

63-3-2

CATALOGED BY ASTIA
AS AD NO. 402015

ASD TR 7-886 (VIII)

ASD INTERIM REPORT 7-886 (VIII)
April, 1963

DEVELOPMENT OF 2400° F FORGING DIE SYSTEM

H. Nudelman
T. Watmough
P. R. Gouwens

ARMOUR RESEARCH FOUNDATION
of

Illinois Institute of Technology
Contract: AF 33(600)-42861
ASD Project: 7-886
ARF Project B220
Interim Technical Progress Report
28 December 1962 - 27 March 1963

The prototype die has been assembled and heating experiments initiated. These indicated that with Calrod heating a die face temperature of 1300° F can be obtained. This will be supplemented by gas flame radiation heating on the die face to attain a temperature of 2400° F. Experiments utilizing calcium flouride-sodium flouride salt combinations to give oxidation protection to the refractory metal die components were successfully performed. A spectrum of viscosities can be obtained with this salt combination by relatively minor adjustments in proportion of either of the components.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

Aeronautical Systems Command
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

402 015

ASTIA
RECEIVED
APR 22 1963
RECEIVED
783A

ABSTRACT - SUMMARY
Interim Technical Progress Report

ASD INTERIM REPORT 7-886(VIII)
April 1963

DEVELOPMENT OF 2400° F FORGING DIE SYSTEM

H. Nudelman
T. Watmough
P. R. Gouwens

Research continued on the third phase of this program designed to evaluate new materials for use as a 2400° F forging die. The ultimate objective is the creation of a true hot-working technology for refractory metals.

Experiments have been continued to determine the feasibility of using a viscous protection coating rather than the conventional solid coating for the refractory metals. It has been shown that salts composed of sodium flouride and calcium flouride in various proportions give a spectrum of fluidity and viscosities between 1800 and 2400° F, while maintaining oxidation protection to both TZC and P4 refractory metal alloys.

The prototype die system has been assembled and heating experiments performed on the lower die using only Calrod heating. Die face temperature of 1300° F were obtained and supplemental gas flame radiation heating to the die face should allow a temperature of 2400° F to be reached.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

ASD TR 7-886 (VIII)

ASD INTERIM REPORT 7-886 (VIII)
April, 1963

DEVELOPMENT OF 2400° F FORGING DIE SYSTEM

H. Nudelman
T. Watmough
P. R. Gouwens

ARMOUR RESEARCH FOUNDATION
of

Illinois Institute of Technology

Contract: AF 33(600)-42861

ASD Project: 7-886

ARF Project B220

Interim Technical Progress Report

28 December 1962 - 27 March 1963

The prototype die has been assembled and heating experiments initiated. These indicated that with Calrod heating a die face temperature of 1300° F can be obtained. This will be supplemented by gas flame radiation heating on the die face to attain a temperature of 2400° F. Experiments utilizing calcium fluoride-sodium fluoride salt combinations to give oxidation protection to the refractory metal die components were successfully performed. A spectrum of viscosities can be obtained with this salt combination by relatively minor adjustments in proportion of either of the components.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

Aeronautical Systems Command
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto. .

Qualified requesters may obtain copies of this report from ASTIA, Document Service Center, Arlington Hall Station, Arlington 12, Virginia.

Copies of ASD Technical Reports should not be returned to the ASD Aeronautical Systems Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

FOREWARD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-42861 from 28 December 1962 to 27 March 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with Armour Research Foundation of Illinois Institute of Technology, Chicago, Illinois, was initiated under ASD Manufacturing Technology Laboratory Project 7-886, "Development of 2400° F Forging Die System." It is administered under the direction of Mr. George W. Trickett of the Basic Industry Branch, Manufacturing Technology Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Mr. Paul R. Gouwens is the project director, with Mr. T. Watmough, and Mr. H. Nudelman principally responsible for experimental work on Phases I, II, and III, respectively. Dr. W. Rostoker and Mr. R. J. Van Thyne are serving as internal ARF consultants. All of the above are members of the Foundation's Metals and Ceramics Research Division. This report is designated as ARF-B220-24 by Armour Research Foundation.

