.1.3M.1	Mix 1921-3X	Babcock & Wilcox Co.
3.1.4A.1	Lumnite	Universal Atlas Cement Co.
3.1.5A.1	Purotab	Mexico Refractories Co.
3.1.5B.1	Purocast	Mexico Refractories Co.
3.1.5C.1	Mill-Crete	Mexico Refractories Co.
3.1.5D.1	Furnascrete Super	Mexico Refractories Co.
3.1.5E.1	Furnascrete Regular	Mexico Refractories Co.
3.1.5F.1	Furnascrete Fine	Mexico Refractories Co.
3.1.5G.1	Furnascrete Coarse	Mexico Refractories Co.
3.1.5H.1	Lo-Erode	Mexico Refractories Co.
3.1.5J.1	Hi-Strength F-303-S	Mexico Refractories Co.
3.1.5K.1	Ramcast	Mexico Refractories Co.
3.1.5L.1	Sakonite	Mexico Refractories Co.

TABLE 45 (Continued

Code No.	Trade Name	Company
3.1.5M.1	I.R.C.	Mexico Refractories Co.
3.1.5N.1	I.R.C. -20	Mexico Refractories Co.
3.1.5P.1	V-Block Mix	Mexico Refractories Co.
3.1.5Q.1	Acitab	Mexico Refractories Co.
3.1.6A.2	Alfrax #58	Carborundum Co., Perth Amboy
3.1.6D.3	Stupalith X (Experimental)	Carborundum Co., Latrobe
3.1.8A.1	33-I	Norton Co.
3.1.8B.1	33-HD	Norton Co.
3.1.8C.1	Magnorite L.M. Cement 1625-2-245 (Experimental)	Norton Co.
3.1.8D.1	Silicon Carbide L.M. Cement 1615-1A-246 (Experimental	Norton Co.
3.1.9A.1	2700° Castable	Butler Refractories Co.
3.1.9B.1	2300° Hi-Strength Castable	Butler Refractories Co.
3.1.10A.1	Duramic Grade S-2	Duramic Products, Inc.
3.1.11B.1	P.H.T. Castable Fine	Laclede-Christy Products
3.1.11C.1	P.H.T. Castable Coarse	Laclede-Christy Products
3.1.11D.1	Firmcast Fine	Laclede-Christy Products
3.1.11E.1	Firmcast Coarse	Laclede-Christy Products
3.1.12A.1	Plicast R	Plibrico Co.
3.1.12B.1	Plicast RS	Plibrico Co.
3.1.12C.1	Pli-Tab-Ram Mix	Plibrico Co.
3.1.12D.1	Pliram 91	Plibrico Co.
3.1.12E.1	Plicast R-A	Plibrico Co.
3.1.12F.1	Plicast R-F	Plibrico Co.
3.1.16A.1	Zircon Tamp Batch ZS-1298	Corhart Refractories Co.
3.1.17A.1	Sample "A"	Carolina Pyrophyllite Co.
3.1.17B.1	Sample "B"	Carolina Pyrophyllite Co.
3.1.18A.1	Bafflemix	North American Refractories Co.
3.1.20A.1	X-10326-C	Chas. Taylor, Sons Co.
3.1.20B.1	X-11508-E	Chas. Taylor, Sons Co.
3.1.21A.1	RR-268D	Richard C. Remmey & Sons Co.
3.1.21B.1	APG-249 (D or W)	Richard C. Remmey & Sons Co.
3.1.21C.1	APG-249-1W (Experimental)	Richard C. Remmey & Sons Co.
3.1.25A.1	Masrock	Glasrock Products, Inc.
3.1.25B.1	Shelrock	Glasrock Products, Inc.
3.1.25C.1	Remrock	Glasrock Products, Inc.
3.1.25D.1	Glasrock Cement	Glasrock Products, Inc.
3.1.25E.1	Glasrock Foam	Glasrock Products, Inc.
3.1.34A.1	Beta Spodumene (S-14)	Zirconium Corp. of America
3.1.39A.1	Harcast	Harbison-Walker Refractories Co.
3.1.39B.1	Harcor K.	Harbison-Walker Refractories Co.
3.1.39C.1	Castolast	Harbison-Walker Refractories Co.
3.1.39D.1	Castolast G	Harbison-Walker Refractories Co.
3.1.41A.1	Kellundite #9	Electro Refractories & Abrasives
3.1.41B.1	Cupola Patch #2	Electro Refractories & Abrasives
3.1.48A.1	Petalite	Foote Mineral Co.
3.1.50A.1	Alumina-Phos	Illinois Clay Products Co.

TABLE 45 (Continued)

Code No.	Trade Name	Company
3.1.50B.1	2400 RDX	Illinois Clay Products Co.
3.1.65A.1	Hot-Top Moldit	Refractory & Insulation Corp.
3.1.65B.1	Moldit D	Refractory & Insulation Corp.
3.1.65C.1	Moldit D.I.F.	Refractory & Insulation Corp.
3.1.70A.1	H & B #10 Extra Strength	Walsh Refractories Corp.
3.1.70B.1	Super #32	Walsh Refractories Corp.
3.1.70C.1	#150 R	Walsh Refractories Corp.
3.1.71A.1	Brikram 80 (Code 460)	General Refractories Co.
3.1.71B.1	Special Hi Alumina Castable	General Refractories Co.
3.1.72A.1	Flint Cast 29	Robinson Clay Products Co.
3.1.81A.1	New Development Petalite	Battelle Memorial Institute
3.1.83A.1	Zircon Cement R60005C	Titanium Alloy Mfg. Div. of the National Lead Co.
3.1.86A.1	CA-25 (Calcium Aluminate)	Aluminum Co. of America
3.1.86B.1	T-60 (Tabular Alumina)	Aluminum Co. of America
3.1.88A.1	Electrotemp Cement No. 8	Sauereisen Cements Co.
3.1.88B.1	Pour-Lay Cement No. 54	Sauereisen Cements Co.
3.1.98A.1	Super-Kastite 3200	Chicago Fire Brick Co.
3.1.98B.1	Kastite - DX (Hi Strength)	Chicago Fire Brick Co.
3.1.102A.1	Covercast	G. & W. H. Corson, Inc.
3.1.108A.1	AA-22	Resco Products
3.1.108B.1	AA-22 Ramming	Resco Products
3.1.108D.1	RS-17A	Resco Products
3.1.111A.1	Shenanglow Cement #58-209	Shenango Refractories
3.1.115A.1	90-Ram	Ramtite Co.
3.1.122A.1	New Development Fused Silica	Georgia Institute of Technology
3.1.122B.1	New Development Fused Silica	Georgia Institute of Technology
3.1.138A.1	#10-450	General Ceramics Corp.
3.1.140A.1	120	S. Paul Ward, Inc.



RF 6051-1

Fig. 1

"Brick Library" in the Ceramic Laboratory.

EXHIBIT 1

STATEMENT OF WORK

EXHIBIT
STATEMENT OF WORK

PB-8-MMp-6060
Dated 6 September 1957

A. PURPOSE:

It is the purpose of this procurement to acquire the necessary engineering services, equipment, and materials as required to develop non-metallic tooling for high temperature applications.

B. OBJECTIVE:

The objective of this contract is to develop low temperature curing castable refractories and/or ceramics for use as tooling for the fabrication of the newer high temperature alloys. The applications under consideration are those wherein the greater portion of the stresses imposed are compressive. The types of tooling investigated and developed should include, but not be limited to, hydroform blocks, draw dies, braze fixtures, stress relief fixtures and stretch form blocks (dies).

C. GENERAL CONDITIONS AND REQUIREMENTS:

The tooling to be developed under this contract is intended to be used in applications which are beyond the temperature capabilities of plastics and the epoxy resins (600°- 2000°F). They must be of such material that they can be cast to finished dimensions, inexpensive, cure in short time at comparatively low temperatures, have high compressive strength at elevated temperatures, be dimensionally stable at operating temperatures and highly resistant to repeated thermal shock.

This tooling must be capable of economical, quick repair or replacement, and of such material that it will bond when cast around various types of core and other reinforcing materials.

This tooling must be non-galling and of such type that lubricant deposit build-up will be at a minimum.

The contractor, with the approval of the Contracting Officer, will to the best of his ability, (1) ascertain which ceramic or refractory materials now available are suitable for use in producing high temperature forming tools or (2) have such a material or materials formulated, or both.

Contractor will use, but not necessarily limit investigation to, titanium alloys, high alloy steels, and AISI 420 sheet steel.

D. SCOPE:

Work prescribed by this contract shall be projected in six phases encompassing the following items:

EXHIBIT 1

PHASE I: Survey available information relative to castable and sprayable ceramics and refractories. This will include survey of available literature as well as material manufacturers and users.

PHASE II: Evaluate various formulae and techniques on the bases of temperature resistance, elevated temperature strength, fabrication, and curing characteristics.

PHASE III: Develop and test formulations in Phase II and techniques of reinforcing. These reinforcements may be internal, external, or a combination of both.

PHASE IV: Design and develop experimental forming tools of various types. Develop and refine manufacturing and operating techniques as indicated by the experimental tools.

PHASE V: Develop standard design, fabrication, and application criteria for various types of forming tools based on the knowledge and experience gained in the first four phases.

PHASE VI: Prepare and distribute final engineering report in accordance with Exhibit LMBM-1, -2, -3, -4, -5, which will include a complete and detailed analysis of the results of the program as well as recommendations for the further development of the state of the art.

E. WORK DETAILS:

PHASE I - Background Investigation

(1) LITERATURE SURVEY

Thorough literature survey will be made to determine present knowledge of castable ceramics and refractories. Such publications as Industrial Heating, American Ceramic Society Bulletin, Journals of the American Ceramic Society, etc., will be given particular attention. In addition to a survey of published literature, a letter requesting technical data will be sent to each major manufacturer or supplier of ceramic or refractory materials. This letter will state the properties desired and will request recommendations relating to the problem as outlined by this Exhibit. Upon receipt, this vendor information will be studied for applicability and additional correspondence will probably result.

(2) Perform a survey of all aircraft and allied manufacturers to evaluate their hot forming methods and their experience, if any, with ceramics and/or refractories as applied to tooling. A personal visit will be made to those companies where such a visit would be of value to the project.

(3) SURVEY OF FORMULATORS

Based on information gained as a result of the literature survey (Item 1) and the "state of the art" survey (Item 2) prospective manufacturers and/or formulators of ceramic and refractory materials will be solicited (in the same manner as in Item 2) to determine the present status of castable, high temperature, inorganic, non-metalic materials suitable for tooling applications.

PHASE II - Materials Development

Based on the information obtained in Phase I and consultations with the subcontractor, applicable ceramic and refractory raw materials will be selected.

In addition to the products developed by the subcontractor, commercially available materials will be evaluated.

The basic physical and mechanical properties of the developed formulations will be compared to those of the present commercial materials by the subcontractor in an effort to fulfill the objective of this Phase, which is, to develop castable materials having the required basic physical characteristics for use as tooling at elevated temperatures in the 600° to 2000°F range.

During this development period the contractor will assist the subcontractor in the casting of test specimens, and in the design and construction of any special test jigs required. As favorable materials are developed, various shapes will be cast by the contractor and casting techniques will be investigated preparatory to Phase III.

PHASE III - Tooling and Reinforcement Development

(1) The selected formulations from Phase II will be evaluated for cure characteristics, temperature resistance, and handling characteristics. Cure temperatures shall be in the range 500°F - 550°F for the selected tooling materials, however, higher temperatures may be considered. Tooling should be able to withstand operating temperature of at least 2000°F with little, if any, deterioration in strength, no shrinkage, and should show good heat shock resistance.

(2) Various flexibilizers and reinforcements to be evaluated from 600°F to 2000°F, but not limited to, are:

a. Raw ceramic fibers
b. Ceramic fibre woven cloths or blankets
c. Steel wool
d. Screen wire and hardware cloth
e. Perforated metal sheet
f. Expanded metal
g. Steel rods

Accelerated tests, to determine the effect of outdoor storage and repeated temperature cycling, will be performed on test blocks 9" x 4 1/2" X 2 1/2" that have been cast and cured. Accelerated weathering will be accomplished using available commercial equipment; Atlas Electric Devices Company, Twin-Arc Weather-Ometer. This equipment will duplicate the effect of outdoor summer storage with a cycle of 1 hour of water spray only, 2 hours of light only, 2 hours of water spray only followed by 6 hours of light only for a total of 11 hours, and repeated once for a total of 22 hours.

EXHIBIT 1

During the remaining two hours in each day the equipment will be turned off. The air temperature inside the specimen holding drum will be maintained at 140 ± 5°F during the light cycle. This cycle will be repeated for 15 cycles or until excessive deterioration is noted.

The effect of freezing and thawing during outdoor exposure will be determined using test specimens 9" X 4 1/2" X 2 1/2" as described above. Initially, the specimens will be immersed in the thawing tank, maintained at 75 ± 5°F, for 4 hours. One cycle will consist of placing the saturated specimens in the freezing chamber for 20 hours followed by 4 hours immersion in the thawing tank. After five cycles the specimens will be stored at 75 ± 5°F for 40 hours then inspected, submerged for 4 hours, and again subject to 5 cycles of freezing and thawing. This will continue for a total of 25 cycles or until apparent disintegration causes the specimen to be withdrawn from the test.

PHASE IV - Tooling Evaluation

(1) Tool construction to be investigated will be of two general types; (a) ceramic or refractory cap cast over a rough core, (b) solid tool cast entirely of the ceramic or refractory tooling material. In both types, reinforcement developed above may be used as necessary.

(2) Ceramic or refractory caps on various types of cores such as concrete, rough metal casting, transite, or other materials which are considered applicable. Standard molds will be made for such tools as stretch form blocks, hydro press blocks (dies), braze and/or stress relief fixtures, and draw dies. The cores are to be made by the most economical standard methods. Finish plaster molds will be made and the castable ceramic or refractory poured in the core pressed in so as to force the excess material around the core in the mold to give a surface cap from 1/2 to 3/4" thick. The surface will then be given the finish cure for use according to the procedures developed in Phase III. The tools will then be tested in their respective machines for the hot forming of parts. Reinforcements developed in Phase III may be used as necessary.

(3) The various types of ceramics and refractories will then be tested as solid cast tools made in molds similar to those in (1) above. The general procedures in (1) above will be followed to prove the tooling materials, tools, reinforcement methods, etc. as applicable to solid cast tools.

(4) Repair techniques will be considered and evaluated for the various types of ceramic tooling materials studied.

PHASE V - Standardization of Tool Design

(1) The data obtained in the first four Phases will be analyzed and evaluated as to practicability, cost, reliability, reproducibility, etc.

(2) The methods devised will be applied to the design of various types of hot forming tools. Standard designs and manufacturing methods will be established for applicable types of tools such as, but not limited to, braze and stress relief fixtures, draw dies, stretch form and hydropress blocks (dies).

EXHIBIT 1

PHASE VI - Final Report

(1) A final detailed engineering report will be prepared and distributed in accordance with Exhibit LMBM-1 through -5 and the distribution list to be furnished by the procuring agency. This report shall cover formulations developed, application methods, handling characteristics, cost data, design standards developed, and any other pertinent data developed during the duration of the contract.

PHASE I

BACKGROUND INFORMATION

June thru October 1958

INTRODUCTION

At the time the Contractor proposed this project, it was thought that the Air Materiel Command would designate which high strength materials would be used for evaluating ceramic forming tools. The Air Materiel Command, however, preferred that the Contractor select the applicable materials. As a result of this decision, it became necessary for the Contractor to extend the proposed background investigation to include a survey of high strength materials used by the aircraft industry as well as a survey of literature, consumers and formulators of ceramic materials.

A compilation of the high strength materials currently used and anticipated for future use is presented in Table 2. How the use of these materials is distributed throughout the aircraft industry is given in Table 3.

This phase of the report will discuss both the high strength materials survey and the survey of tooling materials. Mention of both are made here so that discussions of these aircraft structural materials will not seem foreign to the primary objective of the project which is the development of non-metallic tooling for high temperature applications.

LITERATURE SURVEY

Library Search

Work on the project was begun on June 5, 1958. The first few weeks were used in a search for references on ceramic tooling in the Contractor's library and at the Georgia Institute of Technology Library. Although this search yielded nothing in the way of references to published literature, many references were obtained as to possible formulators, research institutions, and individuals who are authorities in the general field of ceramics.

Back issues of such publications as, "Ceramic Industry", "American Ceramic Society Bulletins, Journals and Excerpts", "Materials in Design Engineering", and "Industrial Heating" were reviewed and were instrumental in compiling mailing lists for technical inquiries.

Letters of inquiry were sent to 204 ceramic formulators, raw material producers, colleges and universities, and research laboratories in the United States and several foreign countries. A list of the contacts with addresses and

the results of the inquiries are given in Table 4. Of the 204 inquiries, 116 answered and 33 supplied data on castable ceramics.

The original letter of inquiry is shown in Exhibit 2.

Of the 204 recipients in Table 4, 174 comprise the ceramic industry, and the remaining 30 are as follows:

Colleges and Universities

Alfred University
Clemson College
Cornell University
Georgia Institute of Technology
Massachusetts Institute of Technology
Ohio State University
Pennsylvania State University
Rensselaer Polytechnic Institute
Rutgers University
University of California, Berkeley
University of California, Los Angeles
University of Illinois
University of London

Research Laboratories

Armour Research Foundation
Battelle Memorial Institute
Bjorksten Research Laboratories
Franklin Institute
Fulmer Research Institute
Hurst Laboratories
Mellon Institute
Office of Naval Research
S-K-C Research Associates

Others

"Ceramic Industry", periodical
Department of Commerce, Office of Technical Services
"Materials in Design Engineering", periodical
National Bureau of Standards
Refractories Institute
The American Ceramic Society
The British Ceramic Research Association
The British Ceramic Society

SURVEY OF THE AIRCRAFT INDUSTRY

Inquiries by Letter, Visits

To begin the survey of the aircraft industry, the Contractor prepared and distributed a questionnaire designed primarily to determine the "state of the art" of using ceramics for tooling applications. See Exhibit 2A.

In addition to questions relating specifically to ceramics, questions as to which high strength materials are being used or expect to be used within the next three years, and questions concerning hot forming techniques for these materials were asked.

A list of the 50 domestic and 43 foreign recipients of this questionnaire and the outcome of this letter survey are given in Table 5.

As indicated in Table 5, 25 of the domestic aircraft companies were visited. Additional and more detailed questionnaires were completed during the visits.

"State of the Art"

Although thirteen aircraft companies, including the Contractor, have reported ceramic tooling activity, only five companies have indicated that they have done anything other than preliminary evaluation work. These five companies, therefore, might justifiably be considered as encompassing the "state of the art" of using ceramic tooling in the aircraft industry, including many foreign aircraft companies. These five companies and discussions of their work follow.

Rohr Aircraft Corporation, Chula Vista

Several years ago Rohr began investigating the use of castable ceramics for what they refer to as creep forming fixtures. According to Rohr, creep forming is a hot sizing operation which may be combined with a heat treating operation such as aging, stress relieving, or drawing. In use, the usually preformed part is placed in the ceramic fixture which resembles a kirksite hammer die and is kept sandwiched between the net cast punch and die which make up the primary components of the fixture.

These cast ceramic fixtures were made of Plibrico Company's Plicast RS castable, weighed up to approximately 1000 pounds, were fired at 1500 F, and can be used for temperatures up to 1500 F. Ordinary air furnaces are used for heating to soaking temperatures for firing and for the creep forming operation. Commercially pure titanium and 17-7PH have been creep formed with this type of tooling.

In addition to the two creep form fixtures, Rohr has made an experimental braze fixture of compound curvature which was cast and which measured approximately 6 x 24 x 24 inches. This type of tool is being considered as a possible replacement for machined graphite in brazing operations.

Rohr has evaluated two other castable ceramics, but found them to be inferior to Plicast RS for creep forming or brazing tools.

This company indicated that the problems associated with the fabrication and use of castable ceramic tooling are those relating to construction, handling, maintenance, and repair techniques. They are, however, optimistic about the future of ceramic tooling for they feel that these problems will be solved with experience.

Boeing Airplane Company, Seattle

Boeing, like Rohr, has constructed castable ceramic creep forming fixtures. The material with which they report most success is regular Furnascrete, a product of Mexico Refractories Company. One fixture made from this material and which very much resembles a large drop hammer die, weighs 4000 pounds and measures approximately 36 x 72 x 40 inches thick when closed. The contour is approximately 26 inches deep. To lighten this tool, Boeing used coring extensively. The firing temperature used was 1400 F. The tool is used for creep forming 6Al-4V titanium alloy.

According to Boeing, one of the major problems in the construction of castable ceramic tools is the speed required in mixing and placing. They indicated that this should be done as fast as possible. In an effort to overcome this obstacle, Boeing purchased Mexico Refractories' Extrud-A-Flow machine. This machine automatically meters the correct proportions of water to dry mix, mixes, and extrudes the wet mix through a hose, ready for use.

North American, Los Angeles

This company has made creep form joggle dies approximately 4 x 8 x 15 inches from Mexico Refractories' Purotab castable ceramic for joggling A-110AT titanium alloy in the 1000 - 1200 F temperature range. They have also made similar tools from Harbison Walker's Harcast and Laclede Christy's Firmcast.

North American is currently investigating other materials and is actively engaged in research and development to apply ceramics to a variety of different types of tools.

Grumman, Long Island, New York

Grumman has used cast ceramic tooling for forming and aging at 1000 F and for heat treating at 1750 F.

The forming tools are 4 x 7 x 12 inch stretch form blocks for 17-7PH and commercially pure titanium. These blocks are made from Norton's 33 HD castable and a Harbison Walker product believed to be Harcast. This company has had difficulty with the 1000 F blank being quenched when brought into contact with the ceramic block. Plans are to imbed resistance

elements in the blocks to permit integral heating. For aging and heating fixtures, North American Refractories' Narco-Hearth and Laclede Christy's Steelcast have reportedly been used.

Lockheed, Georgia

In September, 1956, the Contractor made a heat treating and quenching die from Johns Manville's 3X Blazecrete. This die was about 8 x 12 x 18 inches and was used at 1850 F to prevent sag distortion of a thin gage experimental part made from AISI 420 stainless steel. The fixture was also evaluated as a 600 F interrupted quench die with favorable results. The next heat treat fixture made consisted of a cored punch and die which weighed approximately 1600 pounds and measured 20 x 52 inches and had a 19 inch shut height. Because of the massive sections, another material was selected for this die. This other material, according to the vendor's data, appeared to have sufficient strength and less size change after firing at 1900 F than did Johns Manville's Blazecrete. It was thought that the smaller size change would lessen the tendency for cracks to develop and it was desirable inasmuch as no size change compensation would have to be made. Perhaps Lockheed became too concerned about the size changes, because it was the low as-fired strength that caused this die to be a failure. It was later learned that a firing temperature of 1900 F was the point where the hydraulic bond was virtually destroyed and this temperature was too low for a vitreous bond to be developed.

As a result of this failure, Lockheed evaluated 29 castables from 9 different suppliers. A heat treat fixture as large as the one that failed has not yet been made, but four 6 x 36 x 36 inch heat treat fixtures have been made and used in production. These fixtures have good thermal shock resistance because they have withstood repeated cooling to room temperature from the 1600 F heat treating temperature. They are made from Glasrock Corporation's Masrock, a fused silica castable.

An 8 x 15 x 15 inch heat treat fixture, a 600 F interrupted quench die of the same dimensions, and a similar 2000 F form die of Masrock have been used experimentally with good results.

It should be noted that although a considerable number of castings have been made by the aircraft industry, very few have been made for sheet metal forming other than for creep forming and as far as can be determined, strengthening by internal or external reinforcements has not been investigated.

SURVEY OF CERAMIC FORMULATORS AND RESEARCH INSTITUTIONS

From the information obtained through letter inquiries during the literature survey, travel itineraries were organized and virtually everyone indicating knowledge of castable materials for the project was visited. The companies and research institutions visited are marked by an "X" in Table 4.

Of the 46 visits, seven were to research institutions. These institutions are noted below.

Alfred University
Battelle Memorial Institute
Bjorksten Research Laboratories
Georgia Institute of Technology
Ohio State University
Pennsylvania State University
Rutgers University

During the visits, detailed questionnaires were completed on available properties of each ceramic material to be considered for evaluation in Phase II.

Although these research institutions could not, in most instances, supply data on commercially available formulations, they were very helpful in supplying basic data verbally and in the form of technical papers. These institutions are abreast of most of the latest material developments and gave numerous references as to where the Contractor could find more information on such developments. Information such as knowledge of ceramic materials having a very high thermal expansion approaching that of carbon steel and materials having small or even negative expansions was obtained.

DISCUSSION OF TABLES

Table 2, "Available Formability Data - High Strength Materials", lists all of the high strength materials being used or anticipated for use within the next three years. This list was compiled from the initial questionnaire survey of the aircraft industry and from information accumulated during the visits. Note that, where feasible, these materials are grouped into families. A "Typical Manufacturer" is given for reference so that additional information might be obtained from a material producer. Only room temperature strengths and elongations are given because in almost all cases elevated temperature data, needed for hot forming, are not available. In some instances, where the material has good room temperature elongation, but where the material is known to work harden very rapidly, the forging or even the heat treating temperature is given as the forming temperature.

The application temperature or aircraft design temperature is given for reference only.

Table 3 is the same list of high strength materials showing distribution, those materials which are presently used, and those which are for future use. Note that in addition to giving the aircraft company reporting usage, the total number of companies using or anticipating use of a particular material is also given. The undesignated entries are those materials which were not specifically identified on the questionnaires. For example, some companies indicated that they used stainless steel without giving any further description.

Table 4 is a list of 200 domestic and 4 foreign organizations either in or related to the ceramic or refractory industry. These were recipients of the letter of inquiry concerning knowledge of materials for ceramic tooling. Note that the companies or institutions which were visited are also indicated in this table.

Table 5 is a list of 50 domestic and 43 foreign aircraft and allied companies surveyed for ceramic tooling activity. In addition to showing the results of this letter inquiry, the domestic companies visited are indicated.

Table 6 shows the heating techniques used for hot forming as reported by the aircraft industry. It is significant that more companies either use or plan to use resistance heating of part than any other technique, for it was originally proposed that resistance heating be used extensively for hot forming with ceramic tools.

Table 7 lists the physical properties of ceramic castables and some raw materials which, in the main, have been recommended by formulators and research institutions for evaluation under this project. The data were compiled from vendor's catalogs, technical papers, etc. Note that the properties shown relate back to the curing and firing procedure (temperature).

Most of these formulations are designed for use as monolithic furnace linings and special shapes for furnaces. For these applications it has not been necessary for the manufacturers to determine many of the physical properties which will be needed for the more exacting tooling application. It is for this reason that there are numerous blank spaces in Table 7. The data just are not available.

DISCUSSION OF ANTICIPATED PROBLEMS AND POSSIBLE SOLUTIONS

Forming Tools

Forming sheet metal parts at temperatures as high as 2000 F will automatically produce martensitic transformation or heat treatment of some of the high strength air hardenable materials. Accompanying this transformation is a physical size change which ordinarily is compensated for in the tooling.

As far as size change is concerned, an even greater problem exists due to thermal contraction of the part on cooling from the forming temperature. One method of overcoming this problem is to finish form at room temperature those materials which have sufficient elongation to do so. For the materials that are automatically hardened as a result of cooling from the forming temperature and which would not have sufficient room temperature elongation, partial size change compensation might be possible by finish forming just above the martensite start line which may be as low as 400 F for some materials. This would mean, therefore, that the difference in size change due to contraction from the martensite start temperature and the size change due to transformation, would have to be compensated for in the tooling.

Further complications would arise if the ceramic material selected has a large thermal expansion. It is hoped that it will not be necessary to heat the ceramic forming tool. However, some heating will be caused each time a part is formed and the temperature and, consequently, the size of the tool at any time will depend on the number of parts consecutively formed, the time lapse between parts, the forming temperature, and other factors. This everchanging, difficult to predict size changing, obviously would be objectionable. Also objectionable would be the poor thermal shock resistance which usually accompanies high thermal expansion.

Fortunately, there are some low expansion castables already available and the possibility of developing new ones appears promising. Besides helping to solve the size change problem and promoting good thermal shock resistance, the low expansion ceramics would be better suited for integrally heated forming tools, should such heating become necessary. Even if the tooling is heated to the forming temperature, the problem of compensating for size changes in the part will still exist. The only real consolation, therefore, as far as size changes are concerned, is that by using low, ideally zero, expansion ceramic materials, any other size changes involved can be easily predicted and the necessary compensation applied. Final sizing, however, might still be best accomplished during aging, stress relieving, drawing, creep forming, or by hot sizing.

For hydroform blocks (rubber forming), the problem of burning the rubber is expected to be solved by the use of Carborundum Company's Fiberfrax blanket insulation, or a similar product, between the rubber and the hot blanket (up to 2000 F). Discussion of this problem with Carborundum took place during the survey and the possibility of developing a durable two-way stretch fabric looks promising should existing fabrics to be evaluated prove unsatisfactory.

Stress Relief Fixtures

As far as this project is concerned, aging, creep forming, hot sizing, drawing and stress relief fixtures will be considered similar. Furnace heating of the tool and part will be the primary heating technique studied, although resistance heating of the part only will also be evaluated.

For furnace fixtures, it is desirable that the ceramic castable have a thermal expansion to match the part. It may be possible to accomplish this or at least approximate the part expansion, but it is feared that thermal shock resistance will be sacrificed. The Contractor will, however, evaluate the use of high expansion ceramics for furnace fixtures. If these materials cannot be used, and if resistance heating of the part only is employed, size compensations will be required as discussed in the previous section on forming tools.

As far as conductivity is concerned, for furnace tooling it would be desirable to use ceramic castables having high thermal conductivity values ("K"), but it will probably be necessary to sacrifice high conductivity for other more vital properties. For resistance heating, where the tooling is not purposely heated, a low "K" value would benefit the problem of heat transfer from the part to the tool.

Braze Fixtures

Several of the aircraft companies visited have evaluated ceramics for braze blocks for stainless steel honeycomb brazing. While machined graphite is now satisfactorily doing the job, the necessity of machining and using slip sheets to prevent carbon pick-up is objectionable due to high costs. The Martin Company of Baltimore has evaluated ceramics for braze blocks, and has reported that all the materials evaluated caused contamination. Other companies reported that the shrinkage of the materials evaluated was too great; and still others felt that the relatively low "K" value of ceramics would be troublesome.

All companies contacted, however, indicated that they felt the Contractor should place special emphasis on the development of net cast ceramic braze blocks to eliminate machining. It appears that this type of tool can be developed with relative ease for parts having slight contour. However, if much contour is involved, the difference in expansion between the panel and the braze block may preclude the use of ceramics. A low expansion body will probably have to be used for sufficient thermal shock resistance. As for the contamination problem, it may be necessary to continue using a slip sheet. However, the potential savings in machining costs alone is justification enough for the Contractor to pursue this approach.

CONCLUSIONS

Although ceramic tooling will undoubtably have many limitations, many types of tools will probably be constructed of ceramic materials in the future and at a considerable cost saving. It appears too, that tooling lead time can be reduced by the use of castable ceramics.

The only conclusions that can be drawn at this time pertain to the selection of high strength materials for evaluating ceramic tooling and the selection of formulations to be evaluated in Phase II.

High Strength Materials Selection

It was originally proposed that the Contractor would use AISI 420 stainless steel for most of the evaluation work. Because of the need for hot forming titanium alloys, 6Al-4V or B-120VCA will also be used. Likewise, a representative magnesium-thorium alloy, HM21A, will be used. Because of the wide acceptance of VascoJet 1000, this material is selected to represent the 5% chrome steels. For the same reason, PH15-7Mo is selected for the chromium, nickel, iron group, and Rene' 41 for the nickel-base group. N-155 and L-605 are selected to represent the chromium, nickel, cobalt, iron and cobalt-base groups respectively.

Ceramic Materials Selection

All of the materials given in Table 7 will be used for preliminary tests for castability, size changes, surface finish and strength. Promising new formulations will also be tested as they are developed.

RECOMMENDATIONS

Since this report covers background information, the only applicable recommendation that can be made at this time is to proceed with Phase II.

TABLE 2 - AVAILABLE FORMABILITY DATA - HIGH STRENGTH MATERIALS
(OCTOBER, 1958)

ALLOY	TYPICAL MANUFACTURER	CLASS	ANNEALED			HEAT TREATED			FORMING TEMP °F	APPL TEMP °F	REMARKS
			ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %	ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %			
HK31A	Dow	Magnesium, Thorium	33,000	21,000	23	37,000	29,000	8	650-700	600	H24 temper
HM21A	Dow	Magnesium, Thorium				34,000	25,000	10	650-800	600	T8 temper
ZE41	Dow	Magnesium Alloy				38,000	30,000	12		250	H24 temper
A - 110AT	Rem-Cru	Titanium, 5Al - 2.5Sn	125,000	120,000	18	- - -	- - -	-	1000	600	
AMS 4900A	Rem-Cru	Titanium, C. P.	65,000	55,000	18	- - -	- - -	-	900-1200	600	
AMS 4901B	Rem-Cru	Titanium, C. P.	80,000	70,000	15	- - -	- - -	-	900-1200	600	
B - 120VCA	Crucible	Titanium, 13V - 11Cr - 4Al	140,000	135,000	15	190,000	170,000	6		600-700	
RS 140	Republic	Titanium, 5Al - 1.25Fe - 2.75Cr	164,000	158,000	15	198,000	192,000	8.6	1200	600	1450/2hrs - WQ; 1000/4hrs - AC
Ti - 8Mn	Mallory - Sharon	Titanium	150,000	135,000	15	- - -	- - -	-	Room or 900-1200	700	
Ti - 140A	Titanium Metals Corp.	Titanium, 2.2Fe - 2.1Cr - 2.0Mo	138,000	128,000	20	189,000	160,000	12		750	1480/1hr - WQ; 900/2hrs - AC
4Al - 3Mo - 1V	Rem-Cru	Titanium	135-156,000	130-150,000	13-17	183,700	158,700	8.8	Room or 1000	600	1550/ - WQ; 1000/2hrs - AC
6Al - 4V	Mallory - Sharon	Titanium	155,000	135,000	12	180,000	160,000	12	900-1200	600	1750/½hr - WQ; 1100/8hrs - AC
16V - 2.5Al	Mallory Sharon	Titanium	110,000	55,000	15	175,000	160,000	5.5	1000	600	1400/½hr - WQ; 960/4hrs - AC
En 30B	(British)	Super Alloy				224,000		10		480	480 F (max) temper
Hy - Tuf	Crucible	Super Alloy	148,000	123,000	19.8	230,000	194,000	14			1600/ - OQ; 600 F temper
M - 300	Bethlehem	Super Alloy				289,000	245,500	9.5		600	600 F temper
M - 325	bethlehem	Super Alloy				340,000					
Super Hy - Tuf	Crucible	Super Alloy				294,000	241,000	10			550 F temper
X200	USS	Super Alloy	107,600	76,400	20.5	290,900	238,500	6.8		600	600 F temper
Halcomb 218	Crucible	5% Chromium	86,000	46,000	22	206,000	176,000	7		1100	1100 F temper
Peerless 56	Crucible	5% Chromium				228,000				1000	
Potomac A	Allegheny Ludlum	5% Chromium	95,000	80,000	20	285,000	225,000	8	Room or 200-300	850	1000 F temper
Thermold A	Universal Cyclops	5% Chromium								1000	
Thermold J	Universal Cyclops	5% Chromium				230,000				1000	
Unimach #1	Universal Cyclops	5% Chromium				250,000	210,000	7		1000	1050 F double temper

TABLE 2 - (CONT'D)

ALLOY	TYPICAL MANUFACTURER	CLASS	ANNEALED			HEAT TREATED			FORMING TEMP F	APPL TEMP F	REMARKS
			ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %	ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %			
Vasco Jet 1000	Vanadium-Alloys Steel	5% Chromium	95,000	86,500	17.5	280,000	240,000	6		1000	990 F temper
Greek Ascoloy	Universal Cyclops	12% Chromium				170,200	150,000	13.3		1050	1050 F temper
12MoV	OSS	12% Chromium				247,000	194,000	10.5		900	1350/½hr 900/2hrs temper
410	Crucible	12% Chromium	65,000	35,000	25	200,000	150,000	19		850	1800/ - OQ; 850/3hrs temper
420	Crucible	12% Chromium	95,000	50,000	25	232,000	179,000	6		600	600 F temper
422	Crucible	12% Chromium	149,000	125,000	18	260,000	213,000	6		900	900/2hrs temper
422M	Crucible	12% Chromium	100,000	60,000	12	230,000	185,000	6		900	
A - 286	Allegheny Ludlum	Chromium, Nickel, Iron	91,000	37,000	47.5	146,000	100,000	25	Room or 1650-1800	1300	
AM350 DA	Allegheny Ludlum	Chromium, Nickel, Iron	156,000	78,000	15	185,000	160,000	15	Room	600	
AM350 SCT	Allegheny Ludlum	Chromium, Nickel, Iron	156,000	78,000	15	195,000	172,000	15	Room	600	
AM355 DA	Allegheny Ludlum	Chromium, Nickel, Iron		60,000	15	185,000	164,000	10	Room	600	
AM355 SCT	Allegheny Ludlum	Chromium, Nickel, Iron		60,000	15	223,000	195,000	10	Room	600	
PH 15 - 7Mo	Armco	Chromium, Nickel, Iron	150,000	65,000	25	190,000	170,000	3-5	Room	1000	TH 1050 Hot sizing at 1050 F
Unitemp 212	Universal Cyclops	Chromium, Nickel, Iron									
17 - 7PH	Armco	Chromium, Nickel, Iron	150,000	55,000	20	180,000	150,000	6	Room	900	TH 1050 Hot sizing at 1050 F
19 - 9DL	Universal Cyclops	Chromium, Nickel, Iron	118,300	69,000	55.5				Room or 1650-1800	1200	
GMR 235	Allison Div., GM	Nickel-Base								1700	
Hastelloy "C"	Haynes Stellite	Nickel-Base	128,500	68,200	49	145,800	82,400	44.5		1000	1100/16hrs age
Hastelloy "X"	Haynes Stellite	Nickel-Base				113,300	53,800	41.1	Room	2200	
Inconel	Haynes Stellite	Nickel-Base	93,800	36,800	37.3	- - -	- - -	-	Room	1650	
Inconel "W"	Inco	Nickel-Base	100,000 max.	40,000	35-40	150-160,000	80,000	20-25	Room	1600	1400/1hr age
Inconel "X"	Inco	Nickel-Base	121,000	54,000	43	180,000	120,000	25	Room	1500	Age hardened

TABLE 2 - (CONT'D)

ALLOY	TYPICAL MANUFACTURER	CLASS	ANNEALED			HEAT TREATED			FORMING TEMP F	APPL TEMP F	REMARKS
			ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %	ULTIMATE STRENGTH psi	.2% YIELD STRENGTH psi	e %			
Incoloy 901	Inco	Nickel-Base	109,000	45,000	46	167,000	107,000	25	Room	1000-1400	Transverse 1400/2hrs - AC
M - 252	Universal Cyclops	Nickel-Base	132,200	57,100	44	175,000	98,000	25	Room or 1950	1200-1500	1950/4hrs - AC; 1400/16hrs - AC
R - 235	Haynes Stellite	Nickel-Base	147,500	78,500	43	160,500	98,000	27	Room	1800	2150/ AC; 1600/24hrs age
Rene 41	Cannon - Muskegon	Nickel-Base	130,000	65,000	50	135,000	150,000	6-8	Room or 1950	1750	1950/12min - AC; 1400/16hrs - AC
Udimet 500	Utica Drop Forge	Nickel-Base	- - -	- - -	-	195,000	125,000	16			1975/4hrs - AC; 1550/24hrs - AC; 1400/16hrs - AC
Udimet 600	Utica Drop Forge	Nickel-Base	- - -	- - -	-	170,000	137,000	13		1650	1975/4hrs - AC; 1550/24hrs - AC; 1400/16hrs - AC
Udimet 700	Utica Drop Forge	Nickel-Base	- - -	- - -	-	205,000	140,000	18		1650	1975/4hrs - AC; 1550/24hrs - AC; 1400/16hrs - AC
Waspalloy	Universal Cyclops	Nickel-Base				188,000	115,000	28			1975/4hrs - AC; 1550/24hrs - AC; 1400/16hrs - AC
J - 1650	Carboloy (GE)	Chromium, Nickel, Cobalt, Iron	140,000		45	205,000	148,000	27	Room or 1950	1800	1400/16hrs age
Multimet	Haynes Stellite	Chromium, Nickel, Cobalt, Iron				116,100	56,000	49		2000	2150/ - RAC
N - 155	Universal Cyclops	Chromium, Nickel, Cobalt, Iron				119,000	57,000	43	Room or 1200-1750	1500	
L - 605, (HS 25)	Universal Cyclops	Cobalt-Base	144,500	66,700	58.8	202,000	186,950	16.8	450	1800-1900	20% cold-reduction 1100/16hrs age
Thermenol	Allegheny Ludlum	Iron, Aluminum	85,000	65,000	2-5				800(min)	1000	Used in 1925 F solution treated cond.
Molybdenum			97,000	75,000	19	120-175,000		1	120-1400		From powder
Moly - 0.5Ti	Climax Molybdenum	Molybdenum-Base	150-200,000	120-180,000	2-20	- - -	- - -	-	200-400	1600	
Beryllium	Brush Beryllium		125,000	95,000	1-5				800		
Be. Alloy											
Columbium			39,400	24,200	49	96-130,000		1	Room	1000	Cold worked
Tantalum			55,000	36,000	27.4	110-160,000		1-1.5	Room		Cold worked
Tungsten						70-300,000		0-2			Cold worked

AC - Air cooled; RAC - Rapid air cooled; OQ - Oil quench; WQ - Water quench

TABLE 3 PRESENT AND FUTURE USE DISTRIBUTION - HIGH STRENGTH MATERIALS

HIGH STRENGTH MATERIALS X - Presently Used O - Future Use	Allison	Beech	Bell - Buffalo	Bell Helicopter	Boeing - Seattle	Boeing - Wichita	Cessna	Chance-Vought	Cleveland Pneumatic	Convair - Fort Worth	Convair - San Diego	Douglas - Tulsa	Fairchild	Firestone	Grumman	Hamilton Standard	Lockheed - Burbank	Lockheed - Georgia	Martin - Baltimore	Martin - Denver	McDonnell	North American - Columbus	North American - L. A.	Northrop	Reaction Motors	Republic	Rohr	Ryan	Sikorsky	Solar - Des Moines	Solar - San Diego	Teleo	Westinghouse ACT	Wright Aeronautical	Avro	Canadair	Hawker	D. Napier & Son	Saab	X	O	Total
MAGNESIUM ALLOYS																																										
HK31A								X		X								0	X	X																0					4	2	6
HM21A								X		X								0		X																					3	1	4
ZE 41																																				X					1	-	1
Undesignated						X							X							X																							
TITANIUM ALLOYS																																										
A - 110AT											X										X	X	X						X						X					6	-	6
AMS4900A				X																		X																		3	-	3
AMS4901B			X		X			X															X				X	X			X				X	X				9	-	9
B - 120VCA			0																0				0			0				0					0					-	8	8
RS 140										X																														1	-	1
Ti - 8Mn								X			X							0			X		X	X		X		X			X					X					9	1	10
Ti - 140A																						X						X												2	-	2
4Al - 3Mo - 1V			X																				0			0														1	2	3
6Al - 4V			X		*			X			X	0	0					0	0		X		X	X		0	X	X			X				X			0		11	6	17
16V - 2.5Al										X																														1	-	1
Undesignated	0	X	X			X	X								X		0							0			0	X	X				0						X			
SUPER ALLOYS																																										
En 30B																																				X					1	-	1
Hy - Tuf										X																														1	-	1
M - 300																														0										-	1	1
M - 325														0																0										-	2	2
Super Hy - Tuf														0																										-	1	1
X200										0				0				0																						-	3	3
Undesignated	0																					0																				

TABLE 3 (CONT'D)

HIGH STRENGTH MATERIALS X - Presently Used O - Future Use	Allison	Beech	Bell - Buffalo	Bell Helicopter	Boeing - Wichita	Boeing - Seattle	Cessna	Chance-Vought	Cleveland Pneumatic	Convair - Fort Worth	Convair - San Diego	Douglas - Tulsa	Fairchild	Firestone	Grumman	Hamilton Standard	Lockheed - Burbank	Lockheed - Georgia	Martin - Baltimore	Martin - Denver	McDonnell	North American - Columbus	North American - L. A.	Northrop	Reaction Motors	Republic	Rohr	Ryan	Sikorsky	Solar - Des Moines	Solar - San Diego	Temco	Westinghouse AGT	Wright Aeronautical	Avro	Canadair	Hawker	D. Napier & Son	Saab		X	O	Total
5% CHROMIUM																																											
Class 11													O		O			O													X										1	3	4
Class 13																															X										1	-	1
Halcomb 218								X	O		O				O													O													1	4	5
Peerless 56																		O	X			X	O			O							X									3	3	6
Potomac A																															X										1	-	1
Thermold A																			X			X						O													2	1	3
Thermold J									X													O	O					O													1	3	4
Unimach #1																			X																						1	-	1
Vasco Jet 1000								X	X					O				O	X		O	X	O					O	O	X					X						7	6	13
Undesignated			X							O										X	X					X	O									O							
12% CHROMIUM																																											
Greek Ascoloy																X																									1	-	1
12MoV			O											X																											1	1	2
410	X											O																	X												2	1	3
420																		O																							1	1	2
422																		O	X																						1	1	2
422M			O																																						1	1	2
Undesignated																						O											X			O	X					
STAINLESS STEEL, UNDESIGNATED		O					X								X						X								X							O						
CHROMIUM, NICKEL, IRON ALLOYS																																											
A - 286	X									O	X				O	X			X		O		X		O		X	X		X										9	4	13
AM350	X				O	X				X	X	O	O			O	X	X					X		X		X				X										11	4	15
AM355											X		O						X			X	X			O			O		X										5	3	8
PH15 - 7MO			O		X				O	X		O	O		O			O	X			X	O	O		X	X				X										7	6	13

TABLE 3 (CONT'D)

HIGH STRENGTH MATERIALS X - Presently Used O - Future Use	Allison	Beech	Bell - Buffalo	Bell Helicopter	Boeing - Seattle	Boeing - Wichita	Cessna	Chance-Vought	Cleveland Pneumatic	Convair - Fort Worth	Convair - San Diego	Douglas - Tulsa	Fairchild	Firestone	Grumman	Hamilton Standard	Lockheed - Burbank	Lockheed - Georgia	Martin - Baltimore	Martin - Denver	McDonnell	North American - Columbus	North American - L. A.	Northrop	Reaction Motors	Republic	Rohr	Ryan	Sikorsky	Solar - Des Moines	Solar - San Diego	Temco	Westinghouse AGT	Wright Aeronautical		Avco	Gaundair	Hayker	D. Napier & Son	Pratt		X	O	Total
CHROMIUM, NICKEL, IRON (Cont'd)																																											
Unitemp 212											O														O																-	2	2
17 - 7PH	O	X	X		X	X		X		X	X	O			X	X	X	X			X	X	X	X	X	X	X			X				X	X			0	22	3	25
18 - 8, Otherwise Undesignated										X			X								X		X									X			X						
19 - 9DL																									X		X												1	-	1
19 - 9, Undesignated																							X																		
NICKEL-BASE ALLOYS																																										
GMR 235	X																								O														1	1	2
Hastelloy "C"																X																								1	-	1
Hastelloy "X"																					X			X		X														1	-	1
Hastelloy, Otherwise Undesignated																							X																		
Inconel		O					X							X		X							X											X						5	1	6
Inconel "W"											X																														1	-	1
Inconel "X"					O				O		X				O	X					X	O	X	X	X			X			X									3	4	7
Inconel, Otherwise Undesignated																				O																						
Incoloy 901	X																																							1	-	1
Incoloy, Otherwise Undesignated														X																												
M - 252					O			X																		X					X									3	1	4
Nimonic, Otherwise Undesignated														X																									X			
R - 235											O																O			X									1	2	3
Rene 41									O										X		O	O	O				O			O									1	0	2
Udimet 500																	O	X			O				X	O														0	2	2
Udimet 600																		X								O														1	-	1
Udimet 700																		X																						1	-	1
Waspalloy																									X																1	-	1
Undesignated																															X		X					X					

TABLE 3 (CONT'D)

HIGH STRENGTH MATERIALS X - Presently Used O - Future Use	Allison	Beech	Bell - Buffalo	Bell Helicopter	Boeing - Seattle	Boeing - Wichita	Cessna	Chance-Vought	Cleveland Pneumatic	Convair - Fort Worth	Convair - San Diego	Douglas - Tulsa	Fairchild	Firestone	Grumman	Hamilton Standard	Lockheed - Burbank	Lockheed - Georgia	Martin - Baltimore	Martin - Denver	McDonnell	North American - Columbus	North American - L. A.	Northrop	Reaction Motors	Republic	Rohr	Ryan	Sikorsky	Solar - Des Moines	Solar - San Diego	Temco	Westinghouse ACT	Wright Aeronautical		Avco	Canadair	Hawker	D. Napier & Son	Saab		Total X	Total O	Total
CHROMIUM, NICKEL, COBALT, IRON ALLOYS																																											
J - 1650																										O																1	1	1
Multimet											X																															1	1	1
N - 155											X													X			X		X						X	X						5	1	6
COBALT-BASE ALLOYS																																													
L - 605, HS 25			X															O									X	O			X										3	2	5
Undesignated								O								O																										0	0	0
IRON, ALUMINUM ALLOY																															O											0	1	1
Thermenol																																													
MOLYBDENUM																																													
Unalloyed								O			O								O									O		O											0	5	5
Moly - 0.5Ti			O		O																			X						O											1	3	4
Undesignated	O									O						O			O				O	O										O								0	0	0
BERYLLIUM																																												
Unalloyed								O									O			O			O	O		O	O	O		O											0	0	0
Alloys, Otherwise Undesignated										O																																		
COLUMBIUM								O											O																							0	2	2
TANTALIUM								O											O																							0	2	2
TUNGSTEN																			O																							0	1	1

TABLE 4

RESULTS OF SURVEY OF CASTABLE CERAMIC MANUFACTURERS AND RESEARCH INSTITUTIONS

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
1. Aber Co. Box 2535 Houston, Texas							
2. Acme Brick Co. Fort Worth 2, Texas							
3. Adamas Carbide Corp. Kenilworth, New Jersey							
4. Advanced Vacuum Products, Inc. 430 Fairfield Ave. Stamford, Connecticut	X						
5. Aetna Fire Brick Co. Oak Hill, Ohio							
6. Allied Porcenell, Inc. 6641 S. Narragansett Chicago 38, Illinois	X						
7. Alsey Brick & Tile Co. Alsey, Illinois							
8. Aluminum Company of America Chemicals Division 1501 Alcoa Bldg. Pittsburgh 19, Pennsylvania	X		X	X			X
9. Aluminum Limited Sales, Inc. 630 Fifth Ave. New York 20, N. Y.	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
10. The American Ceramics Society 4055 N. High St. Columbus 14, Ohio	X						
11. American Cyanamid Co. Ceramic Chemicals Section 30 Rockefeller Plaza New York 20, New York	X						
12. American Electro Metal Div. of Firth Sterling, Inc. 320 Yonkers Ave. Yonkers 2, New York	X						
13. American Fire Clay & Products Co. P. O. Box 157 Canfield, Ohio							
14. American Lava Corporation Chattanooga, Tennessee	X		X			X	X
15. American Potash & Chemical Corp. 99 Park Ave. New York 16, New York	X						
16. Armour Research Foundation Illinois Institute of Technology Chicago, Illinois							
17. BG Corporation 321 Broad Ave. Ridgefield, New Jersey							
18. Babcock & Wilcox Co. Refractories Div. 161 E. 42nd St. New York 17, New York	X	X			X	X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
19. Basic Inc. 845 Hanna Bldg. Cleveland 15, Ohio	X						
20. Botteile Memorial Institute 505 King Ave. Columbus 1, Ohio	X					X	X
21. Bettinger Corporation Gore St. Waltham 54, Massachusetts							
22. Bjorksten Research Laboratories P. O. Box 1175 Madison 1, Wisconsin	X					X	X
23. Botfield Refractories Co. Swanson & Clymer St. Philadelphia 47, Pennsylvania	X	X					X
24. The British Ceramic Research Association Queens Road Penkhull Stoke-on-Trent	X						
25. The British Ceramic Society Federation House Stoke-on-Trent Staffs							
26. Brush Beryllium Co. 4301 Perkins Ave. Cleveland, Ohio							
27. Butler Refractories Co. 143 Etna St. Butler, Pennsylvania	X	X					X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	
28. Godfrey L. Cabot, Inc. 38 Memorial Dr. Cambridge 42, Massachusetts	X		X	X			X
29. University of California Div. of Mineral Technology Berkeley 4, California	X						
30. University of California, L. A. Ceramics Department Los Angeles, California	X						
31. Cambridge Tile Manufacturing Co. Cincinnati 15, Ohio							
32. Carborundum Co. P. O. Box 337 Niagara Falls, New York	X	X				X	X
33. Carborundum Co. Refractories Div. Perth Amboy, New Jersey	X	X				X	X
34. Carborundum Co. Refractories Div. Latrobe, Pennsylvania Formerly Stupakoff Division	X	X				X	X
35. Cedar Height Clay Co. 50 Portsmouth Road Oak Hill, Ohio							
36. Centralab Division of Globe Union 900 E. Keefe Ave. Milwaukee 1, Wisconsin	X					X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
37. Ceramaseal Co. P. O. Box 25 New Lebanon Center, New York	X						
38. Ceramic Industry 5 S. Wabash Ave. Chicago 3. Illinois	X						
39. Ceramic Supply Co. Div. of Ferro Corp. Crooksville, Ohio	X						
40. Champion Spark Plug Co. Toledo 1, Ohio	X						
41. Chattahoochee Brick Co. Chattahoochee, Georgia						X	
42. Chicago Fire Brick Co. 1419-67 Elston Ave. Chicago 22, Illinois	X	X					X
43. Clayburn-Harbison LTD Foncier Bldg. Vancouver, B. C., Canada							
44. Clearfield Clay Products Co. P. O. Box 748 Clearfield, Pennsylvania							
45. Clemson College Dept. of Ceramic Engineering Clemson, South Carolina							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
46. Climax Fire Brick Co. Climax, Pennsylvania	X						
47. Columbia Fire Brick Co. 612 First National Bank Bldg. Canton, Ohio							
48. Department of Commerce Office of Technical Services Washington 25, D. C.	X						
49. Commercialures, Inc. Clover, South Carolina							
50. Continental Coatings Corp. 140 S. Dearborn Chicago, Illinois	X						
51. Coors Porcelain Co. 600 Ninth Street Golden, Colorado	X					X	X
52. Corhart Refractories Co., Inc. 940 Commonwealth Bldg. Louisville 2, Kentucky	X					X	X
53. Cornell Aeronautical Laboratory, Inc. of Cornell University 4455 Genesee St. Buffalo 21, New York							
54. Corning Glass Works Corning, New York	X	X				X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
55. G. & W. H. Corson, Inc. Plymouth Meeting, Pennsylvania	X	X			X		X
56. Corundite Refractories Inc. Newman & Lengholz Roads Massillon, Ohio							
57. Crescent Brick Co., Inc. Box 368 New Cumberland, West Virginia							
58. Frederick J. Dando Co. Irondale, Ohio	X						
59. Davis Fire Brick Co. Oak Hill, Ohio	X	X					
60. Denver Fire Clay Co. 2303 Blake Street Denver 17, Colorado	X					X	X
61. Diamonite Product Manufacturing Co. 1232 Cleveland Ave., N. W. Canton 3, Ohio	X						
62. J. Dirat & Co., Inc. Notre Dame St. Westfield, Massachusetts							
63. Du-Co Ceramics Co. Box 587 Butler 8, Pennsylvania	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
64. Duramic Products, Inc. 262-72 Mott St. New York 12, New York (Formerly Technion Design & Manufacturing Co.,Inc.)	X	X				X	X
65. Durex Refractories Co. Jackson, Ohio							
66. Eastern Clay Products Department International Minerals & Chemical Corp. 20 N. Wacker Dr. Chicago 6, Illinois							
67. Electrical Refractories Co. East Palestine, Ohio	X						
68. Electro Refractories & Abrasives Corp. 344 Delaware Ave. Buffalo 2, New York	X	X			X	X	X
69. Eureka Fire Brick Works Mt. Braddock, Pennsylvania							
70. Exolon Company 950 E. Niagara St. Tonawanda, New York	X		X				X
71. Federal Refractories 5300 E. Tallmadge Ave. Akron, Ohio							
72. Findlay Clay Products Co. Washington, Pennsylvania	X					X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
73. Flexibrick Refractories Co. 4209 W. Greenfield Ave. Milwaukee 4, Wisconsin							
74. Foote Mineral Co. 18 W. Chelten Ave. Philadelphia 44, Pennsylvania	X		X		X	X	X
75. J. H. France Refractories Co. 1944 France Rd. Snow Shoe, Pennsylvania	X						
76. Franklin Institute Benjamin Franklin Parkway at 20th St. Philadelphia 3, Pennsylvania	X						
77. Freeman Fire Brick Co. P. O. Box 606 Canon City, Colorado							
78. Freeport Brick Co. Box 402 Freeport, Pennsylvania							
79. Frenchtown Porcelain Co. Frenchtown, New Jersey	X					X	X
80. Fulmer Research Institute Stoke Poges Buckinghamshire, England	X						
81. Garfield Refractories Co. 320 Alberta St. Bolivar, Pennsylvania							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
82. Gem Clay Forming Co. Sebring, Ohio							
83. General Electric Co. Research Laboratories The Knolls Schenectady, New York							
84. General Refractories Co. 1520 Locust St. Philadelphia 2, Pennsylvania	X	X			X	X	X
85. Georgia Institute of Technology Atlanta, Georgia	X					X	X
86. Georgia Sanitary Pottery Co. 1800 Murphy Ave. East Point, Georgia						X	
87. Gladding, McBean & Co. 2901 Los Feliz Blvd. Los Angeles 39, California	X	X				X	X
88. Glasrock Corp. 1101 Glidden St. Atlanta, Georgia (Formerly North Brothers Foundry & Mold Co.)	X	X			X	X	X
89. Glendon Pyrophyllite Co. 1104 E. Wendover Ave. Greensboro, North Carolina	X	X	X		X		X
90. Globe Brick Co. P. O. Box 765 East Liverpool, Ohio							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
91. A. P. Green Fire Brick Co. Mexico, Missouri	X	X			X	X	X
92. Gulton Industries, Inc. 212 Durham Ave. Metuchen, New Jersey							
93. Harbison-Walker Refractory Co. Farmers Bank Bldg. Pittsburgh 22, Pennsylvania	X	X			X	X	X
94. Harshaw Chemical Co. Cleveland 6, Ohio	X						
95. Haws Refractories Co. 407 Main St. Johnstown, Pennsylvania	X						
96. Hill Brick Co. 51 St. & Claire Ave. E. St. Louis, Illinois							
97. Hurst Laboratories 514 37th St. N. St. Petersburg 2, Florida							
98. University of Illinois Dept. of Ceramic Engineering 208 Ceramics Bldg. Urbana, Illinois							
99. Illinois Clay Products Co. 68 N. Chicago St. Joliet, Illinois	X	X			X	X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECENICAL INFO.
100. Industrial Ceramic Products, Inc. Columbus 8, Ohio							
101. Inland Fire Brick Co. Berea & Elinwood Rds. Cleveland 11, Ohio							
102. Ironton Fire Brick Co. Ironton, Ohio	X	X					X
103. Johns-Manville 22 E. 40th St. New York 16, New York	X	X			X	X	X
104. E. F. Johnson Co. 224 2nd Ave., S. W. Waseca, Minnesota							
105. KLG Sparking Plugs Limited Putney Vale London, S. W. 15, England	X						
106. Kaiser Aluminum & Chemical Corp. Chemical Division Columbiana, Ohio							
107. Kearfott Co., Inc. 1378 Main Ave. Clifton, New Jersey	X					X	X
108. Kentucky - Tennessee Clay Co. Paris, Tennessee							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
109. Keystone Refractories Co., Inc. 120 Liberty St. New York 6, New York	X	X					
110. Kingsland Clay Products Co. Box 1105 Binghamton, New York	X			X	X		
111. M. Kirchberger & Co., Inc. 83-91 W. Forest Ave. Englewood, New Jersey	X						
112. Kittanning Brick Co. Adrian, Pennsylvania							
113. Kittanning Refractories Inc. P. O. Box 50 Kittanning, Pennsylvania							
114. Kohler Co. Kohler, Wisconsin	X						
115. Kyanite Mining Corp. Cullen, Virginia	X		X				X
116. Laclede-Christy Products Christy Works 4705 Ridgewood Ave. St. Louis 16, Missouri	X	X				X	
117. Homer Laughlin China Co. Newell, West Virginia	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
118. E. J. Lavino and Co. 3 Penn Center Plaza Philadelphia 2, Pennsylvania	X		X				
119. Lithium Corporation of America 2555 Rand Tower Minneapolis 2, Minnesota							
120. Lockheed Aircraft Corporation Missiles System Division Sunnyvale, California	X						X
121. University of London Prince Consort Road South Kensington London, S. W. 7, England	X						X
122. Louisville Fire Brick Works, Inc. 4554 Louisville Ave. Louisville, Kentucky							
123. Louthan Manufacturing Co. 2000 Harvey Ave. Box 86 East Liverpool, Ohio	X						
124. Malvern Brick & Tile Co. Box 415 Malvern, Arkansas							
125. Marquardt Aircraft Co. 16555 Saticoy St. P. O. Box 2013, South Annex Van Nuys, California						X	X
126. Massachusetts Institute of Technology Dept. of Metallurgy, Div. of Ceramics Cambridge 39, Massachusetts							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
127. Massillon Refractories Co. 1939 Prentice St. Massillon, Ohio							
128. Materials in Design Engineering Reinhold Publishing Corp. 430 Park Ave. New York 22, New York	X						
129. Joseph A. McCollum, Inc. 109 N. 14th St. Camden, New Jersey							
130. McCrady Refractories, Inc. P. O. Box 11566 Pittsburgh 38, Pennsylvania							
131. McDanel Refractory Porcelain Co. Beaver Falls, Pennsylvania	X						
132. Mellon Institute 4400 5th Ave. Pittsburgh 13, Pennsylvania							
133. Merix Chemical Co. 1021 E. 55th St. Chicago 15, Illinois							
134. Mexico Refractories Co. Mexico, Missouri	X	X			X	X	X
135. Mt. Jewett Fire Clay Co. Mt. Jewett, Pennsylvania							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
136. Mt. Savage Refractory Co. 1028 Grant Bldg. Pittsburgh, Pennsylvania							
137. Murray Refractories Co. P. O. Box 338 Murray, Utah							
138. National Bureau of Standards Engineering Ceramics Section Washington 25, D. C.	X						
139. National Carbon Co. Div. of Union Carbide & Carbon Co. W. 117th St. and Madison Ave. Cleveland, Ohio	X					X	
140. National Refractories Co. 225 S. 15th St. Philadelphia, Pennsylvania							
141. National Refractories Limited Port Robinson Ontario, Canada							
142. Department of the Navy Office of Naval Research Materials Branch Washington 25, D. C.							
143. New Castle Refractories Co. New Castle, Pennsylvania							
144. State University of New York College of Ceramics at Alfred University Alfred, New York	X					X	X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
145. Niles Fire Brick Div. of Mexico Refractories Co. 165 E. Park Ave. Niles, Ohio							
146. North American Refractories Co. National City E. 6th Bldg. Cleveland 14, Ohio	X	X			X	X	X
147. North State Pyrophyllite Co., Inc. Greensboro, North Carolina	X		X				X
148. Norton Co. Worcester 6, Massachusetts	X	X					X
149. Oak Hill Fire Brick Co. Oak Hill, Ohio							
150. Ohio State University Engineering Experiment Station Columbus 10, Ohio	X					X	X
151. Old Hickory Clay Co. P. O. Box 271 Paducah, Kentucky	X			X	X		X
152. Orefraction, Inc. 7425 Thomas St. Pittsburgh 8, Pennsylvania							
153. Owens-Illinois Glass Co. Owens-Illinois Bldg. Toledo 1, Ohio	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
154. The Pennsylvania State University College of Mineral Industries University Park, Pennsylvania	X					X	X
155. George F. Pettings, Inc. 1200 Locust St. Philadelphia, Pennsylvania							
156. Plibrico Co. 1800 Kingsbury St. Chicago 14, Illinois	X	X			X	X	X
157. Poor & Co. Promat Div. 851 S. Market St. Waukegan, Illinois	X						
158. Frank B. Pope Co. Frick Bldg. Pittsburgh 19, Pennsylvania							
159. H. K. Porter Co., Inc. Mullite Works 185 Canal St. Shelton, Connecticut	X						
160. Portsmouth Clay Refractories Co. South Webster, Ohio							
161. Pure Carbon Co., Inc. St. Marys, Pennsylvania	X						
162. Pyro Refractories Co. P. O. Box 466 Oak Hill, Ohio	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
163. Quigley Co., Inc. 527 5th Ave. New York, New York							
164. Ramtite Co. Div. of S. Obermayer Co. 2563 W. 18th St. Chicago 8, Illinois	X	X					X
165. Raytheon Manufacturing Co. Waltham, Massachusetts							
166. Refractories Institute Pittsburgh 22, Pennsylvania	X						
167. Refractory & Insulation Corp. 120 Wall St. New York 5, New York	X	X			X	X	X
168. Refractory Specialties Co. 2200 Washington Ave. Philadelphia 46, Pennsylvania	X	X			X	X	X
169. Richard C. Remmey & Sons Hadley St. & Delaware River Philadelphia 37, Pennsylvania	X	X				X	X
170. Rensselaer Polytechnic Institute Ceramics Dept. Troy, New York							
171. Robinson Clay Products Co. Akron 9, Ohio	X	X			X		X

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
172. Rutgers University New Brunswick, New Jersey	X					X	X
173. S-K-C Research Associates 445 5th Ave. Patterson 4, New Jersey							
174. Frank Samual & Co., Inc. 2212 Lincoln Liberty Bldg. Philadelphia 7, Pennsylvania							
175. Sauereisen Cements Co. 3389 Sharpsburg Station Pittsburgh 15, Pennsylvania	X	X					X
176. Saxonburg Ceramics Saxonburg, Pennsylvania	X						
177. Secon Metals 7 Intervale White Plains, New York							
178. Selas Corporation of America Dresher, Pennsylvania	X					X	X
179. Shenango Refractories Div. of Shenango China, Inc. P. O. Box 120 New Castle, Pennsylvania	X	X			X		
180. Sintercast Corporation of America 130 Woodworth Ave. Yonkers 2, New York							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
181. H. C. Spinks Clay Co., Inc. P. O. Box 829 Paris, Tennessee							
182. Sprague Electric Co. Marshall St. North Adams, Massachusetts	X						
183. Sprague of Wisconsin, Inc. 6th & Beech Sts. Grafton, Wisconsin							
184. Standard Fire Brick Co. P. O. Box 1614 Pueblo, Colorado							
185. Standard Fuel Engineering Co. 667 Post Ave., South Detroit 17, Michigan							
186. Stanford Research Institute Menlo Park, California	X						X
187. Star Porcelain Co. Muirhead Ave. Trenton 9, New Jersey	X						
188. Structural Clay Products Research Foundation Geneva, Illinois							
189. Hiram Swank's Sons P. O. Drawer 630 Johnstown, Pennsylvania	X						

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
190. Sylvania Electric Products, Inc. Bayside, New Jersey							
191. Charles Taylor, Sons Co. P. O. Box 58 - Annex Station Cincinnati 14, Ohio	X	X			X	X	X
192. Titanium Alloy Manufacturing Div. National Lead Co. Hyde Park Blvd. & Lafayette Ave. Niagara Falls, New York	X	X				X	X
193. United States Ceramic Tile Co. 217 Fourth St., N. E. Canton 2, Ohio	X						
194. United States Stoneware Co. Alite Division P. O. Box 119 Orrville, Ohio	X						
195. Universal Atlas Cement Co. 100 Park Ave. New York 17, N. Y.	X			X	X	X	X
196. Wahl Refractory Products Co. 420 Dickenson St. Fremont, Ohio							
197. Walsh Refractories Corp. 101 Ferry St. St. Louis 7, Missouri	X	X			X	X	X
198. Wellsville Fire Brick Co. Wellsville, Missouri							

TABLE 4 (Cont'd)

COMPANY NAME AND ADDRESS	ANSWERED INQUIRY	CASTABLE MANUFACTURER	BODY MANUFACTURER	BINDER MANUFACTURER	SUPPLIED SAMPLE MATERIAL	VISITED	REC'D. TECHNICAL INFO.
199. West Darlington Clay Div. Metropolitan Brick, Inc. 1017 Renkert Bldg. Canton, Ohio							
200. West Virginia Fire Clay Manufacturing Co. 708 May Bldg. Pittsburgh 22, Pennsylvania							
201. Western Refractories Co. P. O. Box 1145 San Jose, California							
202. Whitacre - Greer Fireproofing Co. Waynesburg, Ohio	X						
203. Winburn Tile Manufacturing Co. P. O. Box 1369 Little Rock, Arkansas							
204. Zirconium Corporation of America Solon, Ohio	X	X	X				X

TABLE 5

RESULTS OF SURVEY OF DOMESTIC AND FOREIGN AIRCRAFT AND ALLIED COMPANIES CONTACTED

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
1. Aero Design & Engineering Co. Tulakes Airport Oklahoma City, Oklahoma				
2. Aerojet - General Corporation Box 296 Azusa, California				
3. Allison Division General Motors Corporation Indianapolis, Indiana	X			
4. Beech Aircraft Corporation Wichita 1, Kansas	X			
5. Bell Aircraft Corporation P. O. Box 1 Buffalo 5, New York	X		X	X
6. Bell Helicopter Corporation P. O. Box 482 Fort Worth 1, Texas			X	
7. Boeing Airplane Company P. O. Box 3707 Seattle 24, Washington	X		X	X
8. Boeing Airplane Company Wichita, Kansas			X	
9. Cessna Aircraft Company P. O. Box 1977 Wichita 1, Kansas	X			

TABLE 5 (Cont'd)

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
10. Chance Vought Aircraft, Inc. P. O. Box 5907 Dallas, Texas	X		X	X
11. Cleveland Pneumatic Tool Co. 3781 E. 77th Street Cleveland 5, Ohio	X		X	
12. Convair, Division of General Dynamics Corp. Fort Worth, Texas	X		X	X
13. Convair, Division of General Dynamics Corp. San Diego, California	X		X	
14. Douglas Aircraft Company, Inc. 3000 Ocean Park Blvd. Santa Monica, California		X	X	
15. Douglas Aircraft Company, Inc. Tulsa, Oklahoma	X		X	
16. Fairchild Engine & Airplane Corp. Fairchild Aircraft Div. Hagerstown, Maryland	X		X	
17. Firestone Tire & Rubber Co. 1200 Firestone Parkway Akron 17, Ohio	X			
18. Flight Refueling, Inc. P. O. Box 1701 Baltimore 3, Maryland				

TABLE 5 (Cont'd)

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
19. Ford Motor Co., Aircraft Division 7401 S. Cicero Avenue Chicago 29, Illinois				
20. The Garrett Corporation AiResearch Mfg. Div. 9851 Sepulveda Blvd. Los Angeles 45, California				
21. General Electric Co. AGT Division Evendale, Ohio				
22. Goodyear Aircraft Corporation Akron 15, Ohio				
23. Grumman Aircraft Engineering Corp. Bethpage, L. I., New York	X		X	X
24. Hamilton Standard Div. United Aircraft Corp. Windsor Locks, Connecticut	X			
25. Hiller Helicopter Palo Alto, California		X		
26. Hughes Tool Company Aircraft Div. Culver City, California				
27. Jack & Heintz, Inc. Cleveland 1, Ohio				

TABLE 5 (Cont'd)

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
28. Lockheed Aircraft Corp. Burbank, California	X			
29. Lockheed Aircraft Corp. Missiles Div. Sunnyvale, California				
30. Lockheed Aircraft Corp. Missiles Div. Van Nuys, California				
31. Lockheed Aircraft Corp. Georgia Division Marietta, Georgia	Contractor			
32. Marquardt Aircraft Co. 16555 Saticoy St. Van Nuys, California		X	X	X
33. The Martin Co. Baltimore 3, Maryland	X		X	X
34. The Martin Co. P. O. Box 179 Denver 2, Colorado	X		X	
35. McDonnell Aircraft Corporation Lambert-St. Louis Municipal Airport P. O. Box 516 St. Louis 3, Missouri	X		X	
36. North American Aviation, Inc. 4300 E. Fifth Ave. Columbus 16, Ohio	X		X	

TABLE 5 (Cont'd)

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
37. North American Aviation, Inc. International Airport Los Angeles 45, California	X		X	X
38. Northrop Aircraft, Inc. 1001 E. Broadway Hawthorne, California			X	
39. Plasecki Aircraft Corporation Island Rd., International Airport Philadelphia 42, Pennsylvania				
40. Pratt & Whitney Aircraft Div. United Aircraft Corp. East Hartford 8, Connecticut				
41. Reaction Motors, Inc. Denville, New Jersey				
42. Republic Aviation Corporation Farmingdale, L. I., New York			X	
43. Rohr Aircraft Corporation P. O. Box 878 Chula Vista, California	X		X	X
44. Ryan Aeronautical Company 2701 Harbor Drive San Diego 12, California	X		X	X
45. Sikorsky Aircraft Division South Avenue Bridgeport, Connecticut				

TABLE 5 (Cont'd)

AIRCRAFT AND ALLIED COMPANIES	QUESTIONNAIRE COMPLETED	RETURNED INCOMPLETE	VISITED	CERAMIC TOOLING ACTIVITY
46. Solar Aircraft Company Des Moines, Iowa				X
47. Solar Aircraft Company 2200 Pacific Highway San Diego 12, California			X	
48. Temco Aircraft Corporation P. O. Box 6191 Dallas 2, Texas			X	
49. Westinghouse Electric Corporation AGT Division P. O. Box 288 Kansas City, Missouri	X			
50. Wright Aeronautical Division Curtiss-Wright Corp. Wood-Ridge, New Jersey			X	X

TABLE 6 PRESENT AND ANTICIPATED HOT FORMING TECHNIQUES

AIRCRAFT AND ALLIED COMPANIES X - Presently used O - Anticipated for future use	OVEN (TRANSFER)	HOT OIL	HOT SALT BATH	MOLTEN METAL	GAS FIRED - HEATING OF PART	GAS FIRED - HEATED TOOLS	HOT PLATEN PRESS	ELEMENT HEATED METALLIC TOOLS	ELEMENT HEATED CERAMIC TOOLS	RESISTANCE HEATING OF PART	INDUCTION HEATING OF PART	QUARTZ LAMP HEATING OF PART	ULTRASONICS	GAMMA RAY BOMBARDMENT	SOLAR FURNACES	ELECTRON FURNACES
Allison								X		X						
Beech	X							X		X						
Bell - Buffalo	X						X			X						
Boeing - Seattle					X	X		X		X	O	O	O	O	O	O
Boeing - Wichita												X				
Chance - Vought							X	X		X						
Cleveland Pneumatic											X					
Convair - Fort Worth	X					X		X								
Convair - San Diego	X							X		O						
Grumman										O		O				
Lockheed - Burbank	X							X		O	O					
Lockheed - Georgia	X	X					X	X	O	X	X	O				
Martin - Denver							O	X				O				
McDonnell	X						O			O						
North American - Columbus							X	X	O	O	O	O				
North American - Los Angeles	X		O				X			X	X					
Northrop		X		X	X			X		X						
Republic	X							X		X						
Rohr	X							X		X						
Ryan	X						X			X		O				
Sikorsky	X						X	X		O	O					
Solar - Des Moines					X			X		O	O					
Solar - San Diego								X			X					
Temco					X			X		O	O					
Avro	X				X			X		O	O					
Canadair	X				X			X								
D. Napier & Son	X				X											

TABLE 7 - REPORTED DATA ON CASTABLE REFRACTORIES

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.1A.1	Light weight Aggregate (Alumina-Silicate) plus Calcium-Aluminate Cement	Cast		R.T. 220 F 550 1200 1500 1750 2000								Good	Good	2000 F	Dried 56#/ft³	Mix 57# base mat'l. to 43# Ca. Aluminate cement for casting. Add 20.5% water by weight.
3.1.1B.1	Silica grog plus Ca. Aluminate	Tamped	24 48 24	R.T. R.T. 220 F 550 1200 1500 1750	456 675 1027 553 399				 0% -2.0%		1.79 2.51 2.73	Ave.	Good	1800 F		Mix 50# grog to 50# Ca. Aluminate cement. Add 80% water by weight for tamping consistency. Mix water with grog before adding cement. Moist cure 24 hours.
3.1.1C.1		Slap Troweled or Gunned	24 5 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400	9429 5775 4695 4502 3462 3547		1026 871 563 446		-0.3% -0.9% -1.0% -1.4% -3.9% -13.3%			Ave.	Good	2300 F	Dried 120#/ft³ Fired 5 hrs. 1750 F 115#/ft³	Mix with 16% water by weight. Moist cure 24 hours. Maximum strength in 3 days.
3.1.1D.1	Silica-Alumina and Hydraulic Setting Cement	Cast	12 5 5 5 5 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400 2800	630 595 490 690 1690				 -0.2% -0.3% -0.5% +0.3%		 2.22 2.46 2.74	Good	Good	2400 F	Dried 80#/ft³ Fired 1750 F 5 hrs. 75#/ft³	Mix with 40-50% water by weight; 20-25 qts. per 100#. Air setting.
3.1.1E.1	Silica-Alumina and Hydraulic Setting Cement	Cast	12 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400 2800	700 560 300 580 1500				 0% 0% +0.3% +1.6% -1.1%		 3.85 4.12 4.33	Good	Good	2500 F	Dried 115#/ft³ Fired 5 hrs. 1750 F 110#/ft³	Mix with 18-21% water by weight; 9-10½ qts. per 100#. Air setting.
3.1.1F.1	Hi-Alumina plus Hydraulic Setting Cement	Cast	12 5 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400 3000	1670 1065 775 715 1150				 -0.2% -0.2% -0.2% -0.4% -0.7%		 4.60 4.90 5.15 5.40	Good	Good	3000 F	Dried 134#/ft³ Fired 5 hrs. 1750 F 130#/ft³	Mix with 12-15% water by weight; 6-7½ qts. per 100#. Air setting.

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.1G.1	Silica-Alumina plus Hydraulic Setting Cement	Cast	12 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400	1310 1190 740 1190 2130				0% -0.2% -0.6% +1.6%		3.85 4.11	Good	Good	2500 F	Dried 110#/ft³ Fired 5 hrs. 1750 F 110#/ft³	Mix with 13-21% water by weight; 9-10½ qts. per 100#. Air setting.
3.1.1H.1	Silica-Alumina plus Hydraulic Setting Cement	Cast	12 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000	220 210 220 320				-0.2% -0.4% -0.6%		1.68 1.81 1.93	Good	Good	2200 F	Dried 62#/ft³ Fired 5 hrs. 1750 F 58#/ft³	Mix with 62-70% water by weight; 31-35 qts. per 100#. Air setting.
3.1.1J.1	Hi-Alumina plus Hydraulic Setting Cement	Slap Troweled or Gunned	12 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400	570 700 790 1040 2390				0% 0% -0.2% -0.2%		4.60 4.90 5.15 5.40	Good	Good	3000 F	Dried, Trow'd 133#/ft³ Gunned 142#/ft³ Fired 25 hrs. 1750 F Trow'd 130#/ft³ Gunned 140#/ft³	Mix with 13-16% water by weight; 6½-8 qts. per 100#. Air setting.
3.1.1K.1	Silica-Alumina plus Hydraulic Setting Cement	Slap Troweled or Gunned	12 5 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000 2200 2400	1350 1070 1130 1480 2870				-0.1% -0.4% -0.6% -0.4%		3.85 4.11 4.30	Good	Good	2400 F	Dried, Trow'd 116#/ft³ Gunned 124#/ft³ Fired 5 hrs. 1750 F Trow'd 113#/ft³ Gunned 118#/ft³	Mix with 20% water by weight; 10 qts. per 100#. Air setting.
3.1.1L.1	Silica-Alumina plus Hydraulic Setting Cement	Slap Troweled or Gunned	12 5 5 5 5	R.T. 220 F 550 1200 1500 1750 2000	275 338 400 461				-0.3% -0.6% -0.8%		1.61 1.71 1.78	Good	Good	2000 F	Dried, Trow'd 69#/ft³ Gunned 76#/ft³ Fired 5 hrs. 1750 F Trow'd 65#/ft³ Gunned 73#/ft³	Mix with 60% water by weight; 30 qts. per 100#. Air setting.
3.1.1M.1	Chrome Ore plus Hydraulic Setting Cement	Cast												3200 F	Dried 180#/ft³	

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.1M.1	51% Alumina - 40% Silica plus Ca. Aluminate Cement	Cast	24	R.T. 220 F 550 1200 1500 1750 2000 2200 2400	340 530 474 596 653 862				-0.1% -0.08% -0.16% -0.32% -0.3%			Good	Good	2600 F	Dried 77#/ft³	Mix with 45% water by weight.
3.1.2A.1	Silica-Alumina plus Hydraulic Setting Cement	Cast		R.T. 220 F 550 1000 1500 2000 2250	25-4000 14-2700 16-2400 16-2400 20-3000		7-1000 35-550 35-550 35-550 90-750		-0.1% -.5-.1% -.5-.1% -.5-.1% -.2-.5%		4.40 4.58 4.85	Good	Good	2500 F	Dried 135#/ft³ Fired 1500 F 128#/ft³	Mix with 1½ gal. water per 100#. Place in 20 minutes after mixing. High strength hydraulic setting.
3.1.2D.1	Flint Fireclay plus Ca. Aluminate Cement	Cast	24 6-24	R.T. 220 F 550 1500 2000 2250 2500	 10-1500 6-900 5-750 70-1000 25-4000		 3-450 175-275 150-225 300-450 10-1500		0-.1% -0.1% -0.2% -0.5% 0+.5%		3.3 4.2	Good	Good	2700 F	Dried 110#/ft³	Mix with 1 3/4 gals. water to 100#. Can be varied from 2 to 1¾ gals. Sets in 20 minutes.
3.1.2C.1	Flint Fireclay plus Ca. Aluminate Cement	Cast	24 6-24	R.T. 220 F 550 1000 1500 2000 2250 2500	0-1200		225-350 150-225 150-225 175-275 200-300		-0.1% -0.2% -0.3% -0.3% 0+.5%			Good	Good	2500 F	Dried 103#/ft³ Fired 2000 F 83#/ft³	Mix with 1 3/4 gals. water to 100#. 1¾ to 4¼ limits. Sets in 20 minutes.
3.1.2B.1	Super duty grog plus Hydraulic Setting Cement	Cast Rammed Gunned	Must Be Cured Slowly At R.T. 24 Hrs.	R.T. 220 600 1000 1200 1500 1800	35-5500 30-4500 20-3000 14-2100 450-700 200-300		700-1000 600-900 400-600 225-350 125-200 100-150		0-.1% -.1-.2% -.2-.3% -.3-.5% -.3-.5% -.3-.5%		4.29 4.53 4.71	Av.	Good	1200 F For Abrasion 2200 F For Heat Only	Dried 130#/ft³ Fired 1500 F 125#/ft³	Mix with 1 3/4 gals. water to 100#. Sets in 30 minutes. For section + 6" punch 1/2 dia. holes on 6" centers for drying.
3.1.2E.1	Unknown	Cast Tamped	24	R.T. 220 600 1000 1500	 75						.6			1600 F	Dried 122#/ft³	Mix with 1¼ gals. water to 50#. 11 to 12 gal. limits. Sets in 30 minutes.
3.1.2F.1	Unknown		24	R.T. 220 600 1000 1200 1500 2000	250		150				1.57			2000 F	Dried 95#/ft³	Mix with 3 gals. water to 50#. Sets in 20 minutes.

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN/IN/°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.2G.1	Fireclay plus Hydraulic Cement	Cast Rammed Gunned	24	R.T. 220 F 600 1000 1200 1500 2000 2250	14-2100 1350-2000 12-1800 12-1600 13-2000		600-900 400-600 400-600 400-600 500-750		.0-.1% -.1-.2% -.1-.2% -.1-.2% +.3-.5%		3.8 4.01 4.17	Good	Good	2500 F	Dried 124#/ft³ Fired 1500 F 117#/ft³	Same coefficient of expansion as steel.
3.1.3A.1	Calcined Kaolin plus Portland Cement	Cast	48 18-24 5 5 5	R.T. 220 F 550 1000 1500 2000	750 500 450 250		180 90		0 -0.5% -0.6% -0.7%		Prefired 2000 F 1.53 1.84	Av.	Shrinks 0.7%	2000 F	Molded 93#/ft³ Dried 96#/ft³ Fired 53#/ft³	
3.1.3B.1	Calcined Kaolin plus Ca. Aluminate Cement	Cast	48 18-24 5 5 5 5	R.T. 220 F 550 1000 1500 2000 2200	200 200 250 250 250		100 140		-0.155% -0.1% -0.3% -0.3% -0.4% -0.6%		Prefired 2000 F 1.53 1.84		Shrinks 0.6%	2200 F	Molded 98#/ft³ Dried 63#/ft³ Fired 57#/ft³	
3.1.3C.1	Calcined Kaolin plus Ca. Aluminate Cement	Cast Rammed	48 18-24 5 5 5 5 5	R.T. 220 550 1000 1500 2000 2200 2400	3500 2200 1950 1500 2200 3000		820 350 325 325 1000		-0.022% -0.1% -0.1% -0.3% -0.5% -0.6%		Prefired 2400 F 7.19 7.30 7.28	Av.	Grows 0.6%	2400 F	Molded 140#/ft³ Dried 135#/ft³ Fired 128#/ft³	Good abrasion resistance. Cast with use of internal vibrator. Spray with water during R.T. curing cycle.
3.1.3D.1	Calcined Kaolin plus Portland Cement	Cast	48 18-24 5 5 5 5	R.T. 220 550 1000 1500 2000 2200	1000 700 710 250 250		450 400 240 250		-0.2% -0.5% -1.2% -1.6% -1.8%			Av.	Shrinks 1.6%	2300 F	Molded 130#/ft³ Dried 108#/ft³ Fired 103#/ft³	Thin sections only. Plastic-like material.
3.1.3E.1	Calcined Kaolin plus Portland Cement	Cast Rammed	48 18-24 5 5 5 5 5 5	R.T. 220 550 1000 1500 2000 2200 2400 2600	2500 1500 500 400 1500 2500 4000		700 600 150 400		0 -0.1% -0.2% -0.3% -0.2% -0.2% -0.2%		Prefired 2400 F 5.50 6.14 6.62	Av.	Grows 1.3%	2600 F	Molded 136#/ft³ Dried 127#/ft³ Fired 124#/ft³	Resists erosion. Cast with use of internal vibrator.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN /IN /°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.3F.1	Calcined Alumina-Silica Aggregate plus Ca. Aluminate Cement	Cast Rammed	48 18-24 5 5 5 5 5 5 5	R.T. 220 550 1000 1500 2000 2200 2400 2600 3000	800 700 500 400 500 500 1000 3500		400 230 160 170 530		0 0 -0.3% -0.3% -0.5% -0.5% -0.5% -0.5% -0.3%		Prefired 2400 F 7.8	Good	Shrinks 0.5%	3000 F	Molded 146#/ft³ Dried 128#/ft³ Fired 126#/ft³	Good volume stability. Resists spalling. Cast with use of internal vibrator. High humidity during R.T. cure.
3.1.3G.1	Chrome Ore plus Ca. Aluminate Cement	Cast Rammed	48 18-24 5 5 5 5 5 5 5	R.T. 220 1000 1500 2000 2200 2600 2800 3000	1000 600 600 600 600 3000 3000 4000		250 260 300 250 1400		0 -0.1% -0.3% -0.4% -0.6% -0.7% -0.7% -1.0% -1.0%			Av.	Shrinks 1.0%	3100 F	Molded Dried 178#/ft³ Fired 174#/ft³	Good volume stability. Stands high temperature without deformation. Cast with use of internal vibrator. High humidity during R.T. cure.
3.1.3H.1	Fused Mullite	Rammed		R.T. 220 1000 2000 2500 2800 3000 3200	1200 2000 6000		290 350 1500 2200 2400 2500 2800		-0.2% -0.3% -0.4% -0.4% -0.5% -0.5% -0.6%					3200 F	Molded Dried 160#/ft³ Fired 155#/ft³	
3.1.3J.1	Calcined Kaolin plus Ca. Aluminate Cement	Cast Rammed	48 18-24 5-24	R.T. 220 2000 2400			980 320		0 -0.4%			Av.	Good	2600 F	Dried 131#/ft³ Fired 118#/ft³	Cast with use of internal vibrator.
3.1.3K.1	Calcined Kaolin plus Ca. Aluminate Cement	Cast Rammed	48 18-24 5-24	R.T. 220 2000 2400			1090 357		0 -0.2%			Av.	Good	2600 F	Dried 131#/ft³ Fired 118#/ft³	Cast with use of internal vibrator.
3.1.3M.1	Calcined Kaolin plus Ca. Aluminate Cement	Cast Rammed												2600 F		
3.1.5A.1	Tabular-Alumina plus Ca. Aluminate Cement	Cast or Troweled		R.T. 220 600 1000 1500 2000 2250 2400 2732 2910	63-7400 65-7100 70-7200 65-7100 40-4500 38-4100 39-4300 55-6100 63-7000		16-2000 16-1900 17-2100 17-2000 10-1300 10-1200 11-1300 12-1500 16-2000		-.1-.2% -.1-.2% -.2-.3% -.3-.4% -.1+.3% -.4-.6% -.4-.6% -.4-.6% -.2-.4%	$4.5_5 \times 10^{-6}$	9.8 9.46 9.36 9.57			3400 F	Dried 165#/ft³ Fired 2000 F 157#/ft³	Mix with 10-11% water by weight.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.5E.1	Alumina-Silica plus Ca. Aluminate Cement	Cast or Troweled		R.T. 220 F 600 1000 1500 2000 2250 2400 2732 2910	17-2500 16-2500 16-2400 15-2100 12-1500 22-2600 26-4400 40-5900 69-7400		6-750 5-700 4-560 3-460 3-400 6-900 9-1100 9-1100 13-1500		-.1-.3% -.1-.3% -.1-.3% -.1-.3% -.1-.3% -.4-.6% -.5-1% -.5-.8% -.3-.5%		6.4 6.15 5.80 5.72			3000 F	Dried 142#/ft³ Fired 2000 F 139#/ft³	Mix with 10-12% water by weight.
3.1.5G.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	1280-1460 990-1170 785-1000 660-805 645-760 750-860 2200-2520		360-410 280-330 220-280 140-170 110-130 280-320 900-1020		-.1-.2% -.1-.2% -.1-.2% -.1-.4% -.1-.3% -.1-.3% 1.6+1.1		4.32 5.12 5.50 5.88			2700 F	Dried 133#/ft³ Fired 2000 F 128#/ft³	Mix with 10-13% water by weight.
3.1.5D.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	990-1120 795-910 720-830 570-660 490-560 1780-2380 2750-3400		280-330 210-240 190-220 150-175 150-180 490-600 500-650		-.1-.3% -.1-.3% -.1-.3% -.1-.4% -.2-.4% -.1-.3% +.8+.6%		4.68 5.00 5.40 5.80			2800 F	Dried 127#/ft³ Fired 2000 F 122#/ft³	Mix with 14.5-16.5% water by weight.
3.1.5F.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	990-1170 800-990 665-855 630-840 640-850 750-900 1720-2440		310-450 250-310 200-250 150-200 130-175 250-310 630-700		-.1-.3% -.1-.3% -.1-.3% -.2-.4% -.4-.6% -.4-.6% +.1+.6%		4.06 4.33 4.68 5.02			2600 F	Dried 119#/ft³ Fired 2000 F 111#/ft³	Mix with 17-21% water by weight.
3.1.5F.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	1500-2000 1100-1350 990-1400 950-1300 850-1080 1100-1800 1900-2600		460-600 350-500 275-340 250-310 210-280 240-400 530-670		-.3-.5% -.3-.5% -.3-.5% -.4-.6% -.5-.7% -.6+.7% -.4+.9%		4.17 4.45 4.81 5.17			2600 F	Dried 121#/ft³ Fired 2000 F 113#/ft³	Mix with 16-18% water by weight.
3.1.5G.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	1800-2220 985-1220 1100-1400 1070-1315 840-870 1080-1340 1750-2470		500-675 250-350 250-345 225-310 200-300 275-380 690-850		-.1-.3% -.1-.3% -.1-.3% -.3-.4% -.3-.4% -.3-.5% -.1-.5%		4.21 4.53 4.92 5.33			2600 F	Dried 122#/ft³ Fired 2000 F 115#/ft³	Mix with 14-16% water by weight.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.5H.1	Fireclay grog plus Hydraulic Cement	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2400	3410 4070 3772 3515 2764 4212		1416 969 984 1120 972 1217		-0.2% -0.2% -0.2% -0.2% -0.2% -1.0%		5.20 5.10 5.10 5.18			2400 F	Dried 135#/ft³ Fired 2000 F 124#/ft³	Mix with 12.6% water by weight.
3.1.5J.1	Fireclay grog plus Ca. Aluminate	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250	3000-3800 2800-3250 2800-3250 1200-1350 800-900 3000-4500		980-1160 900-1200 900-1200 300-375 275-350 700-1000		-.1-.3% -.1-.3% -.1-.3% -.4-.9% -.6-.8% -1.5-2%		4.18 4.48 4.85 5.19			2300 F	Dried 120#/ft³ Fired 2000 F 114#/ft³	Mix with 17-20% water by weight.
3.1.5K.1	Fireclay grog plus Ca. Aluminate	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000	4805-5620 3250-4040 2300-2300 1020-1460 850-980		850-1025 780-940 500-610 425-560 220-300		-.3-.5% -.4-.6% -.4-.6% -.5-.7% -.5-.8%		4.50 4.81 5.15 5.52			2200 F	Dried 128#/ft³ Fired 2000 F 122#/ft³	Mix with 15-16% water by weight
3.1.5L.1	Unknown	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000	5335-5740 3620-3980 2260-2685 990-1160 820-940		980-1147 870-1010 510-580 320-384 200-280		-.3-.5% -.4-.6% -.5-.7% -.5-.7% -.6-.8%		4.47 4.77 5.10 5.48			2200 F	Dried 127#/ft³ Fired 2000 F 121#/ft³	Mix with 15-16% water by weight.
3.1.5M.1	Unknown	Cast Troweled Extruded		R.T. 220 F 600 1000 1500 2000 2250 2400	585-985 525-860 490-830 430-710 500-800 500-810 790-1330		190-320 170-280 160-270 140-230 155-250 155-250 160-270		-.4-.6% -.4-.6% -.4-.6% -.6-.3% -.6-.8% -.9-1.4 +.1-.4%		2.63 2.83 3.14 3.42			2500 F	Dried 87#/ft³ Fired 2000 F 81#/ft³	Mix with 40-47% water by weight.
3.1.5N.1	Unknown	Cast Troweled Extruded		R.T. 220 F 600 1000 1500	390-490 310-400 300-395 295-390		200-250 160-210 145-190 205-140		-.3-.5% -.5-.7% -.8-1% -1.4-2%		1.46 1.69 2.00			1800 F	Dried 49#/ft³ Fired 1500 F 43#/ft³	Mix with 46-55% water by weight.
3.1.5P.1	Unknown	Cast Troweled Extruded		R.T. 220 F 600 1000 1500			55 48 40 15		-0.3% -0.5% -0.7% -1.1%		0.95 1.18 1.42			1600 F	Dried 25#/ft³ Fired 1500 F 22#/ft³	Mix with 176% water by weight.
3.1.5Q.1	Tabular-Alumina plus Phos.-Acid Bond	Cast		R.T. 600 F 1000 1500 2000	7474		1500-2000 1500-2000 1500-2000 1500-2000				9.1	Good	Good	3600 F	Dried Fired 147#/ft³	High erosion resistance.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.6A.2	Fused Alumina plus Ca. Aluminate Cement	Cast		R.T. 220 F 600 1000 1800 2400				63	Low	8.6×10^{-6}	7.3 7.3 7.3 7.3 8.1	Good		3100 F	Dried 70#/ft^3 Fired 86#/ft^3	
3.1.6D.1	Lithium Alumino Silicate plus unknown binder	Cast	24 24 4	R.T. 220 2000												Experimental material
3.1.6A.1	Alumina plus Hydraulic Cement	Cast		R.T. 220 F 600 1000 1500 2000 2250 2400 2732 2910			750 680 600 500 450 425 600 680 880 950		0.0 -.017% -.021% -.017% -.021% -.025% -.029% -.033% -.083%		7.1 6.2 5.8 5.7 5.6 5.5 5.5			3300 F Hot Face	Dried 100#/ft^3	Mix with 18 pints water per 100#. Sets in 18-24 hours.
3.1.8B.1	Alumina plus Hydraulic Cement	Cast		R.T. 220 F 1000 1500 2000 2500 3000			2150 1200 800 700 1500 2600		0.0 -.25% -.25% -.17% -.21% -1.65%	4.4×10^{-6}	 20.5 17.0 15.5 15.0 14.5			3300 F Hot Face	Dried 170#/ft^3	Mix with 11 pints water per 100#. Sets in 14-24 hours.
3.1.8C.1	Magnesium Oxide plus Calcium Aluminate	Cast	24 24 4	R.T. R.T. 2400												Experimental material
3.1.8D.1	Silicon Carbide plus unknown binder	Cast	24 24 4	R.T. 220 2400												Experimental material
3.1.9A.1	Silica-Alumina plus Ca. Aluminate Cement	Cast		R.T. 220 F 1000 1500 2000 2500 2800			390 260 220 250 430		Nil Nil -0.4% -0.7%					2700 F	Dried 110#/ft^3	Mix with 9 qts. water per 100#.
3.1.9B.1	Alumina-Silica plus Ca. Aluminate Cement	Cast		R.T. 220 F 1000 1500 2000 2500			1000 490 440 480 950		Nil -0.1% -0.2%					2500 F	Dried 114#/ft^3	Mix with 9½ qts. water per 100#.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN. / IN. /°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.10A.1	Unknown	Cast	40 8	R.T. 220 F 1000 1500 2000 2500 3000	3600 3300 2500 2400 3600 4400				0 -0.16% -0.175% -0.155% -0.18% -0.3%	1.25×10^{-6}	16		Good	3000 F	Dried 164#/ft³ Fired 153#/ft³	Special Mixing Instructions.
3.1.12A.1	Calcined clay plus Hydraulic Cement	Cast	24	R.T. 220 F 1000 1500 2000			1200-1300 1000-1100 1000-1100 850-950		0 -0.11% -0.11% -0.44%	2.94×10^{-6}		Good	Good	2000 F	Dried 116#/ft³ Fired 118-122#/ft³	Mix with 7½ qts. water per 100#. Heat at 100 F per hour.
3.1.12B.1	Silica-Alumina plus Hydraulic Cement	Cast	24	R.T. 220 F 550 1000 1500 2000 2500			1150-1250 950-1050 900-1000 900-1000 1000-1100		0 -0.11% -0.11% -0.35% -0.50	2.94×10^{-6}	4.20 4.85 5.42 6.00		Good	3000 F	Dried 116#/ft³ Fired 118-122#/ft³	Mix with 9 qts. water per 100#. Heat at 100 F per hour.
3.1.12C.1	Alumina plus Phosphoric Acid	Ram	24 24 4 4	R.T. 220 750 1000 1500 2000 2500			4750 4750 4750 2750 2250		0.0 0.0 +0.10 +0.10 +0.50	4.2 X 10^{-6}	Fairly High			3500	130#/ft³	
3.1.12D.1	Alumina plus Phosphoric Acid	Ram	24 4 or 4	220 1050 1500 2000 2500			3100 3900 3900 3900 3900		0.0 0.0 + 0.20 + 0.20 + 0.20	4.2 X 10^{-6}	Fairly High			3500	175#/ft³	
3.1.12E.1	Tabular Alumina plus Calcium Aluminate	Cast	24 16 4	R.T. 220 1000 1500 2000			1350 1450 1250 1150		0.0 0.0 + 0.30 + 0.55	3.9 X 10^{-6}	6.63				150/ft³	
3.1.12F.1	High Grade Calcined Clay plus Calcium Aluminate	Cast	24 16 4	R.T. 220 1000 1500 2000			1350 1350 1150 1050		0.0 -0.05 -0.05 +0.10	2.9 X 10^{-6}	5.42 at 1500F				125#/ft³	
3.1.16A.1	Unknown plus Phosphoric Acid	Ram	24 24 4 4	220 550 700 2000												
3.1.17A.1	Pyrophyllite plus Clay and Talc	Cast												2400 F		Mix with 17-18% water by weight.
3.1.17B.1	Pyrophyllite plus Clay and Talc	Cast												2400 F		Mix with 17-18% water by weight.

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.18A.1	Alumina-Silica plus Ca. Aluminate Cement	Cast	12 24 5 5 5 5	R.T. 220 F 550 1000 1500 2000 2300	2200-3300 1300-1800 1000-1700 1500-1900 2200-3100		800-1200 450-650 400-600 550-700 800-1100		0-.1% 0-.1% -.1-.3% -.1-.3% -.5-1.2		4.5 4.7 5.0 5.3 5.5	Good	Good	2600 F	Dried 126#/ft³ Fired 1500 F 121#/ft³	Mix with 6-8 qts. water per 100#. 8 mesh material.
3.1.20A.1	Corundum plus Sodium-Flue-Silicate	Cast	4-12	R.T. 220 F 1000 1500	7000 6000 +10000		1670 2000 2880		Nil Nil Nil	5.7 X 10^{-6}	7.0			2100 F	Dried 160#/ft³	Mix with 5 qts. binder per 100#.
3.1.20B.1	Corundum plus Ca. Aluminate	Cast	48 5	R.T. 220 1000	7400 9800		2095 2195		0 -0.16%	5.4 X 10^{-6}	6.5			3300 F	Dried 160#/ft³	Mix with 10% water by weight.
3.1.21A.1	Alumina plus Ca. Aluminate	Cast	48	R.T. 220 550 1000 1500 2000 2500 3000			1190 1190 1150 1000 780 825 1150 1480		0 -0.16% -0.16% -0.14% -0.18% -0.3%				Good	3400 F	Dried 165#/ft³ Fired 1500 F 155#/ft³	Mix with 1¾-1½ gals. water per 100#. 48 hours for full set. Dry at 300 F 1 hour for 1" thickness. 50 F/hour to 1200 F hold 8-12 hours-heat on up.
3.1.21B.1	Alumina-Silica plus Ca. Aluminate	Rammed		R.T. 3000 F			1000		Nil					3300 F	Dried Rammed 175#/ft³	Mix with 4-4½% water by weight. Ram in 1½ inch layers; roughen between layers. Dry at 300 F 8 hours per inch. Burn at 2000-2500 F 12 hours before putting in service.
3.1.21C.1	Unknown plus phosphoric Acid	Ram	24 24 4 4	R. T. 250 700 2000 3000			1000		0.0	4.3 X 10^{-6}				3300 F	175#/ft³	
3.1.25A.1	Fused Silica plus Proprietary Fused Silica in Water Slip	Stiff mix spun in plaster molds	½to12	R.T. 220 F 615 712 955 1701 1800 2000	 5-16000		100-200 200-700 1000-2500		0-.01% -.01-.3 -.1-.5 -.1-1	0.30x10^{-6}	2.88 3.00 3.72 4.56	Excel't 2000 F To R.T. R.T. To 3100 F	Good	2000 F Short Cycles To 3000 F	Dried Fired 2000 F 106 to 119#/ft³	Set by loss of water to plaster molds.
3.1.25B.1	Fused Silica Slip In Water plus Proprietary Binder	Slip Cast and Spun	½to12	R.T. 220 F 615 712 955 1701 1800 2000	 10-20000		100-200 200-700 1000-2500		-.01-.2 -.01-.4 -.2-1.5 -.25-2	0.30x10^{-6} 0.30x10^{-6}	2.88 3.00 3.72 4.56	Excel't 2000 F To R.T. R.T. To 3100 F	Good	2000 F Short Cycles to 3100 F	Dried Fired 2000 F 111 to 119#/ft³	
3.1.25C.1	Fused Silica Grain Slip plus Proprietary Binder	Rammed	Time By Size And Shape	R.T. 615 F 712 955 1701 1800 2000	 1000-6000		 100-500 100-1200		0-1.0 -.2-2 -.3-3	0.30x10^{-6}	2.88 3.00 3.72 4.56	Excel't Not As Many Cycles As Two Above	Good	2000 F	Dried Fired 2000 F 100-112#/ft³	

TABLE 7 (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN./IN./°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.25D.1	Fused Silica	Cement	Same as 3.1. 25A.1							0.30×10^{-5}		Excel't		2000 F Short Cycles to 3100 F	106-109#/ft³	Used as a cement for repair of 25A. Wet area to be repaired with water or LUDOX. Follow with thin coat of 25D. Place broken pieces together. Dry.
3.1.25E.1	Light Porous Blocks of Fused Silica	Blocks	Same as 3.1. 25A.1							0.3×10^{-6}		Excel't		2000 F Short Cycles to 3100 F	44-55#/ft³	Used as an egg crate reinforcement material for ceramic tools.
3.1.34A.1	<325 Mesh Calcined grog plus Binder	Slip Cast	2 1	R.T. 220 F 1000 1500 2000 2560	100 500 60000		200 300 20000		+0.5% +0.5% +4.0%	-0.28×10^{-6} -0.28×10^{-6} 0	11.6	Excel't 2500 F To 32 F	Good	2500 F	Dried 140#/ft³	
3.1.39A.1	Silica-Alumina plus Hydraulic Cement	Cast		R.T. 220 F 1500 2000 2300 2500 2800	7500 5000 5400 6500 8000 8000		1150 450 550 650 800 800		Nil Nil Nil Nil +0.4% +0.8%	2.7×10^{-6}				2800 F	Dried 130#/ft³	
3.1.39B.1	Tabular Alumina plus Phos. Bond	Rammed Gunned Troweled	18 18 5	R.T. 220 F 550 1000 1500 2000 2550 2730 3140	4000 6300 12000 16000	 7200 3200	1000 1570 3050 3900	 1800 800	0.0 0.0 +0.2% +0.5% +0.7%	3×10^{-6} 2×10^{-6} 5×10^{-6} 5×10^{-6}	21 17.7 15.1 13.6 13.2 13.4 13.7	Good		3200 F	Dried 185#/ft³ Fired 180#/ft³	Mix with 3% water for ramming; 5% water for troweling. Should not be used before thorough drying at 500 F.
3.1.39C.1	Unknown	Cast	24 24 4	R.T. 220 2500 3000			1000 830 1200		 -0.1 -0.5					3200 F	155#/ft³	
3.1.39D.1	Unknown plus Calcium Aluminate	Cast	24 24 4	R.T. 220 1000												High strength experimental material
3.1.41A.1	Alumina plus Ca. Aluminate	Cast	12	R.T. 220 F 1000 2100 2200	 600		1200 850		0-0.1% 0-0.1% 0-0.1%	 35×10^{-6}		Good	Good	2500 F	Dried 130#/ft³	Mix with 12% water by weight. Vitreous bond at 1400-1800 F.
3.1.41B.1	Alumina	Cast Troweled	48	R.T. 1200 F 1800			875 750							3000 F	Dried 200#/ft³	16 mesh and finer. Vitreous bond at 2100 F to 2200 F.
3.1.48A.1	Lithium Alumina Silicate (Petalite)											Excel't		2300 F	Dried 151#/ft³	This is a low expansion base for castables.

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. #	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN / IN / °F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY - CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.50A.1	Tabular Alumina plus Phos. Acid Bond	Cast	Heat Thru	R.T. 220 F 1500 2400	6000-7000		4100 3700 2300		-0.1%	4.1×10^{-6}	24	Good		3800 F	Dried 160 to 175#/ft³	
3.1.50B.1	Unknown	Cast	24 24 4	R.T. 220 2000			900 750		-0.4					2400 F	125-/ft³	
3.1.65A.1	Alumina-Silica plus Hydraulic Cement	Cast	24	R.T. 220 F 1000 1500 2000 2200 2600	2500	1000 720	1300 850 680 580 525		-0.1% -0.3%			Good	Good 0-2200	2600 F	Dried 120#/ft³	Mixing directions on bag.
3.1.65B.1	Alumina-Silica plus Hydraulic Cement	Cast	24	R.T. 220 F 1000 1500 2000 2200 2400	3600	1750 580	1250 1050 980 930 2580		0 -0.25%			Good	Good 0-2200	2400 F	Dried 115#/ft³	Mixing directions on bag.
3.1.65C.1	Alumina-Silica plus Hydraulic Cement	Cast	24	R.T. 2000 F 2200 2400		2100 730	990 2250					Good	Good 0-2200	2400 F	Dried 115#/ft³	Mixing directions on bag.
3.1.70A.1	Unknown	Cast Troweled Tamped	24	R.T. 220 F 550 1000 1100 1500 1600 2000 2300 2450	2300 2100 1650 1900		1092 700-750 500-550 1100		-0.12% -0.24% -0.36% -.5-1% +1 +2%		3.7 4.0 4.2			2600 F One Face	Dried 130-135#/ft³	Mix with 2¼-3 gals. water per 100# for casting; 2-2½ gals. water per 100# for tamping or troweling.
3.1.70B.1	Alumina-Silica plus Hydraulic Cement	Cast Tamped Gunned	24	R.T. 220 F 1000 1500 2000 2550 3000	2010 2500 2900 3600		600-650 725-775 700-750 1200-1500		-0.2% -0.24% +0.17% -.5+.5		5.5 to 6.0 6.25 to 6.75	Good		3000 F One Face	Dried 133-135#/ft³ Fired 2550 F 128#/ft³	Mix with 1 1/3-1½ gals. water per 100# for casting; 1¼ -1½ gals. water per 100# for tamping; 1-1¼ gals water per 100# for gunning.
3.1.70C.1	Unknown	Cast	24	R.T. 220 F 1000 1500 2550	7270 7150 7360 7400		1825 1710 1730 2340		0 -0.12%							2-inch minimum wall thickness.
3.1.71A.1	Hi-Alumina plus Phos- Bond	Rammed		R.T. 1500 F 2550	2000 3650				-0.16% +0.38%			Good		2000 F	Dried 150#/ft³	Mix with 3-5% water by weight.

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN / IN /°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY - CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.71B.1	Hi-Alumina plus Ca. Aluminate	Cast	24 5 5 5 5 5	R.T. 220 F 550 1000 1500 1750 2000 2550	4425 6985 6722 4578 4043 4231 3734		1088 1657 1436 1161 999 738 1585		 -0.15% -0.18% -0.15% +0.04% -0.44%	3.9	9.6 at 2200F				Dried 171#/ft³ Fired 2000 F 157#/ft³	Mix with 4 3/4-5 qts. water per 100#.
3.1.71C.1	Hi-Alumina plus Phos- Bond	Rammed	5 5 5 5	R.T. 752 F 1500 2000 2912	 4000		 1130		-0.12% -0.12% -0.13% +2.0%						Dried 180#/ft³	Bonding agent is shipped separate for adding just prior to placement.
3.1.72A.1	Flint Fireclay plus Ca. Aluminate	Cast		R.T. 220 F 2000	2000	1500	400	200	Nil -0.3%			Good 20 Cycles 2000 F To Water		2000 F		
3.1.83A.1	Zirconia plus Hydraulic Cement	Cast		R.T. 220 F 550 2000 2500	1200 15000 15000				0% -1.0% -2.0%			Good	Good After 2000 F Firing			Mix with 10-11 parts water by weight to 100 parts dry mix. Cast in flexible or demountable mold with vibration. Optimum mix time 60-90 minutes.
3.1.88A.1	Zirconium Silicate plus unknown	Cast	12	R.T.	7200											
3.1.88B.1	Zirconium Silicate plus unknown	Cast	4	R.T. 2000	3300									2000 F	145#/ft³	
3.1.98A.1	Dead Burned Bauxite plus Ca. Aluminate	Cast Rammed	24-48 24-48 5	R.T. 220 F 1500 3050	5000-5500 4000		900-1100		 -2.0%			Good	Good	3200 F	Dried 156#/ft³ Fired 2550 F 150#/ft³	Keep damp during curing. Temperature should reach 250 F at end of drying cycle. Vibrate material when rammed. Use slow heating of large sections.
3.1.98B.1	Crushed Fire Brick plus Ca. Aluminate	Cast Rammed	12-24 24-48 5 5	R.T. 220 F 1700 2280 2550	5000-5100 1530		600-670 540		 -0.15% -0.6%			Av.	Slight Shrinkage	2400 F	Dried 122#/ft³ Fired 2400 F 116#/ft³	Keep wet during curing. Vibrate material when rammed. Slow heating of large sections.

TABLE 7 - (CONT'D)

CODE	BASE MATERIAL & BINDER	RAMMED, SLIP CAST ETC.	CURE & FIRING PROCEDURE HRS	CURE & FIRING PROCEDURE TEMP	COMPRESSIVE STRENGTH TESTED AT R. T. PSI	COMPRESSIVE STRENGTH TESTED AT HEAT PSI	MODULUS OF RUPTURE TESTED AT R. T. PSI	MODULUS OF RUPTURE TESTED AT HEAT PSI	SIZE CHANGE %	COEFF. OF EXPANSION IN/IN/°F	THERMAL CONDUCTIVITY K	THERMAL SHOCK RESIST.	DIMENSIONAL STABILITY-CYCLING	MAX. SERVICE TEMP.	DENSITY	REMARKS
3.1.102A.1	Unknown	Cast		R.T. 220 F 2000 2500			350 170 1210		Nil Nil			Good		2800 F	Dried 125#/ft³	
3.1.108A.1	Alumina plus Phos. Bond	Cast		R.T. 500 F 1000 1500 2000	5600 8000 8000 7600 7400		1650 2140 2220 2120 2060		-0.12% -0.12% -0.12% -0.50%	4.6 X 10^{-6}	5.00 5.82 6.07	Good	Good	3400 F	Dried 150#/ft³ Fired 144#/ft³	Heat setting.
3.1.108B.1	Alumina plus Phos. Bond	Rammed	5	R.T. 500 F	28-46000							Good	Good	3400 F		Heat setting.
3.1.108D.1	Alumina plus Ca. Aluminate	Cast		R.T. 500 F 1000 1500 2000	7000 7120 7340 7318 6060		1800 1960 2100 2000 1520		-0.1% -0.12% -0.22% -0.32%		5.62 6.50 6.47	Good	Good	3400 F	Dried 170#/ft³ Fired 162#/ft³	
3.1.111A.1	Unknown	Cast												2600 F		
3.1.115A.1	Alumina plus Hydraulic Cement	Rammed	168	R.T. 220 F 1500 2500 3000 3100			115 230 1430 1740 2085 2640		0.0% 0.0% -0.2% +1.0% -0.2% -0.4%			Good	Good	3400 F	Dried 177#/ft³	Mix with 5.4% water by weight. 22 impacts to maximum density - wood mallet. Air setting.
3.1.138A.1	Unknown	Slip	Until Solid 24 4	R.T. 220 2000						0.5 X 10^{-6}		Excellent		2900 F		
3.1.140A.1	Unknown	Ram	12 24 4 4	R. T. 220 700 2050	...							Good				

EXHIBIT 2

LETTER AND QUESTIONNAIRE FOR NON-METALLIC TOOLING SURVEY

LOCKHEED AIRCRAFT CORPORATION

GEORGIA DIVISION LOCKHEED MARIETTA, GEORGIA

June , 1958

Gentlemen:

We are undertaking a 2 year project to develop ceramic or refractory tooling suitable for forming high strength steel and titanium sheet metal parts. These forming tools are to operate at temperatures between 600°F and 2000°F.

Our first approach to this development problem is to evaluate existing formulations and then, if necessary, have special formulations made. It is our desire to eventually be in a position to purchase ready mixed ceramic or refractory materials which will require no more than water or liquid binder additions. These materials must be readily castable by pouring, tamping, or slip casting.

The properties desired are:

1. Low drying size change.

2. Low firing size change.

3. Sufficient strength to permit handling before and after firing. (This will require an estimated modulus of rupture of 200 psi, minimum).

4. High compressive strength up to an operating temperature of 2000°F.

5. Smooth as-cast surfaces for minimum friction coefficient or the possible use of a glaze material.

6. Be dimensionally stable at operating temperatures (2000°F maximum).

7. Have high resistance to repeated thermal shock.

June , 1958
Page 2

If you have or have knowledge of a material or materials which you believe might fill the above requirements; or if you have any recommendations, suggestions, or comments concerning materials for this project, please inform us accordingly.

Very truly yours,

LOCKHEED AIRCRAFT CORPORATION
GEORGIA DIVISION

R. B. Cantley
Manufacturing Research Engineer
Department 28-05

RBC:sc

EXHIBIT 2A

LOCKHEED AIRCRAFT CORPORATION

GEORGIA DIVISION LOCKHEED MARIETTA, GEORGIA

Non-Metallic Tooling Survey

Under Contract # AF 33(600)36888

I. A. With what high strength alloys are you currently working, such as but not limited to stainless steels, titanium, and hot work steels?

_____

_____

B. What high strength materials are you considering in the future (up to 3 years)?_____

_____

_____

C. Do you hot form these materials?_____ At what temperatures?_____

_____ What heating techniques are you using?_____

_____

_____

_____

Advantages of the hot forming technique:_____

_____

_____

Disadvantages:_____

_____

_____

D. Are you considering other heating techniques?_____ If so, what?

_____

_____

I. E. Do you have handling problems with present heating techniques?____

_____ Please discuss:_____

_____

_____

_____

_____

II. A. Are you presently using or investigating the use of non-metallic tooling such as but not restricted to hydro blocks, draw dies, stretch form blocks, etc.?_____ Please discuss:_____

_____

_____

_____

_____

B. What type of fabrication is used to produce your non-metallic tools?

_____

_____

Are they repairable?_____ How?_____

_____

C. Are these tools solid or are they caps over a rough core?_____

_____

D. From what material (s) are these tools made?_____

_____

_____

_____

E. How do they compare costwise with similar tools made from conventional materials?_____

_____

_____

II. F. What is the maximum allowable working temperature for these tools?

_____

_____

G. What is the expected life of your non-metallic tools?_____

_____

III. A. Do you use heat treating fixtures?_____ If so, what alloy (s) are you heat treating?_____ In what temperature range?_____ From what materials are the fixtures made? _____

_____

B. Do you use drawing (tempering), stress relieving, or brazing fixtures?_____ what is the operating temperature range?_____ From what materials are they made?_____

_____

_____

C. What problems have you had with these fixtures, in fabrication or in use?_____

_____

_____

PHASE II
MATERIAL DEVELOPMENT
January thru June 1959

INTRODUCTION

Material development was conducted by a three part effort. First, it was considered important to decide on specific ceramic systems for study by research institutions for use as castable refractories so that such effort could get underway. Second, it was felt that before commencing an evaluation of commercial products, a study should be made of mixing and placement techniques - especially vibration. The third part was the extensive evaluation of commercially available castable refractory materials.

PART I - DEVELOPMENT OF NEW FORMULATIONS

References 4 through 22 are technical papers of interest which were studied for guidance in the choosing of non-commercial ceramic systems for research and development.

Particular consideration was given the development of new formulations using phosphoric acid bonding and low expansion grog or aggregate materials. It was thought that if castables of this type could be developed, they would have good strength, thermal shock resistance, and have firing temperatures below 600 F. However, pitting or contamination of the part was recognized as a potential problem. Some of the low expansion grog materials considered include:

Fused Silica, SiO_2
Cordierite, $2MgO.2Al_2O_3.5SiO_2$
Spodumene, $LiO_2.Al_2O_3.SiO_2$ (Petalite)
Pyrophyllite, $Al_2O_3 4SiO_2.1/2H_2O$
Zircon, $ZrO_2.SiO_2$

Alumina, Al_2O_3, and others were also considered, but it was believed that better thermal shock resistance would result by using one or more of the above. Since calcium aluminate cements are continuously being improved, they were also considered along with phosphoric acid type formulations. It was thought that calcium aluminate, colloidal silica, and other types of bonding might prove far superior to the phosphate bond for some types of tools. For brazing fixtures, for example, it was speculated that possible acid action with resulting pitting and contamination might preclude its use.

As indicated in Exhibit "D" of Reference 2, the Georgia Tech Research Institute was engaged to investigate fused silica base formulations. The target properties of Exhibit 3 were applicable to this work.

The Battelle Memorial Institute was engaged to investigate castable refractories based on using petalite as the aggregate. The target properties of Exhibit 3 were also applicable to this contract.

The Georgia Tech Research Institute report is given in Exhibit 4, Pages 198 thru 215. The fused silica aggregate formulations developed are competitive with the best of the commercially available castable refractories on a thermal shock resistance basis, but are low in strength. The Georgia Tech specimen test data are in Table 15, Page 120, as Code Numbers 122A and 122B.

The Battelle Memorial Institute report appears as Exhibit 5, Pages 216 thru 223. The petalite base formulations have good thermal shock resistance, but like the Georgia Tech formulations are low in strength. A cursory investigation of cordierite base formulations indicate that such a system may have good thermal shock and strength properties. The data for the best Battelle petalite formulation are given in Table 15 as Code Number 81A.

PART II - INVESTIGATION OF MIXING AND PLACEMENT TECHNIQUES

INTRODUCTION

The importance of vibration in casting to increase density and improve strength and surface finish had been brought to the Contractor's attention on numerous occasions during Phase I.

Consequently, sixteen organizations were asked for information, including test data, concerning the effect of vibration on castable refractories. These organizations are listed in Table 8. The results indicated that little information is available; most replies referred to data published by the Portland Cement Association involving their work on vibrating concrete. None of the manufacturers produce equipment specifically designed for vibrating refractory castables. Manufacturers' literature described a variety of vibratory equipment for use on concrete and covered a wide range of frequencies.

The only available test data (23) on concrete indicated that the frequency range from 3000 to 7000 vpm had been investigated and that time for compaction decreased sharply with increasing frequencies. It was then decided to investigate the range between 3600 and 28,000 vpm in order to determine what effect the higher frequencies might have on placement of castable refractories.

The Contractor chose a refractory which was believed to be typical of the castables and readily available locally. This castable is composed of high alumina aggregate with a calcium aluminate binder. A screen analysis is shown in Table 9, Page 108 (Sample I). The manufacturer indicates that the material has a density of 135 pounds per cubic foot dried and recommends using 10 to 14 percent water by weight. A value for modulus of rupture was not available. (Reference Code #3.1.1F.1).

Several batches of material were mixed in order to determine the optimum quantity of water necessary to produce a mixture that would be stiff enough to prove the effect of vibration. Ten percent water by weight produced a satisfactory mix.

PROCEDURE

External Vibration

Contractor had ordered a Type DD Twin Shell Blender, manufactured by the Patterson-Kelley Company of East Stroudsburg, Pennsylvania, (with lucite tub) for dry mixing, and a Model #SKG (Laboratory model) Mix-Muller, manufactured by the Posey Iron Works, Inc., of Lancaster, Pennsylvania, for wet mixing. However, due to delays, it was necessary to begin the investigation without these pieces of equipment. Consequently, dry mixing was accomplished in an octagonal barrel made for this purpose. The mixer is shown in Figure 2, Page 143. One hundred pounds of the material were dry mixed for 5 minutes to counteract any particle separation that might have occurred during shipment.

It was found that 27.5 pounds of dry material were required to make three test specimens 2 1/2 x 4 1/2 x 9 inches. The material was accurately weighed and placed in the wet mixer tub shown in Figure 3, in lieu of the mix-muller. The amount of water used was 2.75 pounds. The water was accurately weighed before adding to the dry material. Figure 4 shows the mixer tub on the powered rollers used for mixing. It was mixed for 5 minutes, then enough material was removed to cast one specimen and the remainder replaced on the rollers and mixing continued while that specimen was cast. This procedure was repeated for the remaining two specimens. In Table 10, the time interval between the end of the initial wet mixing and the beginning of placement for that specimen is shown. Since the castable manufacturer specified a 30 minute maximum placement time, it was felt that this information was of importance. Further, Christie and Fentzke[6] reported a decrease of nearly 150 psi in modulus of rupture for a typical refractory castable which was placed 10 minutes after mixing was completed. The curve then tends to level out with modulus of rupture continuing to decrease slightly with time.

It had previously been decided to check the frequency range using four different settings of interference on the vibrator (see Discussion of Equipment, Page 89). Since the carbide pieces on the shaft act as cams to move the top plate of the vibrator, a dial indicator mounted on a height gage was used to set the amount of interference and therefore the amplitude. For the first series of tests, 0.0005 inch amplitude was used.

Attached to the top plate of the vibrator was a fixture with four toggle clamps for holding the mold during vibration. With the mold in place, approximately 9 pounds of material were removed from the mixer. The vibrator (and time) was started when the material was approximately 1/2 inch deep. Then additional material was added until the mold was filled. After 3 minutes, the vibrator was stopped, the mold removed, and the procedure repeated until three specimens had been made for a given set of conditions. Figure 5 shows a specimen being vibrated; note the air bubbles which have risen to the surface.

The molds were then stored and covered with damp burlap to retard rapid drying of the top surface of the specimens. The specimens were removed from the molds after a minimum of 48 hours and were then allowed to continue curing for an additional 48 hours, minimum.

The specimens were then moved to an oven and dried at 220 F for 24 hours and at 550 F for an additional 24 hours. This higher drying temperature was used because Christie and Fentzke[6] reported an extremely sharp decrease in density in the firing range up to 550 F and a tendency to level off beyond this point.

To determine specific gravity, the specimens were weighed in air and submerged in water. A polyethylene bag was used to encase the specimen protecting it from the water. The setup for both weighings is shown in Figures 6 and 7. Specific gravity may be expressed as:

$$S = \frac{Wa}{Wa - Ww}$$

Where: S= Specific gravity
Wa= Weight in air
Ww= Weight when immersed in water

The density of the specimen was obtained by multiplying its specific gravity by the density of water in pounds per cubic foot.

The specimens were then broken by the apparatus shown in Figure 8. This apparatus is driven by a motor and geared so that the upper bearing edge center has a movement of 0.050 inch per minute which is the recommended rate of loading[24] for mechanical testing machines. The distance between the lower bearing edges is 7 inches. The equipment is so designed that the actual load(W) is twice the indicated value(F).

Modulus of rupture is determined from the equation:

$$R = \frac{3\,Wl}{2bd^2} \quad \text{but} \quad W = 2F$$

Where: R= Modulus of rupture, psi
W= Load at which specimen failed, pounds
l= Distance between lower bearing edges, inches
b= Width of specimen, inches
d= Depth of specimen, inches
F= Indicated load on testing apparatus, pounds

Therefore the equipment used, R= 0.75 F.

Internal Vibration

Internal vibration may be necessary when large shapes are cast. To compare the results obtained by both methods, a series of bricks was made using internal vibration.

A small size vibrating head was designed and built to compact materials in the same molds used with external vibration. This head was made to duplicate the range of frequencies used and with amplitudes small enough to prevent throwing material out of the mold. The vibrator was driven by an air motor which had a throttle for speed control and provision for tachometer attachment for checking frequency (see Figure 9). The entire head of this small tool could be immersed in the mix thereby transferring all of the vibratory motion to the material, as shown in Figure 10.

Contractor purchased a laboratory-size internal vibrator with a 7/8 inch diameter head which is the smallest available commercially. Total immersion of this tool in the specimen molds was impossible, however, due to its size.

A series of bricks was cast using the latter vibrator in frequencies duplicating those of the first five series made with external vibration. The vibrator, driven by an electric motor and flexible shaft, was powered by the variable DC supply used to drive the external vibrator. Top speed of the motor limited the maximum frequency to 15,000 vpm. Even at this speed, however, coarse particles of grog and globules of water and fines were thrown out of the mold. Total immersion would have prevented this action which was caused by the excessive amplitude at the point where the vibrator head entered the mix.

DISCUSSION OF EQUIPMENT

External Vibrator

The Contractor has a mechanical vibrator available which had been designed and built for another investigation. It consists of a shaft with eight equally spaced slots around its periphery. These slots are located at each end and cylindrical pieces of carbide, which project above the surface of the shaft approximately 1/8 inch, are brazed into them (see Figure 11). As the shaft rotates, these carbide pieces strike carbide blocks attached to the undersurface of the vibrating plate upon which the mold is placed. Attached to each corner of the vibrating plate are close tolerance guide posts which restrict movement to vertical motion only. Also, around these posts are springs which return the vibrating plate to its original position after a lobe has passed in preparation for being struck by the following lobe. The vibrator is so designed that the interference between the rotating and fixed pieces of carbide is adjustable, thereby allowing the amplitude to be changed and, by driving it with a variable speed motor, the frequency can also be changed.

Work previously reported(25) indicates that impact vibration for this type of work is superior to sinusoidal vibration.

With the type and action of the vibration equipment used for this study, it is within the realm of possibility that the terms frequency and amplitude, as used in this report, are slightly in error. The amount of interference between the rotating and fixed pieces does not mean that this was the actual travel of the vibrating plate since the plate, fixture, and mold all possessed momentum and this momentum was restrained only by spring tension. If this force was of sufficient

magnitude and the period of the spring too slow for the frequency range under investigation, it would be possible for a lobe to pass before the vibrating plate and its load returned to its proper position to be struck again. An attempt to check this was made by attaching a bar magnet to the vibrating plate and suspending a coil around it. The signal generated by this transducer was fed to the vertical plates of a cathode ray oscilloscope and a signal from an audio oscillator was fed to the horizontal plates. When the frequencies are the same, an elliptical pattern is shown on the oscilloscope. However, this apparatus was not successful due to excessive amounts of harmonics appearing on the scope. An attempt to procure more elaborate instrumentation was not made. It is reasonable to assume that the type of vibration produced by this means was impact, which is believed necessary to obtain the best compaction and; therefore, density for castable refractories. Figure 12 shows the vibrator with the mold locked into the holding fixture ready for casting.

The vibrator is driven by a 1 1/2 hp variable speed DC motor with power supplied by an electronic power supply. The console, motor, and vibrator are shown in Figure 13. The concole power supply is a Reliance V-S Drive, Model #0-40941-44, Reliance Electric & Engineering Company, Cleveland, Ohio.

Internal Vibrator, Air

The vibrator designed and fabricated by the Contractor uses a rolling, rotating pendulum which is cylindrical in shape and supported at one end by a universal joint. This pendulum is free to move at the other end inside a tube, which is the outside case of the tool (see Figure 14). The ratio of the circumferences of the outside of the pendulum and the inside of the case is such that the pendulum, when operated, rolls around the inside of the case four times for each revolution.

Motive power is furnished by an air motor, the speed of which is indicated by a tachometer and controlled by a valve used as a throttle. Figure 9 shows the tool ready for use. As can be seen by the size of the brick mold, total immersion of the case or head can be accomplished by placing it lengthwise in the mold (see Figure 10).

In order to prevent pure sinusoidal motion from being generated by the tool, a step is cut in the end of the pendulum in such a manner as to remove one-half the cross section of the pendulum for a distance os 3/4 inch from its end. Impact is introduced by the action of the pendulum rolling up on the end of the step and dropping to strike the inside of the case. This action occurs for each rotation of the pendulum (see Figure 14).

Internal Vibrator, Electric

The vibrator purchased is a special size laboratory model manufactured by Vibro-Plus Products, Inc., Stanhope, New Jersey, (Type ESV-25). The head is approximately 7/8 inch in diameter and 11 inches long (see Figure 15). This vibrator is the smallest available, but is not small enough for total immersion in the brick mold used.

Motive power is provided by a universal wound (AC/DC) electric motor and applied by means of a flexible shaft. The head contains an eccentric weight; therefore, essentially sinusoidal vibration results. The speed was varied by using the electronic power supply which was used with the external vibrator. The maximum output of the tool was approximately 15,000 vpm when using the electronic power supply which was more than the rated 11,000 to 12,000 vpm when operated on 110 volts AC.

Vacuum Mixer

It was believed that vibratory energy would, to a large degree, remove entrapped air from the mix, thereby increasing density. If all the entrapped air could be removed and particles aligned so that no voids would exist, maximum density could be achieved. Since vacuum mixing should remove all entrapped air it was felt that some preliminary work in this area was warranted.

The Contractor has available in his laboratory a rotary mixer which has a capacity large enough to mix material for one specimen. A vacuum chamber was designed and built that would completely enclose the mixer. Figure 16 shows the chamber open. The electrical conductor for the mixer motor is sealed by a special fitting on the underside of the chamber base. The sealed chamber ready for mixing is shown in Figure 17 .

Vacuum Vibrating Chamber

To pursue this idea further, it was decided to investigate the effect of a vacuum on removing entrapped air while the specimen was being vibrated. To do this a chamber was made that would mount on the external vibrator and house a specimen mold (see Figure 18).

DISCUSSION OF RESULTS

External Vibration

Ten percent water by weight appeared to be satisfactory for this study since it produced a very stiff mixture. The effect of vibration on this mixture was obvious from the beginning of the study. As soon as vibration was started the mixture immediately began to flow to all areas of the mold and as more material was added it appeared to fuse into the mixture.

Figures 19 thru 22 are graphs of density vs. frequency and modulus of rupture for the four settings of amplitude. In every case the actual values obtained from each specimen are shown. However, the curves are the arithmetical mean of the three specimens. There are instances where obvious erroneous points were not used to obtain the mean value. Figure 19 shows that 3600 and 7200 vpm at 0.0005 inch amplitude, although helpful in moving the material, does not produce the most dense casting. Density reaches a peak at 10,000 vpm and 0.0005 inch amplitude. However, a second peak appears at 18,000 vpm but severe separation took place during the three minutes of vibration which drastically reduced the strength (modulus of rupture). This study indicates that an optimum frequency, amplitude and vibration time exist which will produce not only the most dense casting but also the strongest.

It should also be noted that all amplitudes above 0.0005 inch resulted in lower densities and strengths. Composite curves for this are shown in Figures 23 and 24.

Figures 25 and 26 are the bottom and edge views of Specimen Code 1F.1-18 which is the most dense (refer to Table 10). The surfaces are comparatively smooth, but some pitting exists showing that all of the entrapped air had not been removed by the influence of vibration. Note in the edge view, the narrow line along the top surface showing that some slight amount of separation took place.

The least dense specimen, 1F.1-10, is shown in Figures 27 and 28. Large voids are prevalent showing that entrapped air was not removed from the material. The edge view shows the roughness of the surface.

Figures 29 and 30 show a comparison of Specimens 1F.1-18 and 1F.1-27. These specimens are the most dense produced at 10,000 vpm and 18,000 vpm respectively at an amplitude of 0.0005 inches. The bottom surfaces appear to have approximately the same amount of pitting. However, -27 shows coarse aggregate over the entire bottom surface whereas in -18 it appears only around the edges of the specimen. Further, the edge views show that -27 has a much deeper layer of separation due to the higher frequency.

Figure 31 shows the top surface of Specimen 1F.1-40. It was vibrated at 7200 vpm and 0.0010 inch amplitude. This is the severest example of surface crazing. Fine particles were still evident even after losing approximately 1/8 inch depth of the surface.

Figure 32 shows the effect of the parting agent on surface smoothness. The specimen molds are made of aluminum (see Figure 33). Although two sides of the mold are removable, a parting agent is necessary to not only aid in the release of the specimen from the mold, but to keep the castable material from attacking the aluminum and to keep the mold cleaning effort to a minimum. In all cases, with the exception of Specimens 1F.1-76 thru 1F.1-91, Dow Corning #DC7 Silicone Parting Agent was used. For -76 thru -91, the molds were cleaned and sprayed with "Form-Lac" produced by Maxwell & Hitchcock, Inc., 191 Simpson Street, N.W., Atlanta, Georgia. Specimens -91 and -92 were made under the same conditions (3600 vpm and 0.0020 inch amplitude). "Form-Lac" was used on the mold for Specimen -91, which resulted in an almost perfectly smooth bottom surface. On Specimen -92 the mold was coated with Dow Corning #DC7 and showed some pitting.

However, it should be noted that the specimens tended to stick to the "Form-Lac" and cleaning the molds after use was much more difficult than with the #DC7.

The Effect of the Amount of Mixing Water used on Modulus of Rupture

Although the choice of 10 percent water by weight appeared to be satisfactory for the vibration study, the strength of castable refractories is dependent upon the amount of mixing water used. However, the quantity of mixing water that is used must also depend on the placing technique. Water is required to hydrate the binder material and, perhaps equally important, to provide the means which enables the material to be easily and thoroughly placed.

To further emphasize this fact, Specimens 1F.1-178 and 1F.1-179 were made using 10 percent water and hand tamped in the molds. Placement was not only difficult but resulted in specimens that contained voids between the coarse aggregate which were not filled with fines as in the case of specimens that were vibrated (see Figures 34 thru 36). These two specimens can be compared with 1F.1-18, Figure 25, for example, because the same material and percent water are used.

