ASD TR 7-886 (IV)

ASD INTERIM REPORT 7-886 (IV)
April, 1962

DEVELOPMENT OF 2400°F FORGING DIE SYSTEM

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A. H. Murphy
T. Watmough
P. R. Gouwens

ARMOUR RESEARCH FOUNDATION
of
Illinois Institute of Technology

Contract: AF 33(600)-42861
ASD Project: 7-886
ARF Project 2220
Interim Technical Progress Report
28 December, 1961 - 27 March, 1962

Evaluation of the upper operating temperature limit of Inconel 713C forging dies is in progress. The dies have been operated at temperatures up to 1700°F under pressing loads of 1000 tons. No deformation of the system has occurred under these conditions. Dies have been cast for use in the hot die extrusion-forging process. Evaluation of metallic, intermetallic, and nonmetallic materials is continuing to assess their utility as 2400°F die materials.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

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

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ABSTRACT - SUMMARY
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Work has continued on the first three phases of the research, comprising the related objectives of:

a) Extending the upper temperature limit of the present hot die system.

b) Minimizing the required forging sequences by using hot dies.

c) Evaluating new materials for use as a 2400°F forging die.

The ultimate objective is a creation of a true hot working technology for refractory metals.

The hot die system was installed in the 1000-ton press, and forging experiments were started to determine the upper operating conditions of the system. A die temperature of 1700°F was used while forging parts under the full 1000-ton load of the press. No die deformation was detected under these conditions. The destructive testing work is continuing.

A set of dies for use in the extrusion-forging process has been cast of Inconel 713C. This set of dies is now having final machining done and is scheduled to be installed in the press when the destructive testing of the first die set is completed.

Evaluation of materials for use as 2400°F die materials has continued. Compression strength tests at 2400°F were conducted on TiB_2, KT SiC, $Ta_2 Be_{17}$, Al_2O_3, high-density graphite, siliconized graphite, and commercial graphite.

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-42861 from 28 December 1961 to 27 March 1962. 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. Geo. 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. A. H. Murphy, 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 2220-12 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 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.

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DEVELOPMENT OF 2400°F FORGING DIE SYSTEM

I. INTRODUCTION

This is the fourth interim technical report, covering the period 28 December 1961 to 27 March 1962 on Contract No. AF 33(600)-42861. This program is an extension of previous Air Force contracts AF 33(600)-35530 and AF 33(600)-35914, which produced a technique for forging steel with high-alloy cast dies maintained at temperatures up to 1600°F. The high temperature of the die reduced its heat sink behavior and the corresponding chill effect on the forging. In this way rapid increases in flow stress during forging are minimized. The production of more than 100 forgings by this method conclusively demonstrated that metal flow increased. Specifically, marked improvements were observed in flange depths of a commercial forging, and during the production of an experimental thin-flanged beam the metal flowed into the flanges to a depth eight times greater for a 1600°F as compared to a 500°F die temperature.

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 presently developed hot die system is also necessarily included. The detailed objectives of the present program are:

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 advance 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.

The research effort during this past quarter has been concentrated on the first three objectives, and since all of these phases are separable although related entities, they are separated by phases in this report.

II. EXPERIMENTAL RESULTS

PHASE I - Upper Temperature Limit of Present Hot-Die System

During this work period the assembly of the upper and lower hot dies was completed. Each die was secured to a heater block directly below it by 310 stainless steel wedges. The Kanthal type calrod heating elements were installed in the heater block and protected by separate Inconel sheaths; the heater block, in turn, was held by wedges to a 310 stainless spacer plate. This spacer plate, then, was wedged to a water-cooled base plate. The entire assembly was clamped to a bolster of the 1000-ton forging press. Both an upper and a lower bolster plate from the press were used. These plates, one with the upper die and the other with the lower dies, were clamped together as one assembly was installed in the press.

Electric power for heating of the dies has been installed on the press. Each die has available 100 amps at 220 volts. An additional 100 amp circuit is also available for use on a separate heating pad between the dies. Each of these circuits is controlled by a separate temperature controller. In addition to the controller, a duty cycle can be imposed on a 15-second cycle which allows for limiting maximum power demand from 0-100 per cent. Each die has 30 heating elements. Each element is rated at 750 watts at 220 volts. All the elements in each die are connected in parallel copper bus strips.

After installation in the press the dies were test-run. Some minor difficulty was encountered with water leaks in the water-cooled base plate of the multilayer die set, but these were readily repaired by welding.

The hydraulic press instrumentation was calibrated to permit very accurate control and readout of the press loads. The calibration sheets in Table I and Table II indicate the following:

TABLE I

TONNAGE CONTROLLER PRECISION

FOR 1000-TON HPM PRESS

Equivalent Tonnage	Control Range, tons	Tolerance, tons
91	89.5 - 94.5	-1.5 +3.5
182	183.5 - 186.5	0 +4.5
272	267.0 - 272.5	-5.0 0
363	359.0 - 362.5	-4.0 0
454	450.0 - 452.5	-4.0 0
545	541.5 - 543.5	-3.5 0
635	632.5 - 634.5	-2.5 0
726	724.5 - 726.5	-1.5 +0.5
817	815.5 - 816.5	-1.5 0
907	905.0 - 905.5	-2.0 0
998	995.5 - 996.0	-2.5 0

An additional source of error of $\pm$ 5.0 tons must be added to these values to allow for inherent variations in the deadweight loading device used for calibration.