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 development 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.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. EXPERIMENTAL RESULTS	1
Phase III. Development of a Die Material Suitable for Service at 2400° F	1
A. Selection of Metallic Materials	1
B. Prototype Die for Heating Experiments	8
III. SUMMARY	9
IV. FUTURE WORK	10
V. LOGBOOKS AND CONTRIBUTING PERSONNEL	11
INTERIM AND FINAL REPORT DISTRIBUTION LIST	

DEVELOPMENT OF 2400° F FORGING DIE SYSTEM

I. INTRODUCTION

This is the eighth interim technical report, covering the period 28 December 1962 to 27 March 1963 on Contract No. AF 33(600)-42861. This program, an extension of previous Air Force contracts AF 33(600)-35530 and AF 33(600)-35914, is designed to extend the previous development of a high-temperature die system for forging steel, which used a die temperature up to 1600° F.

The ultimate objective of the present research is the forging of refractory metals with dies operating at about 2400° F, but determination of the other limitations of the present hot die system was also necessarily included. The detailed objectives of the present program are to:

1. Evaluate the upper operating temperature limit of forging dies cast from Inconel 713C. Previously, failure did not occur even at 1600° F and a load of 1000 tons.
2. Determine the minimum number of forging steps from unshaped blank to advanced finished shape using the hot die system.
3. Attempt to develop a die material of metallic, ceramic, or composite metal-ceramic structure which can operate at about 2400° F, without atmospheric protection and under loads required to hot-work refractory metals.
4. Devise methods for manufacturing die blocks using the materials developed for 2400° F applications.
5. Produce dies and forge sufficient molybdenum alloy parts to prove the process and materials developed.

Work during this past quarter has been concentrated on the third objective. The first and second phases of the research are now completed.

II. EXPERIMENTAL RESULTS

PHASE III - Development of a Die Material Suitable for Service at 2400° F

A. Selection of Metallic Materials

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

The criteria for acceptance of a suitable die material have been established as follows:

1. A minimum compressive yield strength of 25,000 psi at 2400°F.
2. Oxidation resistance for 100 hr at 2400°F.

While these standards are quite arbitrary, there is good indication that the strength requirements represent a realistic appraisal of the conditions to be met during forging of molybdenum at 3000°F.

Resistance to oxidation is the major problem and has been approached by a consideration of solid protective coatings and also by renewable viscous protective media. Previous reports document the failure of the solid coatings on various molybdenum alloys. However, to ensure that every avenue to obtain a satisfactory integral coating was explored, a further series of 97% W-3% Mo samples was submitted to Chromalloy Corporation for application of their proprietary coating. After their return to ARF, one coated sample was evaluated for oxidation resistance at 2400°F in dry air. Figure 1 shows the condition of this sample after three hours in such an environment. It can be observed that coating has started to deteriorate, and rounding of corners has occurred. Consequently this would be considered an unsatisfactory oxidation-resistant coating for the criteria previously detailed.

Previous reports indicated that a preliminary evaluation of the possible use of molten salts to protect the refractory metals against oxidation yielded encouraging results. This aspect was further pursued, and samples of TZC and TZM molybdenum-base alloys and P1 and P4 tungsten-base alloys were immersed in a high speed steel heat treatment salt at 2400°F for a 48 hr period. Table I contains the weight loss data for these experiments; the results obtained are most encouraging.

Difficulties with this type of salt, which is composed mainly of barium chloride, are the extremely low viscosity and surface tension of the molten material. In practice this may lead to difficulty in securing adequate protection for the dies, especially if the dies have any great degree of shape complexity. Accordingly, a basic salt combination was sought whose viscosity

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY



Neg. No. 24352

Mag X5

Figure 1. Coated Specimen of P4 Tungsten Alloy After 4 hr at 2400° F in Dry Air

TABLE I
WEIGHT LOSS OF TZC, TZM, P1 AND P4
IN HIGH SPEED HEAT TREATMENT SALT *

Elapsed Time, hr	TZC	TZM	P1	P4
	Weight, gm			
0	6.8707	16.9336	13.9664	11.0491
24	6.8898	16.9213	13.9803	11.0028
48	6.8762	16.9066	13.9622	10.9963

* Designated Liquid Heat 1500 supplied by E. Houghton.

could be varied with temperature, or with a change in the percentage of one of the constituents. This implies that the press forging temperature of 2400°F would be within the liquidus-solidus boundary of the particular salt combination chosen. A literature search through the ceramic phase diagram data showed a small number of possible combinations, which are listed in Table II.