The results obtained were:

Specimen Number	Density	Modulus of Rupture
1F.1-178	117.44	150
1F.1-179	120.24	243

There had been occasions during the study to determine the optimum frequency and amplitude, when 10 percent water by weight appeared to produce a mixture that was wetter than necessary for the vibration placement technique. As a consequence of this observation, it was decided to check the effect on modulus of rupture by using 9 percent water by weight with external vibration.

Table 11 is the result of this study. Six specimens were made. Three using 10 percent water and three with 9 percent water. All of the specimens were vibrated at 10,000 vpm frequency and 0.0005 inch amplitude. It is important to note here that the material for these specimens came from the same manufacturer's batch that was used in the original study on frequency vs. density (Specimens -10 thru -117). See Page 96 for a discussion of variations in the material. As indicated, the specimens mixed with 10 percent water have the higher modulus of rupture.

The Effect of Vibration Time on Modulus of Rupture

Before beginning the basic study, three minutes vibration time had arbitrarily been chosen. Only after the investigation was under way, did it become evident that this length of time was too long, particularly at highest frequencies and amplitudes, and resulted in severe separation. By the time this was discovered, it was decided that it would be more expedient to continue the study using the three minutes vibration time and determine the optimum time later.

Specimens were made using vibration times of 1, 2, and 3 minutes respectively at 10,000 vpm frequency and 0.0005 inch amplitude in order to determine the optimum time to produce maximum density and strength.

Table 12 is the result of this study and indicates that the optimum vibration time is 1 minute. The curves of density and modulus of rupture are shown in Figure 37.

Internal Vibration

Internal vibrators will be necessary on large castings where external vibrators would be impractical. However, the design of presently available internal vibrators does not lend itself to precise control. The only method of changing amplitude is to change the speed and thereby the frequency of the vibrator. As a consequence of this, there is no basis for recommending an exact frequency and amplitude. Techniques and results must come from experience. As with the external vibrator, caution should be used not to over-vibrate the mix for separation results. With experience, visual observation will determine when good results are obtained.

Ten percent mixing water by weight was used for this study. Vibration time was varied to produce the best results for the particular frequency used and is recorded in Table 13. The time interval between the end of the initial wet mixing and placement is also shown. Figures 38 and 39 are curves of density and modulus of rupture vs. frequency for the air and electrically driven vibrators respectively.

Air Driven Vibrator

A vibrator small enough to permit almost complete immersion in a specimen mold required the pendulum to be quite small (see Figures 9 and 14). The light weight of the pendulum resulted in an amplitude so small at 3600 vpm frequency that the material did not flow. The effect of vibration was not pronounced until frequencies of 10,000 vpm and over were tried.

After 15,000 vpm was reached, there was no apparent increase in frequency and amplitude with an increase in the throttle setting. For this reason, it was felt that frequencies over 15,000 vpm were not obtained with this vibrator. A tachometer indicated an increase in revolutions per minute of the pendulum accompanying an increase in throttle setting but due to slippage as it rolled around the inside of the case, its four rotations per revolution presumably were not achieved.

An attempt to check this by again using the same transducer and audio oscillator hook-up, described in the discussion on external vibration, proved to be unsatisfactory due to the random frequencies produced by the vibrator.

Since the maximum values for density and modulus of rupture appear at a frequency of 10,000 vpm, discrepancies of actual frequency in the higher ranges would not discredit the usefulness of this study.

Figures 40 and 41 are the bottom and edge views of Specimen 1F.1-121 which is the most dense and has the highest modulus of rupture (see Table 13). It was vibrated at 10,000 vpm which is also the frequency which produced the best specimen using external vibration.

Specimen 1F.1-134 is the least dense due to poor compaction at a low frequency (7200 vpm). The bottom and edge views are shown in Figures 42 and 43. Figure 44 shows the top of this same specimen and the absence of fines between the coarse aggregate is apparent.

A second peak density is indicated at 20,800 vpm in Figure 38 which is the curve of density vs. frequency. Figures 45 and 46 show, however, that severe separation took place at the higher frequency.

Electrically Driven Vibrator

The electrically driven vibrator contains an eccentric weight and therefore produces essentially sinusoidal vibration. The frequency was controlled by using the electronic power supply (Reliance V-S Drive) to drive it. Excessive amplitude at frequencies of 10,000 vpm and over resulted in coarse particles and globules of fines being thrown out of the mold.

Figure 39 shows the curves of density and modulus of rupture vs. frequency. Note that with this vibrator the maximum density occurs at 3600 vpm and thereafter decreases with increasing frequency.

This can be attributed to two conditions: first, the size of the vibrating head which could only be immersed in the material for a few inches; and secondly, the excessive amplitude resulting from higher frequencies had a tendency to disturb the mix rather than compact it. On large castings where the entire head could be immersed in the material this tendency would not be a disadvantage since the material itself would tend to dampen the amplitude.

Figures 47 and 48 show the bottom and edge views of Specimen 1F.1-153 which is the most dense.

Specimen 1F.1-158, the least dense, is shown in Figures 49 and 50 and occurred at 10,000 vpm frequency. Figure 51 shows the top surface of this same specimen. Note the absence of fines between the coarse aggregate.

Mixing and Vibrating in a Vacuum

To effect maximum density requires that no voids exist due to entrapped air and that all particles are aligned so that voids do not exist between them.

Vibration has already shown its effect on particle alignment and compaction. In order to determine if density could be increased further, it was decided to investigate the effect of mixing and vibrating in a vacuum to aid in removing entrapped air from the specimen.

Unfortunately at this point, all of the material that came from the original batch number was exhausted. Any data obtained from using the material left over from the internal vibration study could not be related to the specimens (-190, -191, -194 and -197) that had already been made.

Table 14 summarizes this study, the first four lines of data show that a higher density and modulus of rupture resulted when the material was mixed in a vacuum only. This data may also be compared with the data for Specimens -181, -182 and -183, (Table 12) since these specimens were made under the same conditions. This further comparison indicates that vacuum mixing is beneficial. However, whether the improvement shown due to vacuum mixing offsets the difficulties encountered in performing this operation is debatable.

Specimens were run as shown in Table 14. Three specimens (-200 thru -202) were both mixed and vibrated in air to serve as a standard. Two different sets of specimens (-190 and -191 and 203 thru 205) were mixed in a vacuum (Figure 16) and vibrated in air. These showed no significant change in density and a decrease in modulus when compared with the standard, the average of -200 thru -202. Two other sets of specimens (-206 thru -208 and -206R thru -208R) were mixed in air and vibrated in a vacuum (Figure 18). As compared with the standard, these showed an increase in density with no significant change in modulus. These two sets of specimens show an interesting comparison. Difficulty was encountered when vibrating in a vacuum in that pits remained in the top surface of the specimens caused by the collapse of bubbles which had risen to the surface while vibrating. To remedy this condition, the vacuum was released 15 seconds before the end of the two-minute vibration period. This procedure allowed the voids left by collapsed bubbles to be closed before vibration stopped. The bubble-closing technique increased the density as would be expected, but, for some unknown reason, lowered the modulus.

Two sets of specimens (-194 and -197 and -209 thru -211) were both mixed and vibrated in a vacuum. As compared to the standard, the first set of specimens showed decreases in both density and modulus. The second set, done by the bubble-closing technique, had a higher density and a better surface finish, but a lower modulus than the standard. The modulus, however, was twice as great as the modulus of the -194 and -197 set. This difference further emphasizes the difference in properties attainable from different batches of the same commercial product.

Variations in Castable Refractory Used

One of the most provocative findings of this investigation was the variation found in the material used.

When the investigation was initiated, the Contractor purchased 1000 pounds of refractory material which was exhausted by the time Specimen 1F.1-111 was made.

The manufacturer had previously sent the Contractor a 100 pound sample for the Phase II evaluation. When it became apparent that additional material was necessary for the last six specimens, it was decided to use the material on hand. Part of the 100 pounds was used for Specimens -112 thru -117 and, as noted in Table 10, the material when mixed with 10 percent water by weight, appeared to be much wetter than that previously used. The specimens also were a light gray in color as compared to all of the others which were cream colored. It was discovered at this time that the first 1000 pounds used and the 100 pounds used for the last six specimens came from different batches.

A second 1000 pounds, which came from a different distributor, was ordered for the internal vibration study. A screen analysis of the original material called "Sample 1" in Table 9, had previously been made. When the new material arrived, a screen analysis was made (Sample 2) and the results of this comparison are shown in Table 9 and graphically in Figure 52.

After the screen analysis revealed drastic differences between the materials, three specimens were made from this material using the external vibrator at 10,000 vpm frequency and 0.0020 inch amplitude, rather than .0005, since optimum conditions for external vibration had not been established at this point in the investigation. A comparison of these specimens with those made during the study of the effect of frequency on density and modulus of rupture (Specimens -10 thru -117) under the same conditions of frequency and amplitude showed the density of the new material to be approximately 5 percent less and the modulus of rupture to be approximately 22 percent less.

The studies to determine the effect of the amount of mixing water used, the optimum time of vibration, and the effect of mixing and vibrating in a vacuum had not been made. After discovering these variations in the material, an additional 200 pounds of material were procured which came from the same manufacturer's batch as the original 1000 pounds of material. This was necessary to assure that data obtained from these studies could be compared with results obtained from the original study on the effect of frequency on density and modulus of rupture (Specimens -10 thru -117).

All of the differences noted, including batch numbers, were brought to the manufacturer's attention in the hope that a check of their batch numbers might reveal the cause of some of the variations. However, the manufacturer replied that all of their material contains the same constituents and meets all requirements for commercial standards. It may be well to mention at this point, that experience indicates that refractory castables to be used for the tooling application will require closer control than materials that are used in standard refractory applications. It is felt that the refractory manufacturers will have to control more closely the size and distribution of the aggregate and the amount and quality of the binder in order to have materials of sufficient uniformity for use as non-metallic forming tools (see References 19 and 25).

Another precaution to be noted is the total quantity of water used. This water consists of that part added at the time of mixing and the uncontrolled part which has been absorbed from the air. Since calcium aluminate is hygroscopic, it should be properly stored and shielded from moisture-laden air as much as possible. Castables containing this type of binder, which absorbs moisture in storage, may result in a mixture that is too wet, thus reducing the strength of the tool. Lumps may be formed from pressure during storage and should not be mistaken for those caused by dampness. Lumps due to storage are readily pulverized.

CONCLUSIONS

The conclusions reached by this investigation of placement techniques are:

1. Vibration is necessary for quality casting of refractories when minimum mixing water is used.

2. The optimum frequency and amplitude were found to be 10,000 vpm at 0.0005 inch respectively with the equipment used for the external vibration study.

3. Excessive vibration time, particularly at the higher frequencies and with large amplitudes, is detrimental to strength and causes severe separation of the material.

4. Internal vibration cannot be precisely controlled at this time; however, additional studies should provide improved methods.

5. Variations found in the castable refractory used indicate that the commercial grade would be unsatisfactory as a tooling material.

6. Vacuum mixing and/or vacuum vibrating offer little advantage.

RECOMMENDATIONS

The recommendations pertaining to the investigation of placement techniques are:

1. For castables containing hydraulic setting cement, mixing water should be held to a minimum, sufficient only for the placement technique used.

2. Vibration equipment for use with refractory castables should have amplitudes no greater than 0.0005 inch and a frequency in the range of 9000 to 11,000 vpm.

3. Vibration time should be only long enough to obtain good compaction as determined visually.

4. Until such time as specific commercially available formulations can be designated and adequate manufacturing standards determined, users of commercially available castables for tooling should ascertain that all material used for a particular tool is from the same manufacturer's batch.

5. Manufacturing standards for castable refractories should include:

   Chemical analysis
   Sieve analysis
   Particle shape definition

PART III - COMMERCIAL CASTABLE REFRACTORY EVALUATION

INTRODUCTION

The Contractor has either purchased or received gratis 114 commercial materials which have been recommended as prospects for tooling applications.

Due to the large number of materials to be tested, it was decided that the first evaluation would be based on drying and firing size change, hot and room temperature modulus of rupture, density, and surface finish. Additional tests, such as wear resistance, thermal shock resistance, etc., required by succeeding phases will further evaluate the most promising materials selected as a result of this first evaluation.

All of the specimens made during the vibration study previously reported were visually studied and eleven were chosen which were felt to be prime examples of surfaces that ranged from the best to the poorest. This standard was adopted to grade the surface of all the specimens reported herein. The standard surfaces are shown in Figures 53 thru 64, Pages 175 thru 180.

PROCEDURES

Castables Other Than Slip and Ram Types

All dry materials were inspected to determine if they had been exposed to moisture or had in any way tended to set up. The dry materials were then mixed in the Patterson-Kelley Type DD Twin Shell Blender shown in Figure 65, Page 181, for five minutes. After dry mixing, enough material was removed to make one specimen, weighed, and placed in the tub of the Rotary Mixer manufactured by Charles Ross & Sons, Brooklyn, New York, shown in Figure 66, Page 181. A known quantity of water was slowly added to the dry material until the mix appeared to be of the proper consistency for the placement technique used. A specimen was then made to visually check for proper water content. This procedure was repeated, as necessary, until the proper percent mixing water was determined to the nearest 0.01 pound. Material for the remaining specimens of that product was then wet mixed for three minutes in the Model #SKG, Mix-Muller manufactured by Posey Iron Works, Inc., see Figure 67, Page 182, using the percent mixing water so determined. After the initial mixing was completed, the mix-muller was stopped, enough material was removed at one time to cast one specimen, and then the mix-muller was started again. This procedure was continued until all specimens had been cast; however, some of the calcium aluminate binder materials had such a fast set-up time that specimens were mixed in the rotary mixer (Figure 66), one at a time as indicated in the Remarks Column of Table 15.

The specimens were cast in precision aluminum molds. A mold, mounted on the external vibrator is shown in Figure 12, Page 149, and a close-up view of a mold is shown in Figure 33, Page 163. The specimens were vibrated at 10,000 vpm and 0.0005 amplitude for one minute or longer depending on the material, as indicated in Table 15.

The "L" pins which lock the movable sides in place were removed and the bolts holding the springs were unscrewed to a torque of 5 inch-pounds (Figure 68, Page 183). This procedure was followed to permit unrestrained expansion of the castable where applicable. The specimens were than covered with damp burlap to retard rapid drying when recommended by the material manufacturer.

After twenty-four hours, the specimens were removed from the molds, identified, and allowed to continue curing for the time specified by the manufacturer. They were then dried at 220 F and subsequently measured for drying size change.

Measurement of Specimens

A height gage and dial indicator were used to measure both drying and firing size change. The setup for making this measurement is shown in Figure 69, Page 184. An aluminum brick standard which measures 9.0005 inches, shown in this figure was used to calibrate the dial indicator to zero. Each specimen was placed against two rails for location. After a parallel bar had been carefully centered on top of the specimen, the height gage base was positioned against one rail and moved toward the specimen until the front edge of the height gage contacted the back edge of the stop rail. The dial reading was then recorded. For slip cast specimens, the 4 1/2 inch width dimension was used.

Firing of Specimens

The 220 F dried specimens were compared with the standards, Figures 54 thru 64 for surface finish, and the finish was recorded in Table 15. Later, the specimens were fired at the manufacturer's recommended firing temperature for maximum strength and, in some instances, for minimum size change.

For all calcium aluminate binder products, a firing rate of 150 F/hr. was used with a soaking time of four hours at firing temperature. All other products were fired at a rate of 50 F/hr. to 600 F and then 150 F/hr. to firing temperature. These products also were given a four hour soaking period. Specimens were measured again to obtain firing size change and weighed to establish density. Also, surface finish was determined after firing. See Table 15 for values.

Modulus of Rupture

Modulus of rupture was the final test made, see Figure 8, Page 146. After firing at manufacturer's recommended temperature, some specimens, as indicated in Table 15, were heated to 2000 F at a rate of 200 F/hr. and broken hot for the 2000 F modulus of rupture test (Figure 70, Page 184). An equation for modulus of rupture, per A.S.T.M.[24], may be expressed as shown on Page 88.

Slip Type Castables

Slip casting materials were mixed in a blunger (Figure 71, Page 185) or on a roller (Figure 4, Page 144), as recommended by the manufacturer. Mixing was continued until the proper pouring consistency was reached. Plaster molds made from U.S. Gypsum's No. 1 pottery plaster were coated with graphite as a parting agent, Figures 72 and 73, Pages 185 and 186. Three inches excess was allowed on the length of the molds for piping. Specimens were cut to 9 inch lengths after firing.

These materials were allowed to dry in the molds for a minimum of 48 hours at room temperature before removing. Specimens were then dried at 220 F for 24 hours. The remainder of the test procedure was the same as previously mentioned for other castables.

Ram Type Castables

If the ramming mixture was not a ready mixed product, the twin shell blender and mix muller were used for mixing, Figure 65 and 67, Pages 181 and 182 respectively. After mixing, materials were placed into molds, Figures 33, Page 163, and rammed with the rammer shown in Figure 74, Page 186. As recommended by the materials manufacturers, some materials were rammed in layers, with surfaces between layers being roughened to avoid lamination. Other materials were heaped up and rammed, which left an excess of material on the top of the mold. Excess material was then scraped off level with the top of the mold which maintained the proper thickness of the specimen. After finishing the ramming operation, each specimen was handled as previously discussed.

DISCUSSION OF EQUIPMENT

Mix Muller

The Contractor purchased from Posey Iron Works, a mix muller for wet mixing as shown in Figure 67, Page 182. Note that the muller may be adjusted up or down to allow for mixing any grog size. With mix muller opened, cleaning was easily accomplished. Dry sand mixed with sawdust was used for cleaning after mixing each product to avoid contamination of the succeeding products. The muller, scraper and top cover are easily raised for removal of material from the pan and for cleaning.

Twin Shell Blender

The twin shell blender used for dry mixing was manufactured by the Patterson-Kelley Company, East Stroudsbury, Pennsylvania (Figure 65, Page 181). The twin shells rotate in a direction opposite the small center shaft (intensifier bar) which contains pins to aid in breaking up lumps due to compaction in shipment or storage. Note the opening at the apex of the shells. Material was easily removed from this opening after mixing by jogging the apex of the shells to the lower position. The large round openings located opposite the apex of the shells provide ample space for easy entrance of materials.

Molds

Since the specimen molds were fabricated from aluminum, a suitable parting agent had to be selected. After investigating numerous products, the Contractor decided to coat the aluminum molds, Figure 33, Page 163, with a Teflon spray, manufactured by the E. I. DuPont de Nemours Company. This material was a one-coat spray primer #850-202 designed especially for aluminum. In addition to the Teflon coating, peanut oil* was also wiped lightly on the molds to further aid in releasing the specimens. It was found that if an excess of peanut oil was allowed to remain on the molds prior to casting or ramming, small pit holes resulted on the surface of the specimen. The use of these parting agents held mold cleaning to a minimum.

*Novola Brand, product of Planters Edible Oil Company, Suffolk, Virginia

DISCUSSION OF RESULTS

It should be noted that several of the products listed in Table 15 have not been evaluated. These materials and an explanation regarding their status follow:

Codes 86A.1 and 4A.1 CA-25 (Calcium Aluminate) and Lumnite Cement

These binders were not evaluated since many of the formulations tested contain these materials.

Code 86B.1 Tabular Alumina

This material was not evaluated because Codes 39B.1 and 5A.1, which were tested, are representative.

Code 50A.1

This material was not evaluated because Codes 12C.1, 12D.1, 39B.1, and 108B.1, which were tested, are similar.

Six specimens were cast of each calcium aluminate bonded material. The first two were tested for modulus of rupture after drying at 220 F. The last four specimens were fired as indicated in Table 15. The first two fired specimens were broken for modulus of rupture at room temperature. The remaining two fired specimens were then heated to 2000 F, at a rate of 200 F/hr., and broken immediately for the 2000 F modulus of rupture test. See Figure 70, Page 184.

Eight specimens were cast or rammed of materials containing phosphoric acid as the binder. The first four specimens were fired in the range of 500 to 800 F. The remaining four were fired at higher temperatures and later broken for modulus of rupture as indicated in Table 15.

It may be of interest to note severe efflorescence on material Code 98A.1 as shown in Figure 75 and as noted in Table 15. Further, efflorescence was noted on specimens 1A.1-4, -5; 1B.1-4, -5; 1N.1-4, -5; 17A.1-4, -5; and 17B.1-4, -5. This may be attributed to a setup retarding agent in the binder for reducing the setup rate of the material. Material 2J.1 is not air setting in thick sections.

An extremely large aggregate size of approximately 1/2 inch was noted in product 2A.1. Some specimens (1P.1, 2E.1, 5P.1, 41B.1) would not respond to vibration during placement.

Slight separation was noted on product 1H.1, 2C.1, and 5C.1.

The 12C.1 material was too fragile to handle after drying at 250 F; therefore, measurement for drying size change could not be made. The manufacturer stated that this material is fragile until fired at 750 F. Material 3H.1 was crumbly after drying.

Evidence of cracks was noted in Specimens 1A.1-6 thru -11, 3A.1-6 thru -9, 5Q.1-2, -5 thru -11, and 8C.1-4, -5. The manufacturer of material 3A.1 explained that cracking is normal after drying and firing his product (see Figure 76).

Material 21C.1 evidenced the tendency to bulge the mold to a greater degree than other phosphoric acid type binder, rammed castables. However, this tendency was found to be common to all materials of this type.

Longitudinal shrink cracks occurred after room temperature cure of material 5Q.1. Specimens 5Q.1-9 thru -11 cracked severely after firing at 1500 F and could not be measured for size change. Cracks in 8C.1-4 and -5 appeared after drying at 220 F.

Note in Table 15 that modulus of rupture data are missing on some specimens (3D.1, 3E.1, 20A.1, 108B.1). Although firing temperatures were selected from manufacturers' recommendations or physical properties data sheets to produce maximum strength and minimum size change, some specimens (2B.1, 5G.1, 9A.1, 9B.1 and 25C.1) melted, distorted, or cracked so badly that test data could not be recorded.

Surface finish standard No. 1 (Figure 54, Page 175) was checked with a Profilometer and indicated a reading of 95 micro inches. It is of interest to note that of all products tested, the best surface finish was found on material 25B.1. The Profilometer reading of this product indicated a 52 micro inch finish.

Specimen 25B.1-8 exceeded the strength of all other products evaluated for the 2000 F modulus of rupture test. A 7230 pound loading (capacity of machine) would not rupture the specimen on the first try. However, after subjecting the specimen to the test (including reheating) for the second time, failure occurred with a loading of 5615 pounds. See Table 15 for modulus of rupture value.

It was later learned (refer to Table 15) that Code 108A material could be readily cast with the standard vibration technique. By placing in this fashion the surface finish was improved from a No. 9 to a No. 3.

The room temperature modulus of rupture of material Code 21C.1 was approximately one-third stronger after firing at 2000 F than when fired at 700 F. Data for modulus of rupture at 2000 F show the material fired at 700 F to be one-third stronger than the material fired at 2000 F. Reference 10 gives a possible explanation which concerns an incipient decomposition of aluminum phosphate to alumina and volatile phosphorous pentoxide at 2000 F.

The Contractor maintains that the end use of a castable refractory must be known before an evaluation of such products can be made and considers the following to be the three main areas of use:

1. Unfired tooling used at room temperature
2. Fired tooling used at room temperature
3. Fired tooling used at elevated temperature

The main consideration in judging ceramic materials as tools for metal forming is strength, as measured by the modulus of rupture. Important, but lesser considerations are drying or firing size change and surface finish. For fired tools used at elevated temperature the coefficient of thermal expansion and thermal shock resistance are important. Density is not considered an important factor and would only be used in differentiating among otherwise equal materials.

It is helpful in an evaluation program to assign numerical values to the different variables in such a fashion that a final number may represent the worth of a specific promising material. It is even more helpful if the "final numbers" can be presented graphically. The contractor has used such a scheme to evaluate and present the data of Table 15. This information appears in Tables 16, 17, and 18, and in Figures 77 thru 85 (see Pages 135 thru 142 and 188 thru 196).

Table 15 contains data accumulated throughout the contract period, even as late as November 30, 1960. The late data are so indicated by notes in the "Remark column. Tables 16, 17 and 18 rank the materials in two ways, one per the data available in July, 1959, and the other per the final availability of all data produced by the contract. The bar graphs of Figures 77 thru 85 only deal with final data.

To arrive at a "final number", the modulus of rupture is divided by the arbitrary figure of 30 psi = 0.1 inch to obtain a length dimension. From this length dimension are subtracted increments representive of drying or firing size change and surface finish. The drying (for unfired tools) and firing (for fired tools) size changes are divided by the arbitrary figure of 0.03% = 0.1 inch. No surface finish is regarded as perfect. A number 1 surface finish represents a penalty of 0.1 inch, a number 2 surface finish 0.2 inch, etc.

In this manner, the data of Table 15 have been reduced to a tabular and graphical presentation. Only the better half (or less) of the prospective materials are presented. Table 16 and Figure 77 show the relative "worth" of the 50 leading contenders for unfired tools; Table 17 and Figure 78 show the relative "worth" of the 45 leading contenders for fired tools used at room temperature; and Table 18 and Figure 79 show the relative "worth" of the 30 leading contenders for fired tools used at elevated temperatures.

For convenience to those interested in selecting a material solely on the basis of size change, the graphs of Figures 80 and 81 have been prepared; and on the basis of surface finish, the graph of Figure 82 is pertinent.

For needs based entirely on strength considerations, the graphs of Figures 83, 84 and 85 will be useful.

The data of Tables 16, 17 and 18 enable a comparison of the manufacturer-furnished strength and shrinkage data with that obtained from this investigation. In a great many instances the strength data from this investigation markedly surpassed that of the material suppliers. This, the contractor attributes to his placement process employing controlled vibration and minimum water content.

Before doing further evaluation work the contractor decided to reduce to ten the number of materials to be used in subsequent testing. In order to effect this reduction and not eliminate desirable materials a procedure was used which considered:

1. The best materials in each category (8B*, 71B*, 12E, 20A, 20B, 108A, 25B, 25A and 21C).

2. Materials having comparatively high values in all three categories, thereby offering the advantage of minimum inventory.

3. Ram cast materials unacceptable (108B for example).

4. Different aggregate/binder systems (39A).

This selection resulted in the indicated materials.

CONCLUSIONS

It is concluded that of all the commercial formulations evaluated, 10 show particular promise for tooling applications. These materials, which should be further evaluated in Phase III, are as follows:

Code
5A.1
12E.1
12F.1
20A.1
20B.1
21C.1
25A.1
25B.1
39A.1
108A.1

RECOMMENDATIONS

This phase of the report recommends that the selected materials be further evaluated in Phase III.

*In analyzing the data initially, the relative value of materials 8B and 71B was inadvertently overlooked. Consequently, they do not appear as selected materials and were not retested at the beginning of Phase III. These materials were extensively evaluated at a later time and the bar graphs of Figures 77 thru 85 and Table 44 indicate their selection to have been valid.

TABLE 8

INQUIRIES MADE ON VIBRATION

Name and Address	Type	Frequency Range
All American Tool & Manufacturing Company 8033 Lawndale Avenue Skokie, Illinois	External	300- 6,000 vpm
Babcock & Wilcox Company Refractories Division Candler Building Atlanta 3, Georgia		
Branford Company 140 Chestnut Street New Haven, Connecticut		
General Refractories Company 1520 Locust Street Philadelphia 2, Pennsylvania		
A. P. Green Fire Brick Company Mexico, Missouri		
Ingersoll-Rand Company 1700 Third Avenue South Birmingham, Alabama	Internal	6,000- 15,000 vpm
M. B. Manufacturing Company P. O. Box 1825 New Haven, Connecticut	External	120-600,000 vpm
Mexico Refractories Company Mexico, Missouri		
North Carolina State College Raleigh, North Carolina		
Pennsylvania State University University Park, Pennsylvania		
Portland Cement Association 33 W. Grand Avenue Chicago 10, Illinois		
Remington Arms Company Bridgeport 2, Connecticut (Formerly Mall Tool Company)	Internal	1,200- 10,000 vpm
Stow Manufacturing Company 400 State Street Binghamton, New York	Internal	6,000- 15,000 vpm
Syntron Company Homer City, Pennsylvania	External Internal	3,600- 7,200 vpm 7,200- 10,000 vpm

TABLE 8 (Cont'd)

Name and Address	Type	Frequency Range
Universal Atlas Cement Company 100 Park Avenue New York 17, New York		
Vibro-Plus Products Incorporated Stanhope, New Jersey	External Internal	3,600 vpm 12,000 vpm

TABLE 9

SCREEN ANALYSIS OF MATERIALS USED

(Screen Scale Ratio 1.414)

MAYERIAL CODE: 3.1.1F.1 (Sample 1) DATE: Feb. 19, 1959

TYLER MESH	OPENING in.	WEIGHT gms.	PERCENT	PERCENT CUMULATIVE
3	0.263			
4	0.185			
6	0.131	32.1	10.6	10.6
8	0.093	46.3	15.3	25.9
10	0.065	34.1	11.3	37.2
14	0.046	24.5	8.1	45.3
20	0.0328	19.2	6.4	51.7
28	0.0232	12.8	4.2	55.9
35	0.0164	8.3	2.7	58.6
48	0.0116	7.5	2.5	61.1
65	0.0082	7.3	2.4	63.5
100	0.0058	9.1	3.0	66.5
150	0.0041	8.4	2.8	69.3
200	0.0029	27.1	9.0	78.3
325	0.0017	53.0	17.6	95.9
Pan.		12.5	4.1	100.0
TOTAL		302.2	100.0	

TABLE 9 (Cont'd)

SCREEN ANALYSIS OF MATERIALS USED

(Screen Scale Ratio 1.414)

MATERIAL CODE: 3.1.1F.1 (Sample 2) DATE: March 4, 1959

TYLER MESH	OPENING in.	WEIGHT gms.	PERCENT	PERCENT CUMULATIVE
3	0.263			
4	0.185			
6	0.131	16.6	16.1	16.1
8	0.093	19.8	19.2	35.3
10	0.065	13.9	13.5	48.8
14	0.046	9.5	9.2	58.0
20	0.0328	6.3	6.1	64.1
28	0.0232	3.4	3.3	67.4
35	0.0164	1.8	1.7	69.1
48	0.0116	1.6	1.5	70.6
65	0.0082	1.0	1.0	71.6
100	0.0058	0.9	.9	72.5
150	0.0041	2.1	2.0	74.5
200	0.0029	5.2	5.0	79.5
325	0.0017	11.7	11.3	90.8
Pan.		9.5	9.2	100.0
TOTAL		103.3	100.0	

TABLE 10 DATA ON FREQUENCY AND AMPLITUDE vs. DENSITY AND MODULUS OF RUPTURE - EXTERNAL VIBRATION

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	AMPLITUDE in.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
1F.1-10	2	0.0005	3,600	3495.7	1733.0	1.983	123.74	290	218	
1F.1-11	9	"	"	3557.0	1772.0	1.993	124.36	300	225	
1F.1-12	16	"	"	3533.0	1767.5	2.001	124.86	385	289	
1F.1-13	1	"	7,200	3549.7	1778.0	2.004	125.05	235	176	
1F.1-14	6	"	"	3603.0	1834.5	2.037	127.11	240	180	Vib. - 3.3 min.
1F.1-15	12	"	"	3551.0	1767.0	2.013	125.61	240	180	
1F.1-16	2	"	10,000	3686.0	1955.0	2.129	132.85	435	326	Mixed additional 5 min. Pronounced bubbling noted. This
1F.1-17	6	"	"	3748.5	1982.3	2.126	132.66	725	544	
1F.1-18	11	"	"	3815.5	2028.0	2.135	133.22	710	532	was typical for remaining freq. range.
1F.1-19	1	"	12,000	3712.0	1934.5	2.088	130.29	285	214	
1F.1-20	5	"	"	3696.0	1945.0	2.111	131.73	385	289	
1F.1-21	10	"	"	3769.0	1991.0	2.120	132.29	360	270	
1F.1-22	1	"	14,800	3647.5	1912.0	2.102	131.16	250	188	(-22 Vib. - 2.8 min.) Waves
1F.1-23	-	"	"	3651.3	1925.5	2.116	132.04	235	176	or ripples on surface of
1F.1-24	12	"	"	3790.0	2007.0	2.126	132.66	475	356	mat'l noted after approx. 1½ min. of vib. This was typical for remaining freq. range.
1F.1-25	2	"	18,000	3700.0	1959.3	2.126	132.66	315	236	
1F.1-26	7	"	"	3729.3	1977.0	2.128	132.79	265	199	
1F.1-27	13	"	"	3737.5	1983.5	2.131	132.97	475	356	
1F.1-28	1	"	20,800	3698.0	1947.7	2.113	131.85	300	225	
1F.1-29	6	"	"	3749.3	1991.0	2.132	133.04	470	352	
1F.1-30	12	"	"	3744.0	1972.0	2.113	131.85	265	199	
1F.1-31	4	"	24,000	3679.0	1932.0	2.106	131.41	255	191	Vib. - 2.7 min.
1F.1-32	9	"	"	3759.0	1984.3	2.118	132.16	345	259	
1F.1-33	14	"	"	3664.5	1947.7	2.134	133.16	470	352	Lacked mat'l to completely fill mold.
1F.1-34	1	"	28,800	3679.5	1909.7	2.079	129.73	335	251	Vib. - 1.7 min.
1F.1-35	-	"	"	3710.0	1941.3	2.096	130.79	380	285	Vib. - 1.9 min.

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 10 (CONT'D)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	AMPLITUDE in.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
1F.1-36	11	0.0005	28,800	3715.5	1957.0	2.113	131.85	455	341	
1F.1-37	1	0.0010	3,600	3598.0	1858.0	2.066	129.04	300	225	
1F.1-38	6	"	"	3639.0	1874.0	2.062	128.67	295	221	
1F.1-39	12	"	"	3642.0	1876.0	2.062	128.67	170	128	
1F.1-40	2	"	7,200	3571.0	1856.0	2.082	129.92	215	161	(-40 30% of top surface, approx. 1/8" deep, lost due to crazing from particle separation.) Waves or ripples noted. This was typical for remaining freq. range.
1F.1-41	6	"	"	3686.0	1919.0	2.085	130.10	300	225	
1F.1-42	11	"	"	3676.7	1908.0	2.079	129.73	215	161	
1F.1-43	1	"	10,000	3693.0	1879.0	2.059	128.48	200	150	-43 & -44 10% of top surface (see remarks -40)
1F.1-44	7	"	"	3692.0	1920.0	2.084	130.04	280	210	
1F.1-45	12	"	"	3726.0	1949.0	2.097	130.85	180	135	
1F.1-46	1	"	12,000	3654.5	1906.3	2.090	130.42	240	180	
1F.1-47	6	"	"	3708.0	1933.0	2.089	130.35	205	154	
1F.1-48	11	"	"	3740.0	1959.0	2.100	131.04	150	113	
1F.1-49	1	"	14,800	3646.5	1916.5	2.110	131.66	210	158	
1F.1-50	7	"	"	3715.0	1916.0	2.067	128.98	275	206	
1F.1-51	13	"	"	3701.7	1929.0	2.088	130.29	300	225	
1F.1-52	-	"	18,000	3709.0	1943.0	2.100	131.04	325	244	
1F.1-53	7	"	"	3746.0	1934.7	2.080	129.79	320	240	
1F.1-54	13	"	"	3777.0	1976.0	2.097	130.85	310	232	
1F.1-55	1	"	20,800	3708.0	1948.0	2.107	131.48	220	165	
1F.1-56	7	"	"	3752.0	1963.0	2.097	130.85	310	232	
1F.1-57	12	"	"	3714.7	1964.0	2.122	132.41	365	274	
1F.1-58	1	"	24,000	3739.3	1963.0	2.105	131.35	-	-	Data lost.
1F.1-59	6	"	"	3756.5	1974.0	2.107	131.48	-	-	Data lost.
1F.1-60	11	"	"	3779.5	1996.0	2.119	132.23	-	-	Vib. - 2.8 min. Data lost.

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 10 (CONT'D)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	AMPLITUDE in.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
1F.1-61	1	0.0010	28,800	3655.0	1894.7	2.076	129.54	340	255	Vib. - 1.2 min
1F.1-62	4	"	"	3688.5	1938.7	2.108	131.54	225	169	Vib. - 1.5 min.
1F.1-63	-	"	"	3690.3	1964.7	2.139	133.47	200	150	
1F.1-64	1	0.0015	3,600	3708.3	1888.5	2.038	127.17	335	252	
1F.1-65	6	"	"	3720.0	1873.0	2.014	125.67	365	274	
1F.1-66	11	"	"	3677.0	1855.0	2.018	125.92	390	293	
1F.1-67	2	"	7,200	3696.3	1864.3	2.018	125.92	255	191	
1F.1-68	7	"	"	3722.0	1882.3	2.023	126.24	250	188	
1F.1-69	12	"	"	3711.0	1881.0	2.028	126.55	335	252	
1F.1-70	1	"	10,000	3654.5	1854.0	2.030	126.67	275	206	
1F.1-71	7	"	"	3702.3	1935.7	2.060	128.54	375	282	
1F.1-72	12	"	"	3769.5	1941.0	2.062	128.67	320	240	
1F.1-73	1	"	12,000	3690.5	1879.3	2.038	127.17	230	173	-73 & -74 did not appear to react to vibration.
1F.1-74	7	"	"	3674.5	1883.5	2.052	128.04	245	184	
1F.1-75	11	"	"	3731.5	1937.0	2.079	129.73	265	199	
1F.1-76	2	"	14,800	3722.3	1932.0	2.079	129.73	235	176	
1F.1-77	7	"	"	3775.0	1981.0	2.104	131.29	200	150	
1F.1-78	12	"	"	-	-	-	-	-	-	Mold separated during vibration.
1F.1-79	1	"	18,000	3684.5	1896.0	2.060	128.54	265	199	
1F.1-80	6	"	"	3712.0	1911.0	2.061	128.60	335	252	
1F.1-81	12	"	"	3700.0	1907.3	2.064	128.79	325	244	Did not appear to react to vibration.
1F.1-82	1	"	20,800	3696.5	1904.0	2.062	128.67	280	210	
1F.1-83	6	"	"	3720.5	1914.0	2.060	128.54	200	150	
1F.1-84	11	"	"	3693.5	1911.3	2.072	129.29	265	199	
1F.1-85	1	"	24,000	3722.0	1912.3	2.057	128.36	300	225	
1F.1-86	6	"	"	-	-	-	-	-	-	Mold separated during vibration.
1F.1-87	10	"	"	3736.5	1940.0	2.080	129.79	400	300	

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 10 (CONT'D)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	AMPLITUDE in.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
1F.1-88	1	0.0015	28,000	3741.0	1917.7	2.052	126.04	300	225	
1F.1-89	6	"	"	3717.5	1915.0	2.062	128.67	365	199	
1F.1-90	11	"	"	-	-	-	-	-	-	Mold separated during vibration.
1F.1-91	1	0.0020	3,600	3613.0	1838.0	2.035	126.98	455	341	
1F.1-92	6	"	"	3694.0	1909.0	2.069	129.11	410	308	
1F.1-93	11	"	"	3724.3	1904.0	2.046	127.67	550	413	Did not appear to react to vibration.
1F.1-94	1	"	7,200	3715.5	1839.0	2.980	123.55	360	370	
1F.1-95	6	"	"	3732.0	1908.0	2.046	127.67	490	368	
1F.1-96	10	"	"	3777.0	1954.0	2.072	129.29	610	458	
1F.1-97	1	"	10,000	3683.7	1884.0	2.047	127.73	130	98	
1F.1-98	6	"	"	3747.7	1943.0	2.077	129.60	325	244	
1F.1-99	11	"	"	3736.5	1915.0	2.051	127.98	375	281	
1F.1-100	1	"	12,000	3731.5	1892.0	2.029	126.61	200	150	
1F.1-101	6	"	"	3792.5	1940.0	2.047	127.73	530	397	
1F.1-102	12	"	"	3787.5	1960.0	2.073	129.36	310	232	
1F.1-103	1	"	14,800	3698.3	1914.0	2.073	129.36	275	206	
1F.1-104	6	"	"	3771.7	1936.0	2.055	128.23	145	109	
1F.1-105	11	"	"	3664.3	1913.0	2.092	130.54	220	165	50% of top surface (See remarks -40)
1F.1-106	1	"	18,000	3749.3	1952.0	2.080	130.17	345	259	
1F.1-107	6	"	"	3713.0	1930.0	2.048	127.80	215	161	
1F.1-108	11	"	"	3734.7	1931.5	2.071	129.23	290	218	50% of top surface (See remarks -40)
1F.1-109	1	"	20,800	3774.0	1960.0	2.080	129.79	240	180	
1F.1-110	5	"	"	3731.5	1940.0	2.083	129.98	330	248	
1F.1-111	9	"	"	3743.5	1938.5	2.074	129.42	240	180	
1F.1-112	1	"	24,000	3700.0	1924.0	2.083	129.98	270	202	
1F.1-113	5	"	"	3724.5	1940.0	2.087	130.22	245	184	Vib. - 1.6 min.
1F.1-114	8	"	"	3759.7	1920.0	2.044	127.55	235	176	Vib. - 2.0 min.

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 10 (CONT'D)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	AMPLITUDE in.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
1F.1-115	1	0.0020	28,800	3758.7	1941.0	2.068	129.04	285	214	
1F.1-116	6	"	"	3736.5	1936.0	2.075	129.48	235	176	
1F.1-117	10	"	"	3754.0	1911.0	2.037	127.11	125	94	Vib. - 1.5 min. -112 thru -117 After mixing, mat'l appeared to be much wetter and had a grayish color as compared to previous specimens.

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 11 DATA ON PER CENT MIXING WATER vs. MODULUS OF RUPTURE - EXTERNAL VIBRATION
(10,000 vpm frequency and 0.0005 inch amplitude)

SPECIMEN NUMBER	WATER CONTENT %	TIME INTERVAL MIXING TO PLACEMENT min.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi
LF.1-172	10	3	3346	1697	2.029	126.61	494	324
LF.1-173	"	3	3696	1898	2.056	128.29	550	413
LF.1-174	"	8	3653	1850	2.026	126.42	436	329
LF.1-175	9	1	3635	1840	2.025	126.36	594	446
LF.1-176	"	6	3627	1836	2.025	126.36	433	325
LF.1-177	"	11	3342	1690	1.908	119.06	300	225

REMARKS:

Specimen #-172. Material for this specimen mixed separately. Not enough material mixed to completely fill mold.

Specimens #-173 and #-174. Material appeared drier than usual after mixing, mixed an additional five minutes.

Specimens #-175, #-176, and #-177. Material appeared extremely dry after mixing. Pockets of dry, unmixed material found in the bottom of the mixer. This was scraped loose and mixed an additional five minutes.

Specimen #-177. Vibrated 3.5 minutes. Specimen was extremely dry even after vibration. Material did not flow due to vibration as did previous specimens.

NOTE: Mixing time - 5 minutes
Vibration time - 3 minutes
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 12 DATA ON VIBRATION TIME vs. DENSITY AND MODULUS OF RUPTURE - EXTERNAL VIBRATION
(10,000 vpm frequency and 0.0005 inch amplitude)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	VIBRATION TIME min.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi
LF.1-181	1	1	3642	1875	2.061	128.61	420	321
LF.1-182	4	"	3637	1865	2.052	128.04	530	398
LF.1-183	7	"	3521	1810	2.058	128.42	464	348
LF.1-184	1	2	3659	1905	2.066	130.17	310	233
LF.1-185	5	"	3402	1802	2.126	132.66	347	260
LF.1-186	9	"	3656	1915	2.100	131.04	530	398
LF.1-187	3	3	3643	1880	2.066	128.92	303	227
LF.1-188	8	"	3609	1870	2.075	129.48	480	360
LF.1-189	13	"	3672	1908	2.082	129.92	510	383

REMARKS:

All batches appeared dry after initial mixing. Mixed an additional 2 minutes.

Specimen #-183. Not enough material to completely fill mold.

Specimen #-185. Not enough material to completely fill mold.

NOTE: Water - 10% by weight
Mixing time - 5 minutes.
Curing time - 4 days minimum.
Drying time - 24 hours @ 220 F; 24 hours @ 550 F.

TABLE 13 DATA ON FREQUENCY vs. DENSITY AND MODULUS OF RUPTURE - INTERNAL VIBRATION

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	VIBRATION TIME min.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
										Air driven vibrator used.
1F.1-133	1	5	7,200	3608	1703	1.943	121.24	305	229	Little action noted.
1F.1-134	12	5	"	3428	1612	1.898	118.44	305	229	
1F.1-135	18	5	"	3525	1730	1.968	122.80	345	266	
1F.1-121	1	2	10,000	3604	1795	1.994	124.42	330	248	Vibration applied continu-
1F.1-122	8	2	"	3596	1753	1.951	121.74	370	278	ously with dragging motion
1F.1-123	15	2	"	3643	1811	1.992	124.30	420	318	thru mix in mold.
1F.1-136	1	4	14,000	3524	1726	1.960	122.30	260	195	Good action noted. Slow
1F.1-137	6	5	"	3569	1767	1.981	123.61	330	248	dragging motion of vibrator
1F.1-138	12	5	"	3527	1731	1.964	122.55	325	244	thru mix used.
1F.1-139	1	3	18,000	3541	1724	1.949	121.62	295	164	Good action noted.
1F.1-140	6	3	"	3566	1765	1.981	123.61	305	229	
1F.1-141	11	3	"	3492	1679	1.926	120.18	305	229	
1F.1-142	1	3	20,800	3524	1760	1.993	124.60	225	169	Good action. Short time
1F.1-143	5	3	"	3470	1730	1.974	124.43	290	218	used to prevent segregation.
1F.1-144	11	3	"	3463	1721	1.977	123.36	320	240	
1F.1-145	1	3	24,000	3411	1650	1.937	120.87	175	132	Segregation noted.
1F.1-146	6	2	"	3331	1588	1.911	119.25	210	158	
1F.1-147	10	2	"	3447	1712	1.987	123.99	265	199	
1F.1-148	1	2	28,000	3437	1667	1.942	121.16	150	113	Segregation, erratic action.
1F.1-149	6	2	"	3455	1682	1.949	121.62	150	113	
1F.1-150	10	2	"	3406	1645	1.934	120.68	165	124	

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration amplitude - unknown
Curing time - 4 days minimum
Drying time - 24 hours @ 220 F; 24 hours @ 550 F

TABLE 13 (CONT'D)

SPECIMEN NUMBER	TIME INTERVAL MIXING TO PLACEMENT min.	VIBRATION TIME min.	FREQUENCY vpm.	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft	BREAKING FORCE lbs.	MODULUS OF RUPTURE psi	REMARKS
										Electrically driven vibrator used.
LF.1-151	1	2	3,600	3639	1841	2.024	126.30	240	180	Not much action.
LF.1-152	5	2	"	3581	1810	2.022	126.17	320	240	
LF.1-153	9	2	"	3623	1835	2.026	126.42	360	270	
LF.1-154	1	2	7,200	3591	1815	2.022	126.17	245	184	Good action noted in mold.
LF.1-155	4	2	"	3644	1840	2.020	126.05	265	199	
LF.1-156	7	2	"	3625	1825	2.014	125.67	290	228	
LF.1-157	1	2	10.000	3441	1659	1.931	120.49	230	173	Segregation occurred on -157
LF.1-158	4	2	"	3393	1601	1.893	118.12	190	143	and -158. -159 good action.
LF.1-159	7	2	"	3554	1785	2.009	125.36	220	165	
LF.1-160	1	2	12,000	3616	1794	1.985	123.86	265	199	Segregation occurs with over
LF.1-161	4	2	"	3581	1776	1.984	123.80	290	218	vibration. Amplitude of
LF.1-162	7	2	"	3660	1867	2.041	127.36	325	244	vibrator causes material to be thrown from mold. Strong
LF.1-163	1	2	15,000	3588	1802	2.009	125.36	255	191	vibratory action noted; -160
LF.1-164	4	2	"	3510	1708	1.948	121.56	250	188	thru -165.
LF.1-165	7	2	"	3568	1773	1.883	117.50	255	191	

NOTE: Water - 10% by weight
Mixing time - 5 minutes
Vibration amplitude - unknown
Curing time - 4 days minimum

TABLE 14

DATA ON VACUUM MIXING AND EXTERNAL VIBRATION VS. MODULUS OF RUPTURE
(10,000 vpm frequency and 0.0005 inch amplitude)

SPECIMEN NUMBER	MIXED	VIBRATED	WEIGHT IN AIR gms.	WEIGHT IN WATER gms.	SPECIFIC GRAVITY	DENSITY lbs/ft^3	MODULUS OF RUPTURE psi
1F.1-190*	In vacuum	In air	3691	1891	2.050	127.92	360
1F.1-191*	"	"	3635	1882	2.074	129.42	477
1F.1-194*	In vacuum	In vacuum	3595	1835	2.043	127.48	312
1F.1-197*	"	"	3565	1781	2.000	124.80	259
1F.1-200	In air	In air	3789	1954	2.065	128.0	747
1F.1-201	"	"	3736	1900	2.035	127.0	548
1F.1-202	"	"	3794	1990	2.100	131.0	629
1F.1-203	In vacuum	In air	3796	1959	2.065	128.0	749
1F.1-204	"	"	3845	1997	2.080	130.0	814
1F.1-205	"	"	3787	1959	2.075	129.5	574
1F.1-206	In air	In vacuum	3783	1928	2.040	127.5	828
1F.1-207	"	"	3729	1968	2.000	125.0	152
1F.1-208	"	"	3767	1947	2.070	128.5	577
1F.1-206R	In air	In vacuum	3804	2008	2.195	137.0	666
1F.1-207R	"	"	3808	2080	2.205	138.0	574
1F.1-208R	"	"	3787	2022	2.200	137.5	500
1F.1-209	In vacuum	In vacuum	3828	2050	2.155	134.5	749
1F.1-210	"	"	3828	2023	2.120	132.5	472
1F.1-211	"	"	3833	2020	2.110	132.0	472

REMARKS: All specimens made using 8.5 pounds of dry material with .765 pounds (9%) water, *(10%)
All specimens were placed in one minute or less after mixing, *2 minutes, 197 was 3 min.
Mixing time of 3 minutes and vibrating time of 2 minutes used, *5 min. and 1 min.
A vacuum of 21.5 inches of mercury or better was used.
*These specimens were from a different batch than the -200 series.

NOTE: Curing time - 4 days minimum
Dry time - 24 hours @ 220 F; 24 hours at 550 F.

TABLE 15 - PHYSICAL PROPERTIES

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
1A.1-4	57% Alumina-Silicate (light weight) plus 43% Calcium Aluminate	50	Cast	48 hrs. at R.T.	-0.11	-	-	208	-	76	1	Efflorescence noted.
-5		"			-0.07	-	-	199	-	"	1	
-6		"	1 minute - vibration time	24 hrs. at 220F	-0.08	1200	-0.48	81	-	"	1	Cracks noted on surface after
-7		"			-0.11	"	-0.44	102	-	"	2	firing at 1200F on Specimens
-8		"			0	2000	-0.42	72	-	72	1	-6 and -7.
-9		"			-0.06	"	-0.50	76	-	"	1	Cracks noted in Specimens -8
-10		"			-0.02	"	-0.43	-	"	"	-	thru -11 after firing to 2000F.
-11		"			-0.08	"	-0.48	-	"	"	-	*Broken during furnace loading.
1B.1-4	Silica (50% aggregate) plus 50% Calcium Aluminate	64.5	Cast	48 hrs. at R.T.	-0.25	-	-	167	-	64	2	Efflorescence noted.
-5		"			-0.33	-	-	167	-	"	2	
-6		"	1 minute - vibration time	24 hrs. at 220F	-0.24	1750	-1.61	104	-	58	2	
-7		"			-0.26	"	-1.51	104	-	59	2	
-8		"			-0.36	"	-1.71	-	99	53	-	
-9		"			-0.31	"	-1.68	-	70	58	-	
1C.1-4	Alumina Silicate plus Unknown Binder	14	Cast	24 hrs. at R.T.	-0.10	-	-	925	-	127	4	
-5		"			-0.10	-	-	829	-	127	4	
-6		"	1 minute - vibration time	24 hrs. at 220F	-0.14	1200	-0.33	749	-	119	4	
-7		"			-0.06	"	-0.24	729	-	119	4	
-8		"			-0.13	1750	-0.43	569	-	113	4	
-9		"			-0.13	"	-0.47	569	-	117	4	
-10		"			-0.32	"	-0.33	-	422	"	-	
-11		"			-0.06	"	-0.21	-	179	"	-	
1D.1-4	Alumina and Silica plus Calcium Aluminate	40	Cast	12 hrs. at R.T.	∅0.01	-	-	243	-	85	4	Specimens badly distorted after firing.
-5		"			-0.06	-	-	268	-	"	3	
-6		"	1 minute vibration time	16 hrs. at 220F	-0.06	2400	-	699	-	78	5	
-7		"			-0.01	"	-	747	-	77	5	
-8		"			-0.09	"	-	-	85	78	-	
-9		"			-0.04	"	-	-	-	79	-	
1E.1-4	Alumina and Silica plus Calcium Aluminate	15	Cast	12 hrs. at R.T.	-0.11	-	-	495	-	119	1	Vibrating Time 1½ minutes.
-5		"			-0.08	-	-	536	-	"	2	
-6		"	1.5 minutes vibration time	24 hrs. at 220F	-0.03	2200	-0.16	337	-	117	2	
-7		"			∅0.01	"	-0.24	281	-	110	2	
-8		"			-0.13	"	-0.22	-	229	114	-	
-9		"			-0.11	"	-0.22	-	272	114	-	
1F.1-4	Hi Alumina plus Calcium Aluminate	9	Cast	12 hrs. at R.T.	-0.06	-	-	925	-	144	1	
-5		"			-0.03	-	-	847	-	144	2	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.01	2400	-0.63	1240	-	137	1	
-7		"			-0.06	"	-0.67	806	-	136	1	
-8		"			-0.04	"	-0.67	-	399	137	-	
-9		"			-0.03	"	-0.68	-	610	137	-	
1G.1-4	Alumina and Silica plus Calcium Aluminate	18	Cast	12 hrs. at R.T.	∅0.06	-	-	598	-	110	1	
-5		"			∅0.08	-	-	628	-	"	1	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.03	1200	-0.18	398	-	"	1	
-7		"			-0.10	"	-0.26	379	-	"	1	
-8		"			-0.10	"	-0.27	-	239	-	-	
-9		"			-0.03	"	-0.17	-	259	-	-	
1H.1-4	Alumina and Silica plus Calcium Aluminate	50	Cast	12 hrs. at R.T.	-0.12	-	-	116	-	72	2	Separation noted. Surface Finish on all Specimens was Sandy.
-5		"			-0.03	-	-	103	-	"	1	
-6		"	0.8 minutes vibration time	24 hrs. at 220F	-0.04	2000	-0.57	94	-	68	2	
-7		"			-0.18	"	-0.69	124	-	"	2	
-8		"			-0.12	"	-0.62	-	67	"	-	
-9		"			-0.10	"	-0.59	-	67	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
1J.1-4	Hi Alumina	15	Cast		-0.03	-	-	112	-	123	4	
-5	plus	"			0	-	-	100	-	"	4	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	+0.01	1200	-0.11	104	-	"	7	
-7		"	vibration time		+0.02	"	-0.09	104	-	"	6	
-8		"			+0.01	2400	-0.76	510	-	120	10	
-9		"			+0.04	"	-0.70	492	-	121	10	
-10		"			+0.01	"	-0.67	-	212	120	-	
-11		"			+0.03	"	-0.71	-	315	119	-	
1K.1-4	Alumina and	20	Cast		-0.39	-	-	334	-	110	2	*Specimens badly distorted after firing.
-5	Silica	"			-0.38	-	-	323	-	"	4	
-6	plus	"	1 minute	16 hrs. at 220F	-0.31	2400	"	1202	-	"	4	
-7	Calcium Aluminate	"	vibration time		-0.22	"	"	1261	-	"	3	
-8		"			-0.31	"	"	-	271	"	-	
-9		"			-0.32	"	"	-	229	"	-	
1L.1-4	Alumina and	55	Cast	12 hrs. at R.T.	-0.18	-	-	112	-	68	2	All Specimens had a sandy Surface Finish.
-5	Silica	"			-0.27	-	-	100	-	"	3	
-6	plus	"	1 minute	24 hrs. at 220F	-0.13	1200	-0.72	93	-	"	3	
-7	Calcium Aluminate	"	vibration time		-0.10	"	-0.74	93	-	"	3	
-8		"			-0.27	2000	-1.01	115		"	2	
-9		"			-0.27	"	-1.14	131	-	"	2	
-10		"			-0.22	"	-1.03	-	44	"	-	
-11		"			-0.26	"	-1.16	-	66	"	-	
1M.1-4	Chrome	7.15	Cast	24 hrs. at R.T.	-0.17	-	-	888	-	188	5	
-5	Refractory	"			-0.09	-	-	826	-	187	5	
-6	plus	"	1 minute	24 hrs. at 220F	-0.04	2500	-0.22	1605	-	179	5	
-7	Calcium Aluminate	"	vibration time		-0.12	"	-0.26	1879	-	180	5	
-8		"			-0.19	"	-0.32	-	129	"	-	
-9		"			-0.14	"	-0.22	-	74	"	-	
1N.1-4	51% Alumina	36	Cast	24 hrs. at R.T.	-0.07	-	-	274	-	85	1	Efflorescence noted.
-5	49% Silica	"			-0.07	-	-	265	-	"	1	
-6	plus	"	1 minute	24 hrs. at 220F	-0.01	2400	-1.37	148	-	78	2	
-7	Calcium Aluminate	"	vibration time		-0.04	"	-1.37	806	-	77	2	
-8		"			-0.05	"	-1.36	-	144	77	-	
-9		"			-0.01	"	-1.36	-	87	83	-	
1P.1-4	Unknown	33.4	Cast	24 hrs. at R.T.	-0.10	-	-	185	-	93	4	Sandy. Difficult to Vibrate.
-5		"			-0.07	-	-	144	-	93	4	
-6		"	1 minute	24 hrs. at 220F	-0.10	1750	-0.51	33	-	87	5	
-7		"	vibration time		-0.09	"	-0.47	33	-	87	5	
-8		"			-0.09	"	-0.51	-	26	87	-	
-9		"			-0.07	"	-0.48	-	37	87	-	
2A.1-4	Alumina and	11	Cast	24 hrs. at R.T.	+0.04	-	-	1201	-	136	1	Extremely large aggregate, estimated to be approx. $\frac{1}{2}$".
-5	Silica	"			+0.09	-	-	1220	-	"	1	
-6	plus	"	1 minute	24 hrs. at 220F	+0.04	2250	-0.08	709	-	127	3	
-7	Calcium Aluminate	"	vibration time		+0.03	"	-0.06	729	-	"	2	
-8		"			-0.04	"	-0.10	-	399	"	-	
-9		"			+0.12	"	-0.01	-	492	"	-	
2B.1-4	Flint Fireclay	15.5	Cast	24 hrs. at R.T.	0	-	-	394	-	110	4	*Melted in firing.
-5	plus	"			-0.01	-	-	444	-	"	3	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	+0.01	2500	"	"	-	-	3	
-7		"	vibration time		+0.10	"	"	"	-	-	2	
-8		"			+0.12	"	"	-	"	-	-	
-9		"			+0.28	"	"	-	"	-	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
2G.1-4	Flint Fireclay	28	Cast	24 hrs. at R.T.	+0.14	-	-	586	-	102	1	Separation noted - Do not add
-5	plus	"			+0.08	-	-	540	-	"	1	water after initial mixing.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.11	2250	-0.41	459	-	91	2	
-7		"	vibration time		+0.17	"	-0.27	367	-	"	2	
-8		"			+0.17	"	-0.30	-	66	"	-	
-9		"	20 min. (max.) Placement Time		+0.07	"	-0.30	-	37	"	-	
2D.1-4	Unknown	12	Cast	24 hrs. at R.T.	+0.07	-	-	1621	-	136	5	Vibrating time 1½ minutes.
-5		"			+0.11	-	-	1457	-	"	3	
-6		"	1.5 minutes	24 hrs. at 220F	+0.08	600	-0.06	1513	-	127	5	
-7	plus	"	vibration time		+0.06	"	-0.06	1260	-	"	6	
-8	Calcium Aluminate	"			+0.13	"	-0.02	-	179	"	4	
-9		"	30 min. (max.) Placement Time		+0.03	"	-0.07	-	130	"	5	
2E.1-4	Vermiculite	183	Puddled by	24 hrs. at R.T.	-0.03	-	-	33	-	25	11	Material would not vibrate. No
-5	plus	"	hand.		-0.13	-	-	33	-	"	11	manufacturer's recommendations
-6	Unknown Binder	"		24 hrs. at 220F	-0.11	2000	*	*	-	*	-	for drying and firing.
-7		"			-0.14	"	*	*	-	*	-	
-8		"	30 min. (max.)		-0.13	"	*	-	*	*	-	*Destroyed during firing.
-9		"	Placement Time		-0.08	"	*	-	*	*	-	
2F.1-4	Unknown	47	Cast	24 hrs. at R.T.	-0.17	-	-	167	-	76	5	No manufacturer's recommendations
-5		"			-0.27	-	-	187	-	"	5	for drying or firing.
-6		"	1 minute	24 hrs. at 220F	-0.28	2000	-1.11	81	-	66	5	
-7		"	vibration time		-0.27	"	-1.11	67	-	"	5	
-8		"			-0.37	"	-1.13	-	19	"	-	
-9		"	20 min. (max.) Placement Time		-0.33	"	-1.07	-	19	"	-	
2G.1-4	Fire-clay	15	Cast	24 hrs. at R.T.	+0.11	-	-	944	-	121	2	Same coefficient of expansion
-5	plus	"			+0.14	-	-	925	-	"	2	as steel.
-6	Calcium Aluminate	"	1 minute	48 hrs. at 220F	+0.16	600	-0.03	683	-	114	4	
-7		"	vibration time		+0.11	"	-0.06	683	-	"	3	
-8		"			+0.18	2250	-0.17	629	-	"	2	
-9		"	20 min. (max.)		+0.09	"	-0.16	629	-	"	3	
-10		"	Placement Time		+0.19	"	-0.07	-	292	"	-	
-11		"			+0.10	"	-0.13	-	310	"	-	
2J.1-	Tabular Alumina plus Phosphoric Acid		Cast (Packed ready for placement)									Cap material. Material shipped in polyethalene bag in drum - putty consistancy. Material is not air setting for thick section. Specimens not cast.
3A.1-4	Calcined Kaolin	54	Cast	48 hrs. at R.T.	-0.02	-	-	242	-	76	2	Specimens -6 thru -9 severly cracked
-5	plus	"			-0.02	-	-	278	-	"	2	after firing. (Normal)
-6	Portland Cement	"	1 minute	24 hrs. at 220F	-0.06	1000	*	*	-	*	*	*Specimens crumbled during firing.
-7		"	vibration time		-0.04	"	*	*	-	*	*	
-8		"			-0.06	"	*	-	*	*	-	
-9		"	30 min. (max.) Placement Time		-0.07	"	*	-	*	*	-	
3B.1-1	Calcined Kaolin	60	Cast	48 hrs. at R.T.	-0.20	-	-	241	-	74	5	Efflorescence noted.
-4	plus	55			-0.31	-	-	162	-	"	3	May be used for light-weight fills.
-5	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.26	2000	-0.60	124	-	64	7	
-6		"	vibration time		-0.31	"	-0.64	123	-	"	5	
-7		"			-0.37	"	-0.70	-	87	"	-	
-9		"	30 min. (max.) Placement Time		-0.40	"	-0.72	-	185	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
3C.1-4	Calcined Kaolin	12.25	Cast	48 hrs. at R.T.	+0.02	-	-	838	-	136	1	
-5	plus	"			-0.06	-	-	906	-	"	2	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.03	2400	+1.66	1406	-	127	6	
-7		"	vibration time		-0.03	"	-	1457	-	125	6	
-8		"			-0.03	"	+1.89	-	118	125	-	
-9		"	30 min. (max.) Placement Time		+0.11	"	+1.62	-	381	126	-	
3D.1-4	Calcined Kaolin	20	Cast	48 hrs. at R.T.	-0.06	-	-	788	-	112	4	Plastic-like material.
-5	plus	"			-0.01	-	-	808	-	"	3	For thin sections only.
-6	Portland Cement	"	1 minute	24 hrs. at 220F	-0.02	1000	-0.42	387	-	106	3	*Specimen fell apart during heating
-7		"	vibration time		-0.08	"	-0.43	398	-	"	3	for modulus test.
-8		"			-0.10	"	-0.44	-	*	-	-	
-9		"			-0.06	"	-0.39	-	*	-	-	
3E.1-4	Calcined Kaolin	12.5	Cast	48 hrs. at R.T.	-0.10	-	-	1005	-	131	2	Resists Erosion.
-5	plus	"			-0.09	-	-	986	-	"	2	Surface finish on all
-6	Portland Cement	"	1 minute	24 hrs. at 220F	-0.12	1000	-0.12	337	-	127	3	Specimens was dandy.
-7		"	vibration time		-0.07	"	-0.08	524	-	"	3	*Specimen fell apart during heating
-8		"			-0.12	"	-0.12	-	*	-	-	for modulus test.
-9		"	30 min. (max.) Placement Time		-0.12	"	-0.06	-	*	-	-	
3F.1-4	Calcined Alumina	13	Cast	48 hrs. at R.T.	+0.04	-	-	767	-	136	2	
-5	and Silica	"		(Hi Humidity)	+0.01	-	-	826	-	"	2	
-6	plus	"	1 minute	16 hrs. at 220F	0	2500	+0.11	610	-	123	2	
-7	Calcium Aluminate	"	vibration time		+0.01	"	+0.10	548	-	124	4	
-8		"			-0.01	"	+0.16	-	333	-	-	
-9		"	20 min. (max.) Placement Time		-0.03	"	-0.06	-	359	-	-	
3G.1-1	Chrome Ore	10	Cast	48 hrs. at R.T.	-0.26	-	-	346	-	182	1	
-4	plus	"		(Hi Humidity)	-0.26	-	-	767	-	"	1	
-5	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.33	1500	-0.59	455	-	176	2	
-6		"	vibration time		-0.21	"	-0.47	609	-	"	2	
-7		"			-0.24	2500	-0.32	1396	-	"	4	
-8		"			-0.37	"	+0.23	1640	-	"	4	
-9		"			-0.38	"	+0.21	-	213	"	-	
-10		"			-0.31	"	-0.41	-	543	"	-	
3H.1-4	Fused Mullite	-	Rammed	24 hrs. at R.T.	+0.06	-	-	24	-	-	9	Specimens were crumbly after drying.
-5		-			+0.02	-	-	37	-	-	9	*Corners fell off after firing.
-6		-	(Packed ready	18-24 hrs. at	+0.04	2000	*	33	-	-	11	
-7		-	for placement)	220F	+0.06	*	*	24	-	-	11	
-8		-			+0.01	2500	*	37	-	-	11	
-9		-			+0.01	"	*	lost	-	-	11	
-10		-			+0.02	"	*	-	37	-	11	
-11		-			+0.02	"	*	-	67	-	11	
3J.1-4	Calcined Kaolin	16	Cast	48 hrs. at R.T.	+0.03	-	-	1440	-	127	1	Specimens mixed one at a time for
-5	plus	"			+0.09	-	-	1514	-	"	1	2 min.
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.02	2000	-0.39	426	-	117	1	
-7		"	vibration time		+0.04	"	-0.37	405	-	"	1	
-8		"			+0.01	"	-0.37	-	333	"	-	
-9		"	5 min. (max.) Placement Time		+0.01	"	-0.40	-	359	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
3K.1-4	Calcined Kaolin	17	Cast		-0.07	-	-	1386	-	127	2	Specimens mixed one at a time for 2 min.
-5	plus	"			-0.03	-	-	1181	-	"	2	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.01	2000	-0.36	668	-	114	2	
-7		"	vibration time		0	"	-0.34	629	-	"	1	
-8		"			+0.01	"	-0.26	-	314	"	-	
-9		"	5 min. (max.) Placement Time		-0.01	"	-0.33	-	377	"	-	
3M.1-4	Calcined Kaolin	16	Cast	48 hrs. at R.T.	+0.01	-	-	1063	-	127	2	
-5	plus	"			-0.07	-	-	1063	-	"	1	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.12	2000	-0.39	749	-	119	2	
-7		"	vibration time		-0.14	"	-0.44	827	-	"	2	
-8		"			-0.03	"	-0.33	-	426	"	-	
-9		"			-0.02	"	-0.26	-	355	"	-	
4A.1	Lumnite Cement											Material not cast
5A.1-4	Tabular Alumina	9	Cast	24 hrs. at R.T.	+0.07	-	-	1711	-	169	2	Fast Setting.
-5	plus	"			+0.02	-	-	2148	-	"	2	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	+0.05	1000	-0.07	1621	-	161	2	
-7		"	vibration time		+0.18	"	-0.06	2148	-	"	2	
-8		"	12 min. (max.)		0	"	-0.12	-	610	"	2	
-9		"	Placement Time		+0.03	"	-0.10	-	747	"	2	
5B.1-4	Alumina and	8	Cast	24 hrs. at R.T.	-0.03	-	-	1024	-	146	2	Sticky, plastic, fast setting.
-5	Silica	"			-0.01	-	-	985	-	"	2	*Corners broken during firing.
-6	plus	"	1 minute	24 hrs. at 220F	+0.09	600	-0.06	669	-	144	3	
-7	Calcium Aluminate	"	vibration time		+0.03	"	-0.10	669	-	"	2	
-7R1		"			-	1000	-0.16	717	-	"	4	R1, R2, and R3 Data established
-7R2		"			-	"	-0.12	836	-	"	5	(11-30-60)
-7R3		"			-	"	-0.17	650	-	"	4	
-8		"			0	2500	-0.52	1531	-	"	6	
-9		"	20 min. (max.)		+0.03	"	Broken	-	-	"	-	
-10		"	Placement Time		+0.17	"	-0.42	-	592	"	-	
-11		"			+0.06	"	-0.17	-	481	"	-	
5C.1-4	Fireclay	10.6	Cast	24 hrs. at R.T.	+0.04	-	-	559	-	134	1	Separation noted.
-5	plus	"			-0.01	-	-	621	-	"	1	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.04	600	-0.09	316	-	136	2	
-7		"	vibration time		-0.07	"	-0.15	350	-	"	1	
-8		"	12 min. (max.)		-0.01	"	-0.14	-	255	"	1	
-9		"	Placement Time		-0.06	"	-0.15	-	213	"	1	
5D.1-4	Fireclay	12	Cast	24 hrs. at R.T.	+0.18	-	-	512	-	119	3	
-5	plus	"			+0.18	-	-	549	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.03	2250	0	379	-	122	3	
-7		"	vibration time		+0.13	"	-0.02	366	-	"	3	
-8		"	20 min. (max.)		+0.11	"	-0.02	-	63	"	-	
-9		"	Placement Time		+0.06	"	-0.02	-	63	"	-	
5E.1-4	Fireclay	15	Cast	24 hrs. at R.T.	-0.02	-	-	531	-	110	4	Vibrating Time 1½ minutes.
-5	plus	"			+0.01	-	-	512	-	"	5	*Specimens were distorted and had
-1	Calcium Aluminate	"	1½ minute	24 hrs. at 220F	-0.06	2400	+1.52	1424	-	"	6	broken corners after firing.
-6		"	vibration time		+0.01	"	"	1391	-	"	6	
-7		"	20 min. (max.)		-0.13	"	+0.92	-	338	"	-	
-8		"	Placement Time		-0.14	"	+0.81	-	338	"	-	
5F.1-4	Fireclay	16	Cast	24 hrs. at R.T.	-0.10	-	-	628	-	121	5	
-5	plus	"			-0.10	-	-	667	-	"	4	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.02	600	-0.16	251	-	119	2	
-7		"	vibration time		-0.07	"	-0.13	273	-	"	4	
-8		"			+0.07	"	-0.09	-	128	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
5G.1-4	Fireclay	14	Cast	24 hrs. at R.T.	-0.02	-	-	628	-	112	1	Made one at a time.
-5	plus	"			-0.05	-	-	748	-	"	2	Vibrating time 1½ minutes.
-6	Calcium Aluminate	"	1½ minute	24 hrs. at 220F	-0.05	2400	"	1369	-	116	7	*Specimens dirtorted during firing.
-7		"	vibration time		+0.02	"	"	1424	-	117	7	
-8		"	20 min. (max.)		+0.02	"	"	-	455	117	-	
-9		"	Placement Time		+0.03	"	"	-	405	115	-	
5H.1-4	Fireclay	11	Cast	24 hrs. at R.T.	-0.04	-	-	1658	-	127	2	Sticky, Plastic, Fast Setting.
-5	plus	"			-0.09	-	-	1621	-	"	1	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.12	1500	-0.23	2041	-	129	2	
-7		"	vibration time		-0.13	"	-0.22	1878	-	"	2	
-8		"	20 min. (max.)		-0.13	"	-0.22	-	688	"	-	
-9		"	Placement Time		-0.14	"	-0.24	-	566	"	-	
5J.1-4	Fireclay	16	Cast	24 hrs. at R.T.	-0.20	-	-	1181	-	119	3	
-5	plus	"			-0.10	-	-	1122	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.14	600	-0.27	667	-	"	2	
-7		"	vibration time		-0.17	"	-0.31	846	-	"	2	
-8		"	20 min. (max.)		-0.23	"	-0.37	-	111	"	2	
-9		"	Placement Time		-0.27	"	-0.40	-	167	"	2	
5K.1-4	Fireclay	15	Cast	24 hrs. at R.T.	+0.06	-	-	906	-	119	1	
-5	plus	"			-0.04	-	-	965	-	"	1	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.01	600	-0.07	628	-	"	2	
-7		"	vibration time		-0.04	"	-0.11	628	-	"	1	
-8		"	12 min. (max.)		0	"	-0.08	-	185	"	1	
-9		"	Placement Time		+0.01	"	-0.06	-	89	"	1	
5L.1-4	Unknown	13	Cast	24 hrs. at R.T.	+0.02	-	-	1203	-	127	2	Vibrating Time 1½ min.
-5		"			+0.06	-	-	1084	-	"	2	Surface finish on all specimens
-6		"	1½ minute	24 hrs. at 220F	+0.12	600	0	1261	-	"	4	were sandy.
-7		"	vibration time		+0.01	"	-0.09	1587	-	"	4	
-8		"			0	"	-0.09	-	148	124	-	
-9		"			-0.01	"	-0.12	-	213	124	-	
5M.1-4	Unknown	40	Cast	24 hrs. at R.T.	+0.03	-	-	397	-	76	1	
-5		"			-0.07	-	-	397	-	"	2	
-6		"	1 minute	24 hrs. at 220F	-0.09	1000	-0.31	231	-	83	1	
-7		"	vibration time		-0.07	"	-0.27	216	-	"	1	
-8		"			+0.06	"	-0.23	-	144	"	-	
-9		"	20 min. (max.)		-0.04	"	-0.23	-	129	"	-	
			Placement Time									
5N.1-4	Unknown	40	Cast	24 hrs. at R.T.	-0.01	-	-	81	-	76	2	
-5		"			-0.01	-	-	150	-	"	2	
-6		"	1 minute	24 hrs. at 220F	-0.01	600	-0.42	359	-	73	2	
-7		"	vibration time		-0.01	"	-0.42	418	-	73	3	
-8		"			-0.04	"	-0.46	-	37	73	-	
-9		"			-0.03	"	-0.44	-	37	73	-	
5P.1-4	Vermiculite	176	Puddled by	24 hrs. at R.T.	-0.12	-	-	67	-	34	5	Will not vibrate.
-5	plus	"	Hand		-0.13	-	-	67	-	"	9	Puddle by hand in the mold.
-6	Unknown Binder	"		24 hrs. at 220F	-0.12	600	-0.54	67	-	28	10	
-7		"			-0.14	"	-0.53	52	-	28	10	
-8		"			-0.15	"	-0.51	-	63	28	-	
-9		"			-0.13	"	-0.48	-	63	28	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
5Q.1-2	Tabular Alumina	9.53	Cast	24 hrs. at R.T.	-1.11	750	-1.16	1065	-	136	5	Longitudinal shrink cracks noted
-5	plus	"			-0.93	"	-1.09	947	-	"	7	after R.T. cure.
-6	Phosphoric Acid	"	1½ minute	24 hrs. at 220F	-0.94	"	-1.17	-	647	132	7	Cast one at a time.
-7		"	vibration time		-1.04	"	-1.13	-	548	"	7	Material doughy.
-8		"	5-10 min. (max.)		-0.94	1500	-1.11	1104	-	"	5	Vibrating time 1½ minutes.
-9		"	Placement Time		-1.09	"	-	749	-	"	5	
-10		"			-1.03	"	-	-	518	"	-	Specimen 9 thru 11 cracked after
-11		"			-0.96	"	-	-	651	"	-	firing at 1500. Could not be measured.
6A.2-4	Fused Alumina	16	Cast	24 hrs. at R.T.	+0.03	-	-	767	-	102	1	Aggregate in form of round particles.
-5	plus	"			+0.03	-	-	688	-	"	1	Made one at a time.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.05	2000	+0.19	322	-	"	1	Quick setting.
-7		"	vibration time		+0.06	"	+0.13	451	-	101	1	
-8		"			0	"	+0.03	-	274	101	-	
-9		"			+0.04	"	+0.19	-	148	101	-	
6D.3-4	Lithium	40	Cast	24 hrs. at R.T.	-0.07	-	-	124	-	80	1	
-5	Alumino	"			-0.06	-	-	137	-	"	1	
-6	Silicate	"	1 minute	24 hrs. at 220F	-0.08	2000	-0.60	165	-	78	1	
-7	plus Unknown	"	vibration time		-0.06	"	-0.56	146	-	"	1	
-8	Binder	"			-0.07	"	-0.51	-	92	"	-	
-9		"			-0.06	"	-0.56	-	29	"	-	
8A.1-4	Alumina	15	Cast	24 hrs. at R.T.	+0.02	-	-	728	-	119	1	Mixed one at a time.
-5	plus	"			+0.08	-	-	667	-	"	1	*Cracked in firing.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.04	2500	-0.34	766	-	108	1	
-7		"	vibration time		+0.02	"	-0.38	810	-	103	1	
-8		"			+0.04	"	-0.24	-	66	105	-	
-9		"			-0.01	"	*	-	*	105	-	
8B.1-4	Alumina	9	Cast	24 hrs. at R.T.	-0.06	-	-	2438	-	178	2	Specimens cast one at a time.
-5	plus	"			-0.11	-	-	2456	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.10	2500	-0.33	1187	-	165	2	
-7		"	vibration time		-0.09	"	-0.36	1280	-	"	2	
-8		"			-0.09	"	-0.36	-	688	"	-	
-9		"			-0.08	"	-0.39	-	669	"	-	
9C.1-4	Magnesium Oxide	9.1	Cast	24 hrs. at R.T.	+0.02	-	-	315	-	161	1	Vertical cracks noted in specimens
-5	plus	"			+0.09	-	-	379	-	"	1	-4 and -5 after drying at 220F.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.07	2400	-0.89	1335	-	159	3	Both specimen broke along these
-7		"	vibration time		+0.06	"	-0.96	1280	-	"	3	cracks.
-8		"			+0.09	"	-0.75	-	747	"	3	2370°F minimum recommended firing
-9		"			+0.06	"	-0.91	-	688	"	3	temperature.
9D.1-1	Silicon Carbide	7.5	Cast	24 hrs. at R.T.	-0.04	-	-	1635	-	151	2	This material was tested too late
-2	Plus Unknown	"		24 hrs. at 250F	-0.03	-	-	1670	-	150	2	(11-29-60) for complete evaluation
-3	Binder	"	1 minute		-0.04	2500	-0.68	3960	-	-	2	
-4		"	Vibration time		-0.11	"	-0.72	3580	-	150	2	
-5		"			-0.11	"			795	-	-	
-6		"			-0.14	"			945	-	-	
9A.1-4	Alumina and Silica	15	Cast	24 hrs. at R.T.	-0.24	-	-	436	-	119	2	Separation noted.
-5	plus	"			-0.16	-	-	397	-	"	2	*Brick distorted in firing.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.11	2500	*	*	-	-	-	**Broken in furnace
-7		"	vibration time		-0.17	"	-0.03	*	-	-	3	
-8		"			-0.15	"	*	-	**	-	-	
-9		"			-0.14	"	*	-	**	-	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
9B.1-4	Alumina and Silica	15	Cast	24 hrs. at R.T.	-0.16	-	-	867	-	119	1	Separation noted.
-5	plus	"			+0.04	-	-	887	-	"	2	*Melted during firing.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.09	2500	"	-	-	-	-	
-7		"	vibration time		-0.12	"	"	-	-	-	-	
-8		"			-0.22	"	"	-	-	-	-	
-9		"			-0.11	"		-	-	-	-	
10A.1-4	Unknown	10	Cast	3 hrs. at R.T.	+0.03	-	-	927	-	161	4	*Lost in firing.
-5		"		(Hi Humidity)	+0.03	-	-	1045	-	"	4	**Broken
-6		"	1 minute		0	2500	"	-	-	-	-	
-7		"	vibration time	24 hrs. at 220F	-0.01	"	-0.44	1531	-	**	3	
-8		"		(Hi Humidity)	+0.01	"	-0.47	-	907	159	-	
-9		"			+0.05	"	-0.32	-	395	**	-	
11B.1-4	Unknown	10.9	Cast	24 hrs. at R.T.	-0.25	-	-	1299	-	138	2	Specimens made one at a time.
-5	plus	"			-0.19	-	-	1143	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.24	2000	-0.33	1478	-	132	2	Material recommended for caps.
-7		"	vibration time		-0.17	"	-0.23	927	-	132	2	
-8		"			-0.16	"	-0.29	-	143	131	-	
-9		"			-0.12	"	-0.22	-	333	132	-	
11C.1-4	Unknown Aggregate	9	Cast	24 hrs. at R.T.	-0.07	-	-	1371	-	144	3	Fill material.
-5	plus	"			-0.06	-	-	1262	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.04	2000	-0.16	629	-	138	2	
-7		"	vibration time		-0.05	"	-0.13	1201	-	"	2	
-8		"			-0.06	"	-0.13	-	377	"	-	
-9		"			-0.07	"	-0.16	-	292	"	-	
11D.1-4	Unknown Aggregate	13.5	Cast	24 hrs. at R.T.	+0.06	-	-	868	-	127	1	Cap material. Separation noted.
-5	plus	"			+0.09	-	-	936	-	"	1	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.03	2000	0	416	-	122	1	
-7		"	vibration time		+0.03	"	-0.03	518	-	120	2	
-8		"			+0.08	"	+0.01	-	213	121	2	
-9		"			+0.03	"	+0.06	-	148	121	-	
11F.1-4	Unknown	12.6	Cast	24 hrs. at R.T.	+0.09	-	-	868	-	132	1	Fill material.
-5		"			+0.05	-	-	888	-	"	1	*Lost in firing.
-6		"	1 minute	24 hrs. at 220F	+0.02	2000	-0.03	379	-	126	1	
-7		"	vibration time		+0.09	"	-0.04	335	-	"	1	
-8		"			+0.03	"	-0.06		338	"	-	
-9		"			+0.01	"	"	-	-	-	-	
12A.1-4	Calcined Clay	16	Cast	24 hrs. at R.T.	+0.06	-	-	965	-	127	1	
-5	plus	"			+0.02	-	-	867	-	"	1	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	+0.04	1000	-0.14	748	-	119	1	
-7		"	vibration time		0	"	-0.17	728	-	"	1	
-8		"			+0.10	"	-0.09	-	229	"	1	
-9		"			+0.05	"	-0.13	-	314	"	1	
12B.1-4	Alumina and Silica	13	Cast	24 hrs. at R.T.	-0.13	-	-	1240	-	140	1	Cast one at a time.
-5	plus	"			-0.12	-	-	1369	-	"	1	
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.17	1000	-0.36	978	-	131	2	
-7		"	vibration time		-0.14	"	-0.37	898	-	"	1	
-8		"			-0.13	"	-0.40	-	359	"	1	
-9		"			-0.12	"	-0.38	-	566	"	1	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
12C.1-4	Alumina		Ram	24 hrs. at R.T.	-	750	+0.13	2071	-	**	1	Specimens too fragile to handle for
-5	plus				-	"	"	*333	-	174	1	determining drying size change (220F)
-6	Phosphoric Acid			24 hrs. at 220F	-	"		-	533	**	5	*Brick cracked almost in half.
-7					-	"		-	333	179	5	Material received ready for ramming.
-8					-	1000	"	170	-	179	4	**Corner broken off.
-9					-	"	+0.41	1106	-	"	5	
-10					-	"	+0.30	-	806	**	-	
-11					-	"	"	-	259	180	-	
12D.1-5	Alumina		Rammed	24 hrs. at 220F	-	1050	+0.09	767	-	159	9	
-6	plus		(Packed ready		-	"	+0.10	590	-	"	10	
-7	Phosphoric Acid		for placement-	(Do not remove	-	"	+0.06	-	533	163	9	
-8			1 month storage	from mold until	-	"	+0.01	-	514	"	9	
-9			life.)	dried.)	-	1500	+0.07	-	422	"	10	
-10					-	"	+0.07	-	381	"	10	
-11					-	"	+0.13	584	-	159	10	
-12					-	"	+0.16	800	-	"	10	
12E.1-4	Tabular Alumina	11	Cast	24 hrs. at R.T.	-0.21	-	-	2328	-	169	1	Small firing cracks noted in
-5	plus	"			-0.13	-	-	2219	-	"	2	specimen #-7.
-6	Calcium Aluminate	"	1 minute	16 hrs. at 220F	-0.17	1000	-0.32	2566	-	153	2	Quick setting. Has syrupy
-7		"	vibration time		-0.16	"	-0.17	2004	-	"	2	consistency.
-8		"			-0.21	"	-0.24	-	773	156	-	
-9		"	10 min. (max.)		-0.16	"	-0.18	-	851	156	-	
			Placement Time									
12F.1-4	High Grade	11	Cast	24 hrs. at R.T.	-0.18	-	-	1839	-	144	2	Specimens made one at a time.
-5	Calcined Clay	"			-0.10	-	-	1658	-	"	2	
-6	plus	"	1 minute	16 hrs. at 220F	-0.10	1000	-0.23	2096	-	131	2	
-7	Calcium Aluminate	"	vibration time		-0.12	"	-0.27	2529	-	"	2	
-8		"			-0.13	"	-0.28	-	825	134	-	
-9		"	10 min. (max.)		-0.12	"	-0.27	-	869	134	-	
			Placement Time									
16A.1-4	Unknown	1	Rammed	24 hrs. at 220F	+0.13	700	+0.13	569	-	208	2	If dry, up to 2.5% water can
-5	plus	"	(packed ready	*24 hrs. at 550F	+0.18	"	+0.17	588	-	212	2	be added.
-6	Phosphoric Acid	"	for placement)		—	"	+0.20	-	984	212	2	
-7		"			+0.41	"	+0.44	-	1047	212	2	Bricks appeared spongy after
-8		"			+0.13	2000	+0.20	1332	-	215	2	ramming.
-9		"			+0.20	"	+0.26	1332	-	215	2	
-10		"			+0.10	"	+0.21	-	1024	215	-	
-11		"			+0.14	"	+0.28	-	1084	214	-	
17A.1-4	Pyrophyllite,	23	Cast	24 hrs. at R.T.	-0.02	-	-	301	-	95	1	Specimens mixed one at a time for
-5	Clay, and Talc	"			0	-	-	258	-	"	1	20 min. Aggregate estimated to
-6	(30% Grog)	"	1 minute	16 hrs. at 220F	-0.02	1000	-0.18	153	-	93	1	be approx. ¼". Efflorescence noted.
-7	plus	"	vibration time		+0.06	"	-0.11	157	-	"	2	
-8	20% Tri-Calcium	"			-0.07	2000	-0.22	302	-	89	1	
-9	Aluminate	"	10 min. (max.)		+0.02	"	-0.19	294	-	"	1	
-10		"	Placement Time		+0.03	"	-0.17	-	195	"	-	
-11		"			+0.09	"	-0.12	-	240	"	-	
17B.1-4	Pyrophyllite,	26.5	Cast	24 hrs. at R.T.	-0.07	-	-	336	-	97	1	Specimens cast one at a time for
-5	Clay, and Talc	"			-0.04	-	-	301	-	"	1	2 min. Aggregate estimated to be
-6	plus	"	1 minute	16 hrs. at 220F	-0.02	1000	-0.15	196	-	93	1	approx. ¼". Efflorescence noted.
-7	Calcium Aluminate	"	vibration time		-0.01	"	-0.13	213	-	"	2	
-8		"			0	2000	-0.03	342	-	89	1	
-9		"	10 min. (max.)		0	"	-0.08	387	-	"	1	
-10		"	Placement Time		-0.03	"	-0.11	-	213	"	-	
-11		"			-0.04	"	-0.09	-	259	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
19A.1-4	Alumina and Silica	15.9	Cast	24 hrs. at R.T.	+0.04	-	-	796	-	127	2	
-5	plus	"			0	-	-	847	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.06	1500	-0.14	749	-	118	5	
-7		"	vibration time		+0.07	"	-0.13	668	-	113	1	
-8		"	20 min. (max.)		+0.03	"	-0.20	-	336	117	-	
-9		"	Placement Time		+0.04	"	-0.14	-	386	116	-	
20A.1-4	Corundum	None	Cast	24 hrs. at R.T.	+0.03	-	-	1443	-	172	1	Sodium Fluosilicate - slightly
-5	plus	"			-0.10	-	-	1354	-	"	1	amber colored, syrupy liquid,
-6	Sodium-Fluosilicate	"	1.5 minutes	24 hrs. at 220F	0	1500	+0.06	2477	-	168	1	sp. gr. 1.431. Mix grog with
-7	(Na_2SiF_6)	"	vibration time		0	"	+0.02	2942	-	167	1	15% binder by weight. Specimens
-8		"			-0.02	"	+0.04	-	*	"	-	mixed one at a time for 2 min.
-9		"			-0.01	"	0	-	*	"	-	Vibrating time 1½ minutes. *Fell apart at 2000°F.
20B.1-4	Corundum	10	Cast	48 hrs. at R.T.	+0.02	-	-	1460	-	169	2	Cast one at a time.
-5	plus	"			-0.03	-	-	1502	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.02	1000	-0.08	2150	-	157	2	
-7		"	vibration time		+0.03	"	-0.06	2584	-	"	2	
-8		"			-0.02	"	-0.08	-	629	159	-	
-9		"			-0.01	"	-0.08	-	731	"	-	
21A.1-4	Alumina	10	Cast	24 hrs. at R.T.	+0.01	-	-	1473	-	163	2	Mixed one at a time.
-5	plus	"			+0.02	-	-	1241	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	+0.02	2500	-0.42	2294	-	153	2	
-7		"	vibration time		+0.06	"	-0.34	2133	-	"	2	
-8		"			0	"	-0.44	-	907	151	2	
-9		"			+0.07	"	-0.42	-	907	152	2	
21B.1-4	Alumina and Silica	4	Ram	24 hrs. at R.T.	+0.04	-	-	122	-	161	6	Ram in 1½ inch layers.
-5	plus	"		(See remarks)	+0.14	-	-	130	-	"	6	Dry at 300°F for 8 hrs. per
-6	Calcium Aluminate	"			+0.11	2500	+0.19	965	-	157	7	inch of thickness.
-7		"			-0.01	"	+0.18	829	-	154	10	
-8		"			+0.10	"	+0.14	-	768	151	-	
-9		"			+0.02	"	+0.08	-	1221	154	-	
21C.1-4	Unknown	1	Rammed	24 hrs. at R.T.	-	700	-	670	-	144	3	Mold bulged during ramming - drying
-5	plus	"	Ready-Mix		-	"	-	866	-	152	4	size change cannot be determined,
-6	Phosphoric Acid	"		24 hrs. at 250F	-	"	+0.06	-	1143	146	5	except on specimen -11.
-7		"			-	"	+0.10	-	966	143	4	Specimen -11 rammed lightly.
-8		"			-	2000	-0.17	1221	-	146	6	
-9		"			-	"	-0.03	888	-	147	6	
-10		"			-	"	-0.02	-	292	151	-	
-11		"			-0.13	"	-0.22	-	167	"	-	
25A.1-4	Fused Silica		Slip Cast	24 hrs. at R.T	-0.09	-	-	231	-	152	1	Drying size change determined from
-5	plus			24 hrs. at 220F	-0.16	-	-	231	-	"	1	4½" dimension.
-6	Unknown				-0.18	2000	-0.24	1005	-	111	1	
-7					-0.11	"	-0.24	1064	-	"	2	
-8					-0.13	"	-0.22	-	1406	"	-	
-9					-0.13	"	-0.22	-	1299	"	-	
25B.1-4	Fused Silica	Unknown	Slip Cast	24 hrs. at R.T.	-0.33	-	-	220	-	152	1	Size change checked from 4½ dim-
-5	plus	Binder		24 hrs. at 220F	-0.53	-	-	229	-	"	1	ension.
-6	Unknown	Furnished			-0.55	2000	-0.67	1005	-	114	1	*-8 Specimen could not be ruptured
-7					-0.51	"	-0.64	1441	-	"	1	for the hot modulus of rupture test
-8					-0.51	"	-0.63	-	2077*	"	-	with a loading of 7230# on the first
-9					-0.53	"	-0.62	-	2257	"	-	try. It was reheated to 2000 F and tested. This time it broke under a 5615# load.

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
250.1-4	Fused Silica	Unknown	Rammed	24 hrs. at 500F	+0.09	-	-	-	-	-	5	Handle dried specimens with care.
-5	plus	Binder			+0.20	-	-	-	-	-	5	*Cracked too badly for measurement
-6	Unknown	Furnished			+0.12	2000	"	**	-	71	5	after firing.
-7					+0.22	"	"	**	-	75	5	**Cracked too badly for testing.
-8					+0.13	"	"	-	**	73	-	Surface finish on all specimens
-9					+0.11	"	"	-	**	73	-	were sandy.
34A.1-4	Calcined Grog		Slip Cast	24 hrs. at R.T.	—	-	-	-	-	-	-	Only Specimens -8 and -9 were cast.
-5	plus				—	-	-	-	-	-	-	*Melted during firing.
-6	Ball Clay			24 hrs. at 220F	—	2500	-	-	-	-	-	
-7					—	"	-	-	-	-	-	
-8		35			-0.22	"	-	-	"	-	-	
-9		"			-0.22	"	-	-	"	-	-	
39A.1-4	Alumina and Silica	11.5	Cast	12-24 hrs.	-0.31	-	-	1441	-	136	2	
-5	plus	"		at R.T.	-0.23	-	-	1477	-	"	2	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.22	2500	-0.57	2423	-	127	2	
-7		"	vibration time		-0.29	"	-0.60	1931	-	"	2	
-8		"			-0.26	"	-0.57	-	747	"	-	
-9		"	20 min. (max.) Placement Time		-0.29	"	-0.48	-	544	"	-	
398.1-1	Tabular Alumina	3	Rammed	24 hrs. at R.T.	+0.01	500	-0.01	30	-	136	9	Do not use moisture during R.T. cure.
-4	plus	"			-0.04	"	-0.04	76	-	"	9	
-5	Phosphoric Acid	"		24 hrs. at 220F	-0.02	"	-0.06	-	102	132	9	
-6		"			-0.03	"	-0.07	-	52	"	9	
-7		"			-0.03	2500	-0.07	87	-	132	9	
-8		"			+0.02	"	-0.07	120	-	131	9	
-9		"			+0.04	"	-0.02	-	87	130	9	
-10		"			+0.03	"	+0.01	-	87	129	9	
390.1-4	Unknown	14	Cast	12-24 hrs. at	-0.42	-	-	947	-	-	1	Mixed one at a time.
-5		"		R.T.	-0.59	-	-	1005	-	-	1	Considerable shrinkage noted
-6		"	1 minute	24 hrs. at 220F	-0.50	2500	-1.58	610	-	141	1	after drying in mold.
-7		"	vibration time		-0.53	"	"	765	-	144	1	*Too distorted to measure.
-8		"			-0.62	"	"	-	544	143	1	
-9		"			-0.47	"	-1.58	-	444	140	1	
390.1-1	Unknown		Cast	24 hrs. at 220F	-0.03	-	-	2010	-	165	2	
-2	plus				-0.06	-	-	2030	-	"	2	
-3	Calcium				0	-	-	2060	-	"	2	
-4	Aluminate				-	1000	-0.32	1600	-	"	1	
-5					-	"	-0.27	1940	-	"	2	
-6					-	"	-0.34	2000	-	"	2	
41A.1-4	Fused Alumina	11	Cast	24 hrs. at R.T.	+0.02	-	-	966	-	169	1	Separation noted.
-5	plus	"			+0.07	-	-	1005	-	"	1	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.03	2400	+1.36	984	-	159	4	
-7		"	vibration time		+0.05	"	+1.44	925	-	"	4	
-8		"			+0.06	"	+1.60	-	229	"	4	
-9		"			+0.01	"	+1.38	-	167	"	4	
413.1-4	Fused Alumina	20	Cast		-	-	-	-	-	-	-	Specimens mixed one at a time.
-5	plus	"			-	-	-	-	-	-	-	Formed lumpy mixture and would not
-6	Calcium Aluminate	"			-	-	-	-	-	-	-	react to vibration. Is not air setting. Since material appeared impractical only 3 specimens were made. Size change is more than 3%.
43A.1	Petalite Grog											Material evaluated by Battelle. (See Exhibit 3, Page 216.)

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
50A.1-4	Tabular Alumina plus Phosphoric Acid		Ram Ready-Mix	24 hrs. at R.T.		1500			-			Material not cast.
-5						"			-			
-6				24 hrs. at 220F		"		-				
-7						"		-				
-8						2400			-			
-9						"			-			
-10						"		-			-	
-11						"		-			-	
508.1-4	Unknown	18	Cast	24 hrs. at R.T.	-0.42	-	-	366	-	119	2	
-5		"			-0.43	-	-	327	-	"	1	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.31	2000	-0.41	272	-	110	3	
-7		"			-0.44	"	-0.57	252	-	"	3	
-8		"			-0.42	"	-0.56	-	259	"	-	
-9		"			-0.47	"	-0.58	-	281	"	-	
64A.1-4	Alumina and Silica plus Calcium Aluminate	14	Cast	24 hrs. at R.T.	+0.04	-	-	1143	-	136	3	Surface finish on all Specimens was sandy.
-5		"			+0.06	-	-	1143	-	"	5	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.02	1000	-0.22	549	-	125	2	
-7		"			-0.05	"	-0.27	549	-	"	3	
-8		"			-0.02	"	-0.24	-	377	126	-	
-9		"			-0.03	"	-0.27	-	377	"	-	
64B.1-4	Alumina and Silica plus Calcium Aluminate	17	Cast	24 hrs. at R.T.	0	-	-	925	-	125	2	*Bricks too distorted to measure.
-5		"			+0.01	-	-	868	-	"	2	**Damaged too much to determine.
-6		"	1 minute vibration time	24 hrs. at 220F	-0.01	2400	"	1395	-	**	-	
-7		"			+0.01	"	"	1495	-	114	-	
-8		"			-0.02	"	"	-	272	**	-	
-9		"			+0.03	"	"	-	298	**	-	
66B.1-4	Alumina and Silica plus Calcium Aluminate	19.5	Cast	24 hrs. at R.T.	-0.24	-	-	1143	-	125	2	Do not remove from mold for 24 hrs.
-5		"			-0.22	-	-	1104	-	"	2	*Bricks too distorted to measure.
-6		"	1 minute vibration	24 hrs. at 220F	-0.30	2400	"	1124	-	97	-	**Damaged too much to determine.
-7		"			-0.36	"	"	966	-	89	-	
-8		"			-0.28	"	"	-	333	**	-	
-9		"			-0.29	"	"	-	386	**	-	
70A.1-1	Unknown	16	Cast	24 hrs. at R.T.	-0.07	-	-	1143	-	127	3	Sandy mix.
-4		"			-0.15	-	-	925	-	"	2	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.09	2000	-0.33	370	-	115	5	
-7		"			-0.13	"	-0.37	437	-	"	6	
-8		"			-0.16	"	-0.41	-	292	"	-	
-9		"			-0.18	"	-0.45	-	239	"	-	
70B.1-4	Alumina and Silica plus Calcium Aluminate	10	Cast	24 hrs. at R.T.	+0.03	-	-	1025	-	136	2	*Broken.
-5		"			+0.02	-	-	1066	-	"	2	
-6		"	1 minute vibration time	24 hrs. at 220F	+0.01	2500	+0.29	1382	-	"	2	
-7		"			+0.02	"	+0.11	1487	-	"	2	
-8		"			+0.06	"	+0.22	-	292	132	-	
-9		"			+0.06	"	+0.16	-	806	"	-	
70C.1-4	Alumina plus Unknown	10	Cast	24 hrs. at R.T.	-0.16	-	-	1678	-	174	1	Not recommended for casting over 3" thick. Specimens mixed one at a time for 2 min. Thick mix.
-5		"			-0.21	-	-	1371	-	"	1	
-6		"	1 minute vibration time	24 hrs. at 220F	-0.07	2500	+0.10	1261	-	161	2	
-7		"			-0.12	"	+0.26	2567	-	160	1	*Broken.
-8		"			-0.02	"	+0.03	-	592	161	-	
-9		"	10 min. (max.) Placement Time		-0.12	"	+0.03	-	432	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
71A.1-4	Hi Alumina		Rammed			1500			-			Material had set up in bag.
-5	plus					"			-			
-6	Phosphoric Acid					"		-				
-7						"		-				
-8						2500			-			
-9						"			-			
-10						"		-			-	
-11						"		-			-	
71B.1-4	Hi Alumina plus	8	Cast	24 hrs. at R.T.	-0.04	-	-	2331	-	178	2	Specimens mixed one at a time for
-5	calcium aluminate	"			-0.01	-	-	2313	-	"	2	2 min. The -R and -Rx data, new
-5R1		"			-	1000	-	1430	-	"	3	batch, were obtained too late
-5R2		"			-	"	-0.10	1390	-	"	2	(11-30-60) for complete evaluation.
-5R3		"			-	"	-	955	-	"	2	
-6		"	1 minute	24 hrs. at 220F	-0.03	2500	-	*	-	-	-	*Lost in firing.
-7		"	vibration time		-0.05	"	-0.33	2072	-	165	2	
-1R		"			-0.01	"	-0.64	2460	1800	-	3	
-2R		"	5 min. (max.)		-0.07	"	-0.91	3040	1800	-	2	
-3R			Placement Time		-0.07	"	-0.58		1800	-	-	
72A.1-4	Flint Fireclay	17	Cast	24 hrs. at R.T.	-0.02	-	-	315	-	119	2	Surface finish on all specimens
-5	plus	"			-0.02	-	-	363	-	"	1	was sandy.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	0	2000	-0.19	59	-	114	2	
-7		"	vibration time		+0.02	"	-0.21	59	-	"	2	
-8		"			-0.01	"	-0.26	-	76	"	-	
-9		"			-0.02	"	-0.25	-	37	"	-	
81A.1-4	Petalite plus	12.63	Cast	24 hrs. at R.T.	+.02	-	-	735	-	121	2	Battelle formulation.
-5	Calcium Aluminate	"	1 Minute -		+.02	-	-	834	-	121	2	
-6		"	Vibration Time	24 hrs. at 220F	+.03	2000	-.03	554	-	114	1	
-7		"			+.06	"	-.04	672	-	114	2	
-8		"			+.06	"	-.08	-	620	114	1	
-9		"			+.03	"	-.08	-	655	113	1	
83A.1-4	Zircon Cement	7	Cast	24 hrs. at R.T.	+0.06	-	-	359	-	192	2	*Piece missing from brick.
-5		"			+0.12	-	-	333	-	"	2	
-6		"	1 minute	24 hrs. at 220F	+0.19	2000	-0.76	315	-	191	5	
-7		"	vibration time		+0.03	"	-0.82	294	-	"	6	
-8		"	60-90 min.		+0.10	"	-0.63	-	52	183*	-	
-9		"	Placement Time		+0.03	"	-0.83	-	66	190	-	
86A.1	CA-25 Calcium Aluminate Cement											Material not cast.
86B.1	Tabular Aluminum Grog											Material not cast.
88A.1-4	Zirconium Silicate	8.7	Cast	12 hrs. at R.T.	+0.01	-	-	636	-	177	2	Specimens mixed one at a time.
-5	plus unknown	"	1 minute		+0.01	-	-	651	-	"	2	No firing required.
-6		"	vibration time		-0.02	-	-	-	86	"	-	
-7		"	15 min. (max.)		+0.02	-	-	-	179	"	-	
			Placement Time									
88B.1-4	Zirconium Silicate	None	Cast		-0.13	-	-	709	-	127	5	Mixed one at a time for five (5)
-5	plus unknown				-0.11	-	-	688	-	"	5	minutes. Material is thin.
-6			1 minute		-0.12	2000	**	1824	-	115		
-7			vibration time		-0.11	"	**	1698	-	114		*Broken in oven.
-8			Mix one min.		-0.05	"	**	-	-	"	-	
-9					-0.18	"	**	-	179	"	-	**Distorted in firing.

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
99A.1-4	Dead Burned	9.5	Cast	24 hrs. at R.T.	-0.11	-	-	927	-	159	3	Extremely severe efflorescence was
-5	Bauxite	"			-0.07	-	-	1025	-	"	4	noted within 72 hours after casting.
-6	plus	"	1 minute	24 hrs. at 220F	-0.13	1500	-0.12	416	-	153	4	This appeared as a white powder up
-7	Calcium Aluminate	"	vibration time		-0.07	"	-0.13	398	-	"	4	to 1/2" in height and seemed to
-8		"	30 min.		-0.09	"	-0.06	-	259	"	-	emanate from a thin (1/16") surface
-9		"	Placement Time		-0.12	"	-0.16	-	272	"	-	layer.
99B.1-4	Crushed Fire Brick	16.5	Cast	24 hrs. at R.T.	-0.07	-	-	749	-	127	2	
-5	plus	"			-0.13	-	-	388	-	"	3	
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.24	1700	-0.52	669	-	117	2	
-7		"	vibration time		-0.28	"	-0.54	629	-	"	3	
-8		"			-0.22	"	-0.49	-	212	"	-	
-9		"			-0.16	"	-0.44	-	292	"	-	
102A.1-4	Unknown	15.2	Cast	24 hrs. at R.T.	-0.04	-	-	271	-	122	3	*Broken
-5		"			-0.01	-	-	259	-	121	2	
-6		"	1 minute	24 hrs. at 220F	-0.05	2500	-0.03	1329	-	118	2	
-7		"	vibration time		+0.01	"	+0.08	2131	-	119	2	
-8		"			+0.07	"	+0.13	-	259	118	-	
-9		"			-0.02	"	"	-	-	118	-	
103A.1-4	Alumina	3.5	Cast	24 hrs. at R.T.	+0.24	600	-0.03	2494	-	170	9	Remove from molds for 220F cure.
-5	plus	"	Placed by Trowel		+0.18	"	-0.01	2387	-	170	9	
-6	Phosphoric Acid	"	No vibration	24 hrs. at 220F	+0.14	"	-0.01	-	769	169	-	
-7		"			+0.09	"	-0.07	-	788	171	-	
-8		"		Use no moisture	+0.23	1000	+0.01	2623	-	167	9	
-9		"		for R.T. cure.	+0.08	"	-0.08	2405	-	167	9	
-10		"			+0.05	"	-0.03	-	984	167	-	
-11		"			+0.09	"	-0.06	-	1165	168	-	
108A.1-40	Alumina plus	4.2	Cast	24 hrs. at R.T.	-0.01		-	3210	-	-	2	This material vibration casts
-41	Phosphoric Acid	"	1 minute	24 hrs. at 250F	-0.07		-	3210	-	-	3	satisfactorily.
-42		"	vibration		-0.03		-	3090	-	-	2	Improved material data
-43		"	time		0.00	1000	-	2660	-	-	2	established 11-29-60.
-44		"			-0.04	"	-0.36	3210	-	-	2	
-45		"			-0.03	"	-0.68	2850	-	-	3	
109B.1-4	Alumina	None	Rammed	24 hrs. at R.T.		600			-			*Broken in furnace.
-5	plus					"	+0.19	2401	-		3	All specimens fragile - data missing
-6	Phosphoric Acid		(Packed ready	24 hrs. at 220F		"		-				was impossible to determine
-7			for Placement)			"		-	"			
-8						1000			-			
-9						"	+0.44	1739	-		3	
-10						"		-				
-11						"		-				
103D.1-4	Alumina	9	Cast	24 hrs. at R.T.	+0.02	-	-	1336	-	169	5	Recommended for use in reducing
-5	plus	"			-0.06	-	-	1221	-	"	4	atmospheres.
-6	Calcium Aluminate	"	1 minute	24 hrs. at 220F	-0.05	500	-0.11	1640	-	159	2	
-7		"	vibration time		-0.06	"	-0.12	2245	-	158	2	
-8		"			-0.05	1000	-0.15	1391	-	156	3	
-9		"	30 min.		-0.05	"	-0.13	1550	-	"	3	
-10		"	Placement Time		0	"	-0.09	-	566	"	-	
-11		"			+0.05	"	-0.13	-	629	"	-	

TABLE 15 (CONT'D)

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT³	SURFACE FINISH	REMARKS
111A.1-4	Calcined Missouri	12	Cast	24 hrs. at R.T.	-0.03	-	-	827	-	136	1	
-5	Flint Clay and	"			-0.01	-	-	966	-	"	1	
-6	Calcined Alumina	"	1 minute	24 hrs. at 220F	+0.01	1500	-0.12	788	-	132	2	
-7	plus	"	vibration time		-0.01	"	-0.11	749	-	"	2	
-8	Calcium Aluminate	"			-0.01	"	-0.12	-	359	"	-	
-9		"			+0.01	"	-0.10	-	333	"	-	
115A.1-2	Alumina	5.4	Rammed	168 hrs. at R.T.	+0.11	-	-	396	-	152	6	Needs little ramming - over-ramming causes material to become jelly-like.
-4	plus	"			+0.022	-	-	381	-	"	6	
-5	Calcium Aluminate	"		24 hrs. at 220F	+0.083	1500	-0.04	262	-	147	6	
-6		"			+0.017	"	-0.10	255	-	145	6	
-7		"			+0.005	2500	+0.85	366	-	"	4	
-8		"			+0.028	"	+0.78	324	-	"	4	
-9		"			0.00	"	+0.79	-	314	"	4	
-10		"			+0.033	"	+0.82	-	455	"	4	
122A.1-4	Fused Silica plus	16.35	Cast	24 hrs. at R.T.	-.03	-	-	812	-	118	1	Georgia Tech formulation.
-5	Lumnite Cement	15.74	1 Minute -		-.01	-	-	796	-	117	2	
-6		"	Vibration Time	24 hrs. at 230F	-.18	-	-	915	-	118	1	
-7		"			-.20	-	-	875	-	118	2	
-8		"			-.27	-	-	-	414	118	1	
-9		"			-.08	-	-	-	383	118	1	
122B.1-4	Fused Silica and	3	Slip Cast	24 hrs. at R.T.	+.08	-	-	233	-	102	1	Georgia Tech formulation
-5	Fused Silica Slip	Added		24 hrs. at 150F	+.09	-	-	127	-	102	1	
-6	plus Alkophos C	to dry		24 hrs. at 230F	+.09	1000	+.09	336	-	104	1	
-7		Batch		24 hrs. at 550F	+.09	"	+.09	292	-	104	1	
-8		"			+.09	"	+.03	-	629	104	1	
-9		"			+.08	"	+.06	-	606	104	1	
128A.1-4	Unknown	28	Slip	Dry at R.T.	-1.92	2000	-2.72	788	-	-	1	Size change from 4.500" dimension.
-5		"	Mix parts in	until solid	-2.13	"	-3.26	947	-	-	1	Unable to saw end off specimens
-6		"	blunger pour		-2.09	"	-2.82	731	-	-	1	-4 thru -8.
-7		"	in plaster	24 hrs. at 220F	-1.89	"	-3.16	709	-	-	1	
-8		"	molds.		-1.98	"	-3.12	-	907	-	1	
-9		"			-2.07	"	-4.78	-	326	102	1	
140A.1-6	Unknown		Rammed	12 hrs. at R.T.	-0.08	700	0	93	-	110	2	Contains 3 1/8% emulsified wax and 9 3/8% water.
-7					-0.03	"	-0.03	85	-	"	3	
-8			(Packed ready	24 hrs. at 220F	-0.09	2050	+0.20	712	-	99	3	
-9			for Placement)		-0.08	"	+0.21	590	-	"	3	
-10					+0.03	"	+0.34	-	544	"	-	
-11					-0.09	"	+0.23	-	474	"	-	

TABLE 16 EVALUATION OF CASTABLE REFRACTORY DATA FOR UNFIRED TOOLING USES

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						MODULUS			DRYING SHRINKAGE			LINEAR FINISH		LINEAR SHRINKAGE VALUE INCHES
Final	Phase II			CAST	RAM	SLIP	16-24 HOURS AT R.T.	16-24 HOURS AT 220F	16-24 HOURS AT 500	600	700	750	VENDOR PUBLISHED VALUE, PSI	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE,%	ACTUAL, %	LINEAR CONVERSION INCH	ACTUAL	LINEAR CONVERSION INCH	
1		*108A	Alumina plus Phosphoric Acid	X			X	X						3167	10.56		-0.04	0.13	2	0.2	10.43
2	1	6B	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					2150	2447	8.16	0.00	-0.08	0.27	-	0.0	7.89
3	2	71B	HI ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					1088	2322	7.74	-	-0.02	0.07	-	0.0	7.47
	3	108A	ALUMINA PLUS PHOSPHORIC ACID	X			X	X		X			2140	2440	8.13	-0.12	-0.3	1.0	9	0.9	6.23
4	4	108B	ALUMINA PLUS PHOSPHORIC ACID		X		X	X		X			-	2401	8.00	-	+0.19	0.63	3	0.3	7.07
5	5	12B	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					-	2274	7.58	-	-0.17	0.57	2	0.2	6.61
6		*39D	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X					-	2050	6.83	-	-0.04	0.13	2	0.2	6.50
7	6	12C	ALUMINA PLUS PHOSPHORIC ACID		X		X	X				X	-	2071	6.90	-	+0.13	0.43	1	0.1	6.37
8	7	5A	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					1800	1929	6.43	-0.15	+0.04	0.13	2	0.2	6.10
9	8	103D	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X	X				1960	1942	6.47	-0.10	-0.11	0.37	3	0.3	5.80
10		*6D	SILICON CARBIDE PLUS UNKNOWN BINDER	X			X	X					-	1653	5.51	-	+0.04	0.13	2	0.2	5.15
11	9	12F	HIGH GRADE CALCINED CLAY PLUS CALCIUM ALUMINATE	X			X	X					-	1748	5.83	-	-0.14	0.47	2	0.2	5.16
12	10	5E	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	X					1416	1640	5.47	-0.10	-0.06	0.20	2	0.2	5.07
13	11	10B	CORUNDUM PLUS CALCIUM ALUMINATE	X			48	?					2095	1496	4.99	0.00	-0.01	0.03	2	0.2	4.76
14	12	3F	CALCINED KAOLIN PLUS CALCIUM ALUMINATE	X			48	X					980	1477	4.92	0.00	+0.06	0.20	1	0.1	4.62
15	13	10A	CORUNDUM PLUS SODIUM FLUOSILICATE	X			X	X					1670	1398	4.66	NIL	-0.03	0.10	1	0.1	4.46
16	14	2D	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X					950	1539	5.13	-0.05	+0.09	0.30	4	0.4	4.43
	15	70C	ALUMINA PLUS UNKNOWN	X			X	X					1845	1525	5.08	0.00	-0.13	0.43	1	0.1	4.55
17	16	21A	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					1190	1360	4.53	0.00	+0.01	0.03	1	0.2	4.30
18	17	5E	UNKNOWN	X			X	X		X			940	1424	4.75	-0.50	-0.10	0.33	4	0.4	4.02

TABLE 16 (CONT'D)

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						MODULUS			DRYING SIZE CHANGE			SURFACE FINISH		LINEAR WORTH VALUE INCHES
							16-24	16-24	16-24 HOURS AT				VENDOR	ACTUAL,	LINEAR	VENDOR	ACTUAL,	LINEAR	ACTUAL	LINEAR	
Final	Phase II			CAST	RAM	SLIP	HOURS AT R.T.	HOURS AT 220F	500	600	700	750	PUBLISHED VALUE, PSI	PSI	CONVERSION INCHES	PUBLISHED VALUE, %	%	CONVERSION INCH		CONVERSION INCH	
20	18	11C	UNKNOWN PLUS CALCIUM ALUMINATE	X									-	1316	4.39	-	+0.06	0.20	2	0.2	3.99
21	19	2D	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X		X			750	1386	4.62	-0.15	-0.05	0.17	5	0.5	3.95
22	20	3K	CALCINED KAOLIN PLUS CALCIUM ALUMINATE	X			X	X					1090	1283	4.28	0.00	-0.05	0.17	2	0.2	3.91
23	21	39A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					1150	1469	4.90	NIL	-0.27	0.9	2	0.2	3.80
24	22	10B	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					1800	1278	4.26	-	-0.02	0.07	4	0.4	3.79
25	23	2A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					850	1210	4.03	-0.10	+0.06	0.20	1	0.1	3.73
26	24	12B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					1200	1304	4.35	0.00	-0.16	0.53	1	0.1	3.72
27	25	5L	UNKNOWN	X			X	X					1060	1143	3.81	-0.40	+0.04	0.13	2	0.2	3.48
28	26	65A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					1300	1143	3.81	-	+0.05	0.17	4	0.4	3.24
29	27	3H	CALCINED KAOLIN PLUS CALCIUM ALUMINATE	X			48	X					-	1063	3.54	-	-0.03	0.10	2	0.2	3.24
30	28	70B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					750	1045	3.48	-	+0.03	0.10	2	0.2	3.16
31	29	11B	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X					-	1221	4.07	-	-0.22	0.73	2	0.2	3.14
32	30	5J	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	X					1070	1152	3.84	-0.20	-0.15	0.50	2	0.2	3.14
33	31	5B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					675	1005	3.35	-0.20	-0.02	0.07	2	0.2	3.08
34	32	41A	FUSED ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					1200	985	3.28	-0.05	+0.04	0.13	1	0.1	3.05
35	33	5K	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	X					935	935	3.12	-0.40	+0.01	0.03	1	0.1	2.99
36	34	3E	CALCINED KAOLIN PLUS PORTLAND CEMENT	X			48	X					700	995	3.32	0.00	-0.09	0.30	2	0.2	2.82
37	35	12A	CALCINED CLAY PLUS CALCIUM ALUMINATE	X			X	X					1250	916	3.05	-	+0.04	0.13	1	0.1	2.82

TABLE 16 (CONT'D)

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						MODULUS			DRYING SHRINKAGE			SURFACE FINISH		LINEAR GROWTH VALUE INCHES
							16-24 HOURS AT R.T.	16-24 HOURS AT 220F	16-24 HOURS AT				VENDOR PUBLISHED VALUE,PSI	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE,%	ACTUAL, %	LINEAR CONVERSION INCH	ACTUAL	LINEAR CONVERSION INCH	
Final	Phase II			CAST	RAM	SLIP			500	600	700	750									
36	36	11IA	CALCINED MISSOURI FLINT CLAY AND CALCINED ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					-	896	2.99	-	-0.02	0.07	1	0.1	2.82
39	37	10A	UNKNOWN	X			3	X					-	986	3.29	0.00	+0.03	0.10	4	0.4	2.79
40	38	65B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					1250	896	2.99	-	0.00	0.00	4	0.4	2.79
41	39	65C	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					-	1124	3.75	-	-0.23	0.77	4	0.4	2.78
42	40	70A	UNKNOWN	X			X	X					1092	1034	3.45	-0.12	-0.11	0.37	3	0.3	2.78
43	41	11D	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X					-	927	3.09	-	+0.07	0.23	1	0.1	2.76
44	42	3C	CALCINED KAOLIN PLUS CALCIUM ALUMINATE	X			48	X					820	897	2.99	-0.04	-0.04	0.07	2	0.2	2.72
45	43	1F	HI ALUMINA PLUS CALCIUM ALUMINATE	X			12	X					-	886	2.93	-	-0.04	0.13	1	0.1	2.78
46	44	11E	UNKNOWN	X			X	X					-	878	2.93	-	+0.07	0.23	1	0.1	2.60
47	45	9BA	DEAD BURNED BAUXITE PLUS CALCIUM ALUMINATE	X			X	X					1000	975	3.25	-	-0.09	0.30	4	0.4	2.55
48	46	2G	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	40					-	934	3.11	-0.05	+0.15	0.40	2	0.2	2.91
49	47	13A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					1000	831	2.74	-0.05	+0.02	0.07	4	0.4	2.47
50	48	3F	CALCINED ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			48	X					400	796	2.65	0.00	+0.04	0.07	2	0.2	2.36

*Data obtained after evaluation of Phase II

TABLE 17 EVALUATION OF CASTABLE REFRACTORY DATA FOR FIRED TOOLS USED AT ROOM TEMPERATURE

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						FIRING TEMPERATURE & HOURS AT					MODULUS			FIRING SIZE CHANGE			SURFACE FINISH		LINEAR WORTH VALUE INCHES
Final	Phase II			CAST	RAM	SLIP	16-24 HOURS AT R.T.	16-24 HOURS AT 220°F	4 HOURS AT 500	600	700	750	1000	1500	2000	2400	2500	VENDOR PUBLISHED VALUE, PSI	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE, %	ACTUAL, %	LINEAR CONVERSION INCHES	ACTUAL	LINEAR CONVERSION INCH	
1		* 8D	SILICON CARBIDE PLUS UNKNOWN BINDER	X			X	X									X	-	3770	12.57	-	-0.70	2.33	2	0.2	10.04
2		*108A	ALUMINA PLUS PHOSPHORIC ACID				X	X					X						3440	11.47	-	-0.52	1.73	2	0.2	9.54
3	1	20A	CORUNDUM PLUS SODIUM FLUOSILICATE	X			X	X						X				2880	2709	9.03	NIL	±0.03	0.1	1	0.1	8.83
-	2	20B	CORUNDUM PLUS CALCIUM ALUMINATE	X			48	X					X					2135	2367	7.89	-0.16	-0.08	0.27	2	0.2	7.42
	3	108A	ALUMINA PLUS PHOSPHORIC ACID	(1)			X	X					X					2240	2514	8.38	-0.12	-0.04	0.13	3	0.9	7.35
5	4	12Z	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X					-	2285	7.62	-	-0.20	0.67	2	0.2	6.75
6	5	12F	HIGH GRADE CALCINED CLAY PLUS CALCIUM ALUMINATE	X			X	X					X					-	2312	7.71	-	-0.26	0.87	2	0.2	6.64
7		*71B	HI ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X		2750	9.17		-0.71	2.37	2	0.2	6.60
8	6	108A	UNKNOWN	X			X	X									X	1210	1980	6.60	NIL	±0.06	0.20	2	0.2	6.20
9	7	70C	ALUMINA PLUS UNKNOWN	X			X	X									X	2340	1914	6.38	-	±0.10	0.33	1	0.1	5.75
10	8	21A	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X	1150	2213	7.38	-0.13	-0.40	1.33	2	0.2	6.85
11	9	5A	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X					1900	1584	6.28	-0.25	-0.09	0.30	2	0.2	5.78
	10	71B	HI ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X	1535	2072	6.91	-0.44	-0.33	1.10	2	0.2	5.61
12	11	5B	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	X						X				1120	1959	6.53	-0.20	-0.22	0.73	2	0.2	5.60
13	12	3G	CHROME ORE PLUS CALCIUM ALUMINATE	X			48	X									X	1400	1768	5.89	-0.70	-0.04	0.13	4	0.4	5.36
14	13	39A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X									X	800	2177	7.26	±0.40	-0.55	1.83	2	0.2	5.23
15		39D	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X					X					-	1847	6.16	-	-0.31	1.03	2	0.2	4.93
16	14	1M	CHROME REFRACTORY PLUS CALCIUM ALUMINATE	X			X	X									X	-	1742	5.81	-	-0.25	0.83	5	0.5	4.48

TABLE 17 (CONT'D)

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						FIRING TEMPERATURE, 4 HOURS AT					MODULUS OF RUPTURE			FIRING SHRINKAGE			SURFACE FINISH		LINEAR WORTH VALUE INCHES
Plant	Phase II			CAST	RAM	SLIP	16-24 HOURS AT R.T.	16-24 HOURS AT 220°F	4 HOURS AT 500	600	700	750	1000	1500	2000	2400	2500	VENDOR PUBLISHED VALUE, PSI	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE, %	ACTUAL, %	LINEAR CONVERSION INCHES	ACTUAL	LINEAR CONVERSION INCH	
17	15	7CB	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X									X	1350	1569	5.23	±0.17	±0.19	0.63	2	0.2	6.40
18	16	10BD	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X					±100	1470	4.90	-0.12	-0.12	0.40	3	0.3	4.20
19	17	10BB	ALUMINA PLUS PHOSPHORIC ACID		X		X	X					X					-	1739	5.80	-	±0.44	1.47	3	0.3	4.03
20	18	7LB	HI ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X					1436	1258	4.19	-0.15	-0.10	0.33	2	0.2	3.66
21	19	16A	UNKNOWN PLUS PHOSPHORIC ACID		X		X	X	(4						X			-	1332	4.44	-	±0.24	0.80	2	0.2	3.44
22	20	10A	UNKNOWN	X			X	X									X	-	1531	5.10	-0.18	-0.41	1.37	1	0.1	3.43
23	21	11C	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X							X			-	1201	4.00	-	-0.14	0.47	2	0.2	3.33
24	22	5B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X									X	1000	1531	5.10	-0.07	-0.37	1.23	6	0.6	3.47
25	23	11B	UNKNOWN PLUS CALCIUM ALUMINATE	X			X	X							X			-	1202	4.01	-	-0.27	0.90	2	0.2	2.91
26	24	8B	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X	1500	1234	4.11	-0.21	-0.36	1.20	2	0.2	2.71
27	25	25A	FUSED SILICA PLUS UNKNOWN			X	X	X							X			1750	1035	3.45	-0.50	-0.23	0.77	1	0.1	2.58
28	26	21C	UNKNOWN PLUS PHOSPHORIC ACID		X		X	(2)							X			-	1054	3.51	-	-0.11	0.37	6	0.6	2.54
29	27	14C	ALUMINA PLUS PHOSPHORIC ACID		X		X	X					X					-	1106	3.69	-	+0.35	1.17	5	0.5	2.02
30	28	4A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X							2250			625	719	2.40	-0.35	-0.06	0.20	2	0.2	2.00
31	29	11IA	CALCINED MISSOURI FLINT CLAY AND CALCINED ALUMINA PLUS CALCIUM ALUMINATE	X			X	X						X				-	768	2.56	-	-0.11	0.37	2	0.2	1.99
32	30	12A	CALCINED CLAY PLUS CALCIUM ALUMINATE	X			X	X					X					1050	738	2.46	-0.11	-0.14	0.47	1	0.1	1.89
33	31	25B	FUSED SILICA PLUS UNKNOWN			X	X	X							X			1750	1223	4.08	-1.10	-0.64	2.13	1	0.1	1.65

TABLE 17 (CONT'D)

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						FIRING TEMPERATURE 4 HOURS AT					MODULUS OF RUPTURE			FIRING SIZE CHANGE			SURFACE FINISH		LINEAR SHRINKAGE VALUE INCHES
							16-24 HOURS AT R.T.	16-24 HOURS AT 220°F	4 HOURS AT				1000	1500	2000	2400	2500	VENDOR PUBLISHED VALUE, PSI	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE, %	ACTUAL, %	LINEAR CONVERSION INCHES	ACTUAL	LINEAR CONVERSION INCH	
First	Phase II			CAST	RAM	SLIP			500	600	700	750														
34	32	12B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					X					1000	938	3.13	-0.11	-0.38	1.27	1	0.1	1.75
35	33	81A	PETALITE PLUS CALCIUM ALUMINATE	X			X	X							X			-	613	2.04	-	-0.06	0.20	1	0.1	1.74
36	34	21B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE		X		X	(3)									X	-	897	2.99	-	-0.15	0.50	8	0.8	1.69
37	35	16A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X						X				500	708	2.36	-0.20	-0.15	0.50	2	0.2	1.66
38		5B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X					X					480	734	2.45	-0.20	-0.15	0.50	4	0.4	1.55
39	36	8A	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X	660	788	2.63	-0.03	-0.32	1.07	1	0.1	1.46
40	37	2G	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	48								2250		625	629	2.10	-0.40	-0.13	0.43	3	0.3	1.37
41	38	3M	CALCINED KAOLIN PLUS CALCIUM ALUMINATE	X			40	X							X			-	788	2.63	-	-0.35	1.17	4	0.4	1.46
42	42	12D	ALUMINA PLUS PHOSPHORIC ACID		X		X	X					1050					-	678	2.26	-	-0.06	0.20	9	0.9	1.18
43	39	8C	MAGNESIUM OXIDE PLUS CALCIUM ALUMINATE	X			X	X								X		-	1307	4.35	-	-0.88	2.93	3	0.3	1.12
44	40	1F	HI ALUMINA PLUS CALCIUM ALUMINATE	X			12	X								X		-	1023	3.41	-0.40	-0.66	2.20	1	0.1	1.11
45	41	1C	ALUMINA SILICATE PLUS UNKNOWN	X			X	X					1200					-	739	2.46	-0.90	-0.29	0.97	4	0.4	1.09

NOTES: (1) CAST, PLACED BY TROWEL (2) 250°F (3) DRY AT 300°F FOR 8 HOURS (4) 24 HOURS AT 550°F
NO VIBRATION PER INCH OF THICKNESS

*Data obtained after evaluation of Phase II

TABLE 18 EVALUATION OF CASTABLE REFRACTORY DATA FOR FIRED TOOLS USED AT ELEVATED TEMPERATURE

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						FIRING TEMPERATURE, 4 HOURS AT					MODULUS OF RUPTURE		FIRING SIZE CHANGE			SURFACE FINISH		LINEAR SHRINK VALUE INCHES
Final	Phase II			CAST	RAM	SLIP	16-24 HOURS AT R.T.	16-24 HOURS AT 220°F	4 HOURS AT 500	600	700	750	1000	1500	2000	2400	2500	VENDOR PUBLISHED VALUE	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE,%	ACTUAL, %	LINEAR CONVERSION INCHES	ACTUAL	LINEAR CONVERSION INCHES	
1	1	25B	FUSED SILICA PLUS UNKNOWN			X	X	X							X				2167	7.22		-0.64	2.13	1	0.1	4.99
2	2	25A	FUSED SILICA PLUS UNKNOWN			X	X	X							X				1352	4.51		-0.23	0.77	1	0.1	3.64
3		*71B	HI ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X		1800	6.00		-0.71	2.37	2	0.2	3.43
4	3	21C	UNKNOWN PLUS PHOSPHORIC ACID		X		X	(1)			X								1054	3.51		-0.08	0.27	4	0.4	2.84
5	4	108A	ALUMINA PLUS PHOSPHORIC ACID	(2)			X	X					X						1074	3.58		-0.04	0.13	9	0.9	2.55
6	5	16A	UNKNOWN PLUS PHOSPHORIC ACID		X		X	X	(4)						X				1054	3.51		-0.24	0.80	2	0.2	2.51
7	6	16A	UNKNOWN PLUS PHOSPHORIC ACID		X		X	X			X								1015	3.38		-0.32	1.17	2	0.2	2.01
8	7	21B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE		X		X	(3)									X		994	3.31		-0.15	0.50	8	0.8	2.01
9	8	70B	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X									X		806	2.69		-0.19	0.63	2	0.2	1.86
10	9	12B	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X						812	2.71		-0.20	0.67	2	0.2	1.84
11	10	81A	PETALITE PLUS CALCIUM ALUMINATE	X			X	X							X				637	2.12		-0.06	0.20	1	0.1	1.82
12	11	40B	CORUNDUM PLUS CALCIUM ALUMINATE	X			48	X					X						680	2.27		-0.08	0.27	2	0.2	1.80
13	12	5A	TABULAR ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X						678	2.26		-0.09	0.30	2	0.2	1.76
14	13	1F	HIGH GRADE CALCINED CLAY PLUS CALCIUM ALUMINATE	X			X	X					X						847	2.82		-0.26	0.87	2	0.2	1.75
15	14	12AB	**			X	X	(5)X	(5)				X						617	2.06		-0.07	0.23	1	0.1	1.73
16	15	108A	ALUMINA PLUS PHOSPHORIC ACID	(2)			X	X			X								779	2.60		-0.03	0.10	9	0.9	1.60

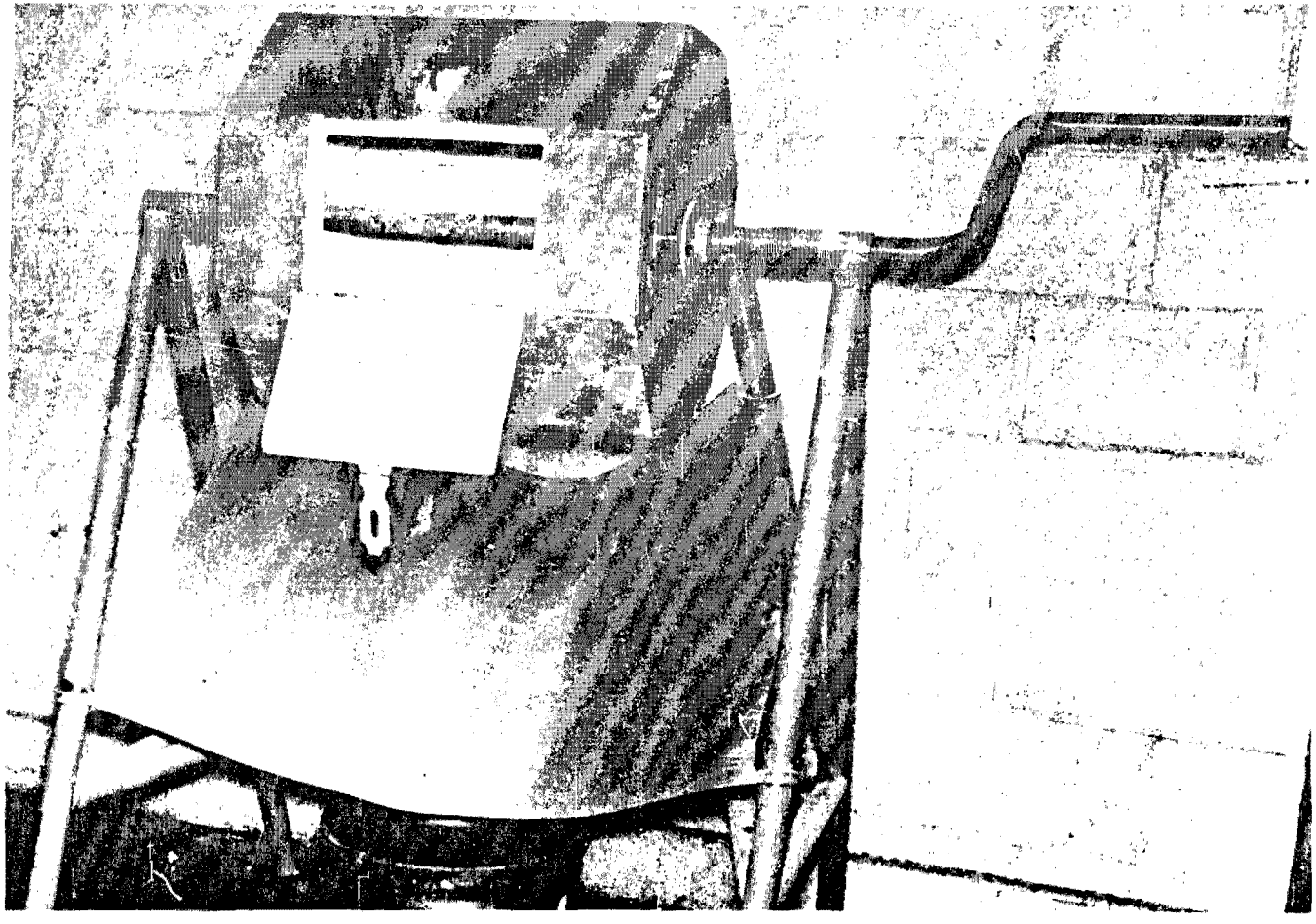
TABLE 18 (CONT'D)

RANK		MATERIAL CODE	AGGREGATE AND BINDER	PLACEMENT METHOD			CURING & DRYING PROCEDURE						FIRING TEMPERATURE 4 HOURS AT					MODULUS			FIRING SIZE CHANGE			SURFACE FINISH		LINEAR WORTH VALUE INCHES
Final	Phase II			CAST	RAM	SLIP	16-24 HOURS AT R.T.	16-24 HOURS AT 220°F	4 HOURS AT 500	600	700	750	1000	1500	2000	2400	2500	VENDOR PUBLISHED VALUE	ACTUAL, PSI	LINEAR CONVERSION INCHES	VENDOR PUBLISHED VALUE,%	ACTUAL, %	LINEAR CONVERSION INCHES	ACTUAL	LINEAR CONVERSION INCH	
17	16	21A	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X		907	3.02		-0.40	1.33	2	0.2	1.49
18	17	10A	UNKNOWN	X			3	X									X		907	3.02		-0.41	1.37	3	0.3	1.35
19	18	108D	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X					X						597	1.99		-0.12	0.40	3	0.3	1.49
20	19	70C	ALUMINA PLUS UNKNOWN	X			X	X									X		507	1.69		-0.10	0.33	1	0.1	1.26
21	20	5E	FIRECLAY PLUS CALCIUM ALUMINATE	X			X	X						X					627	2.09		-0.22	0.73	2	0.2	1.16
22	21	2A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X								2250			445	1.48		-0.06	0.20	2	0.2	1.08
23	22	12C	ALUMINA PLUS PHOSPHORIC ACID		X		X	X					X						806	2.69		-0.35	1.17	5	0.5	1.07
24	23	11E	UNKNOWN	X			X	X							X				338	1.13		-0.04	0.13	1	0.1	0.90
25	24	8B	ALUMINA PLUS CALCIUM ALUMINATE	X			X	X									X		679	2.26		-0.36	1.20	2	0.2	0.86
26	25	122A	FUSED SILICA PLUS LUMNITE CEMENT (6)	X			X	X											401	1.34		-0.13	0.43	1	0.1	0.81
27	26	12D	ALUMINA PLUS PHOSPHORIC ACID		X		X	X					1050						523	1.74		-0.06	0.20	9	0.9	0.84
28	27	13A	ALUMINA AND SILICA PLUS CALCIUM ALUMINATE	X			X	X						X					386	1.29		-0.15	0.50	2	0.2	0.59
29	28	111A	CALCINED MISSOURI FLINT CLAY AND CALCINED ALUMINA PLUS CALCIUM ALUMINATE	X			X	X						X					346	1.15		-0.11	0.37	2	0.2	0.58
30	29	140A	UNKNOWN		X		12	X							2050				509	1.70		-0.25	0.83	3	0.3	0.57

** FUSED SILICA AND FUSED SILICA SLIP PLUS ALKOPHOS C

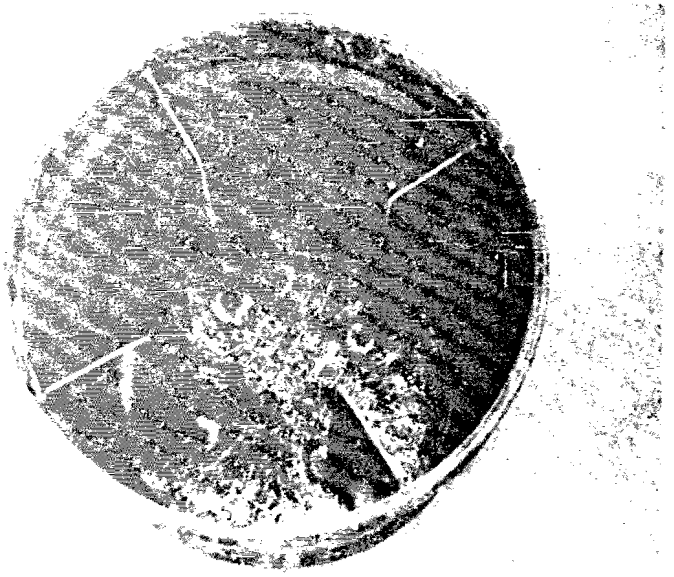
* DATA OBTAINED AFTER EVALUATION OF PHASE II.

NOTES: (1) 250°F (2) PLACED BY TROWEL, NO VIBRATION. (3) DRY AT 300°F FOR 8 HOURS PER INCH OF THICKNESS. (4) 24 HOURS AT 550°F (5) 24 HOURS AT 150°F PRIOR TO 24 HOURS AT 230°F. AFTER 230°F DRYING, CONTINUE DRYING FOR 24 HOURS AT 550°F (6) THIS TOOL WAS NOT FIRED.



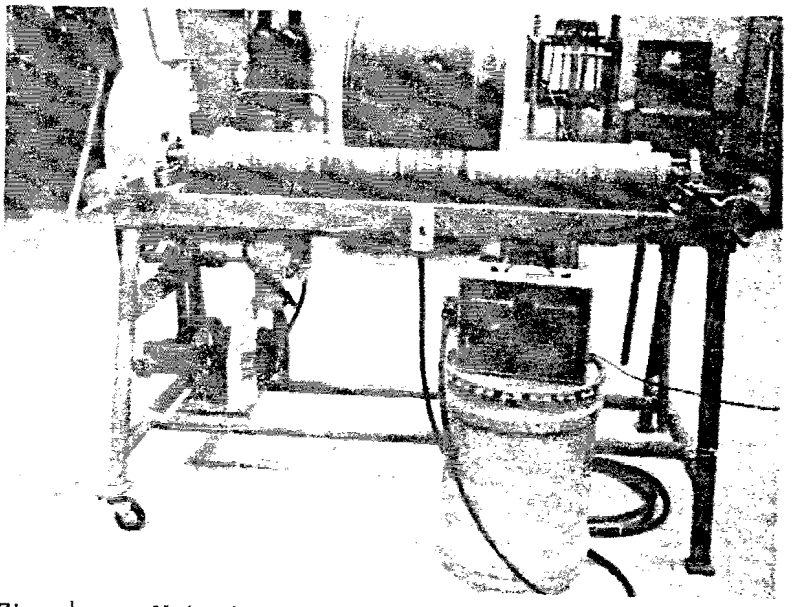
RF 2261-5

Fig. 2 Dry blender used for vibration study specimens only. Replaced by Twin Shell blender shown in Figure 65.



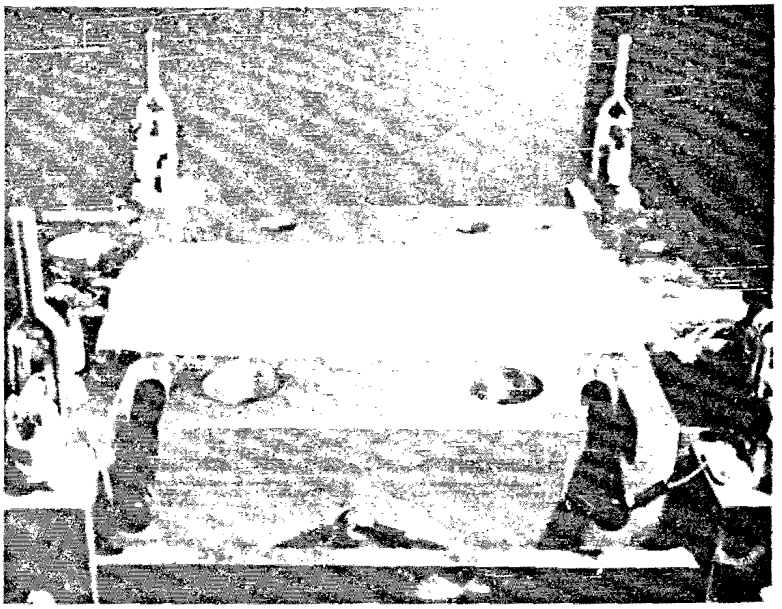
RF 1965-2

Fig. 3 Wet mixer tub used for vibration study specimens only. Replaced by Mix-Muller shown in Figure 67.



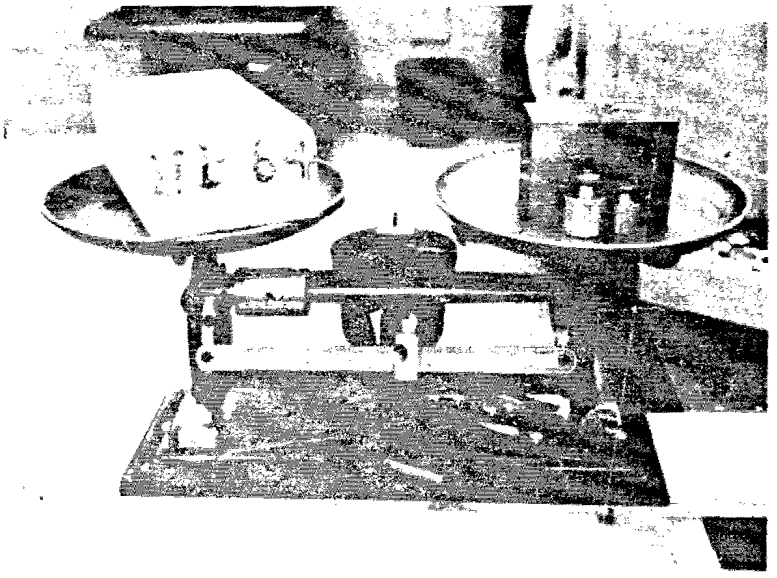
RF 1965-4

Fig. 4 Wet mixer tub on powered rollers.



RF 1965-7

Fig. 5 Test specimen being vibrated externally. Air bubbles indicate air removal due to vibration.



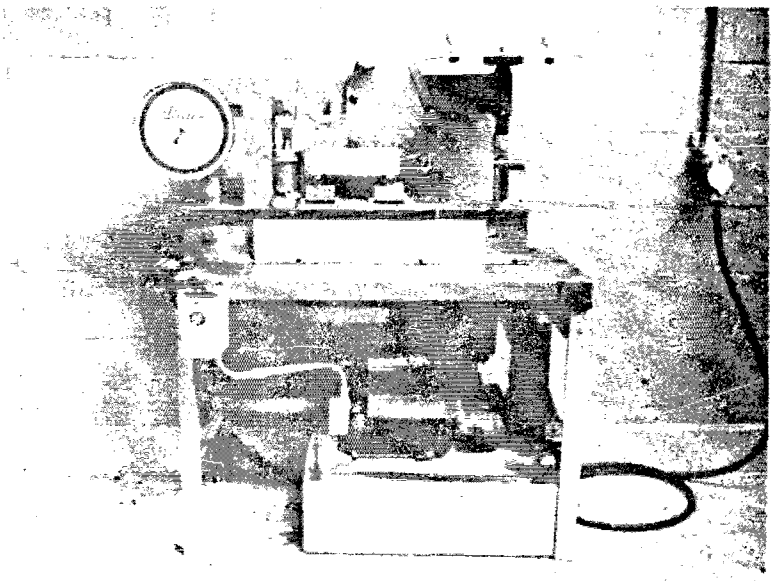
RF 2149-4

Fig. 6 Setup for weighing specimen in air.



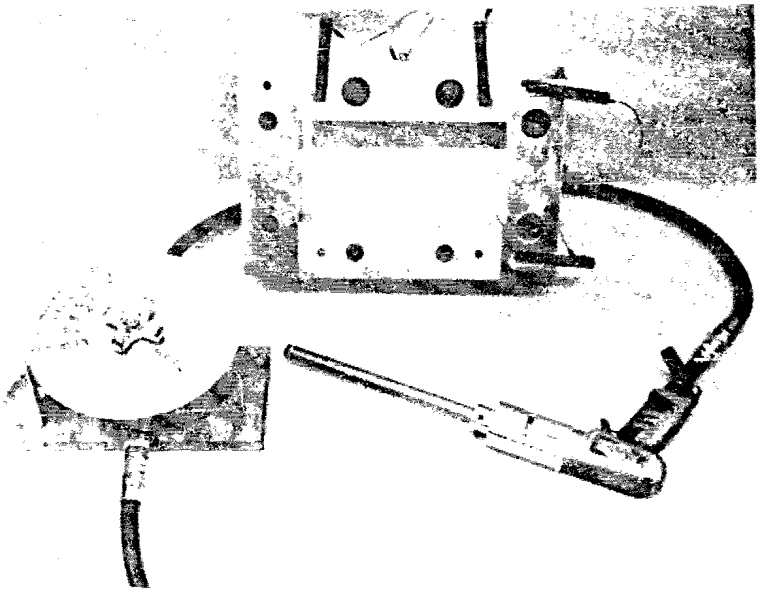
RF 2149-9

Fig. 7 Setup for weighing specimen in water.



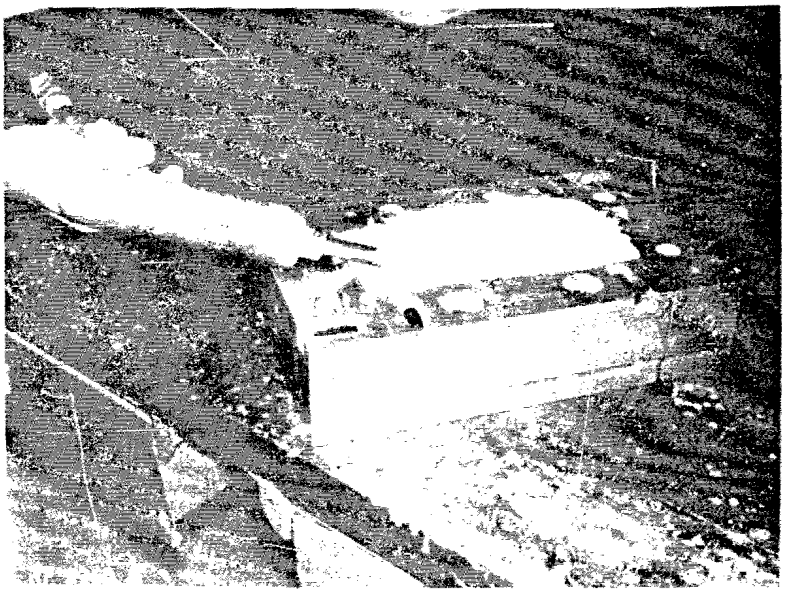
RF 2149-6

Fig. 8 Apparatus for determining modulus of rupture.



RF 2260-6

Fig. 9 Air driven internal vibrator and precision mold. Tachometer to check frequency is mounted in radial slot in housing adapter.



RF 2260-8

Fig. 10 Test specimen being internally vibrated.

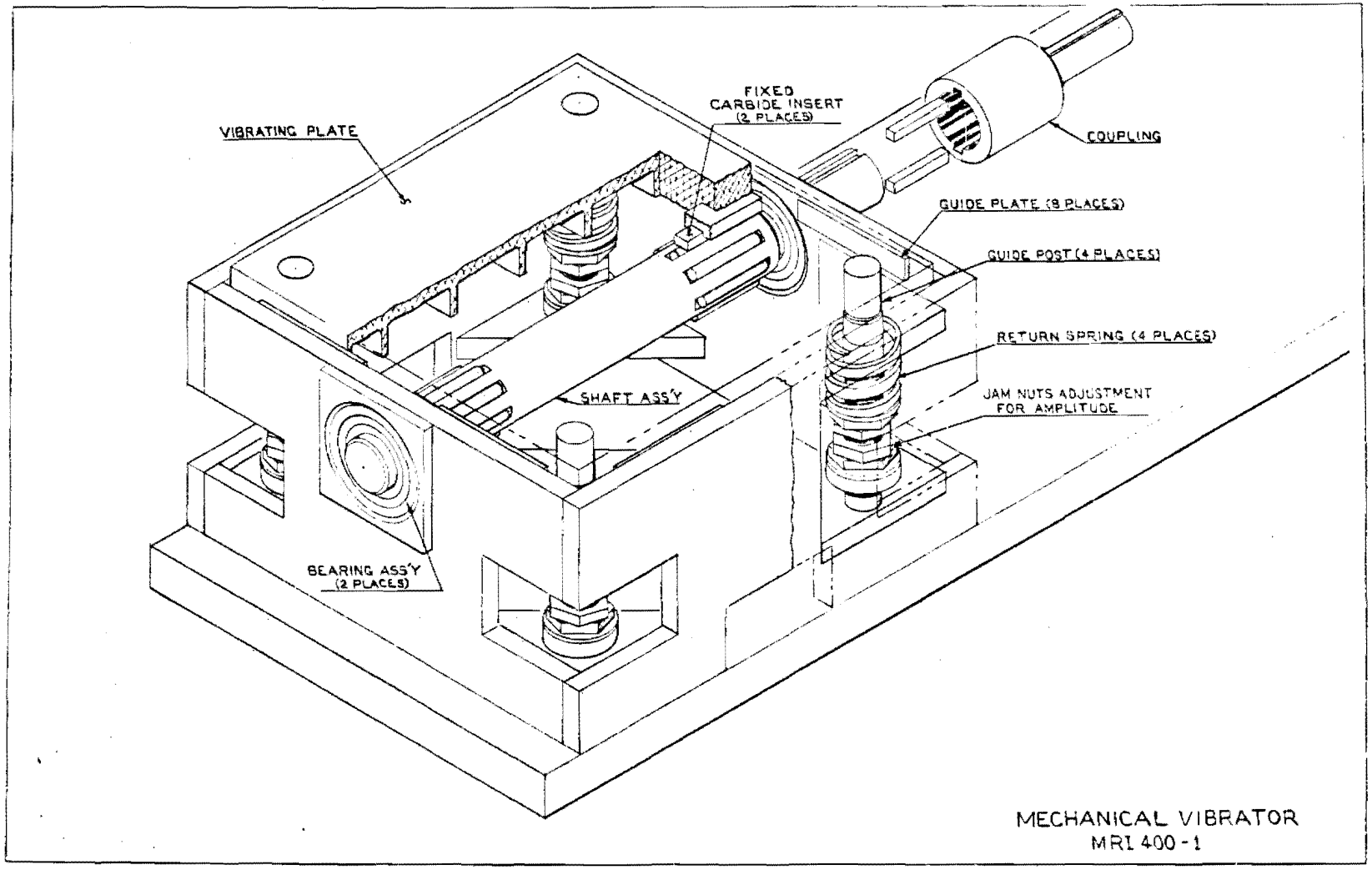
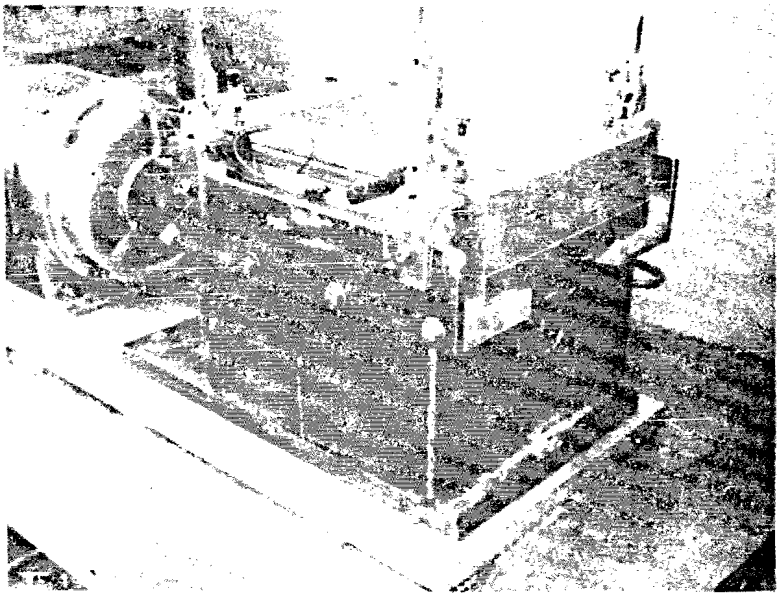
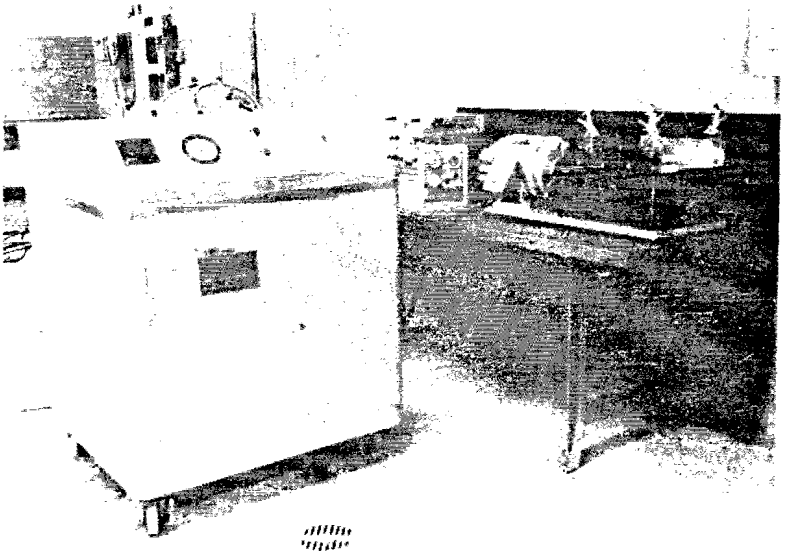


Fig. 11 External vibrator table (cutaway). Refer to Figure 12, photograph.



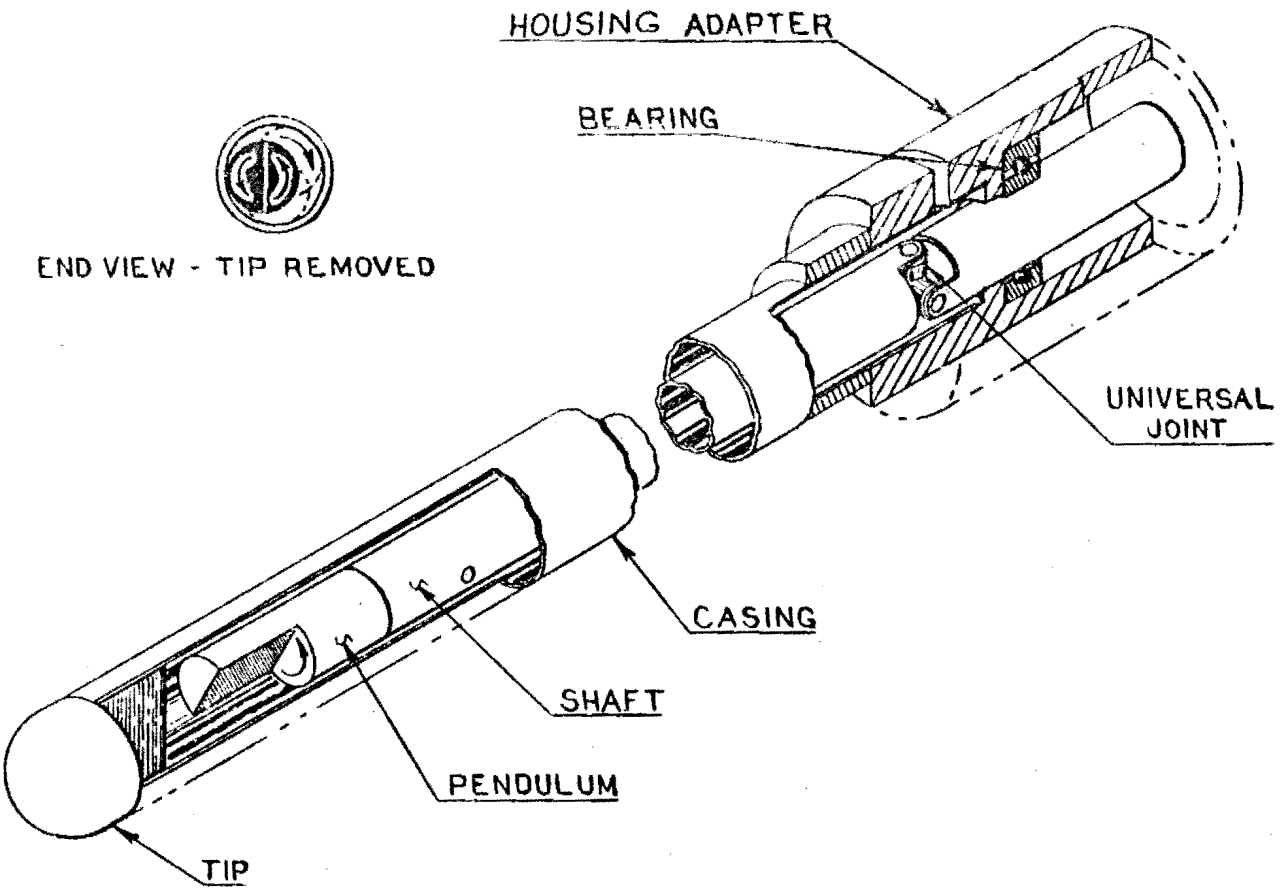
RF 1965-5

Fig. 12 Mold in holding fixture ready for vibration.



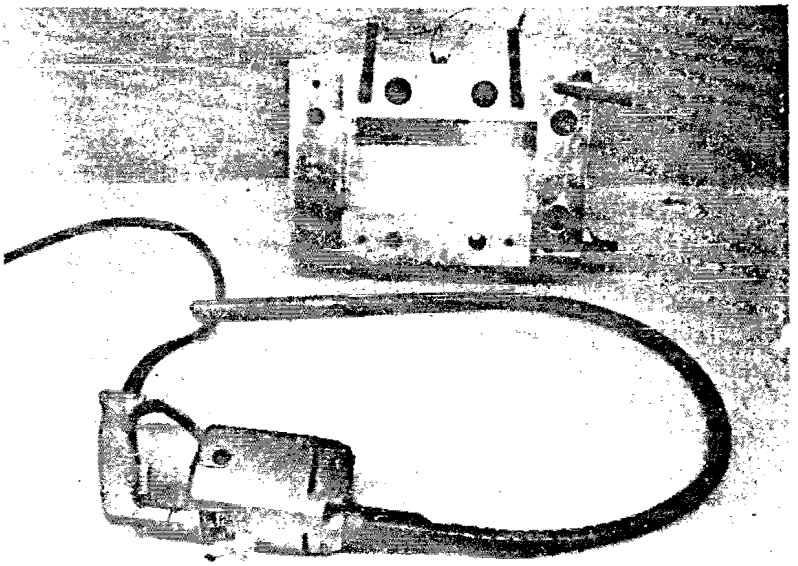
RF 2149-3

Fig. 13 External vibrator table, motor, and control console.



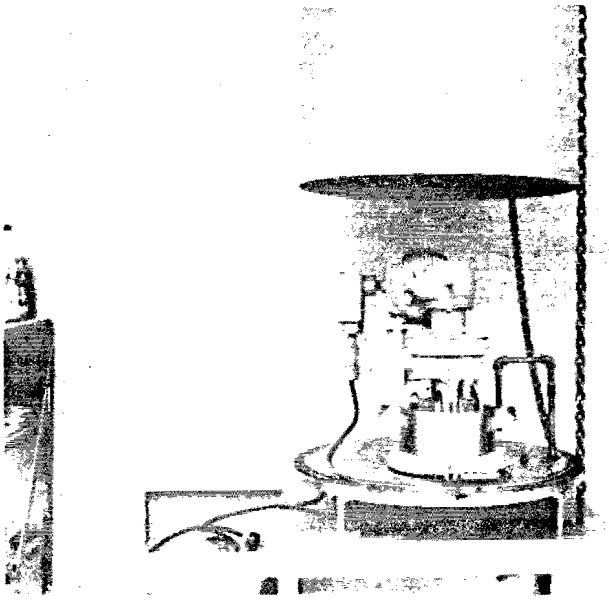
INTERNAL VIBRATOR
E-26H-414-18

Fig. 14 Air driven internal vibrator (cutaway). Refer to Figure 9, photograph.



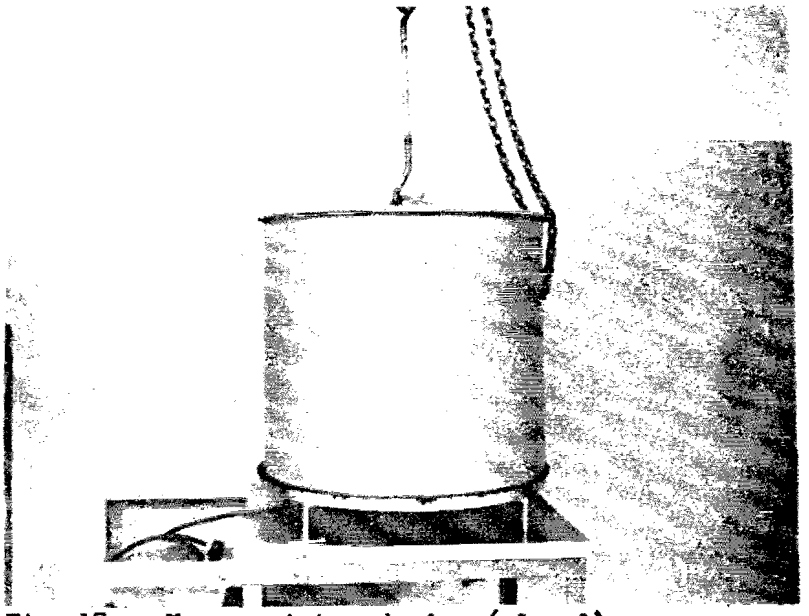
RF 2260-7

Fig. 15 Electrically driven internal vibrator.



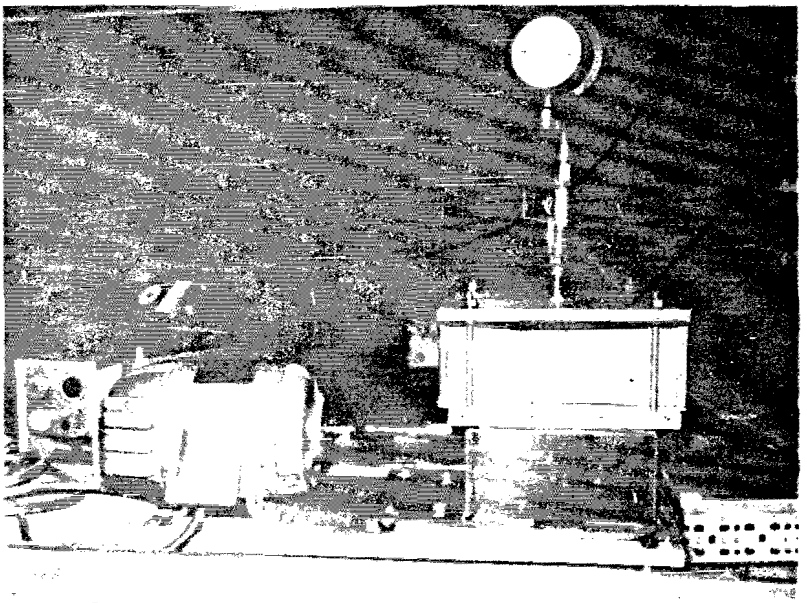
RF 2149-8

Fig. 16 Vacuum mixing chamber (open).



RF 2149-7

Fig. 17 Vacuum mixing chamber (closed).



RF 2261-4

Fig. 18 Vacuum chamber for external vibrator.

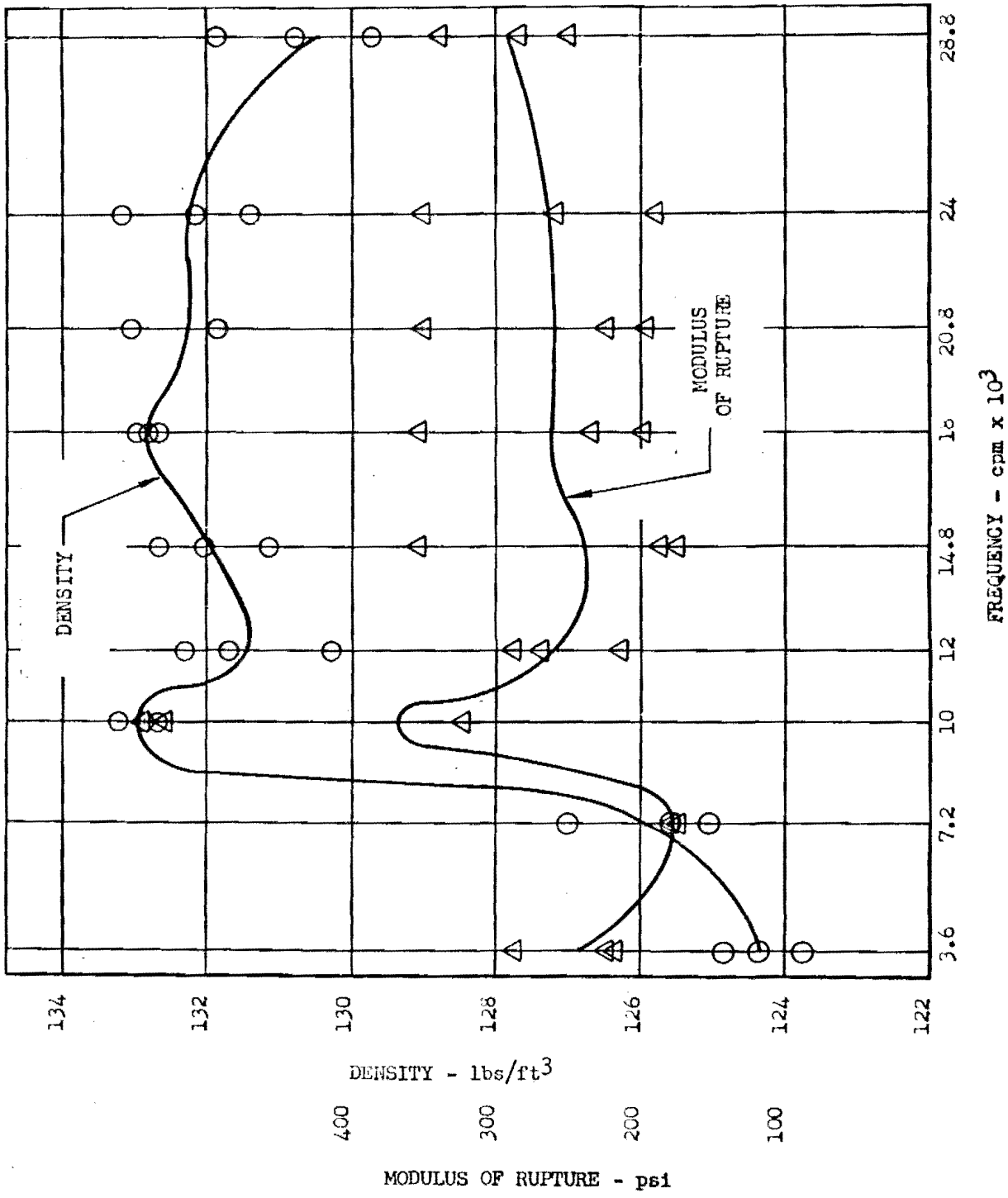


Fig. 19 Density and modulus of rupture vs. frequency - 0.0005 inch amplitude - external vibration.

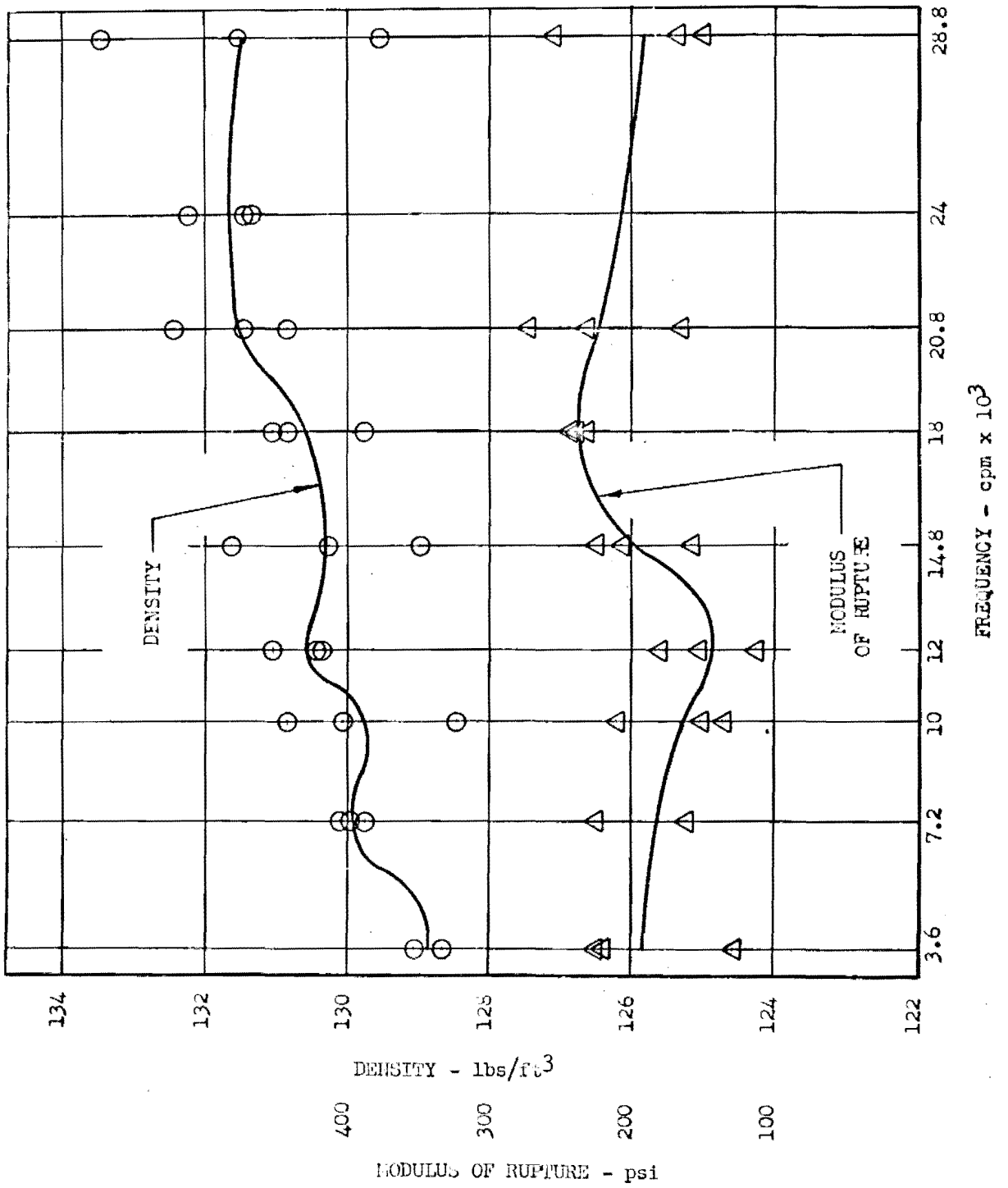


Fig. 20 Density and modulus of rupture vs. frequency - 0.0010 inch amplitude - external vibration.

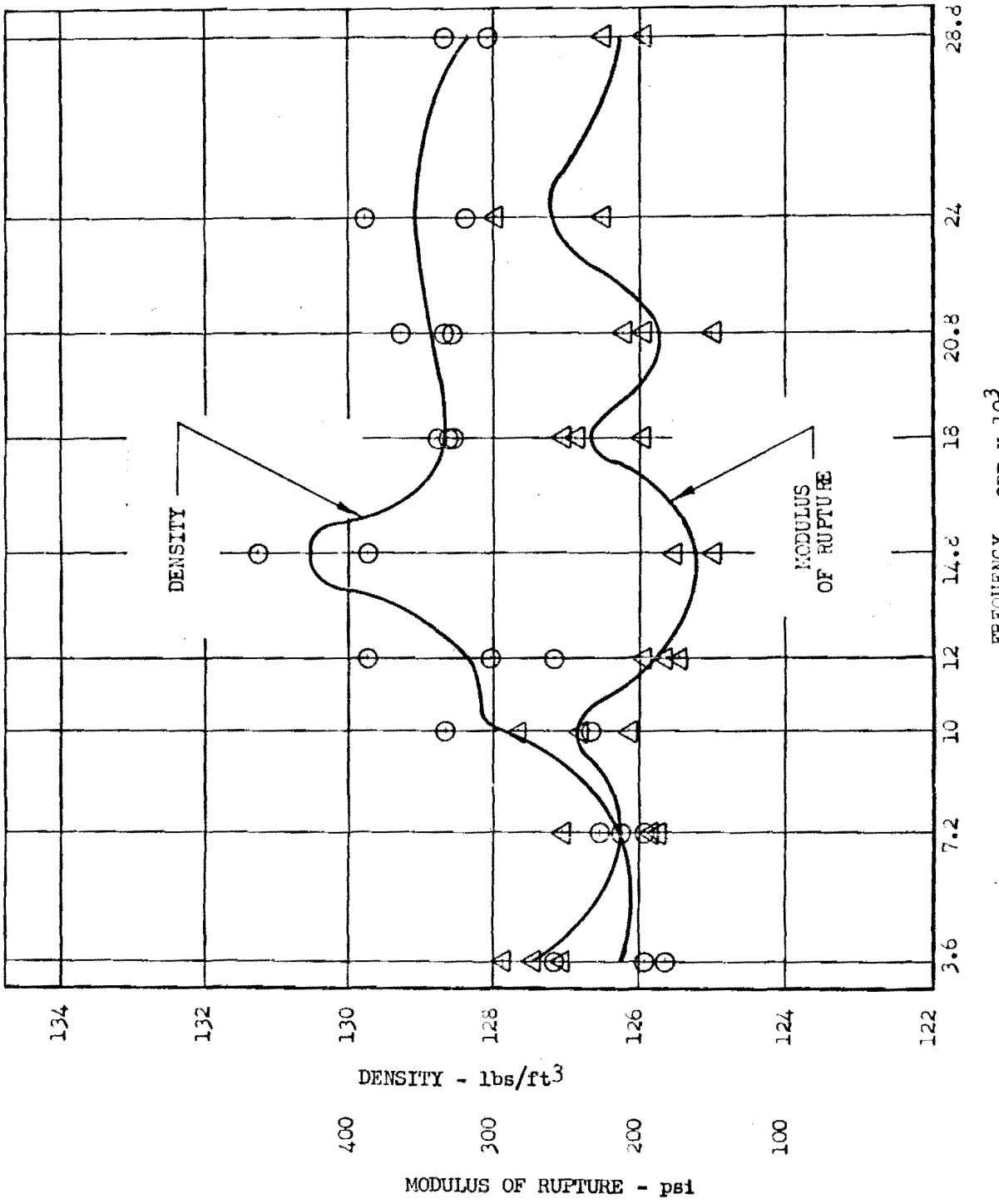


Fig. 21 Density and modulus of rupture vs. frequency - 0.0015 inch amplitude - external vibration.

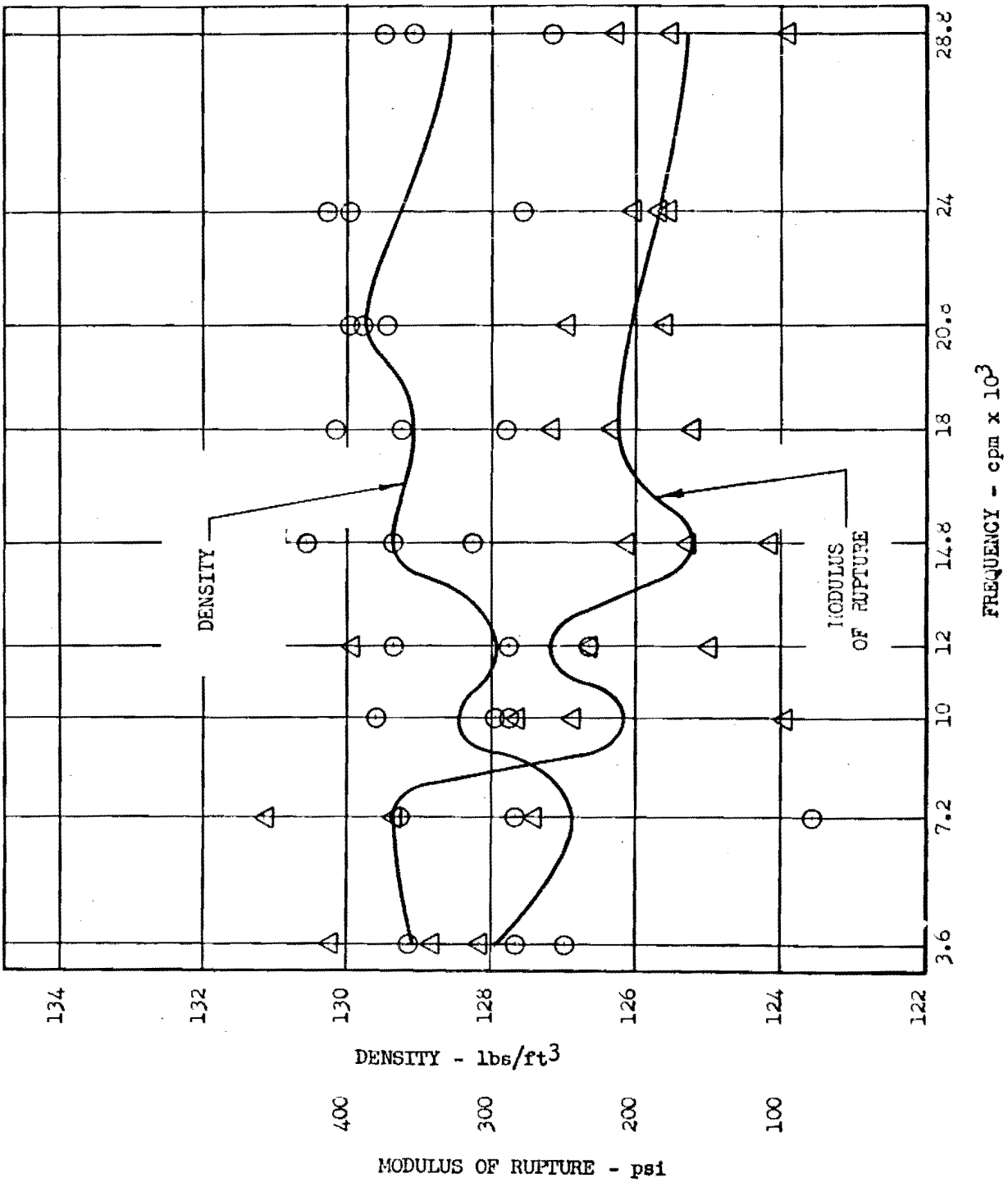


Fig. 22 Density and modulus of rupture vs. frequency - 0.0020 inch amplitude - external vibration.

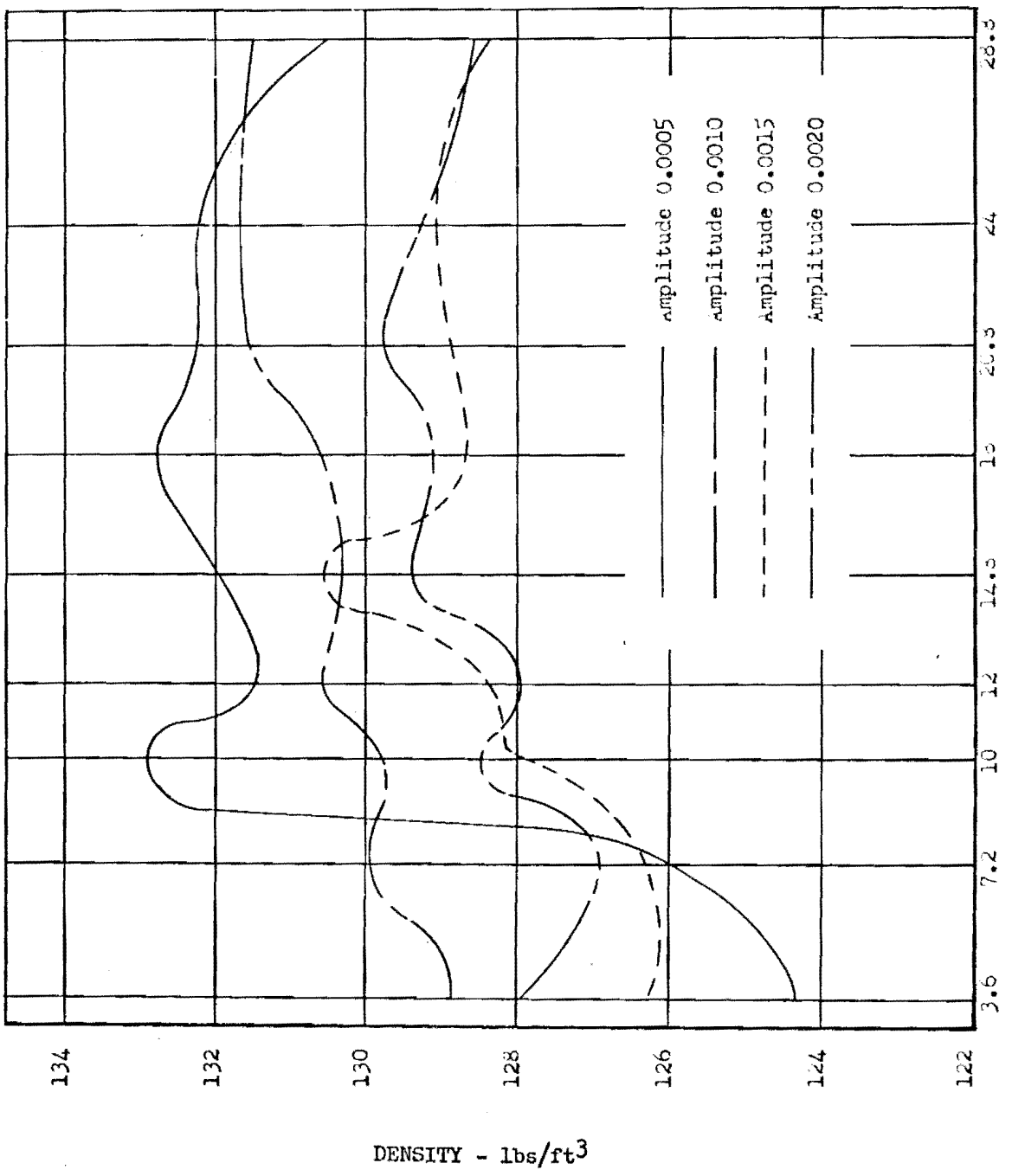


Fig. 23 Density vs. frequency - composite of all amplitudes - external vibration.

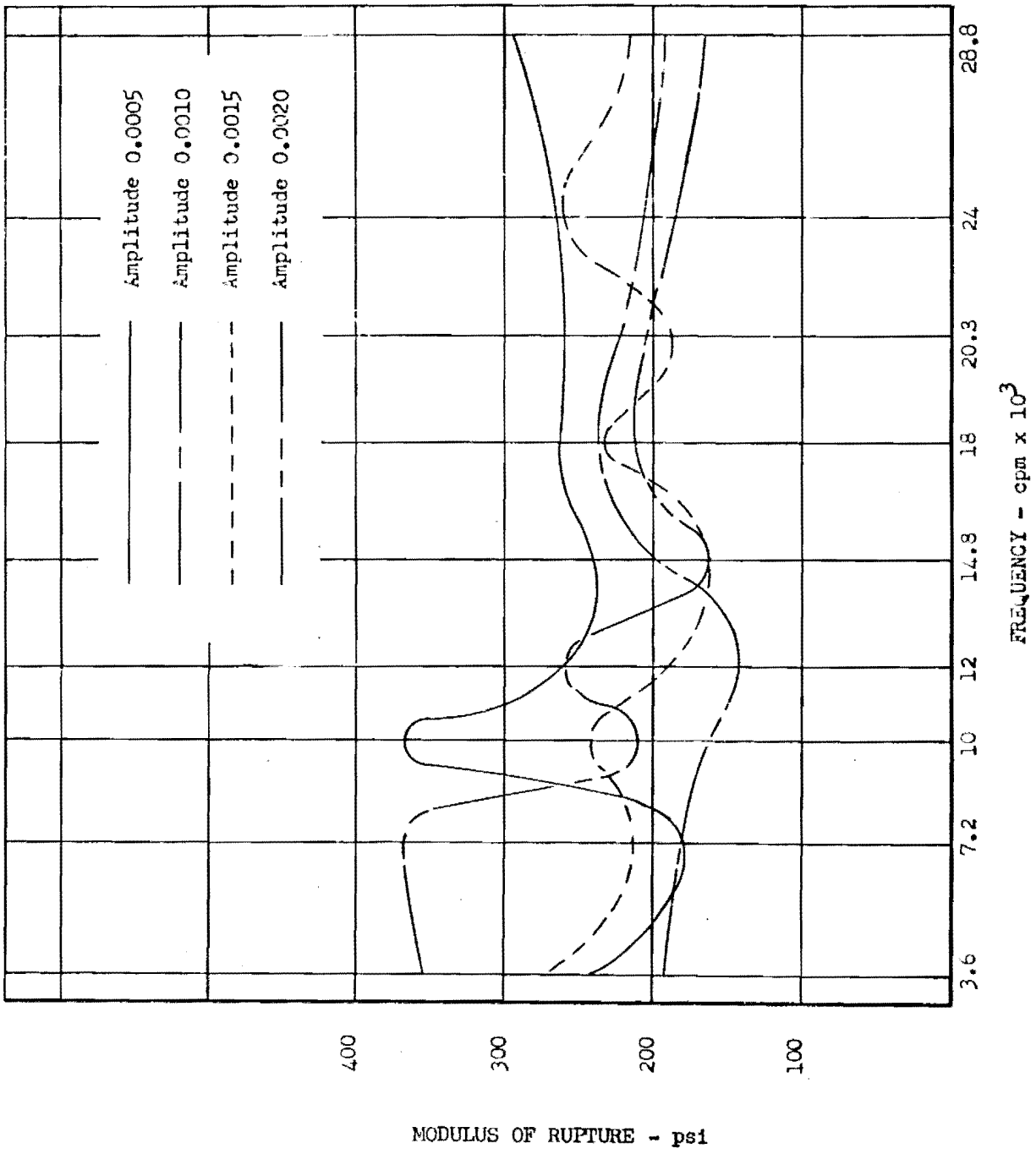
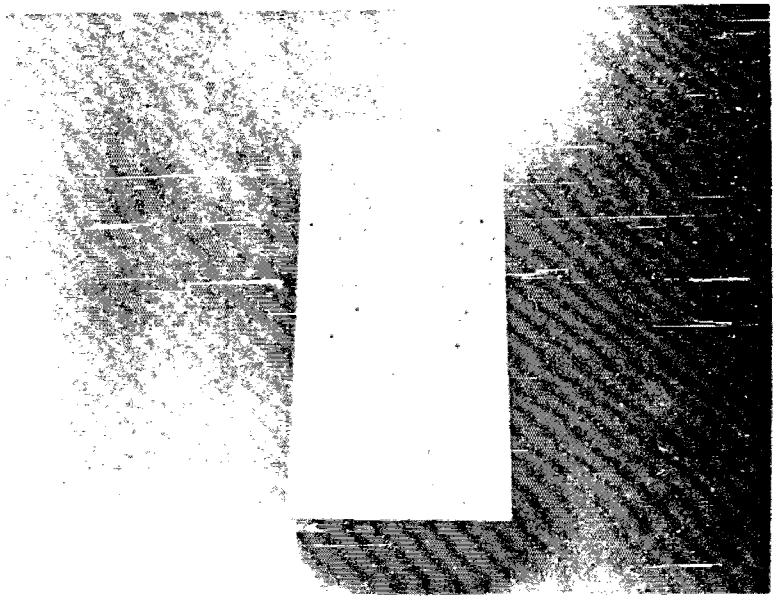
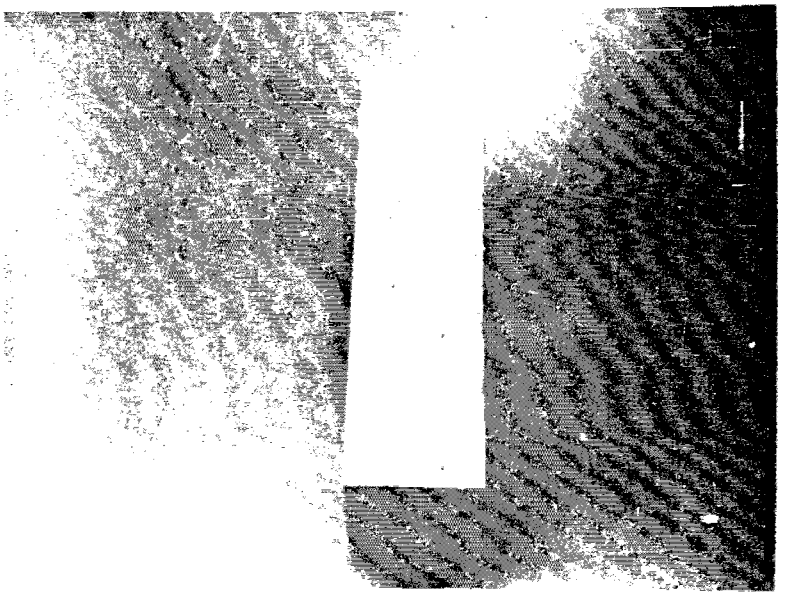


Fig. 24 Modulus of rupture vs. frequency - composite of all amplitudes - external vibration.



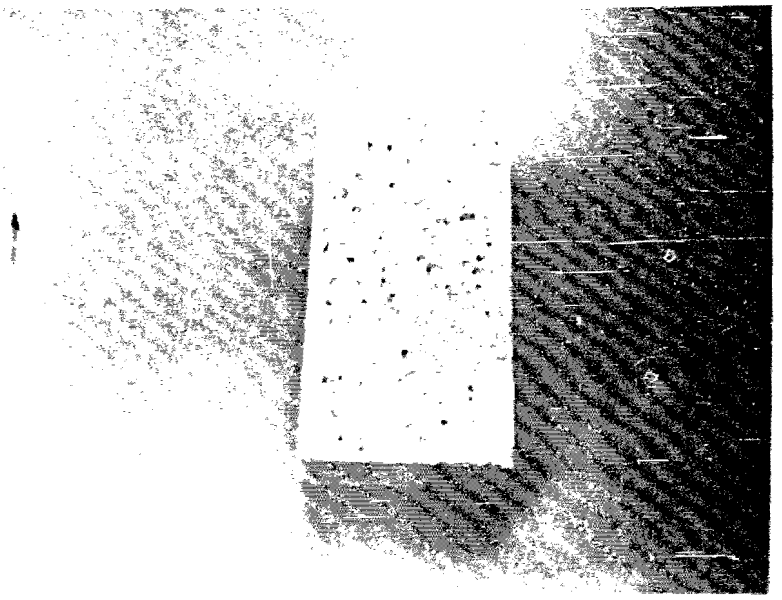
RF 2150-9

Fig. 25 Bottom of Specimen 1F.1-18, the most dense - 0.0005 inch amplitude and 10,000 vpm frequency - externally vibrated.



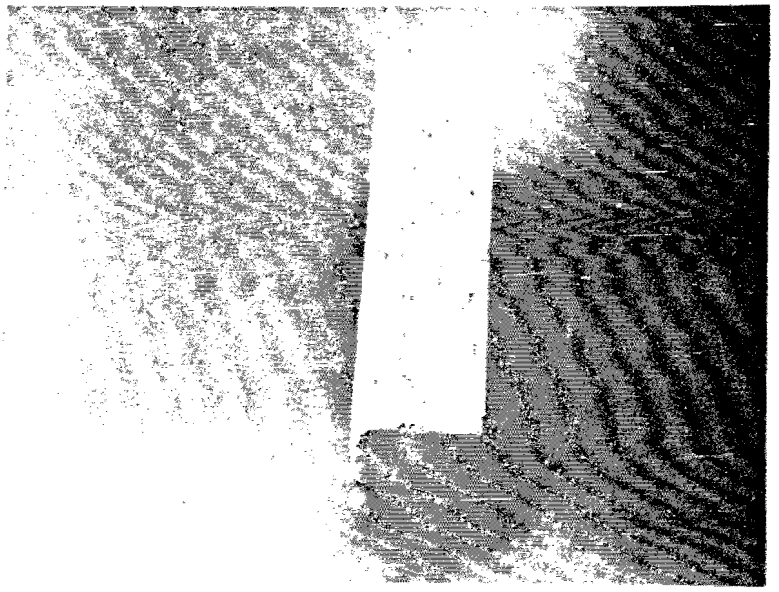
RF 2150-10

Fig. 26 Edge of Specimen 1F.1-18, the most dense - 0.0005 inch amplitude and 10,000 vpm frequency - externally vibrated.



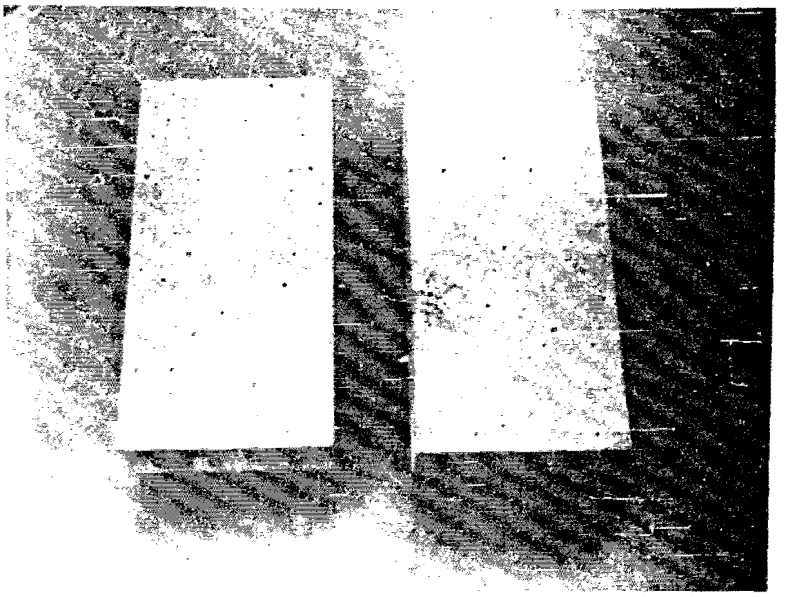
RF 2150-3

Fig. 27 Bottom of Specimen 1F.1-10, the least dense -0.0005 inch amplitude and 3,600 vpm frequency - externally vibrated.



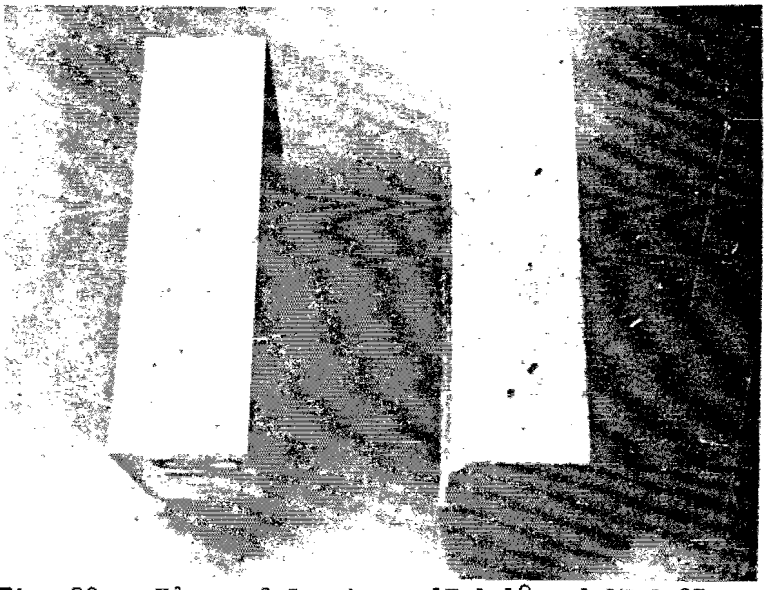
RF 2150-2

Fig. 28 Edge of Specimen 1F.1-10, the least dense -0.0005 inch amplitude and 3,600 vpm frequency - externally vibrated.



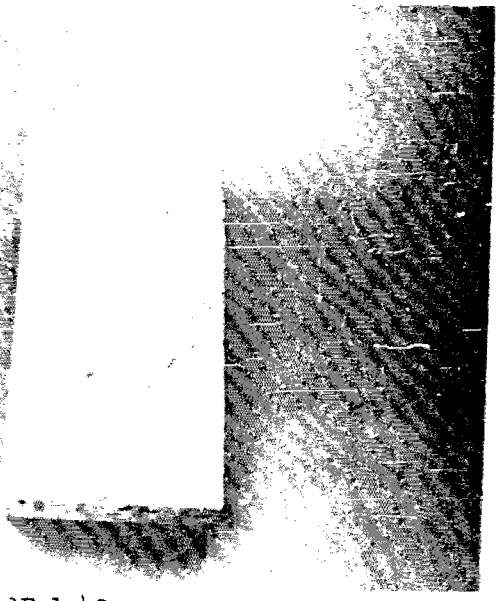
RF 2150-1

Fig. 29 Bottoms of Specimens 1F.1-18 and 1F.1-27, peak densities at 0.0005 inch amplitude and 10,000 and 18,000 vpm respectively - externally vibrated.



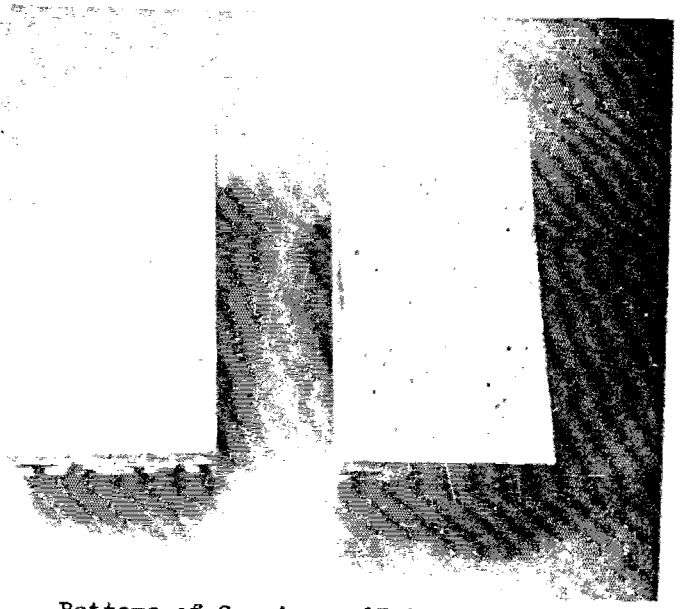
RF 2149-2

Fig. 30 Edges of Specimens 1F.1-18 and 1F.1-27, note depth of separation.



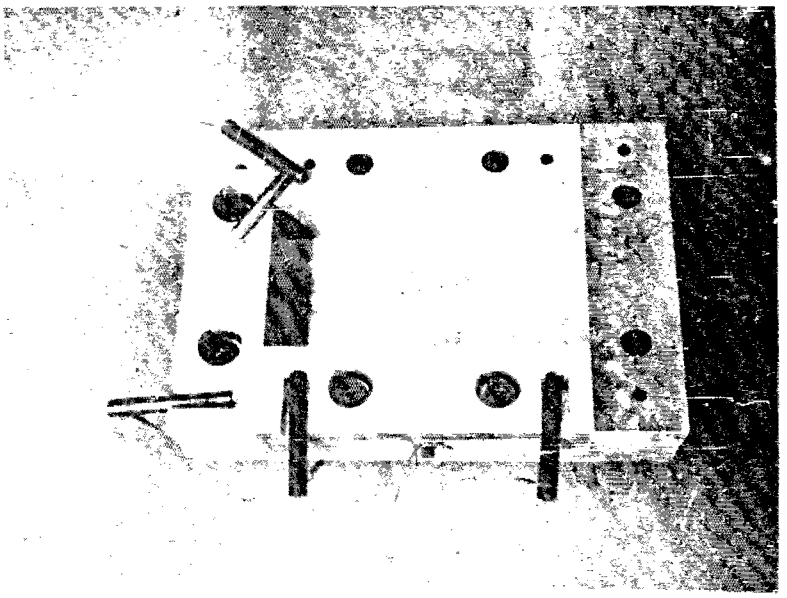
RF 2150-7

Fig. 31 Specimen 1F.1-40, crazing due to separation (inadvertently not covered with damp burlap) -0.0010 inch amplitude and 7,200 vpm frequency - externally vibrated.



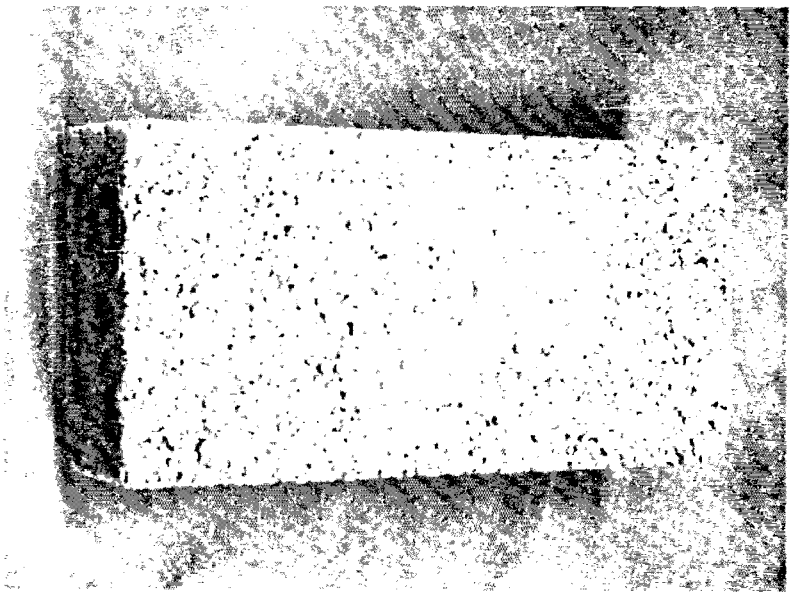
RF 2150-8

Fig. 32 Bottoms of Specimens 1F.1-91 and 1F.1-92 both at 0.0020 inch amplitude and 3,600 vpm frequency but different parting agents were used - externally vibrated.



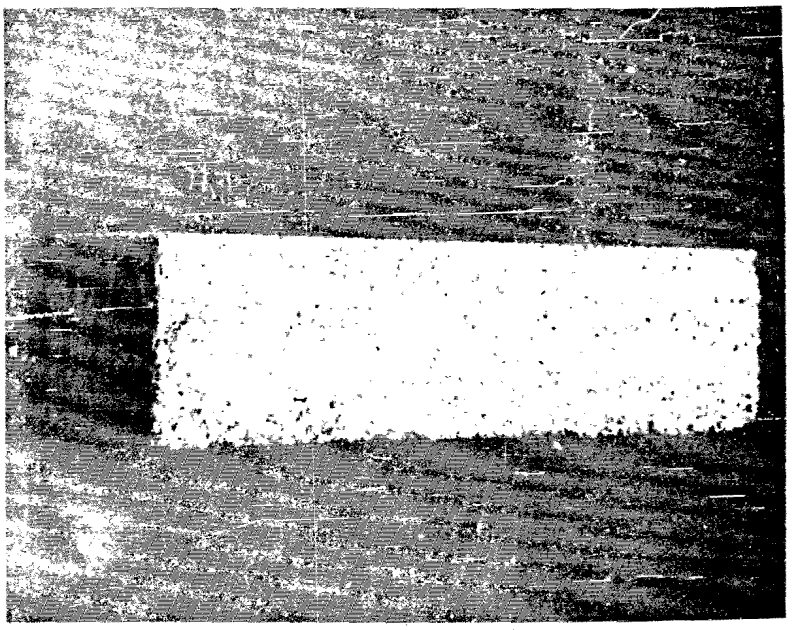
RF 1965-6

Fig. 33 Mold for casting test specimen.



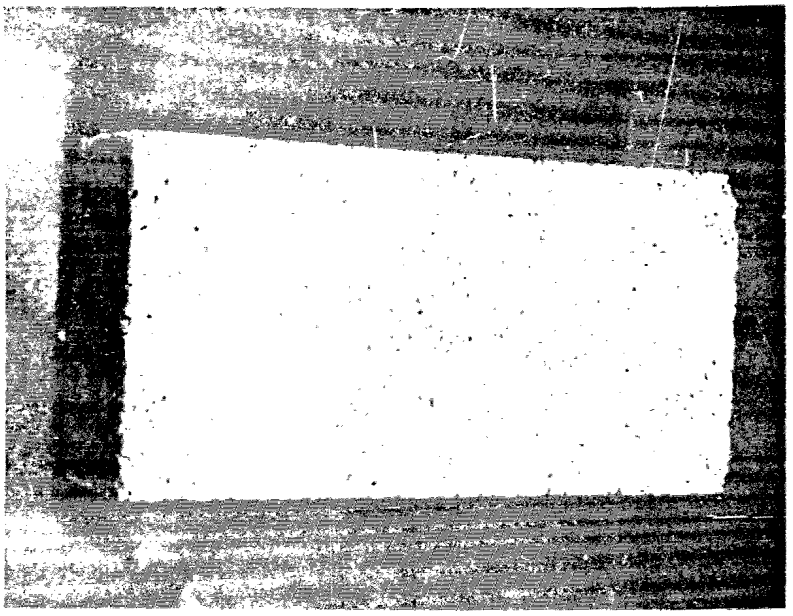
RF 2315-2

Fig. 34 Bottom of Specimen 1F.1-178, hand tamped using 1 x 1 x 16 inch wooden stick.



RF 2315-1

Fig. 35 Edge of Specimen 1F.1-178, hand tamped using 1 x 1 x 16 inch wooden stick.



RF 2315-3

Fig. 36 Top of Specimen 1F.1-178, hand tamped using 1 x 1 x 16 inch wooden stick.

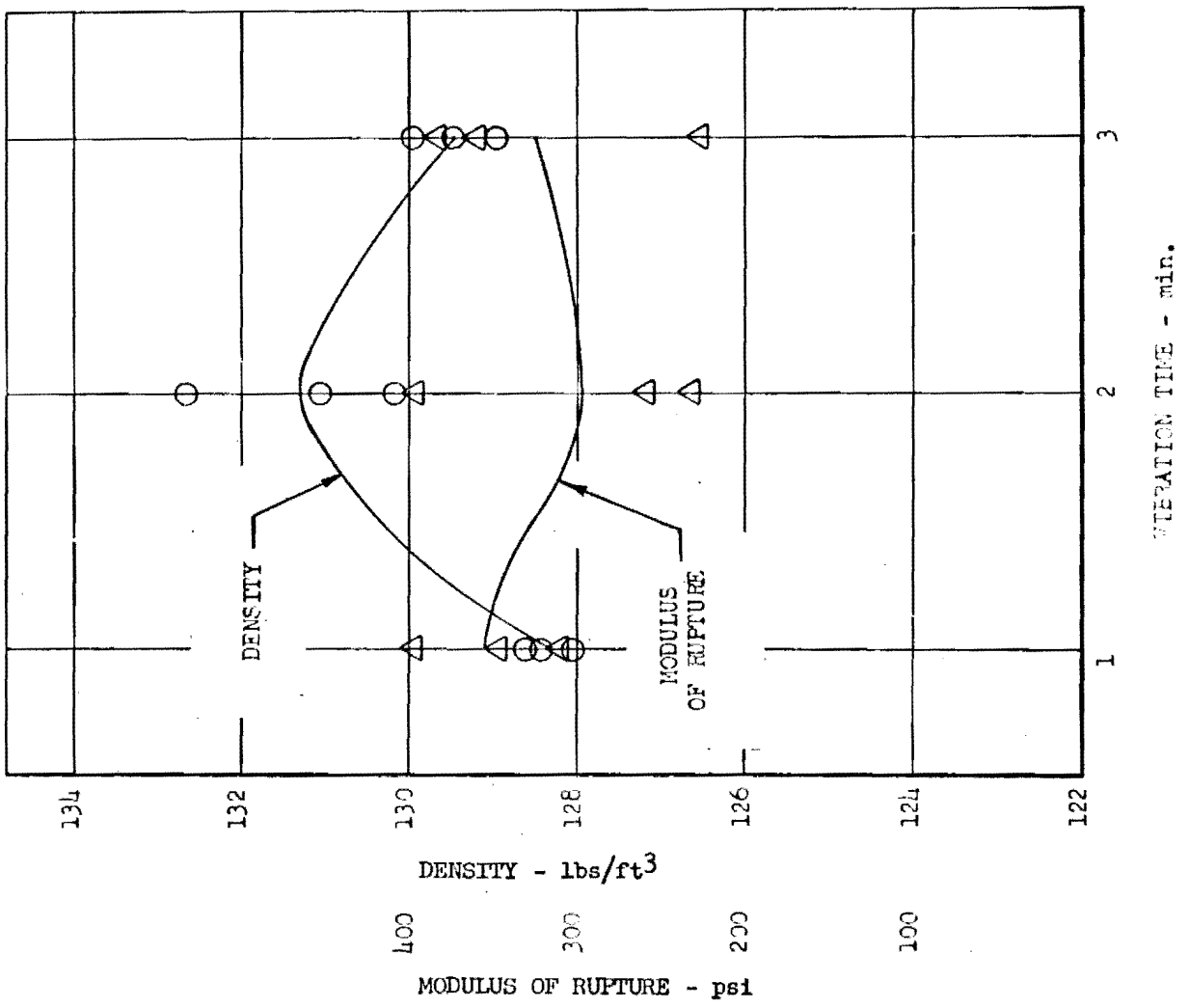


Fig. 37 Density and modulus of rupture vs. vibration time - external vibration.

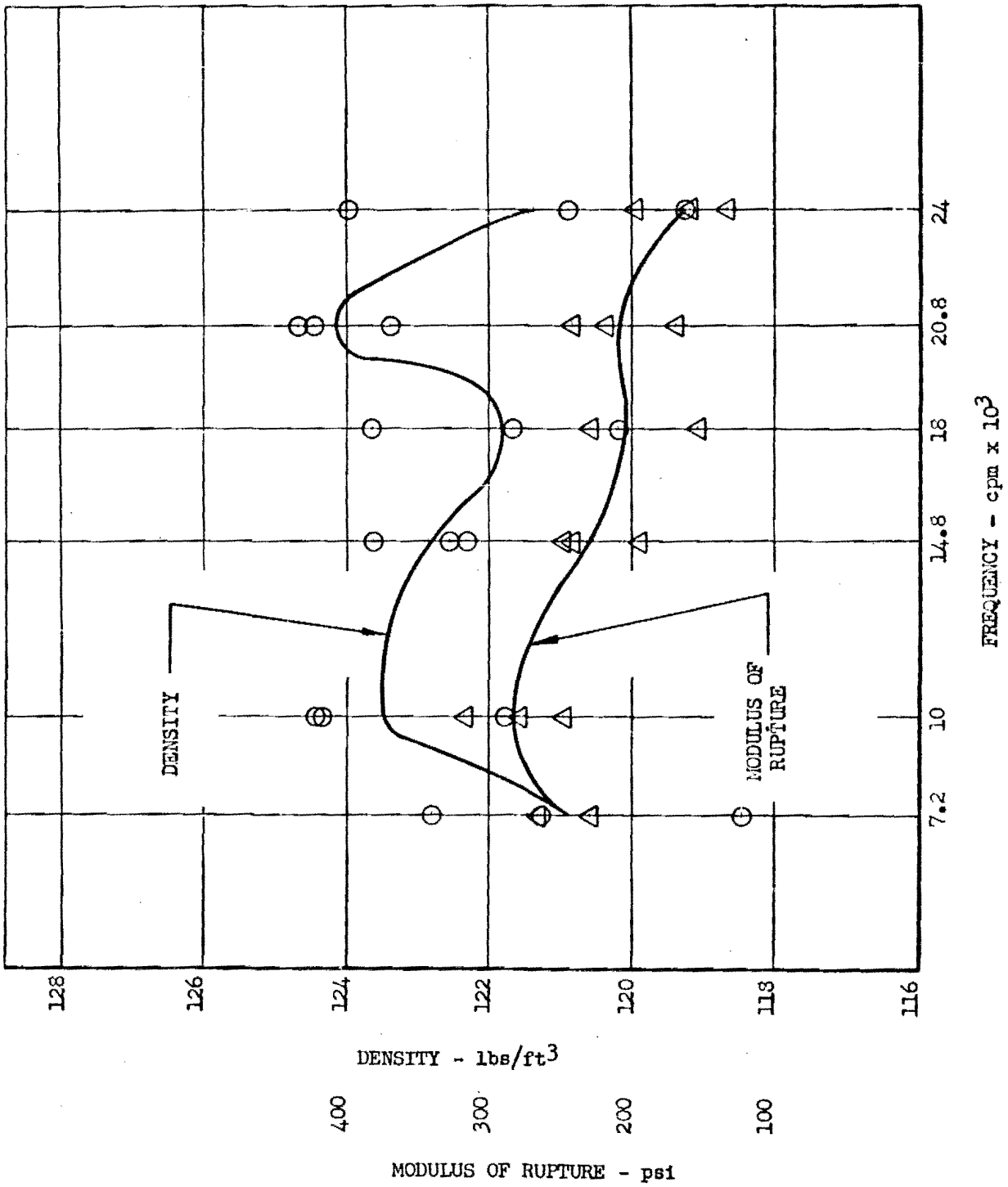


Fig. 38 Density and modulus of rupture vs. frequency - internal vibration (air driven vibrator).

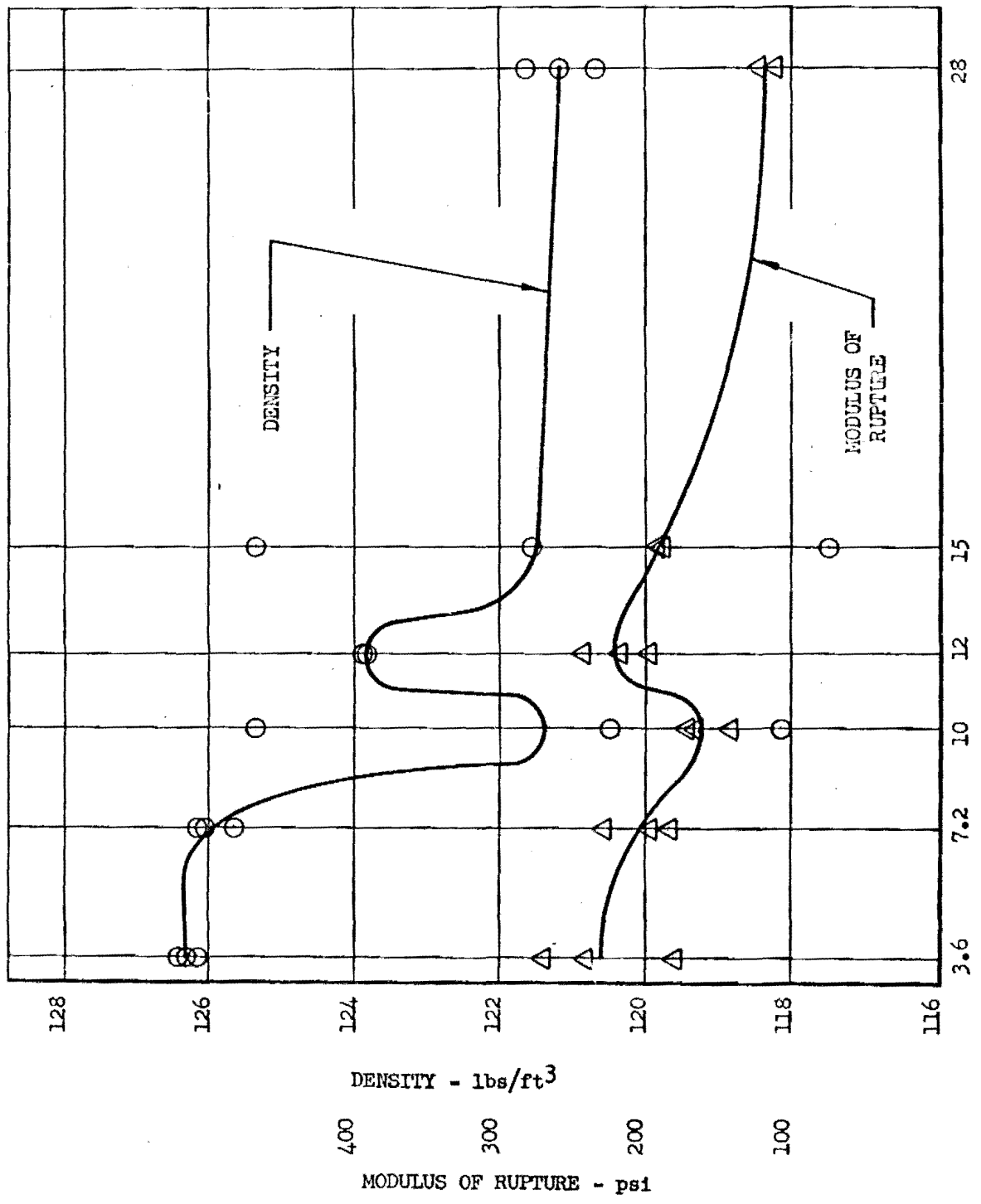
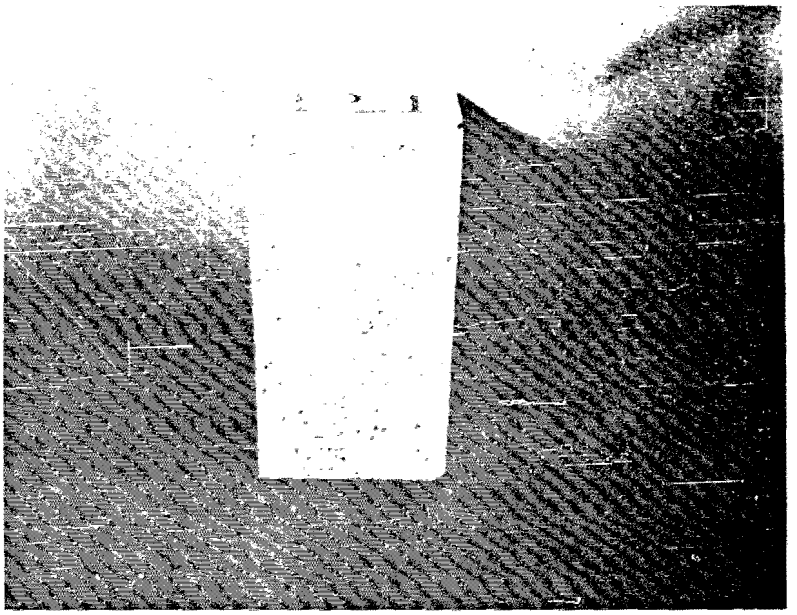
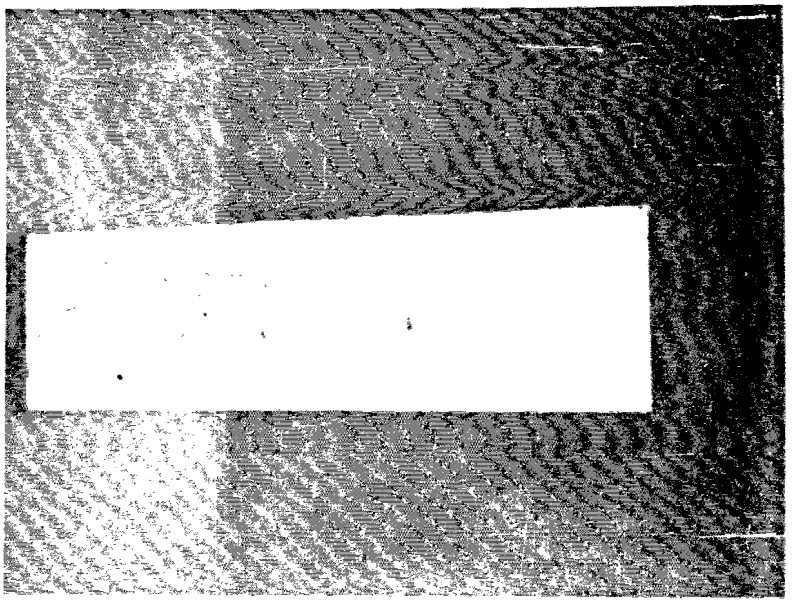


Fig. 39 Density and modulus of rupture vs. frequency - internal vibration (electrically driven vibrator).



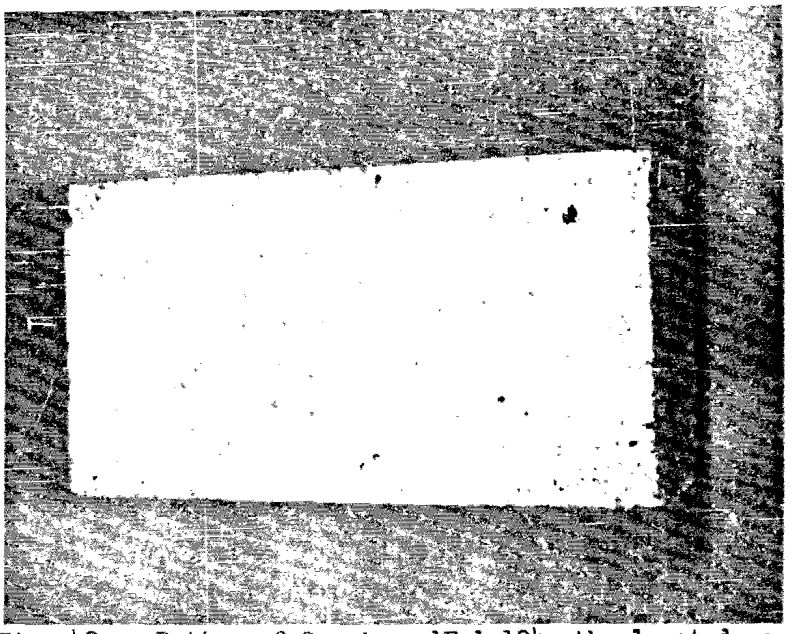
RF 2333

Fig. 40 Bottom of Specimen 1F.1-121, the most dense -10,000 vpm frequency - internally vibrated (air driven).



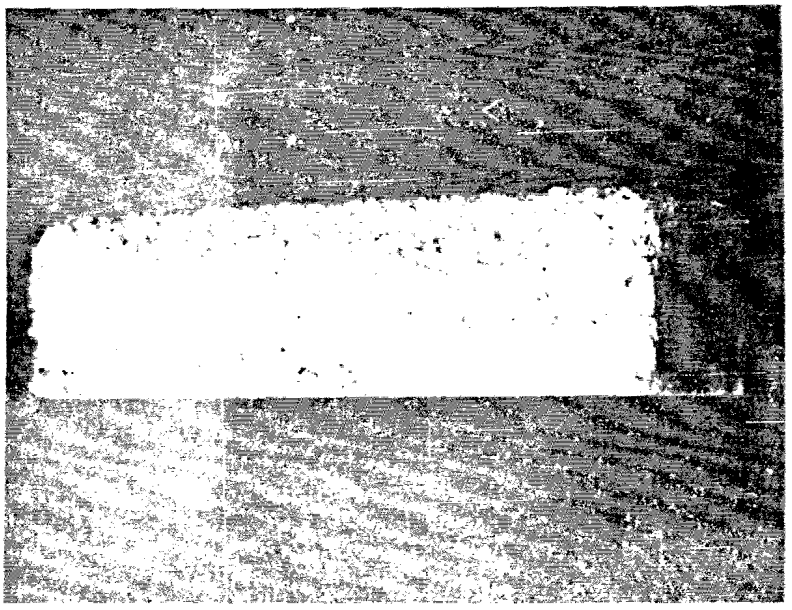
RF 2261-10

Fig. 41 Edge of Specimen 1F.1-121, the most dense -10,000 vpm frequency - internally vibrated (air driven).



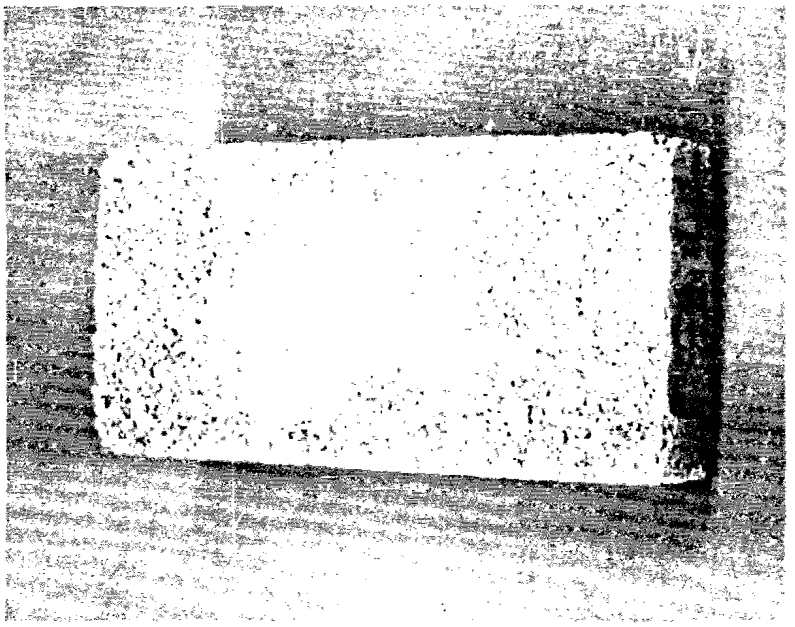
RF 2260-10

Fig. 42 Bottom of Specimen 1F.1-134, the least dense -7,200 vpm frequency - internally vibrated (air driven).



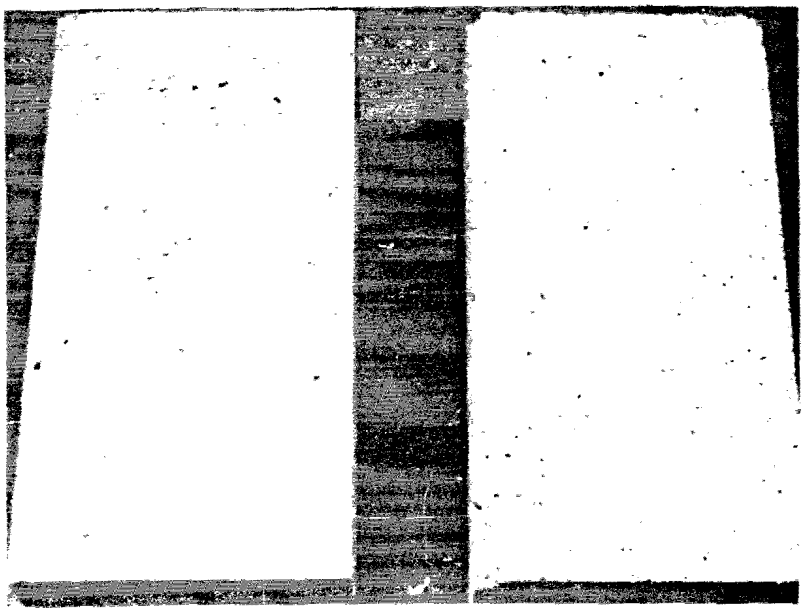
RF 2260-11

Fig. 43 Edge of Specimen 1F.1-134, the least dense -7,200 vpm frequency - internally vibrated (air driven).



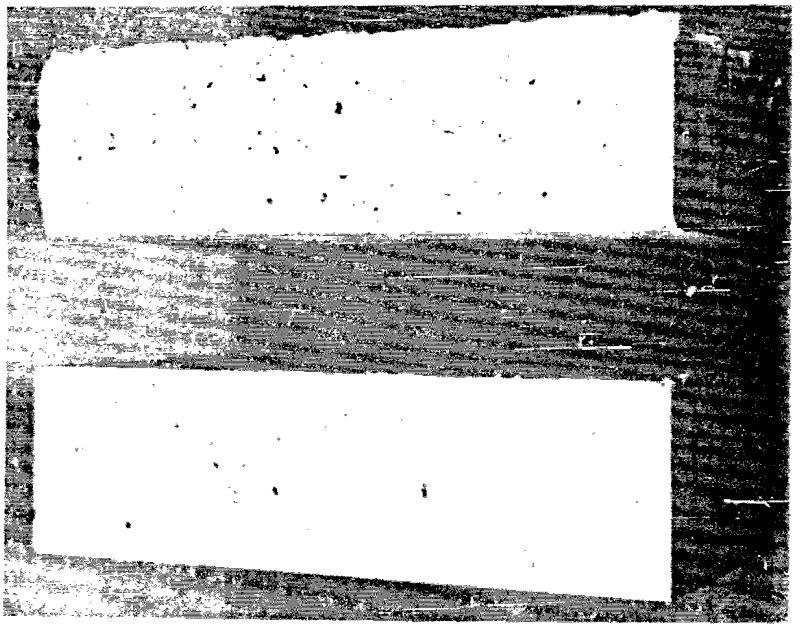
RF 2260-5

Fig. 44 Top of Specimen 1F.1-134, note absence of fines between coarse aggretate -7,200 vpm frequency - internally vibrated (air driven).



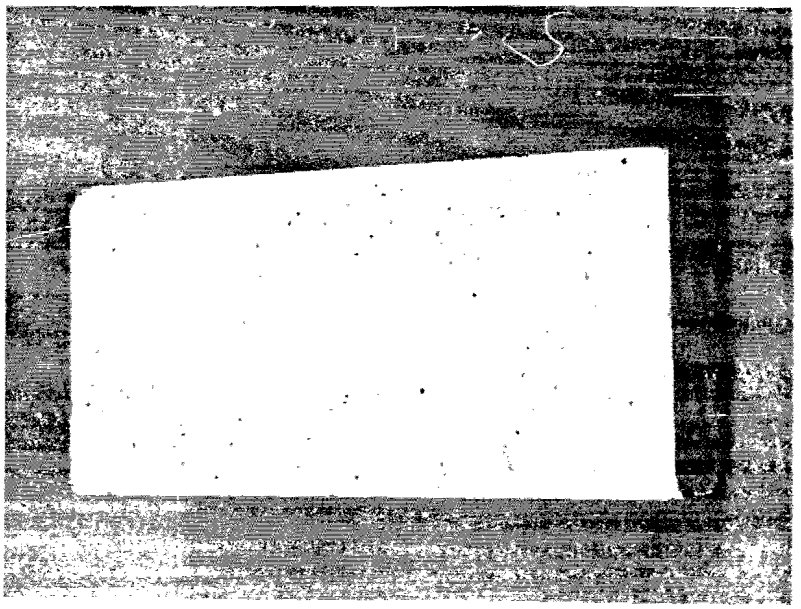
RF 2260-1

Fig. 45 Bottoms of Specimens 1F.1-121 and 1F.1-142, peak densities at 10,000 and 20,800 vpm frequency respectively, internally vibrated (air driven).



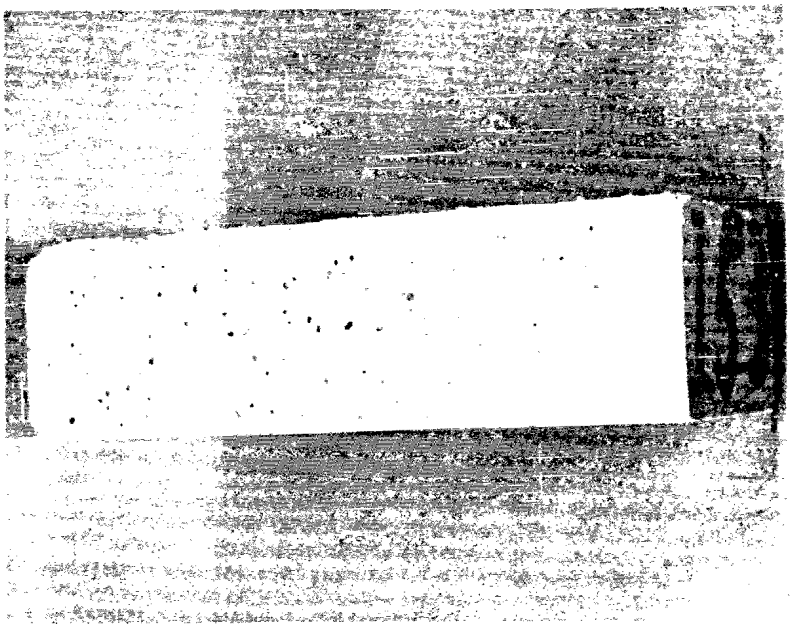
RF 2261-7

Fig. 46 Edges of Specimens 1F.1-121 and 1F.1-142, note depth of separation -10,000 and 20,800 vpm frequency respectively, - internally vibrated (air driven).



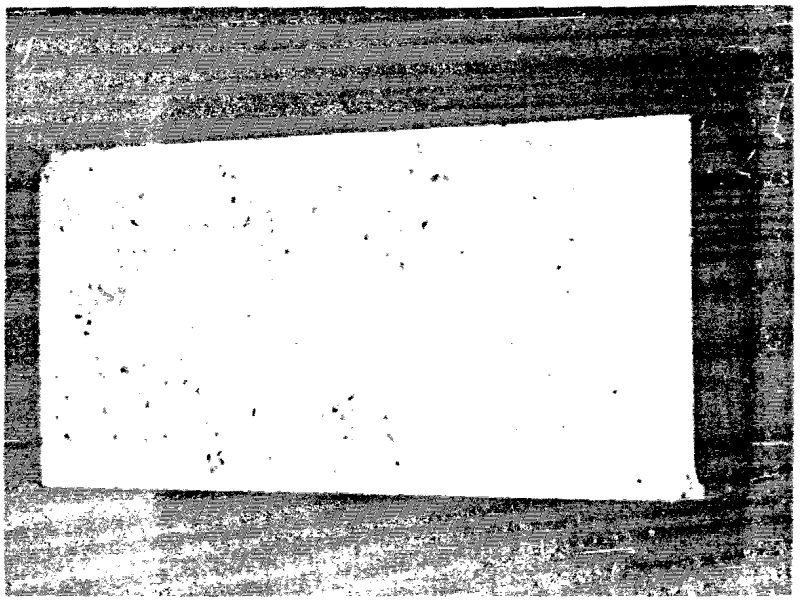
RF 2261-8

Fig. 47 Bottom of Specimen 1F.1-153, the most dense -3,600 vpm frequency - internally vibrated (electrically driven).



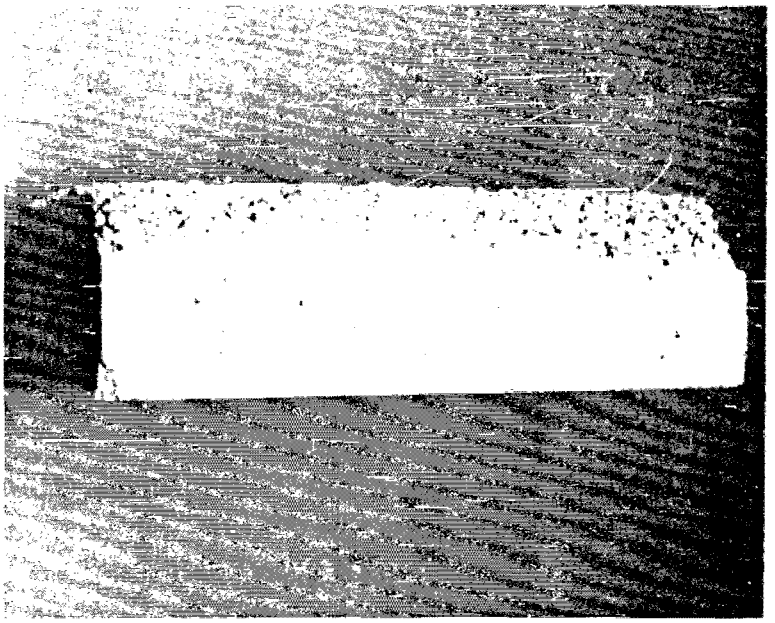
RF 2261-6

Fig. 48 Edge of Specimen 1F.1-153, the most dense -3,600 vpm frequency - internally vibrated (electrically driven).



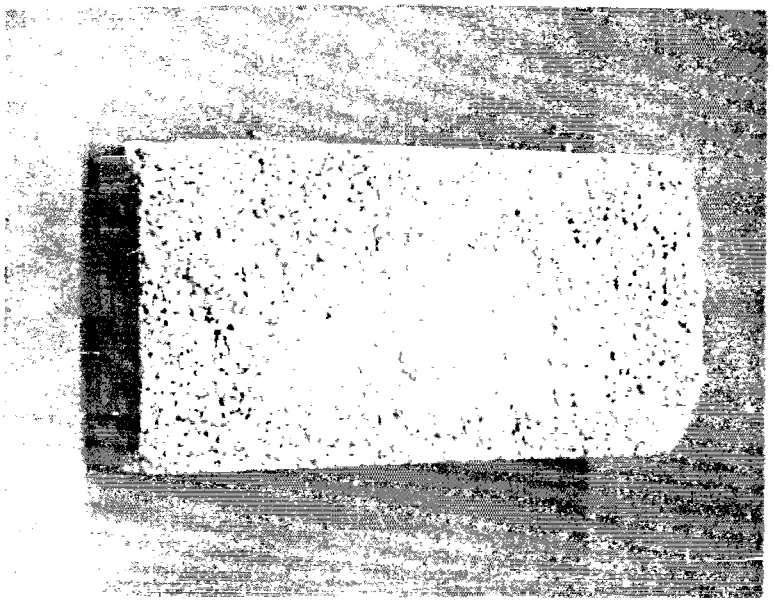
RF 2261-1

Fig. 49 Bottom of Specimen 1F.1-158, the least dense - 10,000 vpm frequency - internally vibrated (electrically driven).



RF 2261-9

Fig. 50 Edge of Specimen 1F.1-158, the least dense - 10,000 vpm frequency - internally vibrated (electrically driven).



RF 2260-3

Fig. 51 Top of Specimen 1F.1-158, note absence of fines between coarse aggregate - internally vibrated (electrically driven).

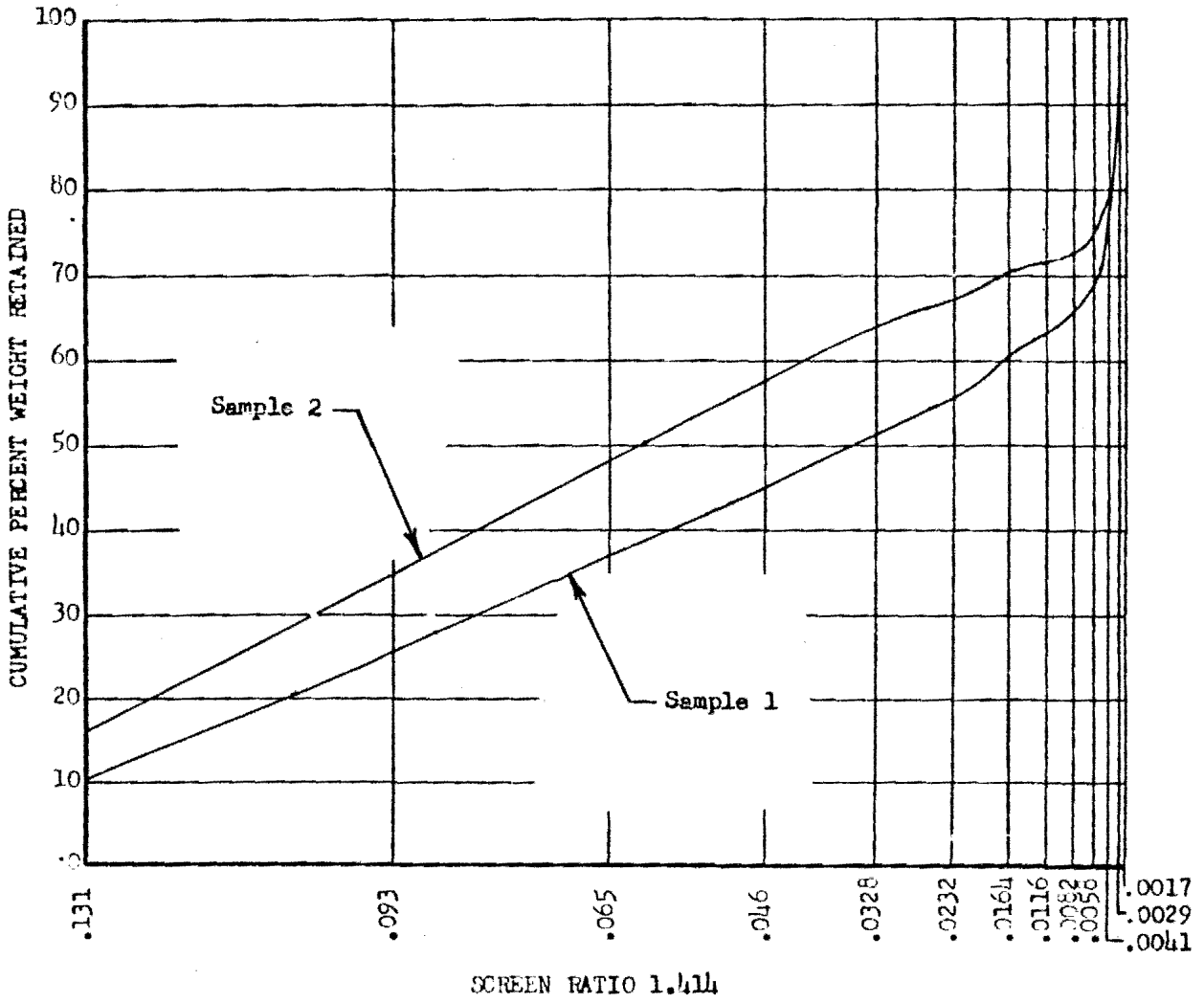
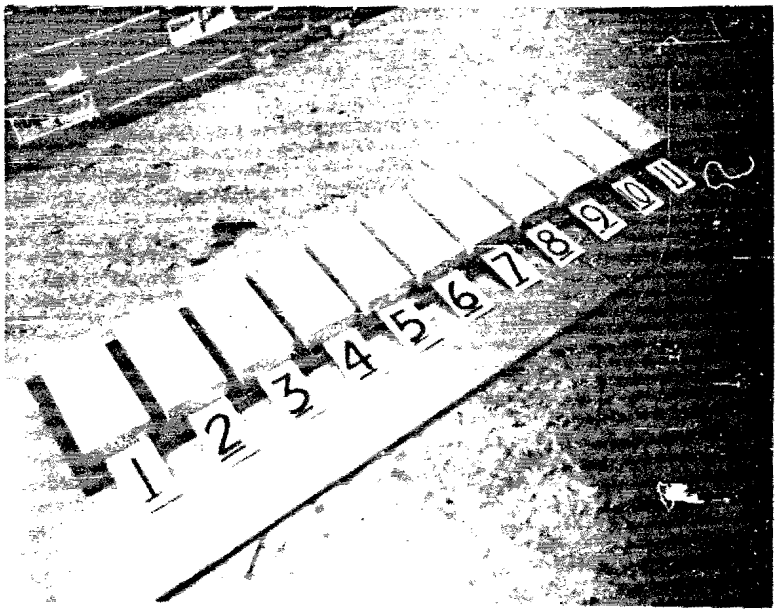
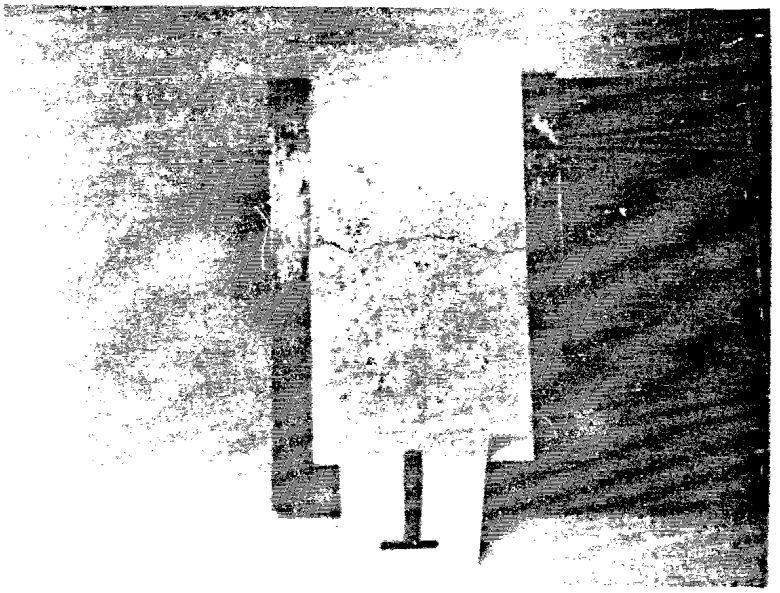


Fig. 52 Cumulative percent retained vs. mesh opening - Sample 1 used in external vibration study and Sample 2 in internal vibration study.



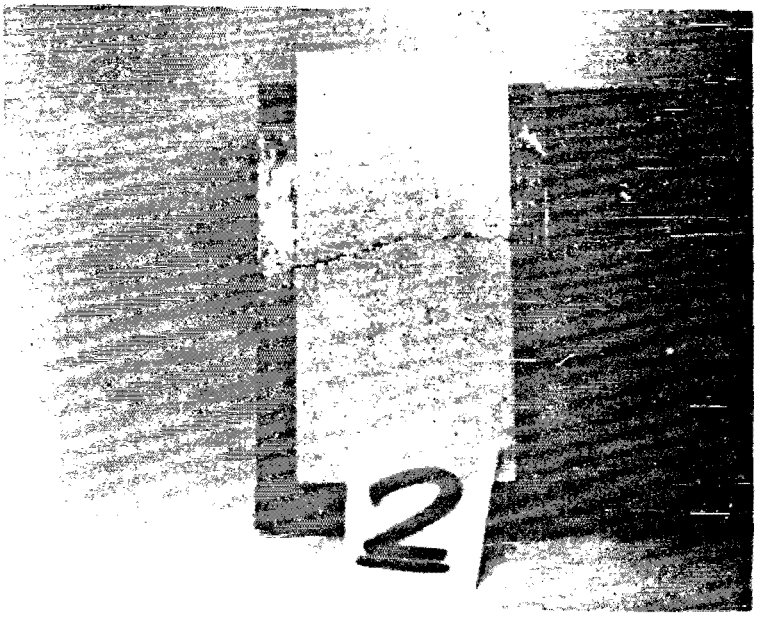
RF 2893-4

Fig. 53 Group photograph of Surface Finish Standards No. 1 thru 11.



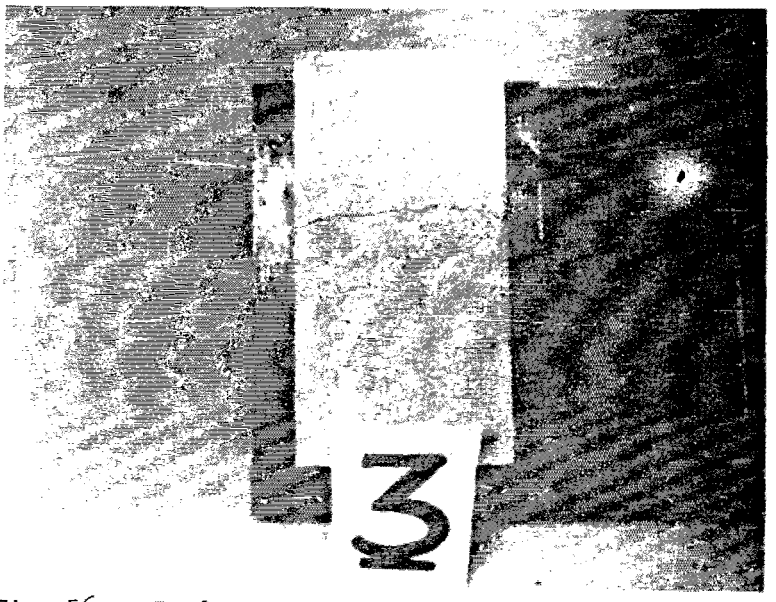
RF 2892-1

Fig. 54 Surface Finish Standard No. 1.



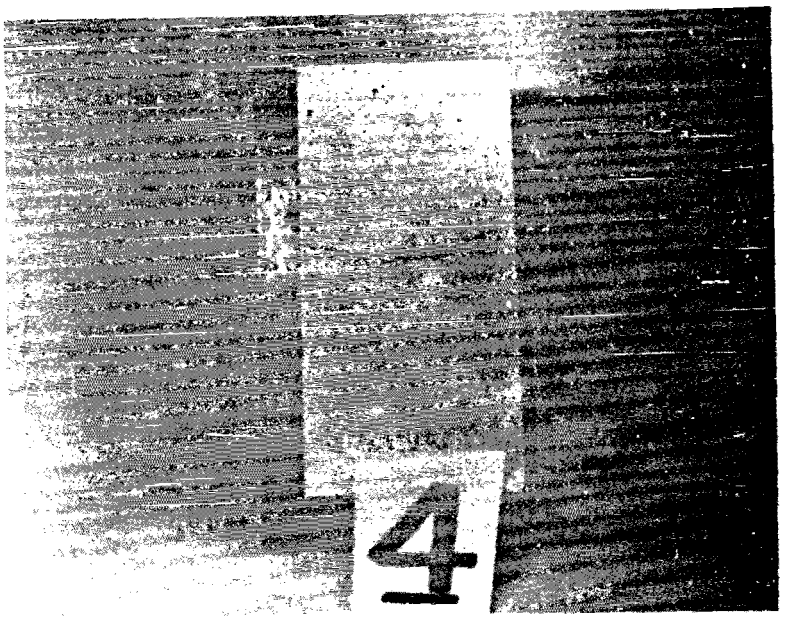
RF 2892-2

Fig. 55 Surface Finish Standard No. 2.



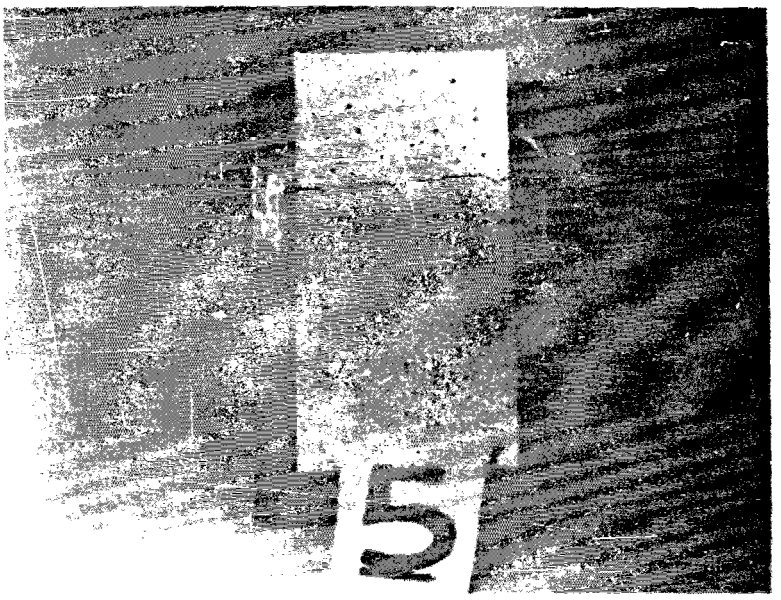
RF 2892-3

Fig. 56 Surface Finish Standard No. 3.



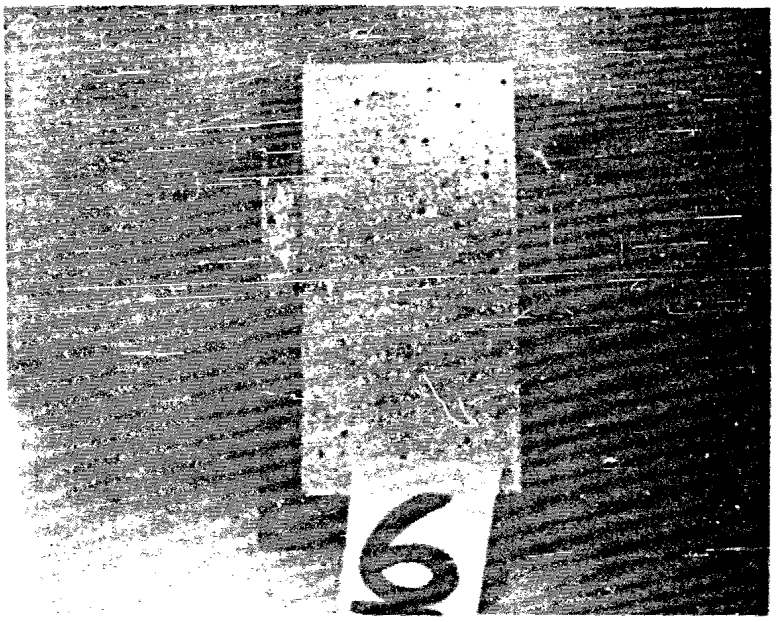
RF 2892-4

Fig. 57 Surface Finish Standard No. 4.



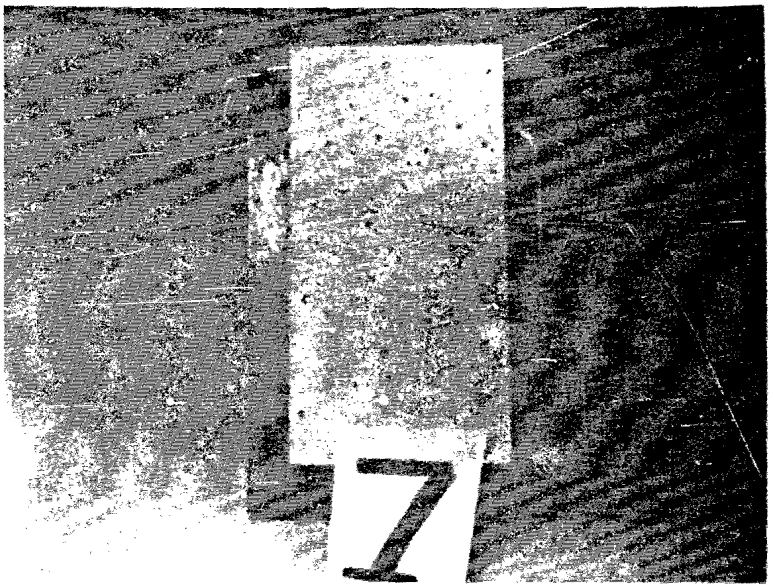
RF 2892-5

Fig. 58 Surface Finish Standard No. 5.



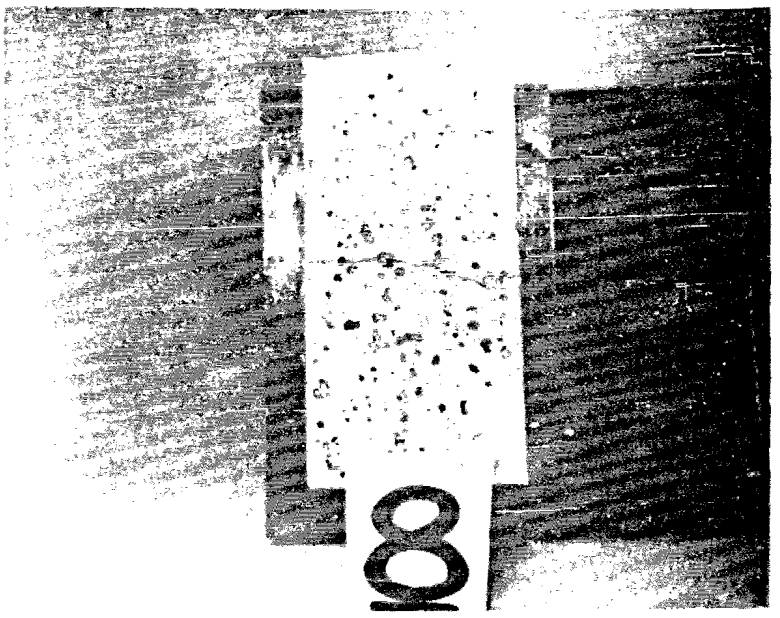
RF 2892-6

Fig. 59 Surface Finish Standard No. 6.



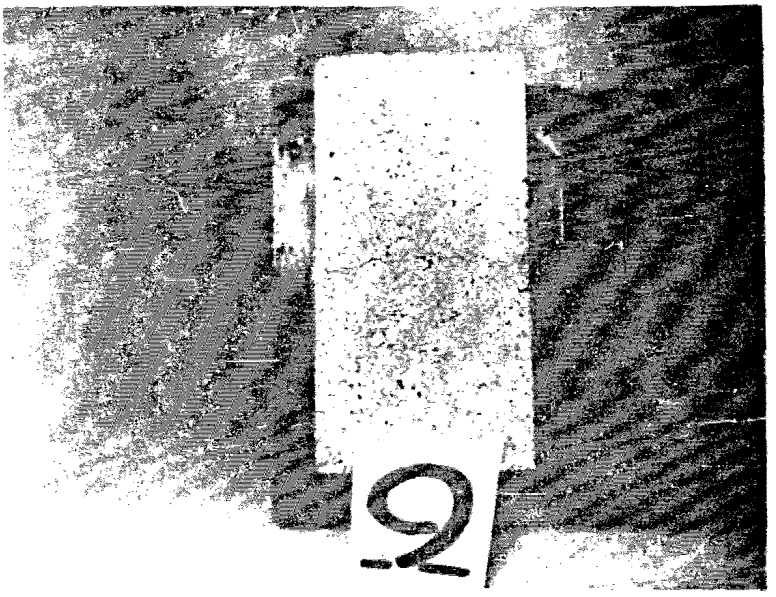
RF 2892-7

Fig. 60 Surface Finish Standard No. 7.



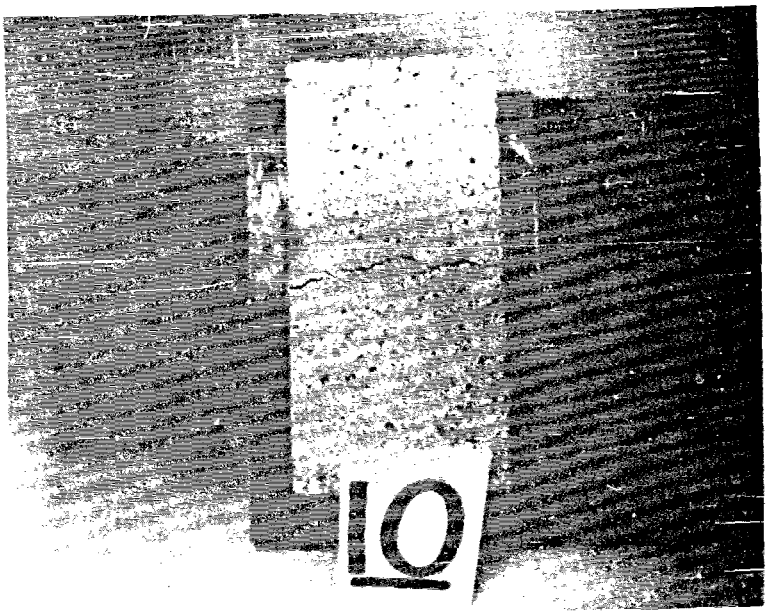
RF 2892-8

Fig. 61 Surface Finish Standard No. 8.



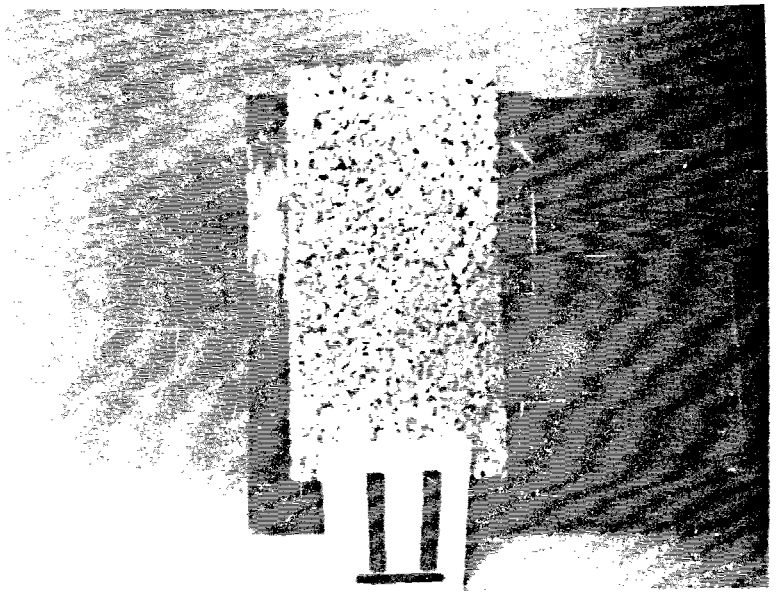
RF 2892-9

Fig. 62 Surface Finish Standard No. 9.



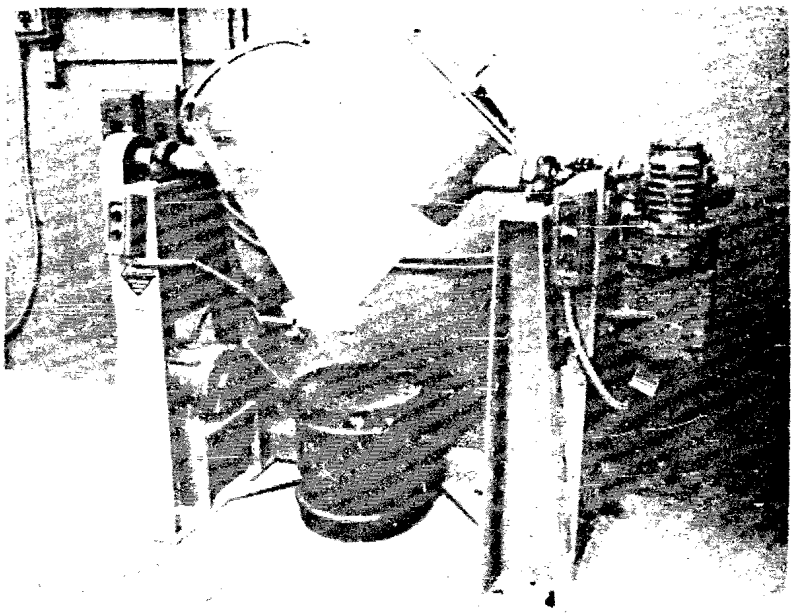
RF 2892-10

Fig. 63 Surface Finish Standard No. 10.



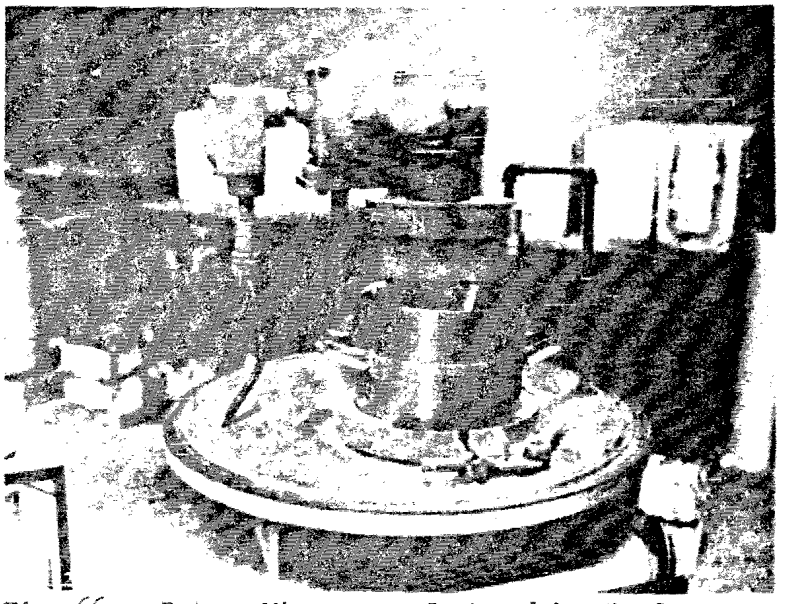
RF 2892-11

Fig. 64 Surface Finish Standard No. 11.



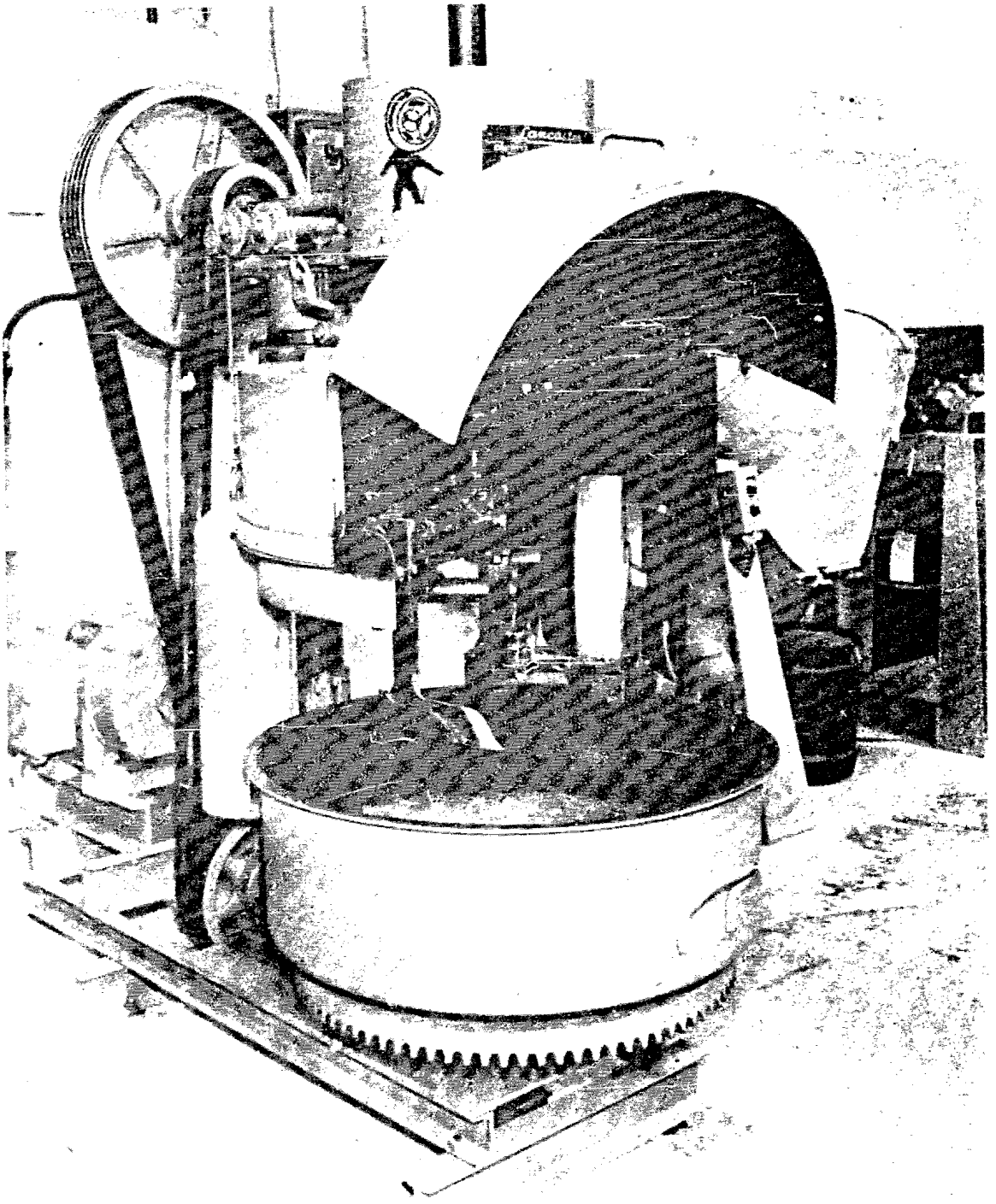
RF 2261-2

Fig. 65 Type DD, Twin shell Blender, manufactured by the Patterson-Kelley Company, East Stroudsburg, Pennsylvania.



RF 2893-9

Fig. 66 Rotary Mixer, manufactured by Charles Ross & Sons, Brooklyn, New York.



RF 2260-9

Fig. 67 Model #SKG, Mix-Muller, manufactured by Posey Iron Works, Incorporated, Lancaster, Pennsylvania.