To obtain an approximate idea of the viscosity of possible salt combinations at various temperatures, a series of heating experiments was performed utilizing the sodium fluoride-calcium fluoride combination. Initially three salt mixtures were prepared for a study of their viscosity characteristics. These were as follows:

Combination 1	53% Sodium Fluoride 47% Calcium Fluoride
Combination 2	25% Sodium Fluoride 75% Calcium Fluoride
Combination 3	10% Sodium Fluoride 90% Calcium Fluoride

Each combination was heated in a clay-graphite crucible to 2400°F and its viscosity visually evaluated. Combination 1 was extremely fluid and heavily attacked an Inconel strip suspended in the molten salt. Combination 2 was somewhat more viscous, but it also attacked the Inconel strip. The third combination was extremely viscous at 2400°F with only a slight attack on the suspended Inconel strip noted. It is realized that protection will have to be afforded the refractory metal at temperatures much lower than 2400°F, and the viscosity at these lower temperatures is also important, if a continuous barrier to atmospheric oxygen is to be maintained. A series of experiments to visually evaluate the viscosity of the salt combinations was therefore performed at 1800°F, and the following observations were made:

Combination 1	very fluid and low viscosity
Combination 2	fluid but high viscosity
Combination 3	low fluidity and pasty consistency.

In view of the extreme fluidity of the Combination 1 salts, at both 1800 and 2400°F, it was decided that this particular pair should be excluded from any further consideration, and consequently another combination was

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

TABLE II
SALT COMBINATIONS WITH FAVORABLE
LIQUIDUS-SOLIDUS RANGES

Salt Combination			Percentage of Salt	Liquidus Temperatures, °C
CaF ₂	+	NaF	0 NaF*	1418
			68 NaF*	810
CaF ₂	+	CaF ₂	20 Ca F ₂ *	670
			100 CaF ₂ *	1418
BeF	+	CaF ₂	0 Be Fe**	1418
			90 Be F**	495
LiF	+	UF ₃	30 UF ₃ *	718
			100 UF ₃ *	1500
NaF	+	UF ₃	30 UF ₃ *	700
			100 UF ₃ *	1500
2Na ₂ P ₂ O ₅	+	Na ₂ O 2SiO ₂	90 Na ₂ O 2SiO ₂ **	820
			30 Na ₂ O 2SiO ₂ **	1350
K ₂ Cl ₂	+	CaSO ₄	30 Ca SO ₄ *	687
			100 K ₂ Cl ₂ *	1450
CaO	+	Cr ₂ O ₃	55 Cr ₂ O ₃ **	900
			35 Cr ₂ O ₃ **	1350
CdO	+	B ₂ O ₃	45 B ₂ O ₃ *	800
			100 Cd O	?
B ₂ O ₃	+	CoO	63 Co O	900
			90 Co O	1350

* Mol. percentage
** Weight percentage

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

was substituted, namely: 82.5% calcium fluoride and 17.5% sodium fluoride, designated as Combination 4. This combination at 1800° F had low fluidity and high viscosity. Combinations 1, 2, and 4 were evaluated at 2000° F for fluidity and viscosity, and the results were similar to those obtained at 1800° F. The variations in viscosity and fluidity obtained, especially in the case of combinations 2 and 4, are encouraging. Specimens of TZC molybdenum alloy and P4 tungsten alloy were immersed in each salt at 2000° F and 1800° F for 6 hr each and then were visually examined. No loss of edges or oxidation of the specimen was apparent after this treatment. Weight loss data will be obtained during the next report period to confirm the protection offered by the three salt combinations at the various temperatures.

Subsequent to the last Interim Report No. VII, tentative recommendations were made to the Contracting Officer and Technical Monitor concerning the selection of die materials. On the basis of work done to date, two materials were selected for construction and evaluation as an actual forging die. The two candidates were selected from the two major material categories investigated, i. e., metallic and ceramic. It was recommended that the bottom die impression be carried in a tungsten alloy, P4, containing 85% W and 15% Mo, and that the top die be fabricated from a self-bonded silicon carbide commercially produced as Refrax. By making the dual material selection, a most valid comparison of relative performance should be obtained. At the same time the design of the forged part (a modified half nozzle of a rocket engine) is such that the stress system active on the top die is essentially one of hydrostatic compression during the deformation stroke. This favors the low ratio of tensile to compression stress characteristic of all ceramics by minimizing the possibility of large tensile components of the forging stress.

The bottom die selection of alloyed tungsten was predicated on acceptable high temperature strength, relatively ready availability of simple cast shapes, and the selection of a viscous salt as an oxidation protection medium. The latter can be most advantageously used under conditions where gravity and die configuration will permit and encourage continued contact with the die; thus a gravity-formed salt pool can really be used only on a bottom die unless thin films would prove to adhere to and protect the upper die.

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

The recommendation was also made that the molybdenum alloy TZM be used as the forging stock during Phase V of the program. All of these recommendations were accepted by means of a telephoned approval, which also authorized proceeding with Phase IV and Phase V research.

B. Prototype Die for Heating Experiments

Several minor machining modifications were carried out to facilitate the assembly of the forging die components. The preparation of the Calrods was completed with the winding of inner and outer coils for the upper and lower die stacks. A series of slots was milled into the stainless steel retainer rings to permit the installation of thermocouples into the prototype die inserts. The lower die stack was assembled, and six thermocouples were attached to the inner and outer areas of the heater blocks directly beneath the lower die surface. Mechanical thermocouple connections were made in which holes were drilled in the heater blocks and peened over after thermocouple insertion. Two additional thermocouples were installed into drilled holes in the prototype die and cemented over. The lower stack was assembled first since this operation was less complex. This approach permitted the development of techniques for installing thermocouples and made disassembly relatively easy.

An angle iron frame was welded together to serve as a heating stand. In this arrangement the upper die stack will be suspended from the top of the frame, while the lower die stack will be supported on a reinforced hydraulic jack within the frame. This will allow the die opening to be adjusted in a manner simulating actual hot forging die practice. After assembly, the lower die stack was installed in place, and a series of heating experiments were performed. Only the Calrod heaters were used for this preliminary work, and the thermocouple emf values were read manually. Current plans call for the use of a 20 point recording potentiometer for advanced heating studies wherein both stacks are in operation.

A 50% duty Calrod cycle provided the heating power for the initial trial. After a 4 hr period the hottest portion, the inner heater block, was 1115°F and the coldest portion, the outer heater block, was 630°F. Die

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

temperatures of 670 and 680°F were recorded. An increase in the duty cycle to a 60% level for an additional 4 hr raised the general temperature level about 200°F.

In order to improve heating efficiency the area between the outer heater block and the shroud was packed with Fiberfrax, a fibrous mullite material, and the exposed upper stack surface was covered with a 1-in. thick transite plate. A second heating trial was conducted over a two-day period in which a 75% duty cycle was maintained during the day and a 25% duty cycle at night. Temperature equilibrium was obtained after about 20 hr and this provided the following temperature levels:

inner heater block	1560°F
outer heater block	1045°F
prototype die	1145-1290°F

This performance appeared satisfactory, and the assembly of the upper die stack was started. A similar thermocouple arrangement will be used, and in addition two thermocouples will be installed on the surface of the retainer ring at the inner and outer edges. As in the lower stack the space between the shroud and outer heater block will be packed with Fiberfrax to minimize heat losses. After assembly the upper die stack will be mounted on the angle iron frame, and both dies will be given a heating trial using only the Calrod heaters. When this is completed and the results are analyzed, gas burner heating will be added. Six burners, of the type used previously in hot-punch experiments, and the same gas-air mixer will make up the additional heating system. This will permit a realistic appraisal of the final heating system, and is expected to provide information facilitating the final hot forging die design and the selection of optimum operating procedures.