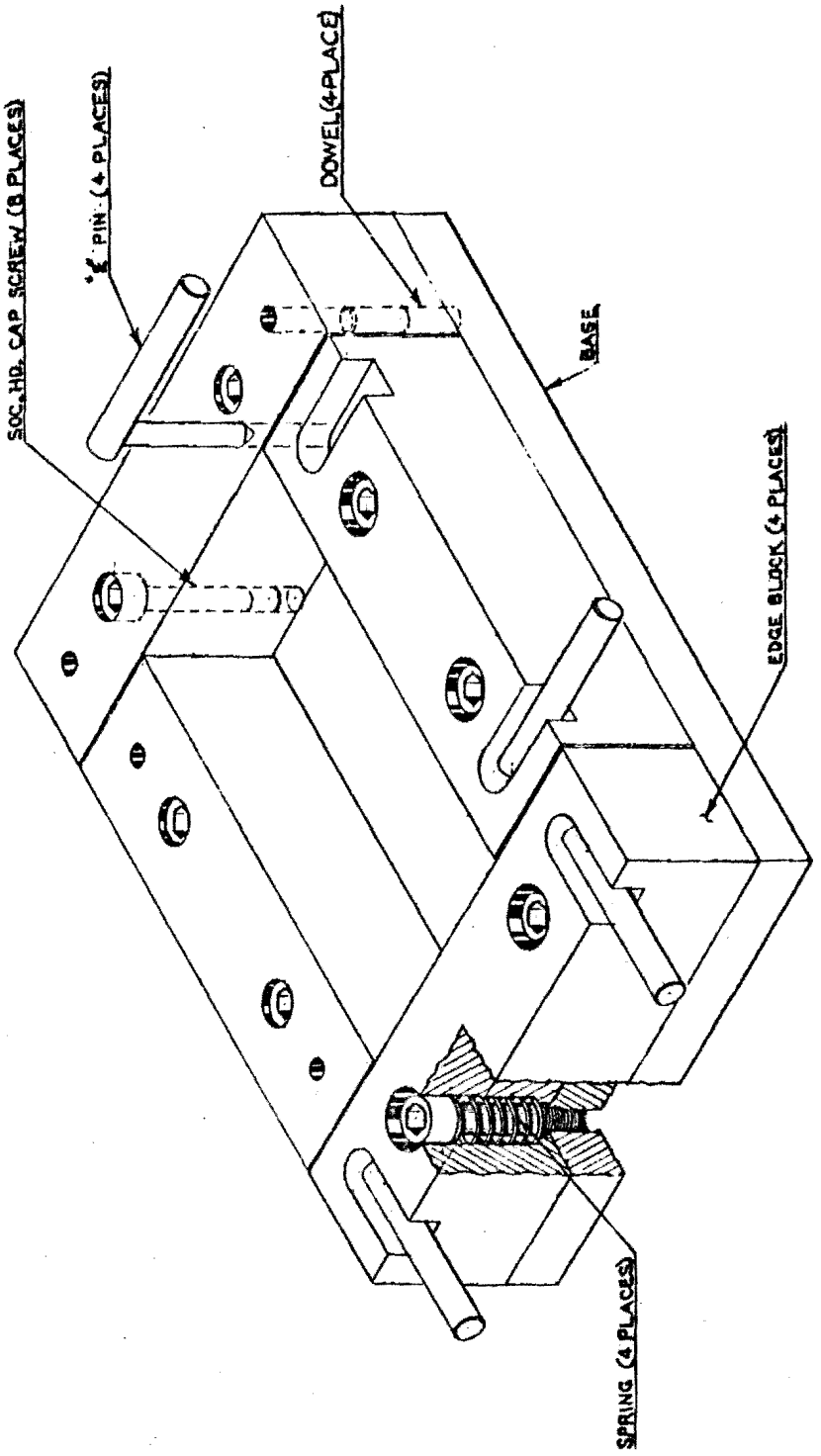
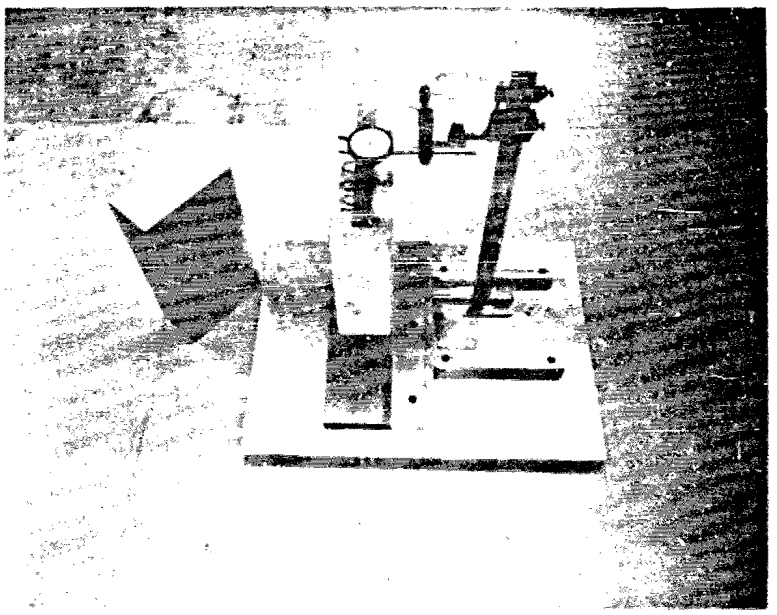
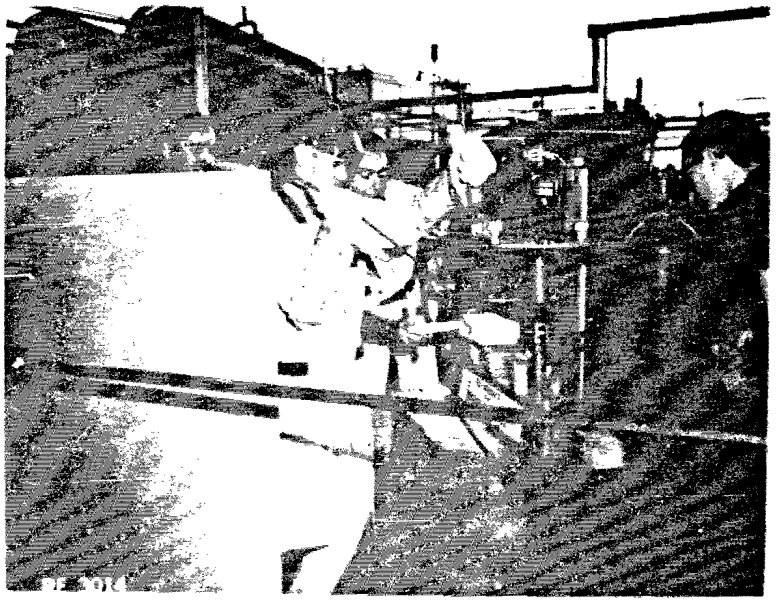


Fig. 68 Mold used for casting specimens other than those from slip.



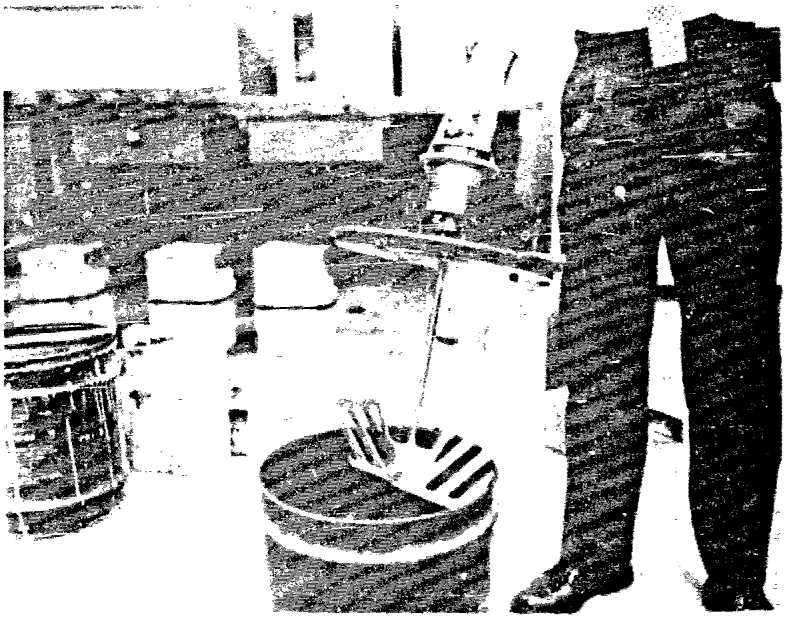
RF 2893-1

Fig. 69 Setup for measuring drying and firing size change showing standard (metal) brick on the left used to "0" adjust.



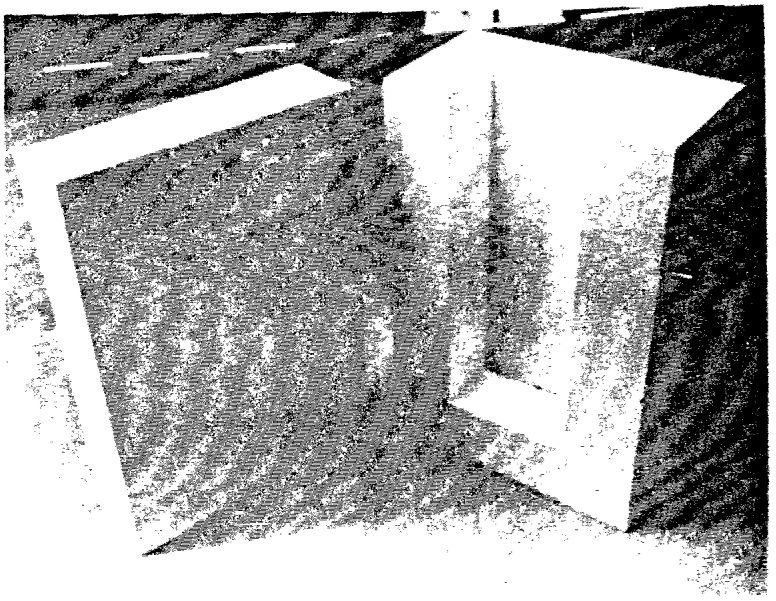
RF 3014

Fig. 70 2000 F modulus of rupture test.



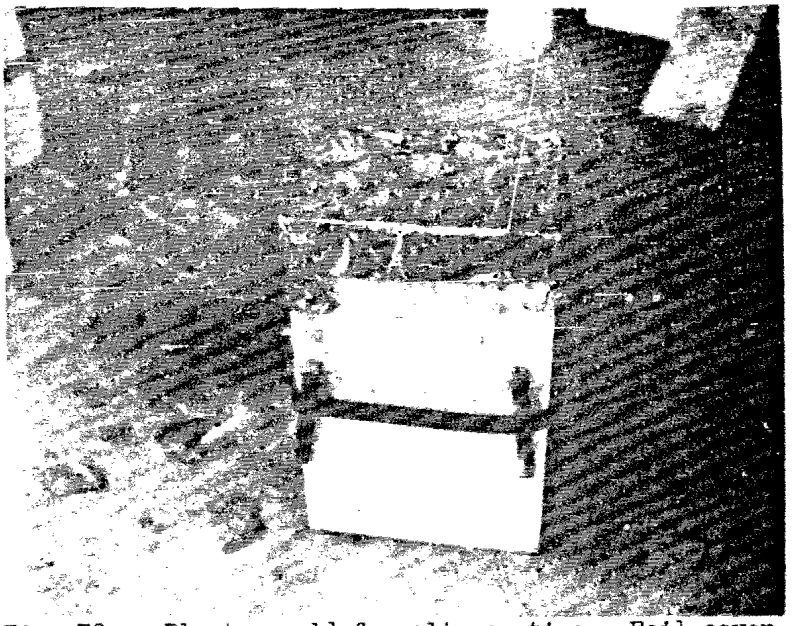
RF 2916-3

Fig. 71 Blunger for mixing slip.



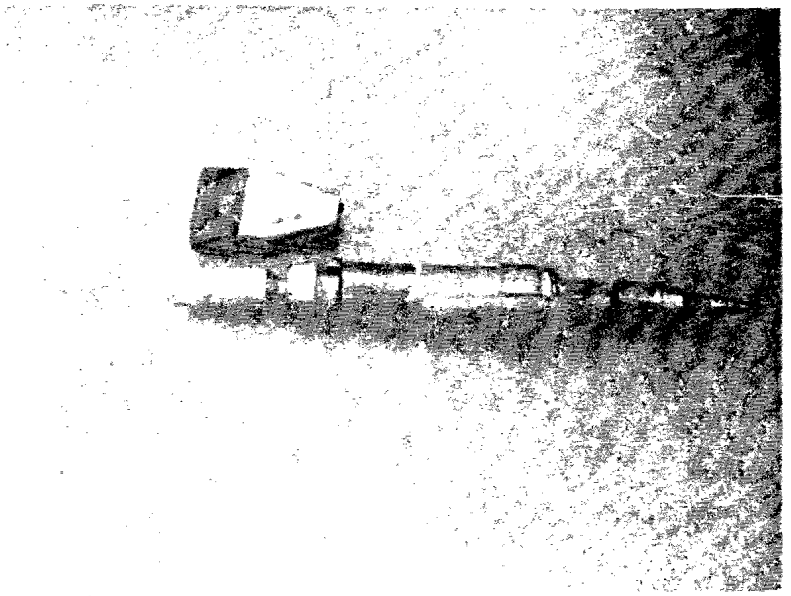
RF 2893-3

Fig. 72 Plaster mold for slip cast specimens.



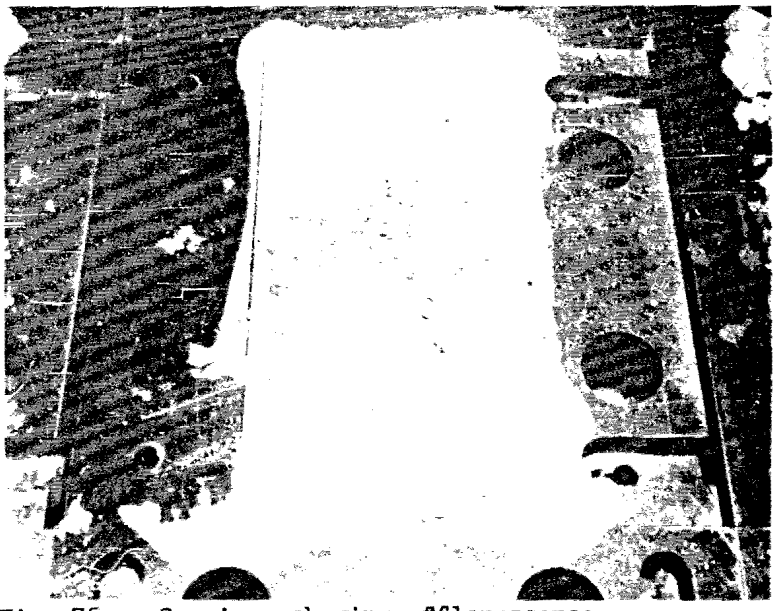
RF 2916-2

Fig. 73 Plaster mold for slip casting. Foil cover is replaced after pouring.



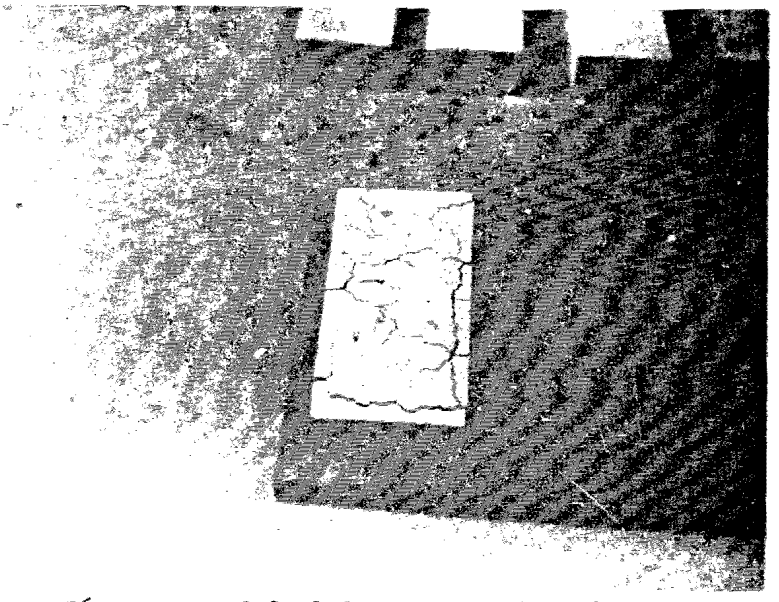
RF 2916-1

Fig. 74 Baby Rammer, manufactured by Master Pneumatic Tool Company, Inc., Catalog #M-210.



RF 2651-4

Fig. 75 Specimen showing efflorescence.



RF 2893-8

Fig. 76 Cracked 3A.1-9 Specimen after firing.

figure 77

COMPOSITE VALUE BAR GRAPH OF MATERIALS FOR UNFIRED TOOLS USED AT ROOM TEMPERATURE

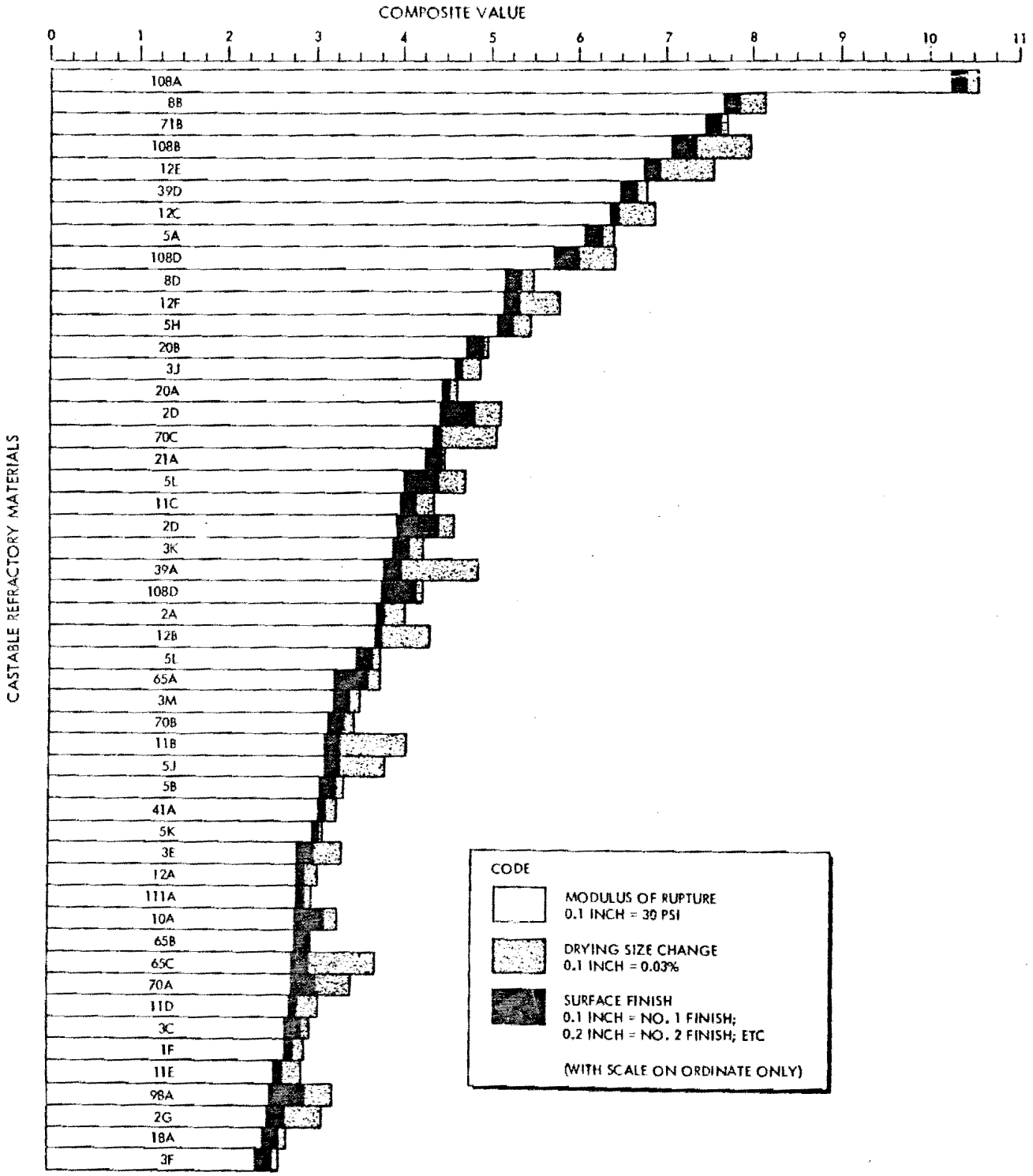
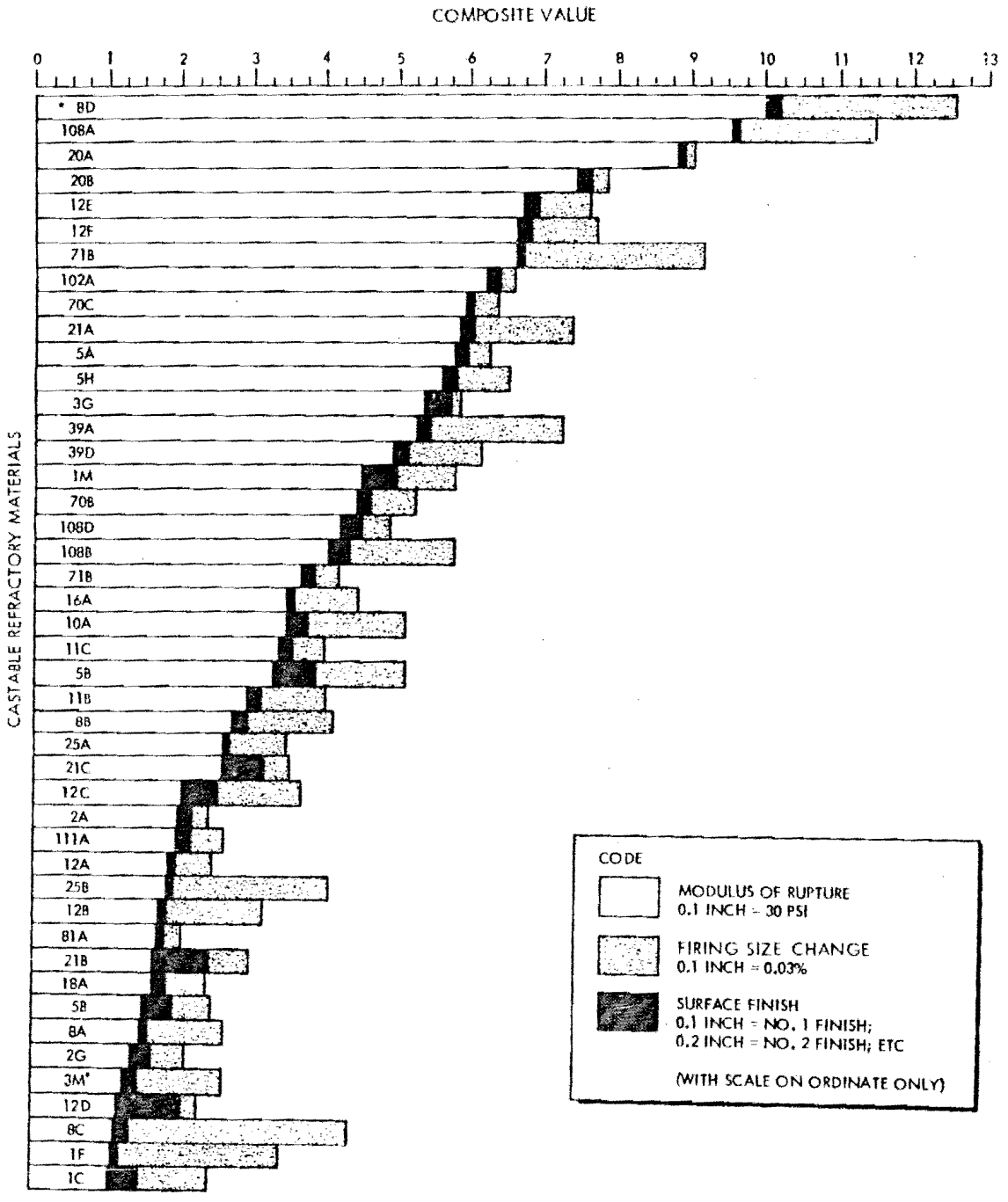


figure 78

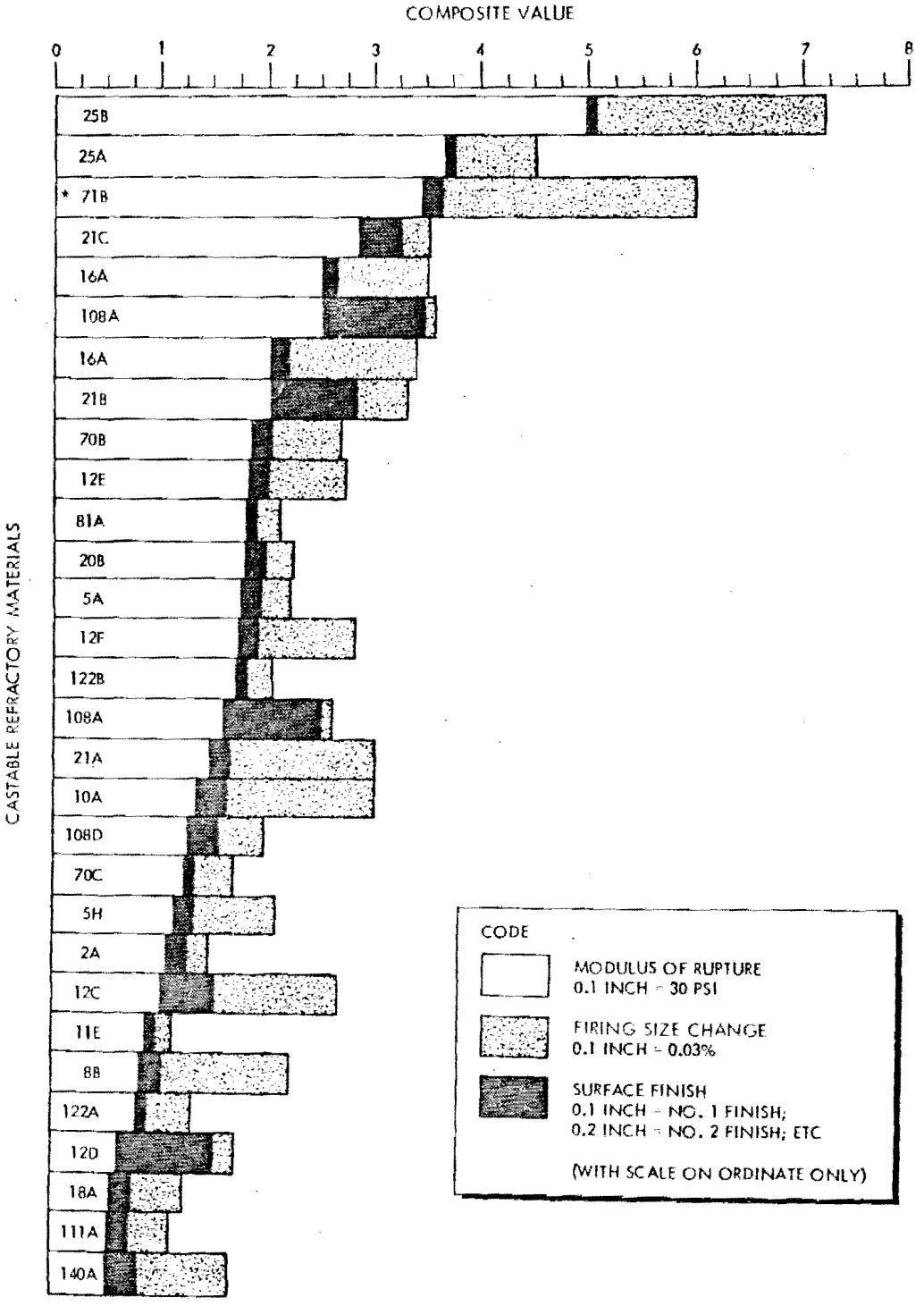
COMPOSITE VALUE BAR GRAPH OF MATERIALS FOR FIRED TOOLS USED AT ROOM TEMPERATURE



*MATERIAL TESTED TOO LATE (11-30-60) FOR COMPLETE EVALUATION

figure 79

COMPOSITE VALUE BAR GRAPH OF MATERIALS FOR FIRED TOOLS USED AT ELEVATED TEMPERATURE



*MATERIAL TESTED TOO LATE (11-30-60) FOR COMPLETE EVALUATION

figure 80

BAR GRAPH OF UNFIRED MATERIALS RANKED PER DRYING SIZE CHANGE

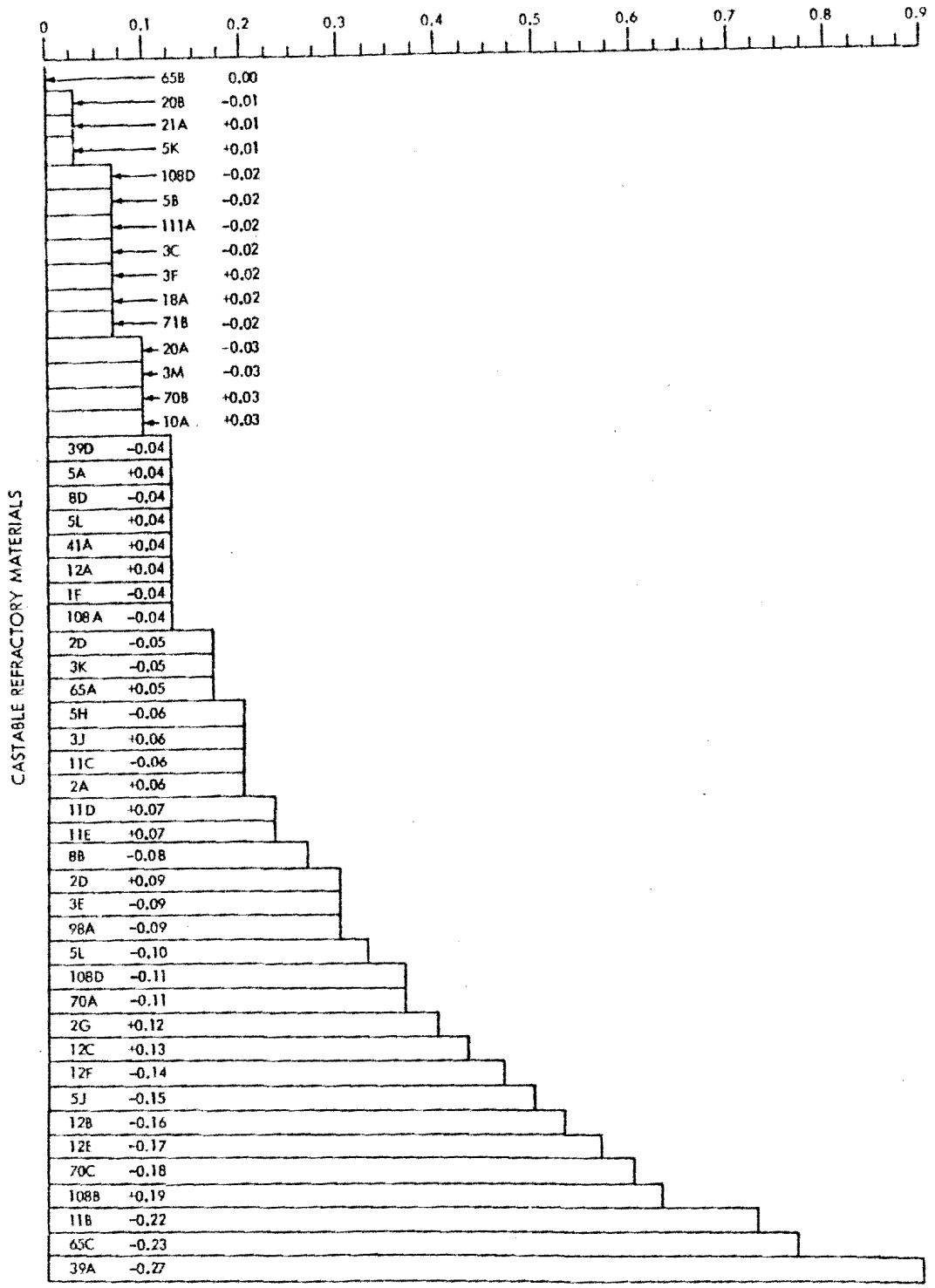


figure 81

BAR GRAPH OF FIRED MATERIALS RANKED PER FIRING SIZE CHANGE

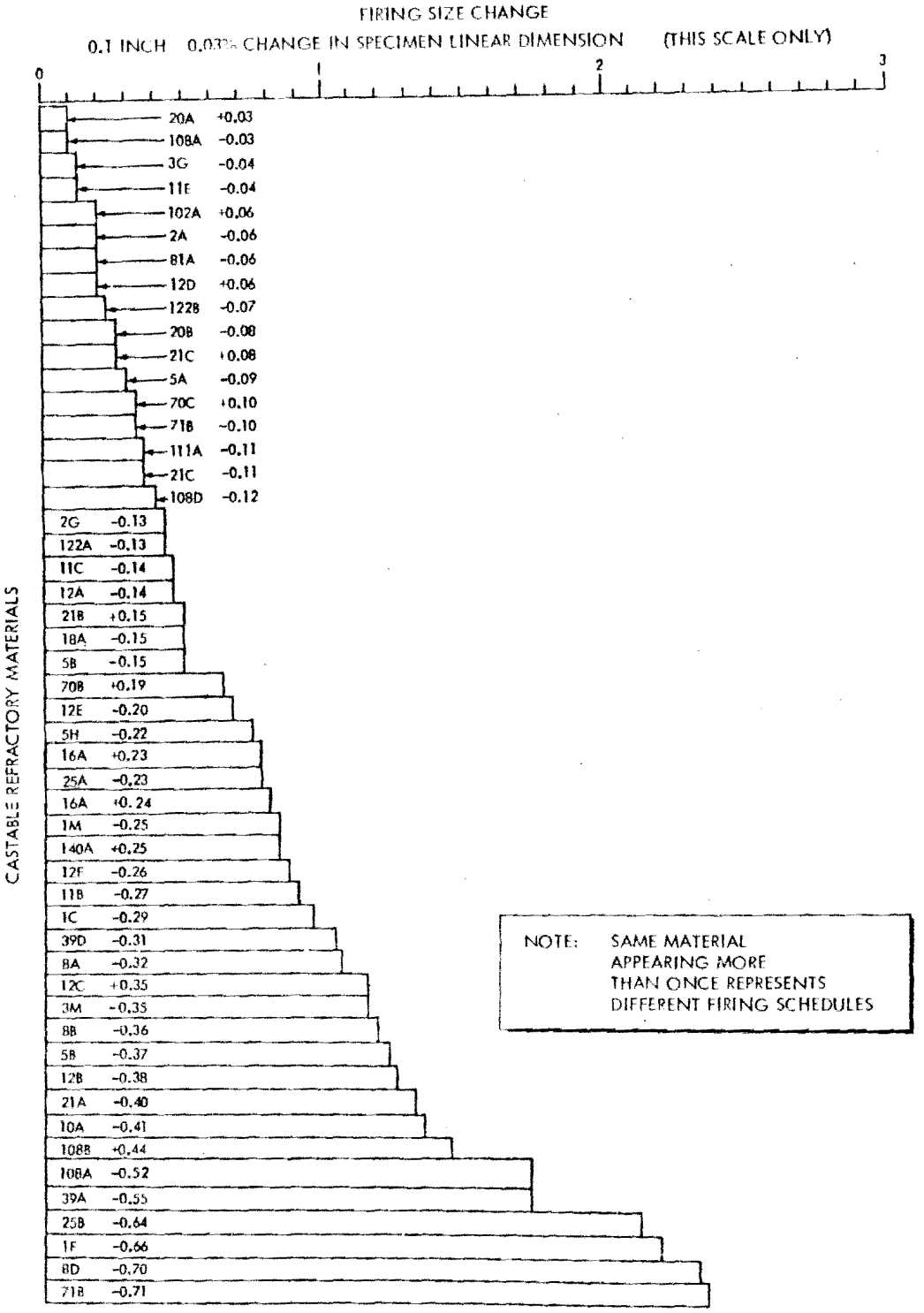


figure 82

BAR GRAPH OF MATERIALS RANKED PER SURFACE FINISH

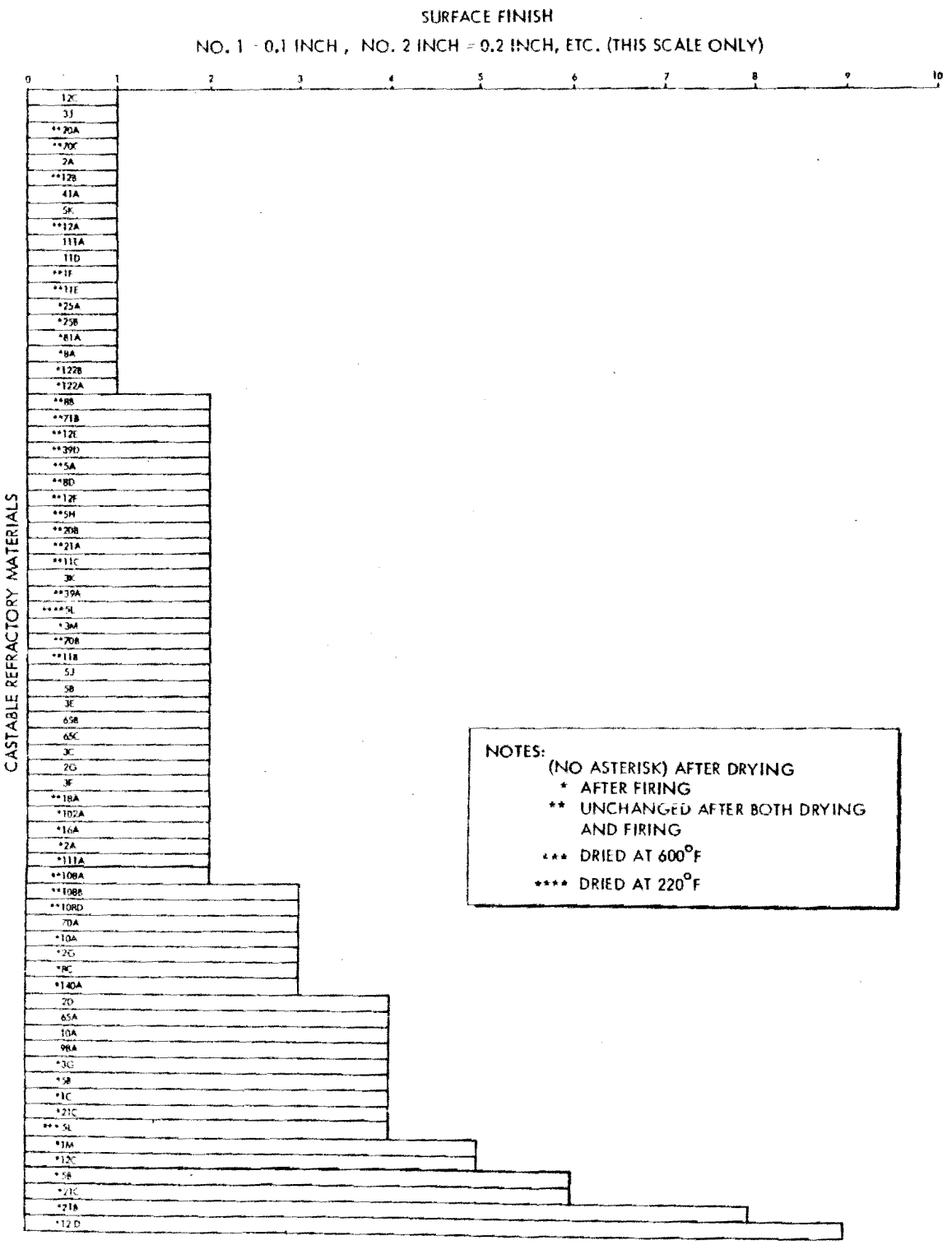


figure 83

BAR GRAPH OF UNFIRED MATERIALS RANKED PER RT MODULUS OF RUPTURE

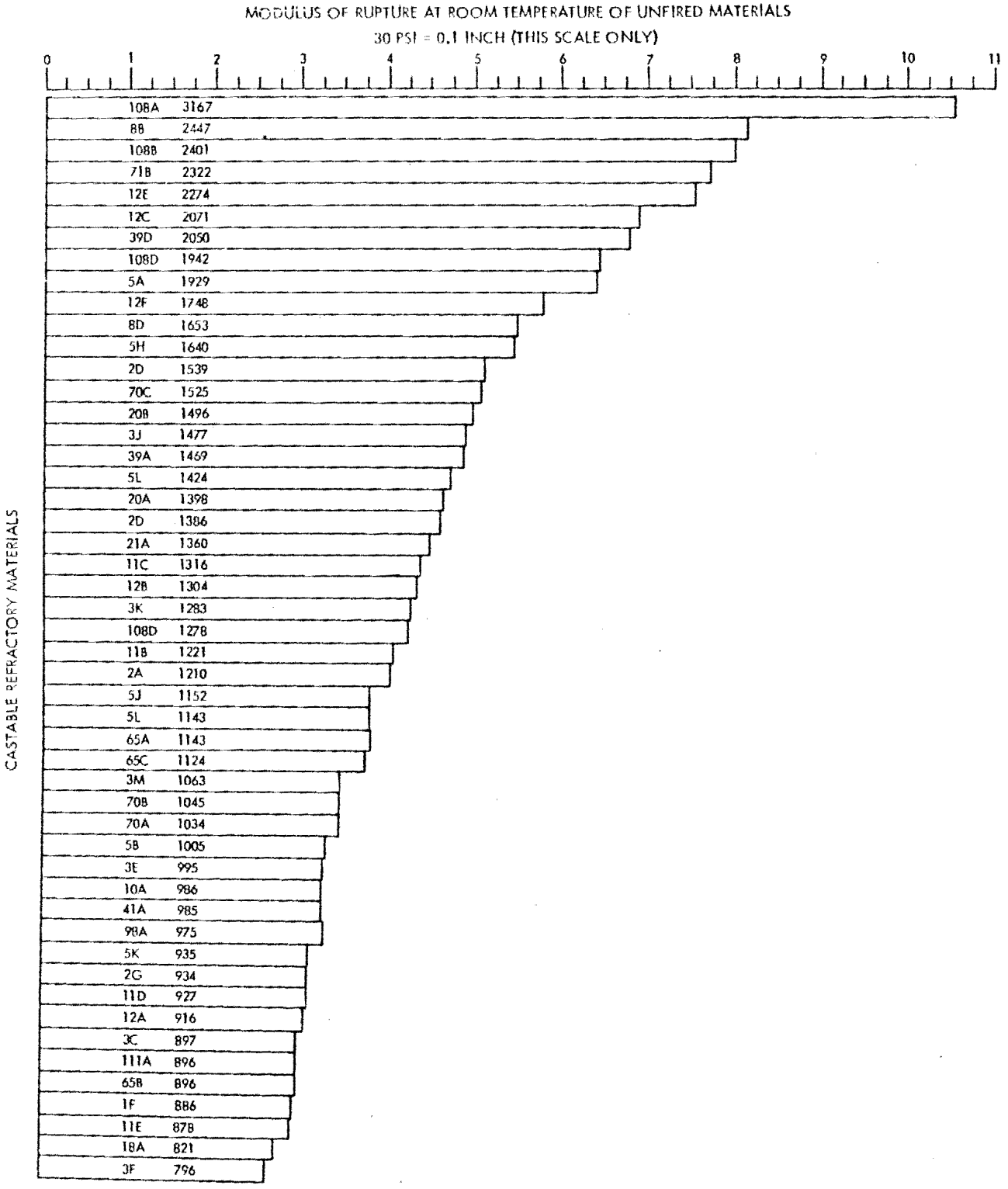


figure 84

BAR GRAPH OF FIRED MATERIALS RANKED PER RT MODULUS OF RUPTURE

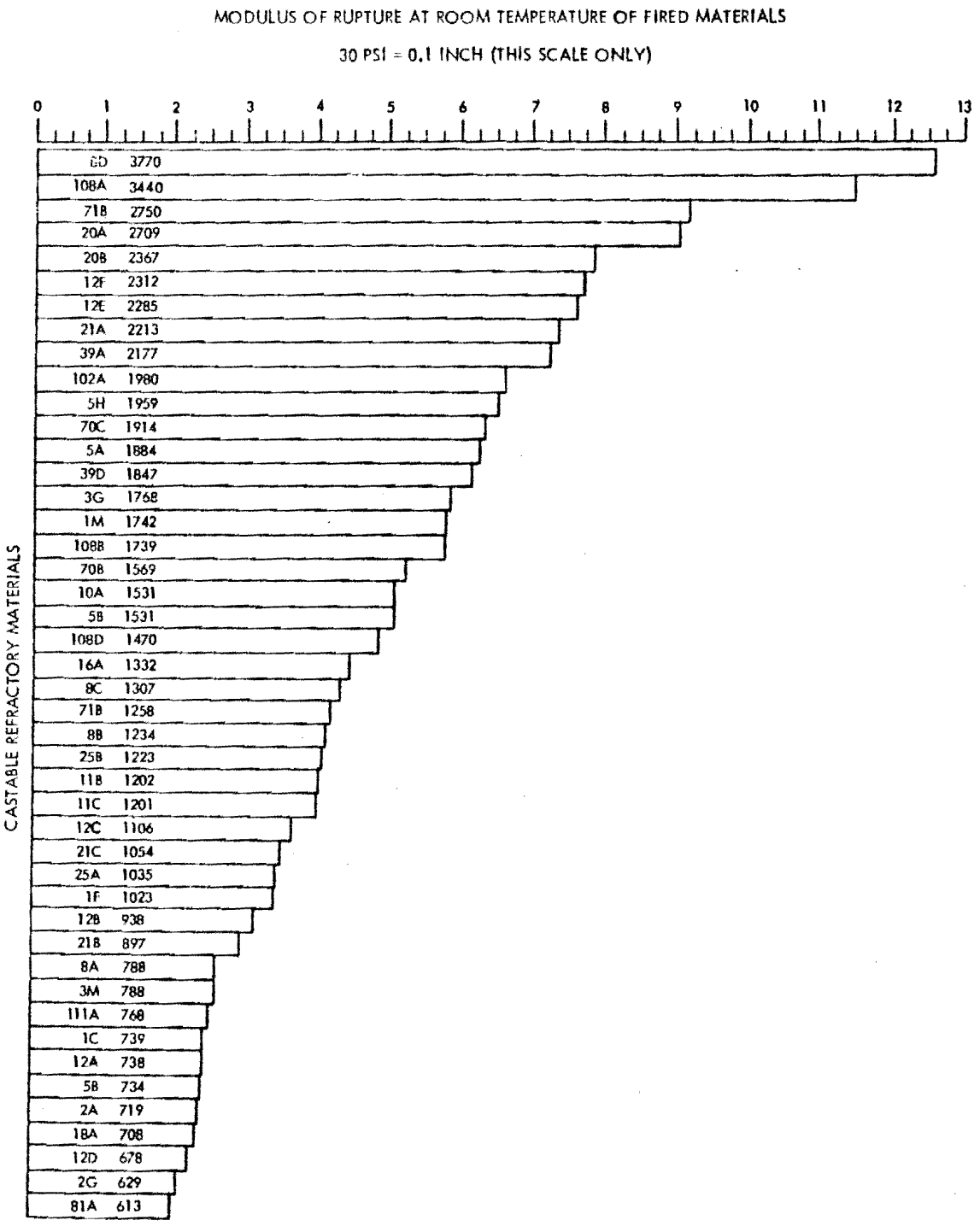


figure 85

BAR GRAPH OF FIRED MATERIALS RANKED PER 2000 F° MODULUS OF RUPTURE

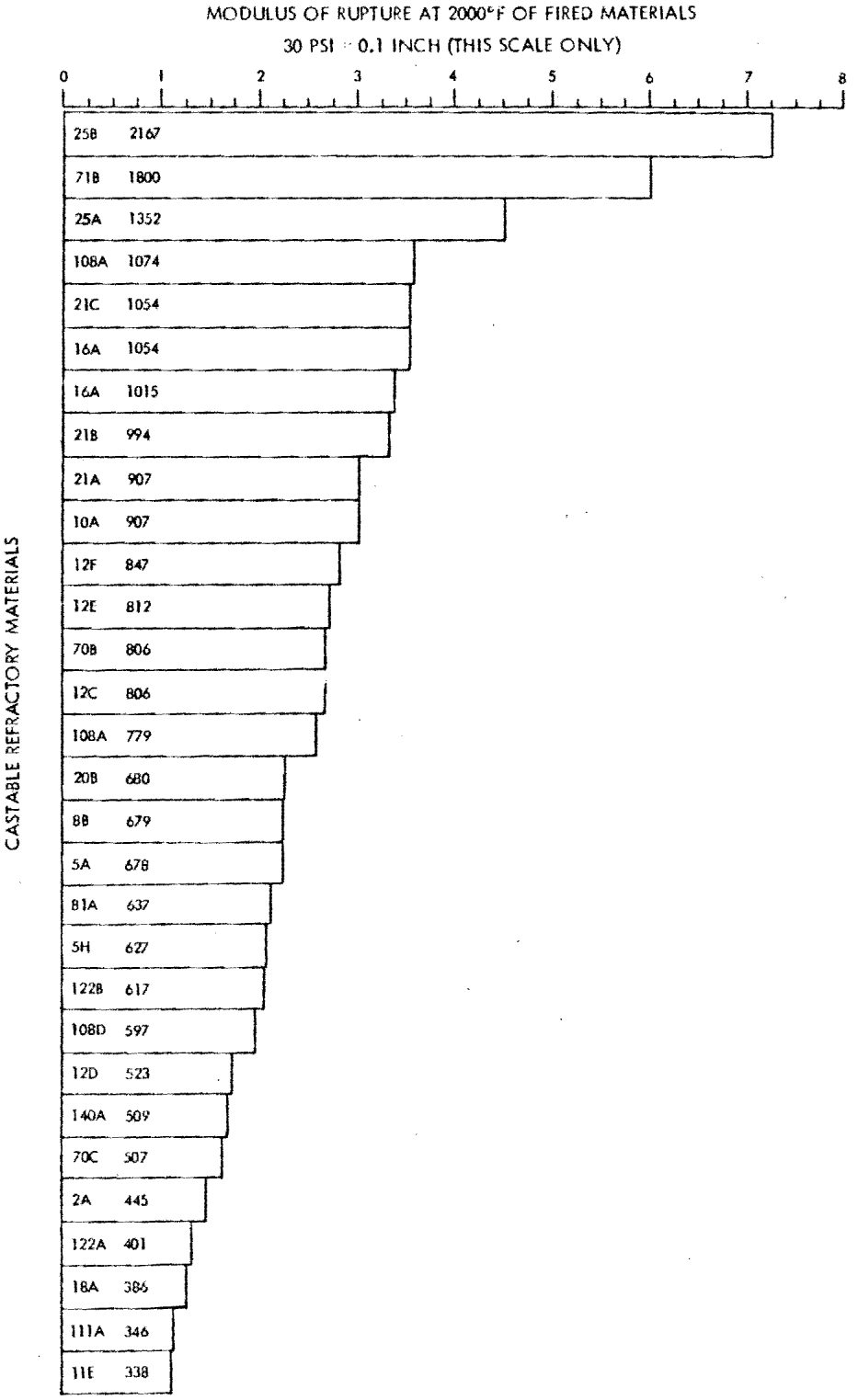


EXHIBIT 3

TARGET PROPERTIES FOR CASTABLE REFRACTORY TOOLING MATERIALS

The following target properties are set forth as a guide to the materials development subcontractor:

1. The castable (castables) are to have good thermal shock resistance as determined by repeated cooling from 2000 F to room temperature still air.

2. Have maximum linear room temperature drying size change of .2%.

3. Have maximum net linear size change after firing of .1%.

4. Sufficient strength to permit handling before firing. (This will require an estimated modulus of rupture of 200 psi, minimum.)

5. Have minimum strength of 1000 psi modulus of rupture tested at room temperature and at 2000 F. The 1000 psi strength figure is to apply to fired shapes only.

6. The material must be capable of casting with smooth as-cast surfaces, 60 R.M.S. maximum.

   Optional: 60 R.M.S. surface may be obtained by a glazing technique providing that glaze does not cause a detriment in other properties.

7. Material must be dimensionally stable at all operating temperatures between room and 2000 F.

8. Material must be capable of being cast and fired in massive sections as great as one cubic yard.

EXHIBIT 4

GEORGIA INSTITUTE OF TECHNOLOGY

FINAL REPORT

PROJECT NO. A-433

INTRODUCTION

Fused silica was used as the aggregate material in this project due to its excellent thermal shock properties. Such binders as aluminum phosphate, Portland cement, and Lumnite cement were evaluated in an effort to obtain a cold or low temperature cure.

Promising compositions developed were furnished to the Contractor for evaluation. See Table 15, Page 134, Basic Code 122, for results.

EXPERIMENTAL WORK

A. Dry Sieve Analysis of Aggregates

A dry sieve analysis was made to determine the grain size of the three monofractions of fused silica used for the experimental work. The three monofractions were -4 +20 mesh, -20 +50 mesh, and -100 +200 mesh. The screen analysis is listed in Table 6.

TABLE 1

SCREEN ANALYSIS OF FUSED SILICA AGGREGATE

U. S. Standard Screen No.	-4 + 20 Mesh Average Per Cent Retained on Screen	-20 +50 Mesh Average Per Cent Retained on Screen	-100 +200 Mesh Average Per Cent Retained on Screen
6	28.4		
12	68.1		
20	3.3	0.5	
30	0.2	9.9	
40		27.44	
50		38.67	
60		16.47	
100			0.62
140			22.99
200			48.27
230			17.87
Pan		7.02	10.20

B. Maximum Packing Density of Fused Silica Aggregates

A test was run to determine the maximum packing density of the three monofractions. Different percentages of the three monofractions were mixed and vibrated into a graduated cylinder. The three combinations with the highest density were used as standard aggregate mixtures for all experimental work. The results of this study are shown in Figure 1.

The following tabulation is the three combinations which were selected as standard aggregates and will be henceforth referred to as titled in the tabulation.

Aggregate No. 1	Aggregate No. 2	Aggregate No. 3
60% -4 +20 Mesh	50% -4 +20 Mesh	30% -4 +20 Mesh
10% -20 +50 Mesh	20% -20 +50 Mesh	40% -20 +50 Mesh
30% -100 +200 Mesh	30% -100 +200 Mesh	30% -100 +200 Mesh

C. Aggregates and Binders

Seven binders were investigated to bond the standard aggregates. Tests were run to determine the usefulness of the aggregate - binders for ceramic tooling. Among the properties tested were green and fired transverse strength, dry and fired shrinkage, per cent absorption, density, and thermal shock resistance.

Plaster molds were made to cast test samples for combinations containing fused silica slip. Two aluminum molds were made to cast cements and compositions not containing fused silica slip.

The seven binders investigated were fused silica slip, Hi-Early Portland Cement, Lumnite (calcium aluminate) cement, Kaolin (E.P.K.), Lead Monosilicate, Alkophos C, and Pennsalt Synar binders.

1. Fused Silica Slip. Test plates (4-inch x 4-inch x 1/2-inch) were made from each of the following tabulated fused silica aggregate - fused silica slip combinations using the three aggregate mixes listed in the Section B.

Fused Silica Slip (%)	Fused Silica Aggregate (%)
60	40
50	50
40	60
30	70

Three per cent water was added to the aggregate. The wetted aggregate was mixed with the slip in the described proportion, placed into Keltexed plaster molds and the molds were vibrated for 3 minutes. The samples were air dried, removed from the mold, dried at 230 F, and fired at 2000 F for two hours. Transverse strength (modulus of rupture) determinations are listed in Table 2 and the values are averages of five test specimens.

TABLE 2

FUSED SILICA SLIP - FUSED SILICA AGGREGATE MIXES

	Aggregate			Average Transverse Strength		
Fused Silica Slip (%)	No. 1 (%)	No. 2 (%)	No. 3 (%)	No. 1 (psi)	No. 2 (psi)	No. 3 (psi)
60	40	40	40	446	336	463
50	50	50	50	812	337	318
40	60	60	60	289	453	249
30	70	70	70	445	-	-

The specimens listed in Table 2 exhibited segregation of the aggregate and binder. The aggregate partially flowed to the bottom of the mold cavity leaving the binder concentrated in the upper section of the mold. This was especially true for those specimens that contained the greatest percentage of binder. As the binder was decreased the segregation of the binder and aggregate tended to decrease but the smoothness of the surface was decreased.

Attempts were made to eliminate the segregation or lamination and/or improve the surfaces of the fused silica slip-fused silica aggregate compositions by increasing the water addition to the dry aggregate. Six per cent and nine per cent water, based on the dry weight of the aggregate, was thoroughly mixed with the aggregate before the fused silica slip was added.

It was found that three per cent water addition to the dry aggregate produced specimens with poor surfaces and cross sections for the sixty and seventy per cent aggregate compositions; however, an increase in the water addition, six and nine per cent, improved both the surfaces and cross sections of these two compositions. It was observed that an increase of fused silica slip from forty to fifty to sixty per cent produced specimens with laminated cross sections.

Compositions listed above were fabricated into 4-inch x 4-inch x 1/2-inch samples and were subjected to thermal shock tests. The samples were cast, dried, and fired to 2000 F for 2 hours. The samples were again fired to 2000 F and remained at that temperature for one half hour. One half of the specimens were quenched in water at 80 F and the remaining half of the specimens were quenched in air. It was found that the compositions which had not laminated sustained both the water and air quench without failing; however, those specimens which were laminated exhibited surface cracks.

There was no measurable dried or fired linear shrinkage for the compositions prepared with the fused silica slip-fused silica aggregate.

2. Hi-Early Portland Cement. Test plates were fabricated using Hi-Early Portland cement and fused silica Aggregate No. 1. The dry aggregate and cement were mixed thoroughly and water was added to the mix until a workable consistency was obtained. The mix was placed into 4-inch x 4-inch x 1/2-inch waxed pasteboard boxes and vibrated for 3 minutes. The samples were kept damp by moistened towel coverings for 24 hours, dried for 24 hours in air, then dried for 24 hours at 230 F. The specimens were cut into 1/2-inch x 1/2-inch x 4-inch bars for transverse strength determinations. The results of this study are listed in Table 3.

TABLE 3

HI-EARLY PORTLAND CEMENT-FUSED SILICA AGGREGATE

Sample No.	Hi-Early Portland Cement (%)	Aggregate No. 1 (%)	H_2O (%)	Average Transverse Strength (psi)	Dry Linear Shrinkage (%)
1	38.5	33.6	27.9	421	9.1
2	29.3	51.1	19.6	649	9.1
3	17.9	62.7	19.4	425	5.4

Some segregation of fused silica aggregate and Hi-Early Portland cement occurred in all three samples with greater segregation occuring with Sample No. 1 than with the other two. Surfaces of Sample No. 2 and No. 3 were poor due to the settling of the aggregate during vibration.

Test plates (4-inch x 4-inch x 1/2-inch) were fired to 2000 F and held at this temperature for one half hour, then one half of the specimens were quenched in water at 80 F and the remaining half were quenched in air. The specimens quenched in water disintegrated and the air quenched specimens failed after standing 48 hours in air.

3. Lumnite Cement. Dry fused silica Aggregate No. 1 and Lumnite cement were mixed thoroughly and water was added to the mix until a workable consistency was obtained. The mix was placed into 4-inch x 4-inch x 1/2-inch waxed pasteboard boxes and vibrated for 3 minutes. The samples were kept damp by moistened towel coverings for 24 hours, dried in air for 24 hours, and dried at 230 F for 24 hours. The test plates were sawed into 1/2-inch x 4-inch x 1/2-inch wide segments for transverse strength measurements. The compositions and their corresponding transverse strengths of the fused silica aggregate - Lumnite cement mixes are listed in Table 4. The strength values are an average of five test specimens.

TABLE 4

LUMNITE CEMENT-FUSED SILICA AGGREGATE

Sample No.	Lumnite Cement (%)	Aggregate No. 1 (%)	Water (%)	Average Transverse Strength (psi)	Dry Linear Shrinkage (%)
1	44.9	33.6	21.4	420	0.0
2	31.5	47.1	21.4	378	0.0
3	19.7	58.9	21.4	319	0.0

NOTE: The density of Lumnite cement used was 3.67 gm/cc

Test plates 4-inch x 4-inch x 1/2-inch were fabricated, as above, for thermal shock resistance studies. The specimens were allowed to reach 2000 F and held at this temperature for one half hour, then one half of the specimens were quenched in water at 80 F and the remaining half of the specimens were quenched in air. These specimens sustained both the water and air quench without failing.

Smooth surfaces (Number 1) were obtained by casting the samples in the aluminum molds and curing the same as described previously. The samples were easily handled and there was no problem with shrinkage.

4. Kaolin. Fused Silica Aggregate No. 1 and Kaolin were mixed thoroughly and enough water was added to obtain desired workability. The mixture was poured into plaster molds 4-inch x 4-inch x 1/2-inch in size. The molds had previously been Keltexed with a 0.2% Keltex solution. The Keltex solution was poured into the molds and allowed to stand for two minutes, then it was

poured out, and then the mixture of Kaolin - fused silica Aggregate No. 1 mix was troweled into the molds and vibrated for 3 minutes. The samples were allowed to remain in the molds overnight and were removed from the molds and dried in air for 24 hours. The samples were then dried at 230 F for 24 hours. Dry shrinkage measurements were made, and the samples were fired for two hours at 2000 F. (Samples were placed in kiln at room temperature and gradually brought up to 2000 F). Test bars 1/2-inch x 1/2-inch x 4-inch for transverse strength determinations were made. Listed in Table 5 are the results of this study.

TABLE 5

KAOLIN - FUSED SILICA AGGREGATE MIX

Sample No.	Kaolin (%)	Aggregate No. 1 (%)	Water (%)	Average Transverse Strengths (psi)	Dry Linear Shrinkage (%)	Fired Linear Shrinkage (%)
1	33.7	35.8	30.5	390	20.8	23.4
2	23.5	49.9	26.6	498	11.7	15.0
3	14.8	62.7	22.5	283	-	-

NOTE: The density of Kaolin used was 2.58 gm/cc.

Test plates 4-inch x 4-inch x 1/2-inch were fabricated for thermal shock resistance studies. These plates were fabricated as previously described. The plates were allowed to reach a temperature of 2000 F and held at this temperature for one half hour. One half of the samples were air quenched while the remaining half were water quenched to 80 F. These compositions sustained both the water and air quench without failing.

Very poor surfaces were obtained using the Kaolin - fused silica aggregate compositions. The shrinkage was hard to control causing difficulty in fabrication of the samples.

5. Lead Monosilicate. Test plates were fabricated using Lead Monosilicate and fused silica Aggregate No. 1. Table 6 lists the compositions that were studied.

TABLE 6

LEAD MONOSILICATE - FUSED SILICA AGGREGATE

Sample No.	Lead Monosilicate (%)	Fused Silica Aggregate No. 1 (%)	Water (%)
1	63.7	26.0	10.3
2	50.3	41.1	8.6
3	33.8	55.1	11.1

NOTE: The density of lead silicate used was 5.6 gm/cc.

Fused silica Aggregate No. 1 was mixed in a gallon jar, with a board 6-inch x 2-inch x 1/2-inch as a mixing aid, until homogeneous. Three per cent (3%) water by weight of dry aggregate was added during mixing to pre-wet the aggregate. Lead Monosilicate was added to the aggregate-water, mixed, and rolled on a ball mill roller until a homogeneous mixture was obtained. Enough water was added to the mixture until a workable body was obtained. The body was then poured into previously Keltexed and graphited molds and dried overnight at room temperature.

After drying, the samples were too weak to be handled. The shrinkage of the samples was high causing the samples to crack in the molds while drying. No tests or measurements were possible due to this inability to fabricate the samples successfully.

6. Alkophos C. Preliminary studies of this binder indicated that the set and drying time were greatly reduced by diluting with water. That is, the drying time was reduced from 96 hours to 18 hours by the addition of 3.5 per cent to 11.5 per cent water to the Alkophos C solution.

The general procedure developed for the Alkophos C fused silica aggregate was to add the aggregate to the Alkophos C solution and vibrate until aggregate was thoroughly wetted. The mix was then poured into aluminum molds, dried in the molds at 230 F for 18 hours, removed from the molds and further dried at 550 F for a minimum of four hours, then fired slowly to 1000 F for one hour and then to a final temperature of 2000 F for minimum of one hour. Transverse strength of both the green (dried at 550 F) and fired (fired at 2000 F) specimens of this mix was determined and the results are listed in Table 7 and are numbered as compositions A-1, A-2, and A-3. Thermal shock was determined on the 2000 F fired specimens and all withstood a thermal quench into water from 2000 F to 80 F.

EXHIBIT 4

TABLE 7

ALKOPHOS C - FUSED SILICA AGGREGATE

Composition No.	Alkophos C	H_2O	Fused Silica Slip	Aggregate No. 1	Average Transverse Strength	
					Green	Fired
	(%)	(%)	(%)	(%)	(psi)	(psi)
A-1	17.4	3.9	-	78.7	198	493
A-2	11.8	8.0	-	80.2	160	958
A-3	6.0	12.3	-	81.7	519	1012
AS-1	15.5	1.9	19.2	63.4	496	967
AS-2	11.1	2.2	12.6	74.1	857	827
AS-3	16.2	1.9	20.0	61.9	-	-

NOTE: The density of Alkophos C was 1.47 gm/cc.

The density of the slip was 1.82 gm/cc.

This mix produced cast specimens which exhibited surface voids. The voids were eliminated and a smooth surface was produced by the addition and partial substitution of the water with fused silica slip. These new mixes are also listed in Table 7 and the resulting samples are numbered AS-1, AS-2, and AS-3. Thermal shock was also determined on the 2000 F fired specimen and all withstood a thermal quench into water from 2000 F to 80 F.

A study was made to determine the effect of various firing temperatures on the transverse strength, per cent absorption, and density of Alkophos C-slip - aggregate bodies. Composition AS-1 was used to fabricate the test specimens and the results of this study are listed in Table 8.

TABLE 8

EFFECT OF FIRING TEMPERATURE - TIME ON THE STRENGTH, ABSORPTION AND DENSITY OF ALKOPHOS C - FUSED SILICA AGGREGATE COMPOSITION AS-1

Time and Temperature	Transverse Strength (psi)	Per Cent Absorption (%)	Density (gm/cc)
18 hrs. at 230 F	568	reverted	1.62
4 hrs. at 550 F	594	14.7	1.63
4 hrs. at 800 F	557	15.0	1.66
4 hrs. at 1000 F	730	17.3	1.66
4 hrs. at 1800 F	663	15.6	1.68
4 hrs. at 2000 F	649	15.3	1.68

NOTE: (1) Transverse strengths are averages of 10 bars.

(2) Per cent absorption measurements are averages of 5 bars.

(3) Density measurements are averages of 3 bars.

The per cent linear firing shrinkage for composition AS-1 fired to 2000 F and held at this temperature for 2 hours was 0.19.

Thermal shock resistance was also determined for composition AS-1. The test specimens were water quenched from 2000 F to 80 F. Table 9 lists the results of the thermal shock resistance with the number of quench cycles.

EXHIBIT 4

TABLE 9

EFFECT OF THERMAL QUENCH ON ALKOPHOS C - FUSED SILICA AGGREGATE COMPOSITION AS-1

No. of Thermal Quenches from 2000°F to 80°F	Firing Time at 2000°F in Hours							
	1/2	1	2	3	4	7	16	24
1	G	G	G	G	G	G	G	G
2	G	G	G	G	G	G	G	G
3	G	G	G	G	G	G	G	G
4	CBD	G	G	G	G	G	G	G
5	G	G	BD	G	G	G	G	G
6	G	G	G	G	G	G	G	G
7	C	G	C	G	G	G	G	G
8	C	CBD	S	G	G	G	G	G
9	C	G	-	G	G	G	G	G
10	S	C	-	CBD	G	G	G	G

NOTE: G - Condition good

S - Shattered

C - Cracked but strong

CB - Corner broken

CBD - Corner broken after drying

BD - Broken (other than corner) after drying

Round 3/4-inch test bars were cast in Keltexed plaster molds from composition AS-1. The test bars were dried and fired by the standard procedure established for Alkophos C compositions. The bars were then fired at 2000 F and held at temperature for increasing periods of time. The purpose being to determine the effect of heating time on the growth of crystobalite in this composition and the resulting strength, both air and water quench from 2000 F to 80 F. Both absorption and density were determined for each of the firing periods. Table 10 lists the transverse strengths, absorption and density results of this study.

TABLE 10

EFFECT OF FIRING TIME ON THE TRANSVERSE STRENGTH, ABSORPTION AND DENSITY OF COMPOSITION AS-1

Firing Time at 2000 F (hr.)	Transverse Strength After Air Quench (psi)	Transverse Strength After Water Quench (psi)	Per Cent Absorption (%)	Density (gm/cc)
1/2	605	536	14.2	1.62
1	590	535	14.2	1.73
2	479	542	15.5	1.77
3	813	463	15.7	1.64
4	649	523	15.3	1.69
7	672	383	20.6	1.62
16	641	424	13.0	1.61
24	275	344	14.2	1.63

Figure 2, Page 215, indicates the per cent crystobalite formed in composition AS-1 with increasing time at 2000 F. The effect of increasing crystobalite on the transverse strength is also indicated. The transverse strength apparently peaks at the 7 hour firing and at 32.5 per cent crystobalite. The deviation for the 2 and 3 hour firing is too large to be acceptable.

It was observed that the fused silica Aggregate No. 1 - Alkophos C - fused silica slip compositions tended to produce warped test plates whenever the test plates were fired above 1000 F. A successful attempt to eliminate this warping was accomplished by changing the particle size distribution of

the fused silica Aggregate No. 1 and reducing the quantity of the fused silica slip and Alkophos C solution. This new composition is compared with the old composition in the tabulation below. It should be noted that the new aggregate is designated as fused silica Aggregate No. 4.

	-4 +20 Mesh (%)	-20 +50 Mesh (%)	-100 +200 Mesh (%)
Aggregate No. 1	60	10	30
Aggregate No. 4	70	10	20

	New Composition AS-4 (%)	Old Composition AS-1 (%)
Aggregate No. 1	-	63.4
Aggregate No. 4	69.4	-
Alkophos C	12.7	15.5
Fused Silica Slip	15.8	19.2
Water	2.1	1.9

Test plates of the new composition did not exhibit any warping after being fired to 2000 F for one hour and then water quenched to 80 F.

7. Pennsalt Synar Binder. Test samples were fabricated using Pennsalt Synar binders, Pennsalt Activator 23, and Pennsalt Activator 05 as the bonding agents. Fused silica Aggregate No. 1 (1200 gms) was mixed with 96 gms. of Activator 23 and rolled on the ball mill until homogeneous. Synar binder was added until the mixture was pourable and poured into aluminum molds. The samples were covered with aluminum foil while drying. The samples cracked and produced laminated surfaces while drying. No data was obtained from these samples.

The experiment was repeated as above using Activator 05 in place of Activator 23. The results of this test were the same as the previous test.

No further work was done with the Pennsalt binders due to lack of time. From all indications it is felt that, with proper combination of Pennsalt Synar Binders, activators, and fused silica aggregate, the cracking and lamination can be overcome thus obtaining a cold set binder for fused silica aggregate.

D. Methods of Casting Aggregates and Binders

Alkophos C and Lumnite cement were found to be the best binders for the fused silica aggregate that was studied. Outlined below are the methods used in casting Lumnite cement - fused silica aggregate and Alkophos C - fused silica slip - fused silica aggregate.

1. Lumnite Cement

The following composition was found to be the best combination studied of the fused silica aggregate - Lumnite cement specimens:

Fused Silica Aggregate No. 1	35.0%
Lumnite Cement	46.2%
Water	18.8%

The following procedure was developed to cast the specimens:

a. Mix fused silica aggregate adding 3% water, based on dry weight of aggregate. Add cement and mix until homogeneous. Add the remaining amount of water and mix thoroughly. A Hobart N-50 mixer was used to mix the compositions for small specimens.

b. Pour fused silica aggregate - Lumnite cement mixture into a non-porous mold of the desired shape and vibrate until air bubbles stop migrating to the surface of the sample.

c. Cover samples with moistened towels and allow to remain wet for 24 hours, dry in air for 24 hours, and dry at 230 F for 24 hours.

2. Alkophos C

The following composition was found to be the best combination studied of the fused silica aggregate - fused silica slip - Alkophos C specimens:

Fused Silica Aggregate No. 4	69.4%
Alkophos C	12.7%
Fused Silica Slip	15.8%
Water	2.1%

The following procedure was developed to cast the specimens:

a. Mix the fused silica aggregate adding 3% water, based on dry weight of the fused silica aggregate, until it is homogeneous.

b. Add the solutions to the wetted aggregate, adding the Alkophos C first then the slip, and mix thoroughly.

c. Pour the above mixture into a Keltexed plaster mold of the desired shape and vibrate from 2 to 5 minutes.

d. Dry and fire the samples following the schedule below:

(1) Dry samples in the molds in air until hard.

(2) Dry in molds at 140 F for 18 hours.

(3) Remove samples from plaster molds and dry at 230 F at least four hours.

(4) Put samples in kiln at 500 F and slowly fire to 1000 F for one hour.

(5) At this point the samples have an average transverse strength of 500 - 800 psi. If desired, the samples can be fired at higher temperatures; however, no further firing is necessary.

It will be noted that the above procedure was developed for small laboratory size samples. When larger samples are desired, the drying and curing time will have to be increased.

CONCLUSIONS

The binders investigated to bond the standard fused silica aggregate were fused silica slip, Hi-Early Portland cement, Lumnite (calcium aluminate) cement, Kaolin (E.P.K.), lead monosilicate, Alkophos C, and Pennsalt Synar binders. Of these seven binders, a combination of Alkophos C - fused silica slip was found to have the best properties for ceramic tooling. The Alkophos C - fused silica slip - fused silica aggregate samples had a transverse strength of 968 psi when fired to 2000 F for one hour, 0.19 per cent linear fired shrinkage, were able to withstand at least 10 thermal water quenches from 2000 F to 80 F, and had no visible surface cracks after quenching. Small samples were easily dried in 18 hours at 230 F and need only be cured to a temperature of 1000 F for one hour. Large samples required longer drying and curing time.

Lumnite (calcium aluminate) cement was found to be the best cold set binder for the fused silica aggregate. An average transverse strength of 420 psi was obtained with no measurable shrinkage. The Lumnite cement - fused silica aggregate samples took thermal water quench from 2000 F to 80 F with no visible failure. There are no limitations as far as size is concerned with Lumnite cement. The curing temperature of the samples was 230 F for 24 hours.

All of the remaining binders exhibited difficulty for one or more of the following reasons; difficult to fabricate, high shrinkage, low transverse strengths, or were unable to take thermal shock.

EXHIBIT 4

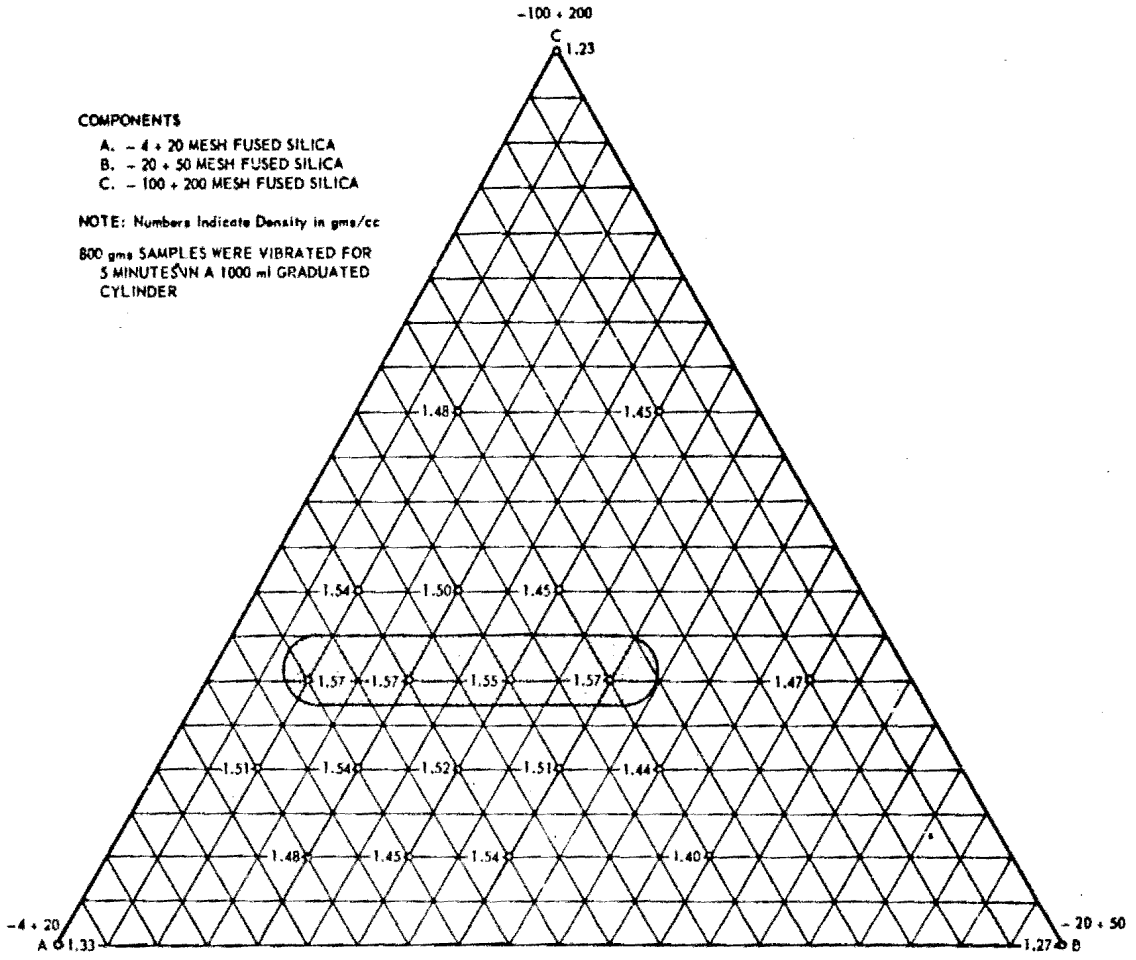


Fig. 1 Maximum Packing Density of Fused Silica Aggregate Monofractions.

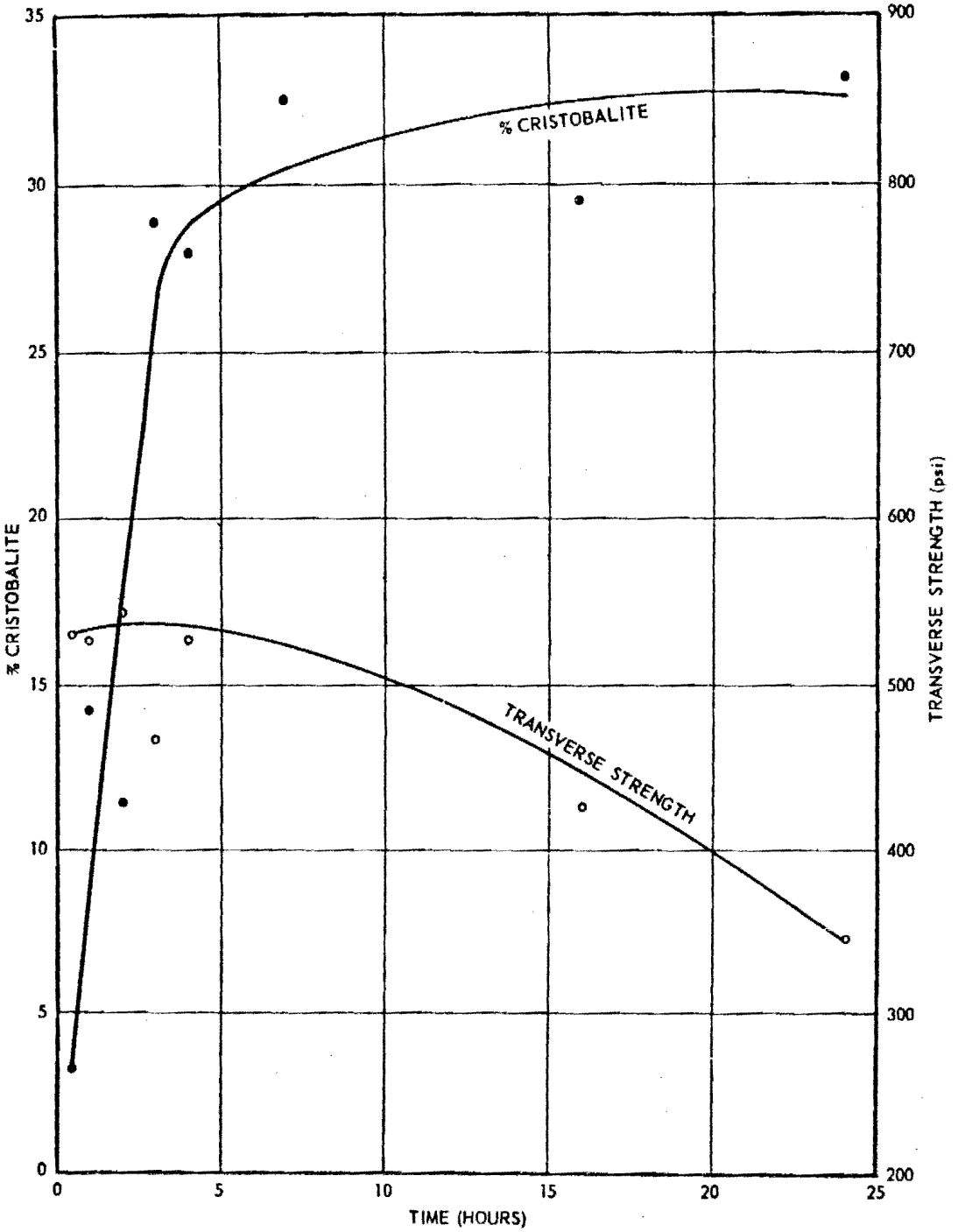


Fig. 2 Percent Cristobalite and Transverse Strength of Water Quenched AS-1 Specimens as a Function of Firing Time at 2,000°F.

EXHIBIT 5

SUMMARY REPORT
(FINAL)

on

DEVELOPMENT OF A REFRACTORY CASTABLE BASED ON CALCINED PETALITE

to

LOCKHEED AIRCRAFT CORPORATION

December 11, 1959

by

H. D. Sheets, C. Hyde, and W. H. Duckworth

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EXHIBIT 5

DEVELOPMENT OF A REFRACTORY CASTABLE BASED ON CALCINED PETALITE

by

H. D. Sheets, C. Hyde, and W. H. Duckworth

INTRODUCTION

The Lockheed Aircraft Corporation, Georgia Division, is engaged in a project for the Air Force under Contract No. 33(600)36888 on ceramic tools for high-temperature, metal-forming operations.

The effort is aimed at developing hydro-press blocks, draw dies, braze fixtures, stress-relief fixtures, stretch-form blocks, and other such tools from ceramics that are commercially available or are developed especially for this purpose.

On the basis of information developed in Phase I of their work, a survey of available materials, Lockheed concluded that castable refractories having lower coefficients of thermal expansion than commercial products might be needed for some applications. Battelle was engaged to develop through the laboratory stage a castable refractory based on calcined petalite, which is known to have a low thermal-expansion coefficient.

Target specifications for the castable were as follows:

(1) Have good thermal-shock resistance, as determined by repeated heating and cooling from 2000 F to room temperature in still air

(2) Have a maximum linear size change at room temperature from drying of 0.2 per cent

(3) Have a maximum net linear size change after firing of 0.1 per cent

(4) Have sufficient strength to permit handling before firing

(5) Have a minimum fired strength of 1000 psi (modulus of rupture) when tested at room temperature and at 2000 F

(6) Be capable of being cast into shapes with smooth as-cast surfaces

(7) Be dimensionally stable at all operating temperatures between room temperature and 2000 F

(8) Be capable of being cast and fired in sections as large as one cubic yard.

This program was conducted during the period from March 1 to September 1, 1959. During this period, interim progress reports were forwarded to Lockheed so that findings and developments could be incorporated into their evaluation program.

SUMMARY

A refractory castable based on calcined petalite was developed for possible use as ceramic tooling. A mixture of 72 weight per cent of the calcined petalite, 3 weight per cent of ball clay, and 25 weight per cent of calcium aluminate cement was judged to be the best of the experimental compositions. While the physical properties of this composition fell short of the target specifications, it is believed that this composition is worthy of consideration for use in tooling applica tions where a low thermal-expansion castable is required.

Preliminary studies indicated that fused cordierite may have use as the aggregrate in castable products for these applications.

EXPERIMENTAL WORK*

Initially this program was directed toward the development of a castable based on calcined petalite with a phosphoric acid bond. Early in the experimental program, it became evident that phosphoric acid would not produce a satisfactory bond and the effort was shifted to the use of Alcoa's calcium aluminate cement. A preliminary investigation of fused cordierite as the aggregate was made also.

Raw Materials

A list of the raw materials used in this program, together with their sources and approximate chemical compositions, is given in Table 1, Page 222.

* The data upon which this report is based may be found in Battelle Laboratory Record Book No. 15641, pages 1 through 49.

Procedure

Lump petalite was crushed to pass a 4-mesh screen, and portions of the crushed material were calcined for 5 hours at the desired temperature. The material then was split into convenient sieve sizes.

The batch compositions were weighed and then dry mixed for 5 minutes in a planetary mixer *. Sufficient liquid then was added to bring the mixture to casting consistency and the wet mass was mixed for about 5 additional minutes. The mixture then was poured into 1 x 1 x 5-1/2-inch brass molds and vibrated into place, using a Syntron vibrator **

The specimens were cured for 24 hours in the molds, and then dried overnight at 140 F followed by 24 hours at 250 F. All firing was done in air in a Globar-heated furnace. Modulus-of-rupture data were obtained by midpoint loading of the cured or fired specimens on a 5-inch span. Shrinkage data were obtained by measurement of length "as cast", dried, and cured.

Results

Batch compositions and property data for the experimental compositions are given in Table 2. On the basis of these data, it was concluded that:

(1) Calcining the petalite at 1200 or 1800 F did not give a volume-stable aggregate, while 2000 F did. Petrographic analyses confirmed that phase changes occurred between 1600 and 2000 F.

(2) The cured and fired strengths of the strongest phosphate-bonded composition were significantly lower than those of the calcium aluminate-bonded compositions. Calcium aluminate is indicated to be a more satisfactory bond for a petalite-based refractory castable.

Composition 40 was chosen for further evaluation by Lockheed. Results of the Lockheed tests are recorded in Table 15, Page 132, Basic Code 81, and are summarized here as follows:

* Model C-100, Hobart Manufacturing Company, Troy, Ohio.
** Model VP 30, Syntron Corporation, Homer City, Pennsylvania.

Specimen Number 81A.1

Linear drying size change (6 specimens)	+0.02 to 0.06%
Size change after firing at 2000 F (4 specimens)	-0.03 to -0.08%
Cured, room-temperature modulus of rupture (2 specimens)	735 and 834 psi
Room-temperature modulus of rupture after firing at 2000 F (2 specimens)	554 and 672 psi
Modulus of rupture at 2000 F (2 specimens)	620 and 655 psi

These data are in reasonable agreement with those obtained at Battelle for this material. The volume stability and surface finish of this composition compared favorably with the most satisfactory commercial castables evaluated, but the strengths were lower.

Ten commercial castables had cured moduli of rupture in excess of 1500 psi, seventeen had fired moduli of rupture in excess of 1500 psi, and five had moduli of rupture at 2000 F in excess of 1000 psi.

Thermal-shock resistance of Composition 40 was evaluated at Battelle. Five 1 x 1 x 5-1/2-inch specimens were placed in a furnace at 2000 F for 15 minutes, and then were withdrawn and cooled in room-temperature air for 15 minutes. Four of the five specimens withstood 10 cycles of this treatment. The fifth specimen broke during the eighth cycle. The modulus of rupture of the specimens which were unbroken during the thermal-shock test averaged 260 psi, or about 40 per cent of the value for cured specimens not exposed to thermal shock.

Fused Cordierite-Based Refractory Castable

At the request of Lockheed, a few preliminary experiments were made to judge the value of fused cordierite for the aggregate in a low-expansion refractory castable. Fused cordierite was obtained from the Muscle Shoals Electrochemical Corporation and handled in the same way as the petalite, except that the calcination step was not necessary.

These trials (see Compositions 44, 45, and 46, Table 2) indicated that this material was more satisfactory for this purpose than was calcined petalite.

The higher strength obtained with Composition 44 (compared with Composition 40) probably is related to the strength of the aggregate itself, rather than to changes in the bonding mechanism. Preliminary results indicated that calcium aluminate cement can be used as a bond for cordierite more satisfactorily than phosphoric acid or phosphoric acid and aluminum hydroxide.

RECOMMENDATION FOR FUTURE WORK

While the best of the castables based on calcined petalite and calcium aluminate cement did not meet the target specifications, it is suggested that consideration be given to trials of Composition 40 in tooling applications. It is believed that substantial improvement in the petalite aggregate could be made by calcining pressed blocks made from finely ground petalite rather than calcining the crude lump. The calcined block would then be crushed and screened to give the desired grain-size distribution. If a harder and stronger aggregate could be made this way, a stronger and less porous castable would be possible.

It is recommended that research be continued on a castable based on fused cordierite.

HDS:CH:WHD/mln

TABLE 1. SOURCES AND COMPOSITIONS OF RAW MATERIALS

Material	Source	Approximate Chemical Composition
Petalite	Foote Mineral Company Philadelphia, Pa.	Li_2O - 4.5 per cent Al_2O_3 - 17.5 per cent SiO_2 - 77.0 per cent
C-730 Aluminum hydrate	Aluminum Company of America East St. Louis, Ill.	Al_2O_3 - 64.4 per cent H_2O - 35.6 per cent
Phosphoric acid	J. T. Baker Chemical Company Phillipsburg, New Jersey	H_3PO_4 - 85 per cent H_2O 15 per cent
Rodine 82	Amchem Products, Inc. Ambler, Pa.	Not available (organic liquid)
Ammonium fluoride	J. T. Baker Chemical Company Phillipsburg, New Jersey	NH_4F
CA-25, Calcium aluminate cement	Aluminum Company of America East St. Louis, Ill.	Al_2O_3 - 80 per cent CaO - 20 per cent
Tennessee No. 7 Ball Clay	Kentucky-Tennessee Clay Company Mayfield, Kentucky	Al_2O_3 - 36 per cent SiO_2 - 48 per cent
Cordierite	Muscle Shoals Electrochemical Corporation Tuscumbia, Alabama	MgO - 14 per cent Al_2O_3 - 35 per cent SiO_2 - 51 per cent

TABLE 2. BATCH COMPOSITIONS AND PROPERTIES OF EXPERIMENTAL CASTABLES

Composition Designation	Type	Calcination Temperature, F	Batch Composition, Parts by Weight: Refractory Aggregate, Grain-Size Distribution: 8 to 14 Mesh	14 to 28 Mesh	28 to 65 Mesh	65 to 150 Mesh	150 Mesh and Finer	Ball-Milled	C-730 Aluminum Hydrate	H_3PO_4 With 1% Rodine Added	NH_4F	Calcium Aluminate Cement	Tennesse No. 7 Ball Clay	Water	Change of Length During Curing, per cent	Cured Modulus of Rupture, psi	Effect of Firing: 2000 F: Linear Change From Cured Size, per cent	2000 F: Modulus of Rupture, psi	2200 F: Linear Change From Cured Size, per cent	2200 F: Modulus of Rupture, psi
10	Petalite	1200	20	25	15	10	15	5	10	7.6	1	–	–	7.6	0	130	+2.4	90	+2.2	95
11	Petalite	1600	20	25	15	10	15	5	10	7.3	1	–	–	7.3	–0.2	330	+2.4	80	+1.8	300
7	Petalite	2000	20	25	15	10	15	5	10	8.8	1	–	–	8.8	–0.2	125	+0.2	35	–0.5	575
12	Petalite	2400	20	25	15	10	15	5	10	8.1	1	–	–	8.1	–0.3	300	+0.2	170	–0.4	555
13	Petalite	1600	20	25	15	10	5	5	–	–	–	20	–	14.2	–0.1	570	+2.8	70	–	–
23	Petalite	2000	20	25	15	10	5	5	–	–	–	20	–	14.2	–0.1	420	+0.2	450	+0.1	670
24	Petalite	2000	20	25	15	10	15	5	10	7.7	1	–	–	7.7	–0.1	175	+0.2	80	–0.1	320
30	Petalite	2000	20	25	15	10	5	5[a]	–	–	–	20	–	14.2	–0.1	620	+0.1	510	–	–
31	Petalite	2000	20	25	15	10	2	5	–	–	–	20	3	14.0	–0.1	660	0	660	–	–
32	Petalite	2000	20	25	15	10	15	7.5	7.5	7.2	1	–	–	7.2	–0.3	<100	+0.2	200	–	–
33	Petalite	2000	20	25	15	10	15	10	5	7.2	1	–	–	7.2	–0.1	<100	+0.1	160	–	–
37	Petalite	2000	20	25	15	10	2	5	–	–	–	20	3	16.0	–	450	–0.1	330	–0.1	520
38	Petalite	2000	20	25	15	10	2	3	–	–	–	20	5	18.0	–	360	–0.2	260	–0.2	400
39	Petalite	2000	20	25	15	10	–	3	–	–	–	20	7	14.0	–	630	0	450	–0.1	530
40	Petalite	2000	20	25	15	10	–	2	–	–	–	25	3	14.0	–	680	0	560	–0.1	760
44	Cordierite	–	20	25	15	10	–	2	–	–	–	25	3	12.0	–	1450	0	835	0	920
45	Cordierite	–	20	25	15	10	15	15	–	7.5	1	–	–	7.5	–	405	–	–	–	–
46	Cordierite	–	20	25	15	10	15	5	10	6.4	1	–	–	6.4	–	<100	–	–	–	–

(a) Calcined at 1600 F.

PHASE III
TOOLING AND REINFORCEMENT DEVELOPMENT
August thru October 1959

PART I - RETEST OF TEN MATERIALS

INTRODUCTION

It was decided by the Contractor that the ten (10) materials selected in Phase II should be tested again as in Phase II.

The main object of this repeat investigation is to have standards of comparison for the reinforcement evaluation. A secondary object is to compare the batch-to-batch consistency of these commercial castables.

PROCEDURE

Specimens of each of the following materials were cast or rammed:

5A.1	21C.1
12E.1	25A.1
12F.1	25B.1
20A.1	39A.1
20B.1	108A.1

The same placement methods were used for these specimens as were used in the previous evaluations under Phase II of this contract. All dry materials were blended in the twin cone blender and wet mixed in the small rotary mixer. Materials were cast in 2 1/2 x 4 1/2 x 9 inch precision aluminum molds which were vibrated at 10,000 cpm, 0.0005 amplitude during casting. The materials cast in this manner include 5A.1, 12E.1, 12F.1, 20A.1, 20B.1, 39A.1 and 108A.1.

Material 25A.1 was mixed in the Lancaster Mix Muller and slip cast in plaster molds without being vibrated. For 25A.1, the binder was added to the grain in the mixer.

Material 25B.1 was slip cast in plaster molds after being agitated for 24 hours on powered rollers. Small amounts of this material were added to the molds periodically as piping down occurred.

Material 21C.1 was air rammed, as received, in precision aluminum molds.

All specimens were cured, dried and fired as indicated by Table 19, Page 238. Drying size changes, firing size changes, moduli of rupture, and surface finish were also determined. The placing techniques described herein are applicable throughout the remainder of this phase of the report.

DISCUSSION OF RESULTS

The results appear in Table 19.

In order to compare the consistency of different shipments of each of these ten commercial castables (presumed to be different batches), Table 20 was prepared. The table shows for each intended use category the percentage change as based on the results of Table 15 - in other words, the difference between the initial material and the reorder.

CONCLUSIONS

1. Generally speaking, the size change and surface finish did not differ significantly between the batches.
2. The modulus of rupture differed markedly and mostly in the downward direction from the initial to the reorder batch.
3. These results substantiate the indication found in Phase I that far too much variation exists in the different batches of particular commercial castable refractories.

RECOMMENDATIONS

1. The variation in the quality from batch-to-batch of commercial castable refractories being too great, specifications for such materials must include chemical, sieve and particle shape definitions.
2. Consider the results as given in Table 15 as being commercially obtainable after suitable quality control, even on a reorder basis.

PART II - REINFORCEMENT EVALUATION - PRELIMINARY

INTRODUCTION

A series of elementary tests were made using various reinforcing materials and, arbitrarily chosen, castable 39A.1. The purpose of these tests was to determine the feasibility of using these reinforcements with respect to fabrication and placement techniques and to roughly determine the degree of bonding between the reinforcement and the castable.

The ceramic reinforcing materials were wet with water prior to placement to prevent them from drawing water from the castable. Several of the ceramic reinforcements were wet with Ludox* (30% water solution of colloidal silica) in an attempt to provide an intermediate system from which a better castable to reinforcement bond was anticipated. Results indicated, however, that the effect of Ludox was not beneficial in this respect; and, consequently, it was not considered for use in later tests.

References 28 thru 31 were studied for guidance in this evaluation.

PROCEDURE

Following the elementary tests, castable 5A.1, because of availability and being representative, was used as a base material for all reinforcements. Reinforcing materials used as indicated in Table 21, Page 240, are illustrated and defined in Figures 86 thru 96, Pages 253 thru 258.

Rectangular shapes (3 1/2 x 8 inches) of ceramic blanket, ceramic cloth, screen wire, hardware cloth and expanded metal were placed directly in the castable. The raw ceramic fibers and the steel wool reinforcements were shaped by hand to approximately 1/2 x 3 1/2 x 8 inches. The perforated metal reinforcements, (3 1/2 x 8 inches) were prepared by drilling 3/8 inch holes through the sheets on 1 inch centers. Kovar** rods 1/8 inch diameter by 8 inches in length were cut from 6 foot lengths of material as received from the vendor. The Kovar turnings were obtained by machining a 2 1/2 inch diameter Kovar bar. They were turned from the bar as long shavings and were then straightened and cut into 8 inch lengths. Their cross-section was approximately half-round with a cross-sectional area equivalent to a 1/8 inch diameter rod.

Four 2 1/2 x 4 1/2 x 9 inch specimens were cast using each reinforcing material (see Table 21).

Pre-blending of each bag of castable was accomplished in the twin shell blender (Figure 65). Each specimen from material 5A.1 was wet mixed individually in the small rotary mixer (Figure 66). Mixing water was held constant at 9% of the dry weight of the castable.

*Product of E. I. Dupont
**Low expansion alloy (54% Fe, 28% Ni, 18% Co), product of the Carborundum Company, Refractories Division, Latrobe, Pennsylvania

Reinforcements were placed approximately 1/2 inch from the bottom of the specimen. This was accomplished by pouring in 1/2 inch of castable, placing the reinforcement and then filling the mold. The Kovar rods and the expanded metal tended to settle to the bottom surface of the specimen when vibrated. This condition was overcome by placing stainless steel wire feet on these specimens (see Figure 97, Page 259).

All specimens were covered with wet burlap immediately after casting and allowed to cure in the molds overnight. They were then stripped from the molds and allowed to air dry at room temperature for 24 hours. Additional drying was accomplished at 220 F for 16 hours. Drying size change and modulus of rupture were obtained in the dried state on two specimens of each reinforcement. Surface finishes were noted.

The remaining two specimens of each reinforcement were fired to 1000 F with a 4 hour soak. Total size change and modulus of rupture were obtained on these fired specimens. Fired surface condition was noted (see Table 21, Page 240).

DISCUSSION OF RESULTS

The results are in Table 21.

Castable-to-reinforcement Bond

Reinforcements can be divided into three groups with respect to relative degree of bonding, excellent, good and poor. Those in the excellent group include expanded metal, Kovar turnings, perforated metal, and screen wire.

Reinforcements exhibiting good bonding ability were Kovar rods, ceramic blanket and ceramic cloth. The materials which bonded poorly with the castable were the raw ceramic fibers and steel wool.

The poor bonding of the steel wool and loose ceramic fibers actually weakened the specimens because large voids were introduced by the inability of the ceramic to bond with the castable (see Table 21).

Strength

Table 22 has been prepared to facilitate the reduction of the strength data of Table 21. The increase in dried modulus of rupture due to reinforcement ranged from zero psi to approximately 900 psi. The ceramic blanket and cloth reinforcements were nearly as effective as the metallic materials in the unfired specimens. After firing to 1000 F, however, the ceramic reinforced specimens were slightly weaker in modulus of rupture than the unfired specimens containing the same reinforcement; and all ceramic reinforced materials were considerably weaker than the metallic reinforced specimens after firing. The three specimens showing greatest strength after firing to 1000 F were those containing perforated metal, expanded metal, and Kovar turnings (see Figures 92, 93, and 95). The Kovar rods did not produce as high a strength as the turnings.

CONCLUSIONS

1. Ceramic reinforcements offer no great advantage.
2. Perforated metal and Kovar turnings, as reinforcements, appreciably increase the strength of unfired specimens.
3. Ceramic reinforcements are a detriment.
4. Kovar turnings and rod, expanded metal and perforated metal enhance the strength of fired specimens.

RECOMMENDATIONS

1. Discard all ceramic reinforcements.
2. For unfired tools, consider perforated metal or Kovar turnings as a reinforcement.
3. For fired tools, consider expanded metal, Kovar turnings or perforated metal as a reinforcement.

PART III - REINFORCEMENT EVALUATION - FINAL

INTRODUCTION

It was decided, for the purpose of the reinforcement investigation, to reduce to five the ten materials previously selected as representing the top prospects.

Of the four calcium aluminate bonded materials, 5A.1, 12E.1, 12F.1 and 20B.1, three were arbitrarily chosen for continued study. These three materials were 5A.1, 12E.1 and 12F.1.

Two other materials were selected from the original list of ten, bringing the number of materials to be studied further to five. Material 25A.1 was selected over 25B.1 because of its easier workability. Material 108A.1 was picked for the following reasons:

1. It represents the phosphoric acid bonded types.
2. Contrary to most phosphoric acid bonded materials, it is not placed by ramming.
3. It has the highest composite linear worth value of any material tested.

Kovar rods rather than turnings, because of availability, and expanded metal were chosen for evaluation with the five selected castables in a manner representing the anticipated end use of the particular castable.

PROCEDURE

The reinforcements were 3/4 inch, Number 9 expanded metal and 1/8 inch diameter Kovar rod (see Figures 94 and 96, Pages 257 and 258).

Except for material 12E.1, from which seven each specimens were made, ten 2 1/2 x 4 1/2 x 9 inch test specimens were cast from each of the five selected castables for each of the two reinforcements, resulting in a total of 94 specimens. The materials were mixed and placed as previously mentioned except that 25A.1 was also cast in aluminum molds.

The molds were first filled approximately 1/2 inch deep so that the reinforcing material could be inserted. The reinforcements were placed as shown in Figure 97. Next, the mold was filled to capacity and the vibrating period commenced.

The expanded metal was cut into 3 1/2 x 8 inch rectangles. The 1/8 inch diameter Kovar rods were cut into 8 inch lengths and knurled on four sides, with a special device, to give them a rough surface finish approximating turnings. One piece of expanded metal or three lengths of Kovar rod were placed in each reinforced ceramic specimen (see Table 23, Page 242).

After casting, the molds were placed on a level surface at room temperature for 24 hours. The 5A.1, 12E.1 and 12F.1 products were covered with damp burlap during this curing period. The 25A.1 and 108A.1 products were left uncovered. All of the specimens were then carefully removed from the demountable molds and dried for 24 hours at room temperature. Specimens were then dried in a forced draft oven at 220 F.

After drying, the specimens were measured to determine drying size change.

The 5A.1 and 12F.1 materials were fired to 1000 F at the rate of 200 F/hr. and held at the temperature for four hours. The 108A.1 material was fired to 1000 F at the rate of 50 F/hr. to 600 F and then 150 F/hr. on to 1000 F. It was held at 1000 F for four hours.

All of the fired specimens were measured, after removing from the oven and cooling to room temperature, to determine firing size change.

DISCUSSION OF RESULTS

The results are in Table 23. Table 24 has been prepared to aid the analysis of data in Table 23.

All of the 12E.1 specimens were tested in the as-dried condition. The properties of this material are such that very little strength is gained by firing. This material is proposed for usage where size or other conditions of the die make it impractical to fire. Also the length of elevated temperature exposure time would be held to a minimum when using this product for forming tools such as draw dies, stretch form blocks, etc.

The 5A.1 and 12F.1 products were tested in both the dried and fired conditions. There is a substantial increase in strength after firing. These materials are intended for moderate temperature applications or for applications where the exposure time at high temperature is brief.

The 25A.1 and 108A.1 materials were tested in both the dried and fired conditions but they are primarily intended for sustained elevated temperature applications. The test results of the 25A.1 material indicate that this low thermal expansion material is not suitable for use with the relatively high thermal expansion steel reinforcement (see Figure 98).

Since expanded metal (mild steel) generally exhibited good results, the Contractor feels that mild steel rods similar to structural concrete reinforcing rods should be considered for use in lieu of Kovar rods. Such a step would greatly reduce the cost of reinforcement materials.

CONCLUSIONS

1. For all materials but 25A.1, expanded metal is a better reinforcement than Kovar rods.
2. Kovar rods are suitable reinforcements for 25A.1, but their contribution to strength is debatable.
3. Of the materials tested, 5A.1 was aided most by reinforcement.
4. The effect of reinforcements on 12E.1 and 12F.1 was slight.
5. Firing improved the strength of reinforced specimens of 5A.1, 12F.1 and 25A.1.
6. Firing drastically decreased the strength of reinforced 108A.1 specimens.
7. As evidenced by the behavior of expanded metal in 25A.1, reinforcements for this low coefficient of expansion material must also have low coefficients - low carbon steel does not.

RECOMMENDATIONS

1. Knurled Kovar rods (or turnings) be considered as a reinforcement for 25A.1.
2. Use materials 12E.1 and 12F.1 without reinforcements.
3. Use material 108A.1 unreinforced for unfired tools used at room temperature.
4. Use low carbon steel as a reinforcement for material 5A.1.
5. Because of its lower cost, consider using mild steel in rod form (reinforcing rods for reinforced concrete) for reinforcing castables such as 5A.1.

PART IV - WEAR TEST

INTRODUCTION

As a part of the preliminary evaluation of materials for tooling purposes, the effects of movement of hot (1700 F) metal over the surface of the castables needed to be studied. To satisfy this need an accelerated wear test was devised.

PROCEDURE

The experimental hydraulic press* was fitted with platens which were provided with fittings to clamp a pair of 2 1/2 x 4 1/2 x 9 inch ceramic specimens in position (see Figures 99, 100 and 101, Pages 261 and 262). The specimens were held so that a 4 1/2 x 9 inch face of each could be placed to sandwich the hot metal blank. The blank was held in the electrode jaws of the tension frame and stretched tightly by means of the cylinders attached to the jaws. The cylinders were actuated with air for this test to make the speed of blank movement more nearly simulate that used in production drawing. Automatic controls were installed to make the reciprocation time constant. Fifty (50) strokes in 56 seconds gave a speed of motion of approximately 22 feet per minute.

Temperature control of the blank, which was heated by its own resistance to electric current, was accomplished by means of a chromel-alumel thermocouple attached to the sheet and a recording potentiometer. Current input was controlled manually to maintain the sheet at temperature.

Thermocouples imbedded in each specimen were attached to a four-channel recording potentiometer to indicate temperature change during the test.

*See Exhibit 6, Page 275.

One thermocouple was placed in the middle of the bottom surface, with respec to the specimen mold, and another was placed approximately at the center of the specimen as shown in Figure 101, Page 262. The bottom thermocouple was positio before the mold was initially filled and the center one was positioned after the reinforcement had been placed. The wires were led out of the side of the specimen in such a manner that the internal positions of the thermocouple hot junctio were known.

Metal blanks were prepared of .031 x 10 x 38 inch 420 CRES by attaching a thermocouple to each in an area not to be contacted by the ceramic specimen during the test. The blank was clamped in the jaws of the tension frame and the upper platen lowered to make a sandwich of the metal between the specimens. To provide some lubrication, at 1700 F, powdered talc was rubbed into the wear surface of the specimens and dusted over the faces of the metal blank.

The pressure applied to the sandwich was held at a constant value for each test. The construction of the press allowed stops to be used to limit the downward movement of the ram. This left the weight of the upper specimen, specimen holder, platen, and platen holder bearing on the metal and lower specimen. This weight determined by a dynamometer was 525 pounds.

When the press, metal sheet, and specimens were in position, electrical power was turned on and the temperature of the sheet was increased to 1700 F, and maintained throughout the test. Upon reaching 1700 F, air pressure was supplied to the cylinders and reciprocation commenced. After 50 strokes, the air supply and electrical power were cut off, the press raised, and specimens and sheet removed for inspection (see Figure 102, Page 263). A new sheet of metal was used for each pair of specimens.

Material 5A.1, with expanded metal reinforcement, was cycled 980 times which produced no further signs of wear (either by size change or by surface finish change) than that given by 50 cycles.

DISCUSSION OF RESULTS

The results are in Table 23. Table 25 has been prepared to aid the analysis of the wear resistance data of Table 23.

This test again showed the futility of trying to put a steel reinforcement in system 25A.1, which, being fused silica, has a very low coefficient of thermal expansion. It also showed that a low expansion metal like Kovar will not always work as a reinforcement.

All specimens showed marked signs of wear with the 25A.1 specimens showing least. Wear occurred as frictional scoring in the direction of motion and as spalls or pits caused by heat. The metal sheets in each test were heavily marked and galled.

The two indices of wear; namely, change in surface finish and size change, gave corroborating evidence. There is a rough inverse correlation between the two indices of wear and thermal conductivity. Good wear resistance accompanies poor thermal conductivity.

If the behavior of system 5A.1 is typical, it would appear as though the signs of wear occur early and do not progress any through an exposure 20 times the initial.

The data from the 50 cycle test indicate that tool life will be short where a forming operation requires hot metal to slide on the surface of a ceramic tool (see Figure 102, Page 263). Talc, used as a hot lubricant, did not provide enough lubrication to protect the tool or the part.

CONCLUSIONS

1. All specimens showed signs of wear and all specimens scored the metal.
2. Talc, the only lubricant tried, did not provide sufficient lubrication.
3. Wear on system 5A.1 did not progress in 980 cycles beyond that which occurred in 50 cycles.

RECOMMENDATIONS

1. As the correlation between this test and the happenings which will occur during the actual use of a forming tool (such as a draw die) is unknown, pursue this no further until such time as a measure of the usefullness of the wear test is known.
2. Determine what lubricants would be useful in this application.

PART V - WEATHERING TEST

INTRODUCTION

For storage, it is desirable to know how weathering might affect castable refractory tools. Accordingly, the effects of weather as simulated by Weather-Ometer and freezing and thawing tests were studied.

The object of this test was to evaluate the influence of outside storage on castable refractories.

PROCEDURE

Weather-Ometer Test

Two Weather-Ometers were used in a weathering test for exposing the castable refractory specimens to simulated outdoor storage conditions. An Atlas Electric Devices Company No. 13-945 GYA 529 Cam, produced the following exposure cycle at a temperature of 140 ± 5 F:

1 hour water spray only
2 hours light only
2 hours water spray only
6 hours light only

The Weather-Ometers are Atlas Electric Devices Company's Models DLTS-X and SL-TS. The Weather-Ometer, shown in Figure 103, Page 264, is a self-contained artificial and accelerated weather producer embodying control over temperature, simulated rain and sunlight.

The Weather-Ometer operates on the principle that if a light source, whose total radiation approximates noon June sunlight, shines on the surface of a specimen, under a controlled temperature and is followed by a water spray of known temperature, pressure, and volume, the exposed specimen will acquire surface and color characteristics similar to those produced naturally but in about 1/25th of the time required for outdoor exposure.

A special adaptor was designed and built to enable the simultaneous exposure of 15 standard brick size (2 1/2 x 4 1/2 x 9 inch) specimens. See Figure 104, Page 265, for the adaptor and Figure 105, Page 266, for the loaded Weather-Ometer.

After an initial examination of the specimens for weight and surface appearance, they were loaded in the Weather-Ometers and given one exposure cycle per day for 15 days. Each day the specimens were checked for changes in appearance as shown by chalking, color change or cracking. At the conclusion of the test the specimens were again weighed, examined for surface finish, and checked for strength (modulus of rupture). See Table 26, Page 246.

Freezing and Thawing Test

Simulated outside storage tests were performed to evaluate the specimen's ability to withstand outside conditions. The equipment used is shown in Figures 106 and 107, Pages 266 and 267. After an initial examination for weight and surface appearance, the specimens were placed in a freezing chamber at a temperature between 0 and 32 F for twenty hours. At the end of this time, the specimens were removed to a room temperature environment for four hours. The freezing and thawing procedure was repeated 19 more times, which amounted to five weeks testing. Visual examination of the specimens was made each week for change in appearance as denoted by chalking, color change or cracking. At the conclusion of the test, the specimens were again weighed, examined for surface finish, and checked for strength (modulus of rupture). See Table 27, Page 248.

The freezing equipment, Figure 106, Page 266, is "Alpha Low-Temperature" manufactured by Alpha Electric Refrigeration Company, Detroit 3, Michigan. It has a chamber large enough to hold 45 brick-size specimens. The temperature can be controlled to ± 5 F throughout the range, 32 F to -80 F.

DISCUSSION OF RESULTS

The results of the Weather-Ometer test are in Table 26 and the results of the freezing and thawing test are in Table 27.

Tables 28 and 29 have been prepared to aid in the analysis of the Weather-Ometer and freezing and thawing data.

Neither surface finish nor weight change were significant factors. All materials absorbed a small amount of water. The modulus of rupture values were very erratic, but they do indicate materials 25A.1 and 108A.1 to be more stable than the calcium aluminate bonded materials (5A.1, 12E.1 and 12F.1) in the Weather-Ometer test; and material 108A.1 to be definitely the most stable in the freezing and thawing test.

No differentiation was evident between the two reinforcements.

System 12F.1 chalked slightly in both tests.

CONCLUSIONS

1. The accelerated exposure tests as determined by surface finish, weight and chalking indicate no significant influence of the weather upon the castable refractories tested.

2. The accelerated exposure tests as determined by modulus of rupture give data too erratic for analysis.

RECOMMENDATIONS

1. Due to the extreme erraticness of the strength data which conceals any significant harm which outside storage exposure may produce in a castable refractory system, it is recommended that such systems not be stored outside.

2. If storing outside must be done it is recommended that the castable be protected from water.

PART VI - THERMAL SHOCK TEST

INTRODUCTION

Thermal shock tests were run to determine the relative resistance to rapid heating and quenching of the materials considered for the tooling evaluation.

PROCEDURE

Two separate tests were made. In the first test two 2 1/2 x 4 1/2 x 9 inch brick specimens of material 5A.1, 12E.1, 25A.1, 81A.1 and 122B.1 were used. With the exception of the 25A.1 material, all specimens were unfired, but 220 F dried, before testing. The 25A.1 bricks were fired according to the standard schedule for that material, as indicated in Table 15, Page 129.

The specimens were heated to 1850 F at a rate of 400 F/hr. for the first hour and then at 320 F/hr. to test temperature. They were held at 1850 F for 20 minutes.

The first five spall cycles consisted of removing the specimens from the kiln and placing them in a blast of room temperature air for 10 minutes (see Figure 108, Page 267) followed by reheating to 1850 F for 10 minutes.

The last five cycles were identical to the first five except that a fine spray of water was used instead of the air blast (see Figure 109).

The specimens were observed for cracking after the 10 cycles, completing the first test.

In the second and more exhaustive test the following materials, using new specimens, were evaluated:

5A	25A
8B	70B
12E	71B
12F	81A
20B	108A
21A	122B

The specimens were put in a cold furnace, brought up to temperature in three hours, soaked for two hours at 2000 F, removed, allowed to cool to near room temperature and examined for signs of deterioration. This cycle was repeated 10 times with photographs taken after the fifth and tenth cycles. (The photograph of the specimens from materials 8B and 71B after the fifth cycle was inadvertently missed.) See Figures 110, 113, 116, 119 and 122; and Figures 111, 114, 117, 120, 123 and 125.

The specimens were given two more cycles in which they were heated by placing in a 1500 F furnace, soaked one hour at 2000 F, quenched in 55 F tap water for 30 seconds and examined for signs of deterioration. The 13th through 15th cycles were the same as the 11th and 12th except that water quench time was 90 seconds. Figures 112, 115, 118, 121, 124 and 126 are photographs taken after the 15th cycle.

RESULTS

During the first test the 5A.1 and 12E.1 specimens cracked quite extensively. These cracks were very fine and limited to the surface.

The 81A.1 and 122B.1 specimens exhibited a few hairline surface cracks in the first test.

Material 70B became so badly cracked and broken that it was discontinued after the tenth cycle. Material 108A cracked and broke during the 15th cycle of the second test; however it was the fifth best product at the end of the 14th cycle.

The 25A.1 specimens were totally unaffected by both thermal shock tests. Table No. 30 tabulates the results of the second test.

CONCLUSIONS

1. Material 25A.1 is definitely superior to all others tested with respect to thermal shock resistance.

2. Non-commercial formulation 122B.1, developed by Georgia Tech under this contract, is second to 25A.1 in thermal shock resistance. (See Table 30 for relative thermal shock resistance for all formulations tested.)

3. Materials 5A and 12E (which were extensively evaluated in later phases) would not be suitable for use in applications involving severe thermal spall conditions such as heat treat fixtures where cross section thicknesses greatly in excess of 2 1/2 inches are involved.

4. Materials 25A.1, 122B.1, 8B.1, 71B.1, 5A.1, 21A.1 and 108A.1 (for 14 cycles) would be suitable for use in applications involving thermal spall conditions. In this respect materials 81A.1, 12E.1, 20B.1 and 12F.1 would be somewhat less suitable.

RECOMMENDATIONS

For applications requiring maximum thermal shock resistance use Material 25A.1.

TABLE 19 - PHYSICAL PROPERTIES - RECHECK

SPECIMEN NUMBER	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE F.	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000 F. PSI	DENSITY LBS/FT^3	SURFACE FINISH	REMARKS
5A.1-21	Tabular Alumina and	9	Cast	24 hrs. at R.T.	-.01	-	-	1273	-	-	3	
-22	Calcium Aluminate	"	1 minute -		-.07	-	-	1195	-	-	3	
-23		"	Vibration Time 12 Min. (max.) Placement Time	16 hrs. at 220F	-.06	-	-	1195	-	-	3	
12C.1-20	Tabular Alumina and	11	Cast	24 hrs. at R.T.	-.10	-	-	1841	-	-	2	
-21	Calcium Aluminate	"	1 minute -		+.07	-	-	1949	-	-	1	
-22		"	Vibration Time 10 Min. (max.) Placement Time	16 hrs. at 220F	-.01	-	-	2169	-	-	1	
12F.1-21	High Grade Calcined	11	Cast	24 hrs. at R.T.	+.02	1000	-.18	1712	-	-	3	
-22	Clay and Calcium	"	1 minute -		-.04	"	-.17	1766	-	-	3	
-23	Aluminate	"	Vibration Time 10 Min. (max.) Placement Time	16 hrs. at 220F	-.01	"	-.18	1730	-	-	3	
20A.1-21	Corundum and Sodium	None	Cast	24 hrs. at R.T.	+.02	-	-	995	-	-	2	
-22	Fluosilicate	"	1.5 minutes		+.03	-	-	1036	-	-	2	
-23	(NA_2SiF_6)	"	Vibration Time	24 hrs. at 220F	+.03	-	-	956	-	-	2	
20B.1-21	Corundum and	10	Cast	48 hrs. at R.T.	+.03	1000	-.06	2333	-	-	2	
-22	Calcium Aluminate	"	1 minute -		+.03	1000	-.06	2169	-	-	2	
-23		"	Vibration Time	24 hrs. at 220F	-.04	1000	-.12	2240	-	-	2	
21C.1-21	Unknown plus	1	Rammed	24 hrs. at R.T.	-.12	700	-.17	554	-	-	3	Sandy Surface Finish.
-22	Phosphoric Acid	"	Ready-Mix		+.01	"	-.11	-	1232	-	3	
-23		"		24 hrs. at 220F	+.01	"	-.07	-	995	-	3	
25A.1-21	Fused Silica plus	Unknown	Slip Cast	24 hrs. at R.T.	-.08	2000	-.21	-	1014	-	1	
-22	Unknown	Binder			-.07	"	-.20	-	993	-	1	
-23		Furnished		24 hrs. at 220F	-.09	"	-.22	-	1194	-	1	
25B.1-21	Fused Silica	-	Slip Cast	24 hrs. at R.T.	-.02	2000	-	-	-	-	-	Specimens Cracked after drying.
-22	plus Unknown	-			-.03	"	-	-	-	-	-	Maximum thickness recommended 1 inch.
-23		-		24 hrs. at 220F	-.14	"	-	-	-	-	-	
30A.1-21	Alumina and Silica	11.5	Cast	12-24 hrs. at	-.20	-	-	956	-	-	3	
-22	plus Calcium	"	1 minute -	R.T.	-.22	-	-	1036	-	-	3	
-23	Aluminate	"	Vibration Time 20 Min. (max.) Placement Time	24 hrs. at 220F	-.16	-	-	915	-	-	4	
108A.1-21	Alumina plus	3.5	Cast	24 hrs. at R.T.	-.88	1000	-1.13	-	1154	-	2	
-22	Phosphoric Acid	"	1 minute -		-1.12	"	-1.38	-	1172	-	3	
-23		"	Vibration Time	24 hrs. at 220F Use no moisture for R.T. Cure.	-.96	"	-1.27	-	1195	-	3	

TABLE 20 - PHYSICAL PROPERTY CONSISTENCY EVALUATION

MATERIAL	APPLICATION			PROPERTIES AS REPORTED IN TABLE													
				15							19						PERCENT CHANGE (BASE OF TABLE 15)
				SIZE CHANGE		SURFACE FINISH	MODULUS OF RUPTURE			LINEAR WORTH VALUE	SIZE CHANGE		SURFACE FINISH	MODULUS OF RUPTURE			LINEAR WORTH VALUE	
	UN-FIRED	FIRED ROOM TEMP.	FIRED HIGH TEMP.	AFTER DRYING	AFTER FIRING		UNFIRED	FIRED R.T.	FIRED 2000 F		AFTER DRYING	AFTER FIRING		UNFIRED	FIRED R.T.	FIRED 2000 F		
5A	X			+0.04		2	1929			6.10	-0.05		3	1221			3.60	-41.0
12E	X			-0.17		2	2272			6.80	-0.01		1	1986			6.49	- 4.6
20A	X			+0.03		1	1398			4.46	+0.03		2	996			3.02	-32.3
21C*	X			+0.08		4	768			2.09	-0.12		3	554			1.15	-45.0
39A	X			-0.27		2	1469			3.80	-0.19		3	969			2.30	-39.5
12F		1000			-0.26	2		2312		6.64		-0.18	3		1736		4.88	-26.5
20B		1000			-0.08	2		2367		7.42		-0.08	2		2247		7.02	- 5.4
21C			*		+0.08	4			1054	2.84		-0.12	3			1113	3.01	+ 9.5
25A			2000		-0.23	1			1352	3.64		-0.21	1			1067	2.76	-24.2
108A			1000		-0.04	9**			1074	2.55		-1.26***	3			1174	3.58	+40.4

* 700 F dry

** Trouble releasing specimens from the mold

*** Unrealistic data caused by too heavy a coating of parting agent. Value of -0.04 used.

TABLE 21 - DATA ON REINFORCEMENTS

SPECIMEN NUMBER	REINFORCEMENT AND WETTING AGENT	AGGREGATE AND BINDER	MIXING WATER %	PLACEMENT TECHNIQUE	CURING AND DRYING PROCEDURE	DRYING SIZE CHANGE %	FIRING TEMPERATURE °F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	SURFACE FINISH	REMARKS
5A.1-24	Raw Ceramic Fibers	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.13	-	-	1531	2	
-25	Short Staple Fine	plus	"	1 minute -		+.07	-	-	1481	2	
-26		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.08	1000	-.06	1419	1	
-27	Water		"	12 Min. (max.) Placement Time		+.08	1000	-.03	1344	1	
5A.1-28	Ceramic Fiber	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.11	-	-	1605	1	
-29	Woven Blanket	plus	"	1 minute -		+.10	-	-	1693	1	
-30		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.10	1000	-.03	1195	1	
-31	Water		"	12 Min. (max.) Placement Time		+.09	1000	-.06	1437	1	
5A.1-32	Ceramic Fiber	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.02	-	-	1693	1	
-33	Woven Cloth	plus	"	1 minute -		+.02	-	-	1820	2	
-34		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.01	1000	-.12	1932	1	
-35	Water		"	12 Min. (max.) Placement Time		-.02	1000	-.10	1568	1	
5A.1-36	Steel Wool	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.03	-	-	1618	3	
-37		plus	"	1 minute -		+.01	-	-	1176	3	
-38		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.04	1000	-.09	1331	1	
-39			"	12 Min. (max.) Placement Time		-.01	1000	-.08	1348	2	
5A.1-40	Screen Wire	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.03	-	-	1232	2	
-41		plus	"	1 minute -		+.01	-	-	1730	2	
-42		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	.0	1000	-.08	2096	2	
-43			"	12 Min. (max.) Placement Time		+.13	1000	+.02	1895	2	
5A.1-44	Hardware Cloth	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.01	-	-	1442	2	
-45		plus	"	1 minute -		+.02	-	-	1493	3	
-46		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.02	1000	-.07	1822	3	
-47			"	12 Min. (max.) Placement Time		+.04	1000	-.08	1876	1	
5A.1-48	Perforated Metal	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.10	-	-	2259	2	
-49	Sheet	plus	"	1 minute -		-.01	-	-	1969	3	
-50		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.03	1000	-.02	2645	3	
-51			"	12 Min. (max.) Placement Time		+.02	1000	-.02	2660	3	
5A.1-52	Expanded Metal	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.06	-	-	1232	3	
-53		plus	"	1 minute -		+.02	-	-	1176	2	
-54		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.01	1000	-.06	2480	2	
-55			"	12 Min. (max.) Placement Time		-.02	1000	-.08	2645	1	
5A.1-56	Kovar Turnings	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.04	-	-	1969	1	*Exceeded Capacity of the modulus of rupture testing machine.
-57		plus	"	1 minute -		+.09	-	-	1969	1	
-58		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.01	1000	-.08	2680*	1	
-59			"	12 Min. (max.) Placement Time		+.02	1000	-.09	2680*	1	
5A.1-60	Kovar Rods	Tubular Alumina	9	Cast	24 hrs. at R.T.	+.08	-	-	1419	1	
-61		plus	"	1 minute -		+.01	-	-	1273	1	
-62		Calcium Aluminate	"	Vibration Time	16 hrs. at 220F	+.07	1000	-.01	1822	2	
-63			"	12 Min. (max.) Placement Time		+.02	1000	-.09	1747	1	

TABLE 22

REDUCTION OF REINFORCEMENT DATA OF TABLE 21

REINFORCEMENT	MODULUS, PSI			DIFFERENCE BETWEEN UNFIRED UNREINFORCED AND UNFIRED REINFORCED, PSI	DIFFERENCE BETWEEN FIRED AND UNFIRED REINFORCED, PSI
	UNREINF. UNFIRED	REINF. UNFIRED	REINF. FIRED		
Raw ceramic fibers short staple fine	1221	1456	1381	235	-75
Ceramic fiber woven blanket	1221	1649	1316	428	-333
Ceramic fiber woven cloth	1221	1756	1750	535	-6
Steel wool	1221	1397	1339	176	-58
Screen wire	1221	1481	1995	260	514
Hardware cloth	1221	1467	1849	246	382
Perforated metal sheet	1221	2114	2652	893	538
Expanded metal	1221	1204	2562	-17	1358
Kovar turnings	1221	1969	2680	748	711
Kovar rods	1221	1346	1784	125	438

TABLE 23 - DATA ON REINFORCEMENTS AND WEAR TEST

SPECIMEN NO.	REINFORCEMENT	DRYING SIZE CHANGE %	FIRING TEMPERATURE °F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000°F PSI	SURFACE FINISH	WEAR TEST CYCLES	WEAR TEST SIZE CHANGE %	WEAR TEST TEMPERATURE CHANGE SURFACE °F	WEAR TEST TEMPERATURE CHANGE CENTER °F	WEAR TEST TIME SEC.	WEAR TEST SURFACE FINISH	REMARKS
5A.1-74	Expanded Metal	+.04	-	-	2680*	-	1	-	-	-	-	-	-	*Exceeded capacity of modulus of rupture testing machine.
-75	"	+.02	-	-	2680*	-	1	-	-	-	-	-	-	
-76	"	+.03	-	-	2680*	-	1	-	-	-	-	-	-	
-77	"	+.06	1000	+.01	2680*	-	1	-	-	-	-	-	-	
-78	"	+.03	"	+.01	2680*	-	1	-	-	-	-	-	-	
-79	"	+.08	"	+.06	2680*	-	1	-	-	-	-	-	-	
-80	"	+.02	"	-.04	-	-	2	50	-.31	275	175	56	4	
-81	"	+.01	"	-.06	-	-	2	50	-.19	275	215	56	4	
-82	-	+.08	"	+.03	-	-	1	980	-.19	1475	1125	2220	4	
-83	-	+.03	"	-.02	-	-	1	980	-.30	1475	1475	2220	4	
5A.1-96	Kaver Rods	+.04	-	-	1357	-	1	-	-	-	-	-	-	
-97	"	+.02	-	-	1357	-	1	-	-	-	-	-	-	
-98	"	+.03	-	-	1320	-	1	-	-	-	-	-	-	
-99	"	+.02	1000	-.02	2005	-	1	-	-	-	-	-	-	
-100	"	+.04	"	-.01	2333	-	1	-	-	-	-	-	-	
-101	"	+.07	"	+.01	2005	-	2	-	-	-	-	-	-	
-102	"	+.09	"	+.04	-	-	1	50	-.15	275	235	55	4	
-103	"	+.06	"	-.01	-	-	2	"	-.34	245	235	55	4	
-104	-	+.10	"	+.03	-	-	2	"	-.11	335	325	58	4	
-105	-	+.11	"	+.09	-	-	1	"	-.08	335	185	53	4	
12E.1-24	Expanded Metal	+.01	-	-	2315	-	1	-	-	-	-	-	-	
-25	"	+.04	-	-	2296	-	2	-	-	-	-	-	-	
-26	"	.0	-	-	1512	-	1	-	-	-	-	-	-	
-30	"	+.03	-	-	-	-	1	50	-.11	335	155	56	6	
-31	"	+.02	-	-	-	-	1	"	-.08	175	165	56	6	
-32	-	-.12	-	-	-	-	3	"	-.49	175	165	55	6	
-33	-	+.11	-	-	-	-	3	"	-.19	285	155	55	7	
12E.1-46	Kaver Rods	-.01	-	-	1456	-	1	-	-	-	-	-	-	
-47	"	-.01	-	-	1456	-	3	-	-	-	-	-	-	
-48	"	+.01	-	-	1419	-	1	-	-	-	-	-	-	
-52	"	+.01	-	-	-	-	1	50	-.40	295	95	54	7	
-53	"	-.06	-	-	-	-	2	"	-.23	365	155	54	7	
-54	-	-.03	-	-	-	-	1	"	-.08	395	95	53	6	
-55	-	-.10	-	-	-	-	1	"	-.08	275	245	53	6	
12F.1-24	Expanded Metal	+.03	-	-	1512	-	1	-	-	-	-	-	-	
-25	"	+.06	-	-	1740	-	1	-	-	-	-	-	-	
-26	"	.0	-	-	1381	-	1	-	-	-	-	-	-	
-27	"	+.02	1000	+.02	1768	-	1	-	-	-	-	-	-	
-28	"	+.02	"	.0	2220	-	2	-	-	-	-	-	-	
-29	"	+.04	"	+.07	1730	-	2	-	-	-	-	-	-	
-30	"	.0	"	.0	-	-	1	50	-.07	415	45	56	8	
-31	"	+.06	"	-.01	-	-	1	"	-.33	415	45	56	8	
-32	-	.0	"	-.08	-	-	2	"	-.08	495	185	59	7	
-33	-	+.01	"	-.07	-	-	2	"	-.34	555	185	59	7	
12F.1-46	Kaver Rods	-.04	-	-	1674	-	1	-	-	-	-	-	-	
-47	"	+.03	-	-	1493	-	1	-	-	-	-	-	-	
-48	"	-.02	-	-	1512	-	2	-	-	-	-	-	-	
-49	"	-.07	1000	-.12	1456	-	1	-	-	-	-	-	-	
-50	"	+.11	"	+.02	1895	-	1	-	-	-	-	-	-	
-51	"	-.08	"	-.17	1932	-	2	-	-	-	-	-	-	
-52	"	-.07	"	-.14	-	-	2	50	-.19	395	65	55	5	
-53	"	-.03	"	+.14	-	-	1	"	-.46	515	65	55	5	
-54	-	+.02	"	-.01	-	-	2	"	-.27	405	345	56	5	
-55	-	-.04	"	-.08	-	-	1	"	-.41	305	65	56	5	

TABLE 23 (CONT'D)

SPECIMEN NO.	REINFORCEMENT	DRYING SIZE CHANGE %	FIRING TEMPERATURE °F	FIRING SIZE CHANGE %	MODULUS OF RUPTURE AT R.T. PSI	MODULUS OF RUPTURE AT 2000°F PSI	SURFACE FINISH	WEAR TEST CYCLES	WEAR TEST SIZE CHANGE %	WEAR TEST TEMPERATURE CHANGE SURFACE °F	WEAR TEST TEMPERATURE CHANGE CENTER °F	WEAR TEST TIME SEC.	WEAR TEST SURFACE FINISH	REMARKS
25A.1-24	Expanded Metal	-.01	-	-	276	-	1	-	-	-	-	-	-	Cast in aluminum molds.
-25	"	-.06	-	-	252	-	1	-	-	-	-	-	-	Specimens with reinforcement cracked
-26	"	-.11	-	-	218	-	1	-	-	-	-	-	-	after firing. Unable to perform
-27	"	-	2000	+.29	-	487	4	-	-	-	-	-	-	wear test.
-28	"	-	"	+.42	-	362	4	-	-	-	-	-	-	
-29	"	-	"	+.17	-	566	3	-	-	-	-	-	-	
-30	"	-	"	+.16	-	-	3	-	-	-	-	-	-	
-31	"	-	"	+.26	-	-	3	-	-	-	-	-	-	
-32	-	-	"	-	-	-	3	-	-	-	-	-	-	
-33	-	-	"	-	-	-	3	-	-	-	-	-	-	
25A.1-46	Kovar Rods	-.06	2000	-.12	1092	-	3	-	-	-	-	-	-	Cast in aluminum molds.
-47	"	-.18	"	-.31	1269	-	3	-	-	-	-	-	-	Specimens with reinforcement cracked
-48	"	-.19	"	-.32	1232	-	3	-	-	-	-	-	-	after firing. Temperature change
-49	"	-	"	-.23	-	728	4	-	-	-	-	-	-	could not be recorded due to
-50	"	-	"	-.11	-	868	3	-	-	-	-	-	-	thermocouple electrical short.
-51	"	-	"	-.31	-	1133	4	-	-	-	-	-	-	
-52	"	-	"	-.16	-	-	4	-	-	-	-	-	-	
-53	"	-	"	-.31	-	-	4	-	-	-	-	-	-	
-54	-	-	"	-.63	-	-	2	50	-.07	-	-	53	3	
-55	-	-	"	-.39	-	-	2	50	-.07	-	-	53	3	
103A.1-24	Expanded Metal	+.12	-	-	2680*	-	4	-	-	-	-	-	-	*Exceeded capacity of modulus of
-25	"	+.14	-	-	2680*	-	4	-	-	-	-	-	-	rupture testing machine.
-26	"	+.10	-	-	1566	-	4	-	-	-	-	-	-	
-27	"	+.03	1000	-.18	-	1475	4	-	-	-	-	-	-	**Temperature change could not be
-28	"	+.04	"	-.16	-	1176	4	-	-	-	-	-	-	recorded due to thermocouple electrical
-29	"	+.06	"	-.14	-	1460	4	-	-	-	-	-	-	short.
-30	"	+.11	"	-.20	-	-	4	50	-.15	75	**	48	5	
-31	"	+.09	"	-.10	-	-	4	"	-.12	**	265	48	5	
-32	-	+.23	"	-.03	-	-	4	"	-.04	475	185	63	5	
-33	-	+.21	"	-.11	-	-	4	"	-.08	445	185	63	5	
108A.1-46	Kovar Rods	+.27	-	-	1547	-	3	-	-	-	-	-	-	Bloating noted on all specimens.
-47	"	+.09	-	-	2650	-	3	-	-	-	-	-	-	
-48	"	"	-	-	1294	-	3	-	-	-	-	-	-	*Stuck to surface of mold.
-49	"	+.43	1000	+.03	-	1133	3	-	-	-	-	-	-	
-50	"	+.64	"	+.28	-	1288	3	-	-	-	-	-	-	
-51	"	+.80	"	+.54	-	1456	3	-	-	-	-	-	-	
-52	"	"	"	"	-	-	4	50	-	-	-	-	-	
-53	"	+.34	"	+.06	-	-	4	"	-.19	475	155	64	5	
-54	-	+.11	"	-.08	-	-	4	"	-.31	415	235	64	5	
-55	-	"	"	"	-	-	4	"	-	-	-	-	-	

TABLE 24

REDUCTION OF REINFORCEMENT DATA OF TABLE 23

MATERIAL	MODULUS OF RUPTURE					
	STANDARD (NO REINFORCEMENT)		REINFORCEMENT			
			KOVAR		EXPANDED METAL	
	UNFIRED	FIRED	UNFIRED	FIRED	UNFIRED	FIRED
5A	1221		1845	2114	2680	2680
12E	1986		1443		2041	
12F		1736	1560	1761	1611	1906
20A	996					
20B		2247				
21C		1113*				
25A		1067*		1198 910*	245	472*
25B						
39A	969					
108A		1174*	1830	1292*	2305	1370*

*Modulus at 2000 F

TABLE 25

REDUCTION OF WEAR RESISTANCE DATA OF TABLE 23

MATERIAL	REINFORCEMENT		SURFACE FINISH		SIZE CHANGE %	TEMPERATURE CHANGE, °F			RATING		
	EXP. MTL.	KOVAR RODS	INITIAL	FINAL		SURFACE	CENTER	DIFFERENCE	THERMAL CONDUCTIVITY	WEAR RESISTANCE	SURFACE FINISH STABILITY
5A	X		1.5	4	-0.25	275	195	80			
		X	1.5	4	-0.17	260	235	25			
(average)			1.5	4	-0.21			52	4	3	3
12E	X		2	6	-0.22	242	160	82			
		X	1	6.5	-0.20	332	147	185			
(average)			1.5	6	-0.21			133	3	4	4
12F	X		1.5	7.5	-0.22	470	115	355			
		X	1.5	5	-0.33	405	135	270			
(average)			1.5	6	-0.27			312	1	5	5
25A	X		2.5								
		X	2.5	3	-0.07						
(average)										1	1
108A	X		4	5	-0.10	475	212	263			
		X	4	5	-0.25	445	185	260			
(average)			4	5	-0.17			261	2	2	2

TABLE 26

SPECIMEN CODE		WEATHER-OMETER TEST												
		EFFECT OF TEST AS MEASURED BY												
		SURFACE FINISH			WEIGHT (LBS.)			OCCURRENCE OF CHALKING				MODULUS OF RUPTURE		
NUMBER	REINF.	INIT.	FIN.	PERCENT CHANGE	INITIAL	FINAL	PERCENT CHANGE	NONE	LITTLE	MEDIUM	MUCH	AVG. INITIAL	AVG. FINAL	PERCENT CHANGE
5A.1-84	Exp.	1	2	-10	9.88	10.47		X						Not
-85	Metal	1	1	0	9.64	10.36	∕6.4	X				2670**	2670**	Deter-
-86		1	2	-10	9.83	10.40		X						mined
-87	None	1	2	-10	9.44	10.11		X						
-88	"	1	1	0	9.44	9.89	∕5.7	X				1220	1390	∕13.6
-89	"	1	1	0	9.48	9.98		X						
-106	Kovar	1	2	-10	9.60	10.21		X						
-107	Rods	1	2	-10	9.53	10.33	∕8.2	X				2115	1395	-52.0
-108		1	2	-10	9.59	10.55		X						
12E.1-34	Exp.	2	2	0	9.59	9.82		X						
-35	Metal	3	2	∕10	9.55	9.84	∕3.5	X				2375	1490	-16.4
-36		1	1	0	9.53	10.00		X						
-37	None	3	2	-10	9.31	9.42		X						
-38	"	3	2	-10	9.32	9.48	∕1.8	X				1985	1440	-37.8
-39	"	2	2	0	9.49	9.73		X						
-56	Kovar	3	2	∕10	9.43	9.88		X						
-57	Rod	2	2	0	9.37	9.76	∕4.1	X				1445	1245	- 7.0
-58		2	2	0	9.42	9.75		X						
12F.1-34	Exp.	2	2	0	7.68	8.49			X					
-35	Metal	2	3	-10	7.71	8.05	∕6.5		X			1905	2485	∕30.5
-36		2	2	0	7.78	8.13			X					
-37	None	1	1	0	7.54	8.46			X					
-38	"	1	1	0	7.60	8.47	∕11.3		X			1735	730	-57.9
-39	"	2	2	0	7.44	8.22			X					

* Indicates 2000°F Modulus
**Limit of Testing Machine

TABLE 26 (CONT'D)

SPECIMEN CODE		WEATHER-OMETER TEST												
		EFFECT OF TEST AS MEASURED BY												
		SURFACE FINISH			WEIGHT (LBS.)			OCCURRENCE OF CHALKING				MODULUS OF RUPTURE		
NUMBER	REINF.	INIT.	FIN.	PERCENT CHANGE	INITIAL	FINAL	PERCENT CHANGE	NONE	LITTLE	MEDIUM	MUCH	AVG. INITIAL	AVG. FINAL	PERCENT CHANGE
12F.1-56	Kovar	3	3	0	7.91	8.25			X					
-57	Rods	2	2	0	7.95	8.25	↑5.7		X			1760	1340	-23.9
-58		1	2	-10	7.76	8.47			X					
25A.1-34	Exp.	4	4	0	6.38	6.45		X						
-35	Metal	4	4	0	6.36	6.44	↑1.1	X				475*	360*	-23.7
-36		3	4	-10	6.40	6.47		X						
-37	None	1	5	-40	5.80	5.89		X						
-38	"	1	4	-30	5.92	5.99	↑1.0	X				1070*	1110*	↑ 3.9
-39	"	1	5	-40	5.77	5.84		X						
-56	Kovar	4	3	↑10	6.06	6.13		X						
-57	Rods	3	4	-10	6.06	6.15	↑1.3	X				910*	1340*	↑47.3
-58		4	4	0	6.25	6.32		X						
108A.1-34	Exp.	3	3	0	9.95	10.39		X						
-35	Metal	4	3	↑10	10.04	10.56	↑4.4	X				1370*	1190*	-13.3
-36		4	4	0	10.23	10.59		X						
-37	None	4	4	0	9.90	10.08		X						
-38	"	3	3	0	9.78	10.00	↑2.3	X				1175*	1310*	↑11.8
-39	"	4	3	↑10	9.64	9.88		X						
-56	Kovar	3	3	0	9.83	10.05		X						
-57	Rods	3	4	-10	10.03	10.28	↑2.4	X				1290*	1125*	-12.5
-58		4	4	0	9.84	10.09		X						

* Indicates 2000°F Modulus
**Limit of Testing Machine

TABLE 27

FREEZING AND THAWING TEST															
SPECIMEN CODE		EFFECT OF TEST AS MEASURED BY													
		SURFACE FINISH			WEIGHT (LBS.)			OCCURRENCE OF CHALKING				MODULUS OF RUPTURE			
NUMBER	REINF.	INIT.	FIN.	PERCENT CHANGE	INITIAL	FINAL	PERCENT CHANGE	NONE	LITTLE	MEDIUM	MUCH	AVG. INITIAL	AVG. FINAL	PERCENT CHANGE	
5A.1-90	Exp.	1	1	0	9.88	10.08		X							
-91	Metal	2	1	∕10	9.73	9.94	∕2.1	X				2670*	2670*	-	
-92		1	1	0	9.76	9.99		X							
-93	None	2	1	-10	9.50	9.72		X							
-94	"	1	1	0	9.45	9.66	∕2.3	X				1220	2120	∕73.8	
-95	"	2	1	-10	9.44	9.66		X							
-112	Kovar	2	1	-10	9.58	9.79		X							
-113	Rods	3	1	-20	9.71	9.91	∕2.1	X				2115	2295	∕ 8.5	
-114		2	1	-10	9.60	9.80		X							
12E.1-40	Exp.	1	1	0	9.61	9.72		X							
-41	Metal	1	1	0	9.63	9.78	∕1.4	X				2040	2450	∕20.1	
-42		1	1	0	9.51	9.63		X							
-43	None	3	2	-10	9.43	9.52		X							
-44	"	2	1	-10	9.57	9.68	∕1.1	X				1985	1270	-36.0	
-45	"	3	2	-10	9.40	9.52		X							
-62	Kovar	3	1	-20	9.47	9.57		X							
-63	Rods	2	1	-10	9.25	9.38	∕1.1	X				1445	1250	-13.5	
-64		2	1	-10	9.23	9.35		X							
12F.1-40	Exp.	2	2	0	7.74	7.94			X						
-41	Metal	2	1	-10	7.86	8.09	∕2.6		X			1905	2100	∕10.2	
-42		2	1	-10	7.80	7.99			X						
-43	None	1	1	0	7.60	7.82			X						
-44	"	1	1	0	7.57	7.78	∕2.9		X			1736	840	-51.6	
-45	"	2	2	0	7.56	7.76			X						

TABLE 27 (CONT'D)

FREEZING AND THAWING TEST															
SPECIMEN CODE		EFFECT OF TEST AS MEASURED BY													
		SURFACE FINISH			WEIGHT (LBS.)			OCCURRENCE OF CHALKING				MODULUS OF RUPTURE			
NUMBER	REINF.	INIT.	FIN.	PERCENT CHANGE	INITIAL	FINAL	PERCENT CHANGE	NONE	LITTLE	MEDIUM	MUCH	AVG. INITIAL	AVG. FINAL	PERCENT CHANGE	
12F.1-62	Kovar	2	2	0	7.67	7.85			X						
-63	Rods	2	2	0	7.58	7.78	↗2.5		X			1761	1460	-17.1	
-64		2	2	0	7.67	7.87			X						
25A.1-40	Exp.	4	4	0	6.30	6.31		X							
-41	Metal	4	3	↘10	6.39	6.39	0.0	X				472	510	↗ 8.1	
-42		4	4	0	6.42	6.41		X							
-43	None	3	4	-10	5.88	5.87		X							
-44	"	3	4	-10	5.85	5.85	0.0	X				1067	935	-12.4	
-45	"	4	4	0	6.01	6.00		X							
-62	Kovar	4	4	0	6.20	6.20		X							
-63	Rods	4	4	0	6.20	6.19	0.0	X				910	1125	↗23.6	
-64		3	3	0	6.16	6.15		X							
108A.1-40	Exp.	4	4	0	10.16	10.35		X							
-41	Metal	4	4	0	10.16	10.35	↗1.6	X				1370	1185	-14.2	
-42		4	3	↘10	10.19	10.34		X							
-43	None	4	4	0	9.82	10.01		X							
-44	"	5	4	↘10	10.19	10.38	↗ .20	X				1174	1155	-1.6	
-45	"	5	4	↘10	9.98	10.17		X							
-62	Kovar	4	4	0	10.00	10.17		X							
-63	Rods	4	3	↘10	10.01	10.17	↗1.7	X				1292	1277	-1.2	
-64		4	3	↘10	9.91	10.08		X							

TABLE 28

REDUCTION OF WEATHER-OMETER DATA OF TABLE 26

MATERIAL	NO REINF. (STD)	AVERAGE OF KOVAR AND EXPANDED METAL REINF.	PERCENT CHANGE IN		
			SURFACE FINISH	WEIGHT	MODULUS OF RUPTURE
5A	X		-3	+5.7	+13.6
		X	-8	+7.3	-52.0
12E	X		-7	+1.8	-37.8
		X	+3	+3.8	-11.7
12F	X		0	+11.3	-57.9
		X	-3	+6.1	+ 3.3
25A	X		-7	+1.0	+ 3.9
		X	-1.5	+1.2	+11.8
108A	X		+3	+2.3	+11.8
		X	0	+3.4	-12.9

TABLE 29

REDUCTION OF FREEZING AND THAWING DATA OF TABLE 27

MATERIAL	NO REINF.	AVERAGE OF KOVAR AND EXPANDED METAL REINF.	PERCENT CHANGE IN		
			SURFACE FINISH	WEIGHT	MODULUS OF RUPTURE
5A	X		+7	2.3	+73.8
		X	+8	2.1	+ 8.5
12E	X		+10	+1.1	-36.0
		X	+6	+1.2	-16.8
12F	X		0	+2.9	-51.6
		X	+3	+2.5	- 3.4
25A	X		-7	0	-12.4
		X	+1	0	+15.8
108A	X		+7	+0.2	- 1.6
		X	+5	+1.6	- 7.7

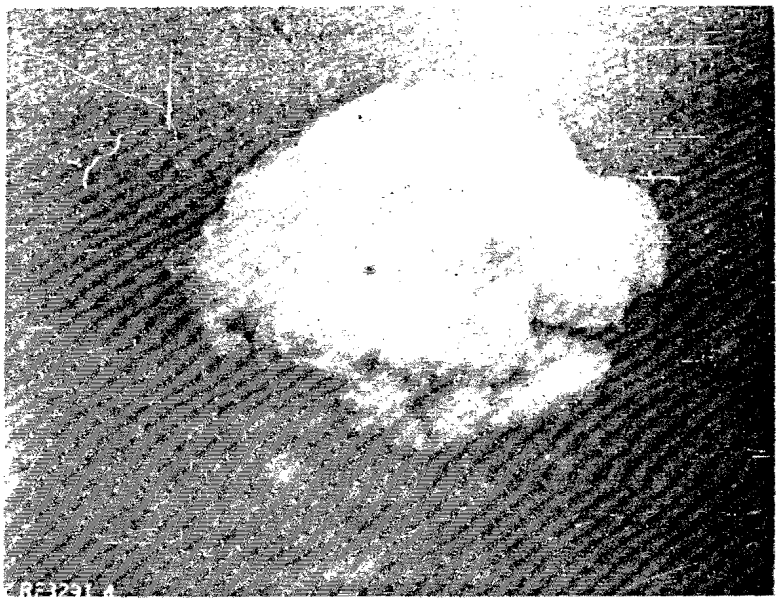
TABLE 30

THERMAL SHOCK TEST

CYCLE NO.	THERMAL SHOCK RESISTANCE RATING											
	1	2	3	4	5	6	7	8	9	10	11	12
	25A.1-6	122B.1-6	8B.1-8	71B.1-1	5A.1-6	21A.1-6	108A.1-6	81A.1-6	12E.1-6	20B.1-6	12F.1-6	70B.1-6
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	2	1	2	1
4	1	1	1	1	1	1	1	2	3	2	3	1
5	1	1	1	1	1	1	1	3	3	3	4	2
6	1	1	1	1	1	1	1	3	3	3	4	4
7	1	1	1	1	2	2	2	4	4	4	5	5
8	1	1	1	1	2	2	2	4	4	4	5	6
9	1	1	1	2	3	3	3	5	5	5	6	12
10	1	1	2	2	3	3	3	5	5	5	6	(12)*
11	1	1	2	2	4	4	3	5	5	6	7	(12)*
12	1	1	2	3	4	4	3	5	5	7	8	(12)*
13	1	2	2	3	5	5	4	6	6	7	9	(12)*
14	1	2	3	4	5	5	5	6	7	8	10	(12)*
15	1	2	3	4	5	6	11	7	8	9	10	(12)*
Average at end of 14 cycles	1.00	1.14	1.43	1.71	2.43	2.43	2.22	3.64	3.86	4.06	5.07	6.65
Average at end of 15 cycles	1.00	1.20	1.53	1.87	2.60	2.67	2.80	3.87	4.13	4.40	5.40	7.00

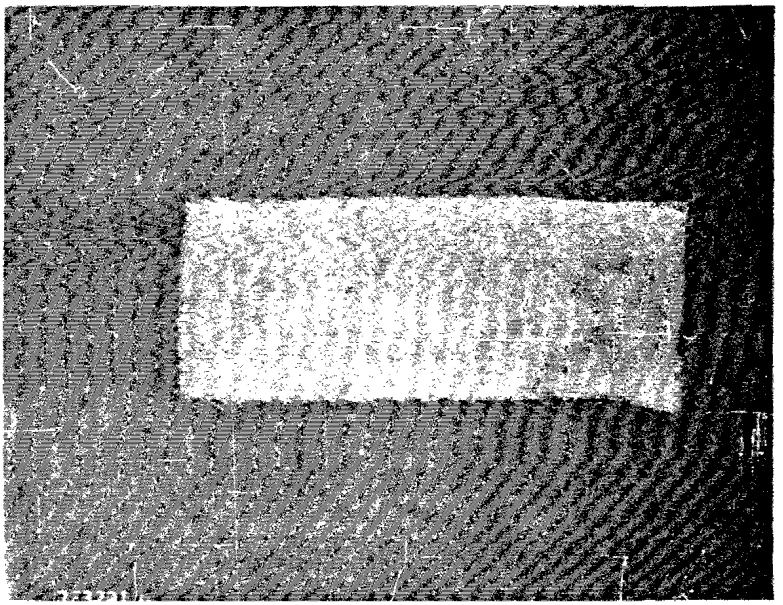
*Material cracked and chipped beyond practical use.