III. SUMMARY

The possibility of using a liquid salt as a medium of protection against oxidation of the refractory metal die components has been further explored. A barium chloride base heat treatment salt successfully inhibited oxidation of TZC, TZM, P1, and P4 samples at 2400°F. However this salt is extremely

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

fluid at this temperature and could give problems in use in the forging dies. A literature search uncovered a number of possible salt combinations whose systems had liquidus-solidus temperatures within the approximate range of 700 to 1400°F. Preliminary evaluation of the sodium fluoride-calcium fluoride salt combination indicated that a spectrum of fluidity and viscosity is obtainable by relatively minor variations in composition. These salts also appear to provide protection against oxidation of the TZC and P4 alloys.

Assembly of the prototype lower die system has been completed, and breaking experiments have been performed utilizing Calrod heating elements.

IV. FUTURE WORK

It is planned to:

1. Conclude study of salt protection systems.
2. Investigate the heating characteristics and temperature distribution of the complete prototype die assembly.
3. Develop the final design for the complete hot forging die system.

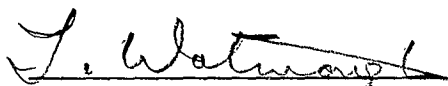
V. LOGBOOKS AND CONTRIBUTING PERSONNEL

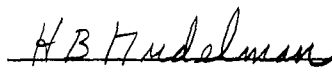
Data gathered during the research work are contained in ARF Logbooks C11166, C11167, C11168, C11169, C11908, and C12901. Foundation personnel include:

R. Corrado	H. B. Nudelman
R. Domkowski	R. J. Van Thyne
J. Dorcic	T. Watmough
P. R. Gouwens	

Respectfully submitted,

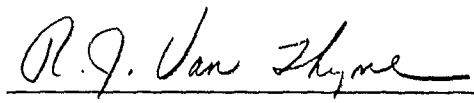
ARMOUR RESEARCH FOUNDATION OF
ILLINOIS INSTITUTE OF TECHNOLOGY


T. Watmough, Research Metallurgist


H. B. Nudelman, Research Metallurgist

Approved:


P. R. Gouwens, Manager
Foundry and Steelmaking Research


R. J. Van Thyne, Assistant Director
Metals and Ceramics Research

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

INTERIM AND FINAL REPORT DISTRIBUTION LIST

Development of 2400°F Forging Die System

Project 7-886 _____

AF 33(600)-42861

	<u>No. of Copies</u>
Aeronautical Systems Division Attn: ASRCTB Wright-Patterson Air Force Base, Ohio	3 + 1 Reproducible
Armed Services Technical Information Agency Document Service Center Arlington Hall Station Arlington 12, Virginia	10
Chief, Bureau of Naval Weapons Department of the Navy Washington 25, D.C.	2
Aeronautical Systems Division Attn: ASRCM Wright-Patterson Air Force Base, Ohio	2
Commanding Officer Attn: Mr. S. V. Arnold, Associate Director Watertown Arsenal Laboratories Watertown 72, Massachusetts	2
Bureau of Naval Weapons Department of the Navy Attn: Mr. S. E. Samfilippo, AE 155 Washington 25, D.C.	1
U. S. Atomic Energy Commission Technical Information Services Extension Attn: Mr. Hugh Voress P. O. Box 62 Oak Ridge, Tennessee	1
National Academy of Science National Research Council Division of Engineering and Industrial Resources Attn: Mr. E. V. Bennett Washington 25, D.C.	1