Numbers in Columns 1 through 12 indicate thermal shock rating per cycle



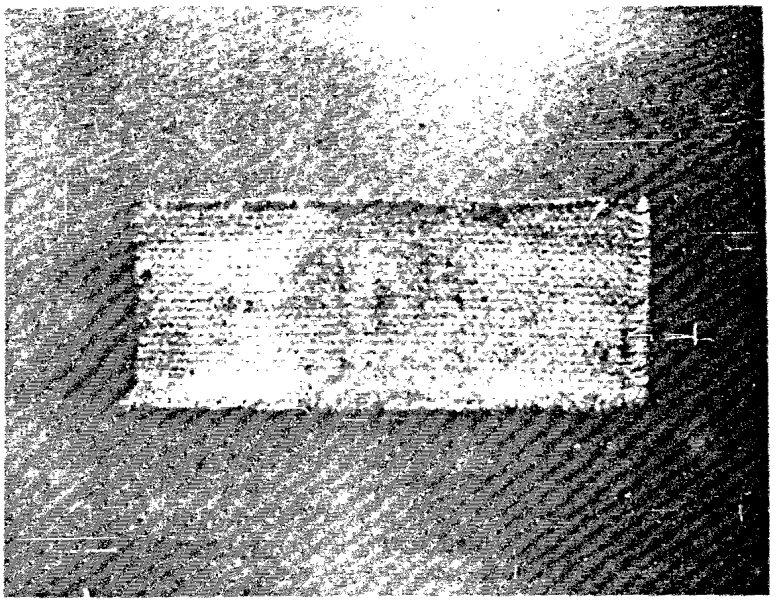
RF 3291-4

Fig. 86 Raw ceramic fiber, short staple fine, reinforcement before placement. (Product of Carborundum Company, Niagara Falls, New York)



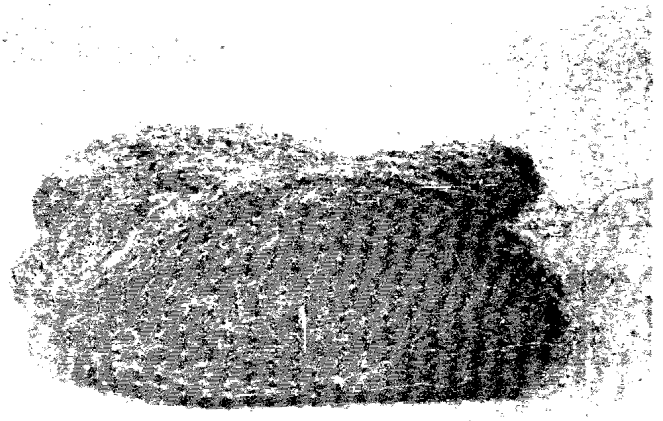
RF 3291-6

Fig. 87 Ceramic fiber woven cloth (Refrasil) reinforcement before placement. (Product of H. I. Thompson Fiber Glass Company, Los Angeles 7, California)



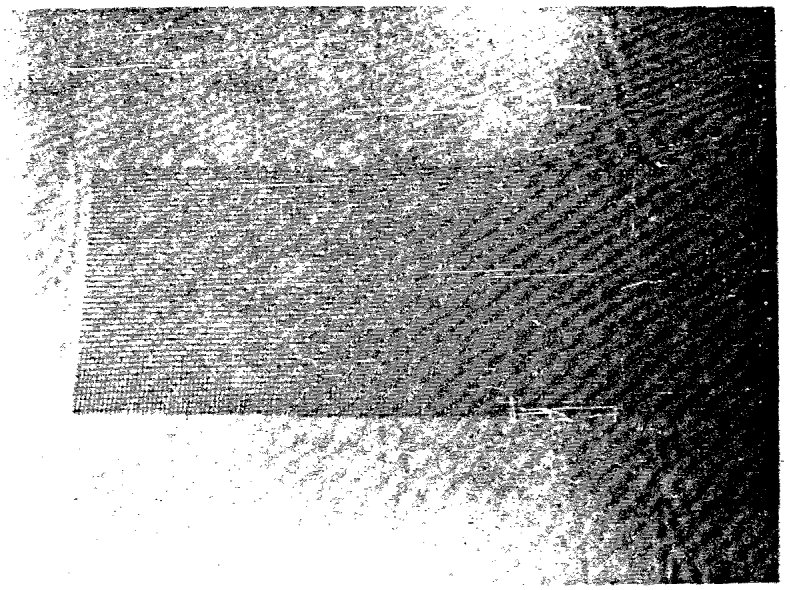
RF 3291-7

Fig. 88 Ceramic fiber broadwoven cloth (blanket) No. 120A reinforcement before placement. (Product of Carborundum Company, Niagara Falls, New York)



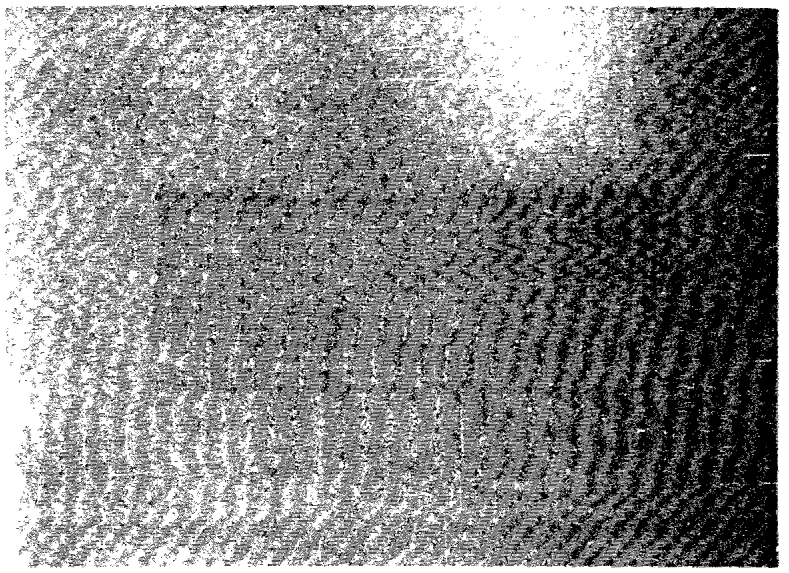
RF 3711-5

Fig. 89 Steel wool, No. 0 reinforcement before placement. Purchased from Sharp-Horsey Hardware, Atlanta, Georgia.



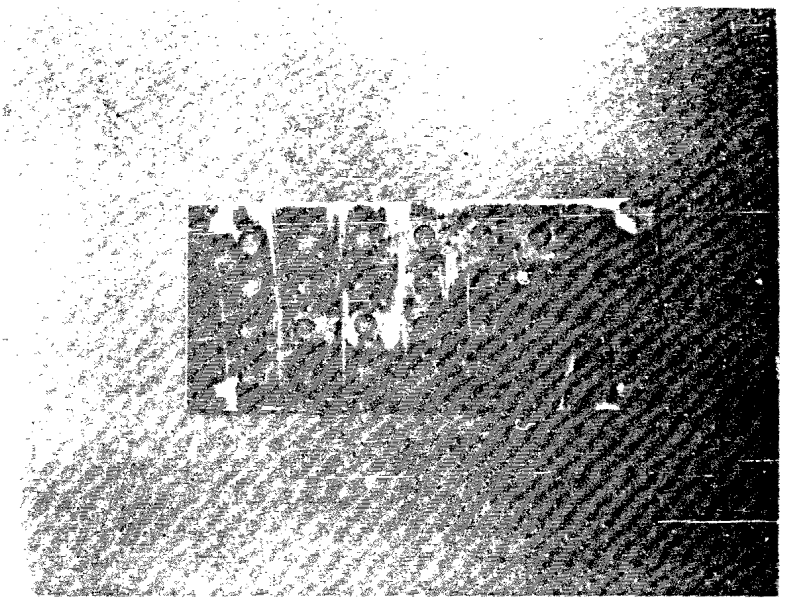
RF 3408

Fig. 90 Screen wire cloth reinforcement before placement, 16 x 16 mesh, 0.012 wire diameter, Type 304 stainless steel. (Purchased from Wirecloth Products Company, Bellwood, Illinois)



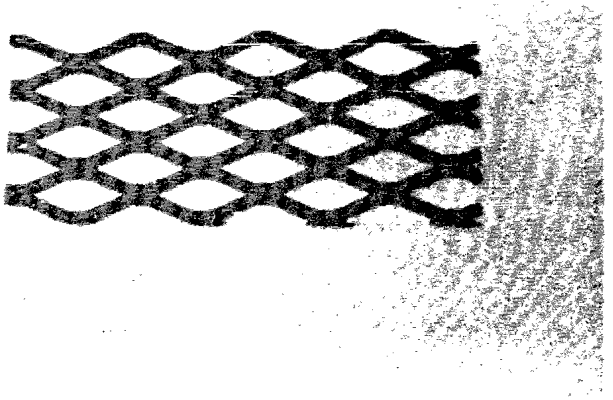
RF 3291-5

Fig. 91 Hardware wire cloth mesh, mesh 2 per inch, gage no. 19, before placement. Purchased from Beck & Gregg Hardware Company, Atlanta 1, Georgia.



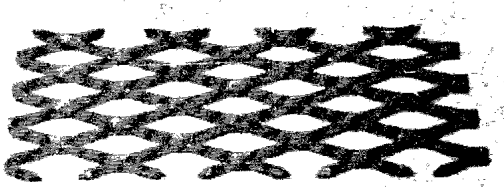
RF 3291-3

Fig. 92 Perforated metal reinforcement before placement, 420 stainless steel, 0.036" thick, 3/8" diameter holes on 1" centers.



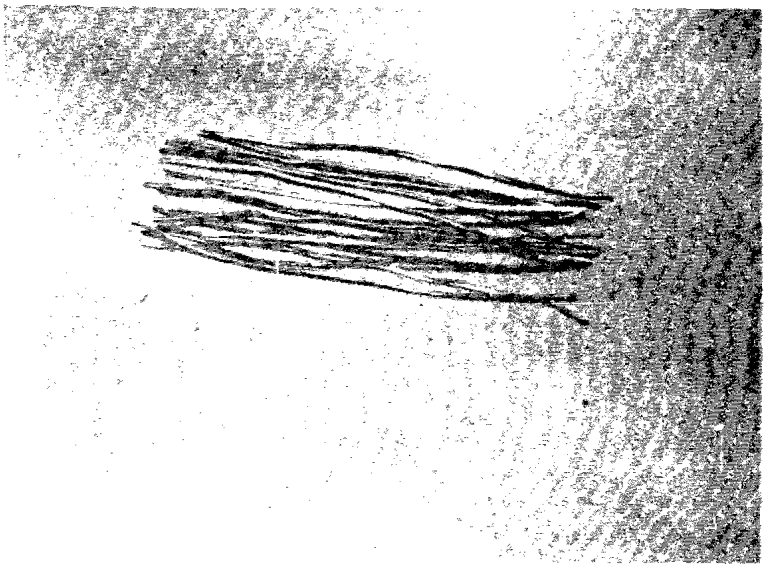
RF 3291-1

Fig. 93 Expanded metal flattened, low carbon steel, 3/4" No. 9-11, before placement. Purchased from J. M. Tull Company, Atlanta, Georgia.



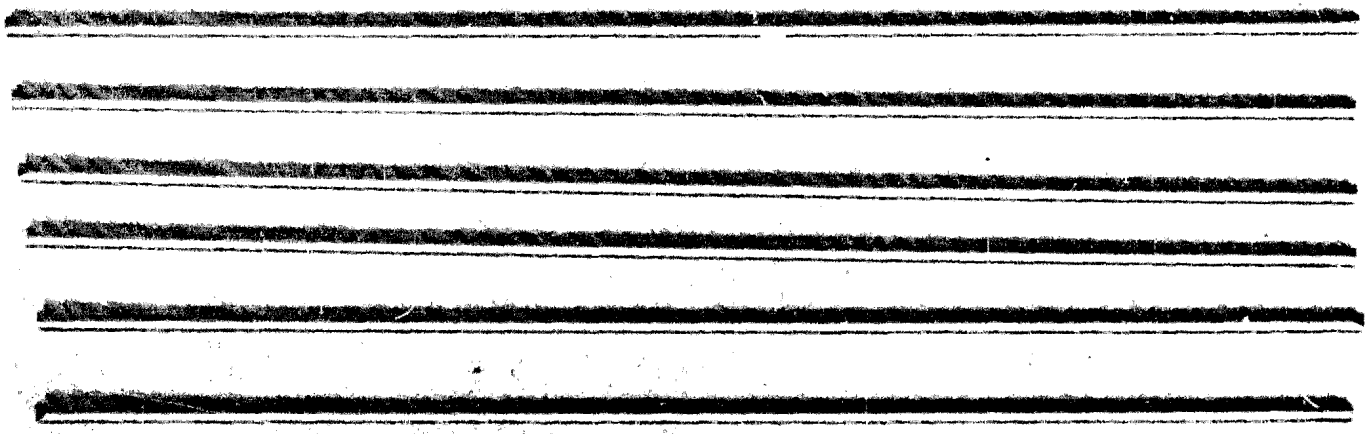
RF 3711-4

Fig. 94 Expanded metal, raised, low carbon steel, 3/4" No. 9, before placement. Purchased from J. M. Tull Company, Atlanta, Georgia.



RF 3711-3

Fig. 95 Kovar turnings reinforcement before placement. Turned from 2 1/2" diameter Kovar rod. (Product of Carborundum Company, Kovar Alloy Department, Latrobe, Pennsylvania)



RF 3327-4

Fig. 96 Kovar rod reinforcement before placement, 1/8" diameter. (Product of Carborundum Company, Kovar Alloy Department, Latrobe, Pennsylvania)

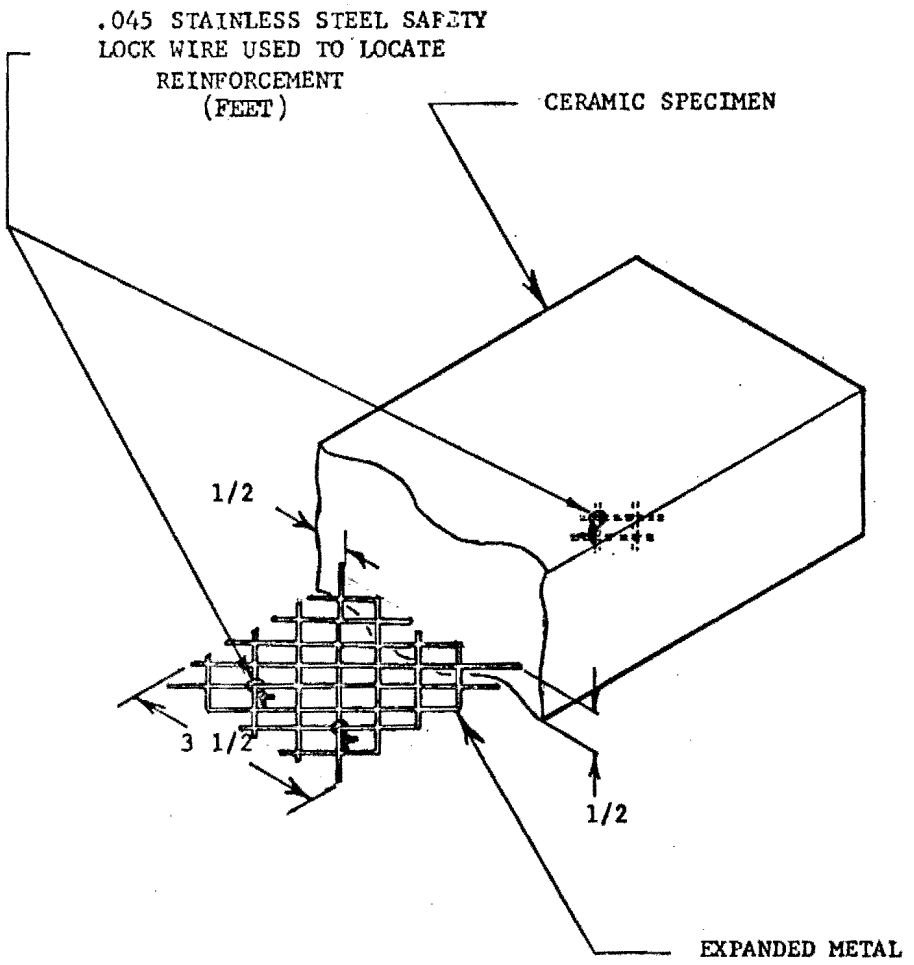


FIGURE 97

ILLUSTRATION SHOWING TYPICAL PLACEMENT
OF REINFORCEMENT MATERIALS

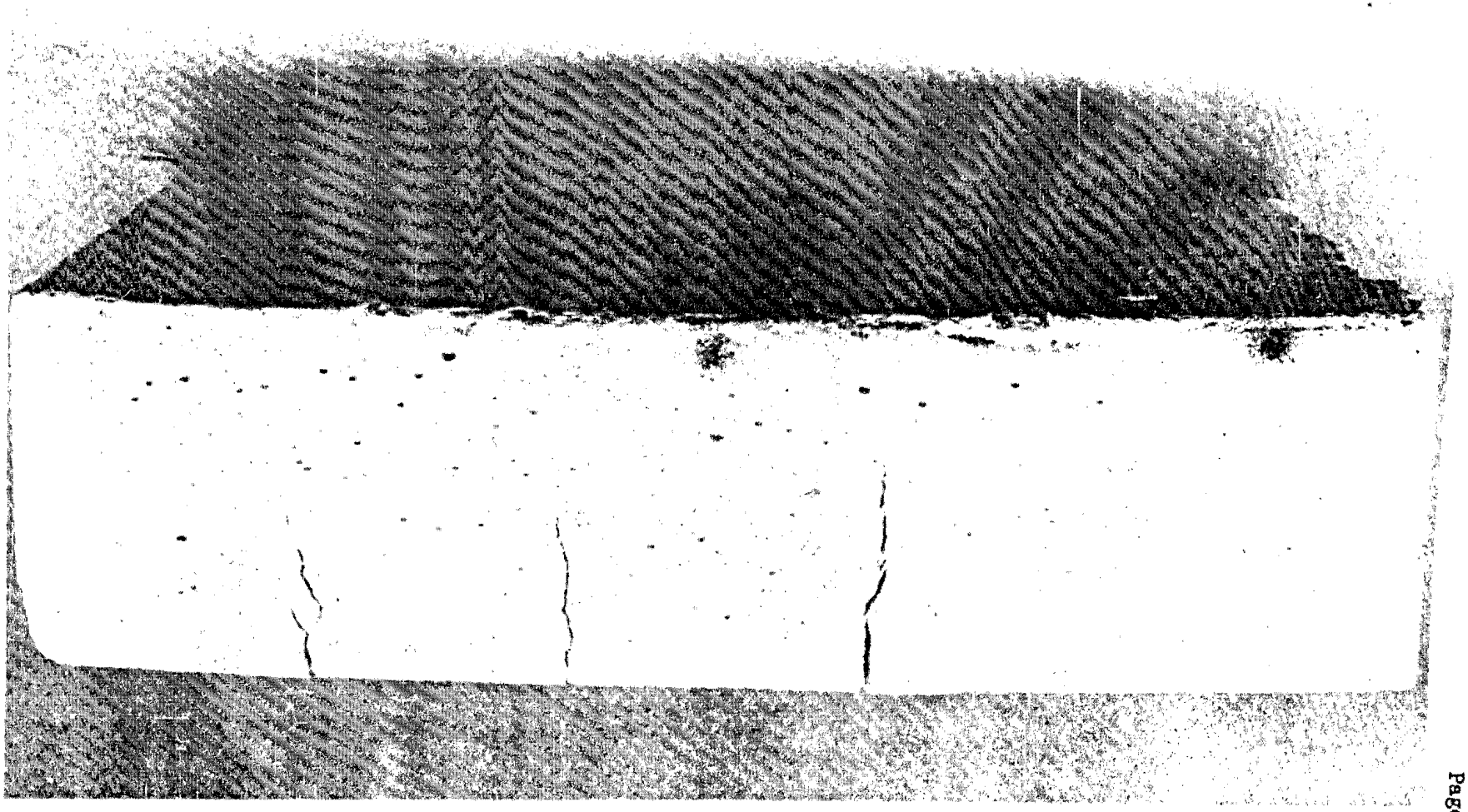
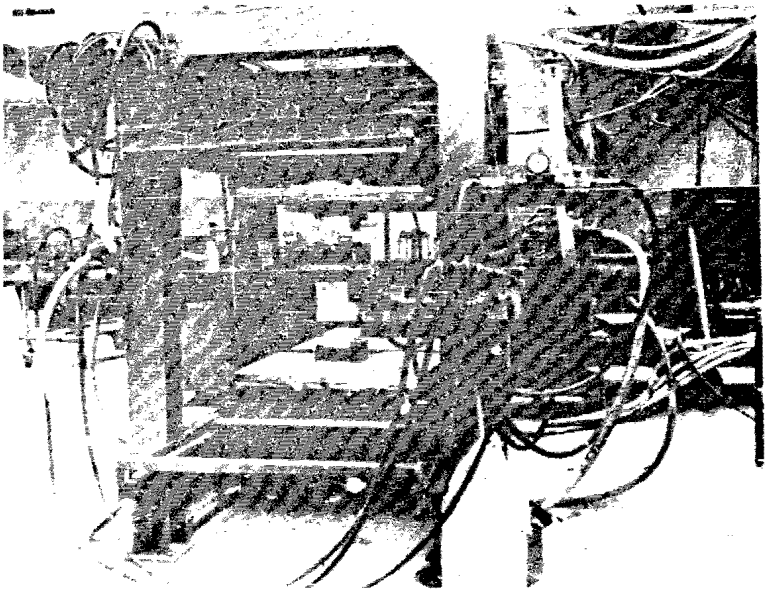
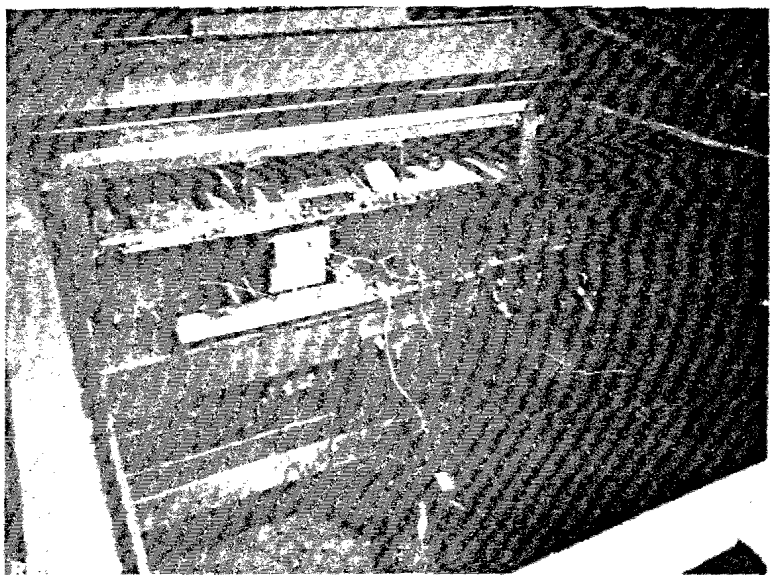


Fig. 98 Specimen 25A.1 showing cracks due to differential expansion between mild steel (expanded metal) reinforcement and ceramic material. (firing temperature 2000 F)



RF 3893-1

Fig. 99 Wear test equipment (open) showing specimens in holding fixture.



RF 3780-2

Fig. 100 Wear test equipment (closed) showing specimens in position for wear test.

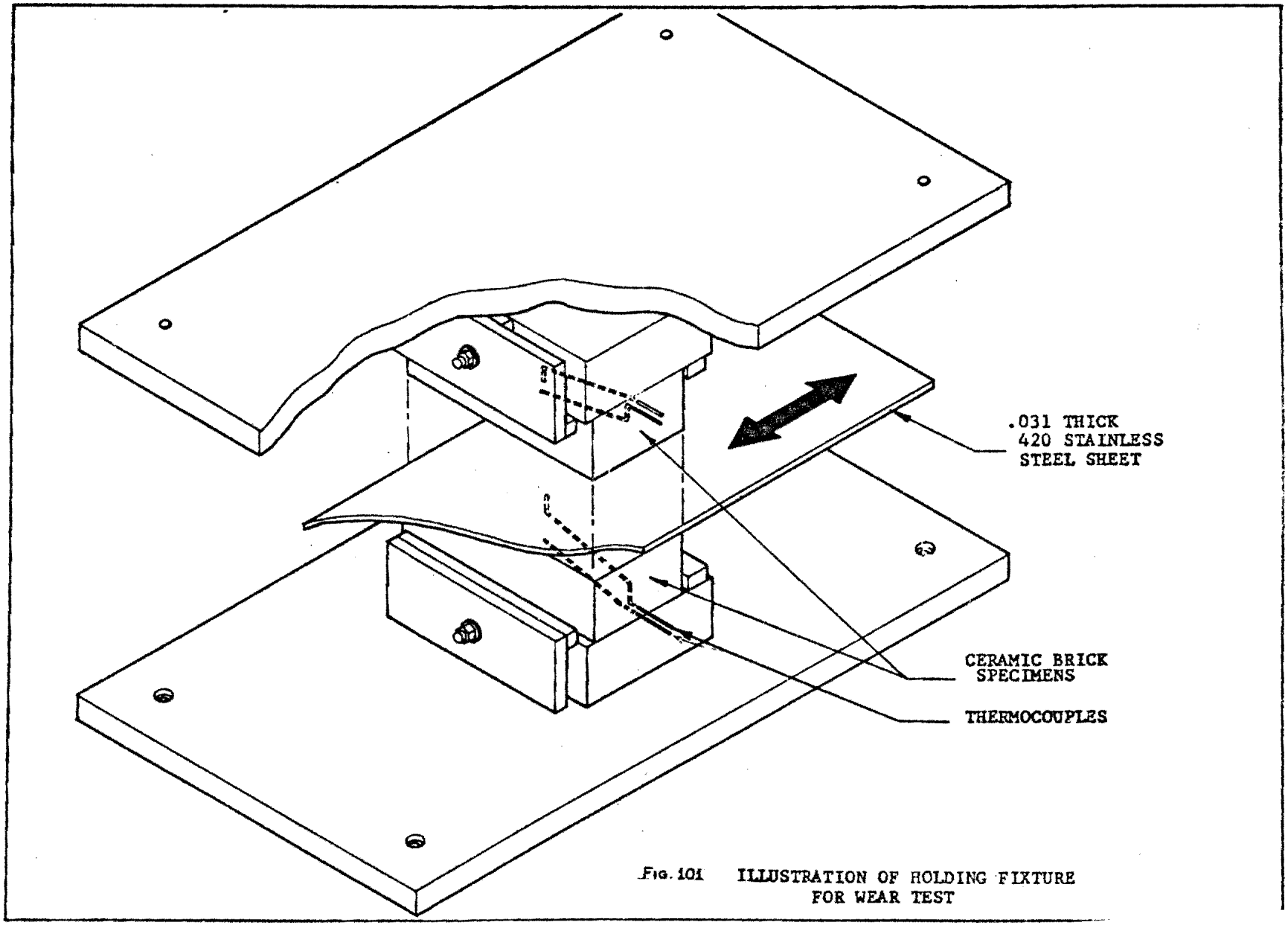


Fig. 101 ILLUSTRATION OF HOLDING FIXTURE FOR WEAR TEST

RF 3780-1

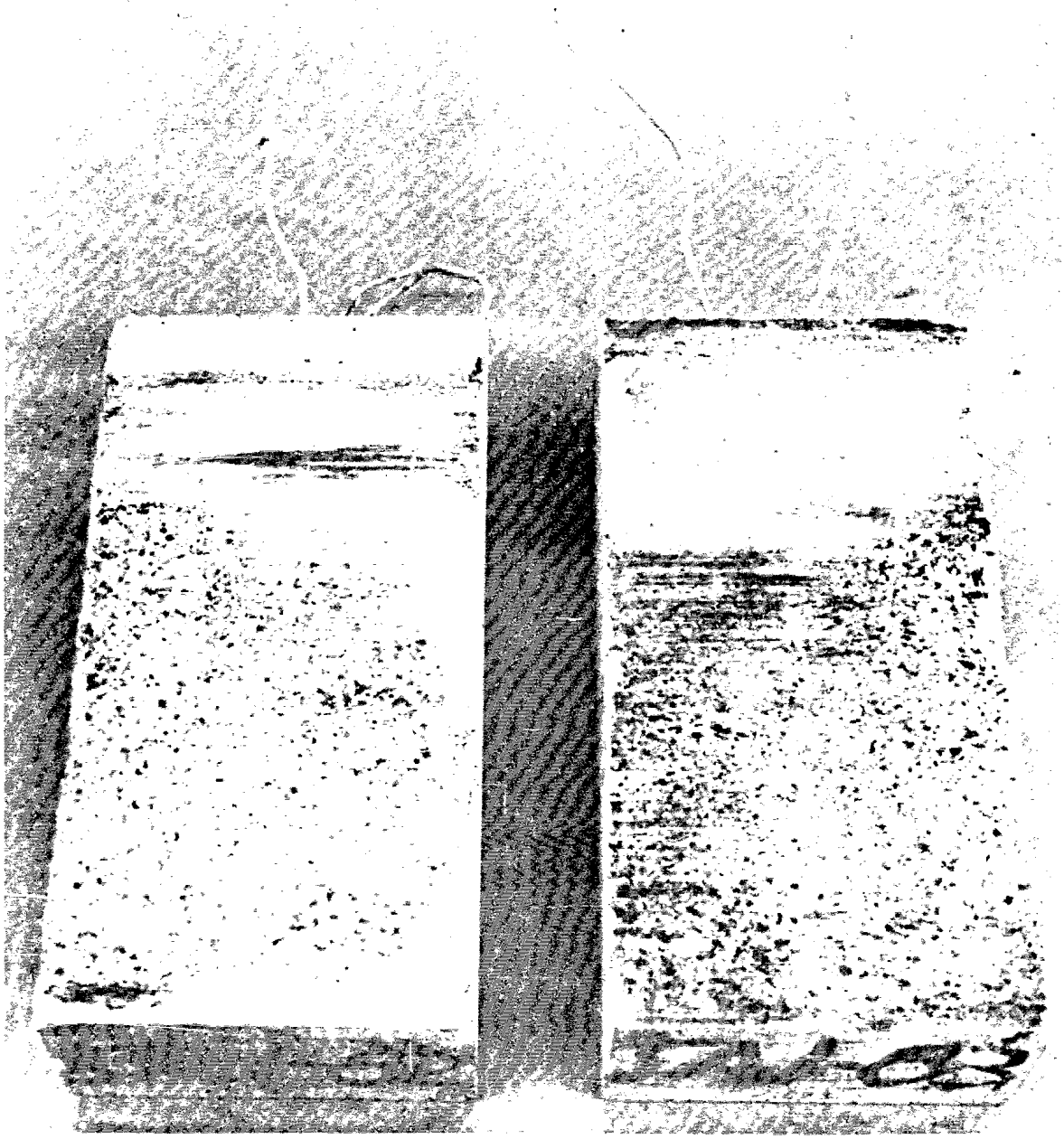
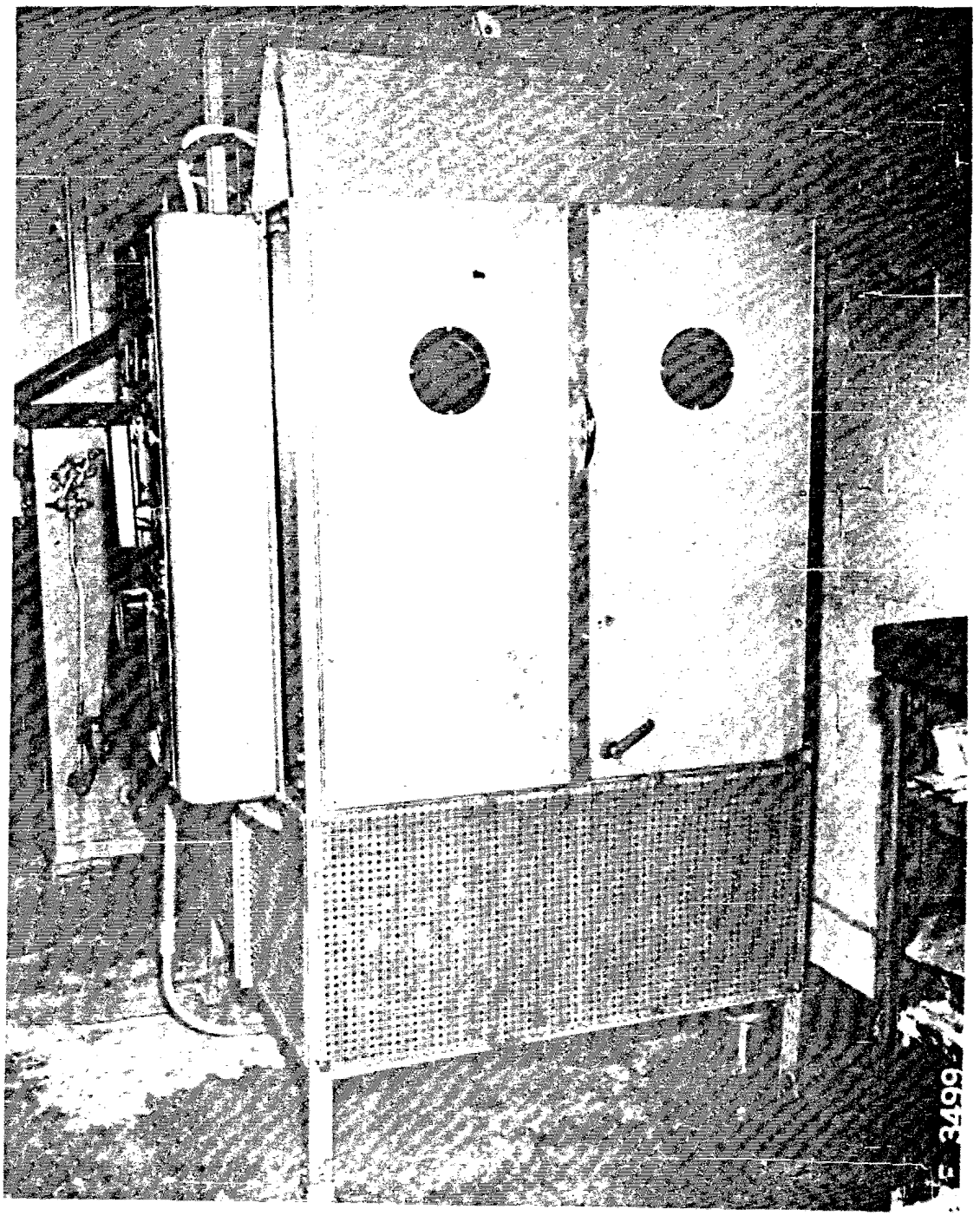


Fig. 102 Specimen 5A.1 after 980 cycle wear test. Appearance was the same after 50 cycles.



RF 3499-2

Fig. 103 Twin-Arc Weather-Ometer, Type DLTS-X (closed), manufactured by Atlas Electric Devices Company, Chicago, Illinois.

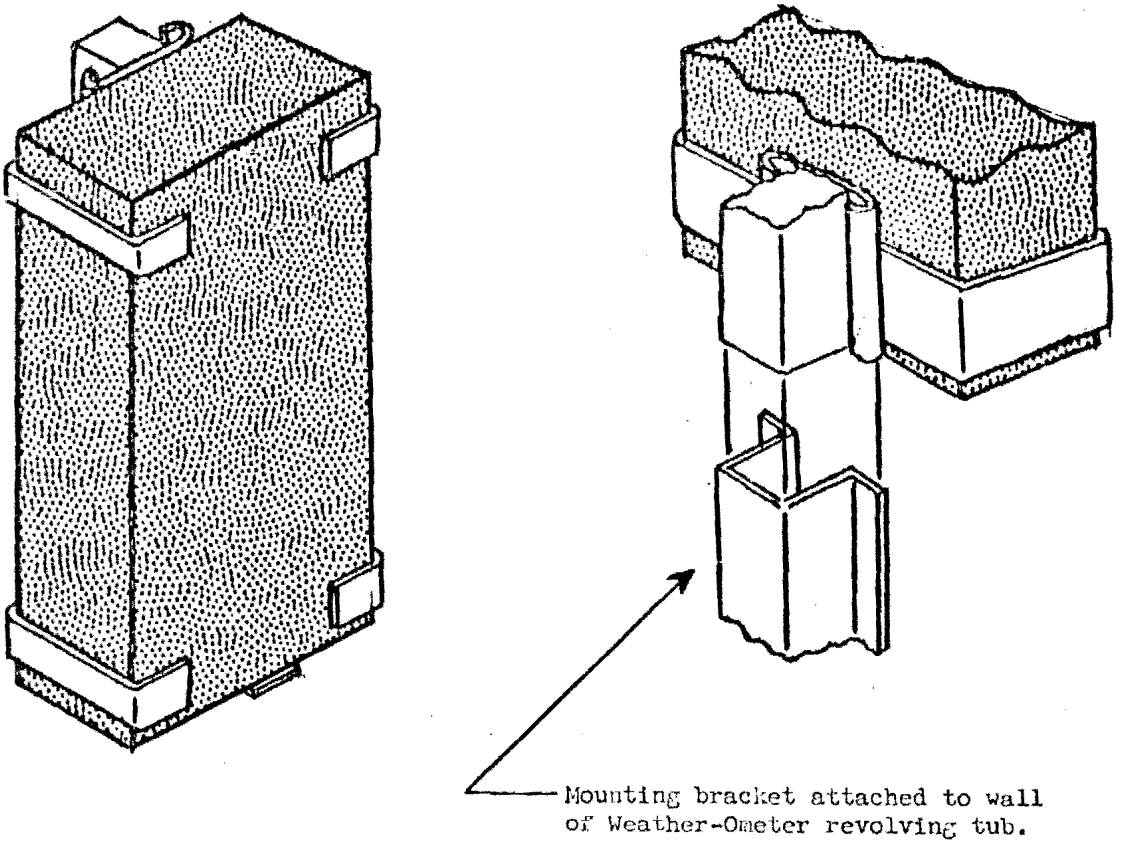
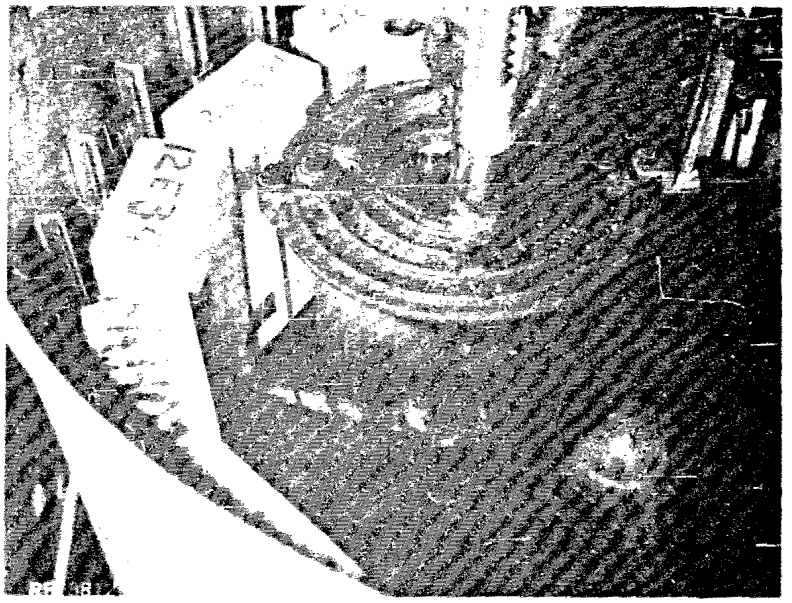
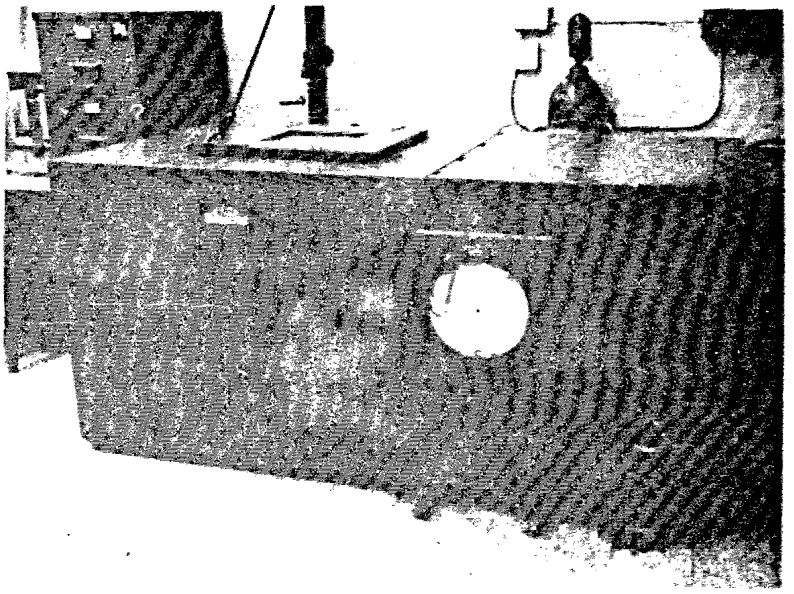


Fig. 104 Illustration of holding fixture for Weather-Ometer



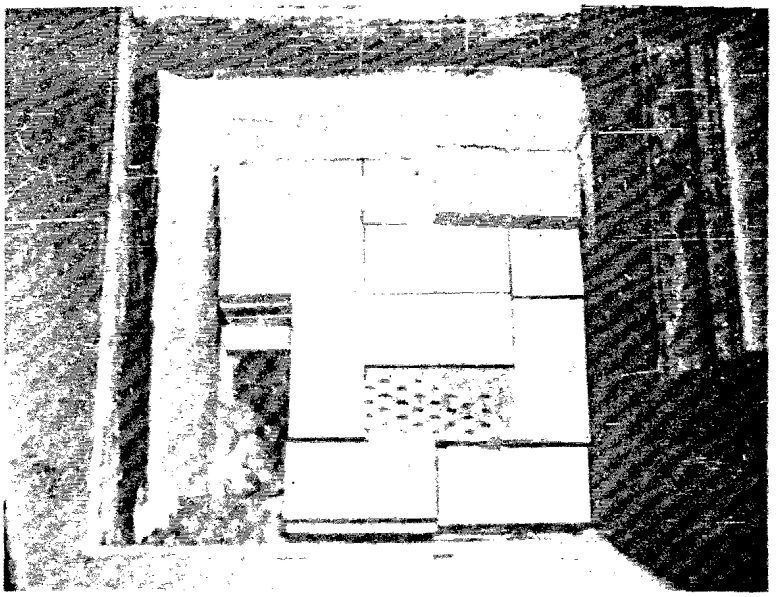
RF 8812-3

Fig. 105 Twin - Arc Weather-Ometer, Type DLTS-X (open), manufactured by Atlas Electric Devices Company, Chicago, Illinois.



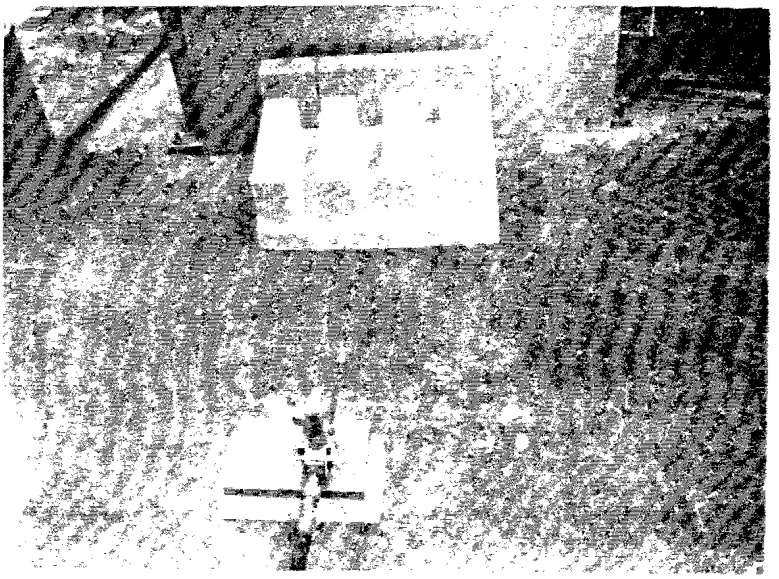
RF 3499-1

Fig. 106 Alpha Low-Temperature freezing box (closed), manufactured by Alpha-Electric Refrigeration Company, Detroit 3, Michigan.



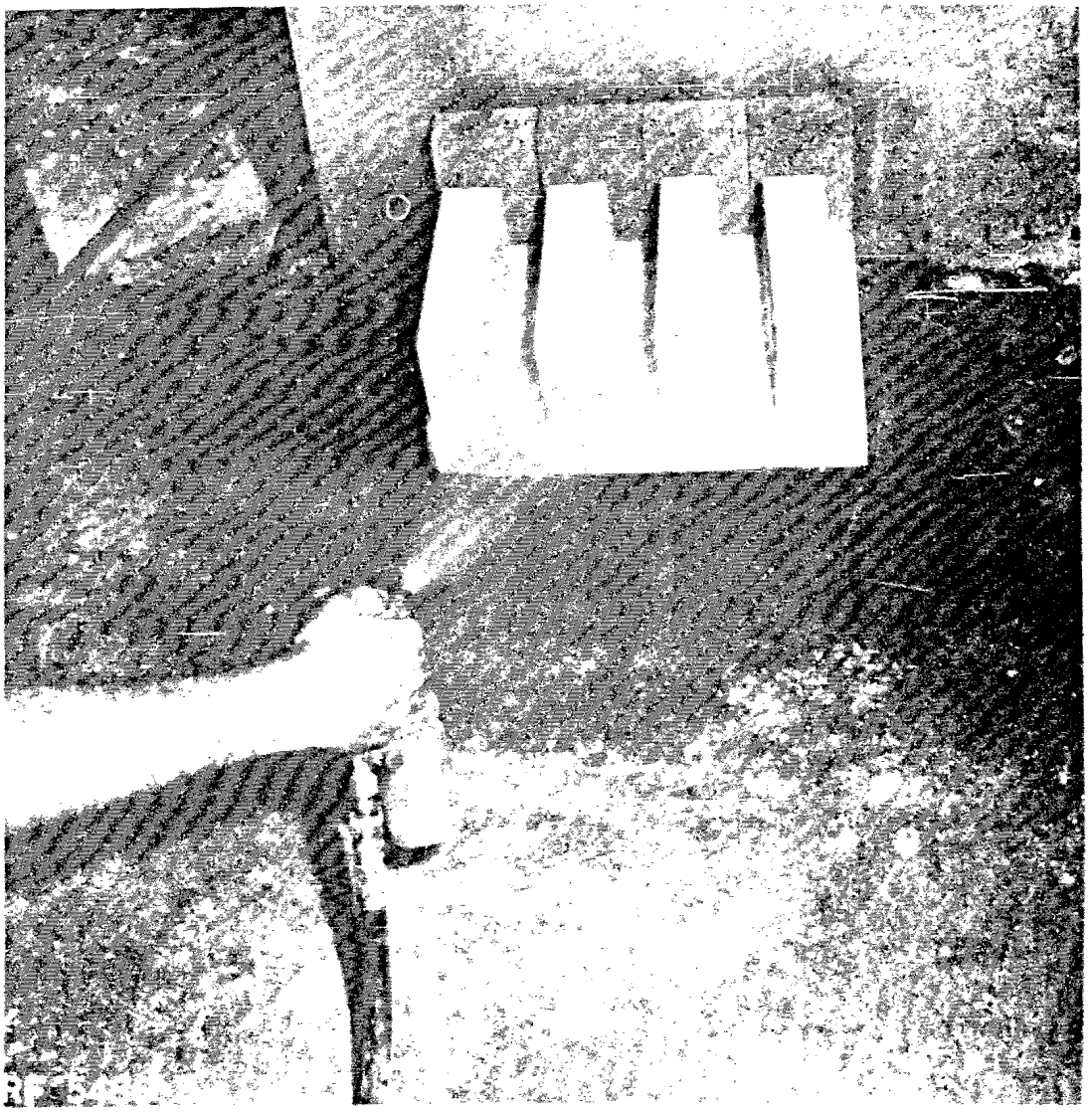
RF 3812-2

Fig. 107 Alpha Low-Temperature freezing box (open), manufactured by Alpha-Electric Refrigeration Company, Detroit 3, Michigan.



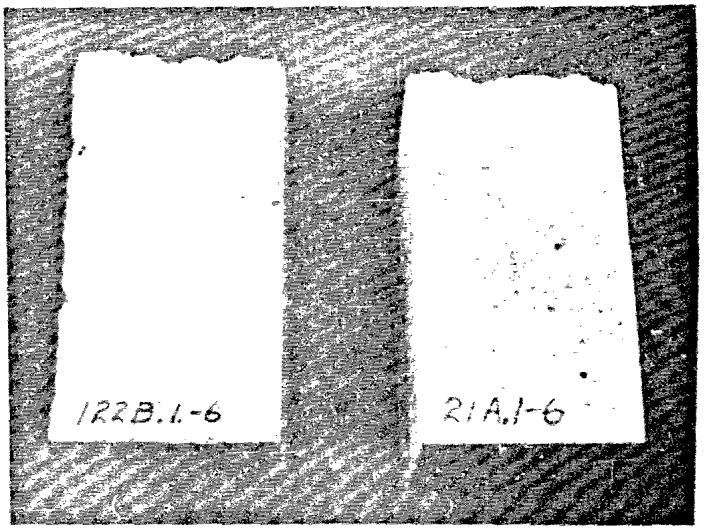
RF 5486-4

Fig. 108 Thermal shock test air blast cycle.



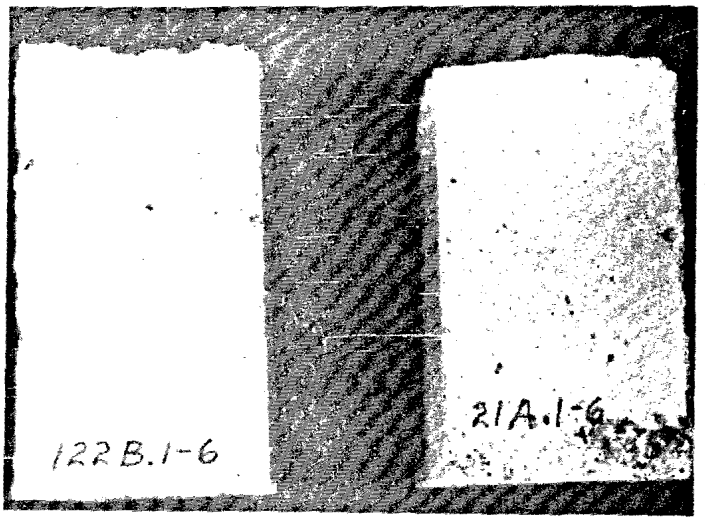
RF 5486-3

Fig. 109 Thermal shock test water spray cycle.



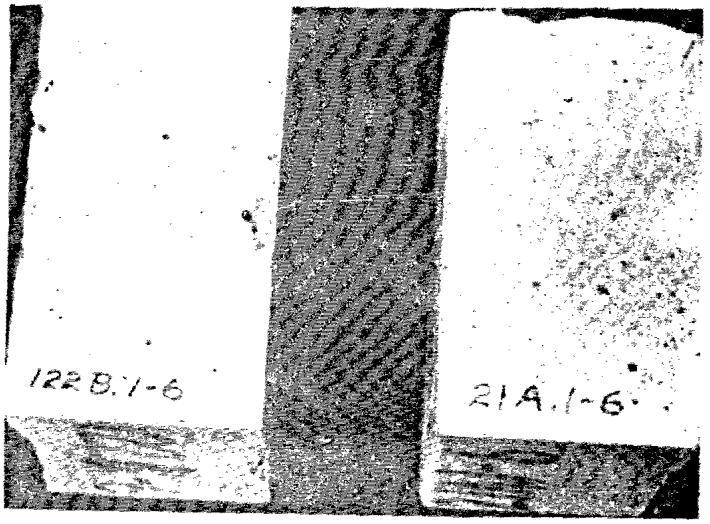
RF 6602-5

Fig. 110 Thermal shock test specimens 122B.1-6 and 21A.1-6 after 5 air-cooled cycles.



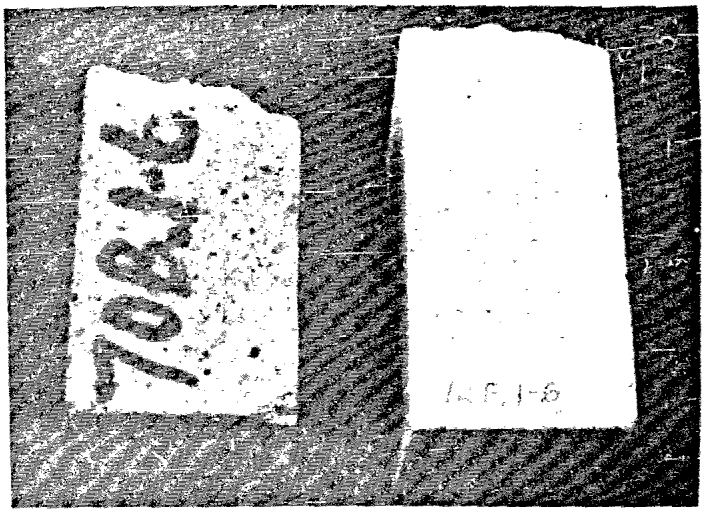
RF 6678-1

Fig. 111 Thermal shock test specimens 122B.1-6 and 21A.1-6 after 10 air-cooled cycles.



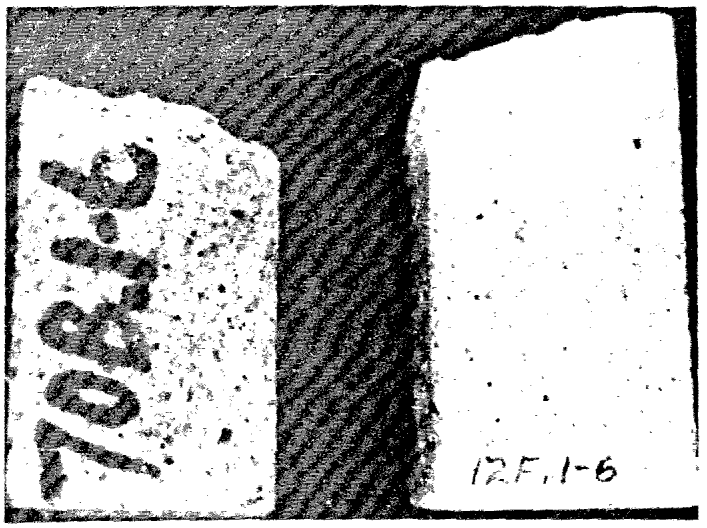
RF 6695-5

Fig. 112 Thermal shock test specimens 122B.1-6 and 21A.1-6 after 10 air-cooled cycles and 5 water-cooled cycles.



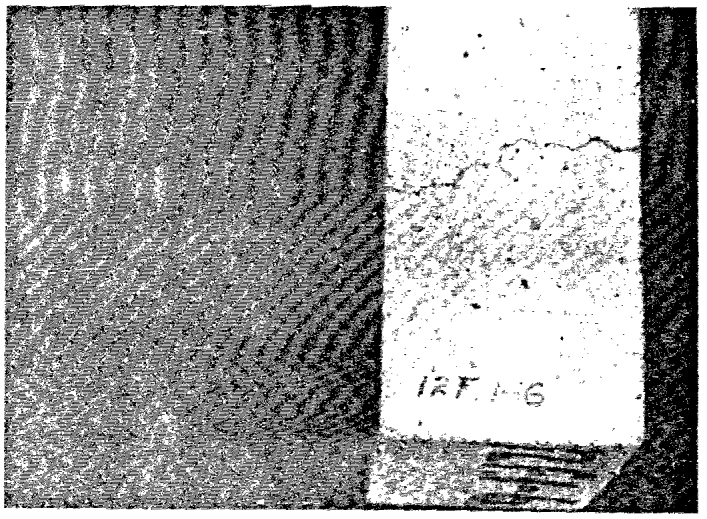
RF 6602-2

Fig. 113 Thermal shock test specimens 70B.1-6 and 12F.1-6 after 5 air-cooled cycles.



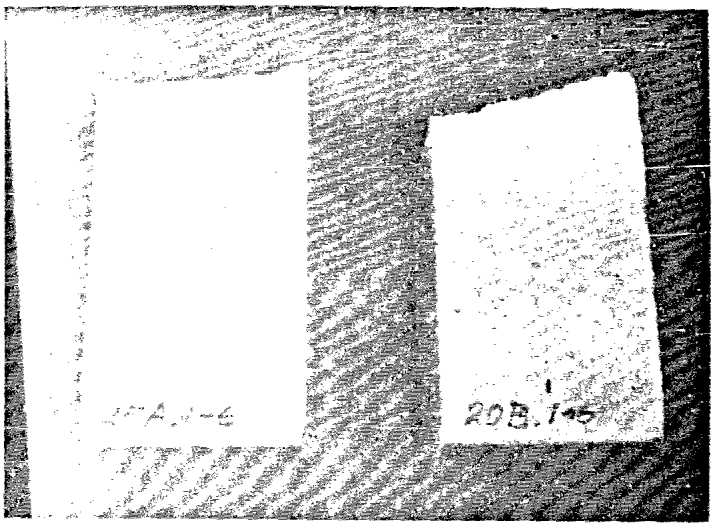
RF 6678-6

Fig. 114 Thermal shock test specimens 70B.1-6 and 12F.1-6 after 10 air-cooled cycles.



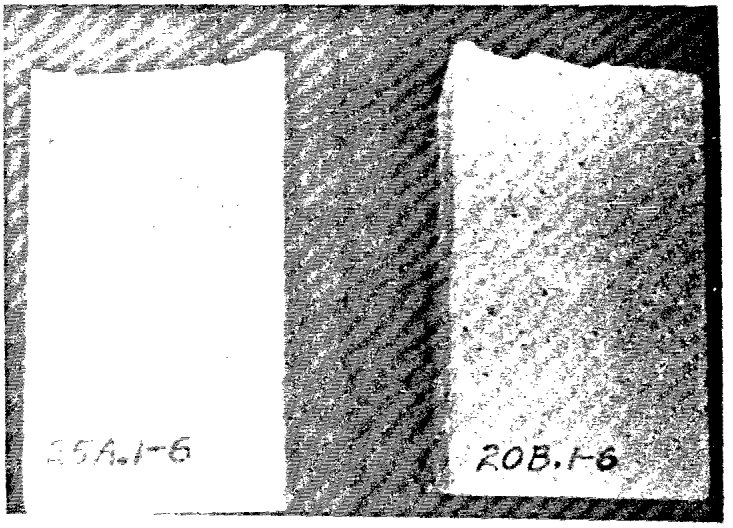
RF 669[illegible]-3

Fig. 115 Thermal shock test specimen 12F.1-6 after 10 air-cooled cycles and 5 water-cooled cycles.



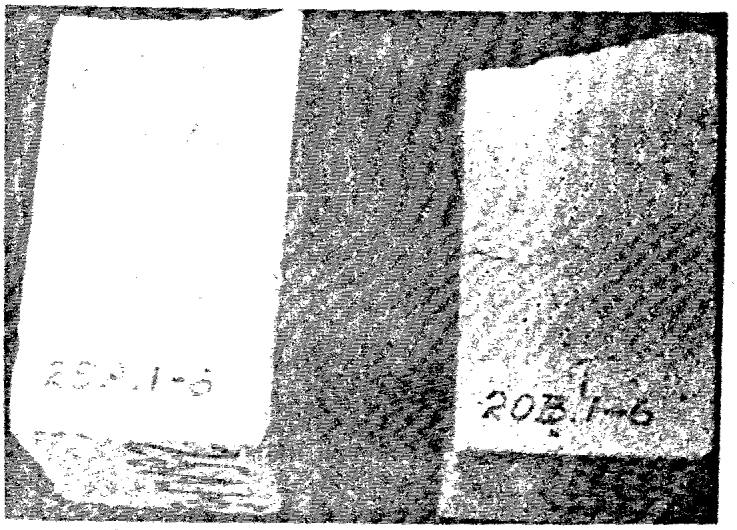
RF 6602-3

Fig. 116 Thermal shock test specimens 25A.1-6 and 20B.1-6 after 5 air-cooled cycles.



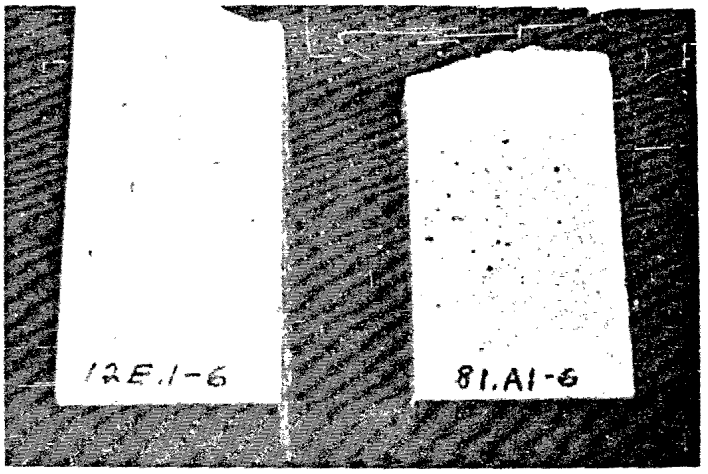
RF 6678-5

Fig. 117 Thermal shock test specimens 25A.1-6 and 20B.1-6 after 10 air-cooled cycles.



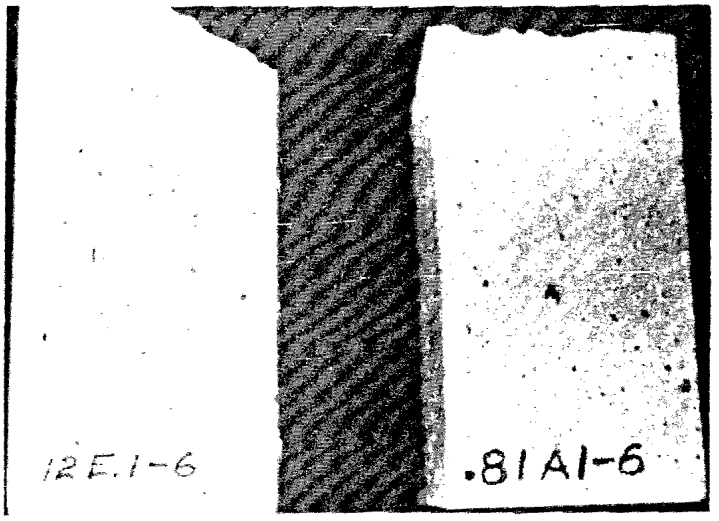
RF 6695-4

Fig. 118 Thermal shock test specimens 25A.1-6 and 20B.1-6 after 10 air-cooled cycles and 5 water-cooled cycles.



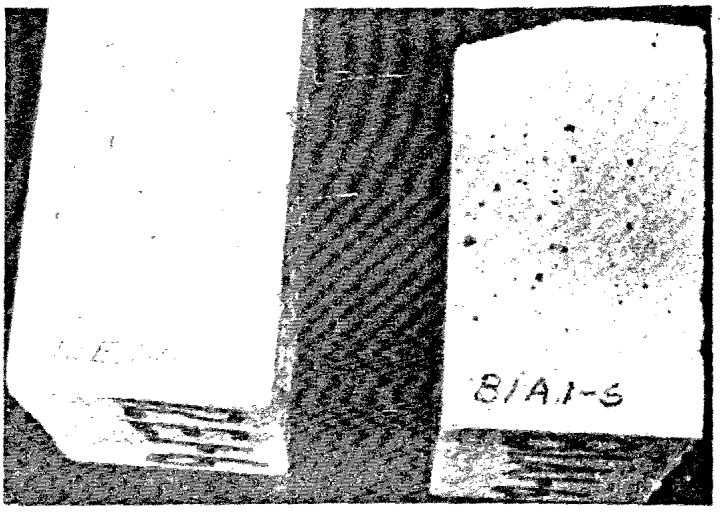
RF 6602-4

Fig. 119 Thermal shock test specimens 12E.1-6 and 81A.1-6 after 5 air-cooled cycles.



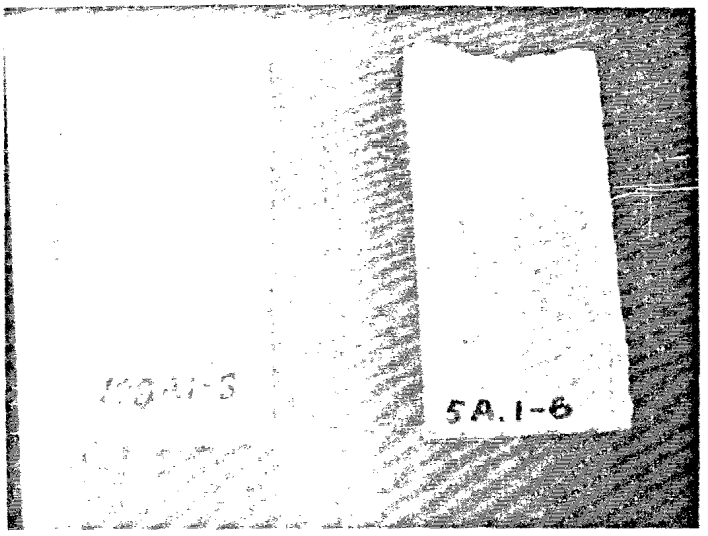
RF 6678-5

Fig. 120 Thermal shock test specimens 12E.1-6 and 81A.1-6 after 10 air-cooled cycles.



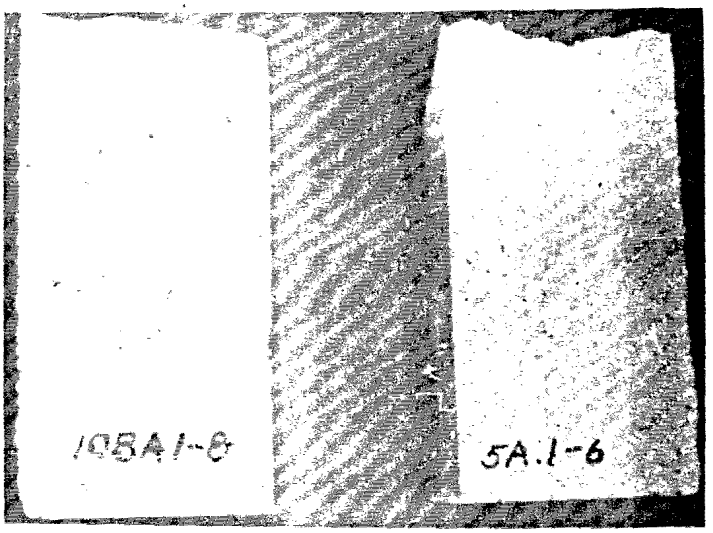
RF 6695-6

Fig. 121 Thermal shock test specimens 12E.1-6 and 81A.1-6 after 10 air-cooled cycles and 5 water-cooled cycles.



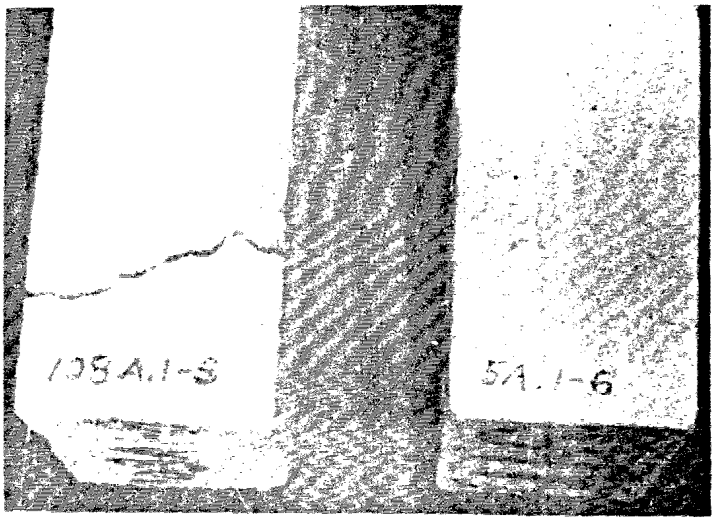
RF 6602-2

Fig. 122 Thermal shock test specimens 108A.1-8 and 5A.1-6 after 5 air-cooled cycles.



RF 6678-3

Fig. 123 Thermal shock test specimens 108A.1-8 and 5A.1-6 after 10 air-cooled cycles.



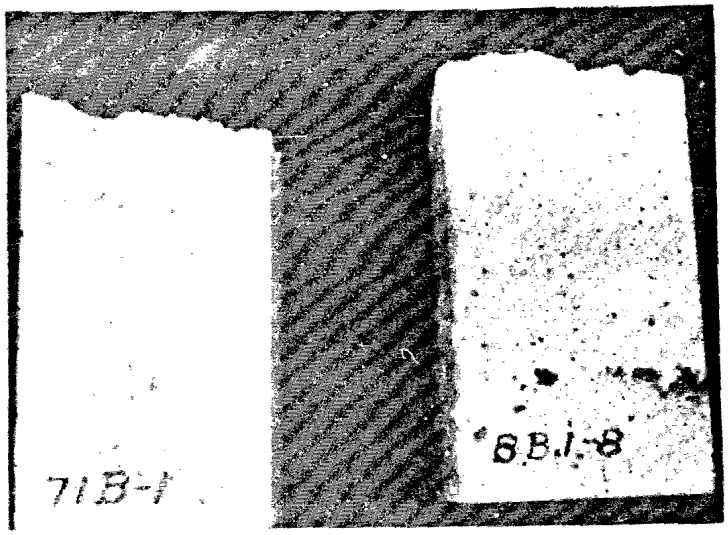
RF 6695-10

Fig. 124 Thermal shock test specimens 108A.1-8 and 5A.1-6 after 10 air-cooled cycles and 5 water-cooled cycles.

PHOTO NOT AVAILABLE

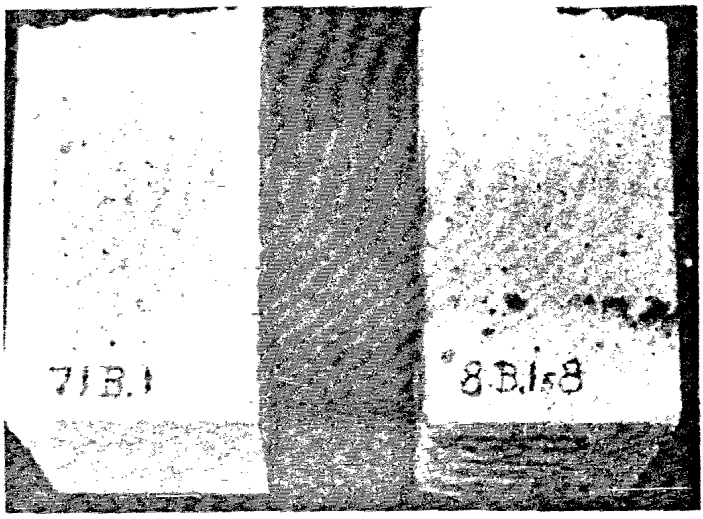
RF 6602-

Thermal shock test specimens 71B.1 and 8B.1-8 after 5 air-cooled cycles.



RF 6678-4

Fig. 125 Thermal shock test specimens 71B.1 and 8B.1-8 after 10 air-cooled cycles.



RF 6695-2

Fig. 126 Thermal shock test specimens 71B.1 and 8B.1-8 after 10 air-cooled cycles and 5 water-cooled cycles.

EXHIBIT 6

FIFTY-TON EXPERIMENTAL HYDRAULIC RESISTANCE HEAT TREATING AND FORMING PRESS

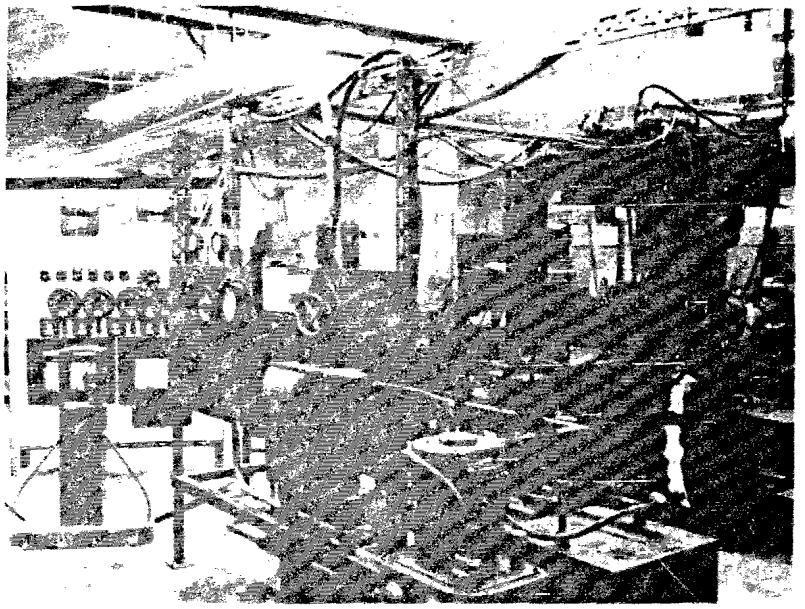
This press can be adapted for a wide range of applications because of its universal construction. It is equipped with two pairs of platens which can be interchanged in less than five seconds. The platens are 20" wide x 32" long. The part to be heated and/or formed is held between the platens in a horizontal position by water cooled jaws which are electrically insulated from the frame of the press. The part can be resistance heated to any desired temperature up to its melting point. In addition to acting as electrodes, the jaws are hydraulically operated for applying up to 25 tons tension to the sheet. The press will handle sheets up to 18" x 36". By suitable sequencing of the heating, ram action and tension cylinder action, the press can be adapted to numerous heat treating and forming experiments. The press is shown in Figure 1, Page 276.

100 KVA Resistance Heating Power Supply and Automatic Control System

Used in conjunction with the press for resistance heating applications is the 100 kva high current power supply shown in Figure 2. The power input to the part being heated can be continuously varied up to the maximum capacity of the supply. Variation can be made manually or automatically. For automatic operation, any desired temperature-time relationship can be programmed by means of a conductive line follower programmer. This allows any desired heating cycle to be repeated an indefinite number of times without introducing human error. The line follower programmer, recorder-controller, and error amplifier are shown in the lower half of Figure 3.

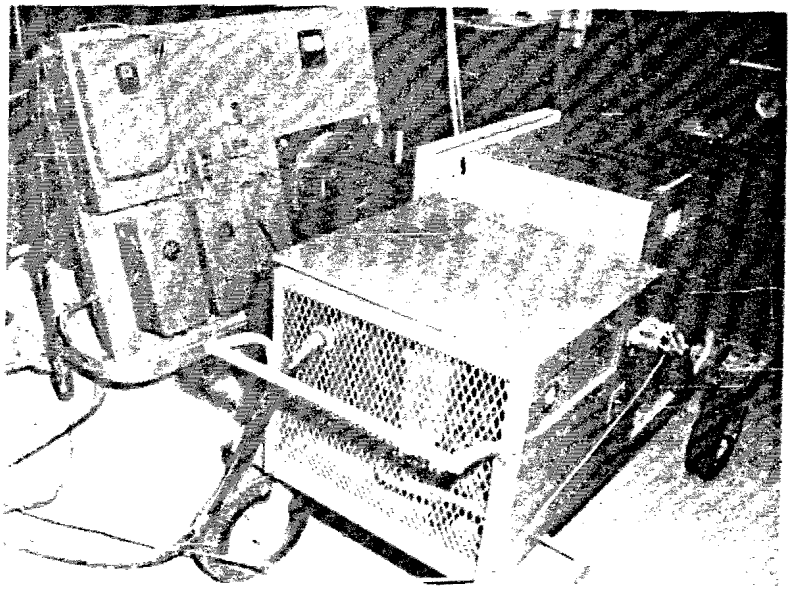
Temperature and Pressure Monitoring System

The instruments shown on the panel in Figure 4 are used to monitor all significant variables during test runs of the experimental hydraulic press. Included are provisions for indicating temperatures at up to 24 thermocouple locations on a test sheet. Six thermocouples can be read simultaneously on instruments 1 thru 6, Figure 3, and remaining ones can be read in groups of six by means of electrically operated stepping switches A, B, C and D. The pressures at each end of the hydraulic ram and tension cylinders are indicated by the large dial instruments on the panel for determination of forces applied to the sheet. Electrical power being applied to the sheet is indicated by the load voltage and current meters just above the line follower programmer and recorder-controller. The readings of all panel instruments are recorded with a 35 mm motion picture camera for later study and evaluation.



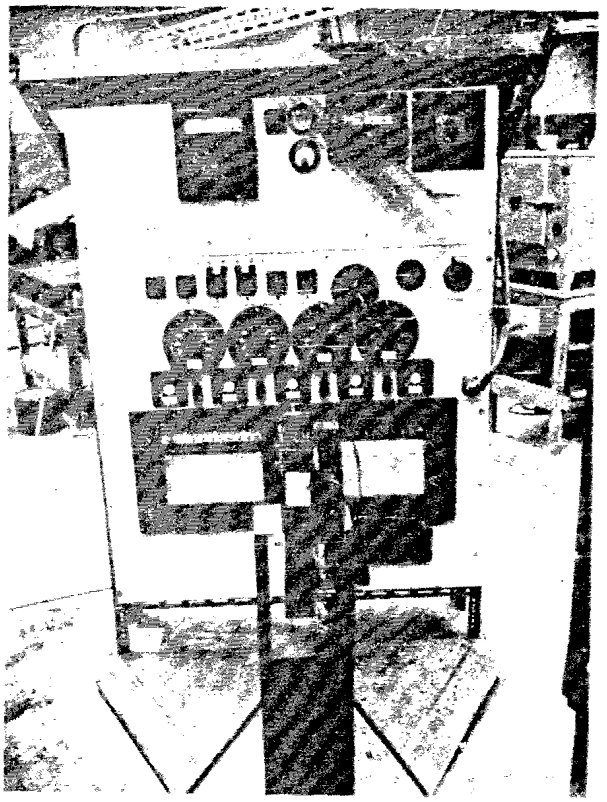
RF 6697-7

Fig. 1 Fifty-ton experimental resistance heat treating and forming press with control panels.



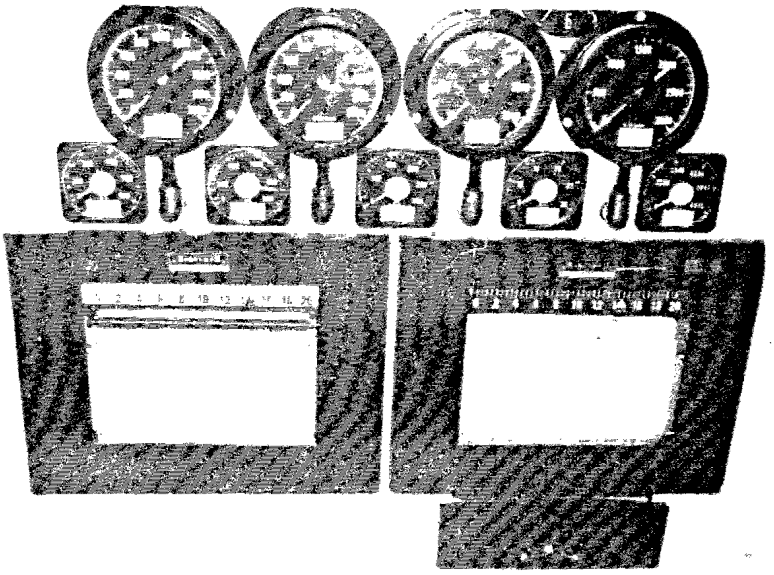
RF 4862-1

Fig. 2 100 KVA resistance heating power supply.



RF 6051-2

Fig. 3 Automatic control system.



RF 3271-2

Fig. 4 Close up of line follower programmer (left), recorder-controller and error amplifier.

PHASE IV
TOOLING EVALUATION
January thru June 1960

INTRODUCTION

For ease of performance, this phase has been divided into three parts. First is a preliminary investigation of mold construction. This obvious beginning step in the manufacture of cast type tools must be readily accomplishable with materials and techniques suitable for the different types of refractory castables. Next follows a laboratory-size evaluation of metal forming tools made from various castables. Finally, there is the fabrication and testing of production size tools making simulated production parts.

PART I - MOLD CONSTRUCTION

PROCEDURE

A multiple groove tool (similar to Figure 127, Page 315) simulating those that the Contractor used to braze stainless steel honeycomb structures, presented an opportunity to use different materials for the groove forms in the mold. Groove forms were made of wax, wood, K-25* and pottery** plaster and plastic. Aluminum cores were used for the mounting bolt hole forms. The wax, plaster and plastic groove forms were made by pouring the respective liquid materials into an aluminum mold. The wood forms were made on a conventional wood shaper. The aluminum cores were turned on a lathe in the usual manner.

The mold with the different material groove forms is shown in Figure 128. The lower part of the mold is hard setting plaster previously poured in a box between templates shaped as shown and splined to their contour.

The mold was given various surface preparations using clear cellulose nitrate lacquer, Simoniz Wax, DC-4 silicone cut with naphtha and Keltex***.

Castings were made of both calcium aluminate and phosphoric acid bonded materials and the different groove forms examined for evaluation of use as mold materials. Figures 129 and 130, Page 316, show some of these castings.

Figure 127 shows a calcium aluminate bonded, 5A.1, casting with square corner rib ends and sides. Some damage to the tops of a few ribs is evident. Figure 129 shows a mating casting of the same material whose rib ends and edges have been rounded. This made it easier to remove the casting from the mold and, consequently, reduced damage. Figure 130 shows the results, on a calcium aluminate type material, of either too little water or too little vibration or a combination of both.

*Product of Bestwall Gypsum Company
**U. S. Gypsum Company, No. 1
*** Product of Kelco Company, Los Angeles, California

DISCUSSION OF RESULTS

The following summarizes the results of the investigation:

1. Wax forms are too temperature sensitive for use.

2. Wood forms are too difficult to seal to prevent sticking of the castable ceramic to them.

3. K-25 with proper surface preparation is satisfactory for calcium aluminate bonded castables.

4. Epoxy plastic with proper surface preparation is satisfactory for calcium aluminate.

5. Pottery plaster with proper surface preparation is satisfactory for slip cast fused silica materials.

6. Square corners on molds should be avoided.

Based on the knowledge of mold materials and the technique of their use gained from this study the contemplated methods of mold construction were decided upon.

Molds are to be made by using a model of the tool desired, coating it with silicone or Keltex parting agent, boxing it in, and pouring or placing the mold material over and around it. Molds made of K-25 plaster are to be made by pouring wet plaster over the silicone coated model, allowing the material to harden before stripping it from the box form, and removing the model; then sealing the cavity with clear lacquer, waxing and polishing and spraying with silicone grease cut with naphtha. Molds made of pottery plaster are to be made identically except that Keltex is to be used and no sealing is to be applied to the cavity. The epoxy resin impregnated glass cloth molds are to be made using the tool model as a layup block, and following standard procedure for using tooling plastics.

The procedure for making plastic molds involves first coating the model with a parting agent. A thin face coat (gel coat) of resin is then applied directly to the model and allowed to partially set up (gel). This coating masks the texture of the glass reinforcing cloth and prevents entrapment of air bubbles next to the model. The Magnolia Plastics Inc. Tooling Plastic consists of six parts by weight of No. 1047 Resin to 1 part by weight No. 214 Hardener. Normally, eight layers of glass cloth (weight and weave optional) are put in a laminate by wetting each layer in place with a full brush coat of resin. A 48 hour cure is given before the mold is removed from the model or pattern.

PART II - LABORATORY SIZE TOOL EVALUATION

INTRODUCTION

The following coded materials, representing the best qualified products as determined by Phases II and III of this investigation, were selected for tool development on a laboratory-size scale. It was believed expedient to gain experience in the making and using of small ceramic tools before attempting to build and use large size tools.

5A.1	25A.1
12E.1	108A.1
12F.1	

It should be noticed that none of these five materials is a ramming mix.

Ramming mixes, at this time, cannot be considered for tooling use for four reasons. First, this method of placement exerts large forces on the mold. In order for a mold to have the strength to retain its shape under the punishing forces of ramming, a mold must be much stronger than for the casting method of placement. This strength requirement could only be met by impractically heavy metal or cement molds. Plaster, plastic, wood or sheet metal molds would not normally have sufficient rigidity. In support of this opinion are the data of Table 15, which shows the expansion of the standard brick-size rammed test specimens. In almost all cases these specimens' expansion sprung the sides of the heavy aluminum molds.

The second reason that ram type castable refractories cannot be considered for tooling use is the longer time required for their placement. The third reason is the degree of dependence on the skill of the operator. It is an art to ram place a large castable satisfactorily without harmful laminations.

Fourth, is the impracticality of casting-in cores and inserts to acceptable tolerances, as these tend to be displaced by the ramming action.

PROCEDURE

The five castable refractory materials selected for further work were used to conduct a small scale evaluation of ceramic tooling. The tools, typical of those used in aircraft plants, are a hydroform block configuration, a stretch form block configuration, and a double action draw press die configuration. They were made by casting the refractory materials in various type molds. A hydraulic press* specially equipped for use with ceramic tooling was used to accomplish the forming processes. AISI 420 corrosion resistant steel 0.031 inch thick was used as the part material. Consequently, a forming temperature of 1850 F was used to accomplish simultaneous forming and heat treating. Table 31, Page 299, lists the methods and treatments used in making each type of tool and designates the castable used.

*See Exhibit 6, Page 275.

Hydroform Block

Tool Fabrication

A curved channel shape was chosen as being a typical part for the hydroform type tool. The form block is 1 1/2 inches high, 2 inches wide and approximately 11 inches long (see Figure 131, Page 317). A model of the hydroform block was made of plaster and from it split molds were made of K-25 plaster, No. 1 pottery plaster, and an epoxy plastic-glass cloth laminate (see Figures 132, 133 and 134). Provisions were made to incorporate part locating pins in the tool.

The phosphoric acid castable, Code 108A.1, stuck to the surface of the plastic mold to the extent that the surface was roughened and pitted when the casting was removed. This adherence of the phosphate bonded castable to the plastic mold occurred regardless of the special attention given the application of sealing coats and the silicone parting agent.

Vibration was applied at the frequency and for the time which was found to be optimum in Phase II, i.e., 10,000 vibrations per minute for a maximum of one minute. Internal vibration, applied by the flexible shaft vibrator shown in Figure 15, Page 151, was used when casting in K-25 plaster molds. The plastic mold was attached to a base which was adapted to fit the vibrator table used previously to vibrate the specimen molds (see Figure 12). One 25A.1, fused silica, hydroform block was cast without vibration by first thinning the regular mix with additional 25B.1 slip material then pouring it carefully onto the bottom of the mold taking care not to let any run down the sides and trap air bubbles in the casting. The No. 1 pottery plaster mold was used after spray coating the mold cavity with Keltex parting agent. A water suspension of Keltex sprays like lacquer.

Attempts were made to smooth off the base surface of the hydroform blocks to prevent uneven loading from breaking them when forming pressure was applied by the rubber punch. Due to the short setting time and coarse grog particles in some of the castables, it was impossible to trowel or screed the surface smooth enough. A satisfactory surface was achieved by placing the finished tool in a puddle of plaster poured in a thin layer on a surface plate which had been first sprayed with a water emulsion of silicone as a parting agent. When the plaster set up, the tool with plaster base was slipped on the plate, removed and placed in an oven to cure. The 12F.1 and 25A.1 castables which require firing at 1000 and 2000 F respectively had their plaster bases applied subsequent to firing.

Testing

Tools were set in the press on a 10 x 15 inch platform designed to fill the opening in the bottom of the punch box. The rubber contained in the box could thus be trapped and caused to transmit the pressure provided by the hydraulic ram to the entire surface of the tool. A developed blank was positioned by the locating pins over the block and electrically connected to the electrodes by flexible straps (see Figure 135). A low-voltage, high-amperage power supply provided the current to heat the blank by its own

resistance to the temperature required for austenitization. The 1850 F temperature, determined by a chromel-alumel thermocouple, was maintained for at least 30 seconds before closing the press to allow austenite formation and, consequently, assure transformation on cooling. A hydraulic pressure of 2000 psi was applied to an 8 inch diameter ram thus providing a unit pressure of approximately 650 psi in the trapped rubber punch to form the heated metal around the ceramic form block.

To protect the rubber punch from the hot metal, several ceramic fiber materials were used. These included a 1/8 inch thick loosely woven blanket*, cloth**, mat***, and bulk in the form of a batt****. The blanket was hung under the face of the punch by wires and an elastic band. A corner of the blanket can be seen in Figure 135. It did not afford sufficient protection as the action of the rubber in forming the flanges of the metal over the edge of the block tore the blanket exposing the rubber to the hot metal. The cloth was much thinner than the blanket even when doubled, but slippage occurring between the layers nullified the forces acting to tear the brittle material and better protection was achieved (see Figure 136). The mat (Figure 137) tore when used as did the blanket. The bulk insulation yielded the best protection (see Figure 138). Bulk material comes as a loosely rolled ribbon 2 to 3 inches thick and 30 inches wide. It has a texture very much like absorbent cotton. In use, a cushion of proper size is easily shaped and laid in position on top of the part blank where it remains during the heating and forming cycle.

Stretchform Block

Tool Fabrication

A block that would form a saddle shaped configuration was chosen for laboratory evaluation of ceramic stretchform tooling (see Figure 139). An existing production stretchform block was selected for use as a model and from it three molds were made. These molds were made of K-25 plaster (see Figure 140), No. 1 pottery plaster, and an epoxy plastic bonded glass cloth laminate.

Materials 5A.1, 12E.1, and 12F.1 were cast in the K-25 mold; 25A.1 material was cast in the No. 1 pottery plaster mold except for one trial in K-25 mold; and 108A.1 in the plastic mold. Except for the 25A.1 material, the molds were sealed. Internal vibration at 10,000 vpm provided by the flexible shaft vibrator was used in making all castings. A three minute maximum time of vibration was used to cast materials for this tool. This time was determined visually as being that which properly compacted the wet castable (approximately 200 pounds) without danger of segregation.

Smooth surfaced castings were obtained from all materials except the 108A.1 material. Areas stuck to the mold as noted before and left pits and rough spots on the tool made from this castable. It was observed that the 108A.1 material became too hot to touch while it was setting up.

*Fiberfrax ceramic fiber Product No. 120, product of the Carborundum Company
**Refrasil, product of H. I. Thompson Company
***Kaowool, product of Babcock and Wilcox Company
****Kaowool, product of Babcock and Wilcox Company

Attempts to obtain flat surfaces by screeding or troweling on the bottom of these tools were abandoned as with the hydroform blocks. Flat bases for mounting in the press were made as before by pouring wet plaster in a puddle on a surface plate and setting the tool in it.

Testing

All laboratory size stretchform blocks were set up in the experimental press for evaluation. The tension frame was fitted with two metal backed quarter round ceramic rails so that the AISI 420 stainless steel blanks would be wrapped around the stretchform blocks by the action of the rails while being restrained at each end by the jaws of the tension frame.

Figure 141 shows, on the right, the mold used to make the 8A.1 quarter round rails, one of which is shown on the left. One leg of the steel angle has been trimmed flush with the ends of the ceramic to enable its placement in the tension frame as shown in Figures 142 and 143. To add rigidity to the quarter round rails, steel angles were "C"-clamped to each. As the tension frame, which is attached to the ram of the press, descends, the ceramic quarter round rails cause the frame to act like a female die in wrapping the blank around the punch.

The jaws of the tension frame were electrically insulated so that current could be passed through the blank by the jaws, thus heating the blank by its own resistance.

The blank was heated to 1800 F before contact was made with the stretchform block. Although the blank was not in contact with the tool during the heating period, the surface of the ceramic tool was heated considerably by radiation. When the blank reached the required temperature, it was forced downward by the draw rails and wrapped around the stretchform block. Contact was continued until the blank was chilled by the tool and was then withdrawn so that the blank temperature again reached 1800 F. This forming action was continued until the desired shape was obtained. The formed blank was allowed to cool while in contact with the block.

After cooling, the formed part was removed from the press jaws and inspected. An inspection was also made of the surface of the ceramic tool.

Draw Die

Tool Fabrication

To represent tooling typical of the double action drawpress type, a bottomless or double ring die was chosen. This tool is to form a rectangular pan 7 inches wide by 8 inches long by 3 to 4 inches deep - one end being 1 inch deeper than the other (see Figure 144). In use, a blank sheet of metal was heated, clamped between the two rings placed face to face, and the punch pushed through the openings thus wrapping the metal around the punch and over the lower ring radius.

In addition to the K-25 plaster molds shown in Figures 145 and 146, which were used to cast the hydraulic setting castables 5A.1, 12E.1 and 12F.1, No. 1 pottery plaster molds were made primarily to cast 25A.1, and plastic molds were made for 108A.1 and used also for some other materials as indicated in Table 31. Because of the necessity for parallel sides on the punch casting, a split mold was needed. The plug which forms the opening in the ring casting is removable by jack screws and has only 0.005 inch draft in its 4 inch overall height. The No. 1 pottery plaster mold was made similar to the K-25 plaster mold, but the plastic mold was made open faced. The plaster molds were filled standing on edge and the mix was vibrated by the flexible shaft vibrator. The plastic mold after coating with Simoniz wax and peanut oil, was filled laying flat and vibrated by the pneumatic vibrator. Satisfactory castings were obtained of all but the 108A.1 material. As before, much heat was evolved and the casting stuck to the mold in patches yielding rough and pitted surfaces.

Testing

The laboratory size draw dies were set up for evaluation in the experimental press (refer to Figure 147). A double acting head attachment was fastened to the press ram so that the pressure pad and the punch would be incorporated in a single unit.

The ceramic tool components were attached to the double acting head and supported by means of independent vacuum chucks.

The components were aligned with shims between the punch and the draw ring before being picked up by the vacuum chucks.

The AISI 420 blank was clamped between the jaws of the tension frame so that the blank could be kept taut during the forming operation. The jaws also served as electrodes for resistance heating the blank. The temperature of the blank was maintained at 1400 F during the forming operation. 1400 F was used because this material(32) has maximum elongation at this temperature.

The ceramic pressure pad was closed on the blank while it was being heated so that the draw ring and the pressure pad were also heated on the surface to some extent.

When the temperature of the blank stabilized, the ceramic punch was forced downward by the double acting head while maintaining a pre-set pressure on the pressure pad. The pad pressure is adjustable by varying the air pressure to the outer ram of the double acting head attachment. On different trials the pressure was changed from a -10 to + 30 psi with + 5 psi being found as the optimum pressure to produce the desired slight drag on the blank as it was being drawn. This 5 psi on the pressure pad ram produced approximately 1 psi holding pressure on the blank.

The metal blank was cooled by the cold ceramic punch as it came into contact and forced it down into the draw ring cavity. Thermocouples were

attached to the blank in the area that contacted the punch so the forming temperature could be monitored. When the sheet cooled to 1000 F, the punch was withdrawn so that the blank temperature could be returned to 1400 F. This procedure was repeated until the blank or ceramic punch failed.

When the test was completed, the tools and formed blanks were checked for damage.

DISCUSSION OF RESULTS

Testing of the Code 108A.1* material must be discontinued until it can be ascertained that the castable can be obtained with longer storage life. The material now in stock must be discarded. The cans containing the wet portion of the two-part castable mix have been corroded through by the contents. The resultant loss of material has rendered it non-representative by changes in properties due to the loss.

Hydroform Block

A part immediately after forming is shown in Figure 148. Note how the rubber punch has formed the metal down over the ends of the block. As the metal cools and contracts it transmits forces to the block which break off the top edge of each end (see Figure 149). Most hydroform blocks broke in use in this manner. A block cast with sloping ends in a mold altered with modeling clay did not break (see Figure 150).

Surface finishes obtained on all but the phosphoric acid bonded castable were acceptable and indications are that a duplication of the finish in the mold cavity can be achieved. The 108A.1 material was roughened and pitted because of sticking in the mold. No evidence of abrasion is evident on the surface of tools after use, due probably to the fact that very little sliding of the metal on the block takes place in this type of operation.

Fine, almost invisible, spall cracks occur on the surfaces of calcium aluminate bonded tools after use. No bad effects due to them were observed after forming five parts on one particular block.

Fully formed parts have been run on form blocks made of four of the five selected refractory castables. The extreme temperatures used enable the low unit forming pressure of approximately 650 psi as contrasted to 3000 psi** pressure for room temperature forming. Table 32 gives test data and results obtained by running parts on the hydroform equipment described. Part Number 7, run on the block cast in the altered mold, indicates that proper tool design can eliminate some of the problems presented by the fragile nature of ceramic tooling materials.

*Shortly after this evaluation, the supplier of material Code 108A.1 added an internal lubricant and improved his packaging which solved the storage problem. The supplier recommended using, as a parting agent, a latex base paint over a waxed surface. This remedy subsequently proved successful.

**Using Verson-Wheelon Press

Stretchform Block

No damage was incurred on any of the stretchform blocks and most of the blanks formed successfully. Difficulty was encountered in tearing of the blanks at the point at which contact was made with the quarter round ceramic draw rails. Air circulation was prevented by contact with the rails and the insulating properties of the rail material,Code 8A.1, retarded absorption of heat from the blank, so a hot area developed under the rails. This area, because of the temperature difierential, had a lower tensile strength than the surrounding metal, so failure under load occurred there (see Figure 151). Table 33 gives test data and results obtained by running parts on the stretch form setup.

Draw Die

Failure by the shearing of the edges and sides was encountered in all of the punches tested (see Table 34 and Figure 152).

A failure also occurred in the 12E.1 material draw ring. This failure was caused by the expansion of entrapped water in the casting which was not removed by drying (see Figures 147 and 153).

A successful draw depth of approximately 1 inch was obtained with the .031 inch thick AISI 420 stainless steel blanks at 1400 F. Several blanks failed at or near this depth by bursting the bottom out of the drawn shape, as shown by Figure 154.

Table 34 gives test data and results obtained by running parts on the draw dies of the various materials.

CONCLUSIONS

1. Materials requiring ram type placement are unsuitable for tooling because of impracticability of mold construction.

2. Tools of each type have been successfully made of all five selected materials except 108A.1.

3. A second operation is required to have a plane surface base on a tool as screeding a flat surface during the casting process is impractical.

4. Hydroform blocks of 5A.1, 12E.1, 12F.1 and 25A.1 enabled the successful hot forming of parts with about 20 percent of the forming pressure required for cold forming.

5. Ceramic fiber materials protect the rubber hydropress pad from the 1850 F resistance-heated metal part. Higher temperature protection with the fiber should be attainable - up to 2000 F.

6. The hydroform blocks broke (after forming of parts) at their corners due to the shearing action of the metal flanges as contraction occurred during cooling - a difficulty indicated to be preventable by proper tool design.

7. Stretchform blocks of 5A.1, 12E.1, 12F.1 and 25A.1 enabled the hot forming of parts with no damage to the ceramic tools.

8. All the draw die punches failed in shear and no parts drawn are considered acceptable.

RECOMMENDATIONS

1. Either external or internal vibration should be used for casting tools from materials having calcium aluminate binder.

2. Ceramic hydroform blocks should have bases leveled with plaster to assure adequate back-up to sustain the compressive loads.

3. Ceramic fiber bat should be used to protect hydroform rubber for forming temperatures up to 1850 F. (2000 F protection is possible.)

4. Do not use ceramic draw dies.

5. Extend investigation to production size tooling.

PART III - PRODUCTION SIZE TOOL EVALUATION

INTRODUCTION

The results of the laboratory size tool evaluation indicated that all five materials* should be used to make production size tools.

PROCEDURE

The five castable refractories were used to make the same type tools, except draw dies, as were used in the laboratory size evaluation plus the addition of draw heat treat fixtures and furnace type austenitizing or solution heat treat fixtures. The procedure used for each tool of each material through mold construction, fabrication, and testing follows. Table 31 lists the methods and treatments used in making each tool of each castable.

Stretchform Block

Mold Construction

A typical production stretchform block was chosen as the model for construction of the molds. These molds were made by the plaster splash method. The model was waxed so that the plaster would not adhere. Hemp fiber was mixed with the outer layers of plaster for strength. Steel pipes and reinforcing rods were incorporated in the molds for rigidity and as handling aids.

*Refer to footnote on Page 285 concerning material 108A.1.

Code 12E.1

For the solid type tool, the mold was cast of a hard plaster (K-25) with a wall thickness of approximately three inches and sealed with lacquer, Simoniz wax and peanut oil.

The mold was then modified by the addition of a plywood face sheet and a plywood end. This modification was done so that the ceramic tool could be cast on end as an inverted cone to prevent the entrapment of bubbles on the working surface.

A cardboard tube was attached to the bottom of the mold so that it would protrude into the center of the casting. This formed a cavity for anchoring an eyebolt which was needed for handling the massive solid casting (see Figure 155).

For the cap type tool, the same splash was used, but a core was used as shown in Figure 158.

Code 25A.1

The mold was cast of Number 1 pottery plaster with a wall thickness of approximately five inches and left porous.

It was then fitted with a plaster end block so that the tool could be cast in the vertical position. A sheet metal-plywood shape, shown in Figure 158 with another mold, was attached to the plywood face sheet that closed the open side of the mold. This core was made to fill up the center of the mold so that the casting wall thickness would be approximately three inches. This was done to facilitate the drying and firing of the Code 25A.1 material.

Tool Fabrication

Code 12E.1 Solid Type

The solid 12E.1 stretchform block was cast in the sealed hard plaster mold. The mold was wiped lightly with peanut oil as the parting agent.

A two and one-half-yard capacity concrete mixer, shown in Figure 156 with a Phase V tool, was used to mix enough of the 12E.1 material to completely fill the mold at one time and avoid lamination. Nineteen hundred pounds of the 12E.1 material and approximately two hundred thirty pounds of water were required to fill the mold.

Waxed, threaded studs with 1/2 x 3 x 3 inch anchor plates attached were placed inside of the mold through the plywood face sheet before casting (refer to Figure 155). These anchored studs were used to attach the stretchform block to the stretch press where it was tested. The studs were waxed so that they could be threaded out of the steel anchor plates which remained in the casting.

After casting, the mold was screeded off at the top and left covered with wet burlap for 24 hours. After this period, the mold end and face

sheets were removed and the casting was lifted away from the mold. No difficulty was encountered in parting the mold from the casting.

Immediately after removal, the casting was wrapped in wet burlap to prevent the surface from drying too rapidly.

The cardboard tube was removed from the end of the tool and a large steel pad eye was inserted into the cavity. Additional 12E.1 material was mixed and cast into the cavity around the rod. The internal electric vibrator was used so that the castable flowed into the cavity very easily. Small rods had been welded to the pad eye for centering the shank in the cast hole and to aid in anchoring the shank to the casting (see Figure 157).

After drying at room temperature for one week, the 12E.1 solid stretchform block was placed in the drying oven at 150 F. The tool was allowed to remain at 150 F for another week, after which it was placed in another drying oven at 250 F for final drying. Upon completion of a week of drying at 250 F the tool was removed for testing.

Code 12E.1 Cap Type

The Code 12E.1 cap type stretchform block was cast in the sealed hard plaster mold. Peanut oil was wiped lightly on the mold as the parting agent.

The sheet metal core was suspended in the mold so that an approximate three-inch wall thickness would be obtained. The mold was placed in a horizontal position with both ends closed with plywood as shown by Figure 158.

The mold was filled in three batches with internal vibration being used to flow the material into place. After filling, the excess material was screeded off level with the top of the mold and the mold was covered with a 0.003 inch Mylar film to retard rapid drying.

The sheet metal core was removed after 24 hours and the mold and casting were covered with wet burlap for additional curing. After curing for 48 hours, the cavity which was left by the removal of the core was filled with a light-weight Vermiculite-Portland cement castable (Code 5P.1).

After the core had dried for four days in the 12E.1 cap, the completed tool was removed from the mold and placed in the dryer at 150 F where it remained for five days before use (see Figure 159).

Code 25A.1 (Cap Type)

The Code 25A.1 stretchform block was cast in the Number 1 pottery plaster mold. The sheet metal core, as used with the cap type 12E.1 stretchform block, was used so that a three-inch tool wall thickness would be obtained. The tool was cast in the vertical position using internal vibration. (Refer to Table 31, Page 305.)

When the mold was filled with the 25A.1 material it was covered with a sheet of Mylar film to prevent surface evaporation. This cover was removed after two days to accelerate the drying.

The mold was placed in a horizontal position and the sheet metal core was removed five days after the tool was cast. The core released from the tool very easily. After the core had been removed, drying cracks were found in the corners of the tool where the top or large end intersected with the sides. Portions of the end containing these cracks were sawed out so that the cracks could be repaired by filling with fused silica cement, Code 25D.1.

A fused silica foam core, 25E.1, was installed in the cast 25A.1 material shell using the 25D.1 cement to hold the shaped foam blocks in place. The 25A.1 stretchform block was reinforced with the foam blocks in an "egg-crate" manner which left open spaces between the reinforcing blocks (see Figure 160).

After the installation of the reinforcing fused silica foam blocks into the 25A.1 stretchform block, the completed tool was placed in a drying oven at 150 F. The tool was then fired using the rates and temperatures previously determined as being optimum for this material.

Testing

The stretchform evaluation was done on a 90-ton capacity Hufford stretch press. One .031 inch thick AISI 420 stainless steel part was formed on each of the three stretchform blocks. The blocks evaluated were: solid type 12E.1, cap type 12E.1, and cap type 25A.1.

A portable type saturable reactor and transformer capable of supplying 65 KVA at 15 volts AC was set up near the production stretch press to supply the power necessary to heat the blank to 1400 F by its own resistance. The block was positioned on the press and the blank was bolted to specially designed adapters which were held in the jaws of the press. Laminated phenolic insulators were placed between the copper electrodes and the above mentioned adapters. Figure 161 illustrates the press setup.

The AISI 420 blanks were heated to 1400 F and stretched into shape with forces ranging from 10 to 12 tons. Electrical power was maintained throughout the stretching operation.

Hydroform Block

Mold Construction

A typical production hydroform block was used as the model. The model was waxed and polished to prevent the plaster splash from adhering.

An open box was built around the model to contain the mixed plaster. After pouring in sufficient plaster to cover the model, additional plaster mixed with hemp fiber was added for strengthening the mold. Two pipes were embedded in the mold material with their ends protruding for handling aids.

Code 12E.1

The mold was made with hard (K-25) plaster. After the plaster had set the mold was removed from the model and dried thoroughly at 150 F. It was then sealed with lacquer, heavily waxed and polished.

Code 25A.1

A Number 1 pottery plaster mold was made with one inch thicker sides than the hard plaster mold, which had three inch thick sides, so that it would have sufficient water absorption capacity.

After the plaster had set, the mold was removed from the model and dried thoroughly at 150 F.

The Number 1 pottery plaster mold was left unsealed so that it would absorb water.

Tool Fabrication

Code 12E.1 Solid Type

The 12E.1 solid hydroform block was cast in the sealed, hard plaster mold. After waxing and polishing, the mold was coated lightly with peanut oil as a parting agent and filled with 150 pounds of the castable, which was mixed in the mix-muller. The surface was then screeded off as flat as possible and covered with a thin sheet of plastic to aid in curing. The casting was removed from the mold after curing for 24 hours and wrapped in wet burlap for an additional 24 hours. The tool was then placed in the drying oven at 150 F, where it remained for one week. Upon the completion of the drying period the tool was placed in the 250 F drying oven where it remained for approximately 10 days before use.

Code 12E.1 Cap Type

The 12E.1 cap type hydroform block was cast in the same mold as the solid 12E.1 hydroform block. The core for this tool was fabricated by welding plates of 1/4 inch thick steel. The core was shaped so that approximately one inch of the castable would surround the core on the working face. The bottom of the tool was left open. Numerous holes were cut in the welded core to allow the castable material to flow up through these holes and anchor the core to the cast cap.

The tool was cast by pouring approximately one inch of the 12E.1 material into the mold and then pressing in the welded core. The setup, before pouring, is shown in Figure 162. More material was then added to completely fill up the space between the core and the mold. Internal vibration was used to make the castable flow easily. The mold was covered with plastic film after it was filled and screeded off.

The tool remained covered in the mold for two days before being removed and air dried at room temperature for 24 hours. It was then placed in the drying oven at 150 F. After drying at 150 F for five days the tool was placed in the 250 F oven where it remained for one week until it was used.

Code 25A.1 Solid Type

The 25A.1 solid type hydroform block was cast in the pottery plaster mold.

A heavy coating of Keltex was sprayed on the mold in an effort to ensure that no difficulties would be encountered in removing the solid 25A.1 hydroform block from the mold. This extra heavy coating of Keltex tended to seal the pottery plaster mold rather than leave it porous as it should have been. When the tool was removed from the mold it was found that this sealing tendency of the Keltex had produced pits in the surface of the tool. The tool also cracked in several places as it was being removed from the mold. This failure was due to a lack of strength which was caused by the moisture in the 25A.1 material not being absorbed by the mold. This first tool was consequently discarded.

After casting the second tool using graphite and slip wash as the parting agent, the mold was covered with a plastic film so that moisture would be absorbed by the porous mold rather than lost through surface evaporation. This method of casting has been found to produce the best fused silica tools.

This second 25A.1 hydroform block was allowed to remain in the mold for five days after casting in order to obtain as much strength as possible in an effort to avoid cracking upon removal from the mold. After the tool was successfully removed from the mold, it was air dried at room temperature for three days. At the end of this period the tool was placed in the drying oven at 150 F where it remained for two weeks before being fired. (Refer to Table 31, Page 304.)

Code 25A.1 Cap Type

The 25A.1 cap type hydroform block was cast in the pottery plaster mold in the same manner as the latter solid tool, except that a fused silica foam core was pushed into the 25A.1 material in the mold. External vibration was applied to the foam core by an electric vibrator to aid in forcing the core into the cap material.

The foam core was built up of shaped foam blocks, 25D.1, cemented together with fused silica cement, 25E.1. The shape of the core was such that a one-inch thick cap of the 25A.1 material surrounded the core after placement.

The mold was covered with plastic film after the core had been vibrated into place. The material was allowed to harden in the mold for four days before the tool was removed for air drying.

While being removed from the mold, the tool cracked along one edge in line with a foam block. This crack was repaired with fused silica cement and the repaired tool was dried at room temperature for one week before being placed in the 150 F drying oven. After drying at 150 F for one week, the tool was fired, but inadvertently never tested or evaluated.

Testing

The 5000-ton capacity Lake Erie Hydropress was used to evaluate the production size hydroform blocks. One .031 inch thick AISI 420 stainless steel part was formed on each of the blocks evaluated.

A portable type saturable reactor and transformer capable of supplying 65 KVA at 15 volts AC was set up near the production hydropress to supply the power to heat the blank to 1400 F by its own resistance.

The hydroform block to be tested was seated either on a 5/16 inch thick rubber pad or on a 3/8 inch piece of plywood. The blanks were connected to the copper electrodes and placed on the block. The blank and electrodes were electrically insulated from the press with a Kaowool* blanket. One and one-half inches of this blanket were placed over the blank to provide thermal protection for the trapped rubber head on the press. Additional protection was provided by a 5/16 inch thick, high temperature rubber mat. This setup is illustrated in Figures 163, 164, and 165.

The blank was heated to 1400 F. The power was cut off just before the trapped rubber head contacted the block. Forming pressures used were 2500 psi** for the solid type 12E.1 block and 1250 psi for the cap type 12E.1 and solid type 25A.1 block. The lower pressure is considered to be minimum for producing an acceptable part of the configuration.

Draw Heat Treat Fixture

Mold Construction

Code 12E.1

The mold for the female portion of the 12E.1 draw heat treat fixture was fabricated by boxing-in the 12E.1 laboratory size stretchform block with plywood sides so that a mating ceramic block could be cast. Allowance was made for metal thickness by the use of thin sheet wax over the stretchform block model.

Waxed tubes were inserted into the mold to form lifting holes.

Tool Fabrication

Code 12E.1

A solid type draw heat treat fixture was cast of the 12E.1 material, using the 12E.1 laboratory size stretchform block for the male half and as a model for casting the female half of the fixture.

*Trade name, Babcock & Wilcox Company

**This ram pressure resulted in 1600 psi on part.

The mold was filled with 12E.1 material using internal vibration so that the castable would flow around the waxed tubes in the mold which formed lifting holes. After the mold was filled, it was leveled off and covered with plastic film for curing.

The casting was removed from the mold after drying for three days and separated from the male half of the fixture. Both halves of the fixture were dried at room temperature for two days before being placed in the 150 F dryer. The tool was then dried at 150 F for five days before being placed in the 250 F dryer where it remained for one week prior to use. (Refer to Figures 166 and 167).

Testing

Code 12E.1

The stress relief or draw heat treat fixture evaluation utilized one of the .031 inch AISI 420 parts which had previously been formed during the evaluation of the laboratory size stretchform blocks. This part was inserted into the working area of the tool for the evaluation run in the furnace (see Figures 166 and 167).

Thermocouples to monitor the run were placed in four positions. Number one was placed in a hole drilled four inches deep in the male portion of the fixture, number two was placed at the interface in the center of the fixture, number three was placed at the interface near the edge, and number four was left exposed to indicate furnace temperature. Grooves were ground into the male part of the fixture to receive the thermocouple wire and, thus, prevent distortion of the part.

The draw heat treat fixture was fired to 1000 F at 100°/hr. before testing. When it had cooled to room temperature the thermocouples were inserted; the part placed in position; and the completely assembled fixture was put into the furnace at 1000 F.

A four-channel temperature recorder was used to make a record of the evaluation run. A Lindberg circulating hot air furnace was used in the evaluation.

Heat Treat Fixture

The Contractor used material 25A.1 during a B-70 manufacturing development program for brazing fixtures and hot sizing tools. Exhibit 7 Figures 12 thru 19 illustrate such tools. Because of this extensive program, only one tool was made and evaluated under this contract - permitting greater exploitation of the forming application. See Pages 441 thru 472 for Exhibit 7.

Mold Construction

Code 25A.1

The 25A.1 laboratory size stretchform block was used as the model for constructing the heat treat fixture. The female half of the tool was fabricated on the existing 25A.1 stretchform block so a complete mold was not needed.

Tool Fabrication

Code 25A.1

A braze and/or heat treat fixture was fabricated of the 25A.1 material using a cast fused silica face over shaped silica foam blocks.

The 25A.1 laboratory size stretchform block was used as the male half of this heat treat fixture and the female half of the tool was fabricated on the stretchform block with allowance being made for metal thickness. A cap of the 25A.1 material was cast on the stretchform block and a back-up core of cemented fused silica foam blocks was cemented to it.

After drying at room temperature, the fixture was placed in the drying oven at 150 F where it remained for five days before being fired.

Testing

Code 25A.1

The fixture was provided with four thermocouples arranged the same as the draw heat treat fixture and a metal part was placed in it for the evaluating run. The assembly with its contained part and thermocouples was placed in the furnace at 1850 F (refer to Figure 170).

DISCUSSION OF RESULTS

Stretchform Block

Table 35 gives test data and results of the stretchform block evaluation. None of the tools was affected by the 1400 F temperature of the blank.

Code 12E.1 Solid Type

This tool was broken in the forming operation because a slight bow on the back surface allowed a build-up of bending forces (see Figure 168). However, a part was formed and this tool could be used again if repaired and properly supported in the press. A load of 12 tons was used to form the part.

Code 12E.1 Cap Type

This tool formed an acceptable part, but an overlap of the blank off the bottom edge set up shear forces which caused the failure as illustrated in Figures 159 and 169. The back surface of this tool was capped with K-25 plaster and further supported in the press with a 3/4 inch thick aluminum plate. A load of 12 tons was used for forming the part.

Code 25A.1 Cap Type

This block was used in forming an acceptable part. No damage to the block was detected. The back side of the stretchform block was capped with K-25 plaster and the 3/4 inch thick aluminum support plate was used. An indicated loading of 10 tons was used in forming the part.

Hydroform Block

Table 36 gives test data and results of the hydroform block evaluation. None of the tools was affected by the 1400 F temperature of the blank.

Code 12E.1 Solid Type

A 5/16 inch rubber pad was placed under this tool on the press table. This block formed an excellent part, but unfortunately the high pressure used broke the block (see Figure 171). The failure occurred due to bending forces set up under the forming pressure. The 1400 F metal had no apparent ill effect on the block.

Code 12E.1 Cap Type

This tool also formed an acceptable part, but a considerable amount of cracking occurred. The block was seated on a piece of 1/2 inch plywood. The cracking observed did not cause complete failure, but it is doubtful if another acceptable part could be formed on this block. Again the cracking was caused by bending forces. Figure 172 illustrates the block after the evaluation.

Code 25A.1 Solid Type

The 25A.1 block formed an acceptable part and only one small crack resulted. This tool was leveled on the bottom by setting it in K-25 plaster. A 5/16 inch rubber pad was placed under this tool on the press table. A forming pressure of 1250 psi was used (see Figure 173).

Draw Heat Treat Fixture

Code 12E.1 Solid Type

As was expected, considerable time elapsed before the center portion of the fixture and part came up to furnace temperature. The furnace naturally lost heat when it received the massive fixture but recovered in approximately one

and one-fourth hours, as indicated by thermocouple Number 4. The edge of t part came up to within 25 F of the furnace temperature in twelve and one-ha hours, but the central portion of the part did not reach such temperature u sixteen and one-half hours had elapsed, as shown by thermocouples 3 and 2 respectively. Thermocouple Number 1, buried in the center of the fixture, still 40 F below furnace temperature when the fixture was removed from the furnace after approximately twenty-one hours.

Similarly, a long period of time was required to cool the assembly. The center of the part was still at 430 F and the center of the fixture was at 500 F, as shown by thermocouples 2 and 1 respectively, four hours after removal of the fixture from the furnace.

The 1000 F temperature had very little effect on the fixture itself. So surface cracking occurred and the depth of cracks extending from the edges toward the center of the narrow portion of the top bridge-like member of the fixture increased. These cracks were noted after the pre-heating before the evaluation run and indicate they will probably be the cause of eventual failu

Heat Treat Fixture

Code 25A.1

A time of one and three-quarter hours was required by the furnace to regain a temperature of 1850 F due to the cooling effect of the fixture. When the fixture had been in the furnace for ten hours, the edge of the part had reached 1600 F, the center of the part had reached 1470 F and the center of the fixture had reached 1530 F. After 15 hours the temperatures were 1775 F, 1750 F, and 1810 F respectively while the furnace temperature had leveled off at an indicated temperature of 1820 F.

The fixture was removed from the furnace and allowed to cool in still air with periodic checks made of the temperature in the fixture. The thermal insulating properties of this material were such that thirty hours after removal from the furnace the center of the fixture still indicated 150 F (see Figure 170).

CONCLUSIONS

1. AISI 420 stainless steel, when resistance heated to 1400 F, can be satisfactorily formed on castable refractory stretchform blocks and hydroform blocks.

2. It is mandatory to provide the tools with a flat base for mounting in the press.

3. Cap type stretchform block and hydroform block tooling performed as satisfactorily as solid type tooling.

4. Cap type tooling has the duel advantage of being lighter and possibly less expensive than solid type tooling.

5. In the hydropress forming operation, the rubber pressure pad was protected from the 1400 F metal by a 1 1/2 inch Kaowool blanket.

6. Material Code 12E.1 performed satisfactorily as a draw heat treat fixture with AISI 420 tempered at 1000 F. The fine surface cracks observed on the fixture after use would not affect the nested metal part. This type fixture is not advisable however, because of the long heating and cooling times required.

7. Material Code 25A.1, the only material evaluated as a heat treat fixture, was unaffected by exposure to the 1850 F heat treating cycle, but like the draw heat treat fixture evaluated, requires excessively long cycle times.

8. Not considering the inefficiency of the long cooling period, which is a limiting factor, the thermal insulating properties of 25A.1 limit its austenitization heat treat fixture use to metals having generous critical cooling rates. This will always be the case unless the tool design incorporates supplementary cooling features as is common with 25A.1 braze fixtures, or a separate quench fixture is provided.

RECOMMENDATIONS

1. Ceramic tools should be thoroughly dried either before firing or before use at elevated temperatures.

2. Ceramic tools must be provided with adequate back-up structure to minimize bending stresses induced by the forming operation.