	<u>No. of Copies</u>
Defense Metals Information Center Battelle Memorial Institute 505 King Avenue Columbus 1, Ohio	1
Jet Propulsion Laboratory California Institute of Technology Attn: Mr. I. E. Newlan 4800 Oak Grove Drive Pasadena 3, California	1
Canton Drop Forging & Manufacturing Company Attn: Mr. Chandis Brauchler 2100 Willett Avenue Canton, Ohio	1
Convair - Astronautics Division General Dynamics Corporation Attn: Mr. V. G. Mellquist, Manager Manufacturing Development P. O. Box 1128 (Zone 290-00) San Diego 12, California	1
Crucible Steel Company of America Attn: Dr. Walter Finley Director of Research P.O. Box 88 Pittsburgh 30, Pennsylvania	1
Curtiss-Wright Corporation Metals Processing Division Attn: Mr. T. A. Weidig, Manager Materials Laboratory P. O. Box 13 Buffalo 15, New York	1
Curtiss-Wright Corporation Wright Aeronautical Division Attn: Mr. R. A. Kaprelian, Manager Manufacturing Services Wood-Ridge, New Jersey	1
Douglas Aircraft Company, Inc. Attn: Mr. C. B. Perry, C-345 Plant Engineering Supervisor 3855 Lakewood Boulevard Long Beach 8, California	1

	<u>No. of Copies</u>
Reynolds Metals Company Attn: Mr. Stuart Smith 503 World Center Building Washington 6, D.C.	1
Rohr Aircraft Corporation Attn: Mr. F. E. Zimmerman, Manager Manufacturing Research P. O. Box 878 Chula Vista, California	1
Ryan Aeronautical Company Attn: Mr. L. J. Hull, Chief Metallurgist Material & Process Laboratory Lindberg Field San Diego 12, California	1
Solar Aircraft Company Attn: Mr. F. M. West, Chief Librarian 2200 Pacific Avenue San Diego 12, California	1
Taylor Forge & Pipe Works Attn: Mr. A. J. Ely, Manager Special Products P. O. Box 485 Chicago 90, Illinois	1
Thompson-Ramo-Wooldridge, Inc. Staff Research & Development Chemical & Metallurgical Department Attn: Mr. A. S. Nemy 23555 Euclid Avenue Cleveland 17, Ohio	1
Chance Vought Corporation Vought Aeronautics Division P. O. Box 5907 Dallas 22, Texas	1
United Aircraft Corporation Attn: Acquisitions Librarian (UAC) 400 Main Street East Hartford, Connecticut	1
United States Steel Corporation Products Development Division 525 William Penn Place Pittsburgh, Pennsylvania	1

	<u>No. of Copies</u>
AF Systems Command Attn: RDTDEG, Mr. Kniffen Andrews Air Force Base Washington 25, D.D.	1
National Aeronautics & Space Administration Lewis Research Center Attn: Mr. George Mandel, Chief, Library 2100 Brookpark Road Cleveland 25, Ohio	1
Hubert J. Altwicker Lebanon, Ohio	1
Aluminum Company of America ALCOA Bldg. Attn: Mr. R. W. Andrews Pittsburgh, Pennsylvania	1
Armour Research Foundation of Illinois Institute of Technology Metals And Ceramics Research Attn: Mr. Frank A. Crossley 3350 South Federal Street Chicago 16, Illinois	1
AVCO Corporation Research & Advanced Development Division Attn: Mr. John V. Erickson, Manager Contracts & Administrative Services 201 Lowell Street Wilmington, Massachusetts	1
Baldwin-Lima-Hamilton Corporation Attn: Mr. Fred A. Fielder Philadelphia 42, Pennsylvania	1
Boering Airplane Company Aero-Space Division Attn: Mr. George Hughes, Section Chief Materials & Processes P. O. Box 3107 Seattle, Washington	1
Charles D. Briddell, Inc. Attn: Mr. C. D. Briddell Crisfield, Maryland	1