3. Sections of cast fused silica tools should be held to a maximum thickness of about four inches for ease of firing.

4. Because of the insulating qualities of ceramics, "soak through" type ceramic furnace fixtures should be avoided.

TABLE 31 TOOL FABRICATION - LABORATORY AND PRODUCTION SIZE

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
	LABORATORY SIZE					
5A.1 hydroform block	K-25 mold int. vib.	9.5	wax and silicone grease	24 hrs. in mold. 48 hrs. at 140 F	none	HFB* castings also made in epoxy plastic mold with ext. vibration. See Figures 132 and 134
stretch-form block	"	"	"	"	"	Mold is shown in Figure 140.
draw die punch	"	"	"	"	"	Mold is shown in Figure 145.
draw die ring (top)	"	"	"	"	"	Top ring cast in K-25 mold for smooth upper face. Mold is shown in Figure 146.
ring (bot.)	plastic mold ext. vib.	9.0 to 10.0	wax and peanut oil	"	"	
12E.1 hydroform block	K-25 mold int. vib.	11.0	wax and silicone grease	24 hrs. in mold. 48 hrs. at 140 F.	none	HFB castings also made in epoxy plastic mold with ext. vib.
stretch-form block	"	"	"	"	"	

*Hydroform block

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
draw die punch	K-25 mold int. vib.	11.0	wax and silicone grease	24 hrs. in mold. 48 hrs. at 140 F	none	
draw die ring (top)	"	"	"	"	"	Top ring cast in K-25 mold for smooth upper surface.
ring (bot.)	plastic mold ext. vib.	"	wax and peanut oil	"	"	
12F.1 hydroform block	K-25 mold int. vib.	11.0	wax and silicone grease	24 hrs. in mold. 48 hrs. at 140 F	250°/hr. to 1000 F. 4 hr. at 1000 F.	Fine spall cracks appear on surface of all 12E.1 tools after firing.
stretchform block	"	"	"	"	125°/hr to 1000 F. 4 hrs at 1000 F.	
draw die punch	"	"	"	"	"	
draw die ring (top)	"	11.5	"	"	"	
ring (bot.)	"	"	"	"	"	

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
25A.1 hydroform block	cast in pottery plaster	3.0	Keltex	24 hrs. in mold. 48 hrs. at 140 F.	500°/hr. to 2000 F. 4 hrs. at 2000 F. Cool in kiln.	Smooth surface obtained with few bubbles. Also, a tool was cast in the plastic mold.
"	cast in K-25 mold with int vib.	3.0	wax and silicone grease	"		Small castings are not difficult to aggregate cast.
stretchform block	solid type cast in K-25 mold int. vib.	3.0	"	48 hrs. in mold. 72 hrs. at 140 F	12-14 hrs. at 300 F 200°/hr to 1000 F.	Casting was grainy on surface. (This tool not tested or evaluated, another tool cast in pottery plaster was used.)
"	cap type. slip cast in pottery plaster to form cap of 25B.1-25A.1. cast in cap while wet.	3.0	Keltex	"	300°-400°/hr to 1800 F. 1 hr at 1800 F. Rapidly to 2000 F. 8 to 12 hrs at 2000 F.	Very smooth surface with fine shrink cracks. Cracks opened up in firing to make block unuseable.
draw die punch	cast in K-25 plaster, int. vib.	3.0	wax and silicone grease	"	"	

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
draw die ring (top)	cast in plastic mold ext. vib.	3.0	wax and peanut oil	48 hrs. in mold. 72 hrs. at 140 F.	300-400°/hr to 1800 F. 1 hr. at 1800 F. Rapidly to 2000 F. 8 to 12 hrs. at 2000 F.	Surface smooth except for bubbles.
ring (bot.)	cast in pottery plaster	3.0	Keltex	"		Smooth surface
108A.1 hydroform block	cast in K-25 plaster mold with int. vib.	3.5	wax and silicone grease	24 hrs in mold. 24 hrs. at 140 F	250°/hr. to 1000 F. 4 hrs. at 1000 F.	Block did not set up. Plaster conducts away heat needed for chemical reaction. One cast in plastic mold.
stretchform block	cast in plastic mold with int. vib.	3.5	wax and peanut oil	"	125°/hr. to 1000 F.	Block rough and pitted in some areas.
draw die punch	"	"	"	"	"	Casting did not release from mold.
draw die ring (top)	"	"	"	"	"	Casting did not release from mold. Pits and holes in surface.
ring (bot.)	not made	-	-	-	-	

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
	Hydrofrom Block Fabrication, Production Size					
12E.1 hydroform block (solid)	cast in K-25 plaster mold with internal vibration	11.0	Simoniz and peanut oil	24 hrs in mold plus 24 hrs at room temp. under wet burlap. 1 week at 150 F. 10 days at 250 F	unfired	There were a few bubbles on the tool surface but most of them occurred in areas that were out of part.
hydroform block (cap type)	cast in K-25 plaster mold with internal vibration to help settle castable around core	11.0	Simoniz and peanut oil	72 hrs. at room temp. 5 days at 150 F. 1 week at 250 F	unfired	A smooth surface resulted with good bonding between castable and core.
25A.1 hydroform block (solid, first tool)	cast in No. 1 pottery plaster mold with internal vibration.	3.0	Keltex	36 hrs. at room temp.	-	Block was pitted on surface and broke on removal from mold. Parting agent applied too heavily to allow water absorption.

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
hydroform block (solid, second tool	cast in No. 1 pottery plaster mold with internal vibration.	3.0	powdered graphite and silica slip wash	5 days in mold and 3 days out, room temp. 2 wks. at 150 F.	fired at 2000 F	Block had very smooth surface. K-25 base was applied to bottom of too.
hydroform block (cap type)	" prefabricated silica foam core used.	3.0	"	4 days in mold and 1 week out at room temp. 1 week at 150 F.	fired at 2000 F	Crack occurred when tool was removed from mold. Was repaired with fused silica cement; but, inadvertently not evaluated.
Stretchform Block Fabrication - Production Size						
12E.1 stretchform block (solid)	cast in K-25 plaster mold with internal vibration	11.0	Simoniz wax and peanut oil	24 hrs. in mold. 1 wk. at room temp. under wet burlap. 1 wk. at 150 F. 1 wk. at 250F	unfired	A waxed paper tube was placed in the mold to provide a cavity for anchoring an eye bolt. Also waxed anchor nuts were positioned to receive mounting studs.

TABLE 31 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
stretchform block (cap type)	same with addition of wood and sheet metal core to make cap approximately 3" thick.	11.0	Simoniz wax and peanut oil	24 hrs. in mold. 48 hrs. at room temp. under wet burlap. 4 days additional at room temp. for core. 5 days at 150 F.	unfired	A lightweight vermiculite cement core, 5P.1, was placed in the cavity formed by the sheet metal core. A K-25 plaster base was applied to provide a flat mounting area.
25A.1 stretchform block (cap type)	cast in No. 1 pottery plaster mold with internal vibration. sheet metal core used as with 12E.1	3.0	water spray	5 days in mold and 2 days at room temp. after foam core placed. 1 wk. at 150 F.	fired at 2000 F	Repairs to the end walls were necessary when casting was stripped from mold. Silica foam core was installed as "egg crate" for backing to cap. three inches thickness thought to be thin enough to fire easily.

TABLE 32 HYDROFORM BLOCK EVALUATION - LABORATORY SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	12E.1 Tool #1	Cast in K-25 plaster mold dried, 140 F	AISI 420 1950 F	Hydraulic pressure of 600 psi not enough to form shrink flange. One thickness of ceramic fiber cloth is not enough insulation to protect rubber punch. Block broken.
2	12E.1 Tool #2	Cast in K-25 plaster mold dried, 140 F	AISI 420 1850 F	Hydraulic pressure of 1200 psi formed shrink flange down but left seven small wrinkles. Ceramic fiber blanket protected rubber except where torn at edges of block. Flexible electrodes will have to be used to prevent stretching blank from rupturing block. Block broken.
3	12E.1 Tool #3	Cast in K-25 plastic mold dried, 140 F	AISI 420 1850 F	Hydraulic pressure of 1200 psi left several small wrinkles in shrink flange. Ceramic fiber bulk, long staple type, did not protect the rubber as well as the blanket. Heated portion of cushion lost resiliency and compressed thin enough to transfer too much heat to the rubber. The block broke on ends. See Figure 149.
4	5A.1 Tool #1	Cast in K-25 plaster mold dried, 140 F	AISI 420 1850 F	Hydraulic pressure of 1600 psi did not entirely smooth out wrinkles in shrink flange. Ceramic fiber blanket used. It became torn, burned, and brittle. Block broken.

TABLE 32 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
5	12E.1 Tool #4	Cast in plastic mold dried, 140 F	AISI 420 1850 F	Hydraulic pressure of 2000 psi forms flanges complete and straightens all wrinkles. Doubled ceramic fiber cloth protects rubber better than blanket. Two layers slide on each other and prevent tearing. High pressure bends metal over ends of block. When metal cools it shrinks thus placing tensile force on block breaking upper end edges. See Figure 149.
6	12F.1 Tool #1	Cast in K-25 plaster mold Fired to 1000 F	AISI 420 1850 F	2000 psi used. No wrinkles in shrink flange. Double ceramic fiber cloth used to protect rubber. Block broke on top at one end.
7	12E.1 Tool #5	Cast in plastic mold dried, 140 F	AISI 420 1850 F	2000 psi used and doubled ceramic fiber cloth used to protect rubber. Ends of mold were filled in with plastic clay to form sloping ends on block. Part formed without wrinkles - block unbroken. See Figure 150 for similar tool.
8	2A.1 Tool #1	Cast in pottery plaster mold. Fired to 2000 F.	AISI 420 1850 F	2000 psi used. Fine short staple bulk ceramic fiber insulation used. Cushion shaped roughly by hand, layed on blank, and left for heat and form cycle. Best insulation used thus far. Block broken.

TABLE 32 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
9	108A.1 Tool #1	Cast in plastic mold	AISI 420 1850 F	An attempt to use limit switch on press malfunctioned. Too much delay until full 2000 psi was applied. Shrink flange wrinkled. Bulk ceramic fiber insulation used. Block unbroken.
10	108A.1 Tool #1	Cast in plastic mold	AISI 420 1850 F	2000 psi used. Good part without shrink flange wrinkles. Marks in part show where patches of material did not release from mold when stripped. Bulk ceramic fiber used. Block broken.
11	25A.1 Tool #2	Cast in plastic mold fired to 2000 F	AISI 420 1850 F	2000 psi used with bulk ceramic fiber insulation. Block broken when stripped from mold, but patched with slip, fired, and tried. Good part made without wrinkles. Block broken.
12	25A.1 Tool #3	Cast in K-25 plaster mold fired to 2000 F	AISI 420 1850 F	2000 psi used with bulk ceramic fiber insulation. Wedges shaped from silica foam were placed at the ends of the block to determine if block breakage could be stopped. Did not help as much as casting sloping end on blocks. Wedges crushed and block broke.

TABLE 33 STRETCHFORM BLOCK EVALUATION, LABORATORY SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	5A.1	Cast in K-25 plaster mold with internal vibration. Unfired, 140 F dried	AISI 420 1800 F	Part did not form all the way. The two rails were not properly spaced. Block was unaffected.
2	5A.1	Same tool	AISI 420	Two rails were repositioned. The part ruptured under one rail on second forming cycle. Block still not harmed. See Figures 141 and 151.
3	12E.1	Cast in K-25 plaster mold with internal vibration. Unfired. 140 F dried.	AISI 420 1800 F	Part formed complete. Two reheating cycles were used. Part thinned out under rail. Block unaffected.
4	12F.1	Cast in K-25 plaster mold with internal vibration. Fired at 1000 F	AISI 420 1800 F	Part formed complete. Four complete cycles were used to form part. Blank became extremely hot at draw rails during reheating. Fine spall cracks on tool surface did not mark part and were not any worse after use.
5	25A.1	Cast in No. 1 pottery plaster mold with internal vibration. Fired at 2000 F	AISI 420 1800 F	Part formed all the way. Six cycles were used with the power turned off at start of stretch. Blank under rail did not overheat so much with power off, but more cycles were needed to form part. See Figures 142 and 143.
6	25A.1	Same tool	AISI 420 1800 F	Six cycles again needed to complete part. Power off stretch cycle used. Rails showed some crumbling. Block was completely unharmed.

TABLE 33 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
7	108A.1	Cast in Epoxy plastic mold with internal vibration. Fired at 1000 F.	AISI 420 1800 F	Part formed in five cycles. The rails failed by crumbling and several pieces fell off each rail when press ram was raised. Rough areas on block did not seem to affect part. Block did not appear to be any worse after use.

TABLE 34 DRAW DIE TOOL EVALUATION

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	5A.1	Cast in K-25 plaster or a plastic mold with vibration	AISI 420 1400 F	The punch and top ring for this tool were cast in K-25 mold with internal vibration, the bottom ring was cast in the plastic mold with external vibration. Part was held with 30 psi on top ring. Punch pushed hole in blank after drawing one half inch deep.
2	5A.1	Same tool	AISI 420 1400 F	Top ring pressure was reduced to -10 psi by pulling a vacuum in the double action ram. The blank wrinkled all the way around and the punch failed by crumbling on the two extended corners and by fractures up two faces. Fig. 152 shows typical failures.
3	12E.1	Cast in K-25 plaster or a plastic mold with vibration	AISI 420 1400 F	Punch and top ring made in K-25 mold, bottom ring made in plastic mold. Zero pressure used on top ring. Part formed approximately 3/4 inch deep. Slight wrinkling around cavity. Bottom of part broke along deepest edge (see Figure 154). Temperature of 1400 F was maintained for sometime in blank while making press adjustments, and when top ring was raised a large section of the bottom ring exploded. This explosion was caused by the formation of steam from entrapped moisture which was not removed by drying. See Figures 147 and 153.

TABLE 34 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
4	12F.1	Cast in K-25 plaster mold with vibration	AISI 420 1400 F	All of tool components were cast in plaster molds. Pressure of 5 psi was used to hold blank. By gaging ram movement it was possible to form a part by successive plunges, each 1/8 to 1/4 inch deeper with reheating of the blank material between strokes. Wrinkles around cavity almost eliminated. Part formed to about 1 inch deep before tearing occurred.
5	12F.1	Same tool	AISI 420 1400 F	Same procedure used with part again forming to 1 inch deep. Some crumbling of punch radius occurred on deepest edge.
6	12F.1	Same tool	AISI 420 1400 F	Same procedure used, but punch failed by shearing off longest face all the way to vacuum chuck.
7	25A.1	Cast in No. 1 pottery and K-25 plaster and plastic molds	AISI 420 1400 F	Punch cast in K-25 mold, top ring cast in plastic mold, and bottom ring cast in pottery plaster mold, all with internal vibration. Part formed about 1 inch deep by using stages then part tore and punch failed by shear, like the others.

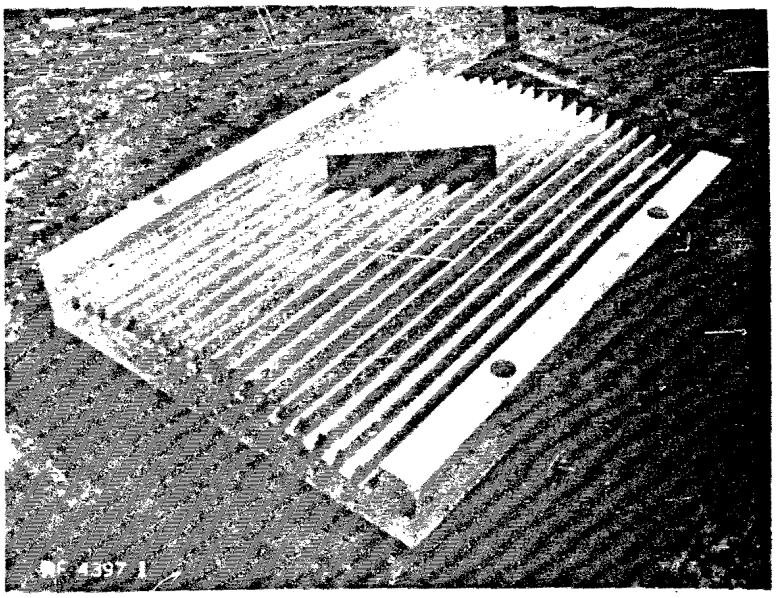
TABLE 35 STRETCHFORM BLOCK EVALUATION, PRODUCTION SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	12E.1 (solid type)	Cast in K-25 plaster mold. Dried 250 F	AISI 420 1400 F	Back surface at bottom was rounded*, causing two top bolts to be pulled out of block. Part formed with few wrinkles. Load of 12 tons used. See Figure 161 for setup, and Figure 168 for the failed tool.
2	12E.1 (cap type)	Cast in K-25 plaster mold. Vermiculite, 5P.1, core. K-25 base applied. Dried 150 F.	AISI 420 1400 F	Block broken by misalignment of blank. 12 ton load used. See Figures 159 and 169.
3	25A.1 (cap type) 25D.1 foam backing	Cast in No. 1 pottery plaster mold with sheet metal core. Foam block backing cemented inside cavity. Fired, 2000 F.	AISI 420 1400 F	Acceptable part made, block unbroken. 10 ton load used.

*Presumably, the plywood face sheet mentioned under Tool Fabrication, Page 288, and shown in Figure 155, deflected when the casting was poured.

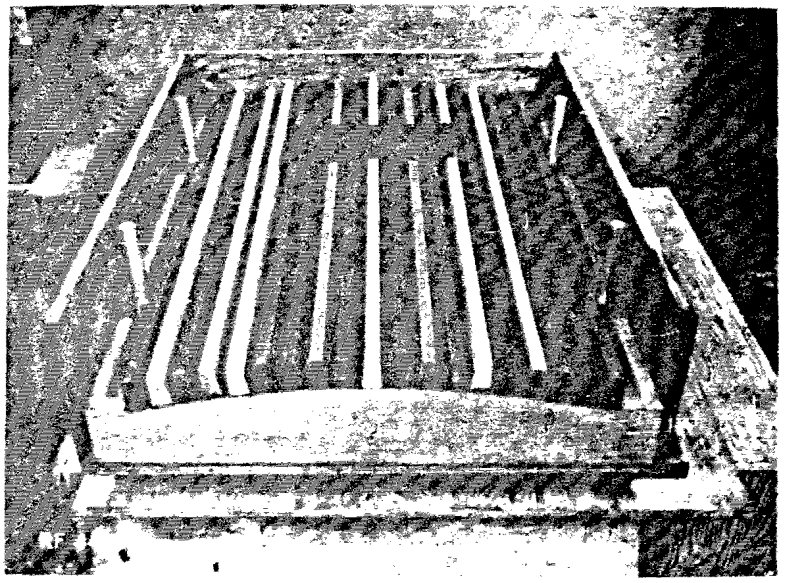
TABLE 36 - HYDROFORM BLOCK EVALUATION, PRODUCTION SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	12E.1 solid type	Cast in K-25 plaster mold.	AISI 420 1400 F	Block was set on 5/16 inch rubber pad. Kaowool insulation was used to protect rubber. 2500 psi pressure was used. Good part formed but corner of block was broken (see Figure 171).
2	12E.1 cap type	Cast in K-25 plaster mold. Welded steel core used.	AISI 420 1400 F	Block was placed on 3/8 inch plywood and forming pressure was reduced to 1250 psi. Kaowool was again used to protect rubber. Block cracked in several places due to uneven load distribution. A part was formed but forming probably could not be repeated (see Figure 172).
3	25A.1 solid type	Cast in No. 1 pottery plaster mold.	AISI 420 1400 F	1250 psi pressure was used with Kaowool insulation to form a good part. The block was set on a 5/16 inch rubber pad. One small crack resulted. K-25 plaster base helped distribute load and reduced cracking. A good part was formed (see Figure 173).



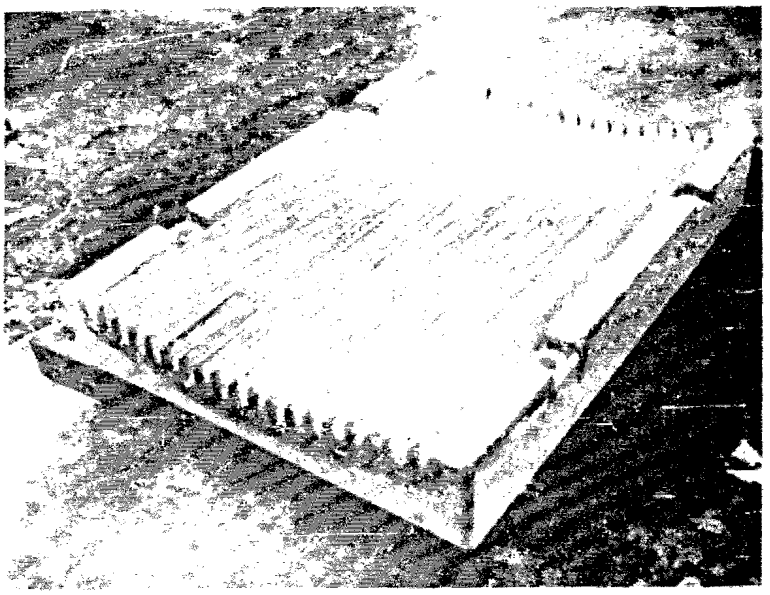
RF 4397-1

Fig. 127 Ceramic castable, 5A.1, brazing fixture with square corner ribs.



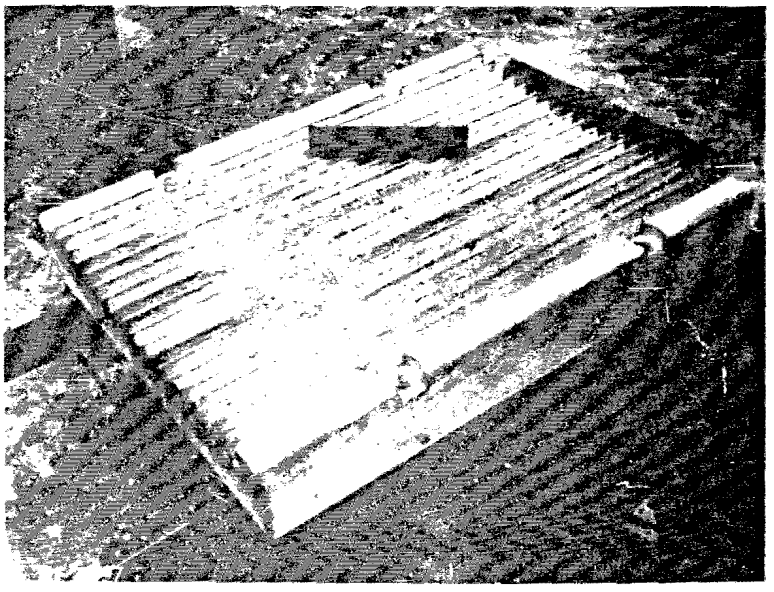
RF 4405

Fig. 128 Braze fixture mold showing wax, wood, plaster and plastic groove forms and aluminum cores for forming mounting bolt holes.



RF 4475

Fig. 129 Ceramic castable, 5A.1, brazing fixture with rounded ribs.



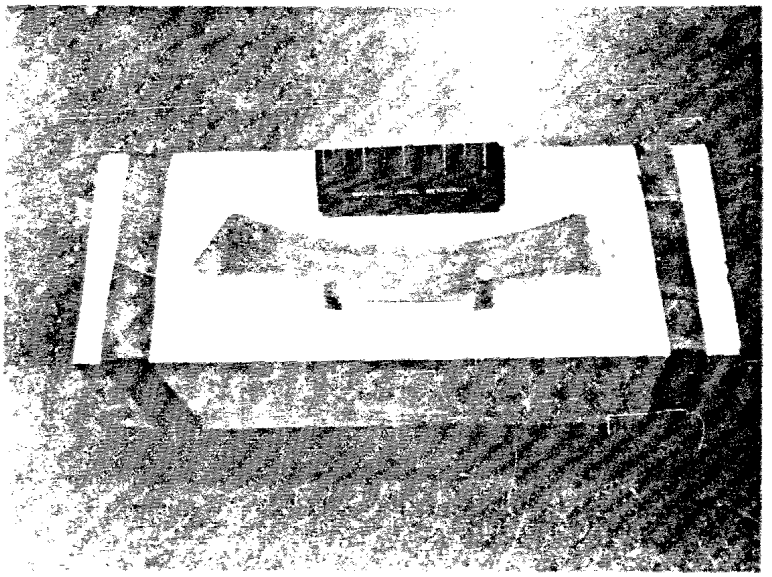
RF 4397-2

Fig. 130 Result of improper placement technique.



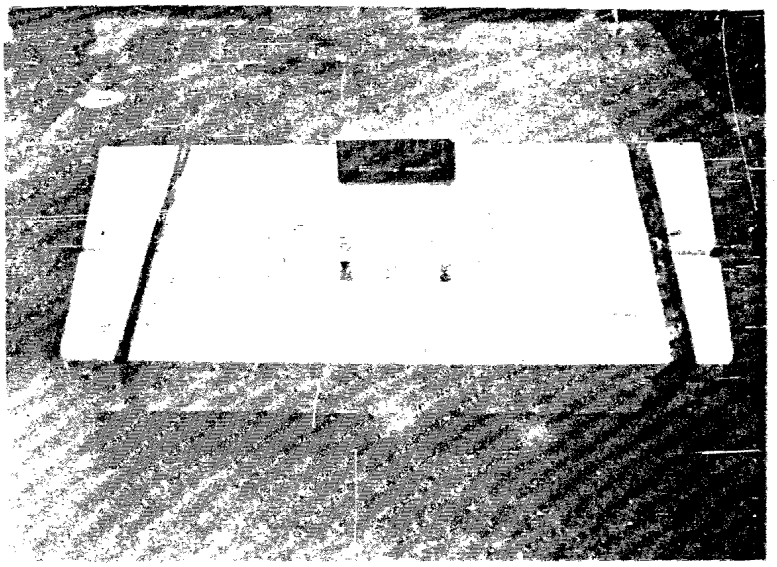
RF 4357-3

Fig. 131 Laboratory size hydroform tool.



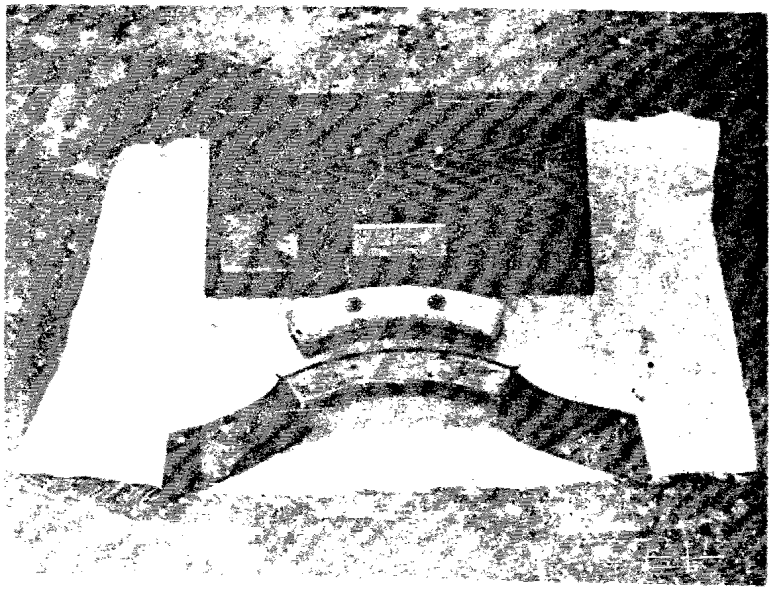
RF 4861-3

Fig. 132 K-25 plaster split mold for laboratory size hydroform tool.



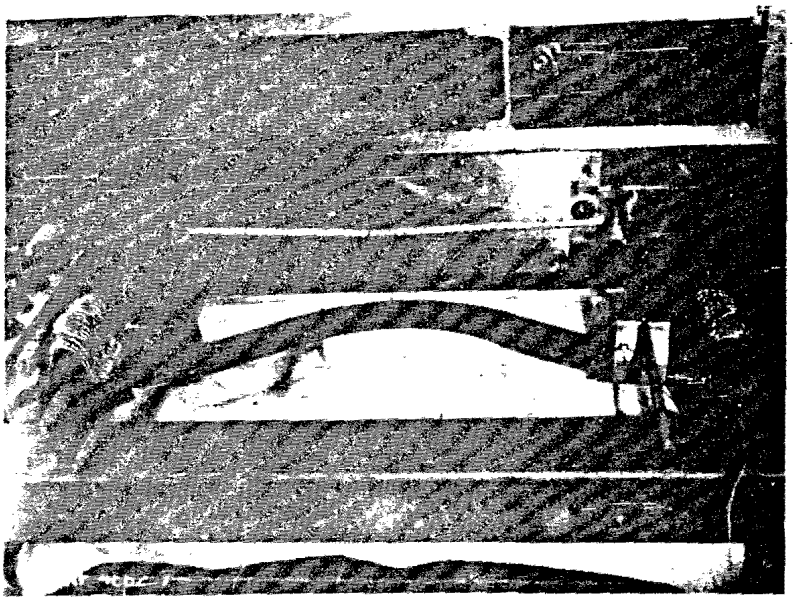
RF 4861-7

Fig. 133 No. 1 pottery plaster mold for laboratory size hydroform block.



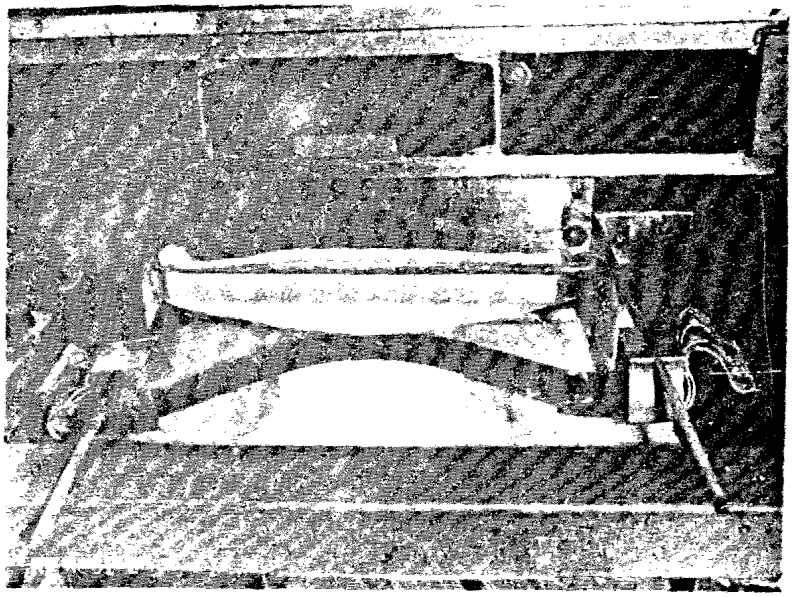
RF 4682-5

Fig. 134 Epoxy resin-glass cloth mold, casting and part formed hot (laboratory size, hydroform).



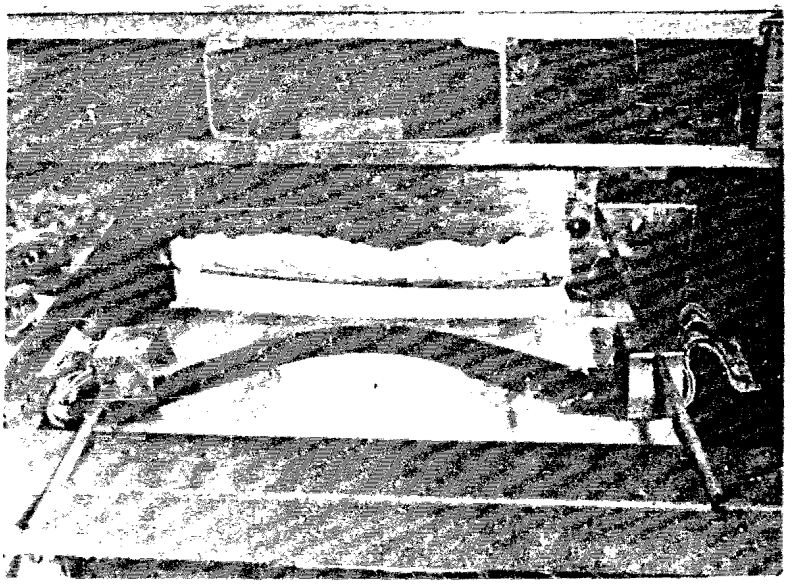
RF 4682-7

Fig. 135 Laboratory hydroform equipment set up to heat and form a part. Blanket insulation.



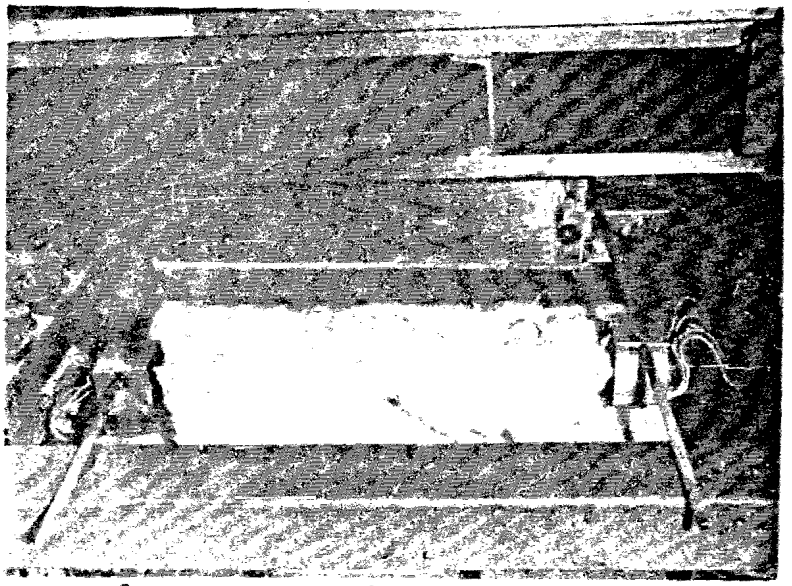
RF 4861-2

Fig. 136 Laboratory hydroform equipment. Doubled ceramic cloth insulation.



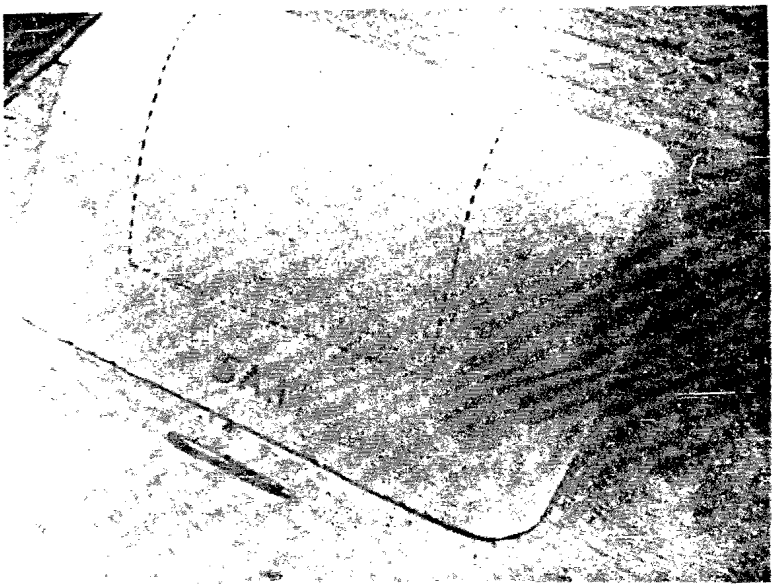
RF 4861-5

Fig. 137 Laboratory hydroform equipment. Ceramic mat insulation.



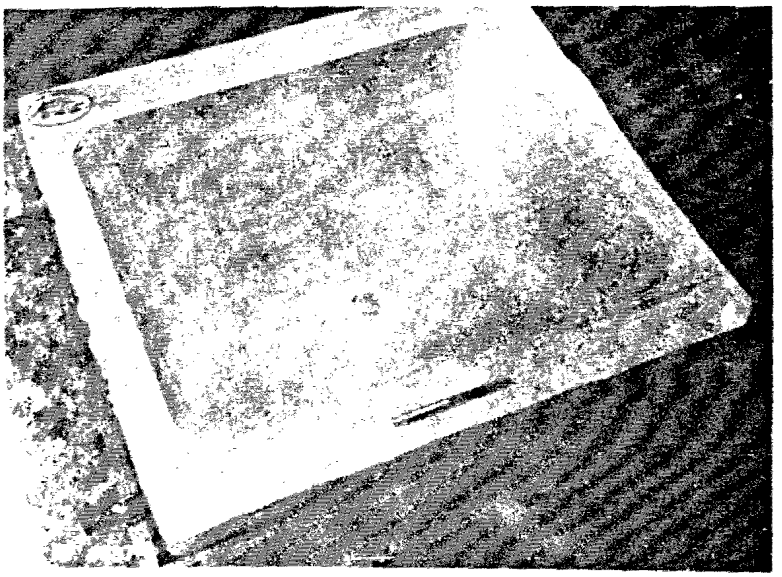
RF 4861-1

Fig. 138 Laboratory hydroform equipment. Ceramic bulk "bat" insulation.



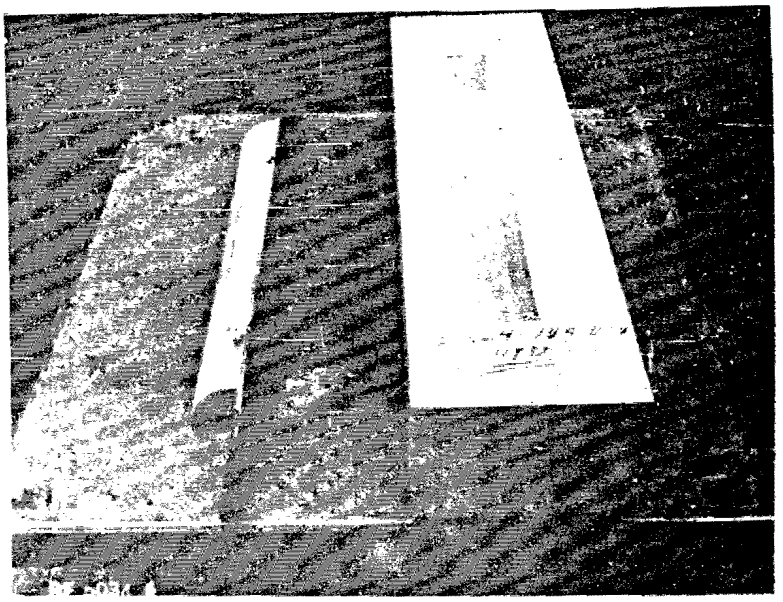
RF 4537-1

Fig. 139 Laboratory size stretchform block.



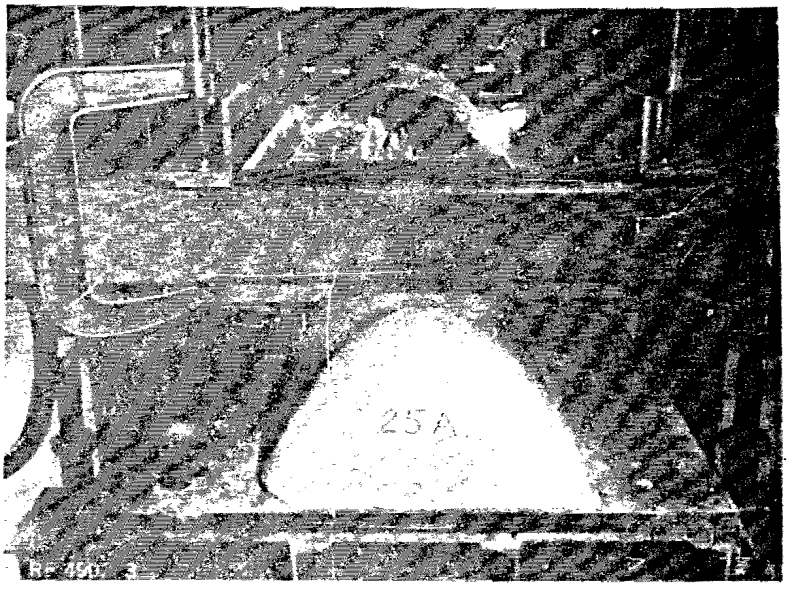
RF 4537-2

Fig. 140 K-25 plaster mold for laboratory size stretchform block.



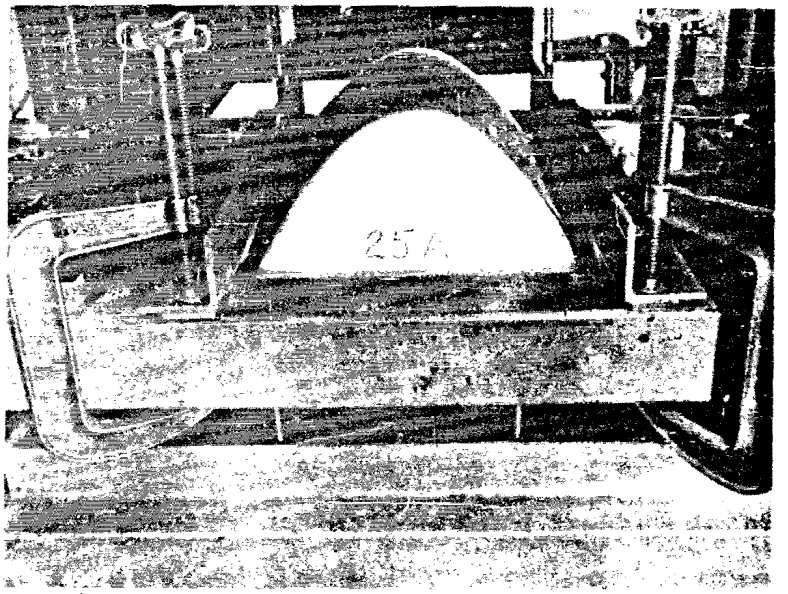
RF 5034-6

Fig. 141 Mold for quarter round ceramic rail, 8A.1, and ceramic rail nested in a steel angle.



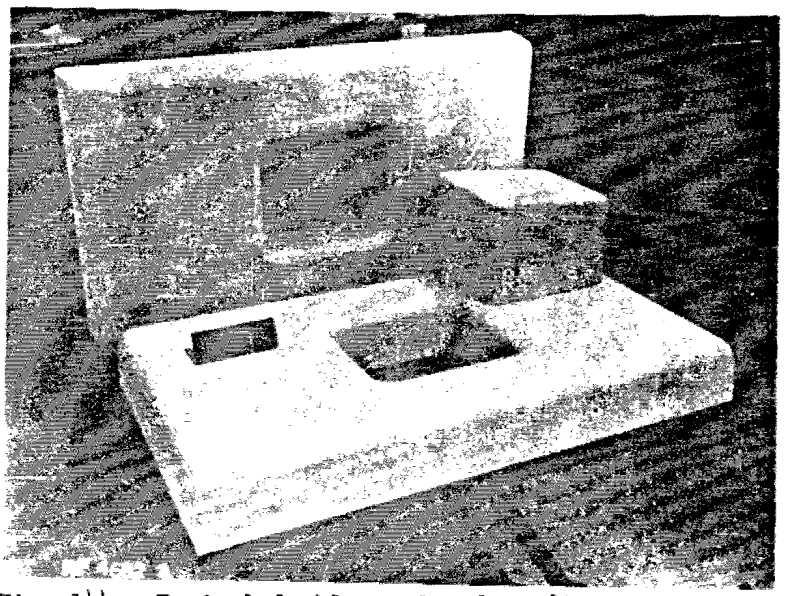
RF 4992-3

Fig. 142 Laboratory size stretchform block with ceramic rail equipped tension frame, with metal blank, positioned for forming.



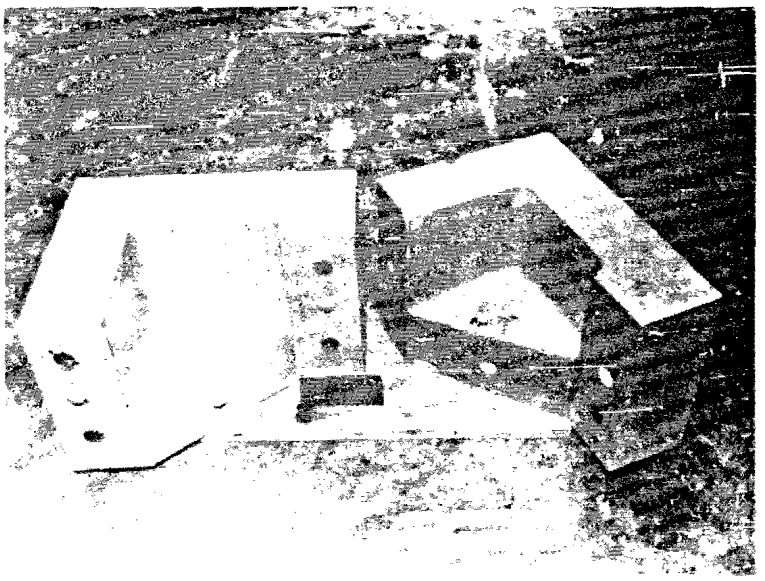
RF 4992-1

Fig. 143 Laboratory size stretchform block with ceramic rail equipped tension frame pulling metal blank down over the stretch-form block.



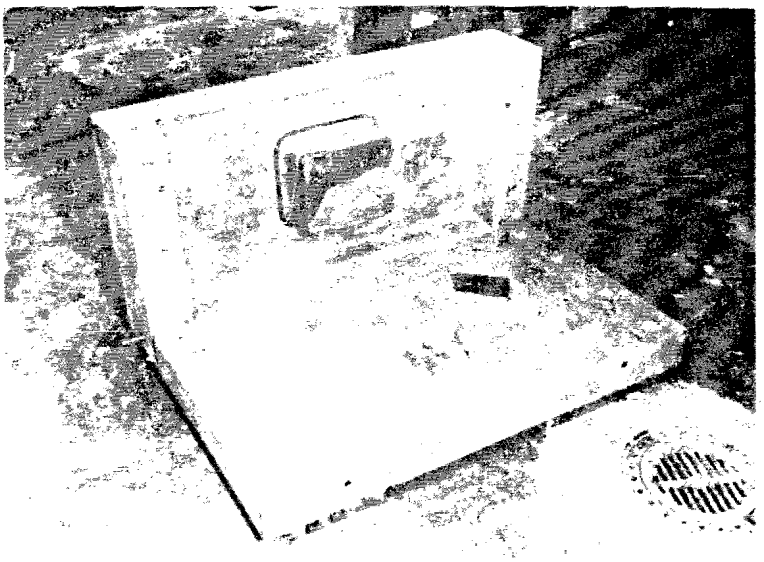
RF 4682-3

Fig. 144 Typical double action draw die.



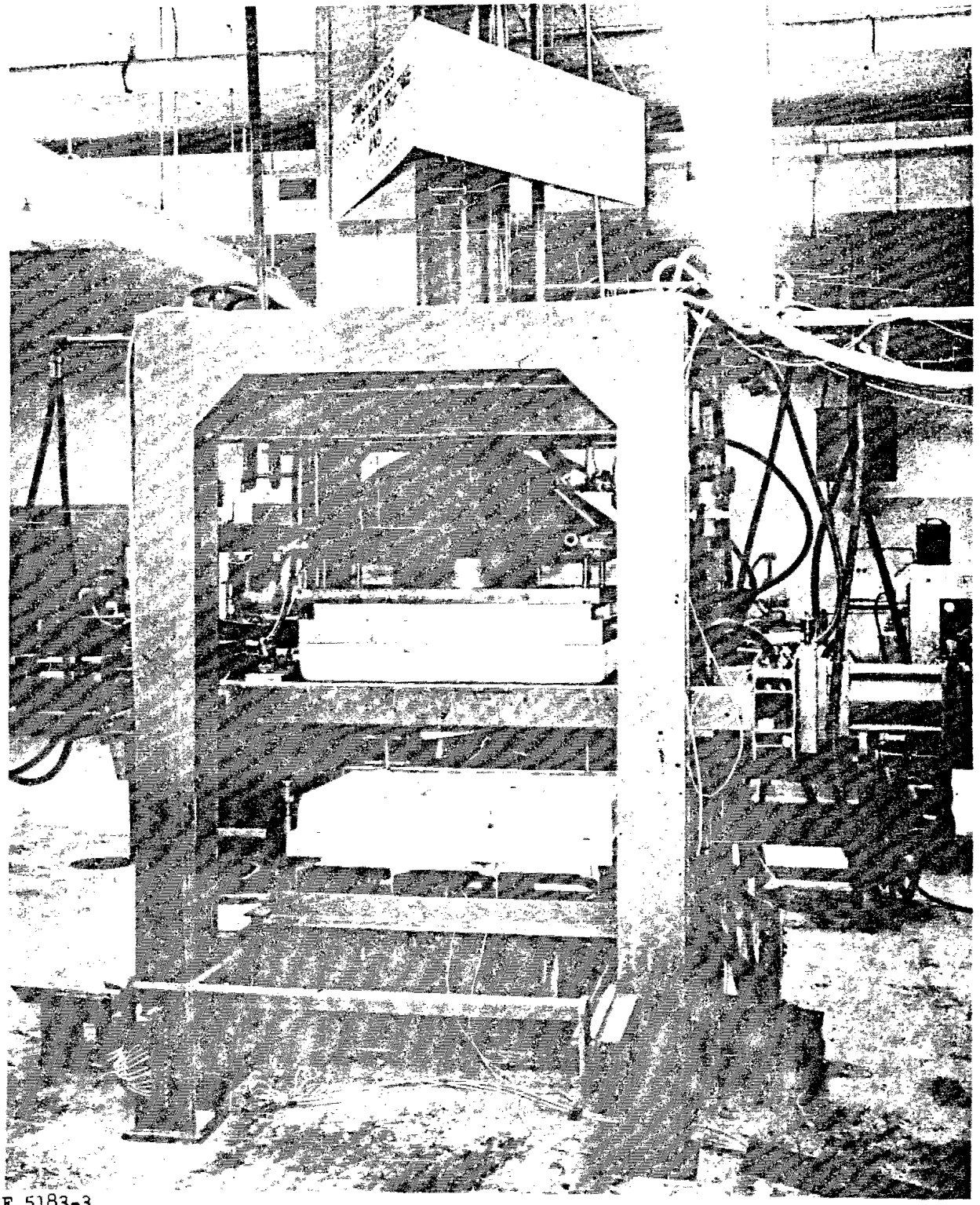
RF 4682-1

Fig. 145 K-25 plaster draw die punch mold.



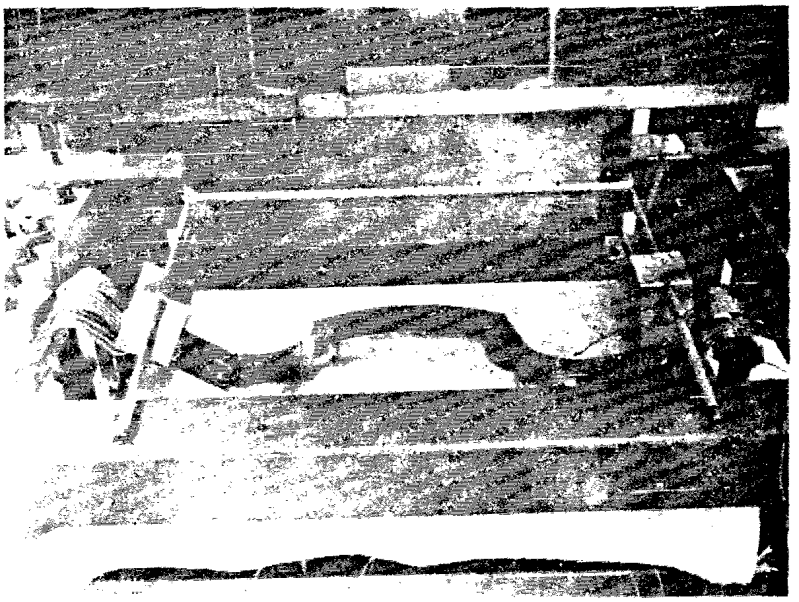
RF 4682-2

Fig. 146 K-25 plaster draw die ring mold.



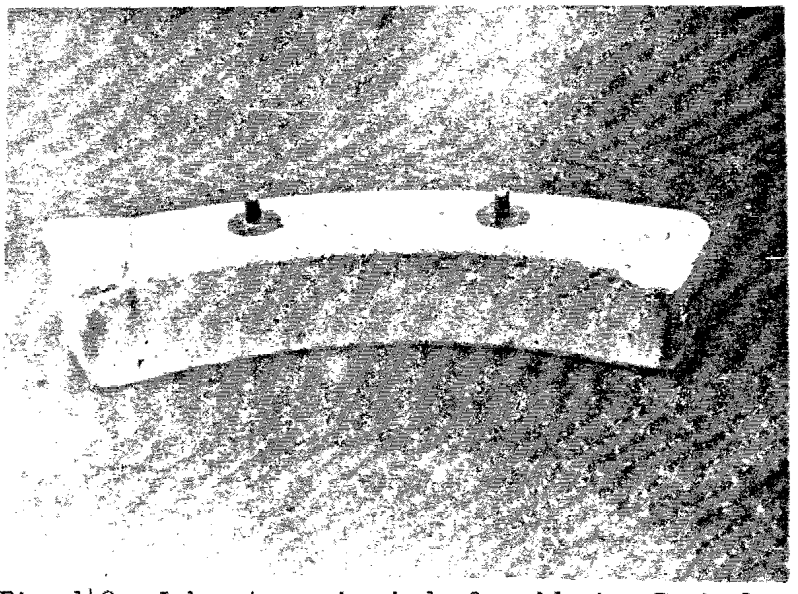
RF 5183-3

Fig. 147 Laboratory size, 12E.1, draw die failure.



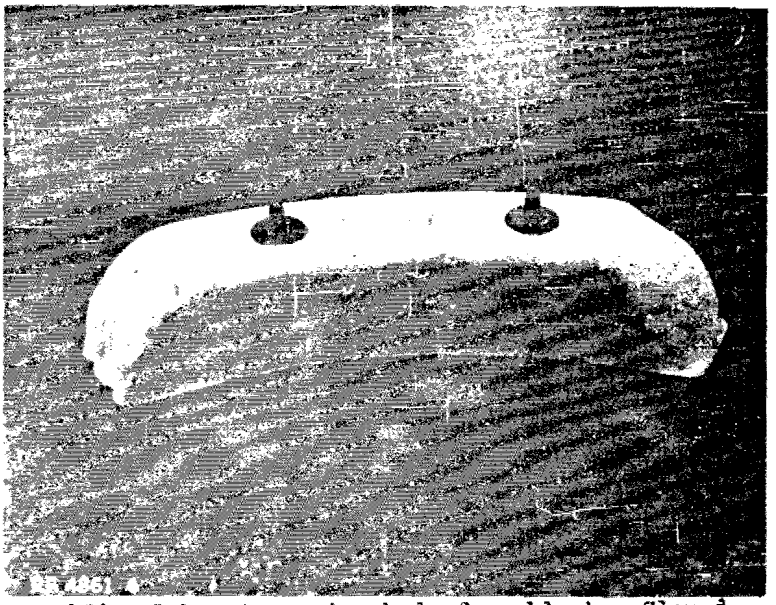
RF 4682-6

Fig. 148 Laboratory hydroform equipment. Heated and formed part.



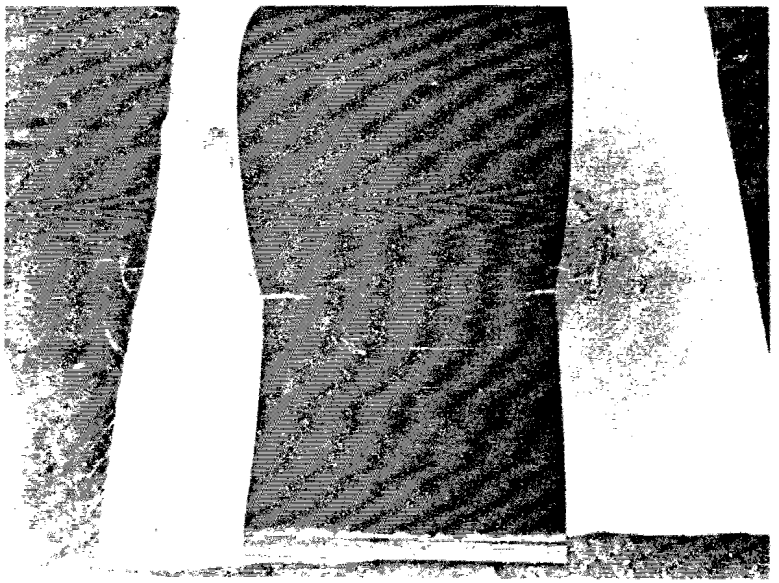
RF 4861-6

Fig. 149 Laboratory size hydroform block. Typical of breaks occurring on most hydroform blocks after use.



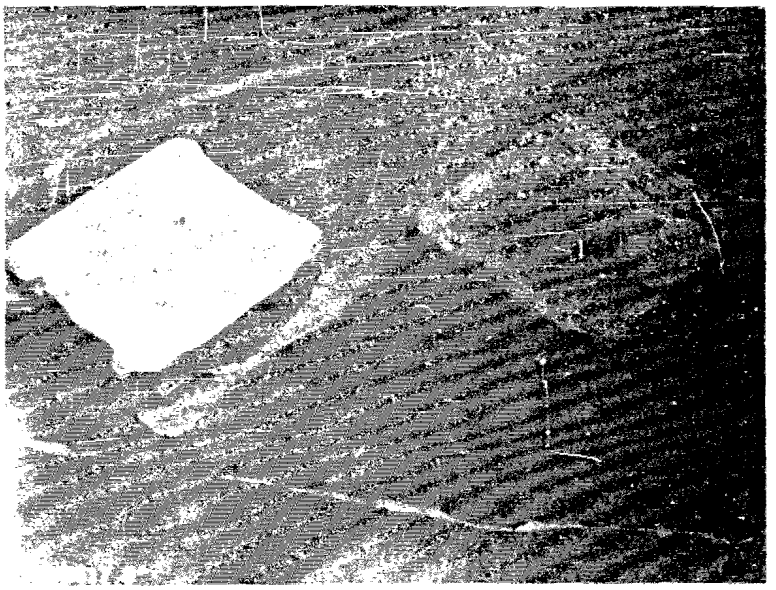
RF 4861-4

Fig. 150 Laboratory size hydroform block. Sloped ends unbroken after use.



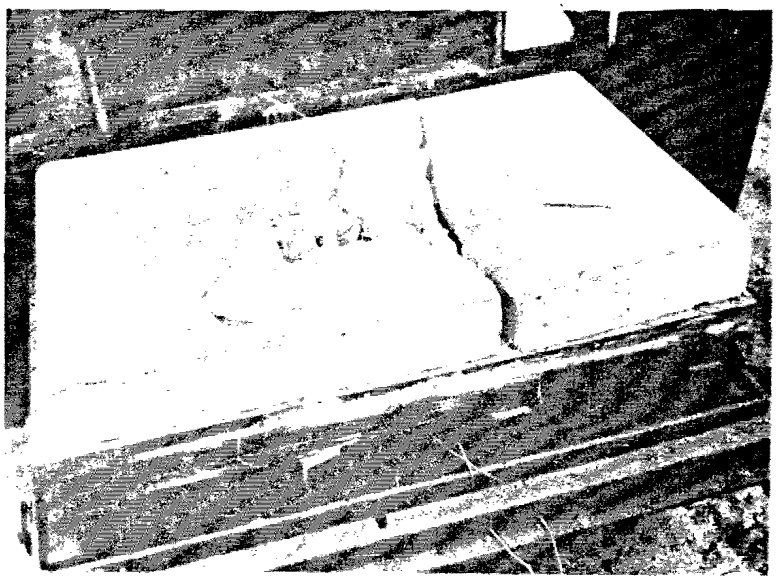
RF 4992-2

Fig. 151 Metal blank, AISI 420, formed on laboratory size stretchform block showing break along contact line with ceramic rail.



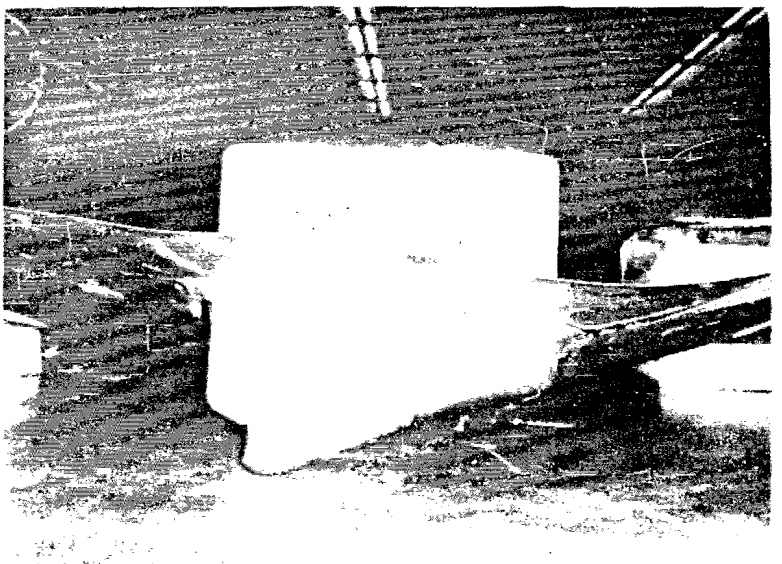
RF 5517-3

Fig. 152 Typical failed draw die punches.



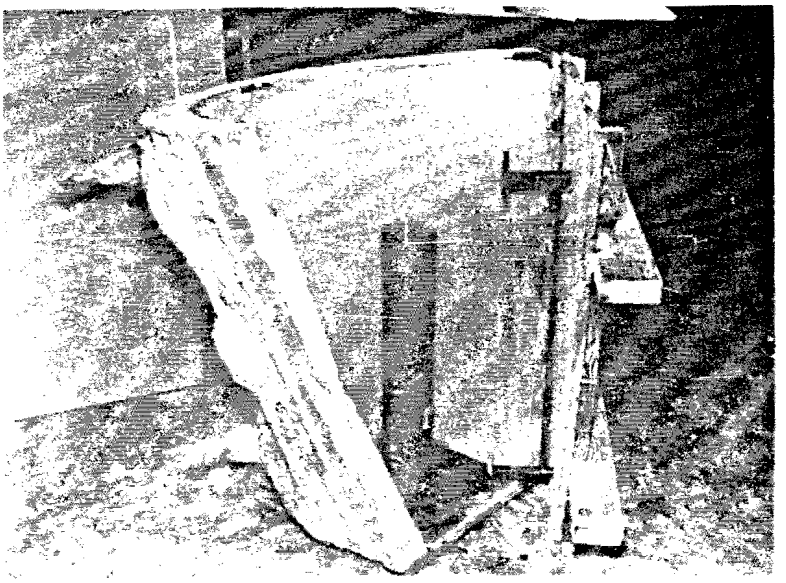
RF 5183-1

Fig. 153 Failed laboratory size 12E.1 draw die. Minor explosion is attributed to inadequate drying.



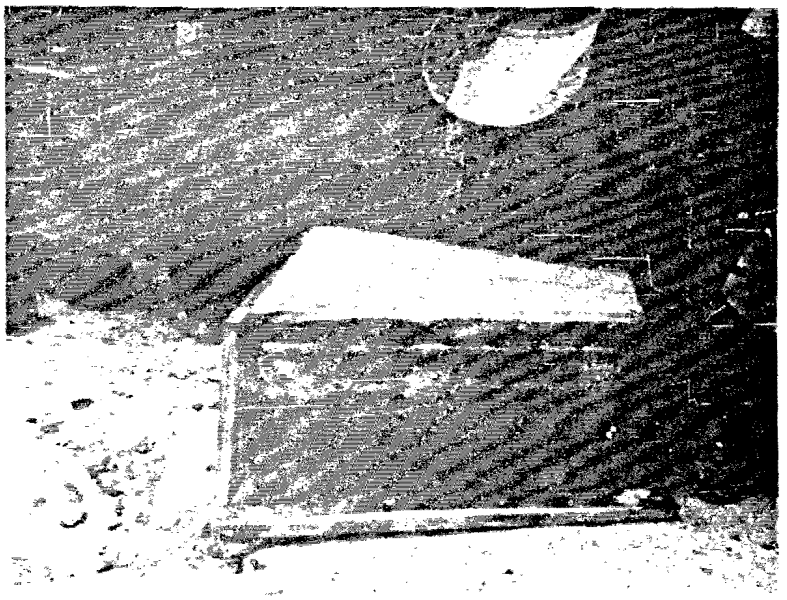
RF 5183-2

Fig. 154 Typical failed AISI 420 draw die part blank.



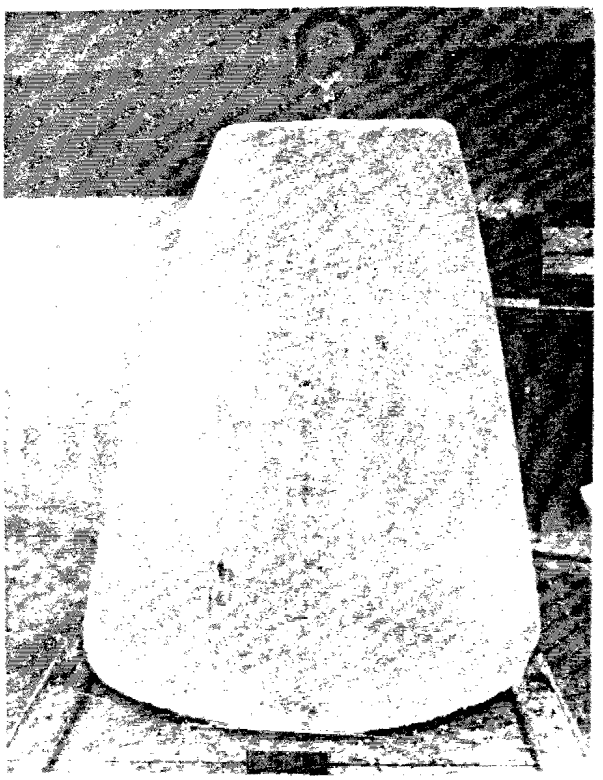
RF 5517-4

Fig. 155 12E.1 solid type production size stretch-form block mold.



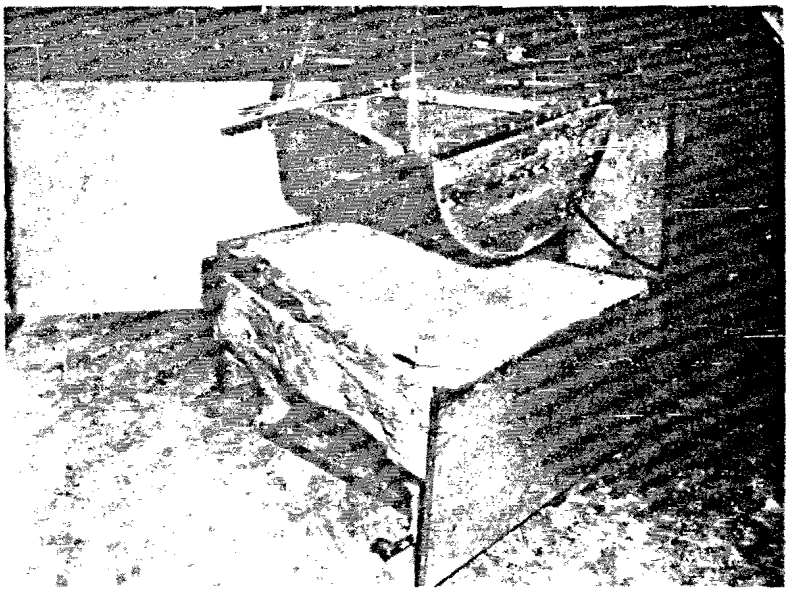
RF 5884

Fig. 156 Two and one-half yard capacity concrete mixer, electric internal vibrator and typical production size stretchform block casting.



RF 5486-6

Fig. 157 Production size 12E.1 solid stretchform block.



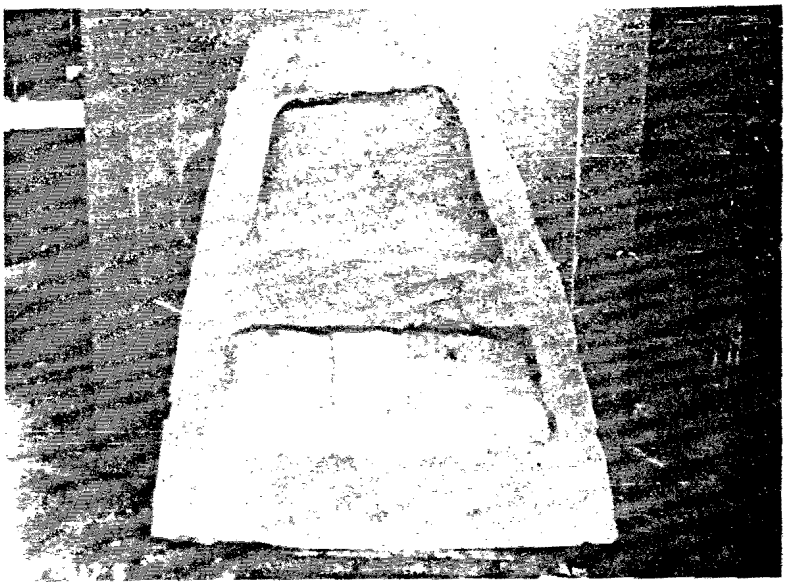
RF 5453-2

Fig. 158 12E.1 cap type production size stretchform block in mold.



RF 5486-7

Fig. 159 Lightweight core, 5P.1, in 12E.1 production size stretchform block. Note crack at lower left (after use).



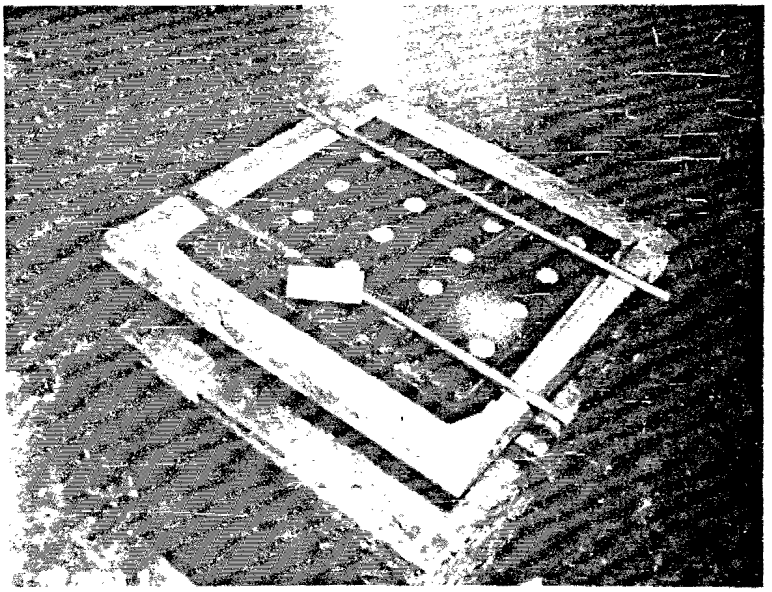
RF 5517-5

Fig. 160 Foam core, 25D.1 and 25E.1, in 25A.1 production size stretchform block.



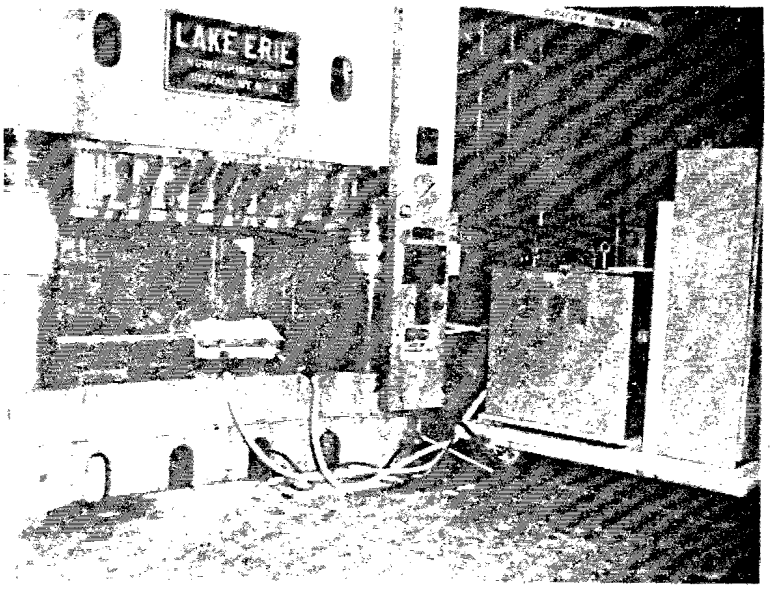
RF 5502-2

Fig. 161 Production stretch press setup with stretchform block and blank in place.



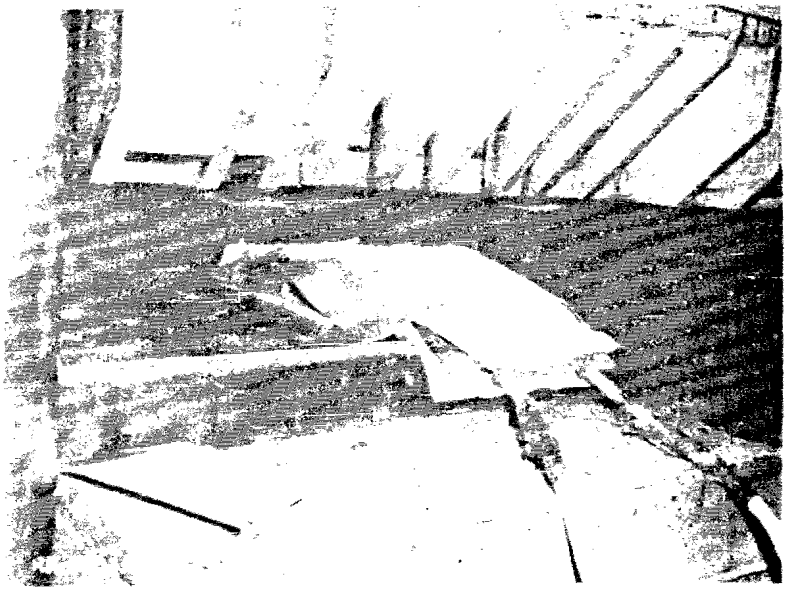
RF 5453-1

Fig. 162 12E.1 cap type production size hydroform block mold arrangement.



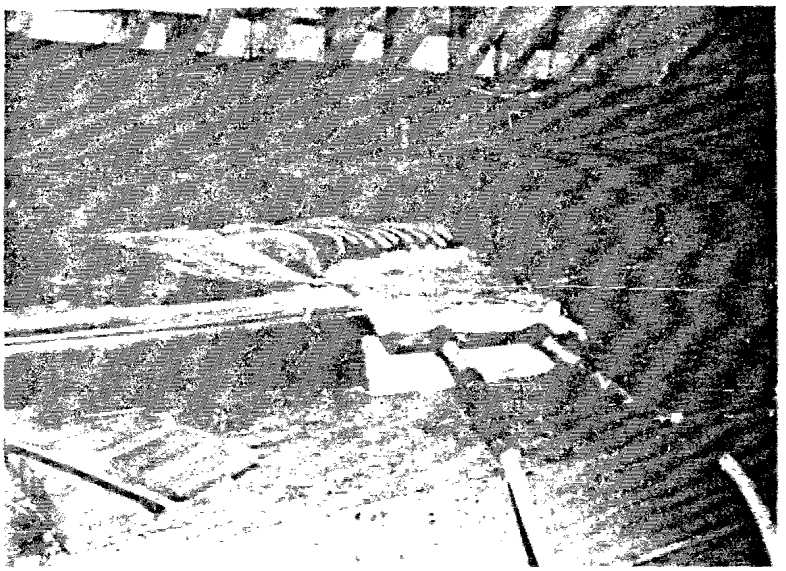
RF 5503-1

Fig. 163 Production hydropress with hydroform block set up for use.



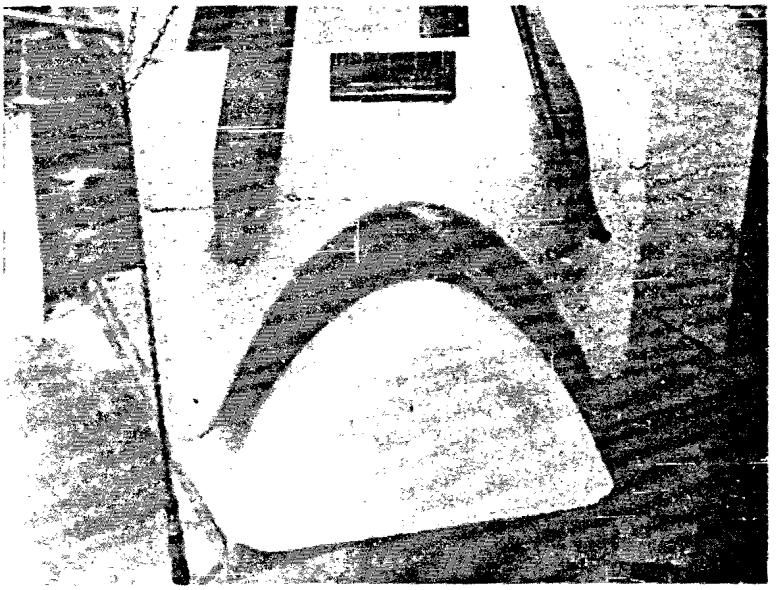
RF 5503-3

Fig. 164 Production hydroform block with blank and insulation in place.



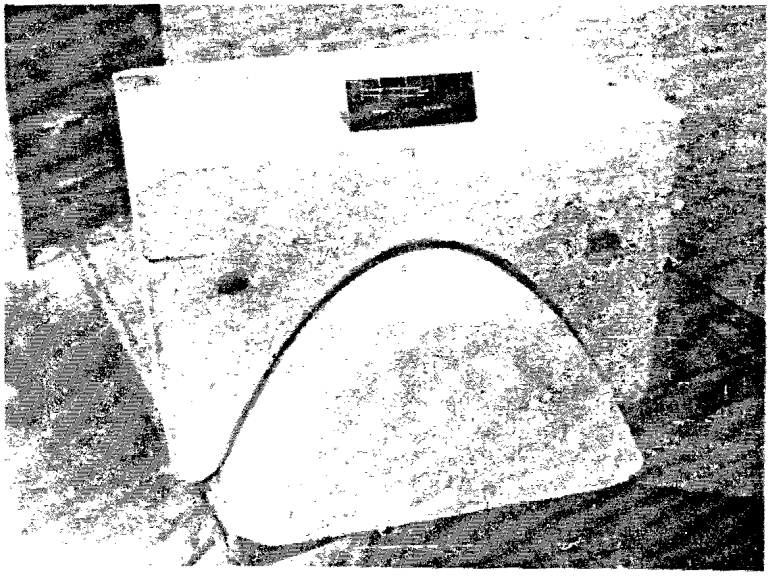
RF 5503-2

Fig. 165 Production size hydropress part after forming.



RF 5486-9

Fig. 166 12E.1 draw heat treat fixture being assembled.



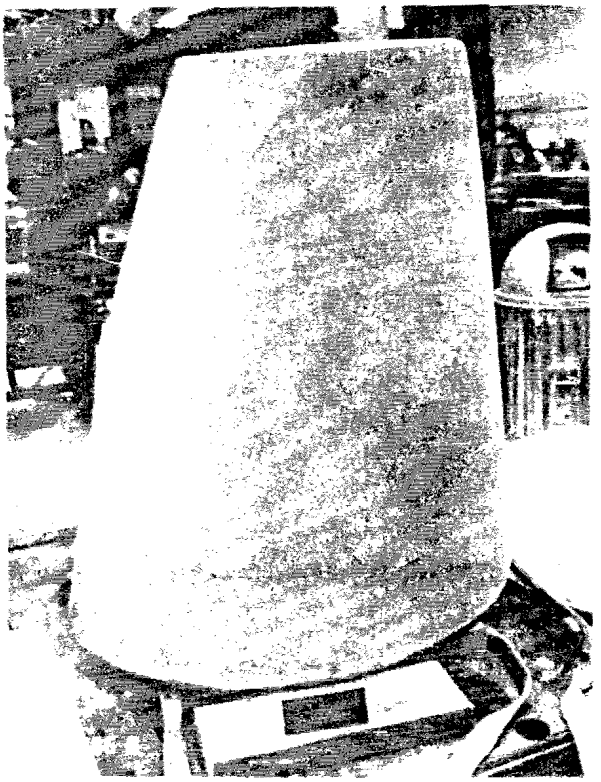
RF 5486-10

Fig. 167 12E.1 draw heat treat fixture ready for use.



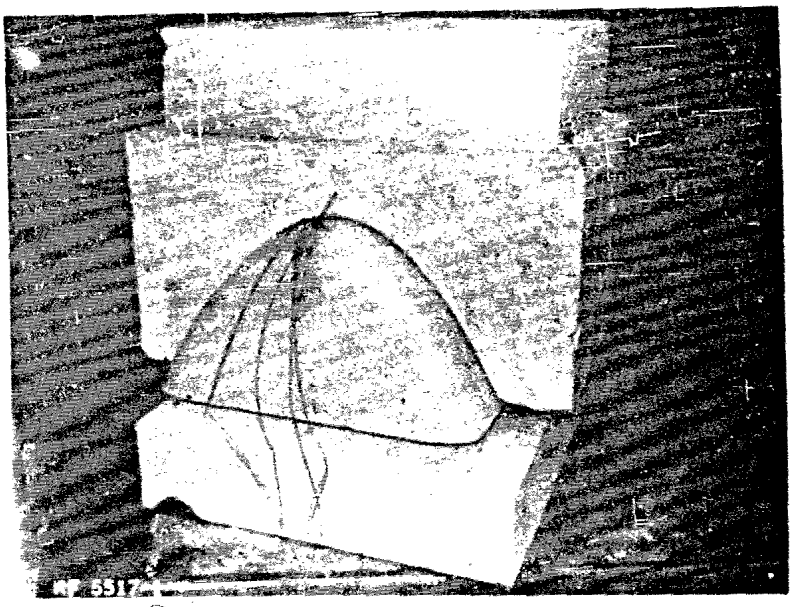
RF 5486-5

Fig. 168 Broken production size solid type 12E.1 stretchform block.



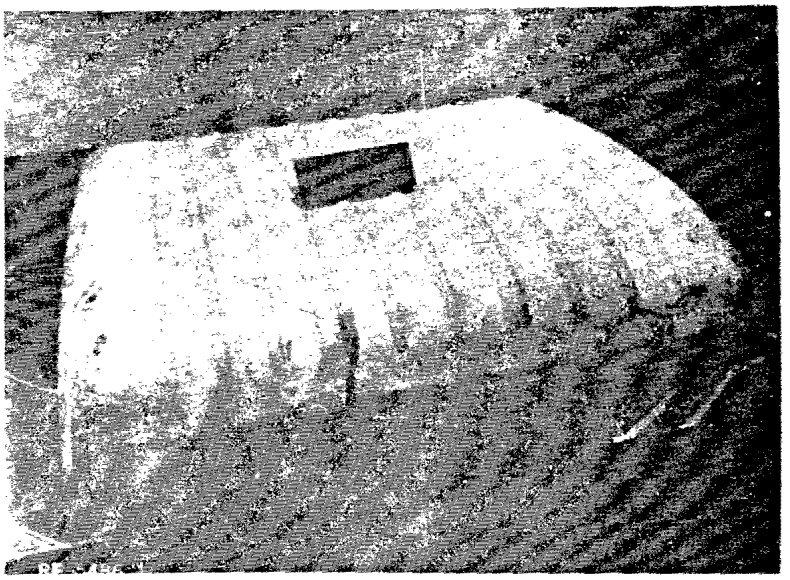
RF 5486-8

Fig. 169 Face of production size 12E.1 cap type stretchform block.



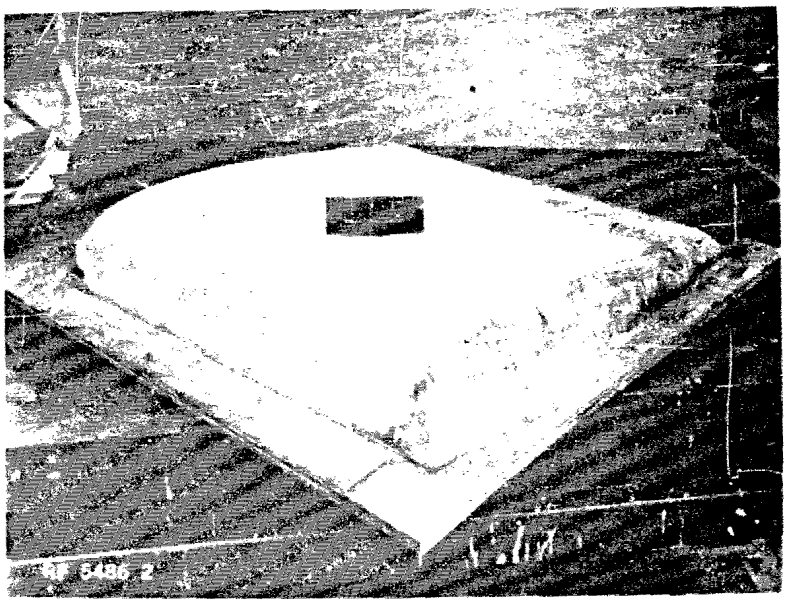
RF 5517-1

Fig. 170 25A.1, 25D.1 and 25E.1 composite type heat treat fixture after use.



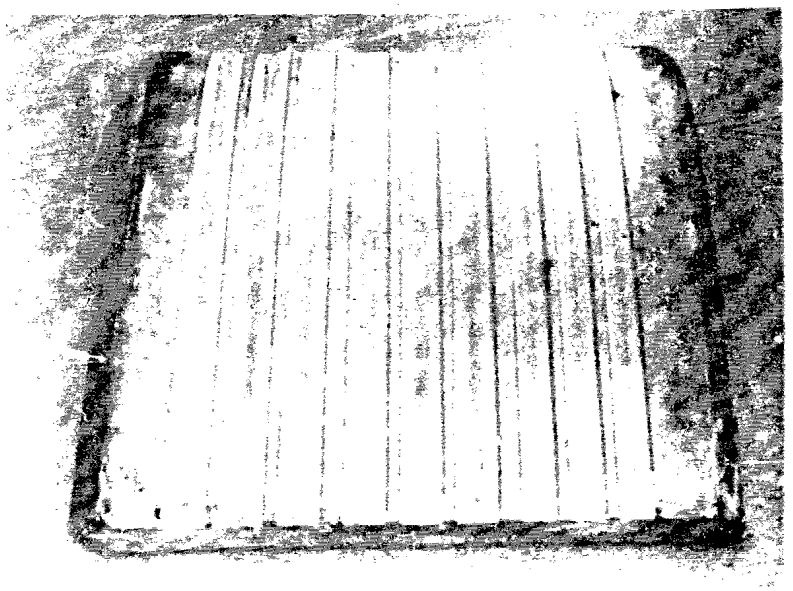
RF 5486-1

Fig. 171 12E.1 solid type production size hydroform block. Corner broken during use. Forming pressure of 2500 psi used.



RF 5486-2

Fig. 172 12E.1 cap type hydroform block. Cracked during use. Forming pressure of 1250 psi used.



RF 5517-2

Fig. 173 25A.1 solid type hydroform block after use. Forming pressure of 1250 psi used.

PHASE V
STANDARDIZATION OF TOOL DESIGN
September thru November 1960

INTRODUCTION

Tool trials during this phase of the non-metallic tooling investigation were intended to yield answers to questions of durability, producibility, economics, and design and manufacturing considerations. Reruns were made of the hydroform block, laboratory and production sizes, the stretchform block, and the stress relief fixture. A new configuration was used for another attempt at draw die development.

Resistance heating was used to heat the part material in all trials. Most of the evaluation work was done with .031 inch thick AISI 420, heated to a temperature of approximately 1350 F. A separate investigation at Lockheed, Georgia Division, shows that superior elongation and better final part properties were obtained with AISI 420 when forming temperature was held to just under the lower critical temperature(32). Forming temperatures used with the additional seven materials included those recommended by their manufacturers (see Table 2, Page 29).

Production machines were used to run the production size hydroform and stretch-form blocks. All other trials were performed on the experimental press or otherwise in the laboratory (see Exhibit 6, Page 275). Epoxy plastic bases were applied to all tool components for the dual purpose of facilitating the use of vacuum chucks for machine mounting, and of evenly distributing the loads applied to the ceramic tools during use.

PART I - HYDROFORM BLOCK, LABORATORY SIZE

INTRODUCTION

Reruns of this type tool were made so that several tool improvements, the need for which have been shown, could be evaluated. Also, tools were made of some few materials which a re-analysis of the data of Table 15 showed had not previously had a fair trial. Another purpose for making these blocks was to serve for one forming method to evaluate the formability of the seven additional sheet materials chosen as a result of the Phase I study of probable future materials of construction (see Table 3, Page 32). The constituents of each different tool were carefully weighed, mixed, placed, and vibrated consistent with the best results of previous efforts.

PROCEDURE

Mold Construction

A new model was machined with the same two-inch width and nine-inch inside radius as previously used but with the ends cut at an angle of 60° instead of 90° The sloping ends were used because it was shown in Part II of Phase IV that they prevented the cooling metal part from gripping and fracturing the ends of the block with the shear forces exerted. Also, sloping the ends of the blocks tended to decrease the size of the fold which occurs in both stretch and shrink flanges. The object of such decrease was to prevent damage to the rubber by the cutting action of the folds. This new model was used to make a fiberglass reinforced, epoxy plastic mold. Model and mold are shown in Figure 174.

Block Fabrication

Hydroform block tools were made of 8B.1, 8D.1, 12E.1, 20A.1, 71B.1, and 108A. castable materials. All were cast in the aforementioned plastic mold using the same apparatus, adapted to this mold, as was used to supply 10,000 vpm external vibration to the brick molds. Cores for forming part locating pin holes were not included in this phase, because it had been shown that breakage would sometimes occur during use at these weakened locations. Furthermore, it was intended that external locators would be employed to position the blank on the block.

The mold cavity was coated with two layers of Simoniz wax, thoroughly rubbed, and then painted with a coating of peanut oil before casting 8B.1, 8D.1, 12E.1, 20A.1, and 71B.1. To cast the 108A.1 material, a sprayed coat of rubber base paint, a procedure recommended by the castable manufacturer, was substituted for the peanut oil. No difficulties were encountered stripping any of the tools from this mold, even though there was no draft angle on the sides. The very slight shrinkage, which occurs when most castables set, aids the stripping operation.

All tools were cured at room temperature (under wet burlap when so stipulated by the supplier), dried at 120 F, and further dried at 220 F. The 8B.1 and 12E.1 tools were used without further treatment except one 8B.1 tool was fired at 2500 F the 108A.1 tool was fired at 600 F; the 71B.1 tools were fired at 1000 F; the 20A. tool was fired at 1500 F, and the 8D.1 tool was fired at 2500 F. All were brought to heat at less than 200 F per hour and held at temperature for two hours which was considered sufficient for the 2 x 2 inch cross section involved. Table 37, Page 364 shows drying and firing cycles for these tools.

Press Preparation

The fifty-ton experimental press in the laboratory was again fitted with the trapped rubber head used in Part II of Phase IV. The 10 x 15 inch opening in the rubber punch could be made to exert a maximum pressure of 650 psi for the forming force. Flexible connectors were used to conduct the low voltage, high amperage, current from the machine electrodes on the tension frame to the "clamp on" electrodes on the ends of the part blank. These latter electrodes were slotted to receive pins placed in position to keep the blank located on the form block (see Figure 182, Page 391).

Base Application

The bases of all these tools had been scraped off level with the top surface of the mold and were essentially flat; but to ensure complete flatness and equal distribution of load during use, plastic bases were applied.

The tools were placed on a waxed and greased surface plate singly or in groups, each setup was then surrounded by a low dam made with modeling clay, and freshly mixed epoxy plastic was poured inside to a depth which filled the spaces under the tools (see Figures 175, 176 and 177, Pages 387 and 388). The plastic bases were trimmed just slightly oversize. They were then ready for use (see Figure 178, Page 389).

Block Trials

A number of preliminary parts were run using .031 inch thickness AISI 420 blanks in an attempt to standardize a setup which would be used throughout the subsequent trials to develop formability data on the seven additional high strength sheet materials (see Page 27). Figure 179 shows a 12E.1 hydroform block and six parts made with it. The maximum forming pressure of 650 psi was selected with the forming temperature at 1350 F. Figure 180 shows eight additional parts of AISI 420 which were run to develop positioning, clamping, and heat shielding techniques. The die was held in position by small lugs on the platen and the ceramic fiber heat shielding material was trimmed to the shape of the blank to prevent it from being forced around and under the blank during the first portion of the forming stroke. Table 38, Page 369, gives the conditions under which each part was run and Figures 181 thru 185, Pages 390 thru 392, are a sequence group of a typical hydroform block trial. Figures 186 and 251 show failed hydroform blocks.

DISCUSSION OF RESULTS

Difficulty was experienced in removing the formed part from the block. Thermal shrinkage of the metal caused the formed flanges to grip the sides of the block so tightly that fractures occurred along the sides, even causing some areas to break off as can be seen in Figure 186. An attempt was made to reheat the part after forming to see if thermal expansion would facilitate part removal. It was thought that this would cause sufficient differential expansion because of the negligible thermal expansion of any ceramic tool material. It was found, however, that it would take an impractical length of time to reheat that portion of the part in contact with the tool without exceeding the temperature limit of the metal off the tool. However, placing a piece of ceramic cloth between the block and the part before forming provided spacing and a type of lubrication which rendered the part easily removeable. The cloth comes apart under the effects of heat and pressure but not before acting as a spacer to make the material form oversize. On three trials on a block which measured 1.996 inches wide, the parts measured 2.026 inches in all cases. This showed that if such measures are found to be necessary, compensation can be made to make the final product have correct dimensions.

All parts run at 1350 F showed some wrinkling of the shrink flange. Since a forming temperature of 1850 F formed good parts in the preceeding phase, and the need for maximum elongation offered by the 1350 F forming temperature was questionable, another blank was formed at the higher temperature. Both flanges formed down with few wrinkles and no difficulty was encountered in removing the part from the block even though the ceramic cloth was not used. This was probably due to the growth of 420 material when the martensitic transformation occurred. The part is shown next to the block in Figure 180, Page 390.

Table 39 gives the forming data and results for each part formed including the castable ceramic tool which was used. Figure 186, Page 393, shows blocks with typical types of failure. Some of the blocks shown do not appear damaged but are cracked, being held together by the plastic base.

CONCLUSIONS

In no case could it be said that heat was the cause of tool failure. Almost all failures could be directly attributed to the forces placed upon the tool by the forming pressure or the thermal changes in the metal part itself. The latter were especially noticed when the 1350 F recommended forming temperature was used. The formed flanges gripped the sides of the hydroform block through thermal contraction and were not relieved by crystallographic changes since the temperature was never high enough to cause them to occur.

RECOMMENDATIONS

Use plastic bases, preferably of a less resilient type similar to that shown in Figure 176 which is an Epocast* resin, as they are easily applied, need no special treatment, and perform the desired function of distributing the load force evenly over the entire block.

For hot hydroforming operations, use heat resistant rubber for the trapped rubber head on the press, continuing of course the practice of using the ceramic bat or equivalent over the blank during heating and forming. It is recommended that the forming stroke be completed as quickly as possible so that less heat be removed from the part material before it is formed. Use the highest forming temperature that does not adversely affect the part material.

*Product of Furane Plastics, Inc., 4516 Brazil Street, Los Angeles, California

PART II - HYDROFORM BLOCK, PRODUCTION SIZE

INTRODUCTION

Due to the fact that so many of the hydroform tools run in the production hydropress were cracked or broken during Phase IV, it was decided to use that forming method for further evaluation. An objective review of previous tests suggested some changes in the test procedure which would probably promote more successful results. Assuring flat surfaces for machine mounting, increasing the strength of the block itself, and raising the forming temperature were conditions incorporated in the procedure for this part of this phase.

PROCEDURE

Mold Construction

The K-25 gypsum plaster mold used in Part III of Phase IV, Page 287, was refinished by making a few minor repairs to areas "out of part" and applying several additional coats of lacquer. Also, the mold was made deeper by the addition of approximately two inches. This modification was accomplished by roughing and thoroughly wetting the rim surface before pouring freshly mixed plaster into the form built up on the existing rim. Two opposite sides were poured at a time. Bonding was good and no cracking occurred after repeated use. Figure 187 shows a high alumina-calcium aluminate bonded castable as removed from the reworked mold.

Block Fabrication

All hydroform blocks made for this phase were made from fresh material ordered for this purpose. The weight of each tool was calculated; and then the proper portions of dry aggregate and water or other binder were mixed in the mix-muller, Figure 67, Page 182. Mixing times were used which gave good previous results for the material being cast. Vibration at 10,000 vpm. was supplied by the internal vibrator (Figure 15, Page 151). Blocks were made of 5A.1 - dried only, 12E.1 - dried only, 20A.1 - dried only, 20A.1 - dried and fired at 1500 F, and 20B.1 - dried only. (Refer to Table 37, Page 364.)

Base Application

Plastic bases were applied to all tools prior to using. Figure 188 shows how the blocks were suspended by three straps hooked under them from a hydraulic lift table. In this way the block could be lowered into a puddle of freshly mixed plastic poured inside a wooden dam on a waxed and greased surface plate. The block was held suspended in the plastic until setting occurred. A plastic base approximately 3/8 inch thick was thus applied to each hydroform block. Figures 189, 190, and 191 show ceramic hydroform blocks with plastic bases after being slid loose from the surface plate and trimmed just slightly oversize to form a protective bumper. Both a handsaw and an air powered sabre saw were used for the trimming operation.

Press Preparation

The large production hydroform press was again used for tool trials. A newly installed sliding table was used and to further ensure that as little bending moment as possible would be transmitted to the blocks by any out of flatness of the press bed, a two inch thick slab of aluminum tooling plate was used to support the blocks during use. The 65 KVA, saturable reactor controlled, power transformer was used to maintain the forming temperature of 1350 F until just prior to the closing of the press. A Minneapolis-Honeywell strip chart recorder was used to monitor the temperature and a ceramic fiber mat was again used to protect the rubber from the hot metal.

The AISI 420 stainless steel blanks which were used on each of the five tools tried were .031 x 24 x 54 inches and were beaded on each end so they could be held in the electrodes which were designed for the stretch press. See Figures 192 and 193. These electrodes were used in the trials because of increased ease with which new blanks could be clamped.

Block Trial

The first block tried was the 5A.1 material. A ram pressure of 1250 psi was used which did not form the metal into the grooves of the tool. The next tool tried was the 12E.1 material using a ram pressure of 1700 psi. The groove shapes were almost completely formed. The next three blocks, 20B.1, 20A.1 (dried), and 20A.1 (fired), all made essentially fully formed parts and were formed at a ram pressure of 2000 psi. This amount of hydraulic pressure exerted on the press ram developed approximately 1330 psi in the trapped rubber.

Following the single part evaluation of each hydroform block, ten parts were run on the 12E.1 block in a durability test. The same temperature and pressure were used as finally selected in the single-part evaluation. Figures 194 thru 199 show various stages of a typical hot hydroform tool run.

DISCUSSION OF RESULTS

No adverse effects of the hot metal on the ceramic tools could be noted after forming one part each per block, nor were any of the blocks cracked or broken. Figures 200 thru 204 show the blocks after use and the parts which were formed on them. As can be seen, the metal has been torn near each end of the form block. This was caused by the action of the rubber which held the metal in two places across a gap and then tried to force it to stretch more than its elongation allowed The gaps were formed as a result of the block sitting on the platen. The blanks were torn over the sharp edge of the hydroform block at its low end and at the deepest part of the gap at the bottom of the block at the high end. This tearing is not detrimental and is sometimes used to advantage in production for hard to for parts. In addition, some blanks were torn off at the edges simply because they wer too short. The box on the press which contains the rubber would descend far enough

near the end of the press stroke to hit the electrodes. This action would stretch the metal between the electrode and the press platen until it tore. This condition was,of course, not desirable; so blanks .031 x 22 x 72 inches were sheared for the durability trial. The decreased width was to prevent the sides of the blank from locking over the sides of the block, a condition which had been noted during the trials with the .031 x 24 x 54 inch blanks.

The 12E.1 block was used for the durability trials as it was the material chosen for use in the as-cast and dried condition. Nine additional parts were made on the tool. Six parts were completed before any ill effects were noted. Inspection at that time revealed that the outside radii of the two edge grooves were failing. The sliding action of the metal, being pulled over each radius under pressure, exerted shear forces on the top corners causing cracks to occur.

Parts seven and eight were acceptable but nine and ten had visible irregularities in the outside radii caused by the loss of fragments. Figures 205 and 206 show the 12E.1 hydroform block after it had been used to form the ten parts.

CONCLUSIONS

1. The use of ceramic tooling for hot hydroforming of high strength material has been shown feasible.

2. Parts which closely conform to the blocks were formed on blocks of all materials (5A.1, 12E.1, 20A.1, and 20B.1).

3. The high forming temperatures could in some cases be used for heat treatment simultaneous with forming.

4. The high forming temperatures also reduce the tendency for springback and make possible the forming of parts which could not be made of the selected materials at room temperature.

5. Ceramic tools are much better suited to withstand the temperatures involved without adverse effects than most metallic tooling.

RECOMMENDATIONS

1. For greater strength, ceramic hydroform blocks should be made with increased cross sections over conventional tools.

2. Materials with sufficient strength, as cast and dried, can be used to make tools for most hot hydroforming uses, but proper base application for distribution of load forces is necessary.

3. Every possibility of speeding up the forming stroke should be used to prevent the loss of as much heat as possible before forming is complete.

4. Precautions should be observed concerning the possibility of fire during hot forming. (Hydraulic machinery is prone to have flammable fluid present from leaks in the high pressure connections. This should be eliminated or circumvented and all flammable materials protected or removed from high temperature regions.)

PART III - STRETCHFORM BLOCK, PRODUCTION SIZE

INTRODUCTION

The need for further evaluation of this type of tool, simulating production practices and using better designed auxiliary equipment, led to the selection of a solid type tool for further trials. Material 12E.1 was used to make the tool. Trials using wrap forming, cyclic forming (heat, stretch, and relax), and conventional stretchforming were made. A total of 23 parts was run on the tool. Various pressures were used, but 1300 F forming temperature and .031 inch thickness AISI 420 blanks were used for all trials.

PROCEDURE

Mold Construction

The same plaster mold as was used in Part III of Phase IV was repaired and refinished for use in casting another tool (see Figure 155, Page 329). Instead of using external clamps to hold the plywood ends on the mold, provisions were made to use a bar threaded on each end located longitudinally through the approximate center of the tool. The ends of the mold were thus held to the edges of the plaster by this tie bar. A heavy coating of Simoniz wax followed by silicone was put on the tie bar and the interior surface of the mold as a parting agent.

Block Fabrication, Production Size

The two and one-half yard cement mixer was used to again mix the 1800 pounds of castable with 10 percent by weight of water. Internal vibration was accomplished by the portable electric vibrator. Figure 156 shows the casting shortly after pouring.

The casting was stripped from the mold after a lapsed time of approximately 48 hours. An attempt was made to slide the bar through the middle toward the smaller end so that a nut and washer on the large end would be recessed into the hollow provided. It could not be moved, so it was concluded that the abrasive nature of the material, during pouring, had rubbed the lubricant from the bar and later allowed a reaction to occur between the metal bar and the castable. Because the bar could not be slid endwise, it had to be threaded further and then cut off to make a flush surface as shown in Figure 207. Upon being placed in the 150 F oven for the preliminary drying cycle it was noted that cracks had occurred radiating from the centrally located bar. An attempt was made to patch them by making a thin mix of the minus 100 mesh fines screened from an extra bag of the same batch of material and pouring it into the cracks. This seemed to do a creditable job so the curing cycle was completed.

The block was placed on a greased surface plate on three spacers of previously poured and hardened plastic scrap. Freshly mixed plastic was poured around the block behind a dam. After the plastic had set, an attempt to slide the tool sideways to the edge of the plate ruptured the block along the previously noted cracks. Figures 207 and 208 show the block after this failure.

Another block was cast as before, except this time the tie bar was encased in a paper tube which was well greased. No difficulty was encountered in stripping the block from the mold or removing the tie bar. The paper tube had to be cut out, but presented no difficulty. An eye bolt, made for the purpose, was then set in the hole. Fresh castable was poured around it and vibrated in place with the internal vibrator.

Base Application

After the curing and drying, a plastic base was applied to the tool. Figures 209, 210, 211, 212, and 213 show the sequence used in applying the plastic base, the last figure being the finished tool with excess plastic trimmed off and ready for use. The block was positioned, as shown, over the surface plate, prepared this time by the use of a sheet of cellophane to act as a parting agent.

Three plastic spacers were placed under the block as before and freshly mixed plastic poured into the space formed by the plywood dam. The block was lowered onto the spacers with the screw jacks. The strap was removed from the large end of the block to get it out of the plastic. No difficulty was experienced this time in sliding the block to the edge of the table to remove the excess plastic.

Press Preparation

Trials were made using the ninety-ton Hufford Stretchpress. To facilitate the trials, a vacuum chuck was designed to fit the press mounting hole pattern and special electrode jaws were made to grip the metal and electrically isolate it from the machine during forming. Figure 214 is the vacuum chuck with rubber seal in place and countersunk mounting bolt holes and vacuum port drilled ready to go into the press. Figures 192 and 193 are an overall and a close-up, respectively, of one of the pairs of electrode-jaws with a metal blank (but for hydropress part) in place. The shank of the "T" shaped member was gripped in the regular jaws of the stretch press, and the metal blanks were then gripped by tightening the two halves of the jaw together with the nine bolts shown. The electrical insulator used is Teflon bonded to the steel "T" section. Electrical connection was then made by "L" shaped lugs fastened under two of the bolts in each electrode. Power was supplied by the 65 KVA transformer previously described. Figure 215 shows the press with vacuum chuck, vacuum pump, stretchform block, electrode jaws, and connected power cables.

Block Trials

Table 40 shows the conditions under which trials were conducted and some pertinent facts concerning each part formed. As can be noted, difficulty was experienced in trying to eliminate the wrinkles and many different variations of

conditions were used. Also tried were variations in forming procedures developed by machine operators .for production parts which were difficult to form, such as: wrap forming, multiple stage or cyclic forming, and use of specially trimmed blanks. Figure 252 shows degree of double contour involved in forming this part.

All trials were run on the same block using .031 inch thick AISI 420 blanks which were sheared to 34 x 72 inches, except the last two were 34 x 90 inches, and beaded on the ends which were held in the electrode jaws. A forming temperature of 1300 F was used as the heating unit did not have quite enough capacity to heat the large blank used the additional 50 F.

DISCUSSION OF RESULTS

The first parts formed had wrinkles and most subsequent efforts were directed toward their elimination. It was noted that the part did not pull down onto the face area of the block at the top. A "wrap around" action was tried without success, as it was too slow (see Figures 216, 217 and 218). Tapering the blank in the center seemed to help prevent some wrinkling, but an increase in stretching force, however, would tear the blank between the block and the jaws. The use of talc as a lubricant dusted on the block allowed the blank to slide enough on the first contact area to form down on the top area. It was also noted that when the power was left on during the forming action the blank would cool in the block contact area and considerable necking down, even tearing, of the area off the block where it was hotter would occur. Cutting the power at the right instant, just at the first contact of the blank on the block, allowed the area off the block to cool simultaneously with the contact area. This action would allow more stretching force to be applied to the part area because of the strengthened condition of the cool metal transmitting the force. Much wrinkling was thus prevented.

Other variations used were to completely form the blank by a sudden single pull or by progressive pulls with intermediate reheating. Due to the nature of the stretchform machine, the speed at which its hydraulic pump could build up pressure was not quick enough to permit complete forming of the part before large temperature differences developed. The action was speeded up some by presetting the machine pressure at maximum for fastest movement, then stopping the action just before it was judged the blank would rupture. Even this procedure would not pull out all of the wrinkles.

The multiple stage or cyclic forming did produce an acceptable part. This technique was suggested by the success achieved in the laboratory size evaluation (see Phase IV, Page 283). The success of the stretchform operation depends greatly on the operator's familiarity with the machine and its actions. The blank was clamped in the jaws and wrapped around the block to such a position that only linear motion of the jaws would be needed to form the part. A little pressure was then applied to the cold metal, just enough to seat the beads in the blank in the electrodes, after which it was backed off the block to a distance of one to two inches. Power was applied and the material brought to forming temperature. The same procedure was then used as with the previously described single pull method except the machine was stopped sooner, the blank backed off, and the power reapplied to repeat the cycle. Three cycles were all that were needed to make

a good part. See Figures 219, 220, 221, 222, and 223 for views of successive stages in forming Part No. 14. Table 40, Page 373, gives the results for each part run. Part No. 14 is shown in Figure 253.

Additional parts were run using some tapered blanks and experimenting with block positioning by putting spacers under the vacuum chuck at the top. Spacers which held the top of the block 2, 3 and 3 1/2 inches off vertical were used. Tilting in this manner was done to make the same distance from jaw to jaw around the block at both top and bottom, thus equalizing the stretch forces in the blank. Also, blanks were cooled away from and in contact with the block to evaluate which procedure yielded the best parts. See Figures 253, 254, and 255, and Table 40.

CONCLUSIONS

Ceramic tools are readily adaptable to the stretchform type operation. Stretchform tools have, for the most part, continuous contours even when compound contours are involved. There are usually few sharp bends, requiring fragile corners which can be easily damaged, and strength requirements are not great since wood and plastic tools are presently in common use. Numerous castable ceramic materials have sufficient strength unfired to meet the requirements when proper steps are taken to ensure that bending forces will not be induced in the tool.

Stretchform block tool life is indicated as being good. Twenty-three parts were made on one tool, and even though it cracked it is still capable of being used.

RECOMMENDATIONS

All stretchform tools should be cast with a flat base or should have one applied before they are used. This base will distribute evenly the applied load and also facilitate mounting the tool on the machine using vacuum chucks, which are also recommended. Vacuum chucks do away with the need for anchoring attach bolts, anchor nuts, or other metallic inserts in the base of a ceramic tool. Metallic material buried in ceramic castings can cause damage when heated or not thoroughly coated with a protective coating and is; therefore, not recommended.

Hot stretchforming should be performed by the single, rapid pull technique for the best part was made by slightly preforming the blank on the block cold to position it firmly in the jaw-electrodes; then backing off slightly, heating to forming temperature, and pulling as rapidly as possible to a position that did not quite break the metal. A good part was also made by multiple stage or cyclic forming method, but due to increased length of time at heat and difficulty experienced in reheating the metal to forming temperature after the first time, it cannot be recommended, at least not for AISI 420. Heating could be better accomplished if the machine was designed with integrally contained jaw-electrodes and a power supply capable of supplying about 100 KVA for the part used.

PART IV - DRAW DIE, PRODUCTION SIZE

INTRODUCTION

The evaluation of ceramic double action draw dies was again attempted in this phase. The new 10 inch diameter cup configuration chosen for the trials was expected to be slightly easier to form than the rectangular shape evaluated during Phase IV.

PROCEDURE

Mold Construction

Models of the new draw ring and punch were machined of cast magnesium tooling billet. The ring has nominal dimensions of 10 inches inside diameter, 20 inches outside diameter, and a 4 inch height. The working face was relieved 0.050 inch to leave a 2 inch wide land around the inside diameter. The outside was tapered approximately 1/2 inch to facilitate removal of the model from a mold or a casting from a mold; the inside, however, was cylindrical, except for .004 inch draft on the diameter. The punch dimensions, also nominal, were 10 inches in diameter and 8 inches high. The outside diameter was tapered only 0.010 inch to preserve as vertical a shape as possible yet still provide some draft angle for separation of the model from the mold and the casting from the mold. Figures 224 and 225 show the ring model and the punch model with a ceramic punch.

The models were used to make molds of both No. 1 pottery plaster and fiberglass reinforced epoxy plastic. Several attempts were made to make molds of K-25 gypsum plaster, but trouble was encountered in that the parting agents failed. The magnesium metal reacted with the constituents of the K-25 plaster with the formation of bubbles at the interface which, consequently, left pits in the mold surface rendering it unfit for use. The No. 1 plaster molds were made by placing a dam around the model on a waxed and greased surface plate, then pouring the fresh mixture around and over the model (see Figure 226). A further refinement was made when difficulty was encountered stripping the 25A.1 material from the mold. Sheet aluminum dividers trimmed to clear the models by 1/4 to 1/2 inch were placed over the models before the plaster was poured. Figures 227 and 228 show the ring mold and Figure 229 shows the punch mold. The models were also used to make plastic molds (see Figure 230). These molds were used to cast hydraulic and chemical setting castables.

Die Fabrication

A complete tool consists of two rings, used face to face, and a punch. Tools were made of 20A.1, 25A.1, and 108A.1. The 20A.1 and 108A.1 were cast in the plastic mold and the 25A.1 was cast in the break-up type No. 1 pottery plaster mold using vibration of 10,000 vpm frequency. Simoniz wax and peanut oil were used as parting agents for the 20A.1 material and a sprayed coat of rubber base paint was applied and allowed to dry before casting the 108A.1 material. No

parting agent was used in the plaster mold for casting 25A.1 material. The interior mold surfaces were sprayed with water, using a paint spray gun, immediately before casting 25A.1 material. This practice seemed to slow down the high rate of water absorption which occurs at first and relieves the tendency for some areas to stick to the mold.

Stripping from the plastic molds was accomplished by inverting the molds containing the castings and introducing compressed air to the interface through previously drilled small holes through the bottoms of the molds. Some impact was also needed to jar the casting loose from the vertical center portion of the ring mold, but the punch mold usually came off the punch casting using only reduced or less than plant air pressure. The green strength of both 20A.1 and 108A.1 was sufficient to permit removal of the ring mold without damage to the casting.

The 25A.1 ceramic castings were cured, dried, and baked per previously determined schedule, Table 37, while still in the break-up type molds. This treatment weakened the bond of the plaster enabling it to be broken apart into sections. See Figures 231, 232, 233, 234, 235 and 236 which show a typical sequence of ring mold removal and punch mold removal.

All draw die components were fired. The 108A.1 material was fired at 600 F, the 20A.1 material at 1500 F, and the 25A.1 material at 2000 F. See Table 37, Page 364, for further details. Figures 256, 257, and 258 show 108A.1 draw die components; Figures 259, 260 and 261 show 20A.1 components; and Figures 262, 263 and 264 show 25A.1 components. Figures 265 and 266 show draw die mounted in press with draw ring retracted and extended respectively.

Base Application

Plastic bases were put on each tool component. Fixtures were made having metal plates with three adjustable legs and hook bars for holding the tool to the metal plate. The fixtures were placed on a surface plate. The ring or punch was clamped up to the metal plate and then a height gage was used to parallel the metal plate to the surface plate by adjusting the length of the legs. The surface plate was properly prepared with wax and grease and a low dam of modeling clay or plywood was put around the assembly. Plastic was then poured around the punch or in the center of the ring. See Figures 237, 238, 239 and 240.

Press Preparation

The same double action head adapted to the experimental press as used in Phase IV was again employed. Different vacuum chucks which conform to components of this tool were used (see Figure 241). These chucks were bolted to the press platens and vacuum lines were attached. The previously used jaw-electrodes were again used to heat the .031 x 18 x 34 inch blanks.

Tool Trials

Several trials were conducted with each of the 20A.1, 25A.1, and 108A.1 tool components. A single draw stroke resulted in rupturing the blank when the punch

had barely formed a radius. Figure 245 shows a typical failure. Trials were then made using repeated, limited depth, strokes with intermediate reheating. Progressive movements of the punch into the die ring were limited to 1/4 to 3/8 inch per cycle. Positive stops were later devised by which definite distances of punch advancement could be preset. Parts were drawn to depths of one inch using temperatures from 1300 F to 1500 F (see Figure 243). Five psi was selected as being optimum for the draw ring for most trials. A ram pressure of 1000 psi was used on the punch. Wrinkling occurred in all trials.

DISCUSSION OF RESULTS

Most of the tool components failed during use. The rings failed through hoop tension by breaking radially into as many as four pieces. The punches failed by shear at the radius (see Figures 244 and 245 for failed draw ring and punch respectively). Lubrication of the action by the use of talc and a silicone grease was tried, but such lubrication was found inadequate.. Table 41 shows pertinent data concerning the evaluation of these tools.

CONCLUSIONS

The 20A.1 castable which was fired to 1500 F before use seemed to be the best suited of the three materials used for this evaluation. Five trials were completed before the draw ring failed by cracking radially. Two trials only were completed by any other tool before one of the three tool components failed. Neither talc nor silicone grease used as lubricant performed with any great degree of success. The metal was scored and galled in the area where it was pulled over the die ring radius. Very little metal movement took place in the clamping area of the rings even though clamping pressure was little enough to allow wrinkles to form. Most forming done was accomplished through stretching of the metal in the radius area.

RECOMMENDATIONS

Since all tools that were used failed through tension or shear forces, it is recommended that tool design for ceramic tooling for this use include a box type container for the die or die ring or an increased mass of material to withstand the tensile forces applied. In addition, since little true draw forming action (plastic flow) had occurred because of lack of metal movement between the clamping areas, a recommendation is made to further investigate to find a means to lubricate this action.

PART V - DRAW HEAT TREAT FIXTURE, PRODUCTION SIZE

INTRODUCTION

The re-evaluation of the draw heat treat fixture was run in an effort to determine the effectiveness of using resistance heating to stress relieve a formed part. The previous test was run by placing the ceramic fixture containing the formed part in an oven at the desired temperature. This method required quite a lengthy period of time for the formed part to reach a stabilized temperature, so a faster method of bringing the formed part to temperature was desirable.

PROCEDURE

The 25A.1 material heat treat fixture which was evaluated in Phase IV was used as a draw heat treat fixture for this resistance heated part stress relief fixture. This 25A.1 material tool was chosen because of its excellent thermal insulating properties.

As described in Phase IV, the male half of this tool was cast of the 25A.1 material and the female half was fabricated by casting a 25A.1 face on the male half and then strengthening this cast face with cemented fused silica foam blocks.

Nine thermocouples were attached to the AISI 420 formed part. Grooves were cut in the male block to provide clearance for the thermocouple leads.

An AISI 420 part, which was previously formed during the laboratory size stretchform block evaluation of Phase IV, was placed on the male half of the 25A.1 draw heat treat fixture and covered with the female half of the tool. The thermocouple leads were placed in their grooves in the block so that the formed metal part would contact the ceramic fixture completely.

Copper bar-type electrodes were then attached to each end of the formed part which extended out of the ceramic draw heat treat fixture. These electrodes were attached to a transformer by means of large copper cables. The power to the transformer was furnished by a saturable core reactor so that small power adjustments could be made in order to obtain the desired temperature.

A multichannel temperature recorder was used to monitor the nine thermocouples which were attached to the part in the draw heat treat fixture. The locations of these thermocouples are shown in Figure 246, Page 423. The assembly of this fixture is shown in Figures 247, 248, and 249, Pages 424 and 425.

Power was applied to the part using the saturable reactor and transformer on a program such that the highest indication of any of the nine thermocouples would be maintained at 1000 F. This temperature was maintained for seven and one-half hours. The complete test setup is shown in Figure 250, Page 425.

DISCUSSION OF RESULTS

Thermocouple Number Seven, which was located in the center of the formed part, reached 1000 F in approximately five minutes after heating was begun. The power requirements for maintaining the highest temperature thermocouple on the part at 1000 F was approximately 500 amps at 5 volts.

As the center thermocouple reached 1000 F, the outside thermocouples, numbered one and three, had reached 800 F. At the end of seven and one-half hours, during which time the center of the part had been maintained at 1000 F, the outside of the part had dropped to 700 F.

This loss in temperature is due primarily to the fact that as the ceramic fixture became hotter next to the formed part, it was necessary to reduce power so as not to overheat the center of the part. The edges of the formed part were located approximately 3/4 inch from the outside of the female half of the ceramic fixture while the distance from the center of the part through the fixture to the outside was six inches. This difference in insulation allowed the center of the part to be maintained at the desired temperature while the outside of the part became progressively cooler. This condition would continue until the heat loss equals the heat gain at which time the temperature differential would stabilize.

CONCLUSIONS

The temperature differential which was obtained in the evaluation of this ceramic stress relief fixture was too great for its successful use as either a draw heat treat or as a stress relief fixture.

The insulating properties of the 25A.1 material are such that a very small amount of power is required for maintaining formed metal parts at the desired temperature. The metal part also responds very quickly to small power adjustments.

RECOMMENDATIONS

It is recommended that draw heat treat fixtures be constructed so that the formed metal parts are enclosed by the ceramic material such that the distance from the part through the ceramic will be approximately equal in all directions. This will tend to equalize the heat loss and to reduce the temperature differential in the metal part.

It is further recommended that resistance heated part type ceramic draw heat treat fixtures be constructed of materials having low thermal conductivity and that materials for furnace type fixtures have high thermal conductivity.

PART VI - FORMABILITY

INTRODUCTION

As previously mention in Part I - Hydroform Block, Laboratory Size, the purpose of these formability trials was to show what results could be expected when ceramic tools were used to form parts of high strength heat resistant materials for airframe and missile structures. To make comparisons, three temperatures were used to form parts: room temperature, an elevated temperature recommended by the material manufacturer, and a still higher temperature, the use of which probably would not be possible without ceramic tooling. The first two temperatures are in current use for forming some of the materials with conventional metallic tooling.

PROCEDURE

For preliminary trials the sheet materials, which had beer selected in Phase I, were blanked out with the same steel-rule die used to make the AISI 420 blanks for the laboratory size hydroform block evaluation. As mentioned earlier, blank locator pins were not placed in the ceramic form blocks, for it was felt that a single set of external locators could be devised, thus avoiding locator complications in all of the blocks. Three or more blanks were made of each material.

For the production-size evaluation,one blank each was sheared to the dimensions used for the durability trials, .031" x 22" x 72". These runs were made using the same higher temperatures which were used in the previous laboratory-size trials.

These preliminary trials were run on blocks of various ceramic materials as are indicated in Table 42, Page 381, but the production-size trials were all run on one block made of unfired 20A.1 material. See Table 43, Page 386.

Figures 181, 182, 183, 184, and 185 are a sequence of stages of a typical preliminary laboratory-size run. The production-size trial followed the same sequence as used in the durability run shown by Figures 194, 195, 196, 197, 198, and 199.

DISCUSSION OF RESULTS

The laboratory hydroform block trials point out vividly the increased formability of all the metals tried as forming temperature is raised. Figures 267, 268, and 269 show parts formed at room temperature, recommended temperature, and some higher temperature, respectively. Examination reveals how increased temperature decreases the number and size of wrinkles and the amount of spring-back.

The production-size trials made on the 5000-ton Lake Erie hydropress served to further emphasize the fact that high forming temperatures reduce forming pressures. The metals heated to the highest temperature used in the laboratory trials all formed on the hydroform block in an acceptable manner, except the HM-21-A material. This material split along the radii of the ribs on the block face, due probably to the quenching effect of the block. It does not form well when cold, as shown by cracking of part when room temperature forming was attempted on the laboratory-size hydroform block. The action of the press was slow and magnesium is a good heat conductor, so the blank was readily cooled by the cold block before forming pressure was applied. Figures 270, 271, 272, 273, 275, 276, and 277 show the parts formed on production-size hydroform blocks run in the production hydropress. Figures 278 and 279 show overall and close-up of typical hydroform block failure.

CONCLUSIONS

The metals formed for this evaluation were those chosen as being typical of future materials of construction and show that better conformance of material to tool can be achieved at high temperatures. The use of ceramic tools, shown to be capable of performing this type of function, makes the upper temperature limit depend only on the material being formed. Springback, caused by the high modulus of elasticity possessed by most of the materials, was the characteristic most notably responsible for non-conformance of part to form block at lower temperatures. Its effects can be nearly nulified by the use of high temperatures. As noted previously, maximum elongation is not prerequisite for hydroforming many configurations. For such configurations, the use of high temperature, with accompanying lower elongation and less springback, is more desirable. (Refer to discussion at top of Page 342.)

RECOMMENDATIONS

The forming temperature should be as high as can be used without detrimental effects on the material being formed. Embrittlement by gas absorption and excess scaling are two examples of detrimental effects. Ceramic tooling should be considered for high temperature forming because of its inherent resistance to heat. Machine tools to be used for hot forming should be prepared by the removal of all combustible materials from the blank vicinity and the repair of hydraulic oil leaks so common around hydraulically operated equipment.

CONCLUSIONS

GENERAL

Non-metallic tooling, or, specifically, refractory ceramic tooling, has been shown by this investigation to have a definite place in many applications requiring high temperature operations. The negligible effect or absence of affect of heat on tools made of this type of material has been illustrated in almost all of the applications investigated. Hot forming of sheet metal constitutes the great majority of possible ceramic tooling applications, but joining such as by: brazing, soldering, and welding, is another important field of application. Heat treating and stress relieving are also important areas of application. Characteristic properties needed for each type of tool will dictate the choice of the refractory ceramic for its construction. It has been found that in practically every case a commercially available product can be obtained that will make a tool possessing the desired properties.

Within the areas investigated under this contract, the strength of a castable both as dried and fired, determined by a modulus of rupture test, was the characteristic considered foremost in the material selections. Other characteristics were also considered and are used as column headings in Table 15, Page 120.

The column headed "Surface Finish" indicates to some extent the grain size and distribution of a particular product. Grain size affects other characteristics also in that large grains will lower shrinkage and the proper distribution of large and small grains will provide a strong, smooth, dense, product.

Castable Types

The ceramic castables which were evaluated can be broadly grouped into three classifications.

1. Hydraulically bonded
2. Chemically bonded
3. Heat bonded

Castables which could be grouped in two or three classes do exist, as well as those which are bonded by only one method listed above.

Hydraulically bonded castables set-up at room temperature and form products which in that state are nearly as strong as they will ever be. Portland cement, gypsum cement, and Lumnite* or CA-25** cements are typical constituents of most of the castables which are bonded in this manner. They are calcined products that combine with water to grow accicular crystals which impart strength. Most calcium aluminate bonded castables can also be fired at temperatures ranging from 2000 F to 3000 F thereby gaining varying amounts of strength. As a word of caution, however, it should be noted that as temperature is increased a point is reached at which the hydraulic bond is destroyed and the vitreous bond is not yet formed, so the castable is in a weakened state. This condition occurs in the neighborhood of 1900 F, for most castables but should be determined for a specific castable so that firing in that range can be avoided. Material Codes 5A.1, 12E.1, 20B.1, 39A.1 and 71B.1 are typical examples of hydraulically bonded castables. (Page 10).

*Domestic calcium aluminate cement, a product of the Universal Atlas Cement Co.
**Calcium Aluminate, a product of the Aluminum Company of America

Chemically bonded castables do possess good "as cast" strength as a rule, but require some moderate amount of heat to gain maximum strength. Temperatures ranged from 600 F to 1500 F to bond those which were evaluated during this investigation. The bonding compounds which were formed were alumino-phosphates and alumino-silicates. This type of castable was generally received as a two-part shipment, one to be mixed with the other immediately prior to placement. Material Codes 20A.1 and 108A.1 are typical of chemically bonded materials.

Heat bonded castables for the most part have very little "green" strength, and require firing to temperature of 2000 F or more. For this reason few castables are solely heat bonded, but contain some binder which will provide handling strength until firing can be accomplished. Most of this type of castable set by loss of water, so the use of porous molds is advantageous. Material Codes 25A.1 and 25B.1 are typical of the heat bonded type.

Cost Analysis

Since "cast to dimension" ceramic tools are intended for use at temperatures above the usefulness of other "cast to dimension" materials, no real cost comparison can be made. Compared to "machined to dimension" tooling for applications at temperatures, up to 2000 F, the use of "cast to dimension" ceramic materials will obviously result in a cost saving.

HYDROFORM BLOCKS

A refractory ceramic tool to perform this kind of function must:

1. Withstand compressive loads.
2. Be capable of producing a flat mounting surface.
3. Permit heat on face only without ill effect.
4. Support occasional requirement for small radii.
5. Be capable of producing a smooth surface.

Hydraulically bonded castables using calcium aluminate cement and a high alumina aggregate will yield castings possessing these characteristics. Firing of the tools is not necessary and high temperatures have a minimum adverse effect on them. Some typical materials which have been investigated and are suited to the application are: 1F.1, 5A.1, 8B.1, 12E.1, 20B.1, 21A.1, 41A.1, 71B.1, and 108D.1, but 8B.1, Norton Company's 33-HD, is believed to be superior. Refer to Pages 5 and 10.

It is not logical to attempt establishment of standard tool drawings at this time, but the tool design should carry some standard items in the bill of material and should show some standard general notes in all cases.

The bill of material should list:

1. Name and amount of castable and water or binder needed.
2. Kind of parting agent to be used in mold.
3. Number and types of attachment and handling accessories to be used for inclusion in casting.
4. Name and amount of mold material needed.
5. Number and kind of mold reinforcement or handling accessories needed.
6. Name and amount of material for flat base.

General notes should include:

1. Stencil on tool: CERAMIC TOOL - FRAGILE - HANDLE WITH CARE.
2. Stencil on tool: DO NOT CLEAN WITH COMPRESSED AIR.
3. Stencil on tool: STORE INDOORS.
4. Use largest practical draft and nonfunctional radii.
5. Master model number is _____.
6. Minimum tool thickness to be 3 inches.
7. Maximum tool size to be _____ by _____ inches. (Governed by size of hydropress bed)

The bill of material should also list additional items specifically applicable to the tool design. The general notes will include engineering part number, references, type of mold to be made, what, if any, provisions are necessary to compensate for thermal shrinkage or other dimensional changes in part after forming hot, and specific items peculiar to that tool design.

DRAW DIES

Although the use of ceramic draw dies is not recommended, it is realized that some companies will still desire to pursue their development. Ceramic draw die components and necessary functions are:

1. Punch to withstand compression and shear load.
2. Die ring to withstand compression, shear and tension.
3. Draw ring to withstand compression.
4. All components capable of being stud mounted or vacuum chuck mounted, the latter being preferred.
5. All components capable of withstanding heat on one face only.
6. Rings must have a smooth, non-grainy draw surface.

Chemically bonded castables produce the best ceramic tools for this function. High strength is a prime prerequisite to handle the tension and shear loads applied to the tool components in use. It would be advantageous to make the die, especially the ring, as massive as possible.

This type of tool has presented unsolved problems which have prevented an entirely complete evaluation from being made. A plastic type draw action, typical with conventional draw die operation, has not been achieved. This failure to produce plastic flow is attributed mainly to inadequate lubrication.

The limited number of draw press die trials which have been attempted show that the metal is merely stretched and consequently thinned-out in the radius area. All trials ended with broken dies, but one material, Code Number 20A.1*, stood up under the tests better than the others. It is a two part castable with a binder which forms a glassy type bond. A bond of this type may have a small amount of "give" under high loads. This particular castable softens at temperatures near 1800 F.

It is believed that this investigation has not produced enough information to make an attempt at specifying a standard manufacturing method for draw dies.

*The Charles Taylor Sons Company's X-10326C

STRETCHFORM BLOCKS

To use this kind of tool a material must:

1. Withstand compressive loads.
2. Be capable of producing a flat mounting surface with or without buried anchor nuts for stud mounting or for vacuum mounting, the latter being preferred.
3. Permit heat to be applied to one face only without ill effect.
4. Be capable of being made as a solid or a cap type tool, the former is generally preferred.
5. Be able to produce a smooth surface.

In general, the same high alumina-calcium aluminate bonded castables as are suited for hydroform block use are suited for stretchform blocks also. Many stretchform blocks used for the production of aluminum sheet metal parts are quite large, being on the order of five by twelve feet. A block to hot form a high strength metal part of similar size would need to be a cap type tool to conserve material and reduce weight. A rigid back-up plate would have to be provided to use the tool on a conventional machine and a large capacity heating unit would be needed.

The bill of material should list:

1. Name and amount of castable and water or binder needed.
2. Kind of parting agent to be used in mold.
3. Name and amount of core material needed if a cap type tool is to be made.
4. Number and type of attachment and handling accessories to be included in casting.
5. Name and amount of mold material needed.
6. Number and kind of mold reinforcements or handling accessories needed.

General notes should include:

1. Stencil on tool: CERAMIC TOOL - FRAGILE - HANDLE WITH CARE.
2. Stencil on tool: DO NOT CLEAN WITH COMPRESSED AIR.
3. Stencil on tool: STORE INDOORS.
4. Use largest practical draft and nonfunctional radii.
5. Master model number is _____.
6. Prick punch locations to be per _____.
7. Minimum tool thickness to be 6 inches.
8. Orient base for equal elongation of top and bottom of blank.

Bill of material will also list those items that apply specifically to the tool design.

The general notes will also state those engineering part references needed, the type of mold to be used, references to existing jigs which are to be used, and other pertinent items peculiar to the particular tool.

HEAT TREAT AND BRAZE FIXTURES

Ceramic heat treat and braze fixtures will be:

1. Subject to light loads only.
2. Flat surface, furnace hearth mounted, except when used with the electric blanket brazing process.
3. Subject to high temperatures and large temperature variations.
4. Subject to severe thermal shock, particularly when used for electric blanket brazing tooling.

Heat bonded castables are best suited to this application. They are capable of being maintained at high temperatures for extended lengths of time without harm. In addition to heat resistance, and equally as important, is a requirement for good thermal shock resistance. The castable materials most suited for this application, based on investigations to date, are 25A.1 thru 25E.1 (products of Glasrock Products, Inc.). They are materials which use fused silica as their major constituents, and therefore have practically no thermal expansion. An upper temperature limit of 2100 F, for extended periods of time, must be observed.

The bill of material should list:

1. Name and amount of castable and water or binder needed.
2. Kind of parting agent to be used in mold.
3. Name and amount of core material if a cap type tool is to be made.
4. Number and type of handling accessories.
5. Name and amount of mold material
6. Number and kind of mold reinforcement and handling accessories needed.

General notes should include:

1. Stencil on tool: CERAMIC TOOL - FRAGILE - HANDLE WITH CARE.
2. Stencil on tool: DO NOT CLEAN WITH COMPRESSED AIR.
3. Stencil on tool: STORE INDOORS.
4. Use largest practical draft and nonfunctional radii.
5. Master model number is _____.

The bill of material will also include such items as part locating pins, guides for positioning fixture cover, and handling dollys if required.

The general notes will in addition furnish all pertinent data such as engineering part reference numbers, the type mold to be used, explanation of how parts are to be located in fixture, and notes flagging procedures to be followed during construction.

STRESS RELIEF FIXTURES

Ceramic stress relief or draw fixtures will be:

1. Subject to light loads only.
2. Flat surface, usually oven floor mounted.
3. Subject to elevated temperatures and temperature variations.

This application requires a castable with heat and thermal shock resistant properties which are not quite as stringent as for heat treat and braze fixtures. Operating temperatures are generally from 1000 F to 1200 F and seldom exceed 1500 F. Therefore, many of the more economical calcium-aluminate bonded castables with high alumina bodies will serve for furnace type tools if they are previously fired to temperatures that will develop in them a vitreous bond. Such castables would be 8D.1 and 71B.1. For furnaceless type tools, materials 25A.1 thru 25E.1 should be used. Refer to Pages 6 and 10.

The bill of material should list:

1. Name and amount of castable and water or binder needed.
2. Kind of parting agent to be used in mold.
3. Name and amount of core material if a cap type tool has been designed.
4. Number and type of handling accessories.
5. Name and amount of mold material.
6. Number and kind of mold reinforcement and handling accessories required.
7. Kind and number of part locators.
8. Type and number of guides to be used.

General notes should include:

1. Stencil on tool: CERAMIC TOOL - FRAGILE - HANDLE WITH CARE.
2. Stencil on tool: DO NOT CLEAN WITH COMPRESSED AIR.
3. Stencil on tool: STORE INDOORS.
4. Use largest practical draft and nonfunctional radii.
5. Master model number is _____.

The bill of material will, of course, also list those items which are normally required to complete any tool design.

The general notes will include engineering part references, type of mold to be used, method to be used for part location, and special instructions or precautions that are needed, such as with the use of vibration.

RECOMMENDATIONS

The applicable recommendations are listed in the Summary on Page 7.

"STATE OF THE ART" SURVEY

Because it had been approximately two and one-half years since the original "State of the Art" Survey of Phase I, and since it was known that some outstanding developments had been made in the field of ceramic tooling by other companies, the Contractor has concluded his work with a new survey (see Exhibit 7, Page 441).

TABLE 37 - TOOL FABRICATION, PHASE V RERUNS

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
5A.1 hydroform block production size	cast in K-25 plaster mold with internal vibration	9.5	Simoniz wax and peanut oil	24 hrs. under wet burlap. 6 days 150 F 2 days 250F	unfired	Plastic base was applied.
8B.1 hydroform block laboratory size	cast in plastic mold with internal vibration	9	Simoniz wax and peanut oil	18 hrs. under wet burlap. 2 days 150 F 2 days 250F	300 F/hr to 2000 F 250 F/hr 2500 F. cool in furnace	Very smooth surface on block. Plastic base was applied.
hydroform block laboratory size	same	9	same	same	unfired	Plastic base was applied.
8D.1 hydroform block laboratory size	cast in plastic mold with external vibration	7.5	Simoniz wax and peanut oil	18 hrs. at room temp. 2 days 150F 2 days 250F	300 F/hr to 2000 F 250 F/hr to 2500 F cool in furnace	Smooth surface as cast, but got grainy when fired. Plastic base applied.
12E.1 hydroform block laboratory size	cast in epoxy plastic mold with external vibration	11	peanut oil	24 hrs. under wet burlap 24 hrs. at 150 F 24 hrs. at 250 F	unfired	Two tools made. Both had plastic bases applied.

TABLE 37 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
25A.1 draw die rings (three rings cast)	cast in No. 1 pottery plaster break up type molds 4 parts grain 6 parts slip	3	none. mold cavity sprayed with water just before placement	48 hrs. under cover 48 hrs. at 250 F	fired to vendor's specification at vendor's plant	Rings are smooth, but slightly sandy. Grain size is very fine at surface. One ring was cracked and repaired, two others are whole. Plastic bases applied.
draw die punch (two punches cast)	same	3	same	same	same	Radius of each tool is in good condition. Some flaws in casting surface out of part. Plastic bases applied.
108A.1 hydroform block laboratory size	cast in plastic with ext. vib. 4 parts dry 6 parts wet	3.5	Simoniz and rubber base paint	24 hrs. rm. temp. 24 hrs. 250 F	200 F/hr. to 1000 F	Several casting attempts failed because of parting agent breakdown. Good tool cast using rubber base paint.

TABLE 37 (CONT'D)

CASTABLE AND TOOL	CASTING PROCEDURE	PERCENT WATER	PARTING AGENT	CURING DRYING	FIRING PROCEDURE	REMARKS
108A.1 draw die ring (three rings cast)	cast in plastic mold with int. vib. 4 parts dry 6 parts wet	3.5	same	same	100 F/hr. to 600 F	First ring broke in removal from mold. Two more cast for tool evaluation. Plastic bases applied.
draw die punch (two punches cast)	same	3.5	same	same	same	Both punches are smooth with few bubbles. Plastic bases applied.

TABLE 38 - PRELIMINARY HYDROFORM BLOCK EVALUATION, PHASE V RERUNS

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	12E.1	cast in new plastic mold with vibration. dried, 250 F. epoxy plastic base applied	AISI 420 1350 F	Pressure of 1250 psi used with Kaowool insulation. Part stuck on block and had several wrinkles in shrink flange. Stretch flange not formed down.
2	12E.1	same tool	AISI 420 1350 F	Pressure of 1500 psi used with Kaowool insulation. Part had to be pried off block. The block had cracks along each side. A fragment pulled off the block and stuck to the part.
3	12E.1	same tool	AISI 420 1350 F	Pressure at 1700 psi used with Kaowool insulation. Attempt was made to reheat part on block after forming for easy removal through differential expansion. Ends of blank became overheated without making center hot enough to release.
4	12E.1	same tool	AISI 420 1350 F	Pressure at 1700 psi used with Kaowool insulation. A piece of Refrasil cloth shaped to duplicate blank was placed between blank and block. Part was easily removed, cloth was pulverized, and no further damage was done to block.

TABLE 38 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
5	12E.1	same tool	AISI 420 1350 F	Repeat conditions with same results.
6	12E.1	same tool	AISI 420 1350 F	Repeat conditions with same results. Parts 4, 5, and 6 averaged 0.030 inches wider at the mold line than the block. The block must be made smaller to compensate for thickness of cloth if such methods are to be used.

TABLE 39 HYDROFORM BLOCK EVALUATION, PHASE V RERUNS

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	108A.1	cast in new plastic mold with vibration, fired at 1000 F epoxy plastic base applied	AISI 420 1300 F	Pressure of 1700 psi used with Kaowool insulation. Flange wrinkled. Forming may not be fast enough.
2	108A.1	same tool	AISI 420 1300 F	Pressure of 1700 psi used with Kaowool insulation. Press speeded up. Blank was misaligned and made shrink flange 0.1 inches long. Fewer wrinkles.
3	71B.1	cast in new plastic mold with vibration, fired at 1000 F epoxy plastic base applied	AISI 420 1300 F	Pressure of 1700 psi used with Kaowool insulation. Electrodes drilled to slide on guide pins for alignment. Blank tore in two at each end of block, center portion formed with very few wrinkles. One flange 1/16 inch longer than other. Some wrinkles. Insulation forced around and under flanges.
4	12E.1	cast in new plastic mold with vibration, dried only. epoxy plastic base applied	AISI 420 1300 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Blank was offset 1/16 inch to compensate for last part, and formed 0.1 inch off the other way. Did not tear. Wrinkle in shrink flange.
5	20A.1	cast in new plastic mold with vibration, fired at 1500 F epoxy plastic base applied	AISI 420 1350 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Part centered on block with few wrinkles in shrink flange. Block broke through middle.

TABLE 39 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
6	8B.1	cast in new plastic mold with vibration dried only. epoxy plastic base applied	AISI 420 1350 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Blank was centered on block and few wrinkles formed. Blank tore off at one end. Block broke with crack progressing from inside toward outside radius.
7	71B.1	same tool as part 3 above	AISI 420 1350 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. A spacer was made to fit around existing pedestal on press platen to more completely fill rubber box opening. Holes in blank electrodes were slotted to allow longitudinal movement. Shrink flange had some wrinkles. Block unbroken.
8	71B.1	same tool	AISI 420 1800 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Part formed slightly off center. Practically no wrinkles were formed. Formed part very easily removed from block when cooled. Block will be located with tabs to keep it from moving for the formability evaluation.

TABLE 40 STRETCHFORM BLOCK EVALUATION, PHASE V RERUNS

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	12E.1	cast in K-25 plaster mold with vibration. dried 250 F. epoxy plastic base applied	AISI 420 1300 F	Twenty-one ton load used. Slight wrinkling occurred. Blank temperature rises slowly after reaching 1300 F. Jaws retract slowly and gradually build up load.
2	12E.1	same tool	AISI 420 1300 F	Eighteen-ton load used. Same results.
3	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used. Same results and blank necked down in center.
4	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used. Same results. Blank necked down.
5	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used. Same results.
6	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used. Blank tapered by cutting curve off each side of blank one inch deep in middle. Part wrinkled and tore at edge near end of part.

TABLE 40 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
7	12E.1	same tool	AISI 420 1300 F	Thirteen-ton load used. Wrap forming with blank under tension and tried hot, but blank wrinkled and tore.
8	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used with talc dusted on block as a lubricant. Straight pull used. Better part formed with few wrinkles,
9	12E.1	same tool	AISI 420 1300 F	Twelve-ton load used with talc. Blank tapered as with Part 6, very few wrinkles formed. Blank tore.
10	12E.1	same tool	AISI 420 1300 F	Eighteen-ton load used, with talc. Jaw pull cylinders actuated as rapidly as possible for sudden pull. Stopped at above load. Three small wrinkles were formed.
11	12E.1	same tool	AISI 420 1300 F	Eighteen-ton load used, with talc. Full jaw travel accomplished in three strokes with intermediate heating. Wrinkles formed across face of part.
12	12E.1	same tool	AISI 420 1300 F	Eighteen-ton load used, with talc. The pressure of the press was set to 150,000 psi to make movement faster. Forming action was stopped when load built up to that given above. This sudden pull technique resulted in three small wrinkles. This practice was used for balance of stretchform trials.

TABLE 40 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
13	12E.1	same tool	AISI 420 1300 F	Load stopped at 18 tons, talc used. Sudden pull, three small wrinkles.
14	12E.1	same tool	AISI 420 1300 F	Load stopped at 18 tons, talc used. Three-stage forming as with Part II. No wrinkles, but not completely formed at top.
15	12E.1	same tool	AISI 420 1300 F	Load stopped at 35 tons, talc used. The block was tilted forward two inches at the top and braced under vacuum chuck to make blank pull equally at top and bottom. Part not formed at top of part, but no wrinkles.
16	12E.1	same tool	AISI 420 1300 F	Load stopped at 19 tons, talc used. No wrinkles, good part except for incomplete forming at top.
17	12E.1	same tool	AISI 420 1300 F	Load stopped at 22 tons, talc used. Blank pulled out of jaws because not adequately tightened. Few wrinkles, but still not completely formed at top.

TABLE 40 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
18	12E.1	same tool	AISI 420 1300 F	Load stopped at 21 tons, talc used. Block tilted out three inches at top and rebraced. Power was cut at contact with block to equalize cooling rate. Wrinkles on left side (see photographs, Figures 219 thru 223).
19	12E.1	same tool	AISI 420 1300 F	Load stopped at 32 tons, talc used. Blank tapered as with Part No. 6. Power cut too soon. Blank cooled before forming. Did not form to top and wrinkles, left side.
20	12E.1	same tool	AISI 420 1300 F	Load stopped at 20 tons, talc used. Blank tapered, power cut at contact. Block still set out three inches at top. Good part, no wrinkles.
21	12E.1	same tool	AISI 420 1300 F	Load stopped at 21 tons, talc used. Tapered blank, block tilted out three and one-half inches at top. Power cut at contact. Slight wrinkles, left side.
22	12E.1	same tool	AISI 420 1300 F	Load stopped at 22 tons, talc used. Blank 18 inches longer, same width. Power cut at contact, wrinkled on left side. Cooled off of block.

TABLE 40 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
23	12E.1	same tool	AISI 420 1300 F	Load stopped at 23 tons, talc used. Long blank. Power cut at contact. Wrinkled out of part. Did not form down at top. Cooled on block.

TABLE 41 - DRAW DIE EVALUATION, PHASE V - RERUNS

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	20A.1	cast in plastic mold with external vibration.	AISI 420 1300 F	Single stroke formed blank only to radius depth, punch broke through blank at radius. Ten psi used on draw ring, no lubricant used.
2	20A.1	same tool	AISI 420 1300 F	Several strokes limited in movement used with intermediate heating. Ten psi draw ring pressure used and talc used for lubricant. Some wrinkles formed in clamp area. Punch tore part at 3/4 inch depth.
3	20A.1	same tool	AISI 420 1500 F	Same conditions as Part 2 with similar results.
4	20A.1	same tool	AISI 420 1500 F	Same condition as Part 2 with 5 psi on draw ring, few more wrinkles. Talc liberally applied to tool.
5	20A.1	same tool	AISI 420 1500 F	Rapid movement of punch to fixed stops preset to allow 1/4 to 3/8 inch advances. Five psi used on draw ring, and 1000 psi on punch. Part wrinkled and draw ring cracked radially.
6	25A.1	cast in No. 1 pottery plaster break up mold with internal vibration	AISI 420 1500 F	Five psi draw ring pressure, 1000 psi punch pressure. Part broke on second of progressive strokes. Fixed stops used. Talc lubricant used.

TABLE 41 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
7	25A.1	same tool	AISI 420 1500 F	Same conditions used. The die ring cracked radially and the punch crumbled on radius. Talc used as lubricant.
8	25A.1	same tool	AISI 420 1300 F	Same conditions, but silicone grease lubricant used. Progressive strokes were used and 1500 F for last stroke. Die ring broke radially into four pieces. Punch stuck in part.
9	108A.1	cast in epoxy plastic mold with external vibration	AISI 420 1500 F	Successive strokes were made with gradually increasing ring pressure to iron out wrinkles. Silicone grease was used for lubricant. Part broke through on fifth stroke. Punch crumbled on radius and draw ring cracked radially in one place.
10	20A.1	same tool as Part No. 1	AISI 420 1500 F	Ten psi draw ring pressure used, with talc lubricant. Part broke through on second stroke.
11	20A.1	same tool	AISI 420 1500 F	Same conditions with silicone lubricant. Part broke through on second stroke at a depth of 5/8 inch.
12	20A.1	same tool	AISI 420 1700 F	Same conditions. Part drawn to one inch depth with several strokes. Die ring broke radially, and punch radius was worn. Wrinkling occurred. Silicone grease lubricant used.

TABLE 41 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
13	108A.1	same tool as used for Part No. 9	AISI 420 1500 F	Five psi draw ring pressure used with talc lubricant. Part broke through on third stroke. Punch radius showed failure and die ring cracked on outside.

TABLE 42 HYDROFORM BLOCK, FORMABILITY EVALUATION, LABORATORY SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	108A.1	cast in new plastic mold with vibration. fired to 1000 F epoxy plastic base applied.	B-120-VCA 400 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Block located with tabs. Spring-back of metal left flanges formed to 45° only. Wrinkles were formed in shrink flange.
2	108A.1	same tool	PH15-7Mo 1050 F	Same forming conditions. Flanges did not form completely. Wrinkles formed in shrink flange.
3	108A.1	same tool	HM-21-A 660 F	Blank burned in two on initial heat up at the location of one of the two pin holes in the blank.
4	108A.1	same tool	HM-21-A 650 F	Same conditions of pressure, insulation and block location as with Part #1. Blank centered on block. Two small wrinkles in shrink flange. Stretch flange formed all the way down.
5	108A.1	same tool	VascoJet 1000 1450 F	Same forming conditions. Blank centered on block. Stretch flange formed good, shrink flange wrinkled.
6	108A.1	same tool	N-155 1500 F	Same forming conditions. Stretch flange formed completely, shrink flange wrinkled. Flanges same length.
7	108A.1	same tool	Rene' 41 1950 F	Same forming conditions. Shrink flange not formed down and was wrinkled, stretch flange not formed down either. About 50% springback at ends of block. Block has hairline cracks on top surface.

TABLE 42 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
8	108A.1	same tool	HS-25 2000 F	Same forming conditions. Part formed slightly off center. Considerable springback and shrink flange wrinkled. Block broken. The ends of block broke vertically at intersection of top surface and sloping ends.
9	8B.1	cast in new plastic mold with vibration. fired at 2500 F epoxy plastic base applied	B-120-VCA room temperature	Pressure at 1700 psi used without insulation. Block located with tabs. Flanges formed down only 30 degrees because of springback. Some wrinkles in shrink flange.
10	8B.1	same tool	PH15-7Mo room temperature	Same forming conditions. Flanges not formed down. Shrink flange wrinkled.
11	8B.1	same tool	HM-21-A room temperature	Same forming conditions. Flanges not formed completely. Shrink flange wrinkled and cracked at ends, stretch flange cracked at middle and ends. Ends of blank tore off at end of block.
12	8B.1	same tool	VascoJet 1000 room temperature	Same forming conditions. Flanges not formed down and shrink flange wrinkled. Surface coating on metal flaked off at bends.

TABLE 42 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
13	8B.1	same tool	N-155 room temp.	Same forming conditions. Flanges not formed down and shrink flange wrinkled. Vertical hairline cracks in block at center on shrink flange side.
14	8B.1	same tool	Rene' 41 room temp.	Same forming conditions. Flanges not formed down and shrink flange wrinkled. Crack slightly wider.
15	8B.1	same tool	HS-25 room temp.	Same forming conditions. Flanges not formed down and shrink flange wrinkled. Crack propagated from shrink flange side across top of block to stretch flange side. Plastic base not cracked.
16	12E.1	cast in new plastic mold with vibration. dried at 250 F epoxy plastic base applied	HM-21-A 650 F	Pressure of 1700 psi used with Kaowool insulation cut to shape of blank. Blank electrodes slotted for guide pins and longer flexible leads used. Blank centered on block. Shrink flange wrinkled very little.
17	12E.1	same tool	B-120-VCA 1700 F	Same forming conditions. Blank centered on block. Shrink flange had four large wrinkles.
18	12E.1	same tool	B-120-VCA	Same forming conditions. Same except only three small wrinkles on shrink flange.

TABLE 42 (CONT'D)

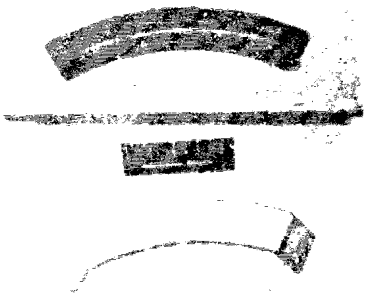
PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
19	12E.1	same tool	PH15-7Mo 1800 F	Same forming conditions. Blank centered on block. Three small wrinkles in shrink flange.
20	12E.1	same tool	VascoJet 1000 1800 F	Same forming conditions. Three small wrinkles on shrink flange. Block broken. Cracks occurred across sloped end and top. Plastic base to ceramic bond failed.
21	71B.1	cast in new plastic mold with vibration. fired at 1000 F epoxy plastic base applied	Rene' 41 1950 F	Same forming conditions. Three large wrinkles in shrink flange. Considerable springback where ends of blank form over ends of block.
22	71B.1-1	same tool	N-155 2000 F	Same forming conditions. Four wrinkles in shrink flange. Top face on one end of block crumbled and came off.
23	71B.1-2	different tool same material same treatment	AISI 420 room temp.	Same forming conditions. Three large wrinkles on shrink flange. Considerable springback.
24	71B.1-2	same tool	AISI 420 1900 F	Same forming conditions. Four small wrinkles in shrink flange. Flanges formed down good. Block crumbled on one end.
25	71B.1-2	same tool	HS-25 2000 F	Same forming conditions. Three small wrinkles in shrink flange. Some springback.

TABLE 42 (CONT'D)

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
26	8D.1	cast in new plastic mold with vibration. fired at 2500 F Furane tooling plastic base applied	AISI 420 2000 F	Same forming conditions. Flanges formed down good. Three small wrinkles in shrink flange. Plastic base used here was more rigid, 70-80 durometer. Block unbroken.
27	8D.1	same tool	AISI 420 1300 F	Pressure of 2000 psi used with Kaowool insulation cut to shape of block. Several wrinkles in shrink flange.
28	8D.1	same tool	AISI 420 room temp.	Pressure of 1700 psi used without insulation. Approximately 10^{o} springback occurred. Shrink flange wrinkled; stretch flange did not form completely down.
29	8D.1	same tool	AISI 420 room temp.	Pressure of 2000 psi used without insulation. Lake Erie 5000-ton hydropress used with blank resting on block. Ends of blank supported on blocks of rubber. Three wrinkles, about 5^{o} springback on either flange.
30	8D.1	same tool	AISI 420 room temp.	Same forming conditions and results. Block, left in press without blanks, broke on fifth cycle.

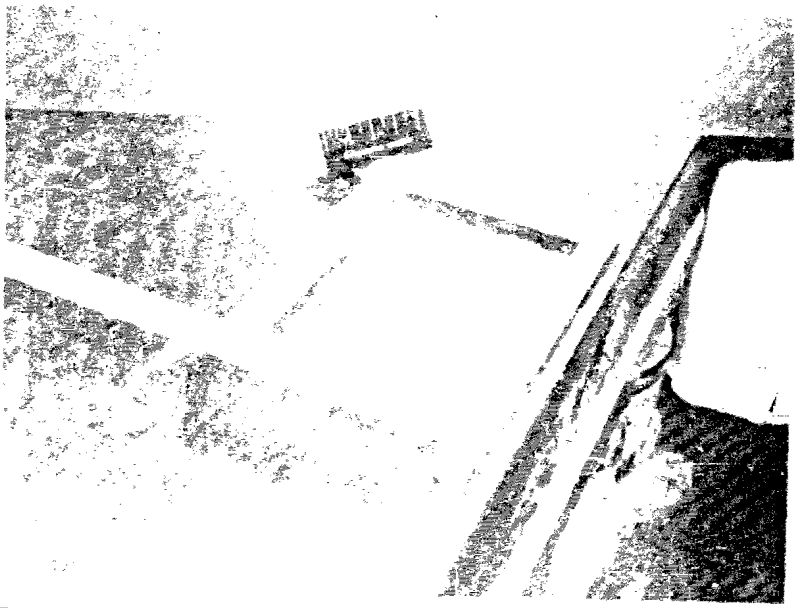
TABLE 43 HYDROFORM BLOCK, FORMABILITY EVALUATION, PRODUCTION SIZE

PART NUMBER	BLOCK MATERIAL	TOOL CONSTRUCTION	ALLOY AND FORMING TEMPERATURE	REMARKS
1	20A.1	cast in K-25 plaster mold with vibration. dried, only, at 250 F. epoxy plastic base applied	AISI 420 1750 F	Pressure of 2000 psi used with Kaowool insulation covering entire surface of metal to be touched by trapped rubber head. This part run to check press set up. Acceptable part was made.
2	20A.1	same tool	HM-21-A	Same forming conditions used with 2000 psi. Part split along several radii. Metal quenched out before forming.
3	20A.1	same tool	B-120-VCA 1700 F	Same forming conditions used with 2000 psi. Part formed good. Block began showing wear on outside radii.
4	20A.1	same tool	PH15-7Mo 1650 F	Same forming conditions used with 2350 psi. Part formed to block very good.
5	20A.1	same tool	VascoJet 1000 1700 F	Same forming conditions used with 2000 psi. Block radius failure continues, part formed into block grooves good.
6	20A.1	same tool	Rene' 41 1800 F	Same forming conditions used with 2000 psi. Part formed to block good.
7	20A.1	same tool	N-155 2000 F	Same forming conditions used with 2000 psi. Part formed to tool even to conforming to voids caused by loss of particles from radii.
8	20A.1	same tool	HS-25 2000 F	Same forming conditions used with 2000 psi. Part formed to tool showing voids in radius. Tool surface reached a temperature of 220 F. The plastic base softened and, during removal of form block from press, came loose.



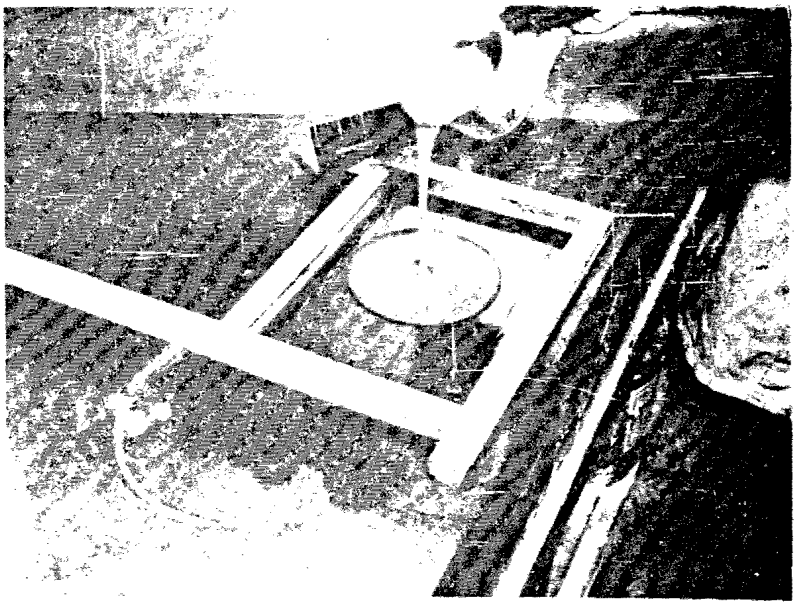
RF 6697-3

Fig. 174 Laboratory size hydroform block model and plastic mold.



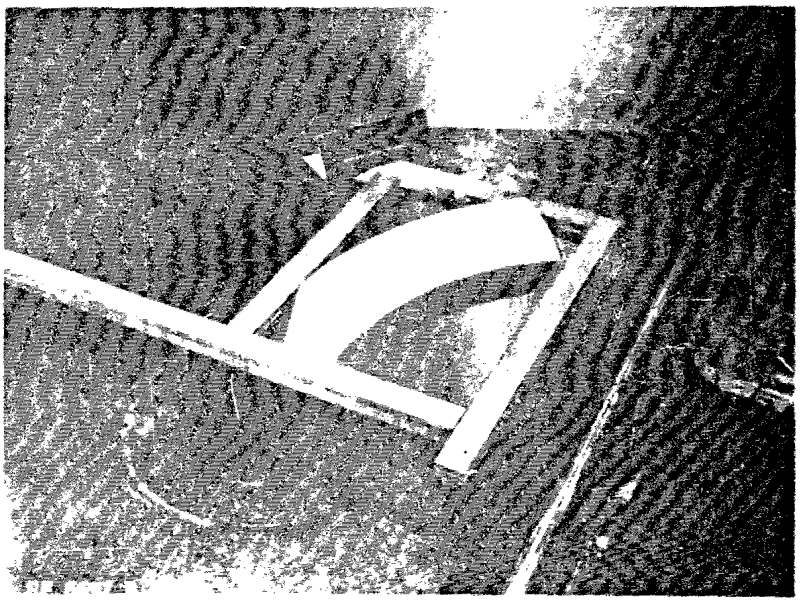
RF 6697-6

Fig. 175 Dam for casting laboratory size hydroform block plastic base.



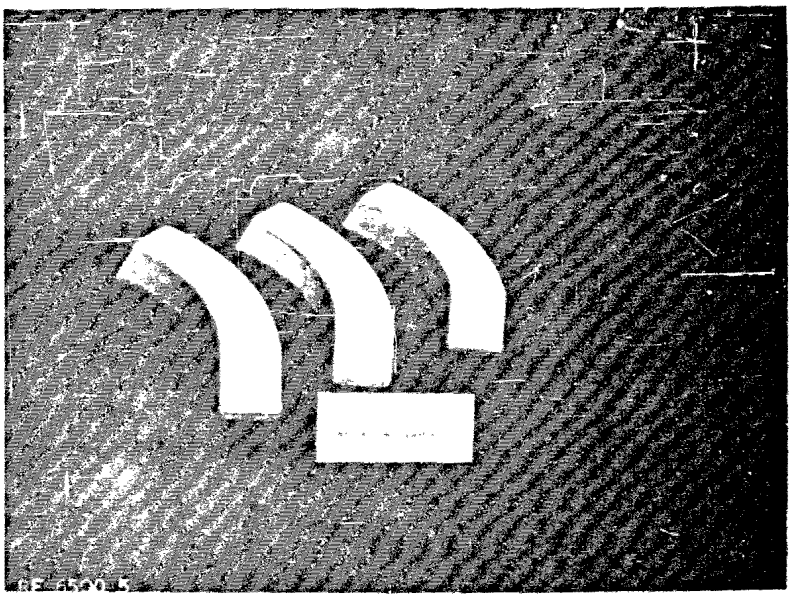
RF 6697-9

Fig. 176 Epoxy plastic being poured into dam.



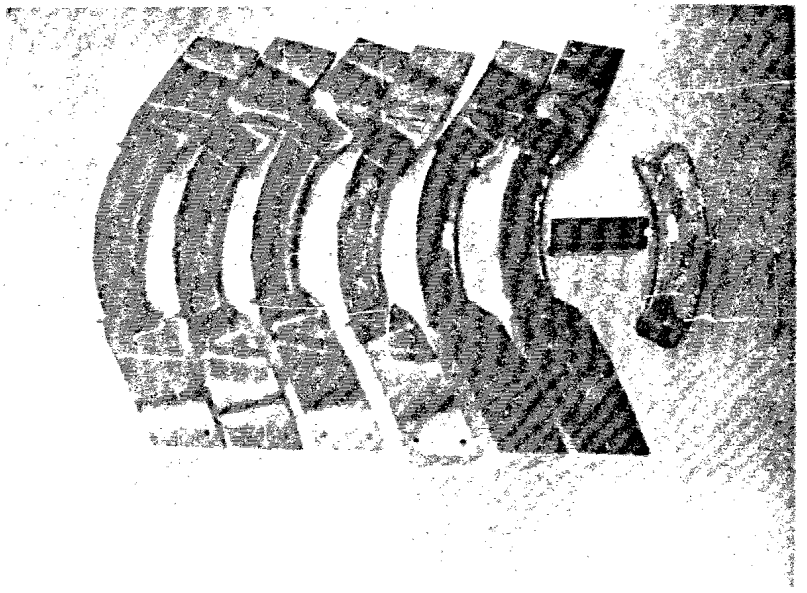
RF 6697-5

Fig. 177 Laboratory size hydroform block in plastic puddle.



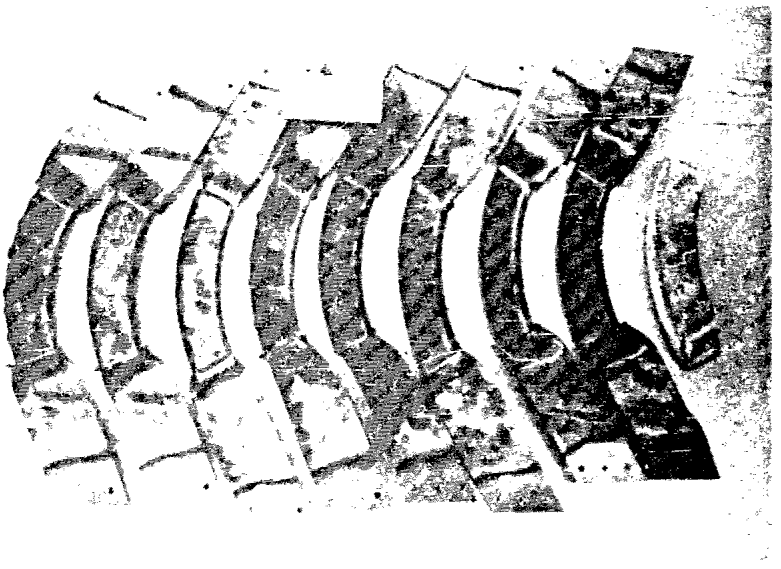
RF 6500-5

Fig. 178 Laboratory size hydroform blocks after trimming plastic base.



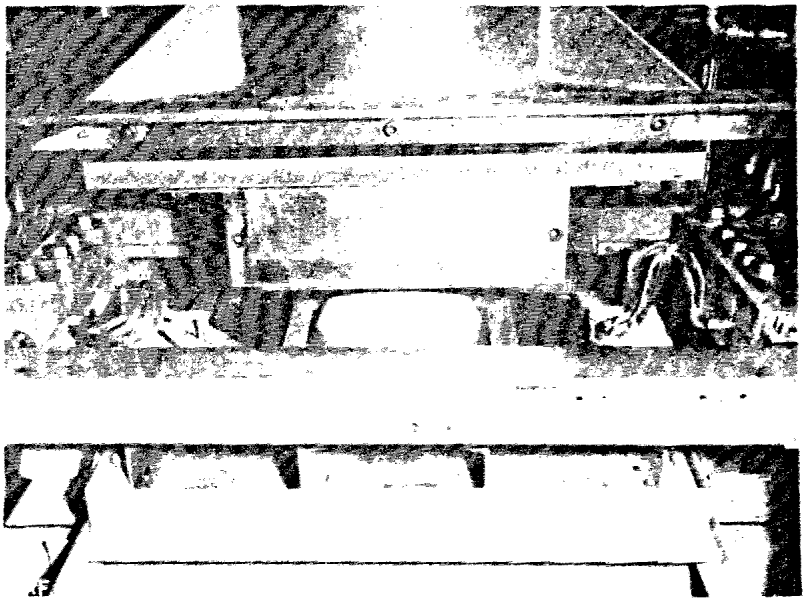
RF 6697-13

Fig. 179 Laboratory size 12E.1 hydroform block and AISI 420 formed parts.



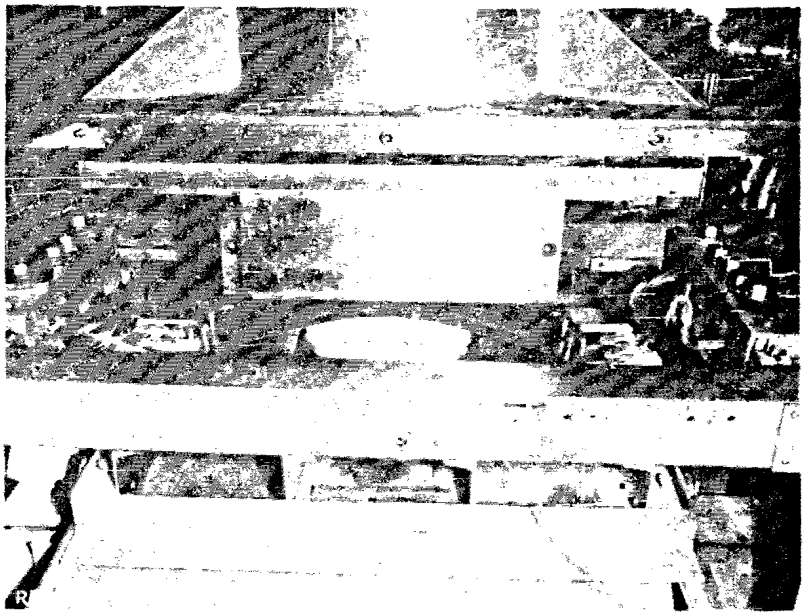
RF 6697-10

Fig. 180 Laboratory size 71B.1 hydroform block and AISI 420 formed parts.



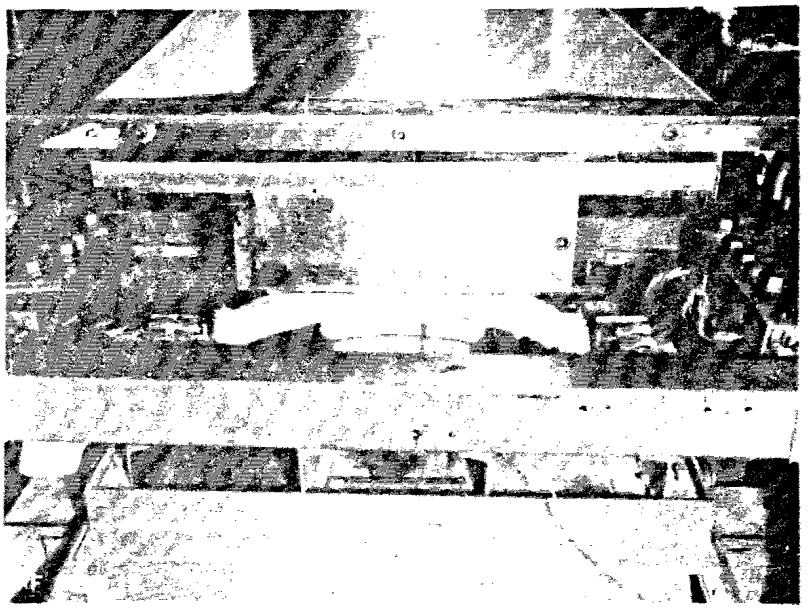
RF 6697-16

Fig. 181 Laboratory size hydroform block in place on press platen.



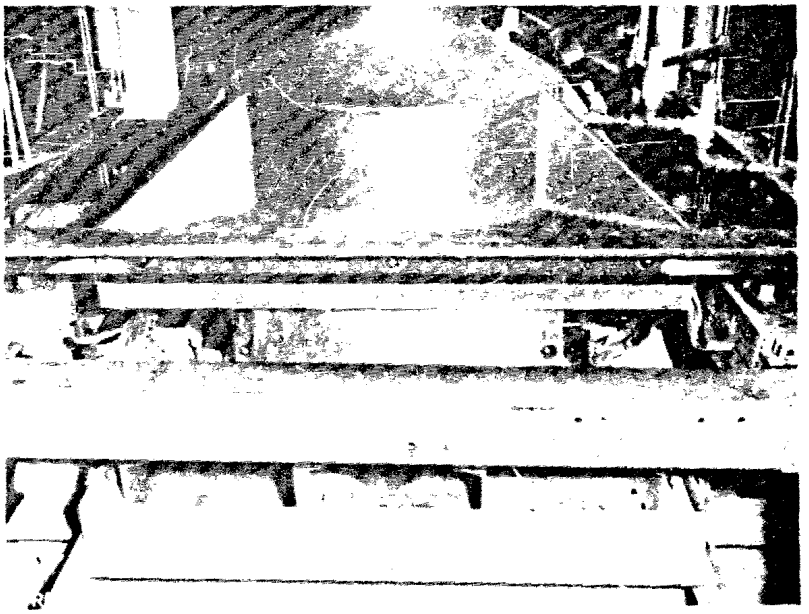
RF 6697-15

Fig. 182 Blank positioned on block and attached to electrodes.



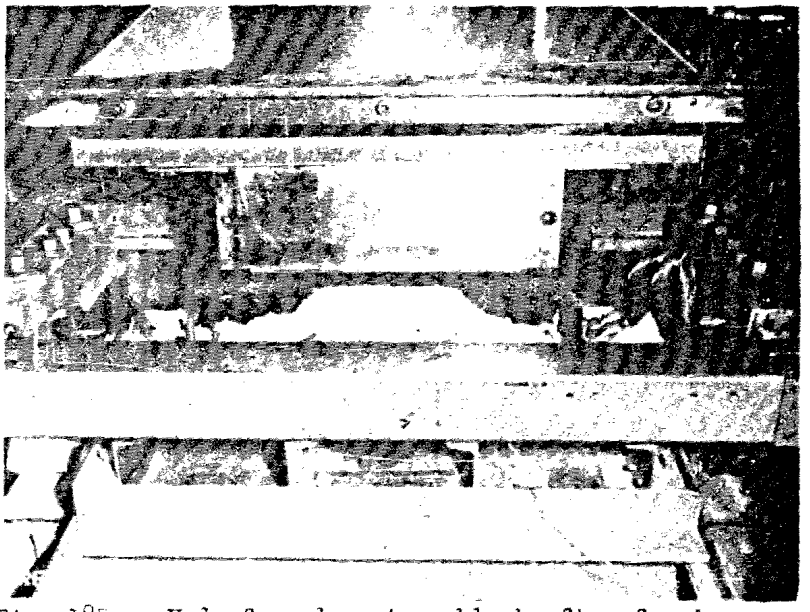
RF 6697-17

Fig. 183 Ceramic fiber bat in place on blank.



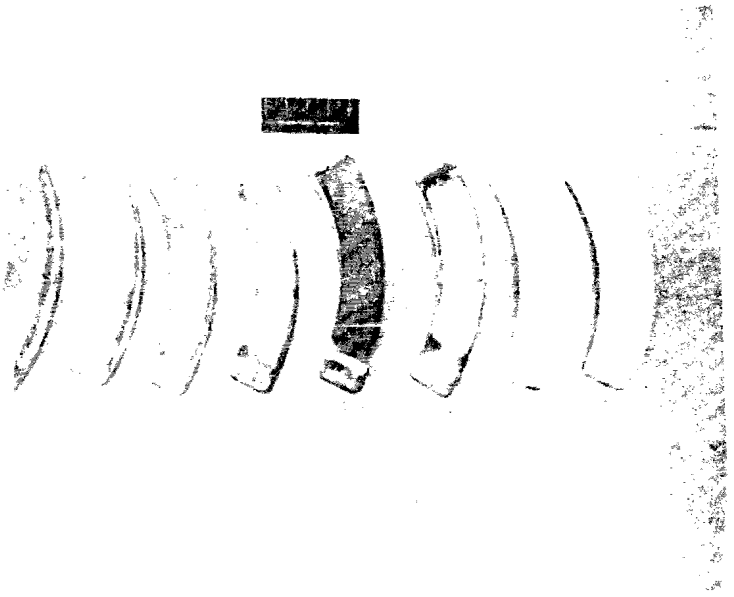
RF 6697-8

Fig. 184 Trapped rubber head closed on hydroform block and heated blank.



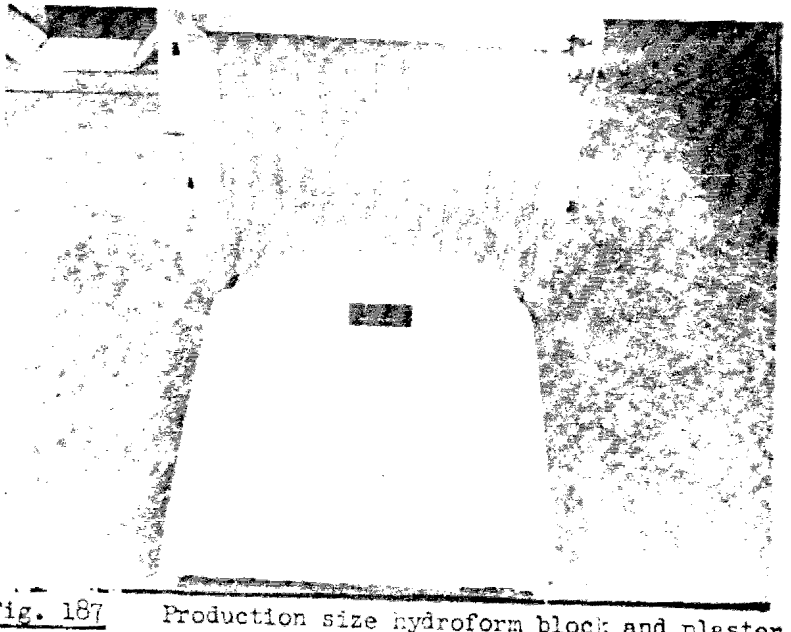
RF 6697-14

Fig. 185 Hydroformed part on block after forming.



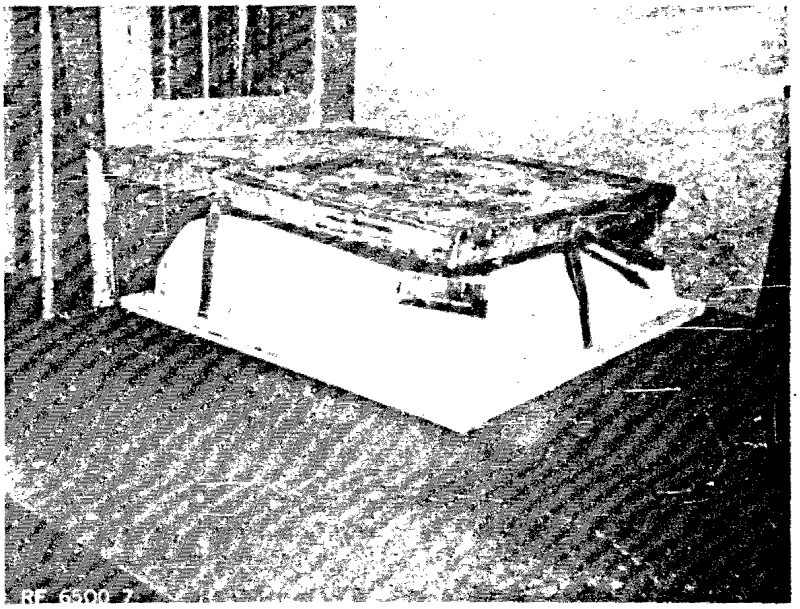
RF 6697-2

Fig. 186 Failed laboratory size hydroform blocks.



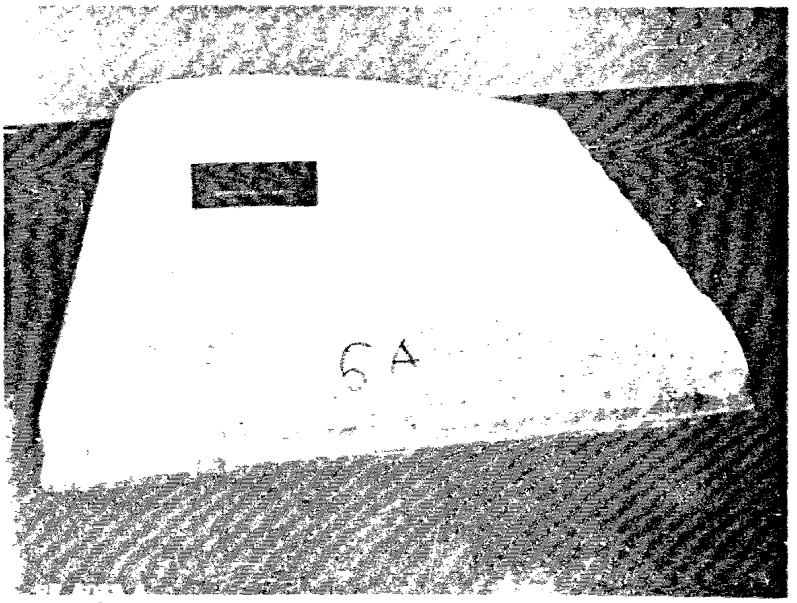
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Fig. 187 Production size hydroform block and plaster mold.



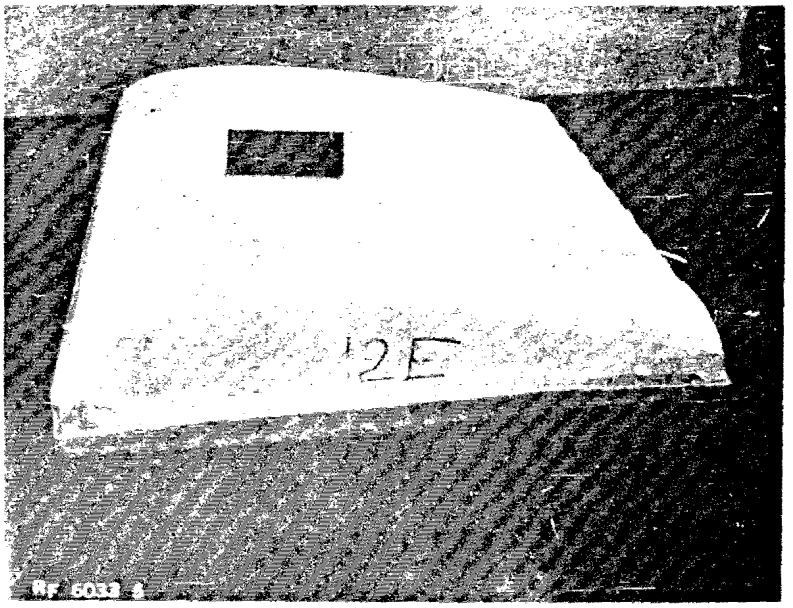
RF 6500-7

Fig. 188 Production size hydroform block being lowered into plastic puddle.



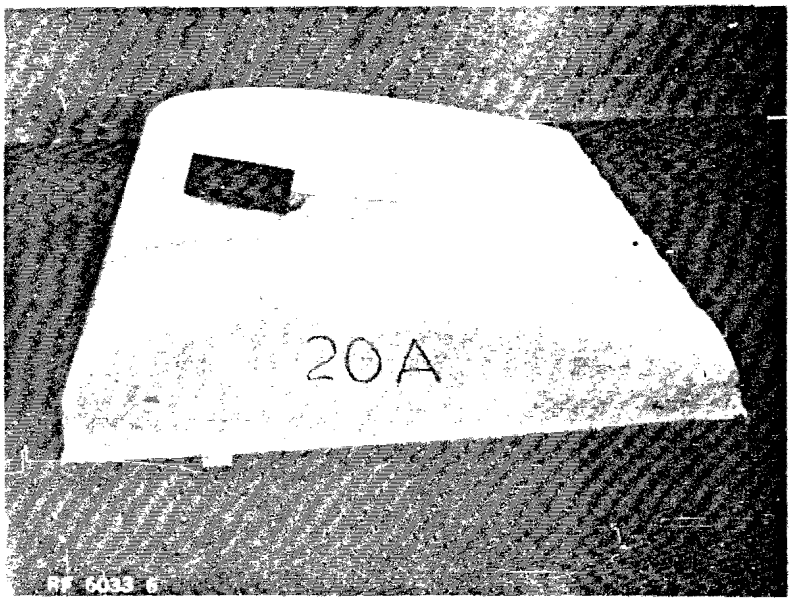
RF 6033-4

Fig. 189 Production size 5A.1 hydroform block with plastic base.



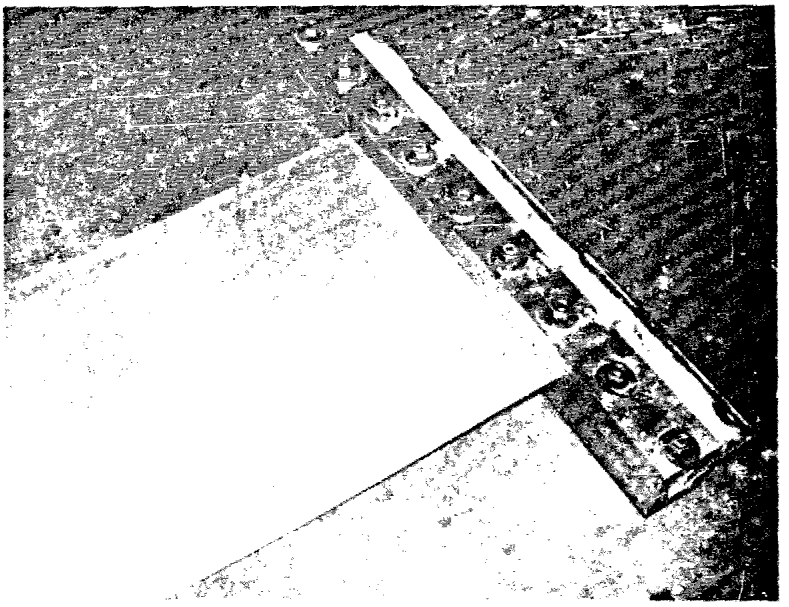
RF 6033-5

Fig. 190 Production size 12E.1 hydroform block with plastic base.



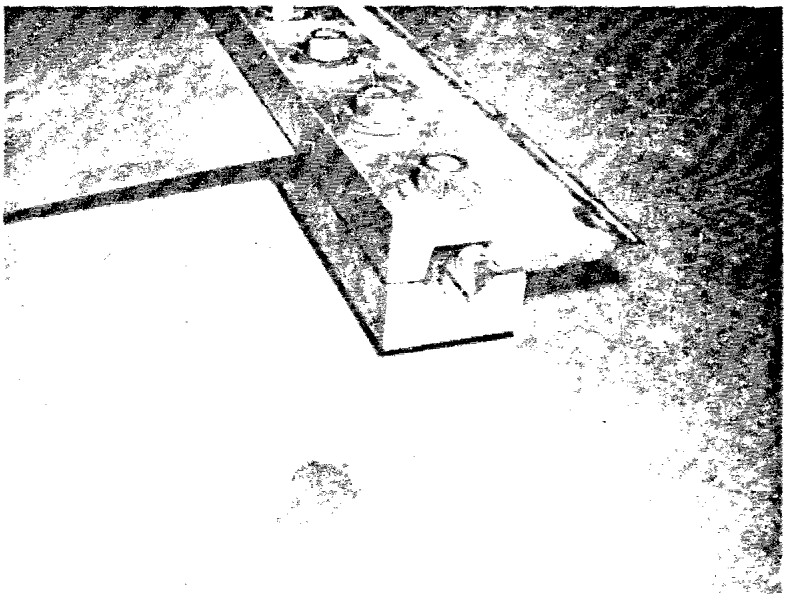
RF 6033-6

Fig. 191 Production size 20A.1 hydroform block with plastic base.



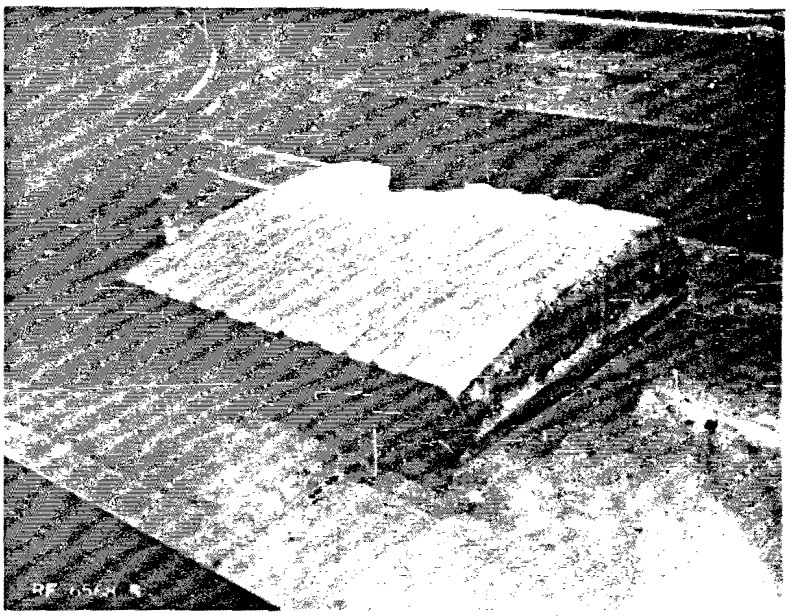
RF 6500-3

Fig. 192 AISI 420 blank clamped in electrode.



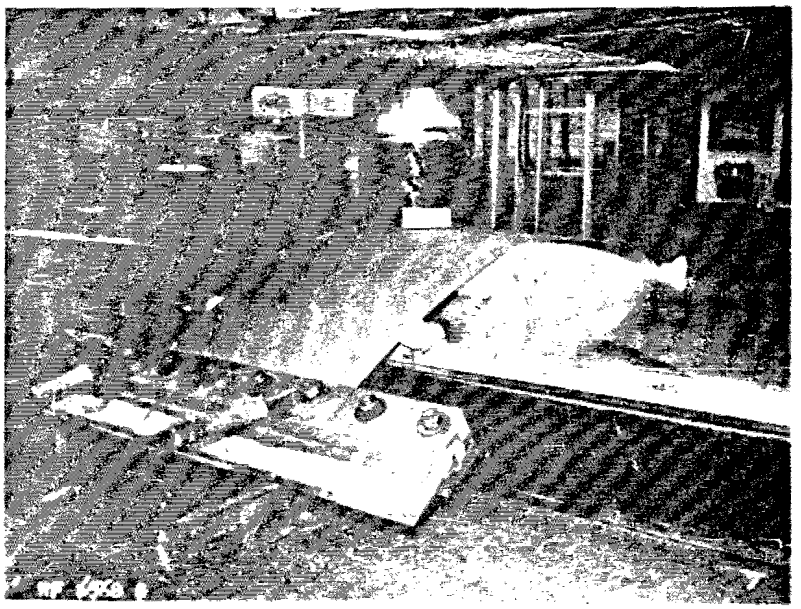
RF 6500-6

Fig. 193 Detail view of insulated electrode.



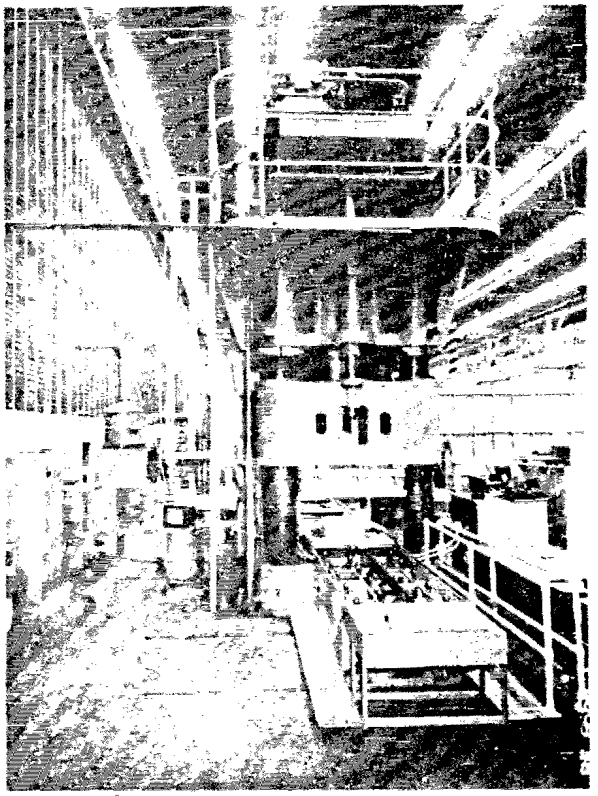
RF 6568-5

Fig. 194 Production size hydroform block on 2 inch thick aluminum tooling plate.



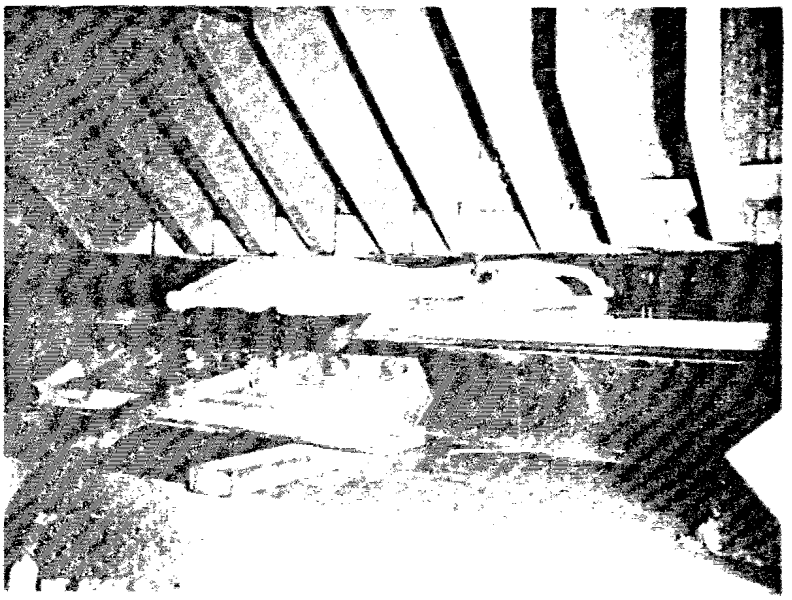
RF 6568-6

Fig. 195 Blank positioned over hydroform block on production press bed.



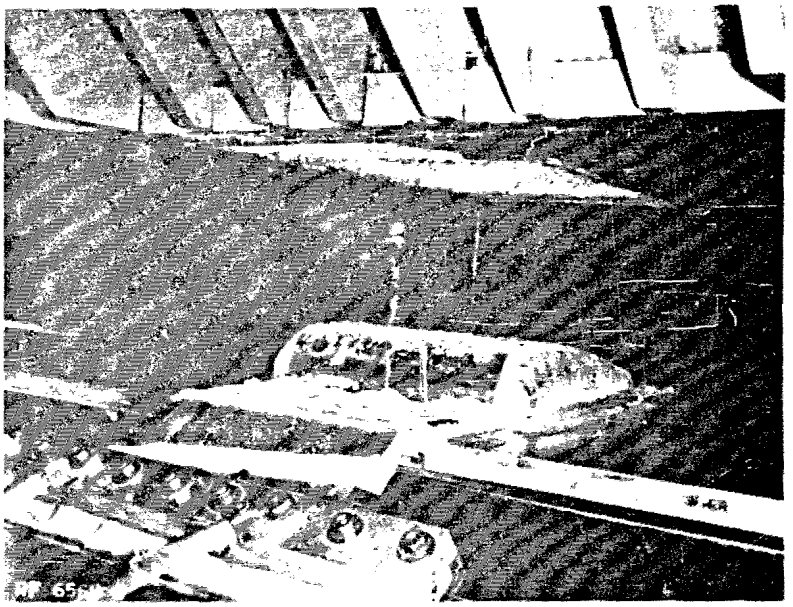
RF 6568-7

Fig. 196 Protective ceramic fiber bat on blank in 5000-ton press.



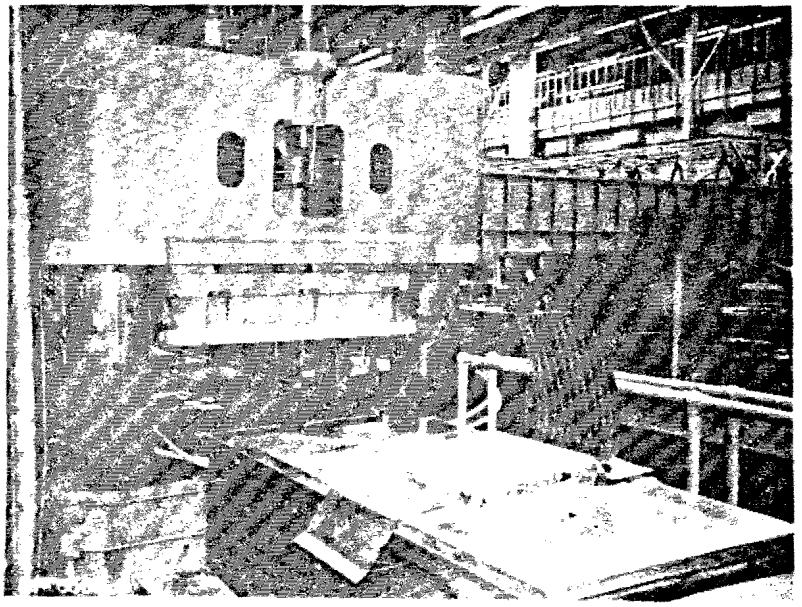
RF 6568-4

Fig. 197 Trapped rubber head closing on heated blank.



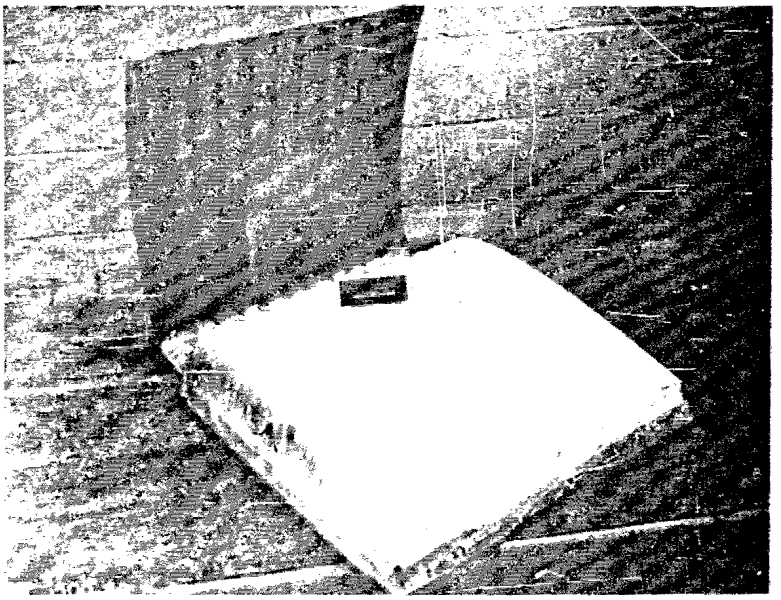
RF 6568-8

Fig. 198 Hydroformed part on block after forming.



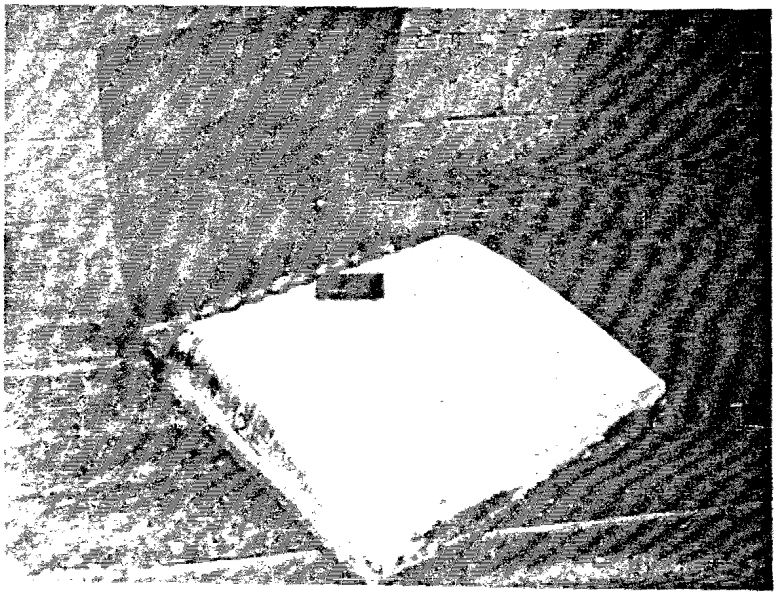
RF 6568-3

Fig. 199 Hydroform part removed from block after forming.



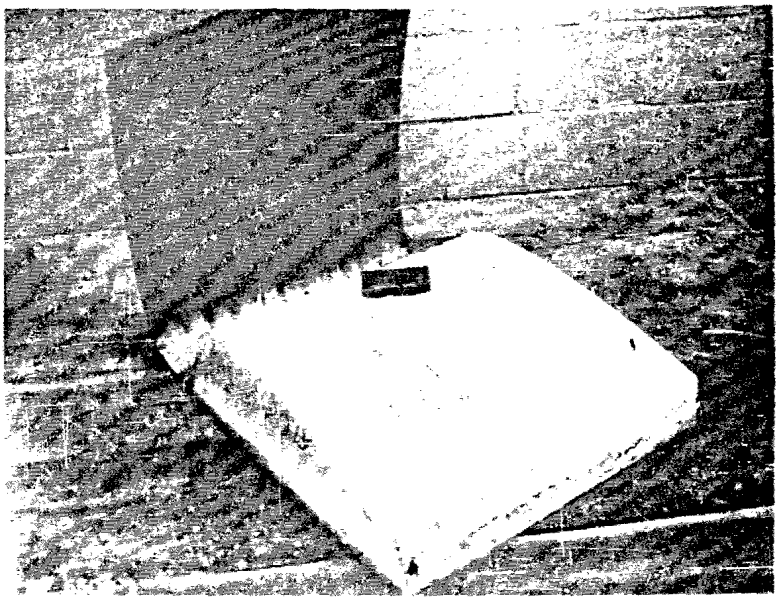
RF 6500-10

Fig. 200 Production size 5A.1 hydroform block and AISI 420 part.



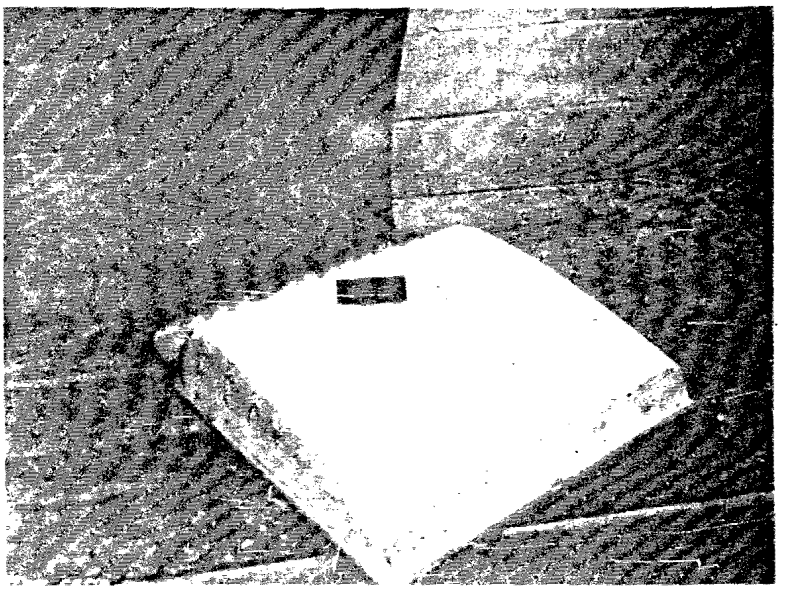
RF 6500-2

Fig. 201 Production size 12E.1 hydroform block and AISI 420 part.



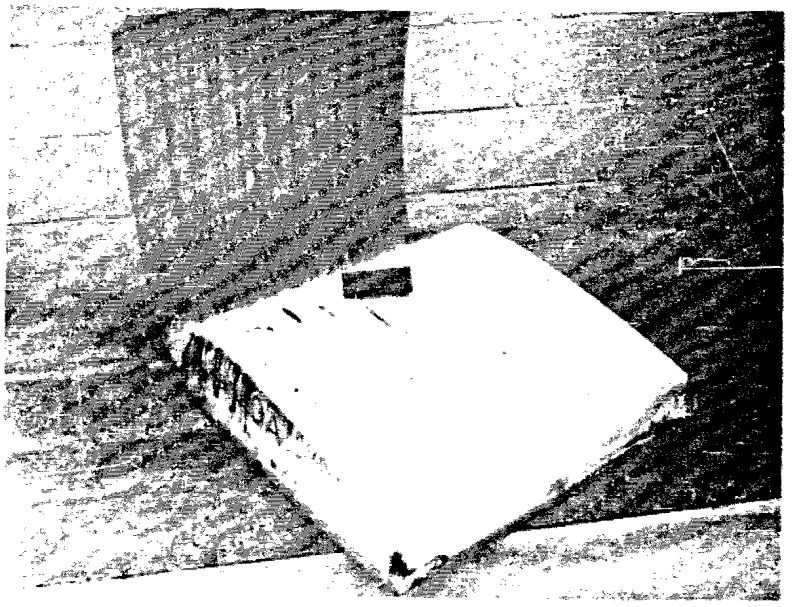
RF 6500-1

Fig. 202 Production size 20B.1 hydroform block and AISI 420 part.



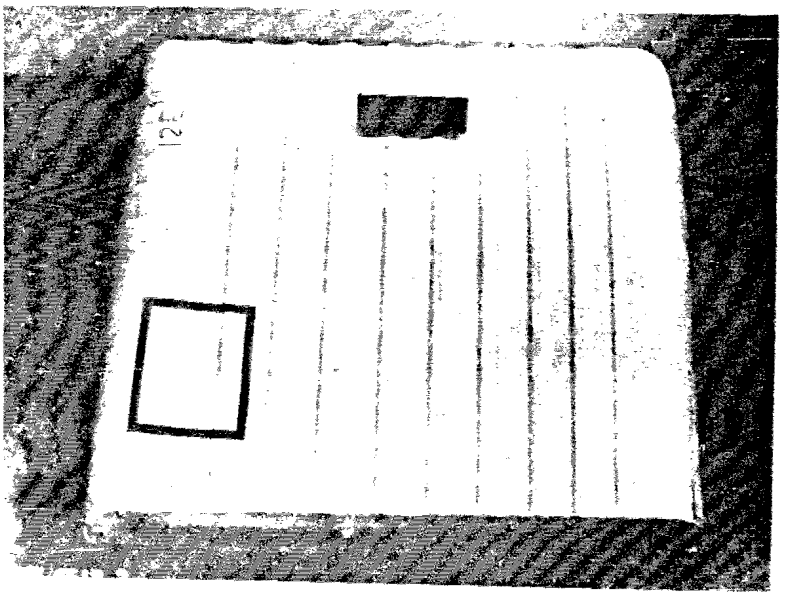
RF 6500-9

Fig. 203 Production size 20A.1 hydroform block (dried only) and AISI 420 part.



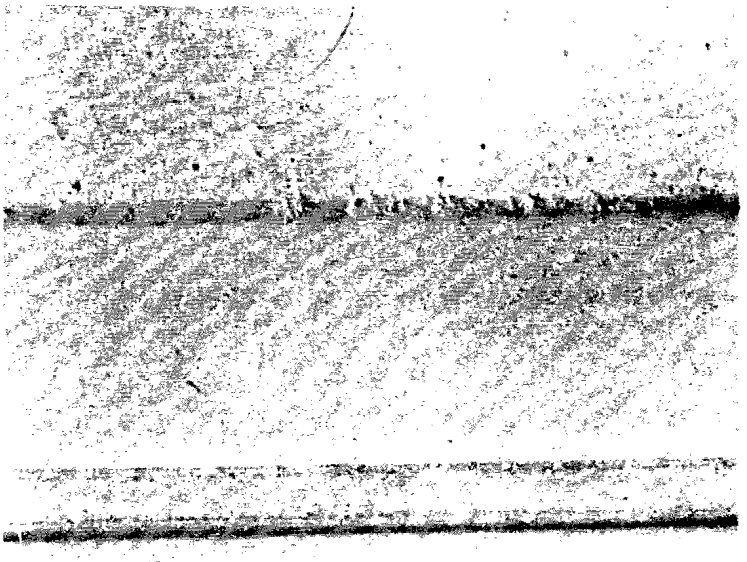
RF 6500-11

Fig. 204 Production size 20A.1 hydroform block (fired) and AISI 420 part.



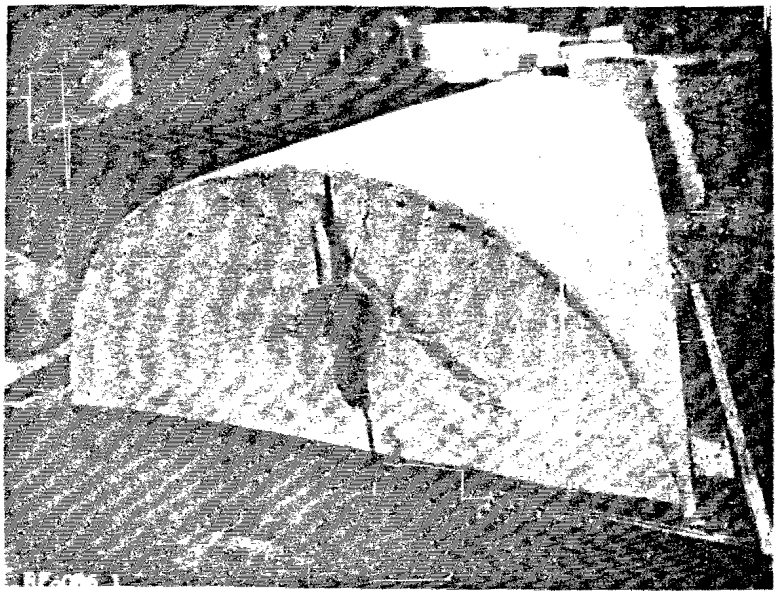
RF 6618-2

Fig. 205 Production size 12E.1 hydroform block after durability test of forming 10 AISI 420 parts. Indicated area is shown enlarged in Figure 206.



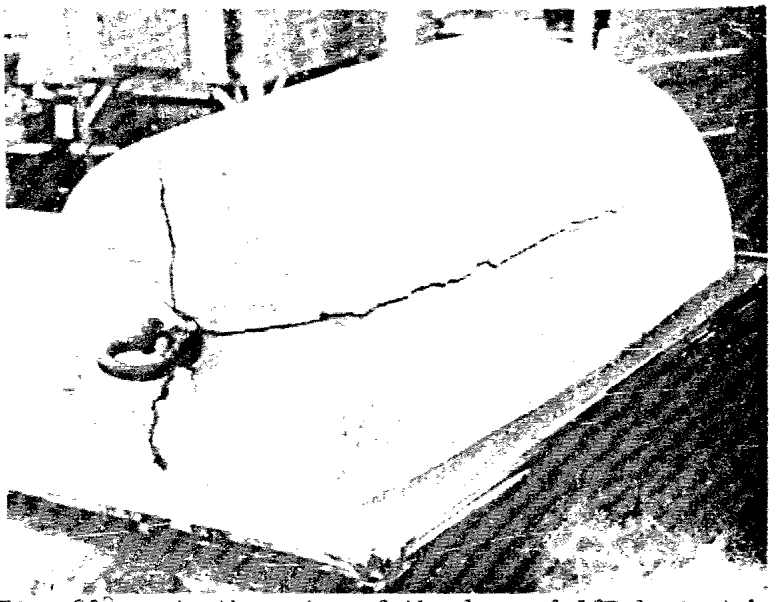
RF 6618-1

Fig. 206 Close-up of failed area of 12E.1 block after durability test of running 10 AISI 420 parts.



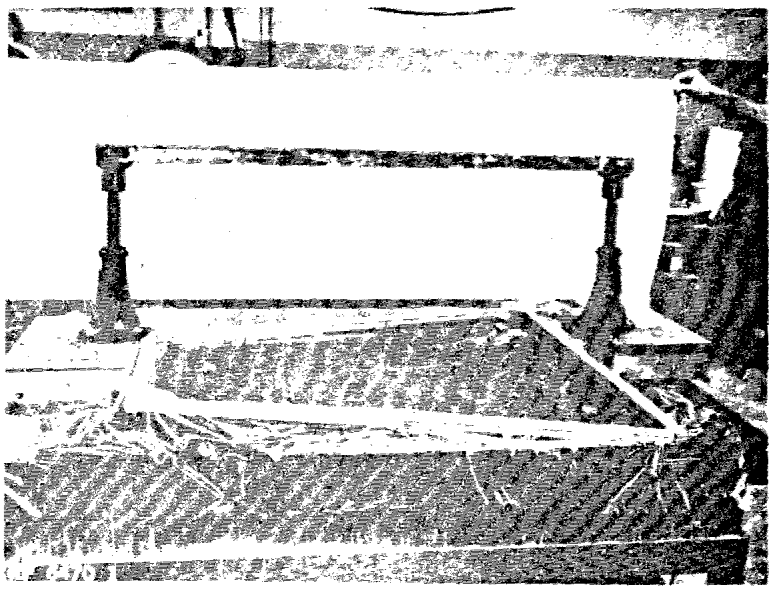
RF 6086-1

Fig. 207 Production size 12E.1 stretchform block after damage. (Refer to text, Page 348.)



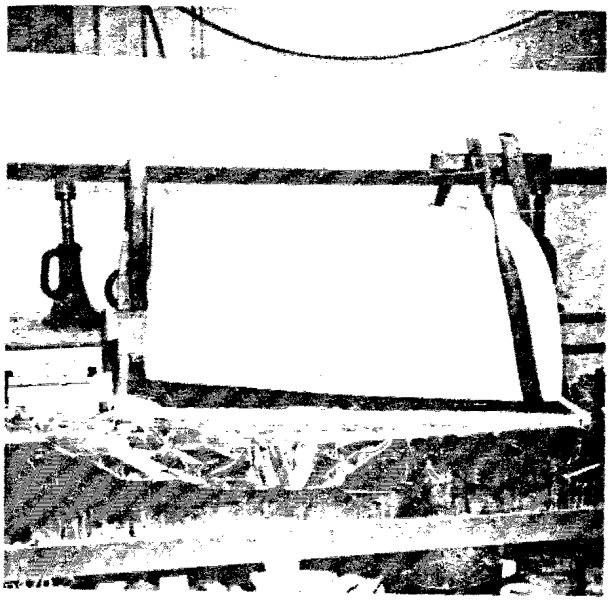
RF 6086-2

Fig. 208 Another view of the damaged 12E.1 stretch-form block shown in Figure 207.



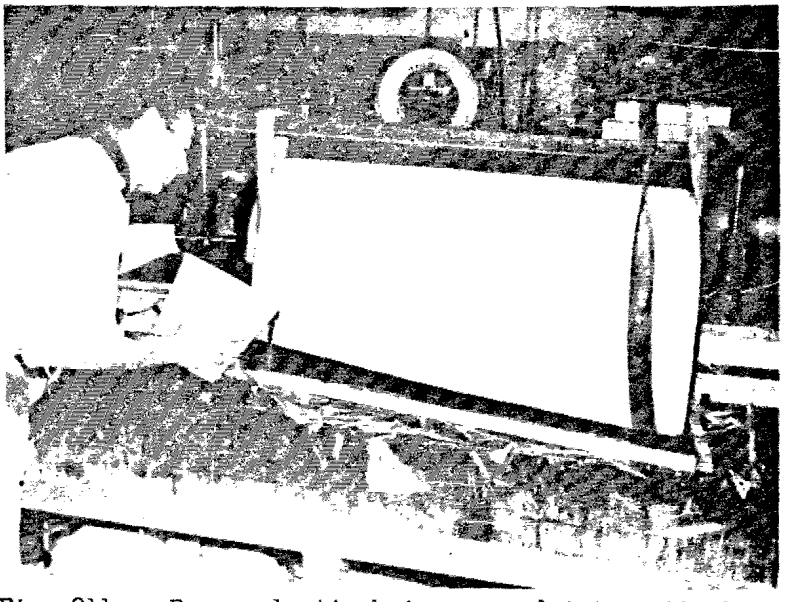
RF 6470-1

Fig. 209 Cellophane over plywood strips to form dam for casting plastic base on production size stretchform block.



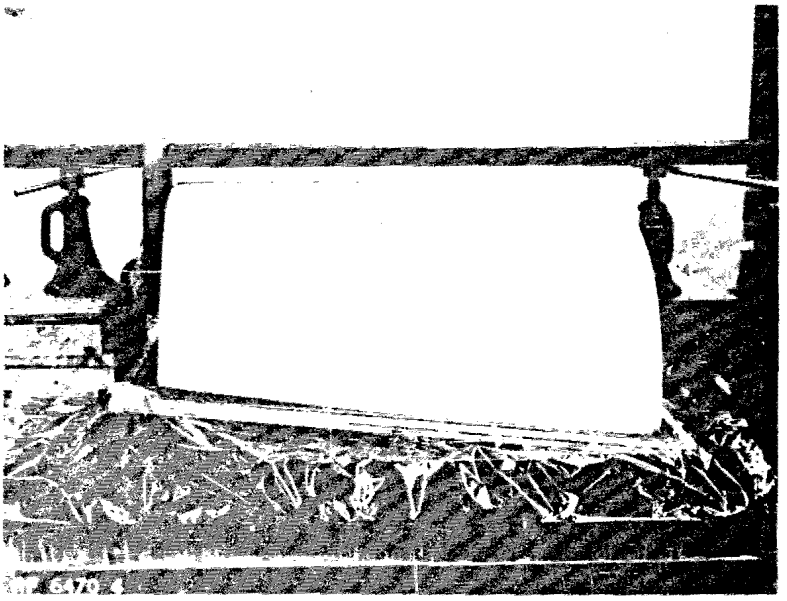
RF 6470-2

Fig. 210 12E.1 stretchform block positioned over plywood frame.



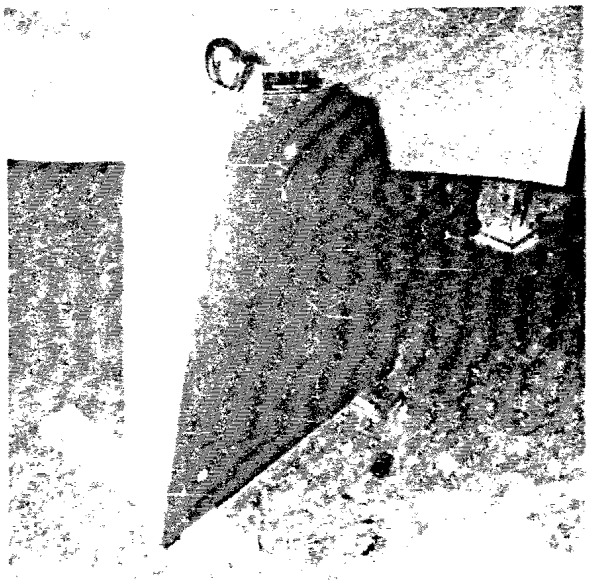
RF 6470-3

Fig. 211 Epoxy plastic being poured into cellophane covered plywood frame.



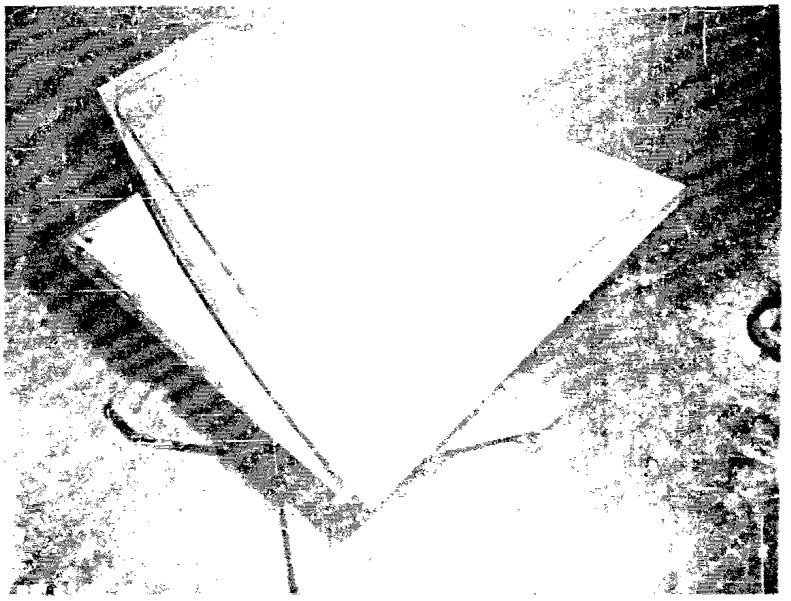
RF 6470-4

Fig. 212 12E.1 stretchform block resting on spacers in plastic puddle.



RF 6500-8

Fig. 213 Trimmed plastic base on stretch-form block.



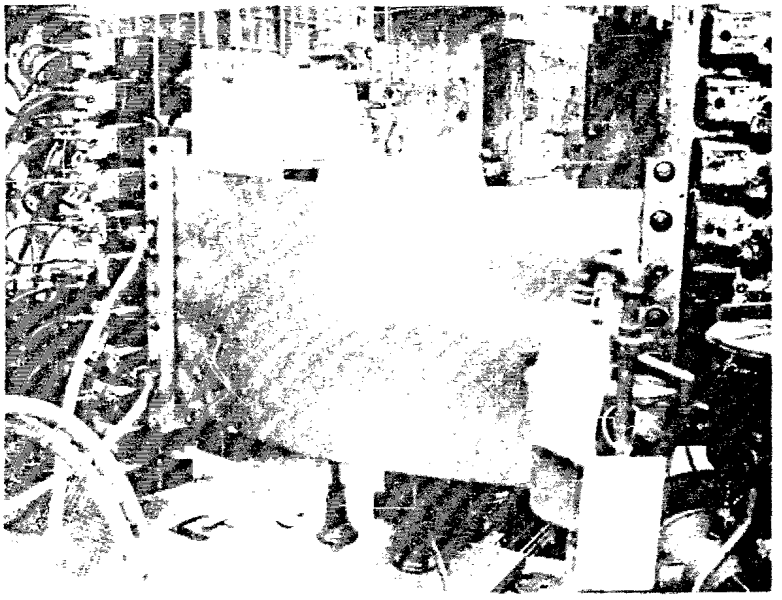
RF 6500-4

Fig. 214 Stretchform block vacuum chuck.



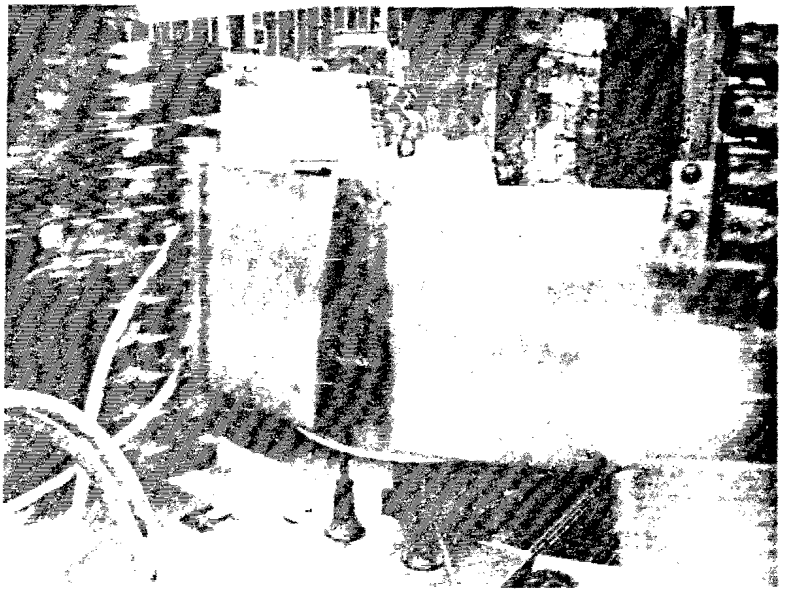
RF 6577-1

Fig. 215 Stretchpress with carbide stretchform block installed on vacuum chuck.



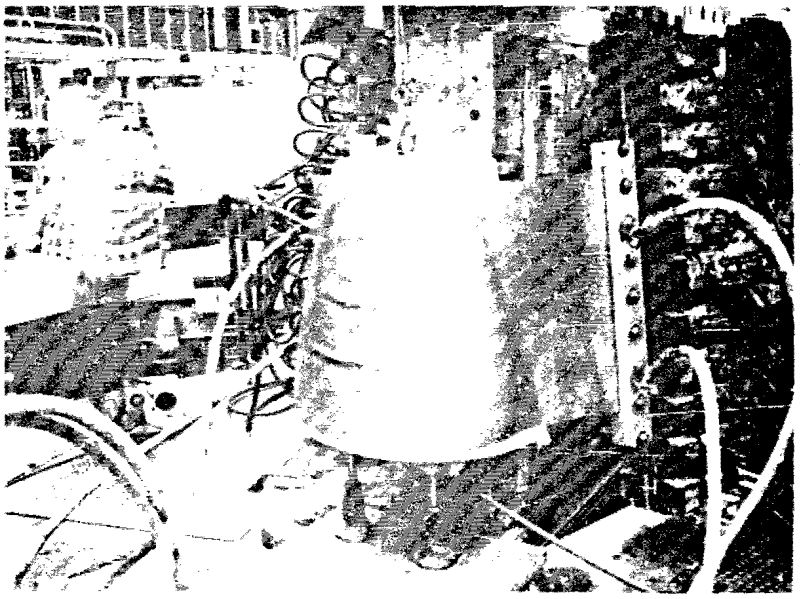
RF 6569-19

Fig. 216 Stretchpress jaws positioned for wrap forming AISI 420 part.



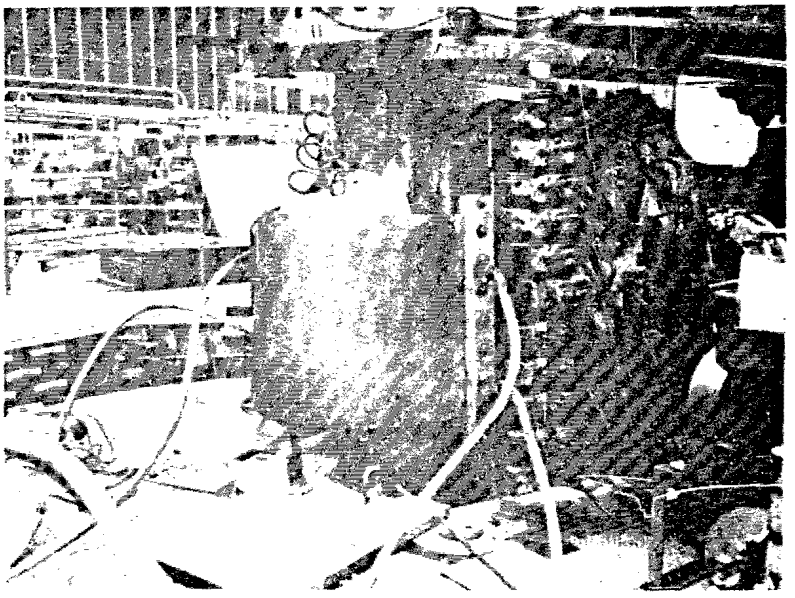
RF 6569-3

Fig. 217 Heated AISI 420 blank, 1300 F, being wrapped around stretchform block.



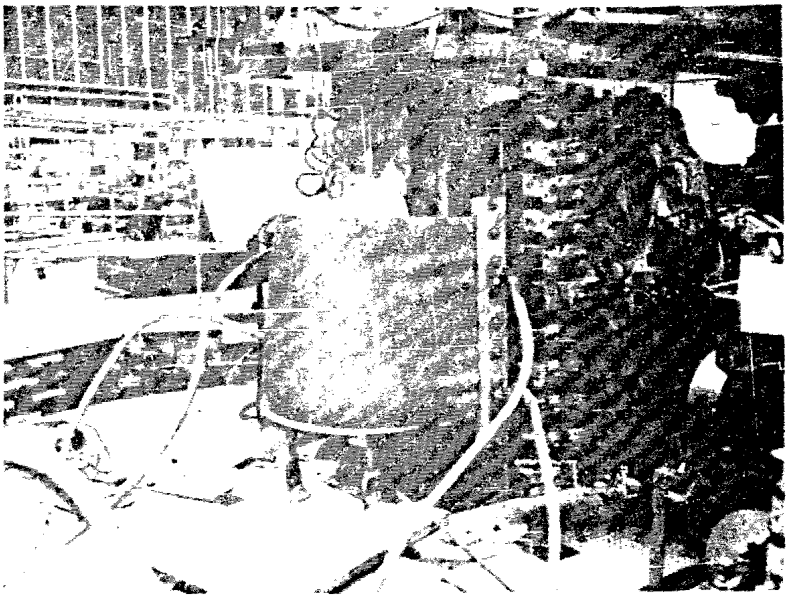
RF 6569-9

Fig. 218 Stretchformed part attempted with wrap around action.



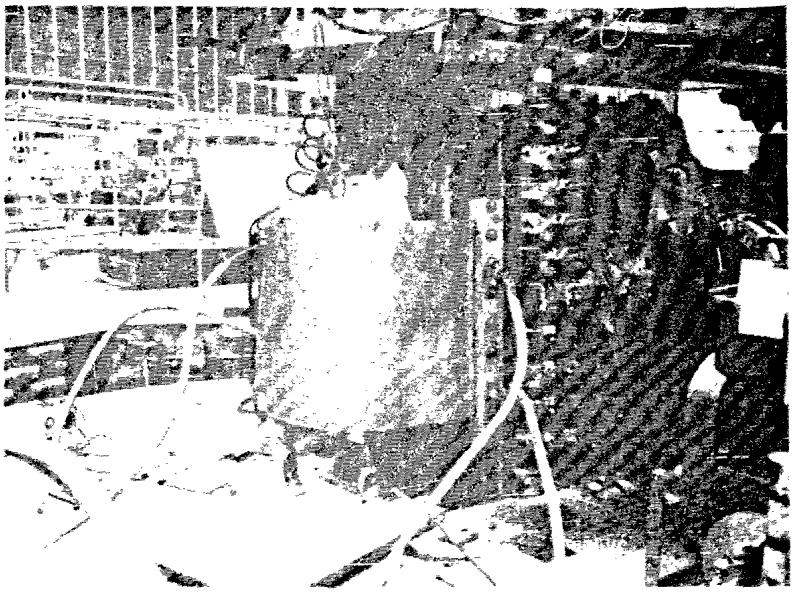
RF 6604-4

Fig. 219 Heated blank, AISI 420, held off of ceramic stretchform block.



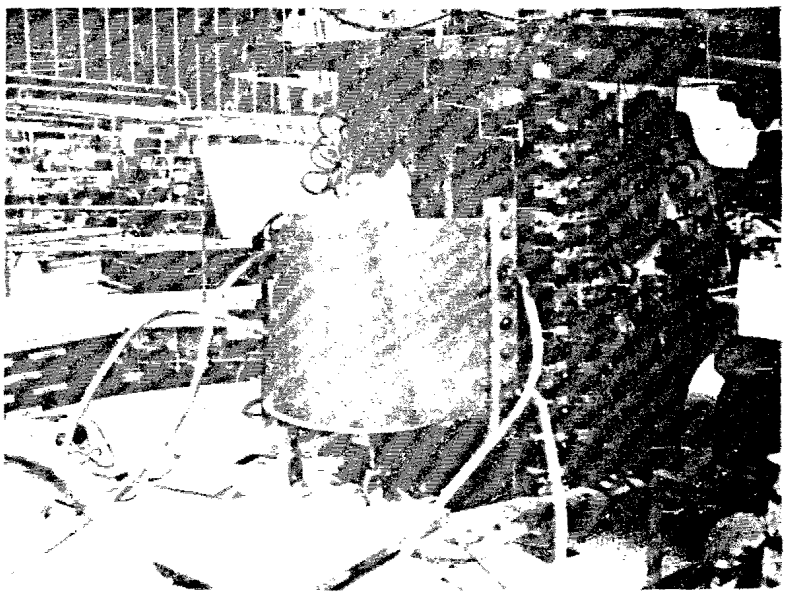
RF 6604-10

Fig. 220 Heated blank being pulled against block.



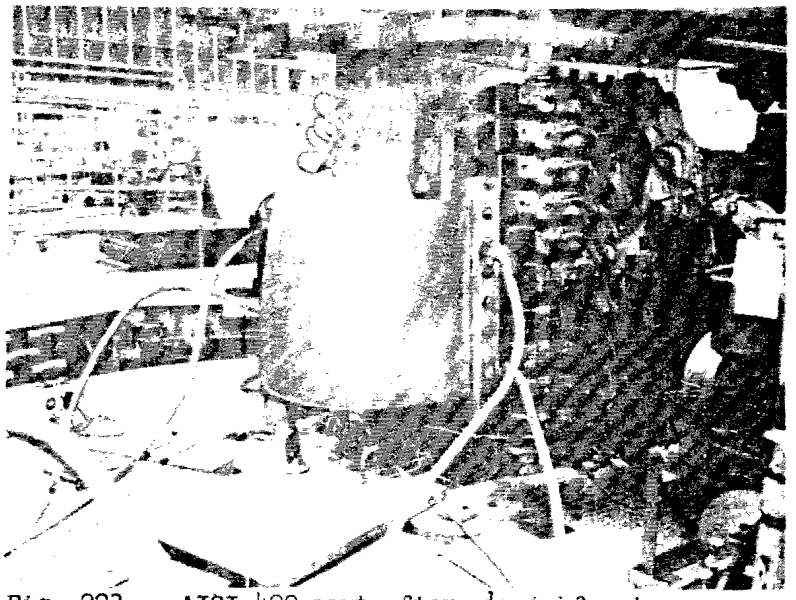
RF 6604-9

Fig. 221 Blank relaxed and removed from block for reheating.



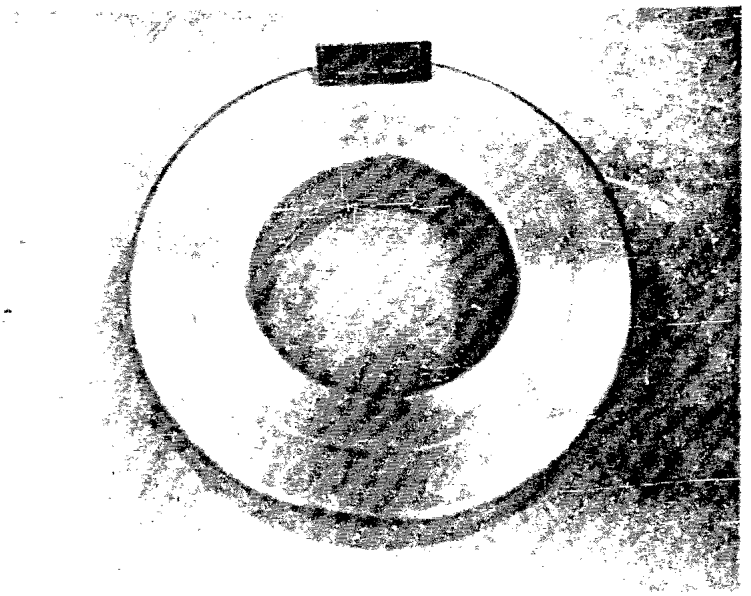
RF 6604-6

Fig. 222 Heated blank, 1300 F, again being pulled against block.



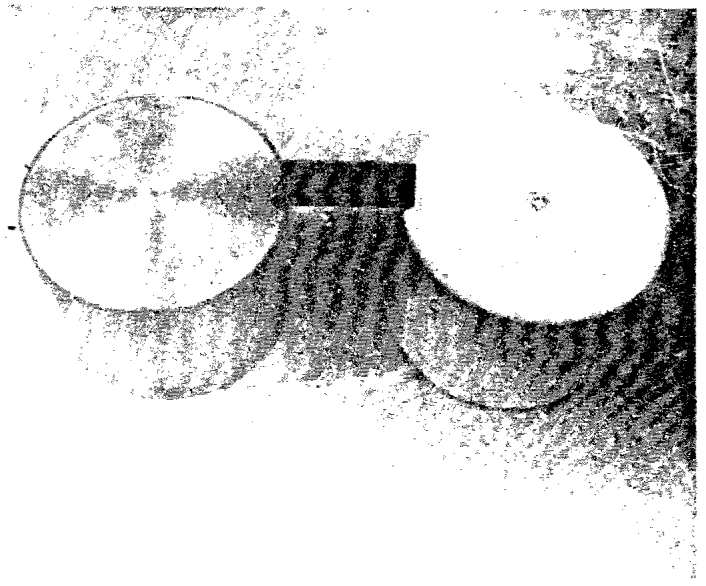
RF 6604-5

Fig. 223 AISI 420 part after stretchforming.



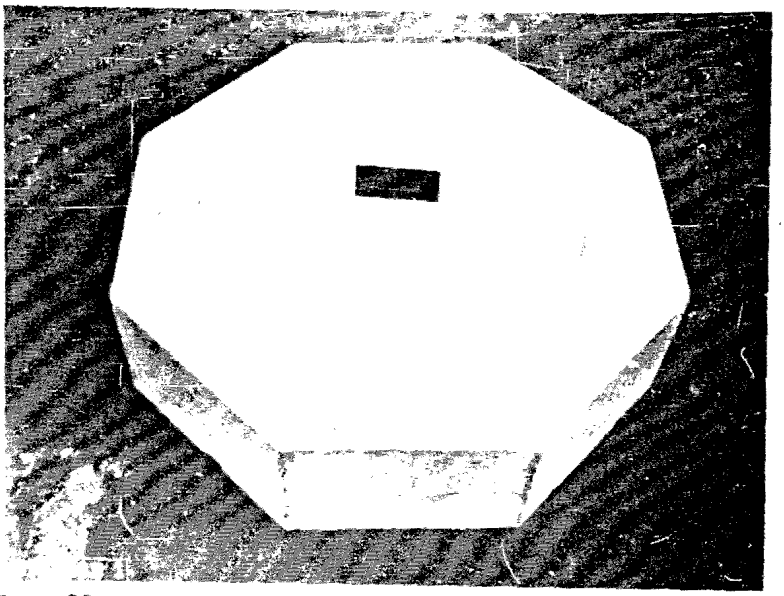
RF 5936-2

Fig. 224 Magnesium draw ring model



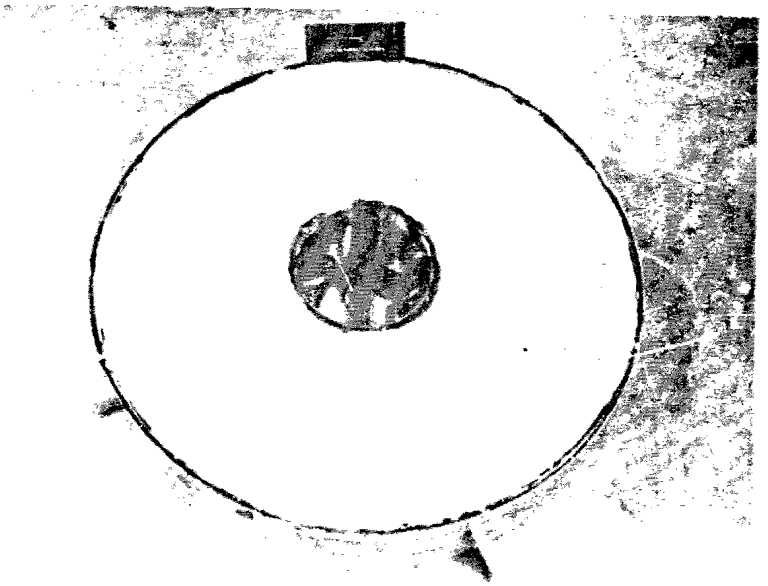
RF 5936-3

Fig. 225 Magnesium punch model and ceramic punch.



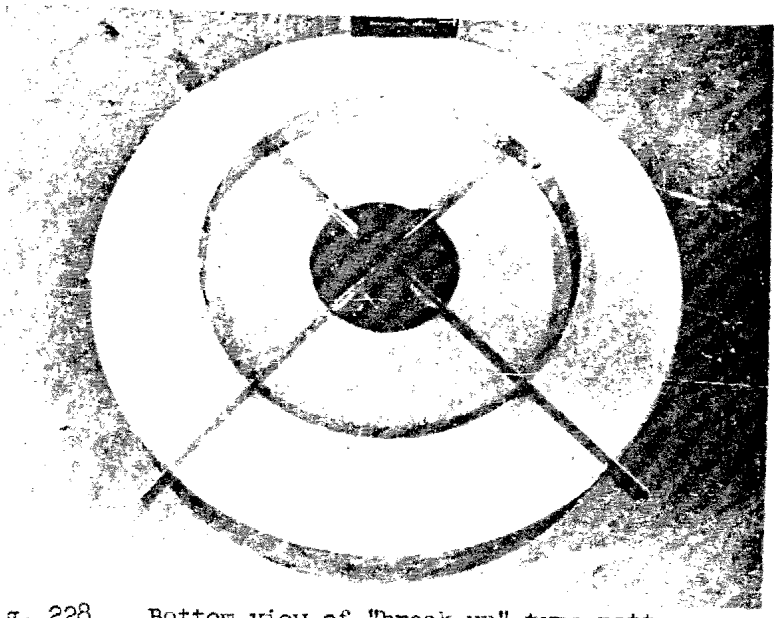
RF 6033-1

Fig. 226 No. 1 pottery plaster mold for draw ring.



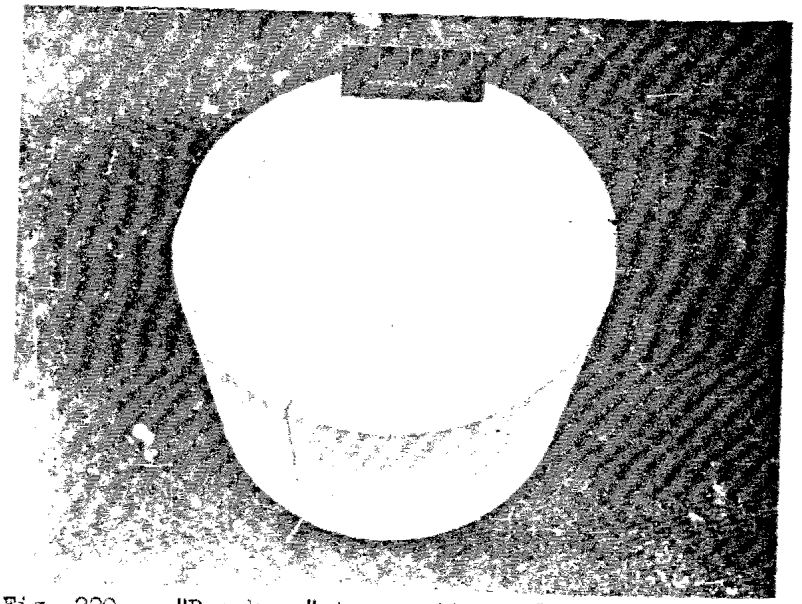
RF 5936-6

Fig. 227 Top view of "break-up" type pottery plaster draw ring mold.



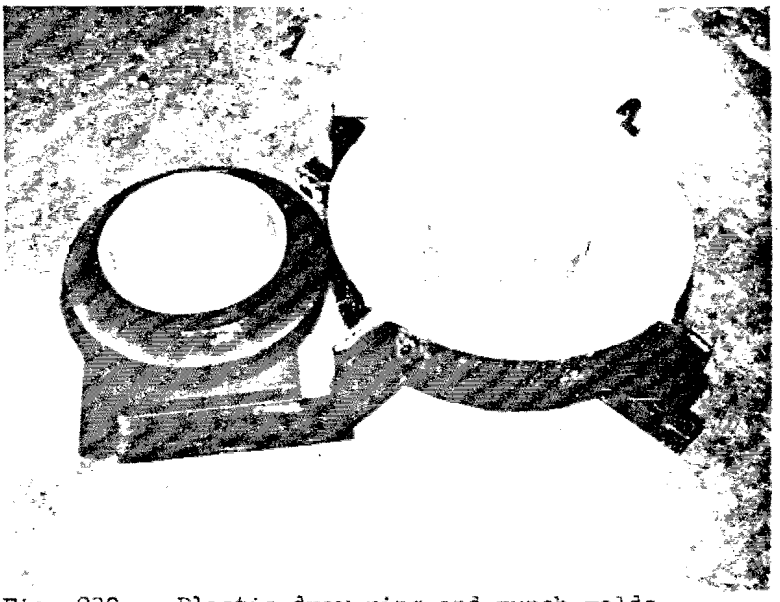
RF 5936-4

Fig. 228 Bottom view of "break-up" type pottery plaster draw ring mold.



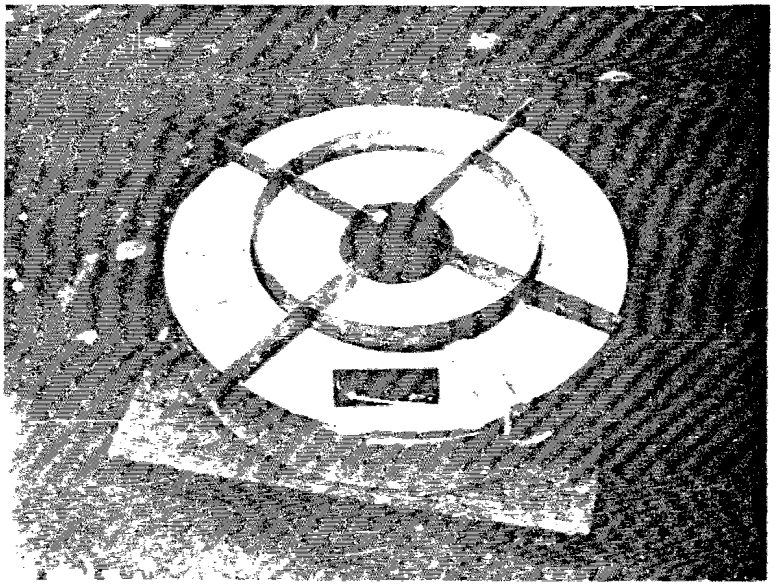
RF 6033-3

Fig. 229 "Break-up" type pottery plaster punch mold.



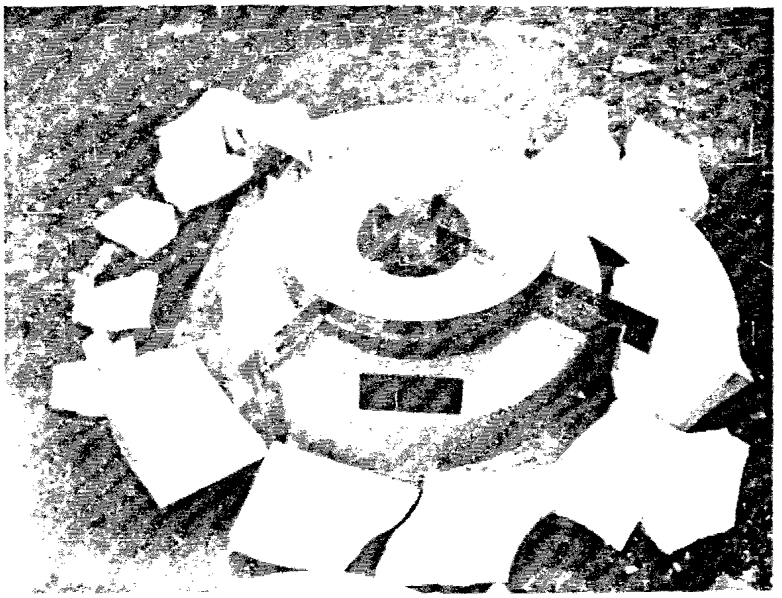
RF 6285

Fig. 230 Plastic draw ring and punch molds.



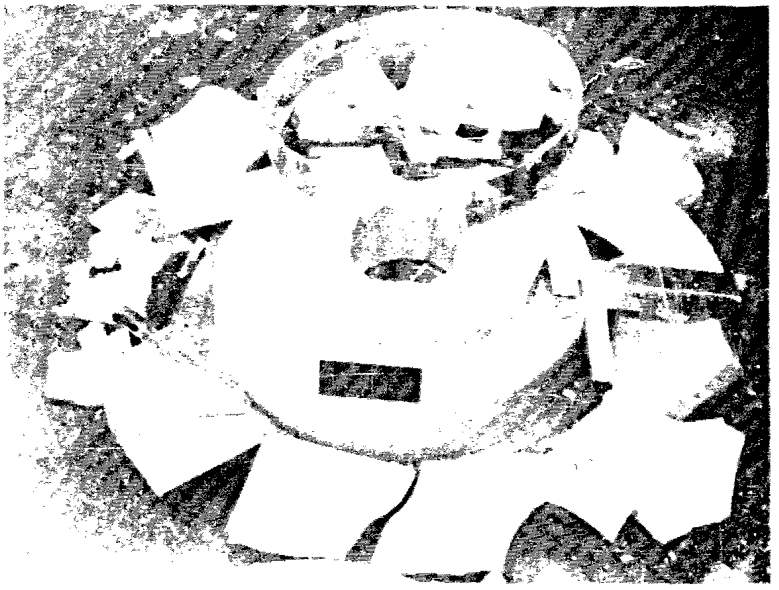
RF 5984-2

Fig. 231 "Break-up" type pottery plaster draw ring mold after oven drying.



RF 5984-4

Fig. 232 "Break-up" type pottery plaster draw ring mold with outside portion removed.



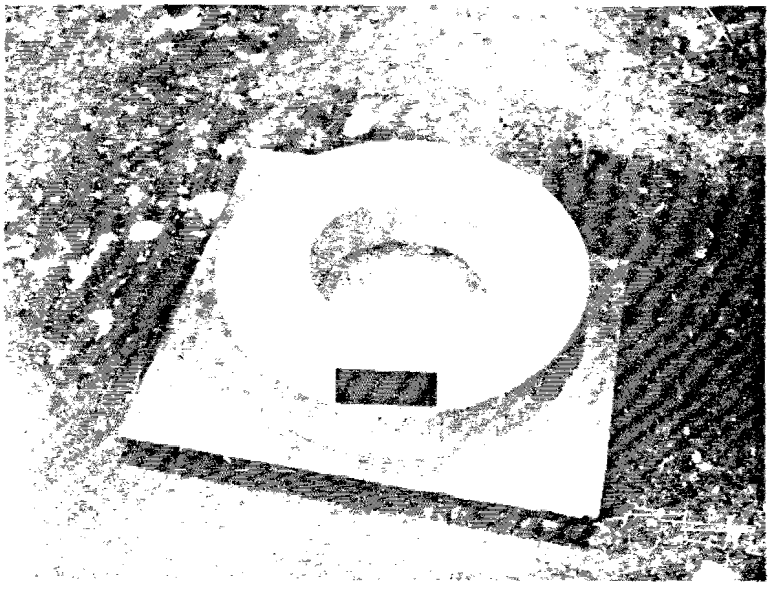
RF 5984-3

Fig. 233 "Break-up" type pottery plaster draw ring mold with metal inserts removed.



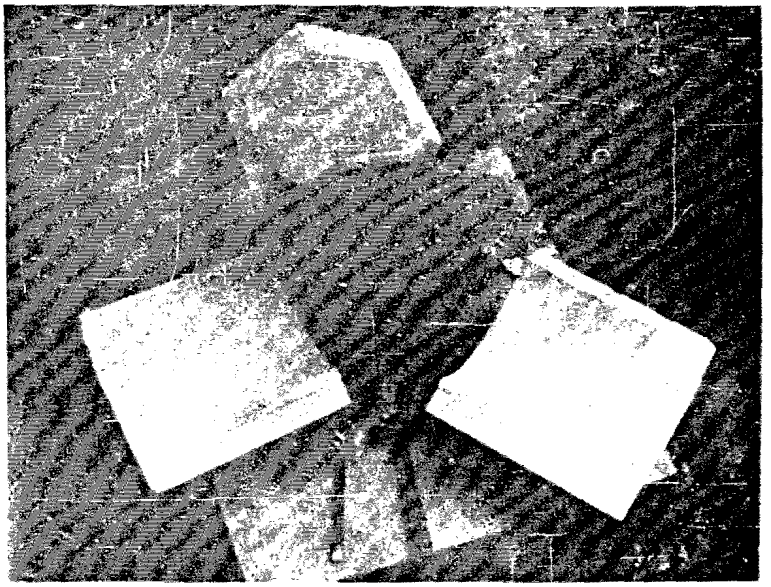
RF 5984-5

Fig. 234 "Break-up" type pottery plaster mold removed from ceramic draw ring.



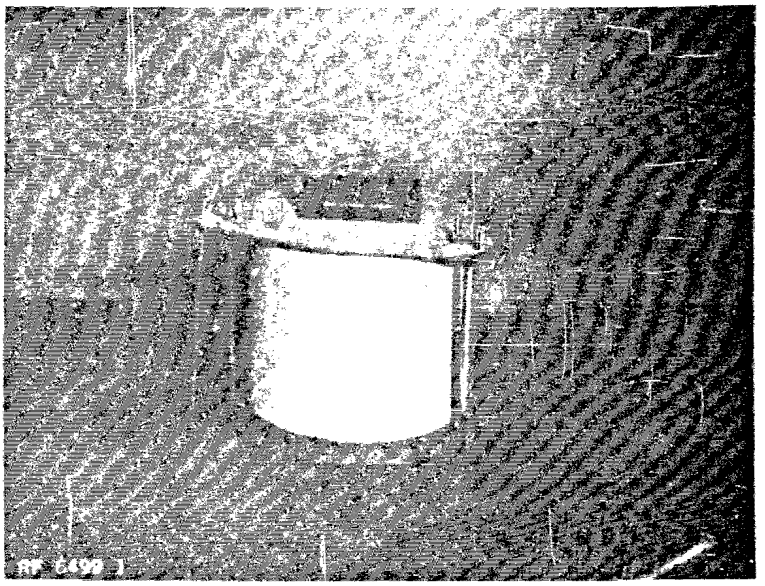
RF 5984-1

Fig. 235 2)A.1 draw ring casting showing damage to inside radius.



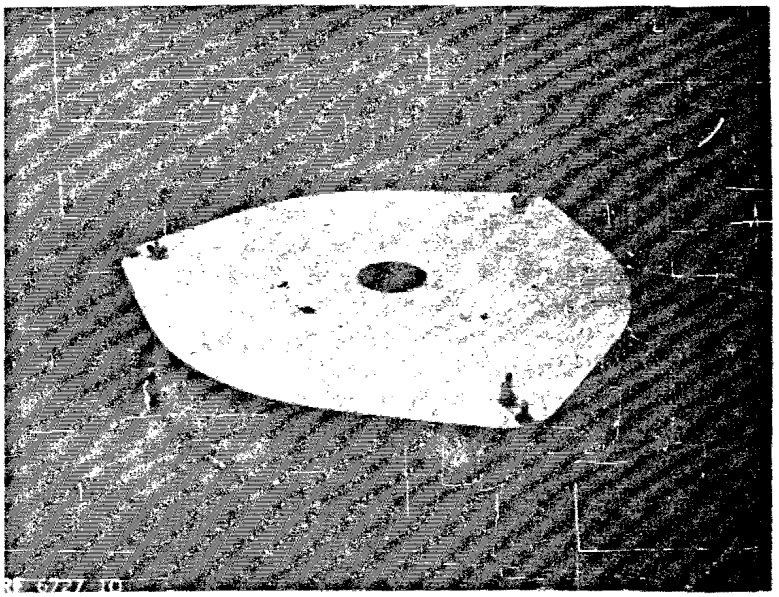
RF 5936-1

Fig. 236 23A.1 punch with plaster "break-up" mold removed.



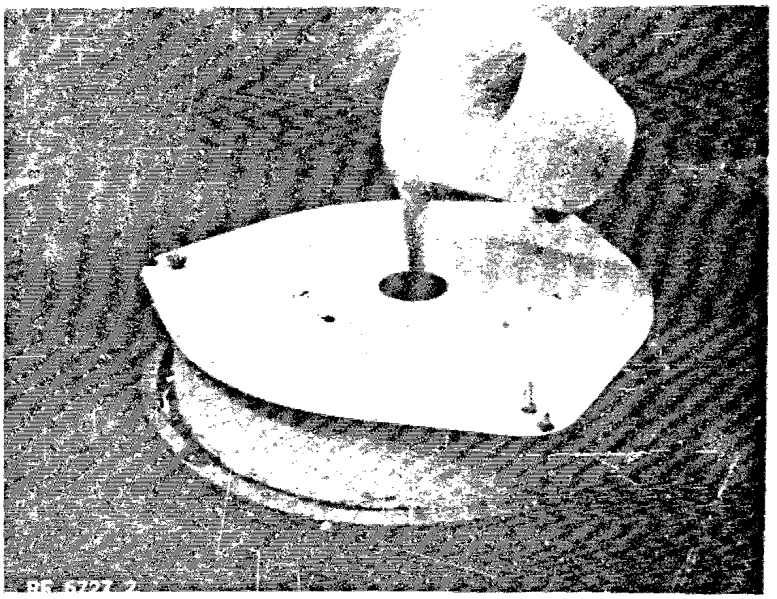
RF 6499-1

Fig. 237 Plastic base casting arrangement for draw die punch.



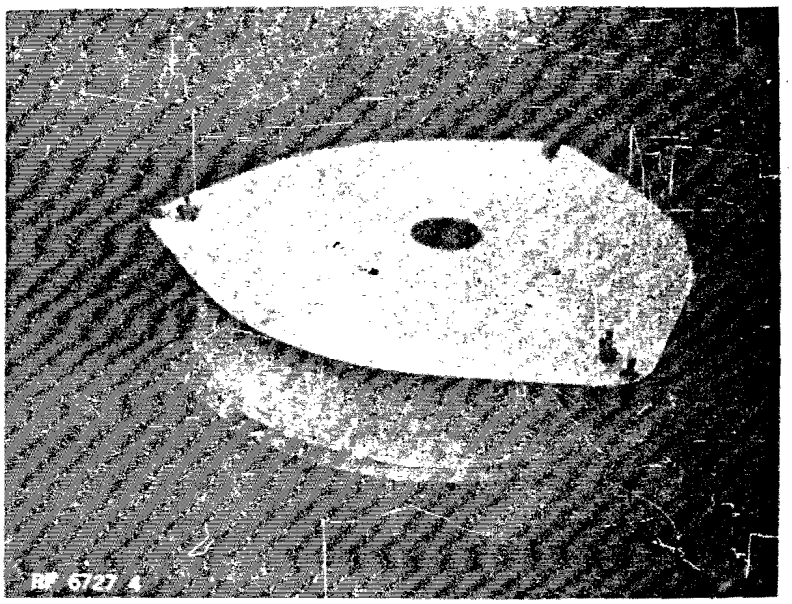
RF 6727-10

Fig. 238 Ceramic draw ring mounted in holding fixture for plastic base application.



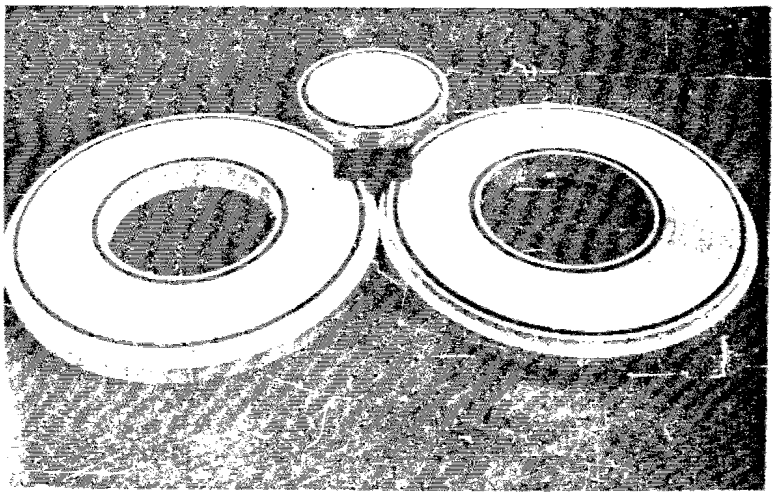
RF 6727-2

Fig. 239 Epoxy plastic base material being applied through center of draw ring.



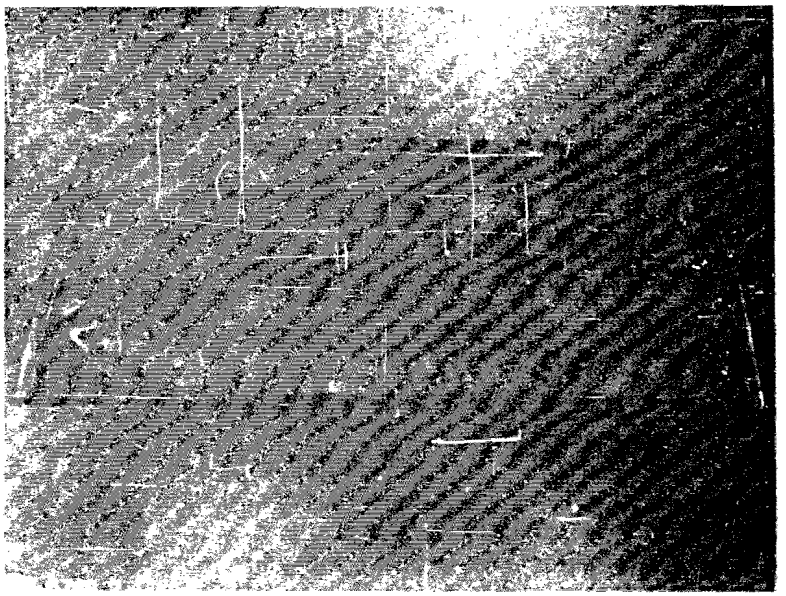
RF 6727-4

Fig. 240 Epoxy plastic after flowing under draw ring to form flat base.



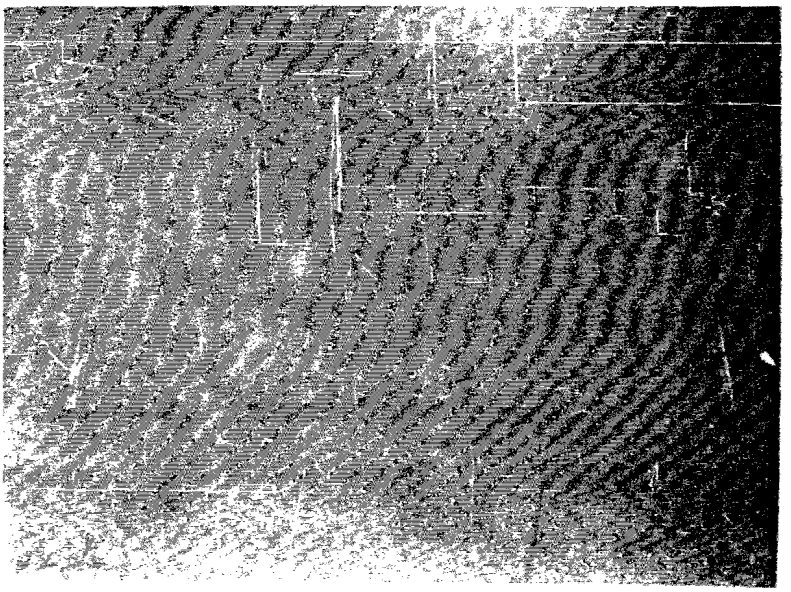
RF 6033-2

Fig. 241 Vacuum chucks for attaching ceramic draw dies to experimental press.



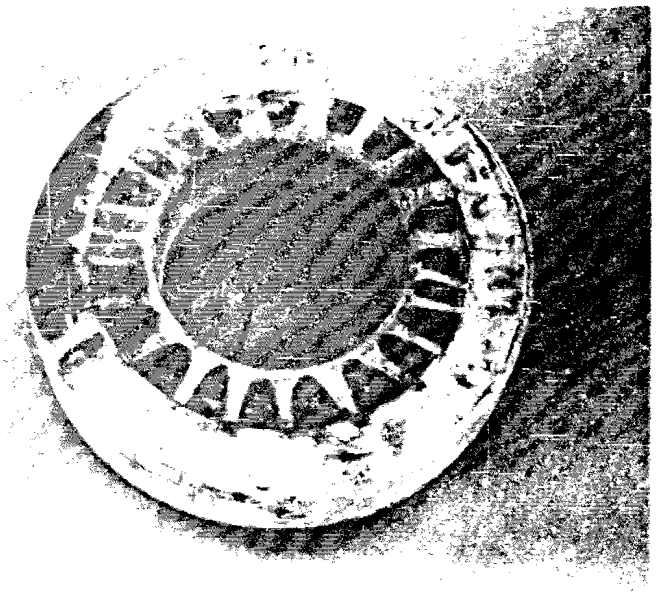
RF 6749-2

Fig. 242 Typical failure of AISI 420 drawn part. Refer to Table 41, Page 378.



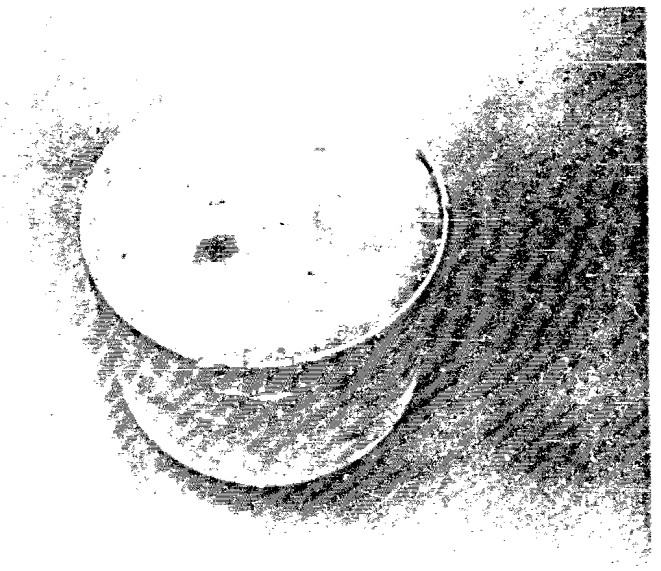
RF 6749-3

Fig. 243 AISI 420 part formed to one inch depth by cyclic forming.



RF 6749-1

Fig. 244 Typical failed ceramic draw ring, 25A.1 shown.



RF 6749-4

Fig. 245 Typical failed ceramic punch, 25A.1 shown.

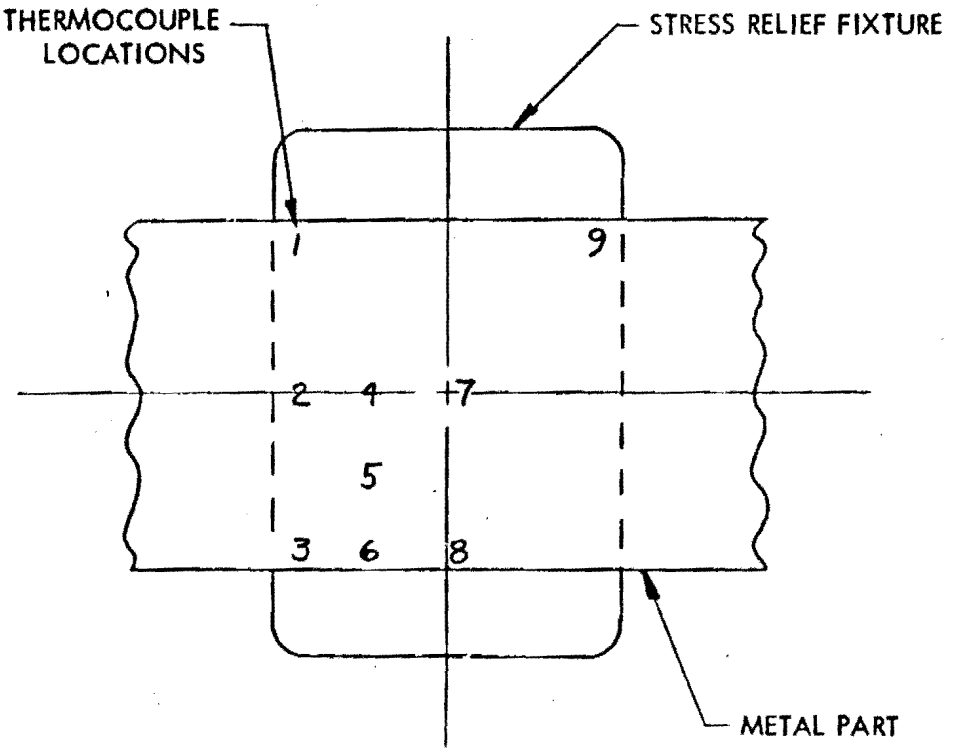
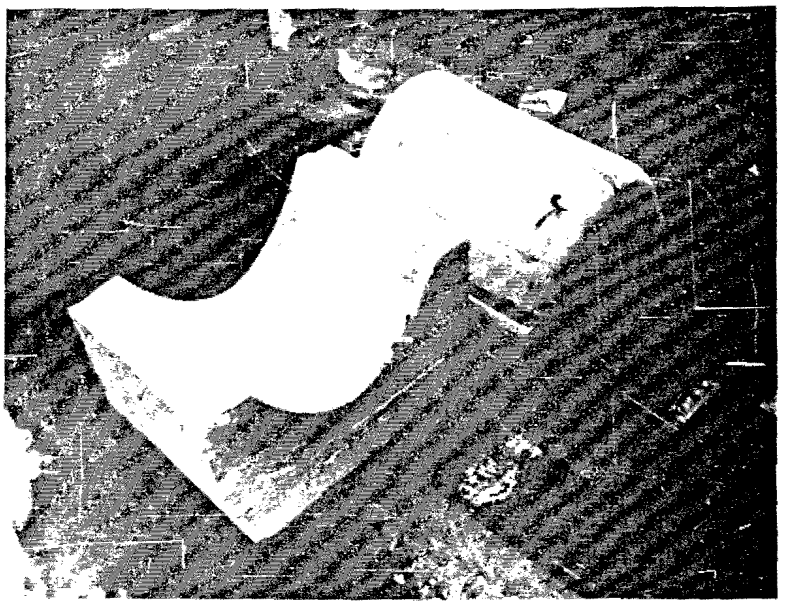


Fig. 246 Thermocouple location on AISI 420 formed part for stress relief fixture evaluation.



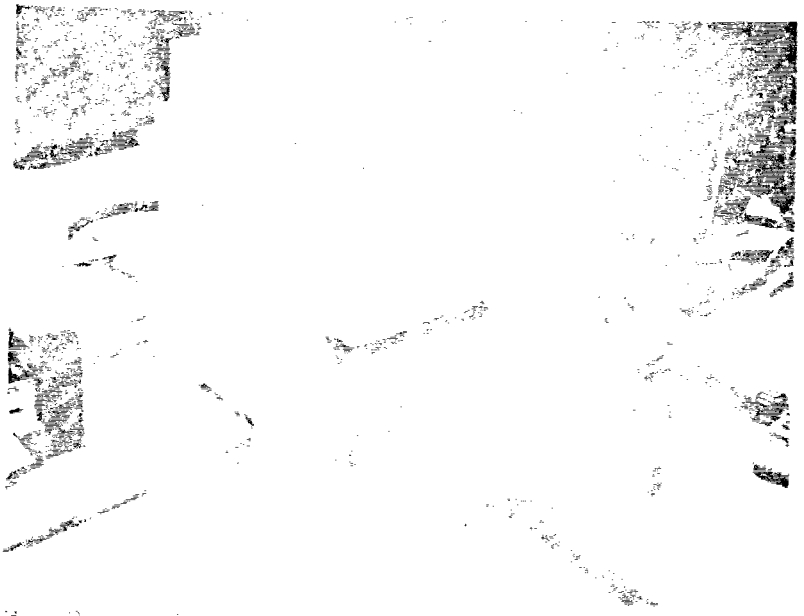
RF 6728-1

Fig. 247 Ceramic draw heat treat fixture (25A.1, 25D.1 and 25E.1) in open position.



RF 6728-11

Fig. 248 Formed AISI 420 part on lower block with thermocouples and electrodes attached.



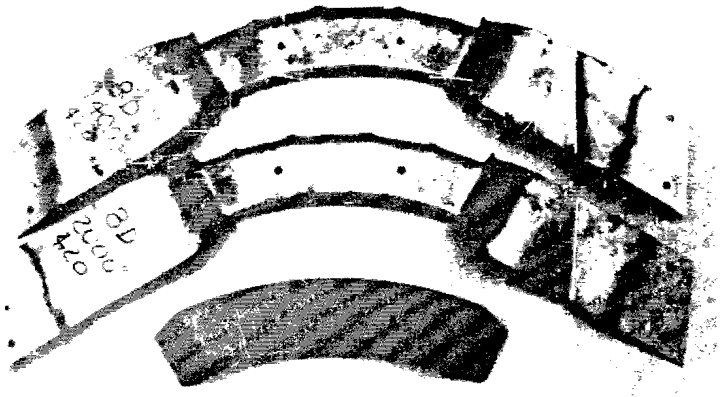
RF 6695-9

Fig. 2a



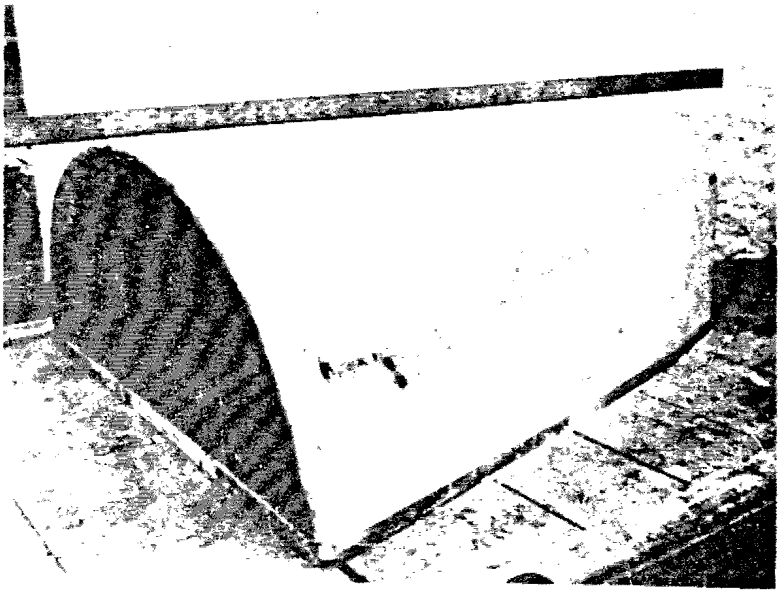
RF 6695-8

Fig. 2b



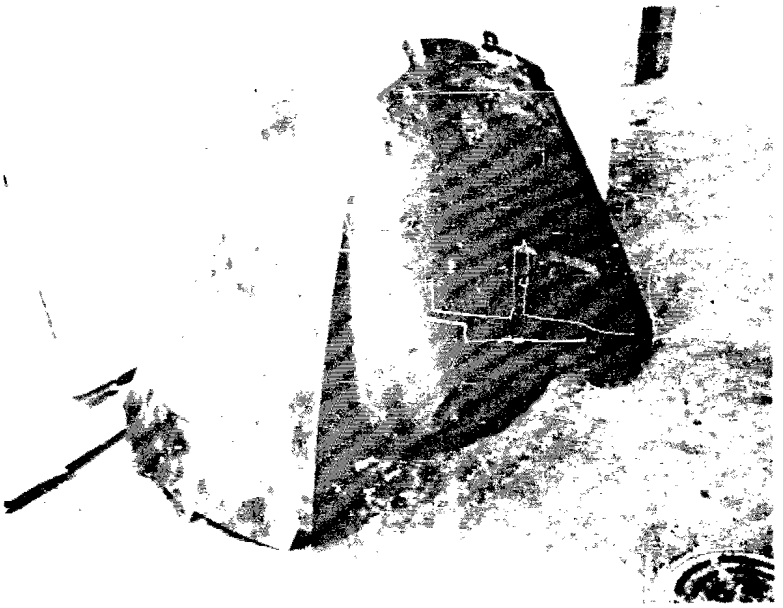
RF 6727-12

Fig. 251 Formed parts and failed 8D.1 hydroform block.