	<u>No. of Copies</u>
Ladish Company Attn: Mr. Paul Verdow Cudahy, Wisconsin	1
Lockheed Aircraft Corporation Attn: Mr. Elliot Green, Manager Production Engineering Department Burbank, California	1
Magnathermic Corporation Attn: Mr. J. A. Logan Youngstown, Ohio	1
The Martin Company Attn: Mr. L. E. Laux, Chief Manufacturing Research & Development Mail Zone No. U-666 Baltimore 3, Maryland	1
McDonnell Aircraft Corporation Attn: Mr. C. E. Zoller P. O. Box 516 Lambert - St. Louis Municipal Airport St. Louis 3, Missouri	1
NORAIR Division Northrop Corporation Attn: Mr. J. A. Van Hamersveld, General Supervisor Materials Research & Product Analysis 1001 East Broadway Hawthorne, California	1
Nuclear Metals, Inc. Attn: Mr. Klein, Vice President Concord, Massachusetts	1
Precision Forge Company Attn: Mr. M. A. Perry 1548 18th Street Santa Monica, California	1
Republic Aviation Corporation Attn: Mr. A. Kastelowitz, Director of Mfg. Research Farmingdale, Long Island, New York	1
Republic Steel Corporation Republic Research Center 6801 Breckville Road Cleveland 31, Ohio	1

	<u>No. of Copies</u>
Douglas Aircraft Company, Inc. Attn: Mr. A. J. Carah, Chief Design Engineer Santa Monica, California	1
E. I. DuPont de Nemours & Company, Inc. Pigments Department Attn: Mr. E. M. Mahla, Technical Mgr. Metals Products Wilmington 98, Delaware	1
Fansteel Metallurgical Corporation Attn: Mr. A. B. Michael, Director, Metallurgical Research 2200 Sheridan Road North Chicago, Illinois	1
The Garrett Corporation Air Research Manufacturing Division 9851 Sepulveda Boulevard Los Angeles 45, California	1
General Electric Company Aircraft Gas Turbine Division Attn: Mr. G. J. Wile, Engineering Manager Metallurgical Engineering Operations, Large Jet Engine Dept., Bldg. 501 Cincinnati 15, Ohio	1
Grumman Aircraft Engineering Corporation Manufacturing Engineering Attn: Mr. W. H. Hoffman, Vice President Plant 2 Bethpage, Long Island, New York	1
Harvey Aluminum, Inc. Attn: Mr. G. A. Moudry, Technical Director 19200 South Western Avenue Torrance, California	1
Jones & Laughlin Steel Corporation Attn: Mr. Robert S. Orr, Commercial Research Librarian 3 Gateway Center Pittsburgh 30, Pennsylvania	1
Kropp Forge Company Attn: Mr. J. A. Nelson, Chief Metallurgist 5301 W. Roosevelt Road Chicago 15, Illinois	1
Kaiser Aluminum & Chemical Corporation 349 West First Street Dayton 2, Ohio	1

	<u>No. of Copies</u>
Universal-Cyclops Steel Corporation Refractomet Division Attn: Mr. P. C. Rossin, General Manager Bridgeville, Pennsylvania	1
Vanadium Corporation of America Attn: Mr. C. N. Cosman, Metallurgical Engineer Graybar Building 420 Lexington Avenue New York 17, New York	1
Wah Chang Corporation Attn: Mr. K. C. Lee, Jr. 233 Broadway New York, New York	1
Wyman Gordon Company Attn: Mr. Arnold Rustay, Technical Director Grafton Plant Worcester Street North Grafton, Massachusetts	1
Westinghouse Electric Corporation Bettis Atomic Power Division Attn: Virginia Sternburg, Librarian P. O. Box 1468 Pittsburgh 30, Pennsylvania	1
Westinghouse Electric Corporation Materials Manufacturing Department Attn: F. L. Orrell, Section Manager Blairsville, Pennsylvania	1
Sandia Corporation Livermore Laboratory Attn: Mr. M. W. Mote, Jr. P. O. Box 969 Livermore, California	1
The Martin Company Denver Division Attn: Mr. R. F. Breyer Materials Engineering Mail No. L-8 P. O. Box 179 Denver 1, Colorado	1

	<u>No. of Copies</u>
A. O. Smith Corporation ATTN: Mr. H. D. Barnes, Director Government R & D Division P. O. Box 584 Milwaukee 1, Wisconsin	1
ASD (ASRCMP-4) Wright-Patterson Air Force Base, Ohio	1
Massachusetts Institute of Technology Attn: Dr. Merton C. Flemings Associate Professor of Metallurgy Cambridge 39, Massachusetts	1
Utica Division Kelsey-Hayes Company Attn: Mr. Phillip E. Munson Utica 4, New York	1