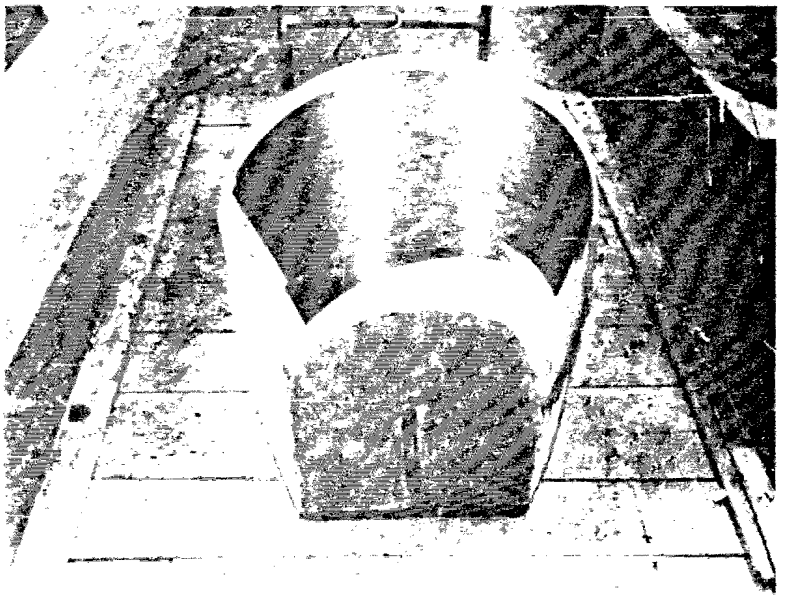
RF 6727-8

Fig. 252 View showing degree of double contour on production size stretchform block.



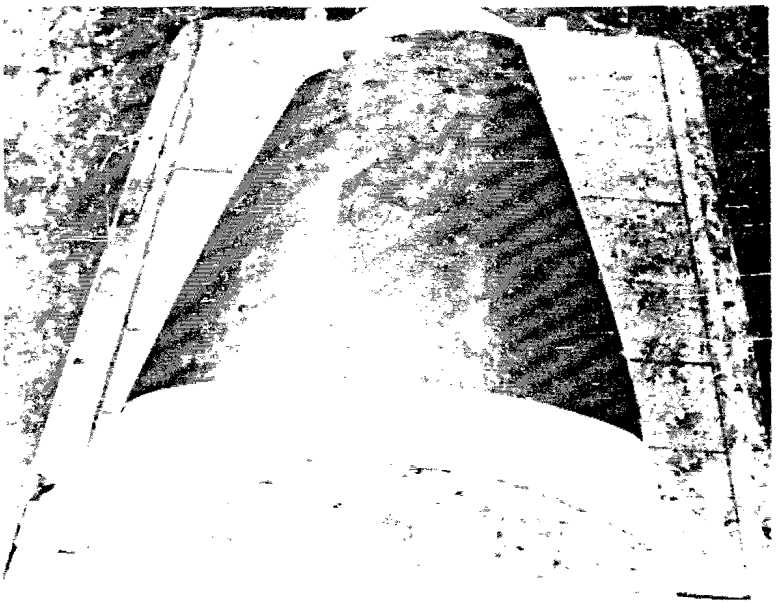
RF 6727-1

Fig. 253 AISI 420 stretchformed parts, Numbers 14, 15, and 20, reading left to right. Refer to Table 40.



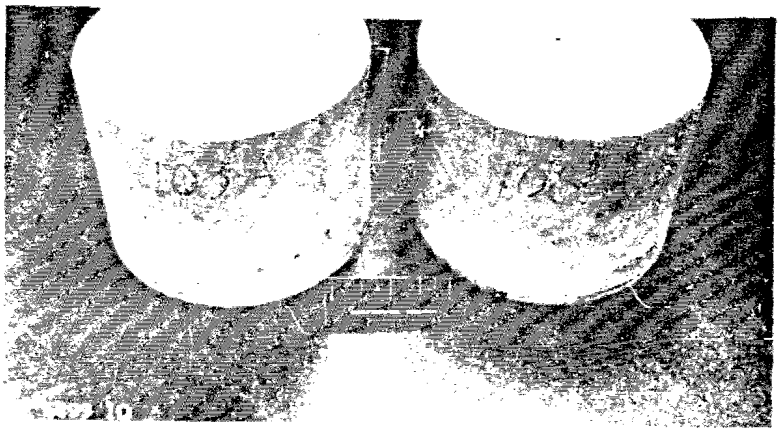
RF 6736-2

Fig. 254 AISI 420 stretchformed part No. 20 on ceramic block. Refer to Table 40.



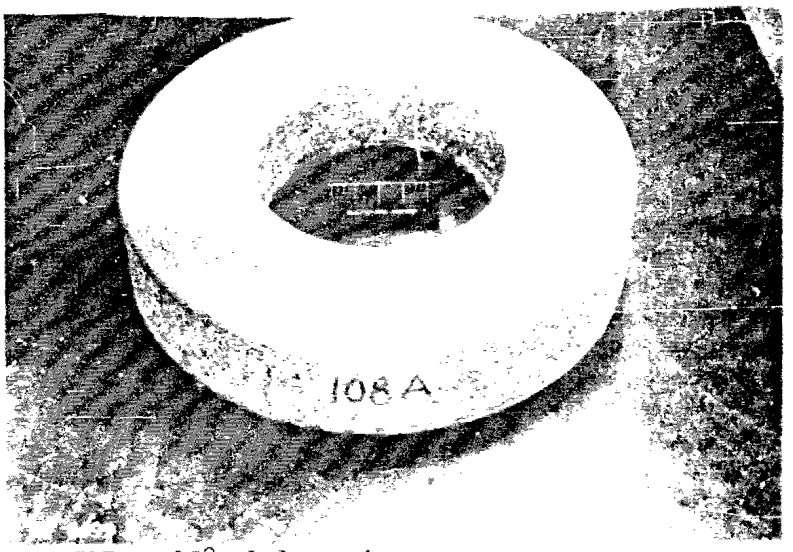
RF 6736-1

Fig. 255 AISI 420 stretchformed part No. 20 on ceramic block.



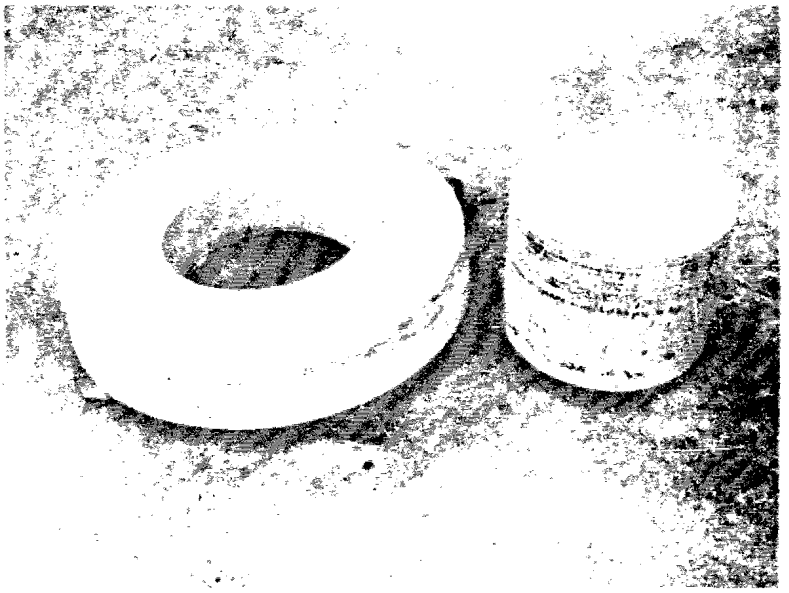
RF 6499-10

Fig. 256 108A.1 draw die punches.



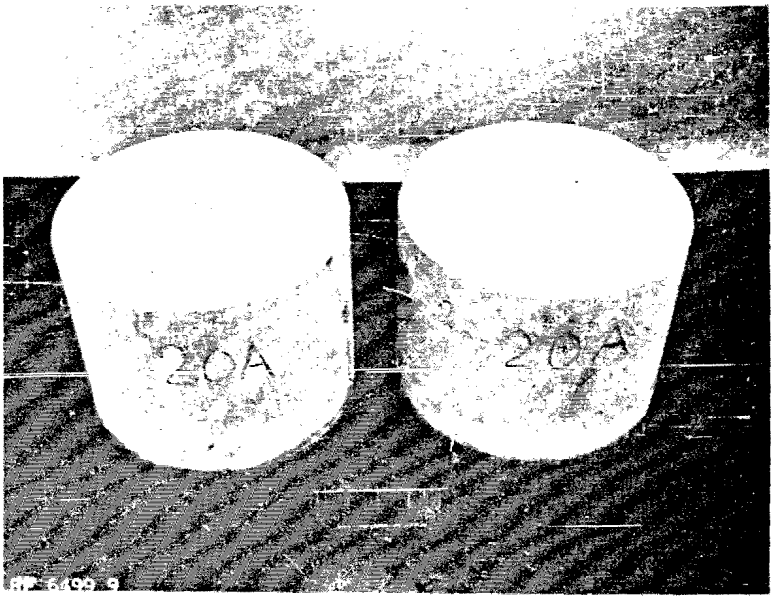
RF 6499-5

Fig. 257 108A.1 draw ring.



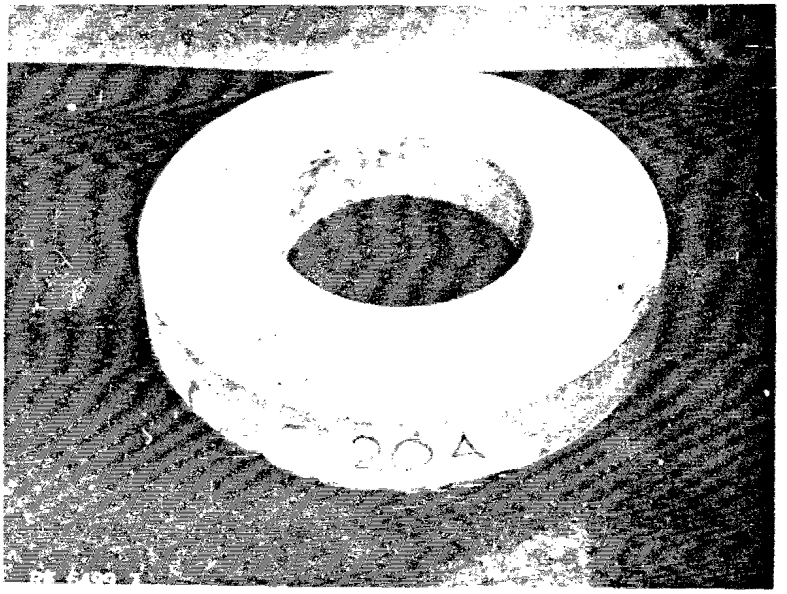
RF 6086-5

Fig. 258 108A.1 punch and draw ring (after firing).



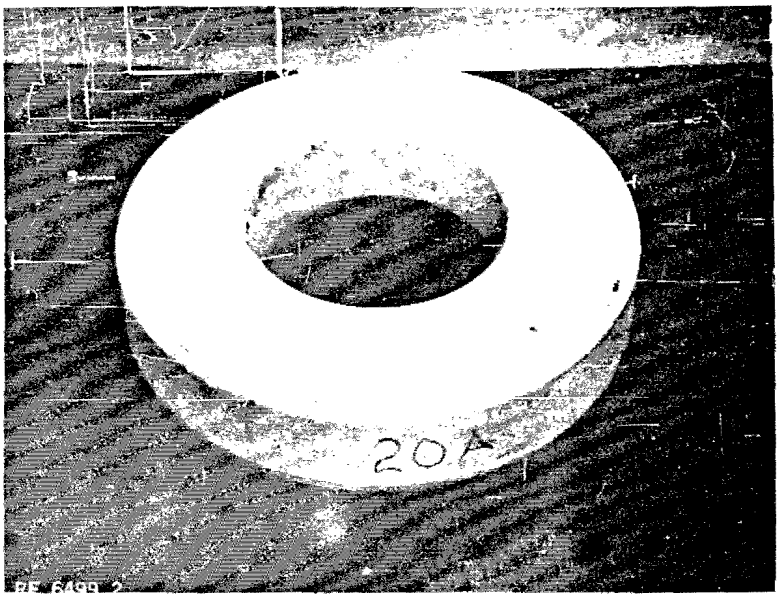
RF 6499-9

Fig. 259 20A.1 draw die punches.



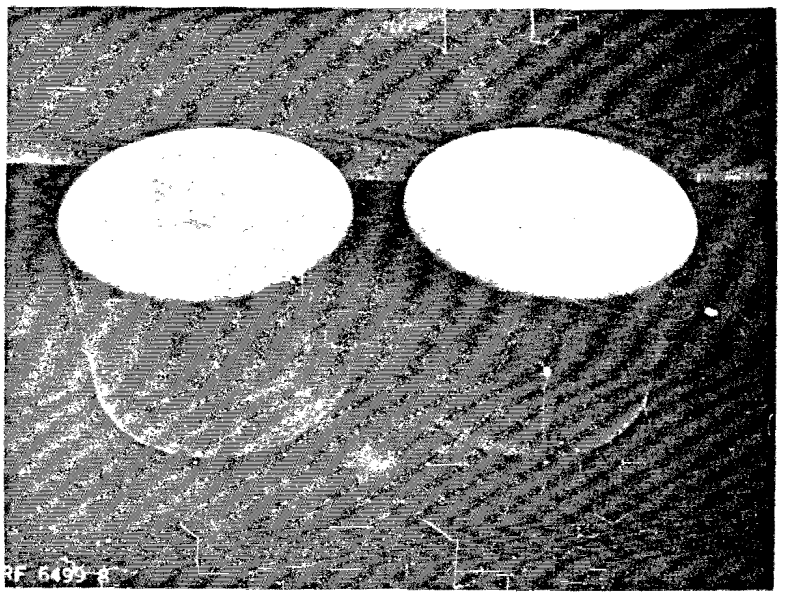
RF 6499-3

Fig. 260 20A.1 draw ring.



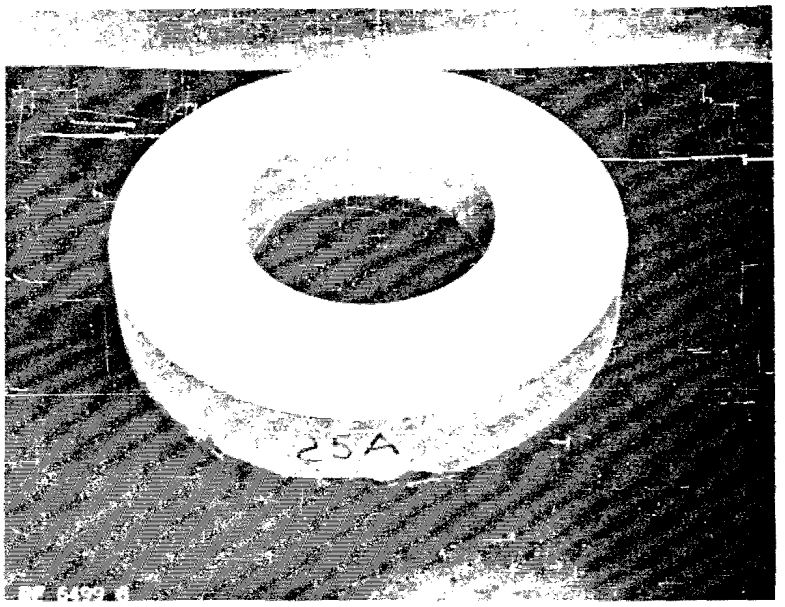
RF 6499-2

Fig. 261 20A.1 draw ring.



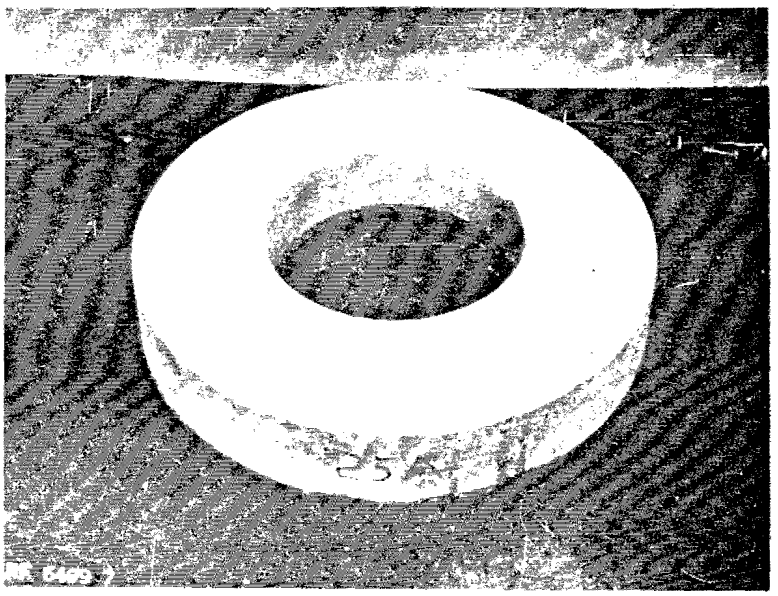
RF 6499-8

Fig. 262 25A.1 draw die punches.



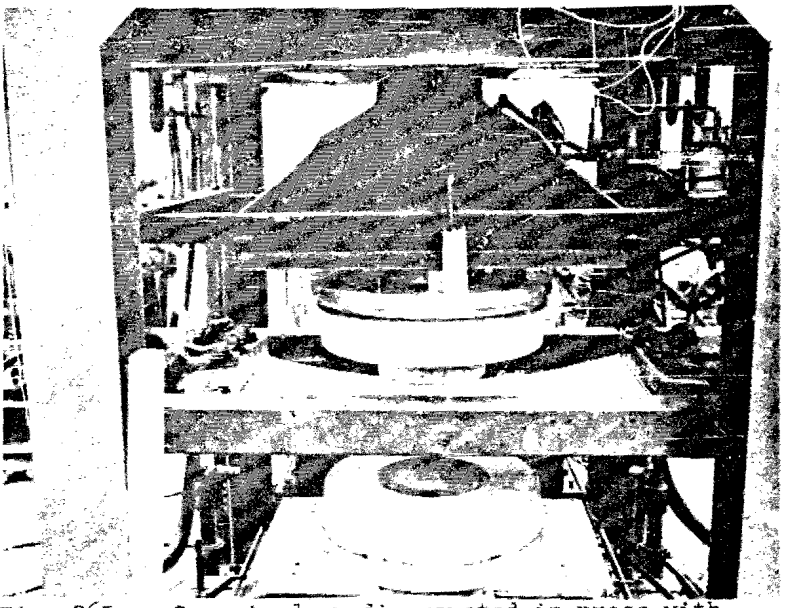
RF 6499-6

Fig. 263 25A.1 draw ring.



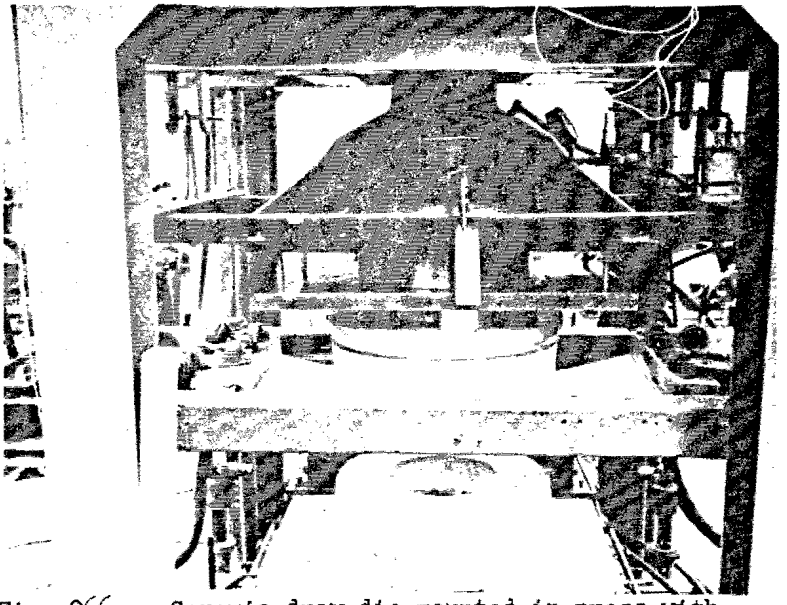
RF 6499-7

Fig. 264 25A.1 draw ring.



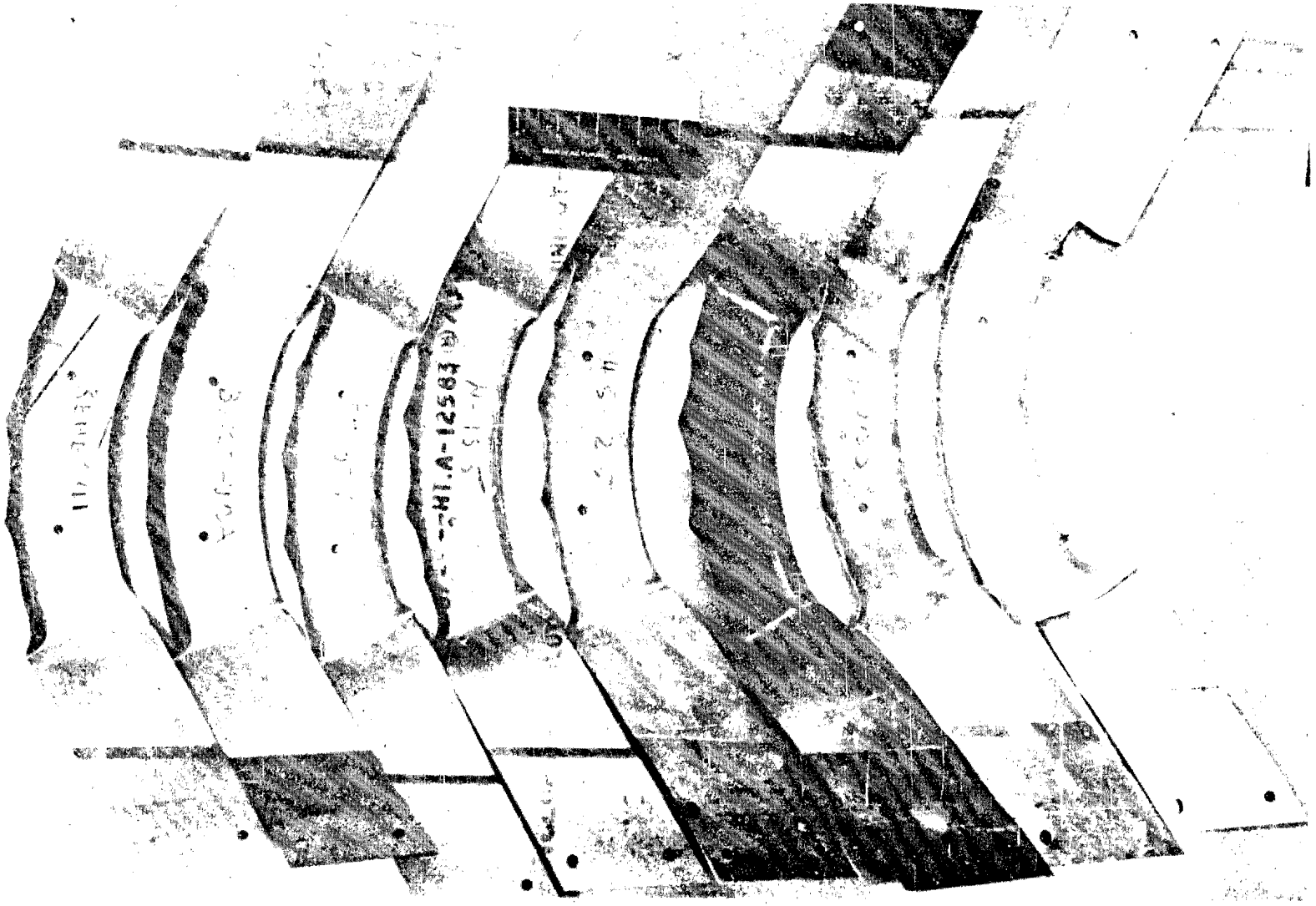
RF 6728-12

Fig. 265 Ceramic draw die mounted in press with draw ring retracted showing punch (20A.1 shown).



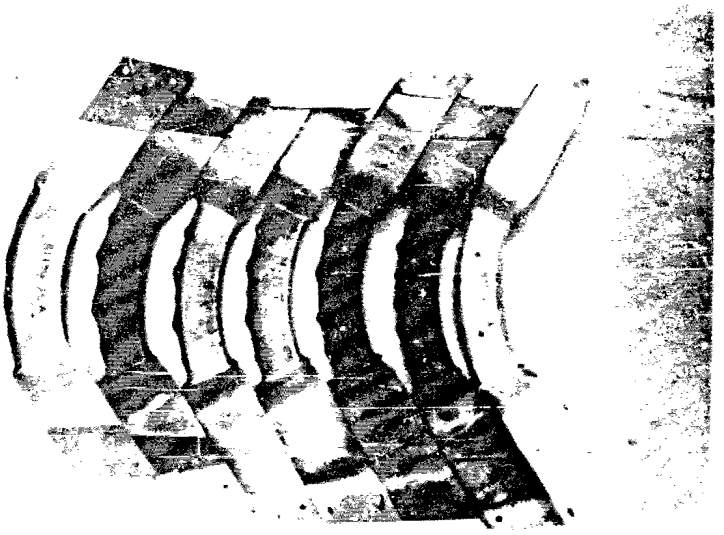
RF 6728-13

Fig. 266 Ceramic draw die mounted in press with draw ring extended (20A.1 shown).



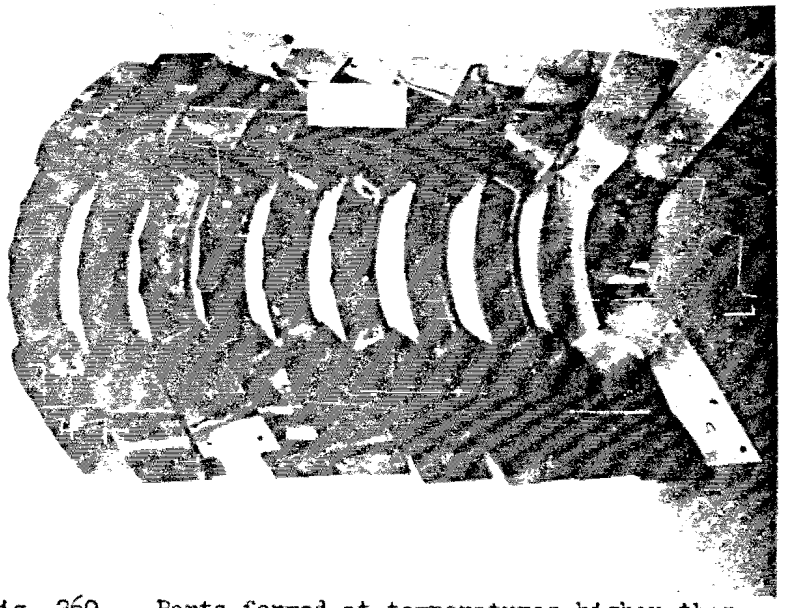
RF 6697-11

Fig. 267 Parts formed at room temperature of high strength matals. Left to right are Rene' 41, B-120-VCA, PH15-7Mo, N-155, HS-25, VascoJet 1000, 420 SS, and HM-21-A.



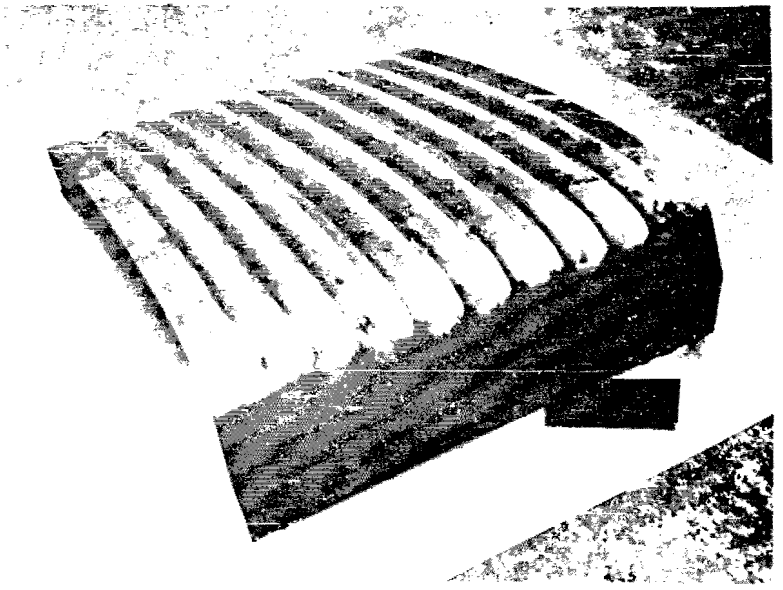
RF 6697-12

Fig. 268 Parts formed at vendor recommended forming temperature. Left to right are B-120-VCA, Rene' 41, PH15-7Mo, N-155, VascoJet 1000, HS-25, and HM-21-A. Refer to Table 42.



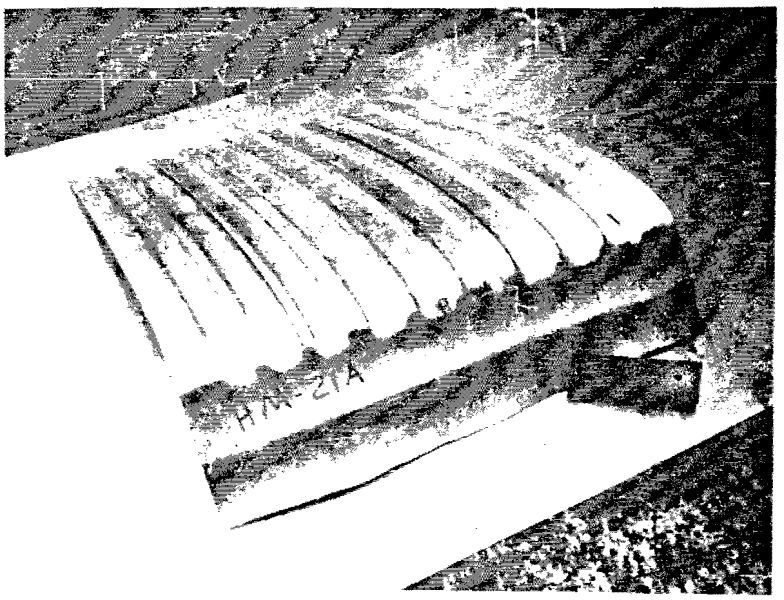
RF 6697-1

Fig. 269 Parts formed at temperatures higher than those recommended by vendors. Left to right are PH15-7Mo, VascoJet 1000, Rene' 41, N-155, B-120-VCA (formed at 1900 F) B-120-VCA (formed at 1700 F), HS-25, 420 SS, HM-21-A, and HM-21-A (overheated). Refer to Table 42.



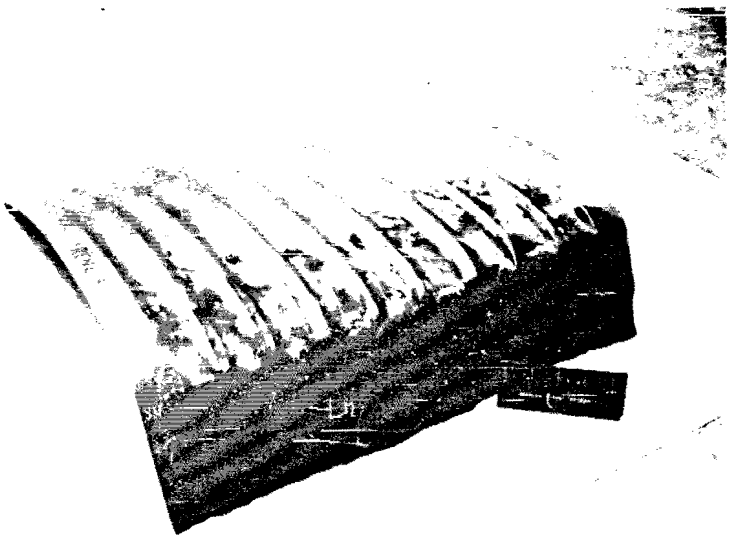
RF 6727-6

Fig. 270 AISI 420 hydroformed part. Formed at 1750 F.



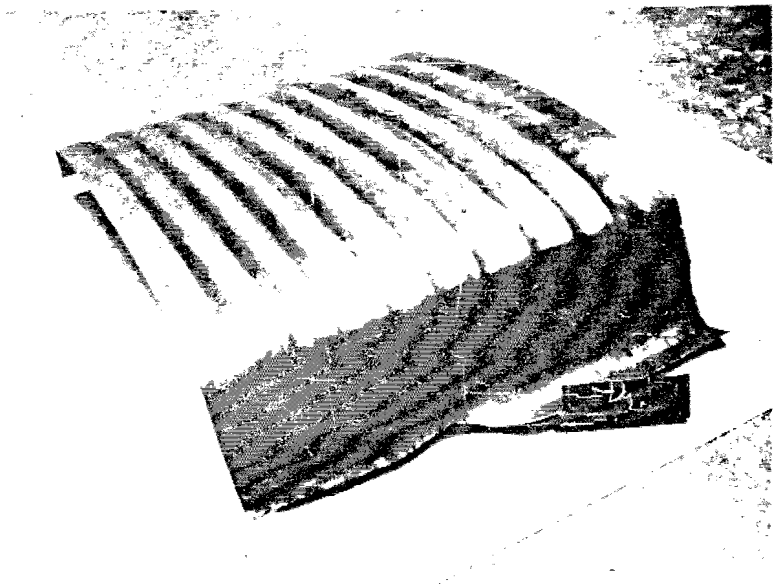
RF 6728-6

Fig. 271 HM-21-A hydroformed part. Formed at 650 F.



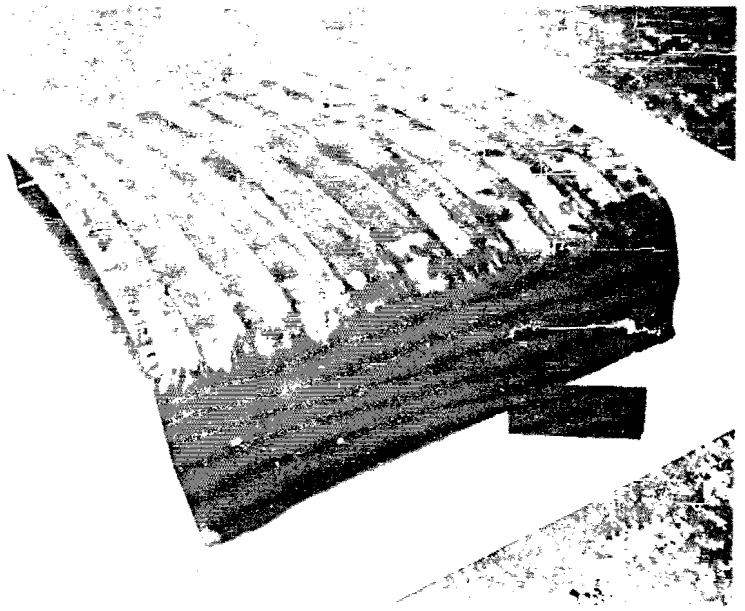
RF 6728-5

Fig. 272 Rene' 41 hydroformed part. Formed at 1800 F.



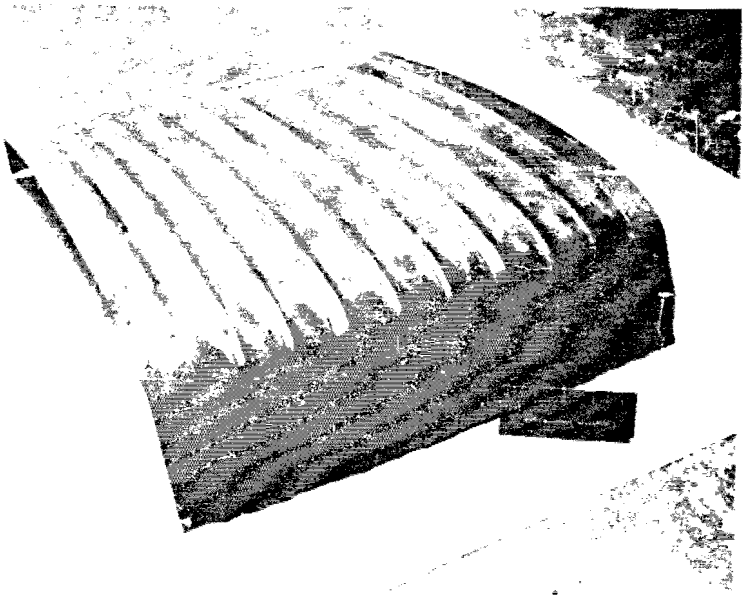
RF 6727-9

Fig. 273 B-120-VCA hydroformed part. Formed at 1700 F.



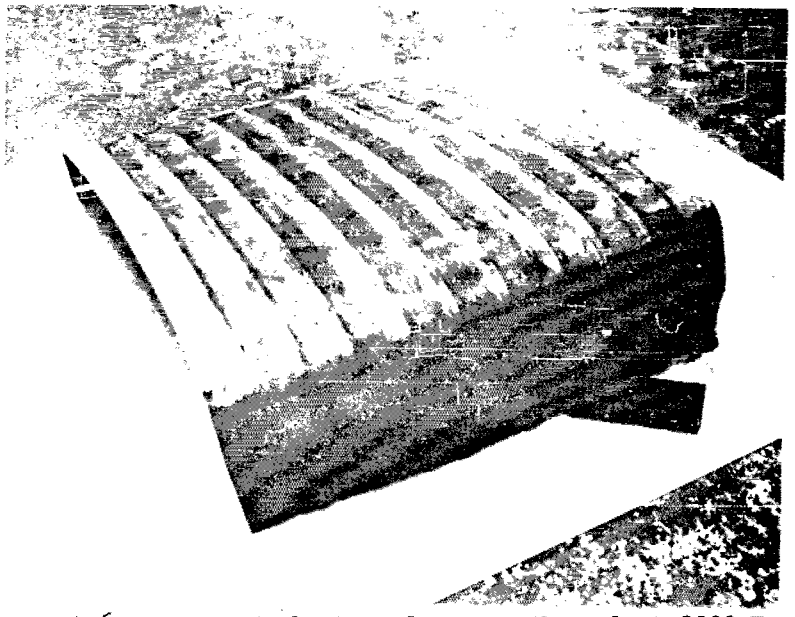
RF 6727-13

Fig. 274 HS-25 hydroformed part. Formed at 2000 F.



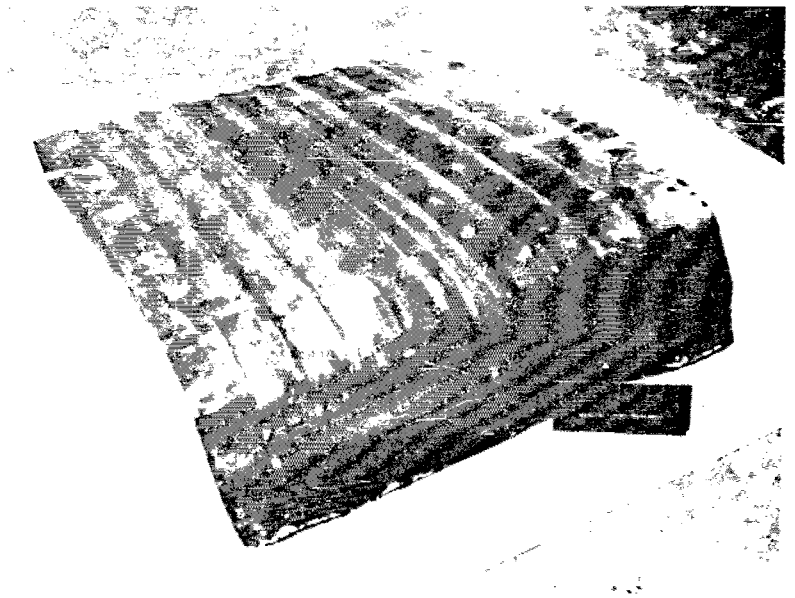
RF 6728-2

Fig. 275 VascoJet 1000 hydroformed part. Formed at 1700 F.



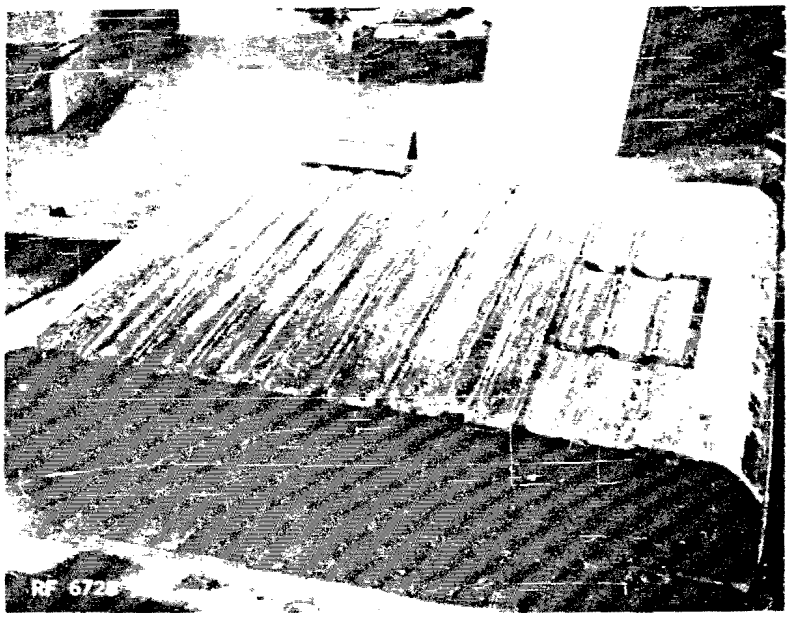
RF 6727-3

Fig. 276 N-155 hydroformed part. Formed at 2000 F



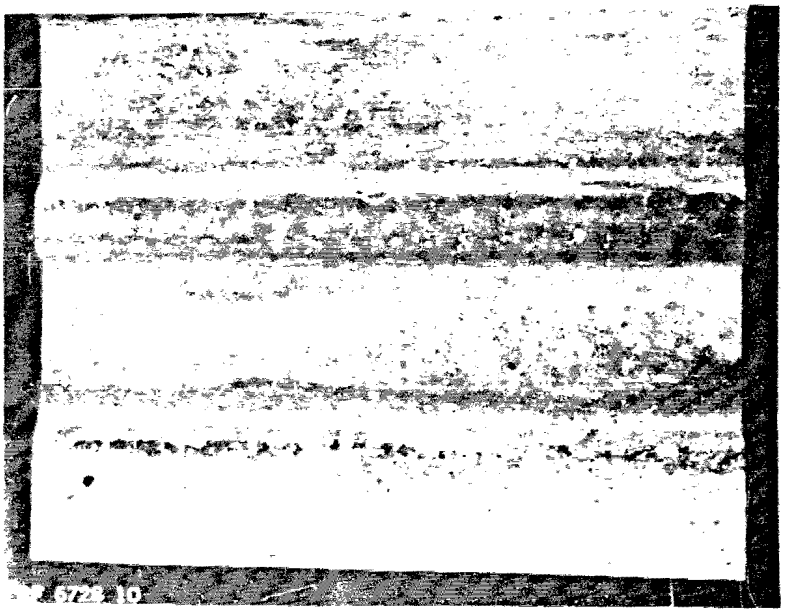
RF 6728-3

Fig. 277 PH15-7Mo hydroformed part. Formed at 1650 F.



RF 6728-7

Fig. 278 20A.1 hydroform block showing damaged area after formability trials, (eight parts).



RF 6728-10

Fig. 279 Close-up view of damaged area of 20A.1 block.

EXHIBIT 7

"STATE OF THE ART" SURVEY
(as of December 1960)

INTRODUCTION

At the time organization of this final report was begun, it occurred to the Contractor that another "state of the art" survey should be made. Considerable ceramic tooling development is known to have progressed at other companies since the original survey reported in Phase I. It has been approximately two and one-half years since this original survey.

PROCEDURE AND RESULTS

The recent survey was conducted solely by letter, a copy of which is presented as Exhibit 7A. A list of recipients and the results are tabulated in Table 1, Page 443. In some instances the reply simply indicated that there was nothing new to report; that is, nothing that the Contractor was not already aware of. In the following discussions by company, the Contractor, in some instances, found it necessary to report his general knowledge of developments without tangible back-up information.

Avco Manufacturing Corporation, Nashville, Tennessee

This company is known to have done some extensive development for brazing. A description of this tooling may be found in Reference 33 (see Page 475).

Boeing Airplane Company, Aero-Space Division, Seattle 24, Washington

Boeing provided the Contractor with a 46-page report, Reference 34, covering "Ceramics for Spacecraft" which included ceramic tooling developments. In their letter of reply they suggested which pages would be applicable to the survey. Figures 1 through 6, Pages 449 through 454, are applicable photographs and captions.

Convair, Fort Worth Texas

Convair has developed what they term a modified conception of the brazing approach. This concept employs ceramic platens in conjunction with stainless steel pressure diaphragms. They have been successful in brazing B-58 panels without welding them in an envelope. This is accomplished by utilizing a metal picture frame around the panel and flowing argon internally with a positive pressure smaller than that on the diaphragm. More details on this tooling may be found in Reference 33. Figures 7 through 11, Pages 455 through 459 further illustrate Convair's contribution to ceramic tooling development. (Reference, "Glasrock" materials have been reported as Code Numbers 25A.1 through 25E.1.)

EXHIBIT 7

Lockheed, Georgia Division, Marietta, Georgia

As a part of the B-70 Program, this Company developed the brazing concept illustrated by Figure 12, Page 460. In this figure, the operator is shown checking the relationship between the top of the envelope, which contains the panel to be brazed, and the braze box flange. When the similar top portion of the tool is positioned it rests on this flange to carry its weight and to maintain the proper clearance. Figures 13 through 17 are variations of this type tooling. Figure 18, Page 466 shows one of the large castings (at Glasrock Products, Incorporated, Atlanta, Georgia). Figure 19, Page 467 is B-70 tooling just before the B-70 contract cancellation, December 1959.

North American Aviation, Incorporated, Los Angeles, California

This Company, being the prime B-70 contractor, has done extensive ceramic tooling development. By the use of "Glasrock" foam block and cement they have developed electric blanket braze fixtures which permit all thermal treatments of PH15-7Mo to be performed consecutively without moving the panel. Reference 33 describes the process in narrative and with pictures.

Republic Aviation Corporation, Farmingdale, Long Island, New York

Figures 20 through 23, Pages 468 through 471 depict, in general, some of the tooling applications where Republic Aviation Corporation has made use of ceramic materials.

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
Aerojet - General Corporation 6352 N. Irwindale Avenue Azusa, California	X				
Aeronca Aircraft Company Middletown, Ohio	X				
Allison Division General Motors Corporation P.O. Box 894 Indianapolis 6, Indiana	X				
Avco Manufacturing Corporation Nashville Division Nashville 1, Tennessee	X				
Beech Aircraft Corporation Wichita 1, Kansas	X				
Bell Aircraft Corporation P.O. Box 1 Buffalo 5, New York	X				
Bell Aircraft Corporation P.O. Box 482 Fort Worth 1, Texas	X				
Bendix Products Division Bendix Aviation Corporation 401 Bendix Drive South Bend, Indiana	X				
Boeing Airplane Company P.O. Box 3707 Seattle 24, Washington					X

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
Boeing Airplane Company Wichita Division Wichita, Kansas	X				
Cessna Aircraft Company Wichita, Kansas				X	
Chance Vought Aircraft, Inc. P.O. Box 5907 Dallas, Texas	X				
USI Clearing Division of U.S. Industries, Inc. Aircraft - Missile Division 6160 South Boyle Avenue Los Angeles 58, California		X			
Convair - Division of General Dynamics Corporation San Diego 12, California	X				
Convair - Division of General Dynamics Corp. P.O. Box 1011 Pomona, California	X				
Convair - Division of General Dynamics Corp. Fort Worth, Texas					X
Curtis-Wright Corporation Wood-Ridge, New Jersey			X		
Curtis-Wright Corporation Propeller Division Fairfield Road Caldwell, New Jersey	X				

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
Douglas Aircraft Company, Inc. 300 Green Park Blvd. Santa Monica, California				X	
Douglas Aircraft Company, Inc. 3855 Lakewood Blvd. Long Beach 8, California	X				
Douglas Aircraft Company, Inc. El Segundo, California	X				
Douglas Aircraft Company, Inc. 2000 N. Memorial Drive Tulsa, Oklahoma	X				
Fairchild Aircraft Division Fairchild Engine & Airplane Corp. Hagerstown, Maryland	X				
General Electric Company Cincinnati 15, Ohio	X				
General Electric Corporation Aero - Science Lab. Philadelphia 24, Pa.			X		
Grumman Aircraft Engineering Corp. Bethpage, Long Island, New York	X				
Hughes Tool Company Aircraft Division Florence Avenue at Teale Street Culver City, California	X				

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

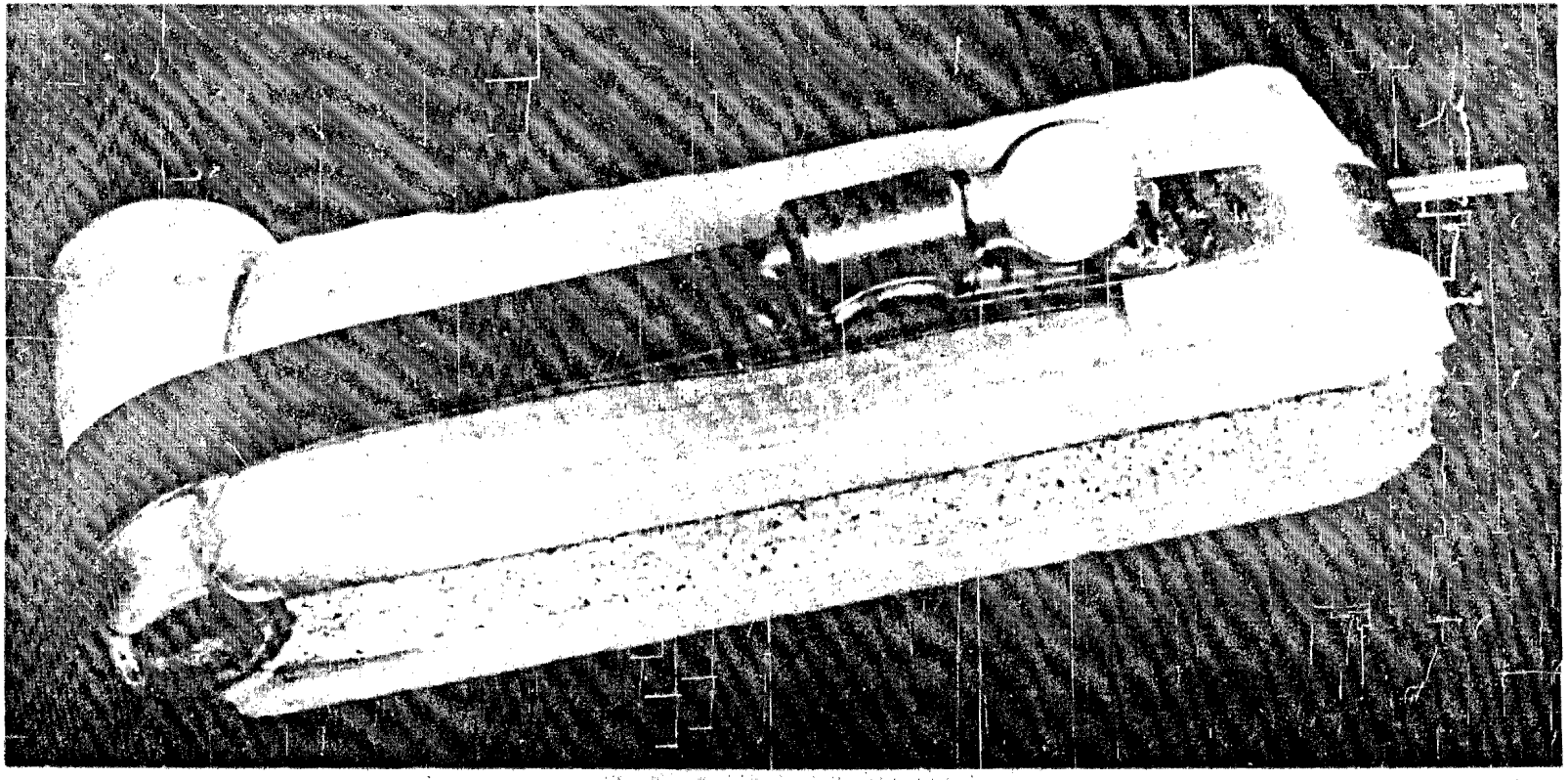
RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
I.T.E. Circuit Breaker Company 645 Erie Avenue Philadelphia, Penn.	X				
Kaiser Metal Products, Inc. Briston, Pennsylvania	X				
Lockheed Aircraft Corporation P.O. Box 511 Burbank, California			X		
Lockheed Aircraft Corporation Missiles and Space Division Sunnyvale, California				X	
Lockheed Aircraft Corporation (Contractor) Georgia Division Marietta, Georgia					X
Lycoming Division Avco Manufacturing Corporation Stratford, Connecticut	X				
The Martin Company Baltimore 3, Maryland				X	
Marquardt Aircraft Company 16555 Saticoy Street Van Nuys, California			X		
Marquardt Aircraft Company Box 670 Ogden, Utah	X				

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
McDonnell Aircraft Corporation P.O. Box 516 Lambert St. Louis Municipal Airport St. Louis 3, Missouri	X				
North American Aviation, Inc. International Airport Los Angeles 45, California	X				
North American Aviation, Inc. Columbus Division 4300 E. Fifth Avenue Columbus 16, Ohio				X	
Northrop Corporation 1001 East Broadway Hawthorne, California	X				
Pratt & Whitney Aircraft Division United Aircraft Corp. United, Florida	X				
Radioplane Company 8000 Woodley Avenue Van Nuys, California			X		
Republic Aviation Corporation Farmingdale, Long Island, New York					X
Rocketdyne Division of North American Aviation, Inc. 6633 Conoga Avenue Aonoga Park, California			X		
Rocketdyne Division of North American Aviation, Inc. Neosho, Missouri			X		
Rohr Aircraft Corporation P.O. Box 878 Chula Vista, California				X	

RESULTS OF STATE OF THE ART SURVEY
EXHIBIT 7 TABLE 1

RECIPIENT OF "STATE OF THE ART" SURVEY LETTER	NO REPLY	PLANS TO ENTER FIELD	NOT ACTIVE IN CERAMIC TOOL DEV.	ACTIVE IN CERAMIC TOOLING DEV.	CONTRIBUTED APPLICABLE DATA
Rohr Aircraft Corporation P.O. Box 643 Riverside, California	X				
Ryan Aeronautical Company 2701 Harbor Drive San Diego 12, California	X				
Solar Aircraft Company San Diego 12, California	X				
Solar Aircraft Company 1900 Bell Avenue Des Moines, Iowa	X				
Temco Aircraft Corporation P.O. Box 6191 Dallas, Texas	X				
Temco Aircraft Corporation P.O. Box 397 Garland, Texas	X				
Thompson Products, Inc. 23555 Euclid Avenue Cleveland 17, Ohio	X				
Twin Coach Company Aircraft & Missile Division Buffalo 25, N. Y.		X			
Vertol Division Boeing Airplane Company Morton, Penn.				X	
Westinghouse Electric Corp. Air Arm Division P.O. Box 746 Baltimore 3, Md.	X				



BOEING - Seattle

Fig. 1

CERAMIC WELDING TRAILING SHIELD CLAMPED TO WELDING CUP

Inert gas flows through the porous ceramic (center) protecting the weldment from contamination. The porous ceramic is cut from a standard insulating firebrick then coated with a gas-tight sealing material.

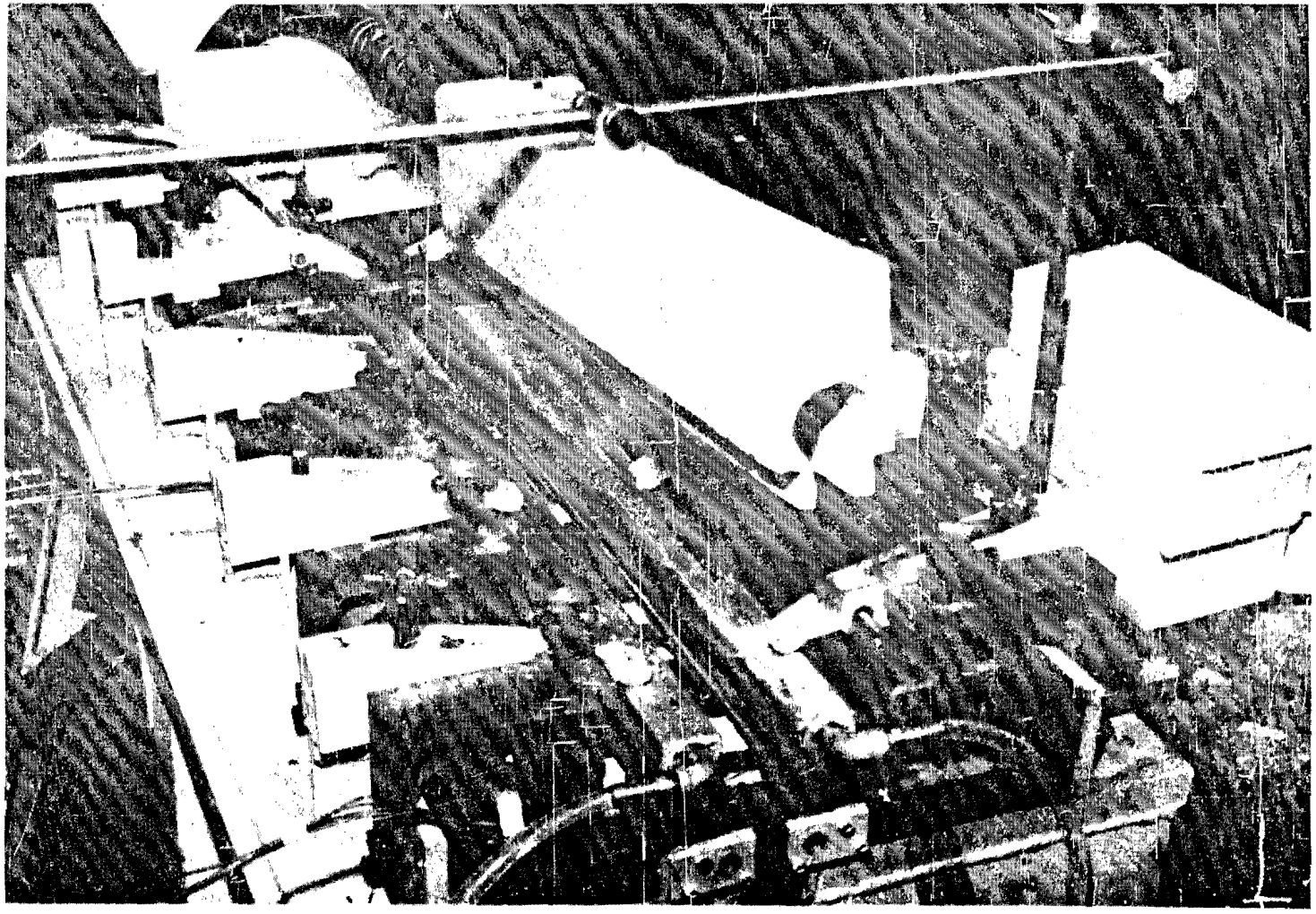


BOEING - Seattle

Fig. 2

CERAMIC BACK-UP BLOCK USED TO PROVIDE THERMAL
INSULATION IN TORCH BRAZING FIXTURE

The insulating block was machined from American Lava Company's "Lava A."



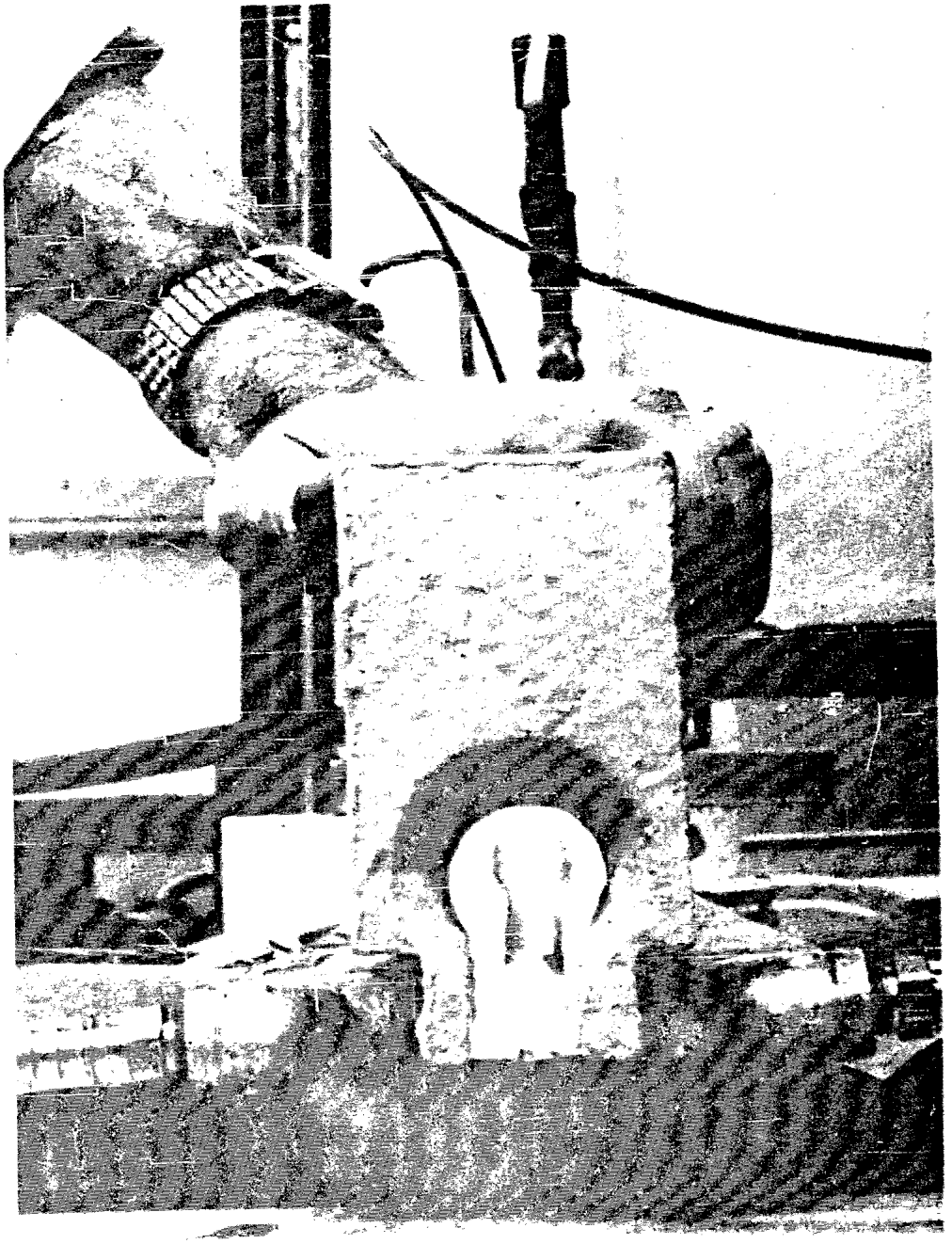
BOEING - Seattle

Fig. 3

PORTABLE POROUS CERAMIC RADIANT FURNACE
FOR STRESS RELIEVING WELDMENT

The burner was fabricated from permeable insulating firebrick with a gas-tight seal applied to the

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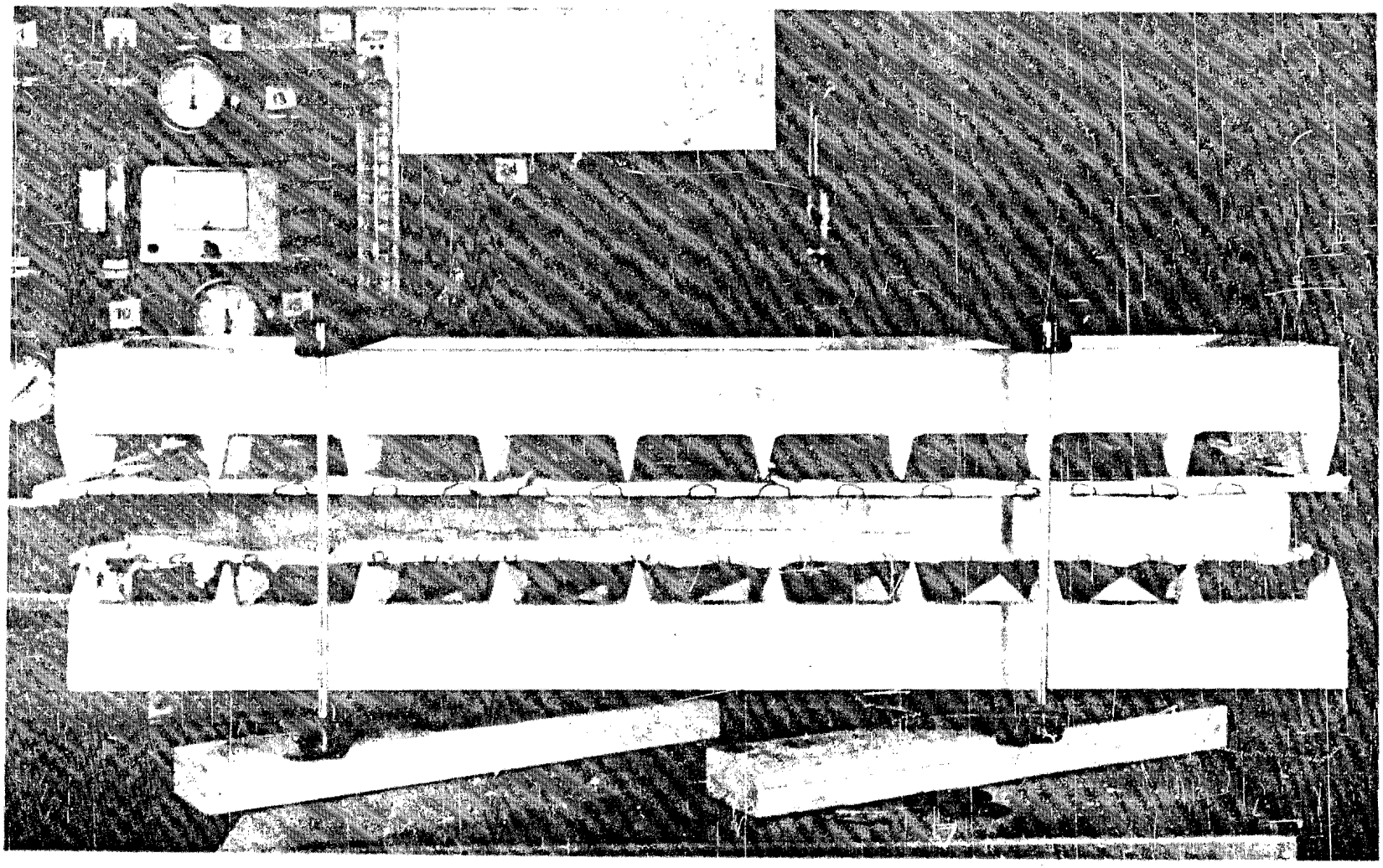


BOEING - Seattle

Fig. 4

PORTABLE POROUS FURNACE

Porous ceramic protects man's hand from 2200°F temperature in radiant furnace. This is the same furnace shown in Figure 3.



BOEING - Seattle

Fig. 5

CERAMIC FIXTURE FOR BRAZING HONEYCOMB PANELS

The ten knife edges lie in a true plane $\pm$ 0.001. The conventional outer retort is eliminated by the ceramic fixtures. These reference platens for furnace brazing of stainless steel honeycomb panels were cast from fused quartz slip produced by Glasrock Products, Inc. (Reference, Code No. 25B.1)

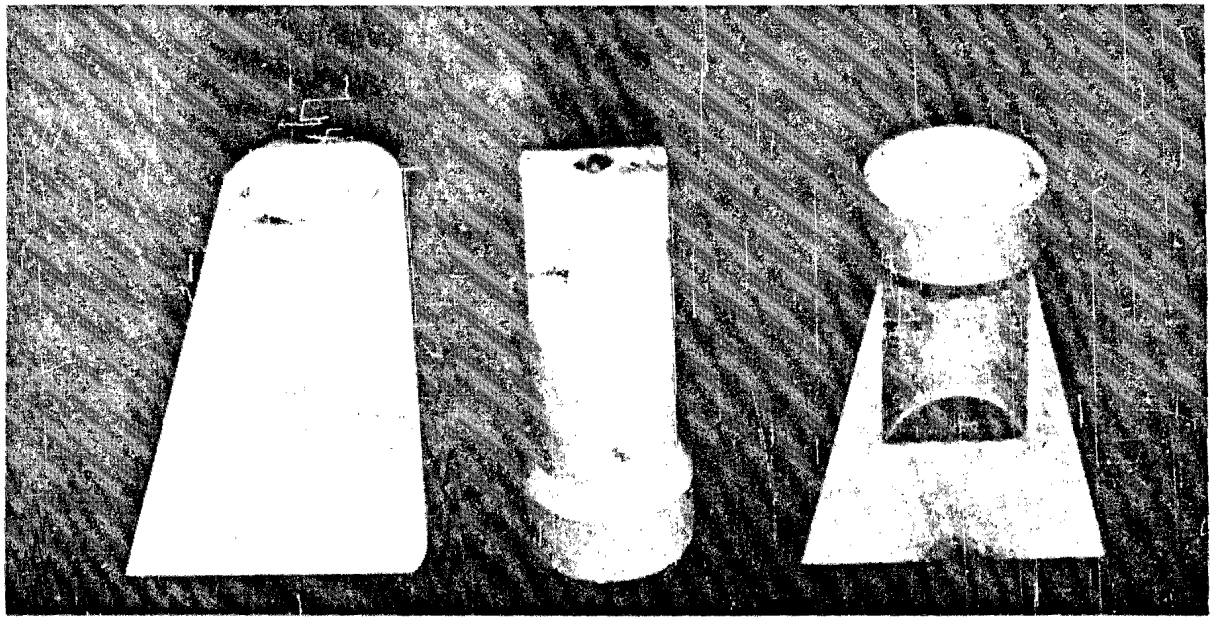
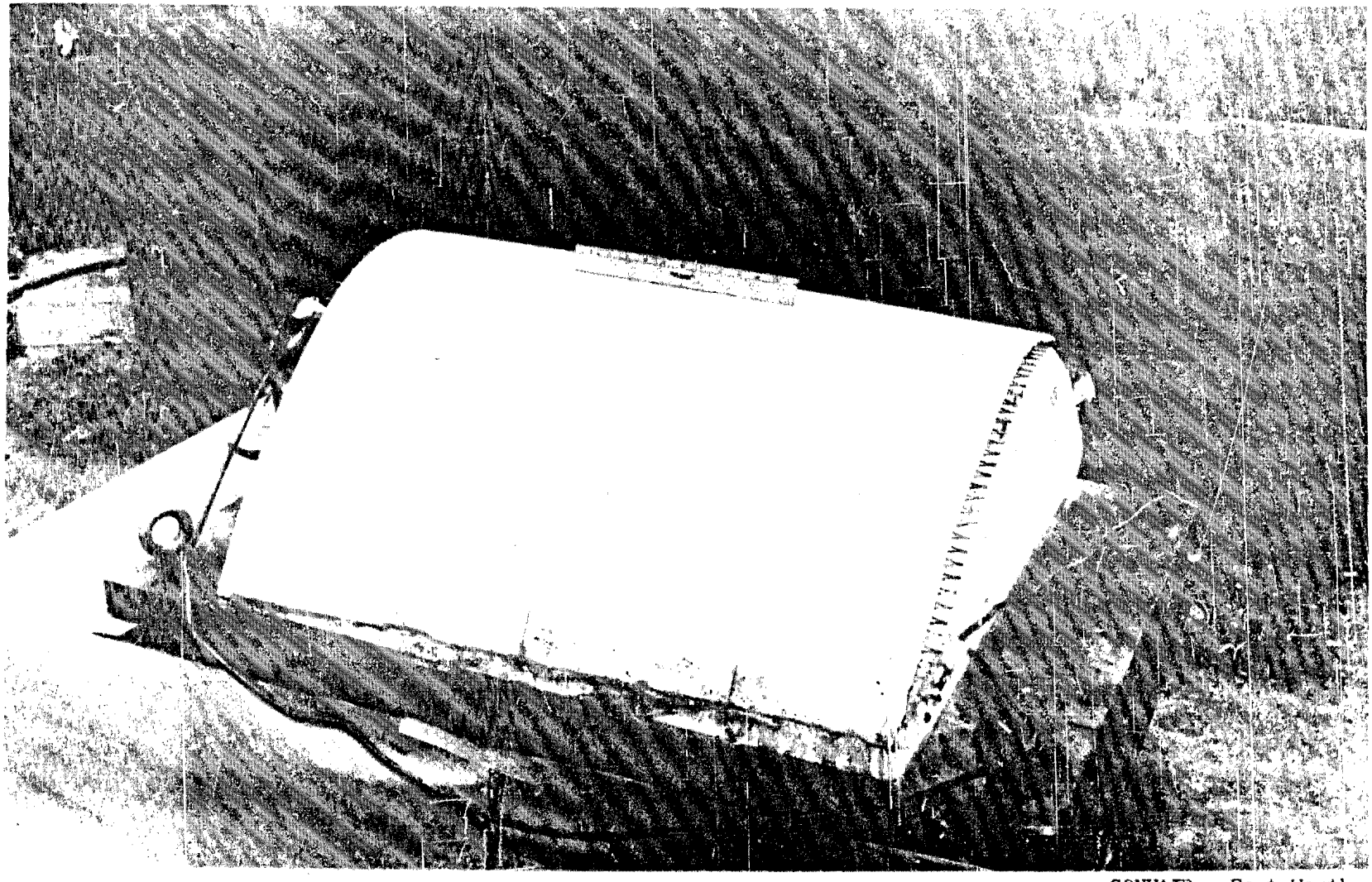


Fig. 6

BOEING - Seattle

FUSION WELDING CUPS

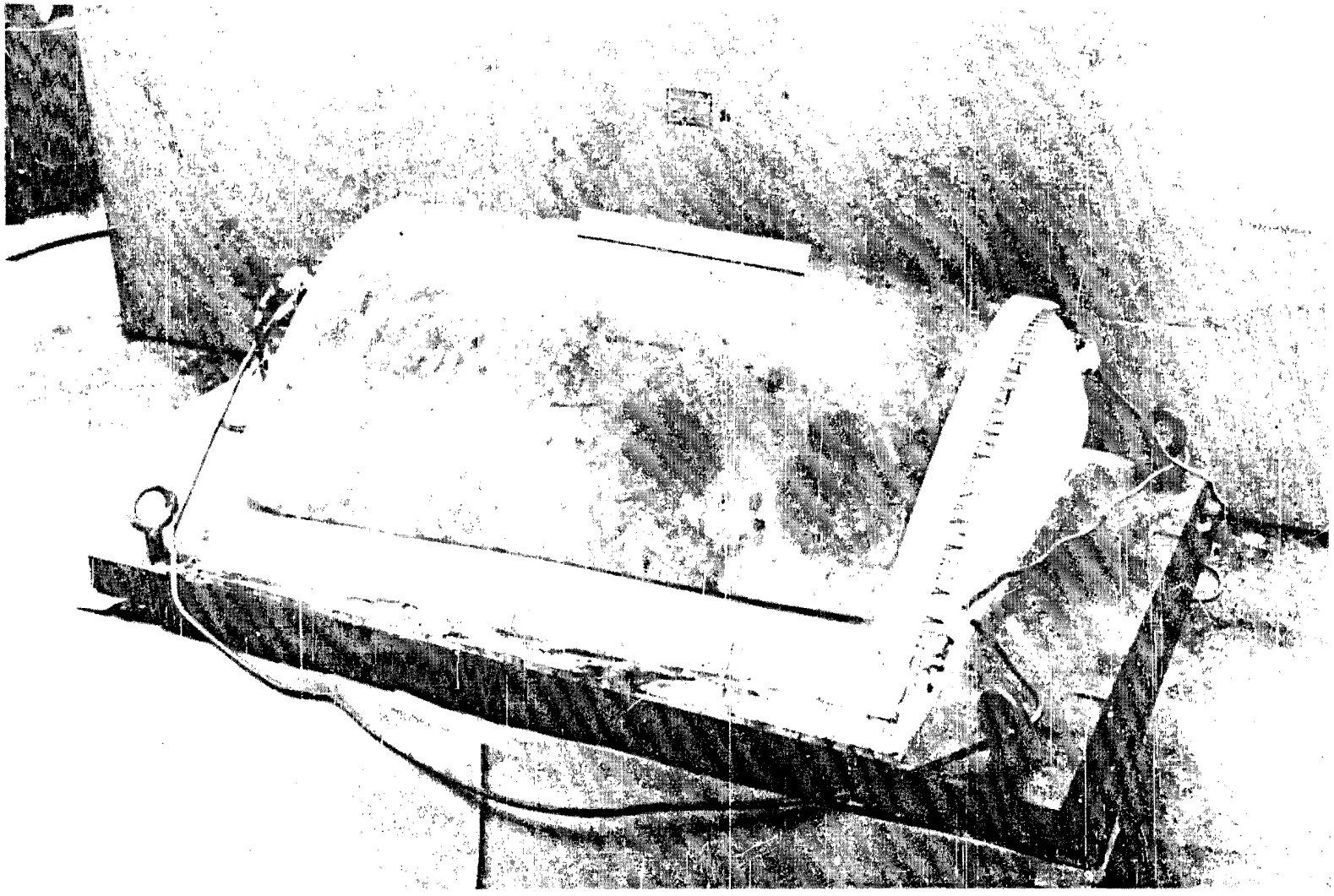
These cups were machined from American Lava Company's "Lava A."



CONVAIR - Fort Worth

Fig. 7

Ceramic electric heated stretcher form for stretching .060 inch thickness titanium at 1100 F. "Glasrock" cast cement and foam block construction with heating elements and steel reinforcing plate attached. (Reference Codes 25D.1 and 25E.1)



CONVAIR - Fort Worth

Fig. 8

Ceramic electric heated stretcher form with .080 inch thickness titanium stretched and trimmed part. Forming temperature 1100 F. "Glasrock" cast cement and foam block construction with heating elements and steel reinforcing plate attached.

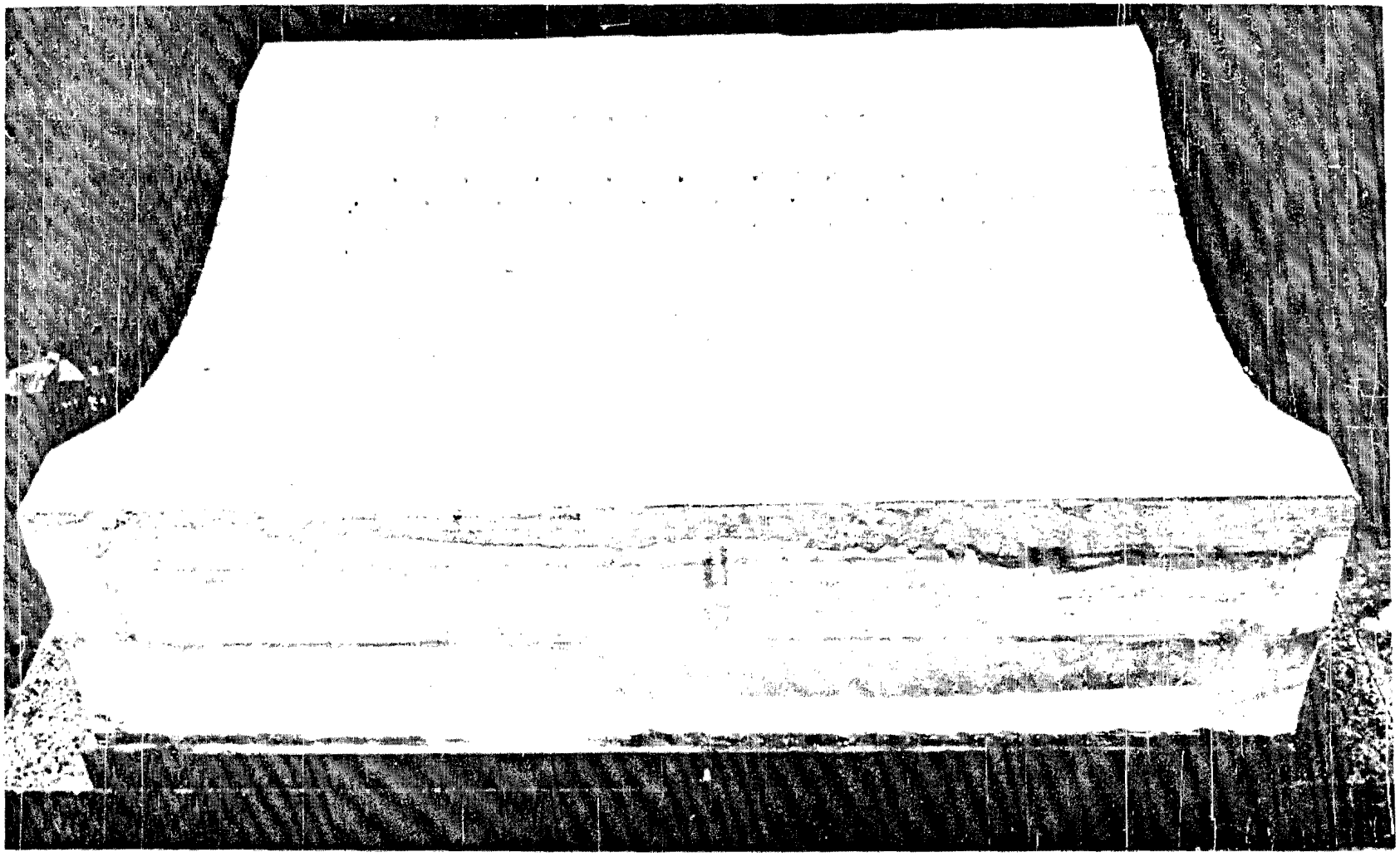
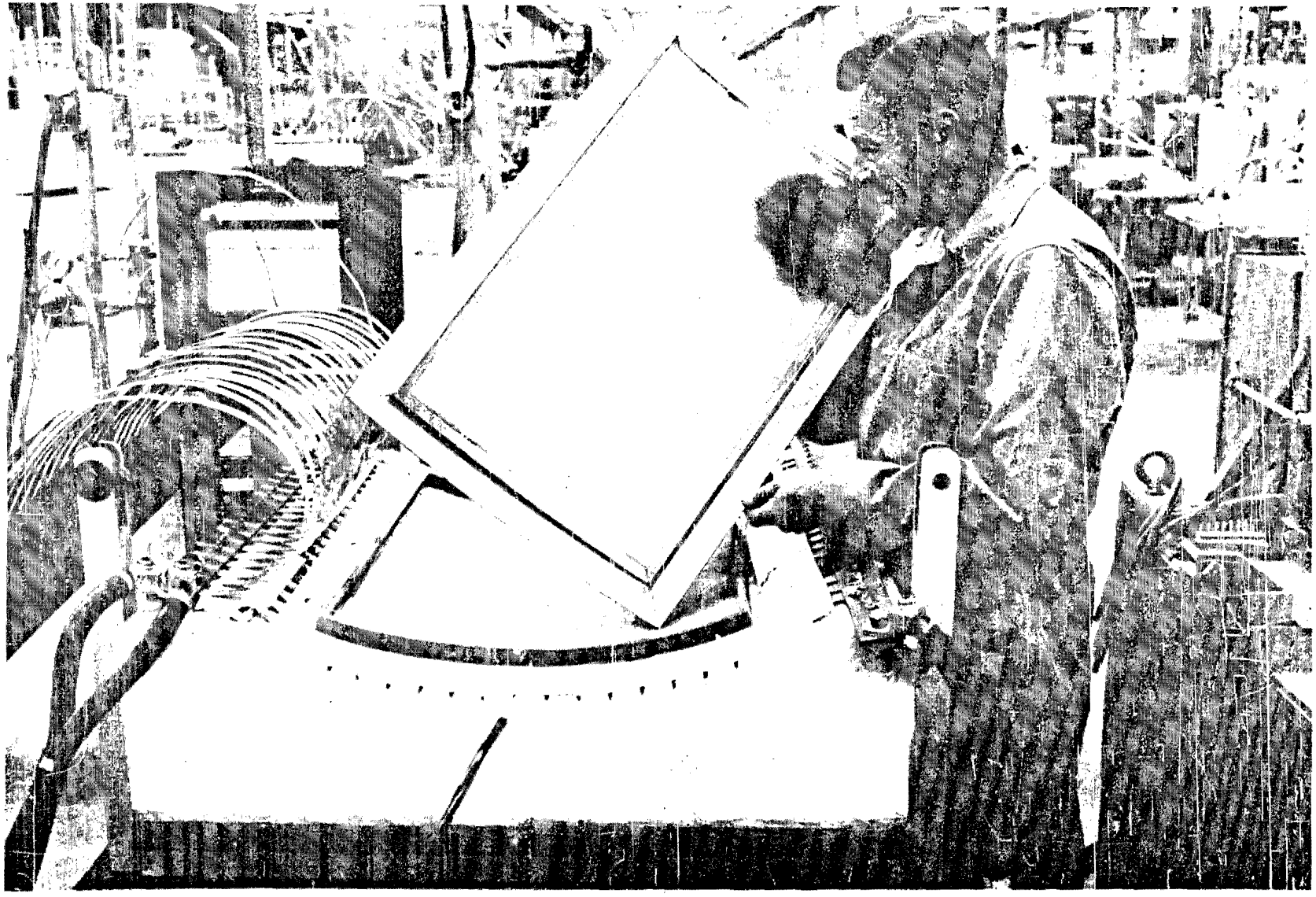


Fig. 9

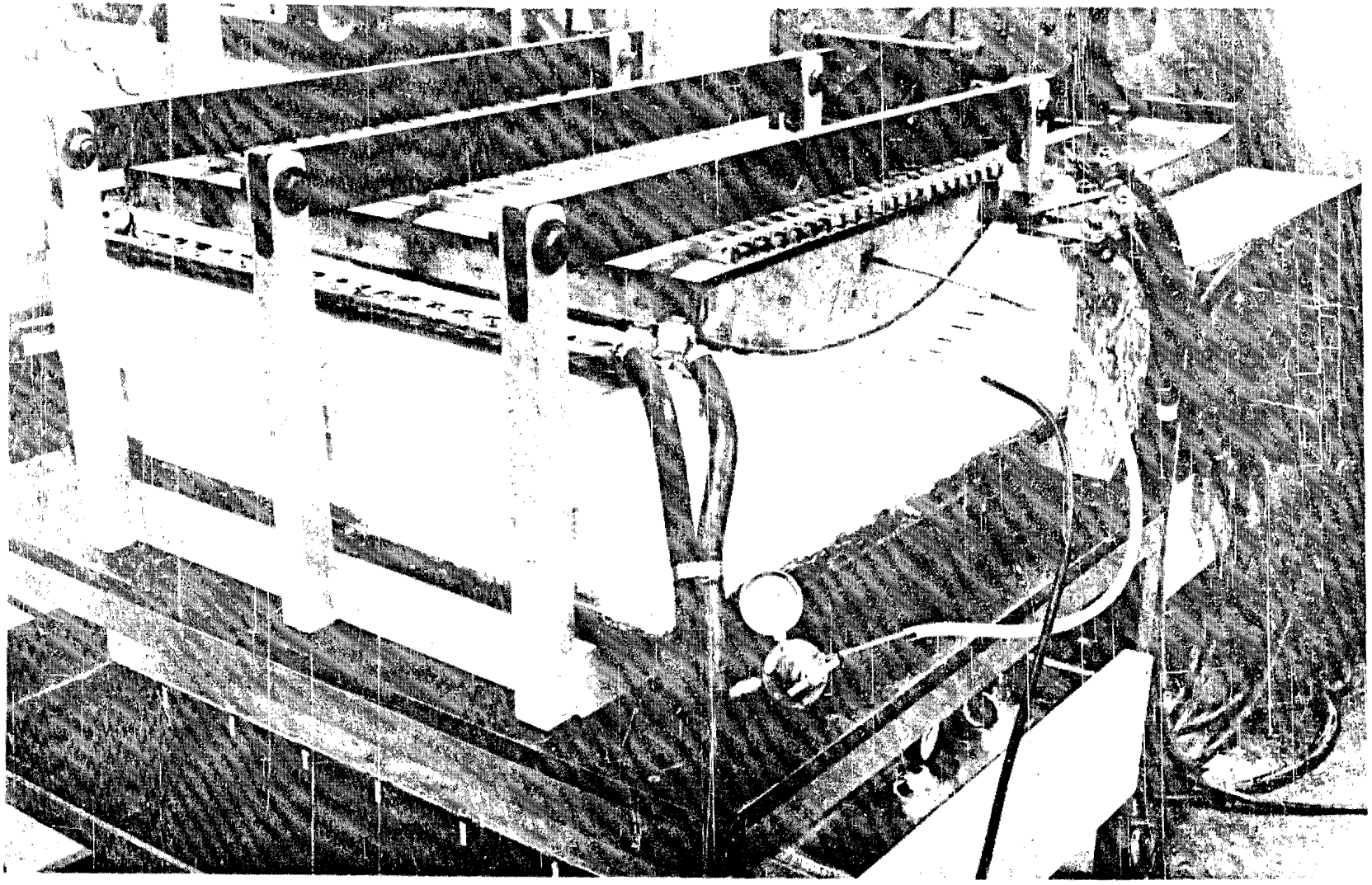
Ceramic electric brazing fixture for brazing compound contour B-58 stainless steel panels. "Glasrock" cast cement and foam block construction with plenum chamber attached and cooling slots.



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Fig. 10

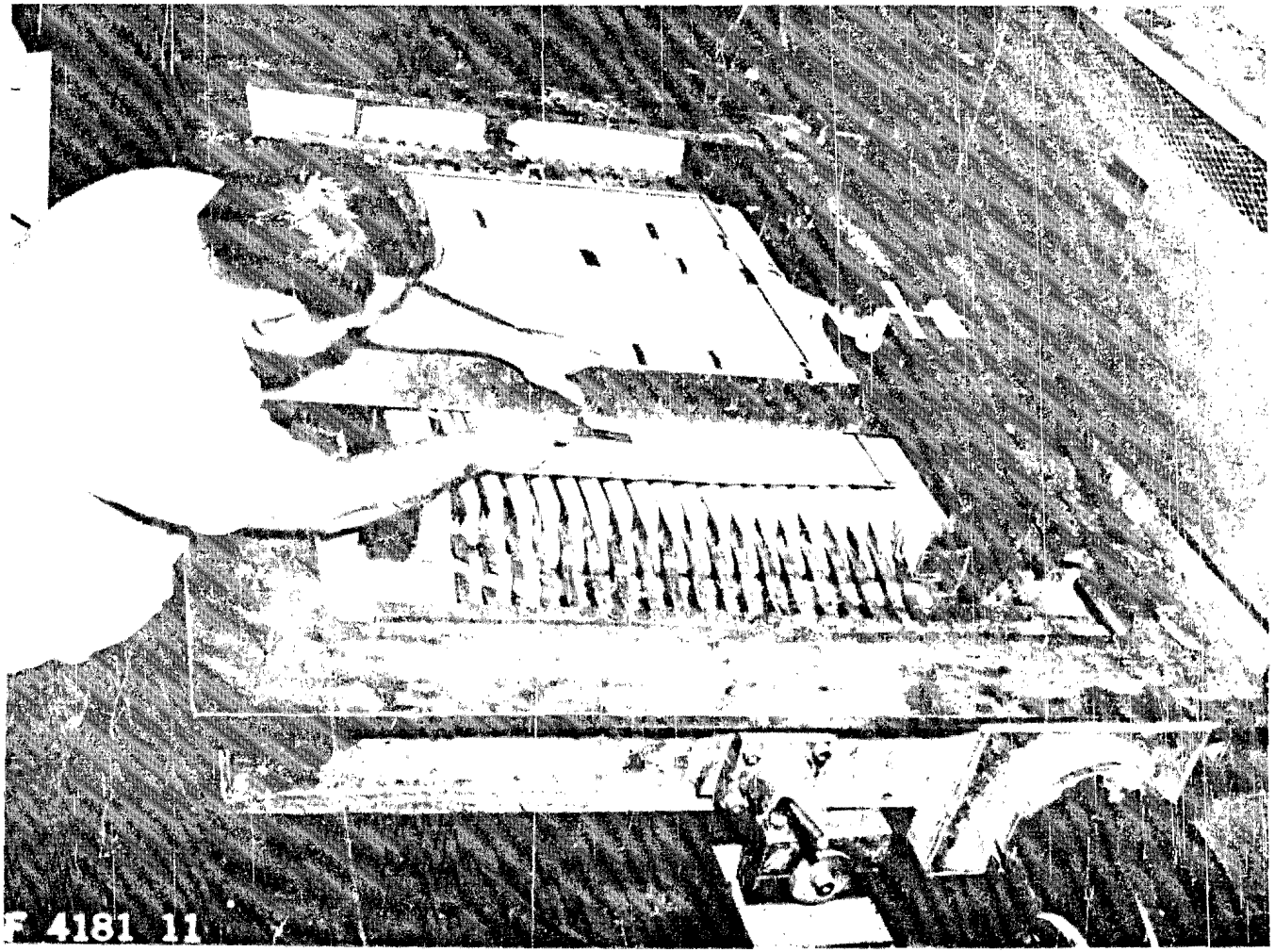
Compound contour stainless steel panel for B-58 brazed on "Glasrock" ceramic fixture with electric resistance strip heating elements both above and below panel assembly.



CONVAIR - Fort Worth

Fig. 11

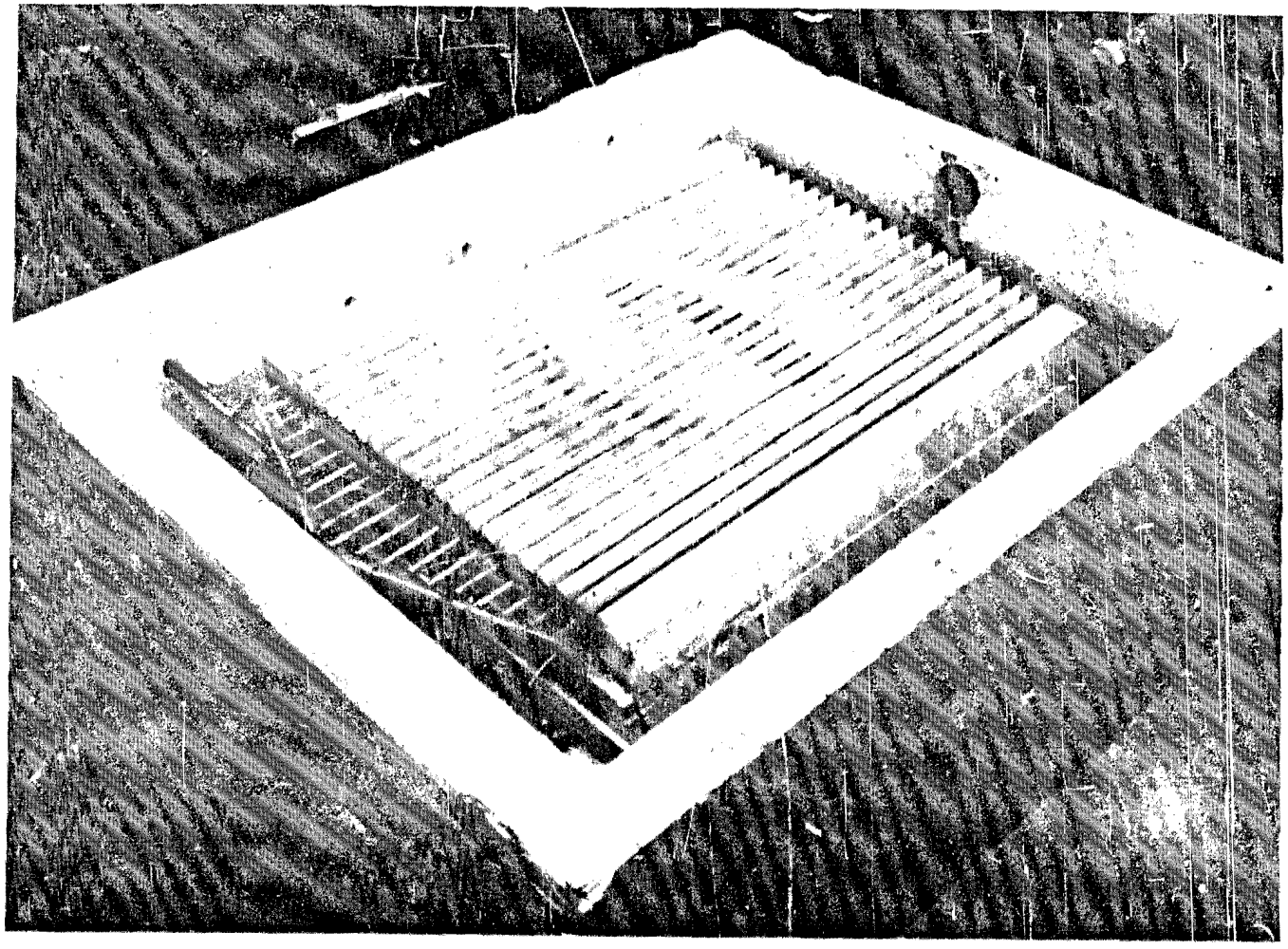
"Glasrock" ceramic electric brazing fixture for brazing compound contour B-58 stainless steel panels. Complete assembly ready for brazing is shown.



LOCKHEED - Marietta

Fig. 12

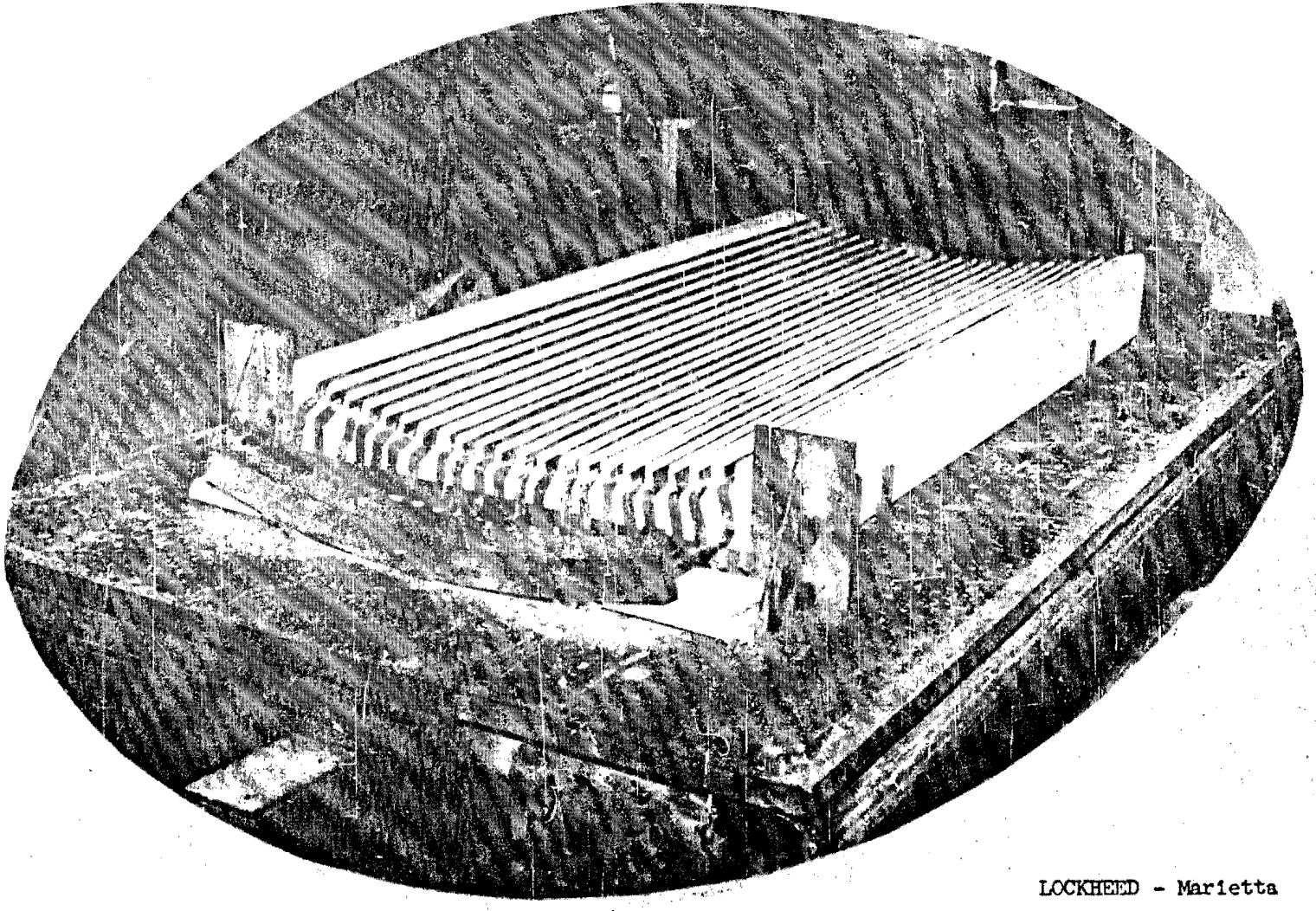
This photograph shows a braze box for brazing stainless steel honeycomb panels. Note that no ceramic liner is used. The relationship between the envelope assembly and the steel flange is being checked to assure the weight of the top half of the box will be carried with the proper clearance (Reference, Code 25A.1).



LOCKHEED - Marietta

Fig. 13

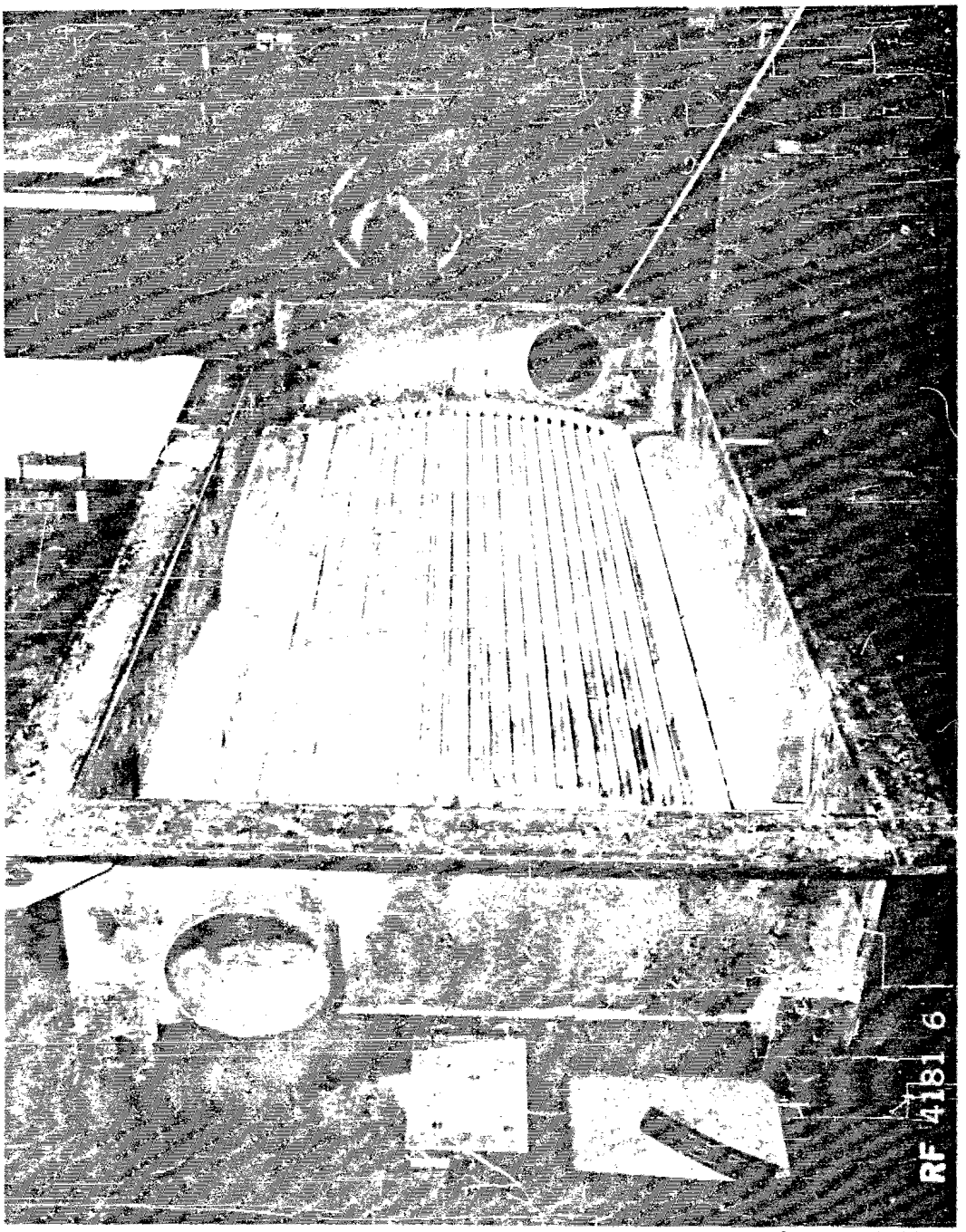
This photograph shows the lower half of a braze box which utilizes one-piece cast ceramic liner construction, and a cast one-piece, grooved, reference surface. The mating top half of this box is identical to the lower except for the offset between the reference surface and the steel flange; and the location of the coolant manifold, which is at the opposite end in the upper half. The liner is 50" x 64" x 14" overall height and has a wall thickness of 4" at top with a 10^{o} draft angle. The material has withstood repeated thermal shock as a result of injecting fog through the grooves and flashing it to steam for cooling. (Reference, Code 25A.1)



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Fig. 14

This photograph shows a female ceramic reference block as it appears with the top assembly removed. This cast ceramic braze tool is 4" thick, minimum; 30" wide and 60" long. (Reference, Code 25A.1)



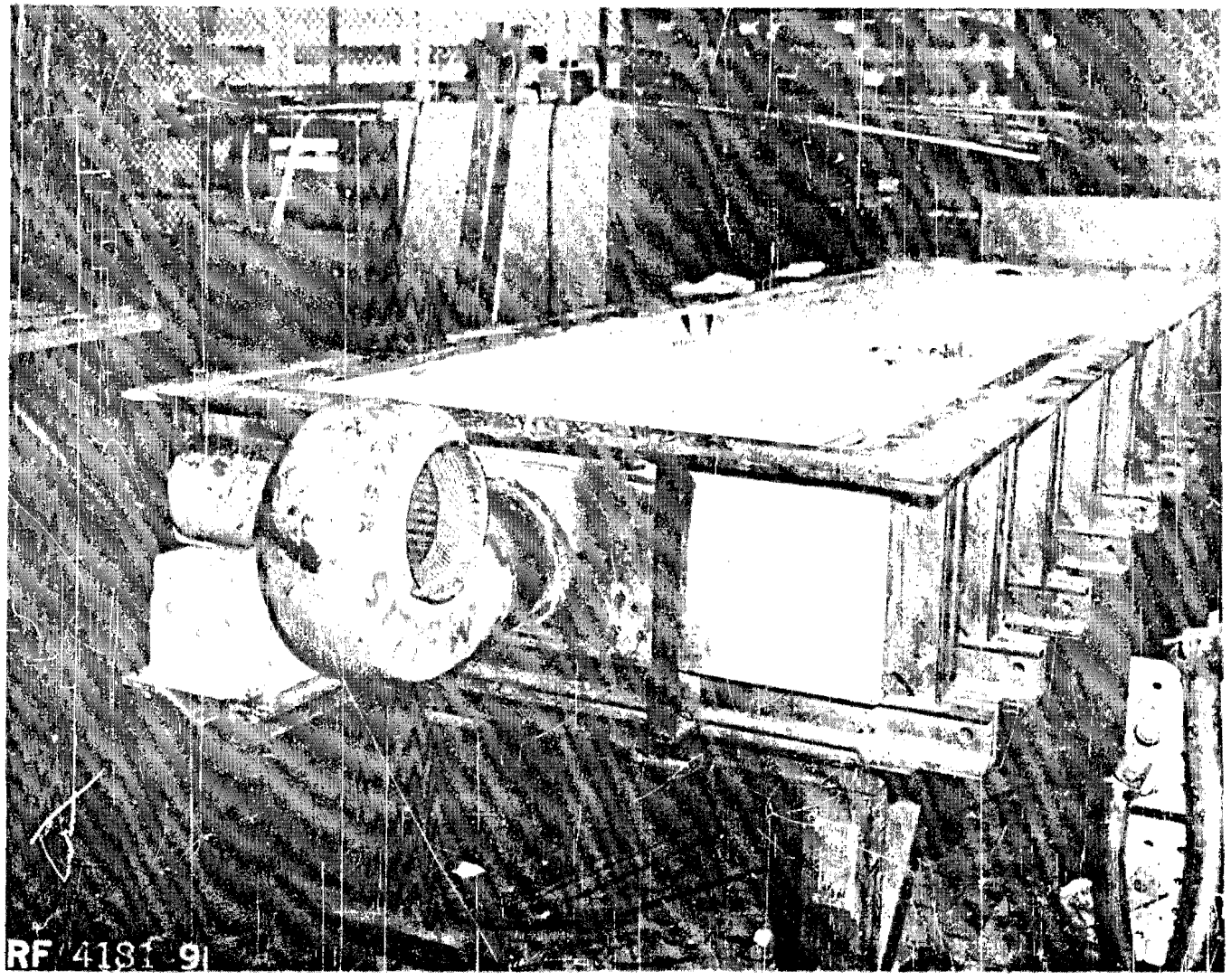
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Fig. 15

This photograph shows the top assembly which is a part of the tool in Figure 14. It is upside down on a work stand. Note that a castable ceramic has been used to "dog-in" the ceramic reference block. (Reference, Code 25A.1)

Fig. 16

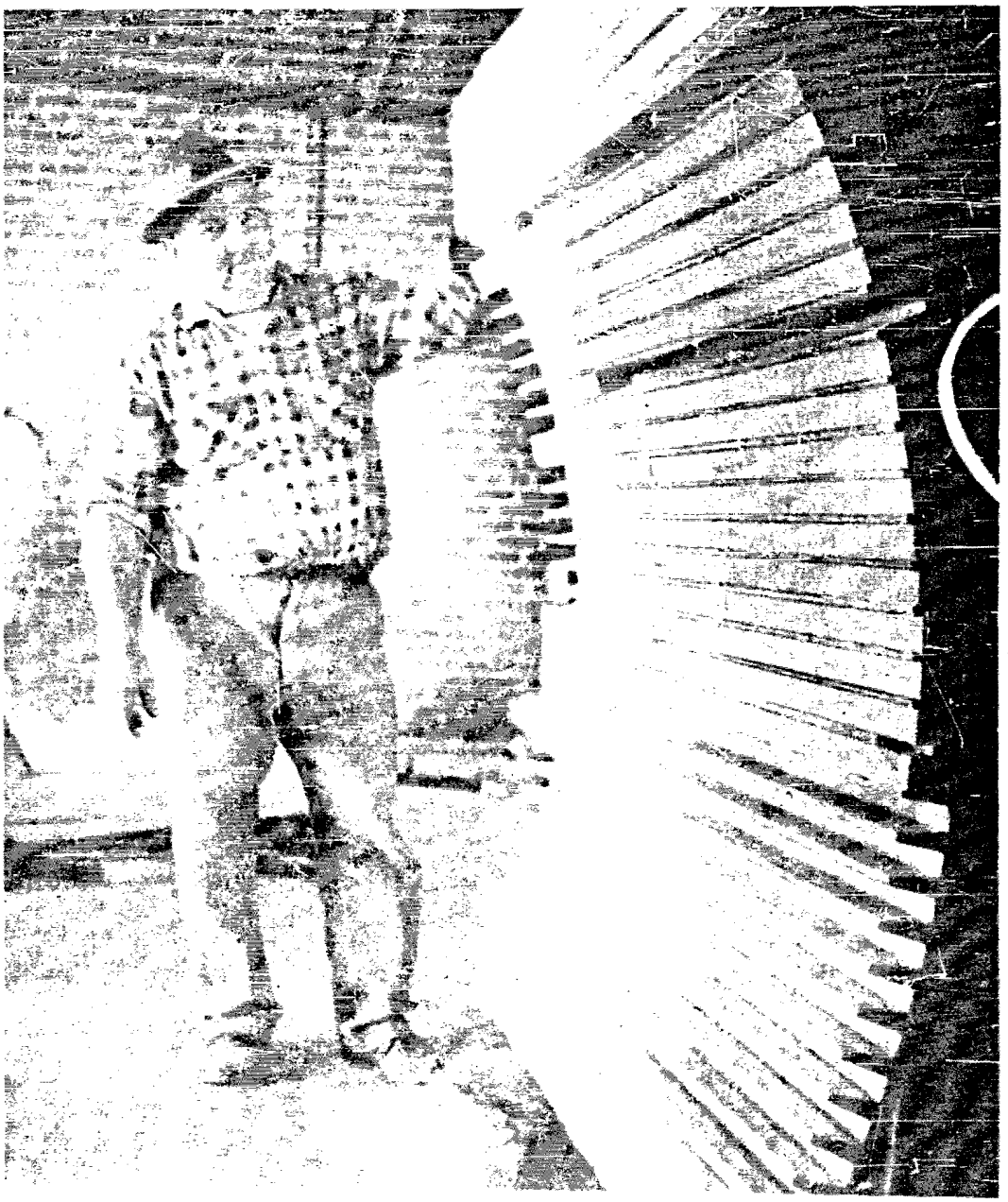
This photograph was taken through the opening provided for the blower. This is the assembly of components shown in Figures 14 and 15. The ribbon elements were operating at 1600 F.



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Fig. 17

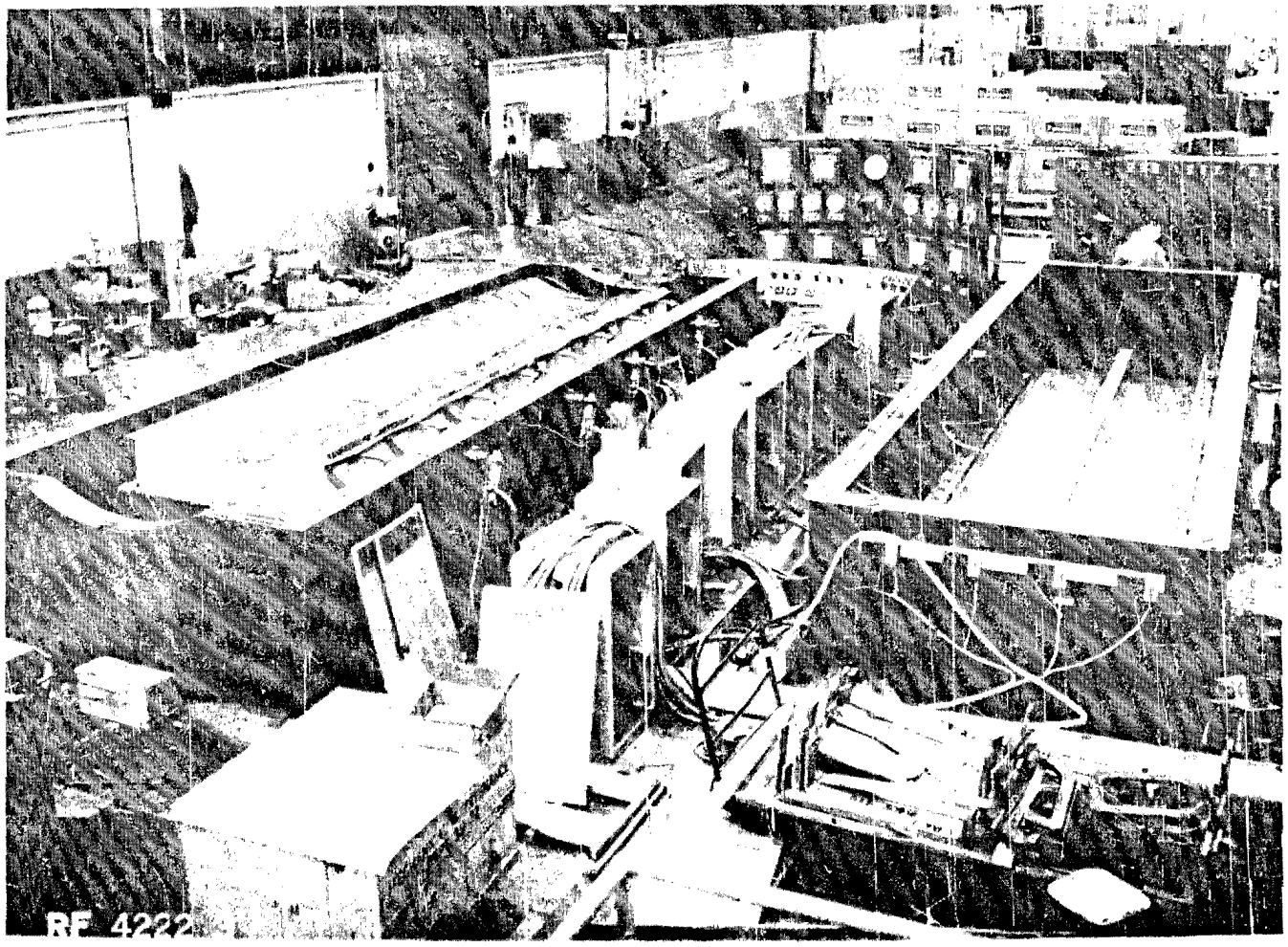
Ceramic braze fixture down for repairs to ribs. (reference, Code 25A.1)



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Fig. 18

This photograph shows one of the four segments of a ceramic reference block which was to be used for the lower tool surface for brazing a B-70 panel. The upper (male) sections have also been successfully cast, and techniques have been developed for making repairs to ribs. Plaster cores are used to form the grooves for the heating elements and for cooling. The block shown is 11" thick at the center and 18" thick at the edges. It is 64" wide by 60" long. (The reference surface is cast with a dimensional accuracy of .030" which is good enough since final sizing of the panel occurs in a subzero transformation fixture and during the aging of the PH15-7Mo panel.) This tooling is designed for cooling by steam generation. The plumbing is similar to that shown in Figure 13. (Reference, Codes 25D.1 and 25E.1)

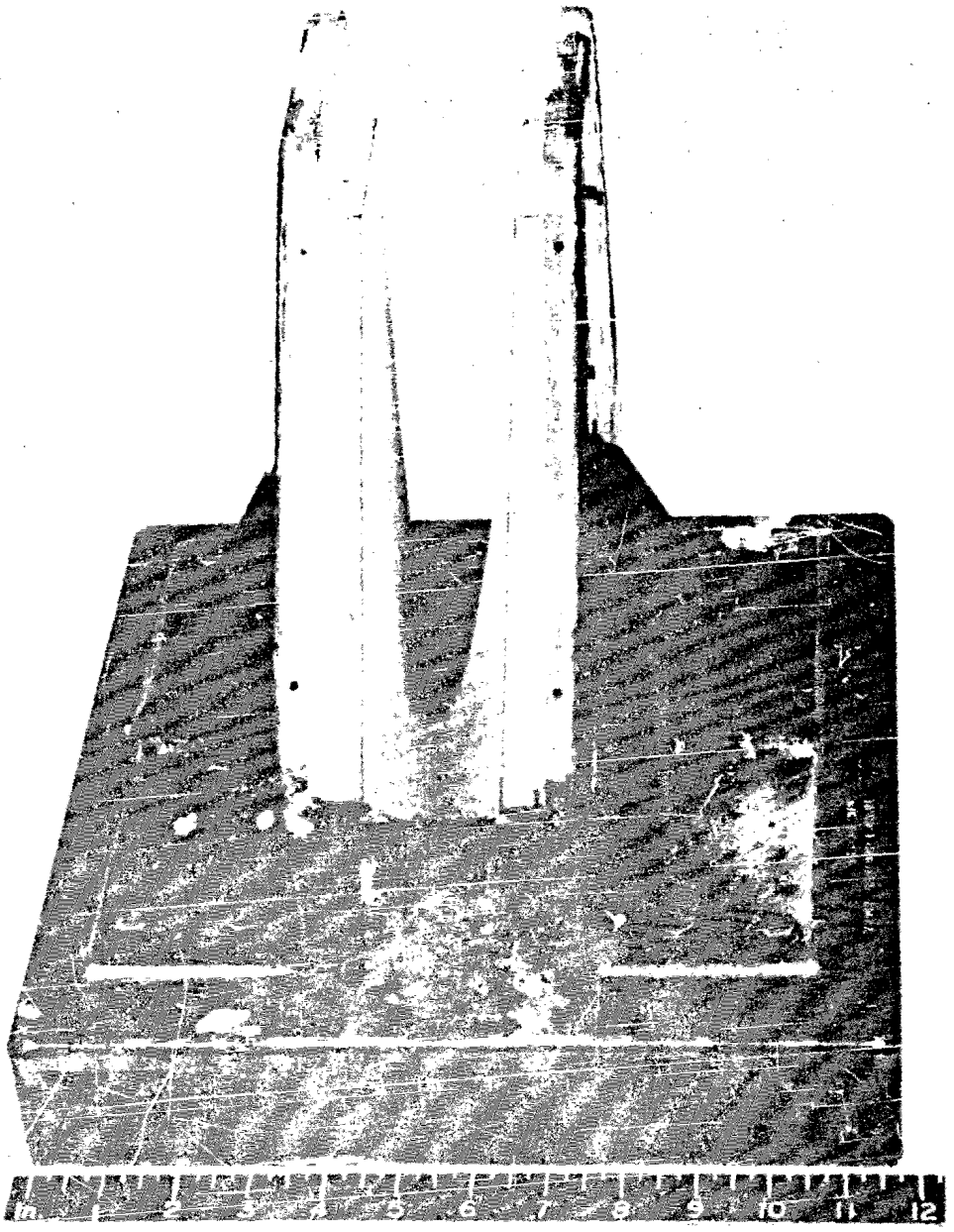


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Fig. 19

This photograph shows the B-70 hot forming and braze tooling being installed. The braze box for tooling of the type shown in Figure 18 is at the right. The continuous surface ceramic hot forming block is shown assembled in the hot forming box at left. This ceramic tool is 64" wide x 240" long and is made up of four 60" long sections in the same manner as for the braze tooling. Since vacuum pressure is applied to the surface of the block during the 1900 F forming of a skin or face sheet, the hot bearing load of the ceramic is considerable. (Reference, Codes 25D.1 and 25E.1)

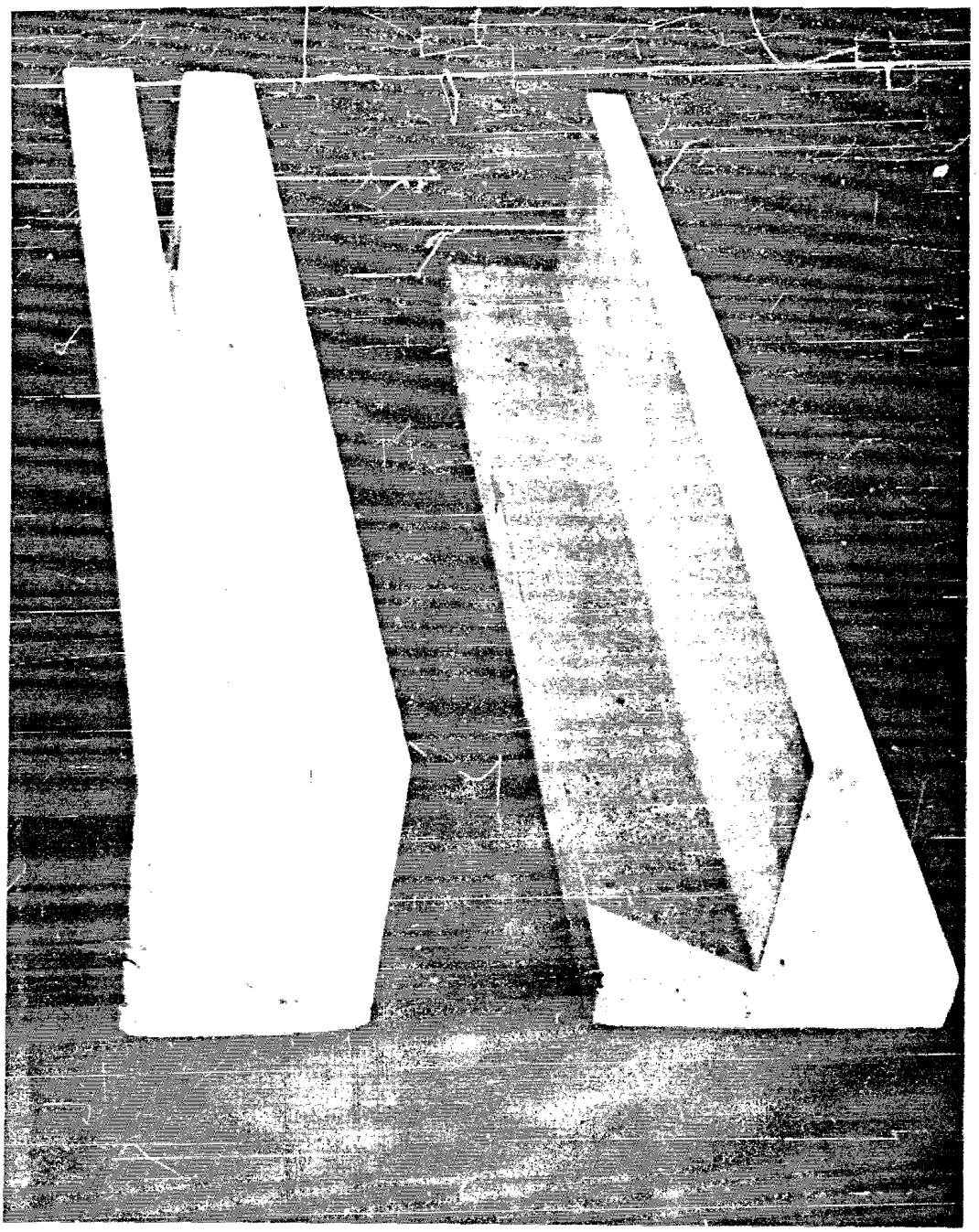
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Fig. 20

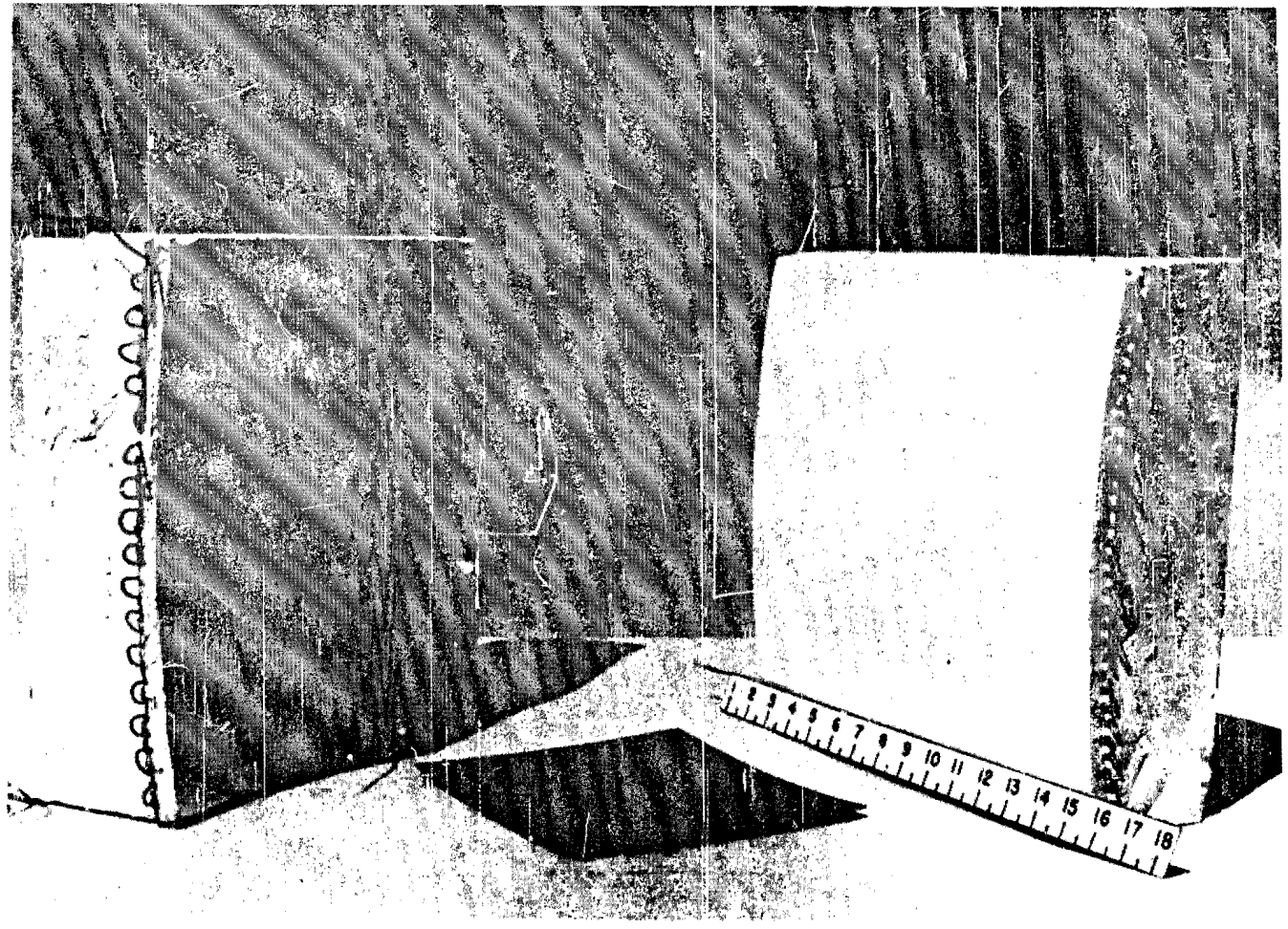
Brazing fixture used in production for aluminum skins. Ceramic castable is basically a phosphate bonded zircon of RAC formulation.



REPUBLIC - Farmingdale

Fig. 21

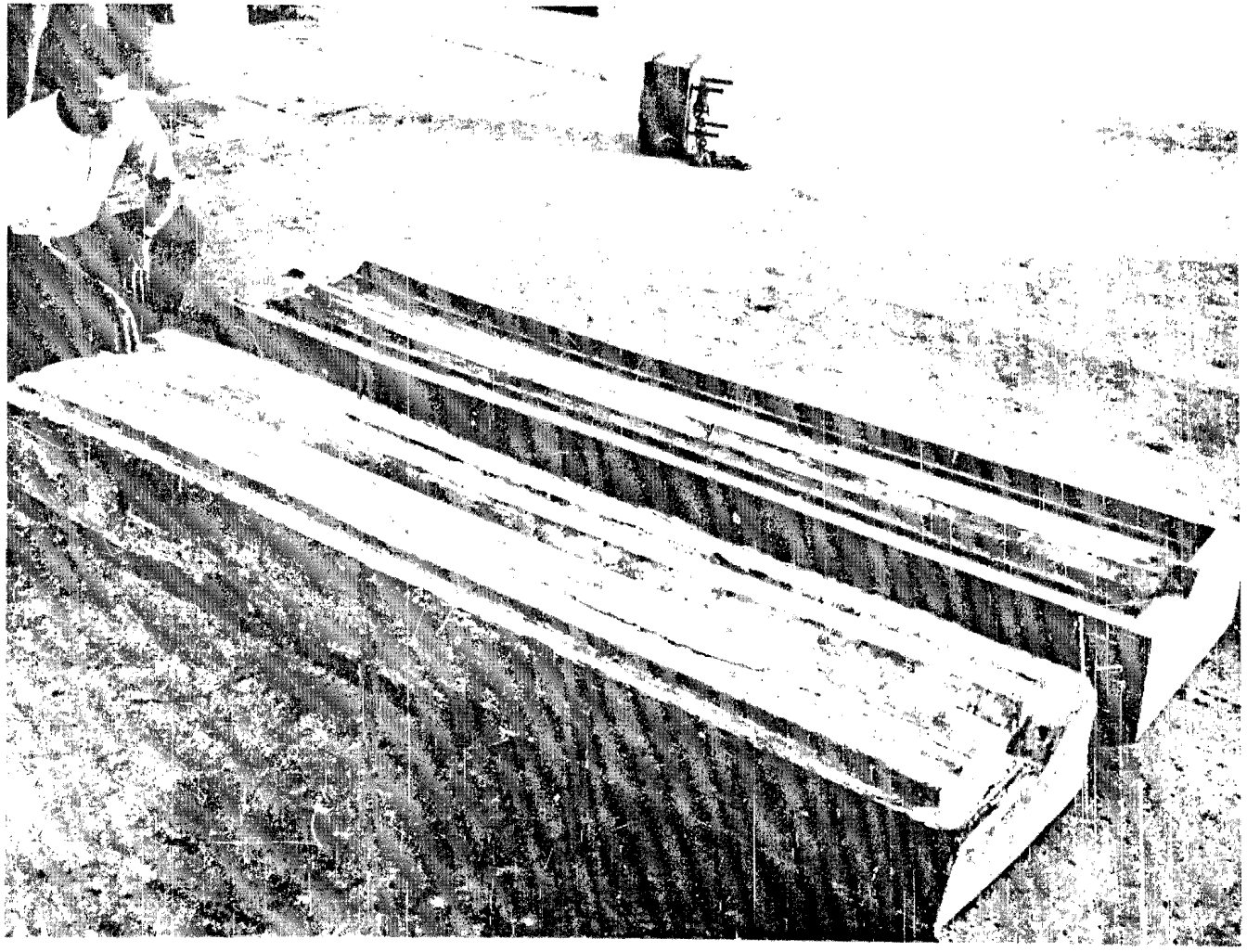
Heat treat fixture used successfully for 17-7PH channel sections. Composition of ceramic is essentially a phosphate bonded zircon modified slightly from that used in brazing fixtures.



REPUBLIC - Farmingdale

Fig. 22

Creep forming tool. This is a forerunner of subsequent tooling to be used for forming Inconel X and Rene' 41 parts at elevated temperatures. Ceramic is fused silica glass, backed by fused silica foam blocks.



REPUBLIC - Farmingdale

Fig. 23

Kirksite drop hammer die (front) showing ceramic impregnated asbestos-glass paper used as parting media for casting Kirksite punch. Ceramic laminate is applied directly to die (thickness equivalent to part to be ultimately formed) and molten Kirksite poured directly on to it. Punch in rear of photograph is shown immediately after it has been cooled and removed from die.

LOCKHEED AIRCRAFT CORPORATION

GEORGIA DIVISION LOCKHEED MARIETTA, GEORGIA

November 1, 1960

Gentlemen:

We are now in the process of compiling data for the final report on "Non-Metallic Tooling for High Temperature Applications" under AF 33(600)36888.

This work began with a "state of the art" survey as reported in Pages 4 thru 7 of Report No. 1, June thru October 1958.

It seems fitting now to conclude this contract, some two and one half years later, with another "state of the art" survey.

We are aware of some truly outstanding developments, by other companies, in the field of ceramic brazing tooling, heat treating tooling, hot sizing tooling, and ceramic forming tooling.

It is our desire to summarize this work, mainly with photographs, so that the total effort in ceramic tooling development might become mutually beneficial to all of you who receive these reports.

Please send us photographs which in general represent your own accomplishments to date. A short narrative description, including identity of ceramic used, is also needed. This industry-wide experience will be published in January 1961.

Very truly yours,

LOCKHEED AIRCRAFT CORPORATION
GEORGIA DIVISION

R. C. Stewart

R. C. Stewart, Manager
Manufacturing Research

RCS:RBC:et

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