TABLE II

CALIBRATION OF PEAK TONNAGE INDICATOR ON 1000-TON HPM PRESS

Equivalent Tonnage	Peak Reading, tons	Variation, tons
100	100	0
200	203	+3
300	308	+8
400	405	+8
500	501	+1
600	608	+8
700	712	+12
800	810	+10
900	913	+13
1000	1005	+5

Maximum error on peak reading is 1.3% of full scale.

1. Tonnage control is accurate to ± 10 tons in the load range of 100 to 1000 tons.

2. Peak tonnage readout is accurate to ± 2.3% of the full scale.

3. Direct tonnage readout is accurate to ± 1.7% of the full scale.

After this calibration, forging operations on the hot die system were started. The initial heat-up of the dies to 1500°F was accomplished using 50% of the power available. During this period several of the outer heating elements failed. The ones which failed were used elements from a previous test. It is likely that during handling they were subjected to some bending, which would account for their failure. When the elements were replaced with new elements, the operation was normal.

Once the heating system was in operation and the controlling mechanism proven, the forging was started. The first series of forgings was made under the following conditions:

Die temperature, °F	1500
Heater block temperature, °F	1560
Work temperature, °F	2150
Force applied, tons	250, 500, 750, 1000

This series was run so as to overlap previous work and re-establish working procedures. Another series was run with the dies at 1600°F as follows:

Die temperature, °F	1600
Heater block temperature, °F	1720
Work temperature, °F	2150
Force applied, tons	250, 500, 750, 1000

This series brought the system up to the peak temperature and tonnage it had established in the past. During this run the potassium iodide-graphite lubricant was used as before. It was noted that extraction of the work from the die was much less of a problem than it had been previously. As more forgings are produced, the die surface becomes polished and thus prevents sticking of the work in the cavity. When the 1600°F series was completed, the die temperature was raised to 1700°F and another series of forgings produced as follows:

Die temperature, °F	1700
Heater block temperature, °F	1850
Work temperature, °F	2150
Force applied, tons	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000

During this series the die was gauged after each forging to determine if the die had deformed. Also each forging produced was inspected in order to detect local die deformation. No deformation was detected. It was noted that as the temperature of the die was increased, the temperature gradient between the die and the heater block increased in the following manner:

Per Cent Power* Required	Die Temp., °F	Heater Block Temp., °F	Gradient, °F
50	1500	1560	60
60	1600	1720	120
70	1700	1850	150
90	1800	~2000	~200

* 100% power is 44 kw

This temperature gradient indicates the increased heat loss that is to be expected as the temperature rises.

At a die temperature of 1700°F, only 70% of the power available was required. When the 1700°F series was completed, the temperature of the dies was raised to 1800°F. During this heat-up period 100% of power was applied for a short time. At this power setting numerous heating elements failed. The failure of the elements prevented the dies from reaching and maintaining 1800°F. However, it was established that the remainder of the elements could be run at 90% of full power for at least 16 hours without one failure occurring.

The dies were partially dismantled on the press in order to remove the burned out elements. Of the new elements ordered as replacements, a partial shipment has been received and these new elements are being installed. As soon as the remainder of the elements are delivered and installed, forging tests will continue.

PHASE II - Reduction of Number of Die Sequences

A. Background Information

The purpose of this phase of the program is to produce the forging shown in Figure 1 using the minimum number of die sequences by application of hot dies. The hot dies operating at a minimum temperature of 1600°F have been produced in Inconel 713C alloy. The nominal composition of this alloy in weight per cent is:

C	0.20 max	Mo	3.5 to 5.5
Mn	1.00 max	Ti	0.25 to 1.25
S	0.015 max	Al	5.5 to 6.5
Si	1.00 max	Fe	5.0 max
Cr	11.0 to 14.0	Cb + Ta	1.0 to 3.0
		Ni	remainder

This is essentially a casting alloy since machining of shapes in this composition presents considerable difficulties. Two sets of hot dies and two heater blocks have been produced. The first set of Inconel 713C dies are conventional insofar as metal flow of the forging stock is concerned. However, the second set of dies is unconventional because of the severe lateral restrictions which will be placed upon the forging stock. Exhibited in Figure 2 is the pattern for the lower die, illustrating the configuration that will be used for the extrusion forging experiments. Figure 3 illustrates the plunger pattern for construction of the upper die. The forging stock will be placed in the lower die cavity and, when contacted by the upper die punch, will be severely restricted insofar as possible directions of metal flow are concerned. It is postulated that this restriction, in combination with the hot dies, may result in metal flow patterns which will reduce the number of steps required to produce a forging. The normal production of the forging selected involves five separate steps beginning with a piece of material 2 5/8 inch (round cornered square) by 7 inches long. These steps are: flatten, draw, roll, block, and finish. The stock produced at each step, except for the last one, is shown in Figure 4. It is planned to press-forge a number of each of these pieces

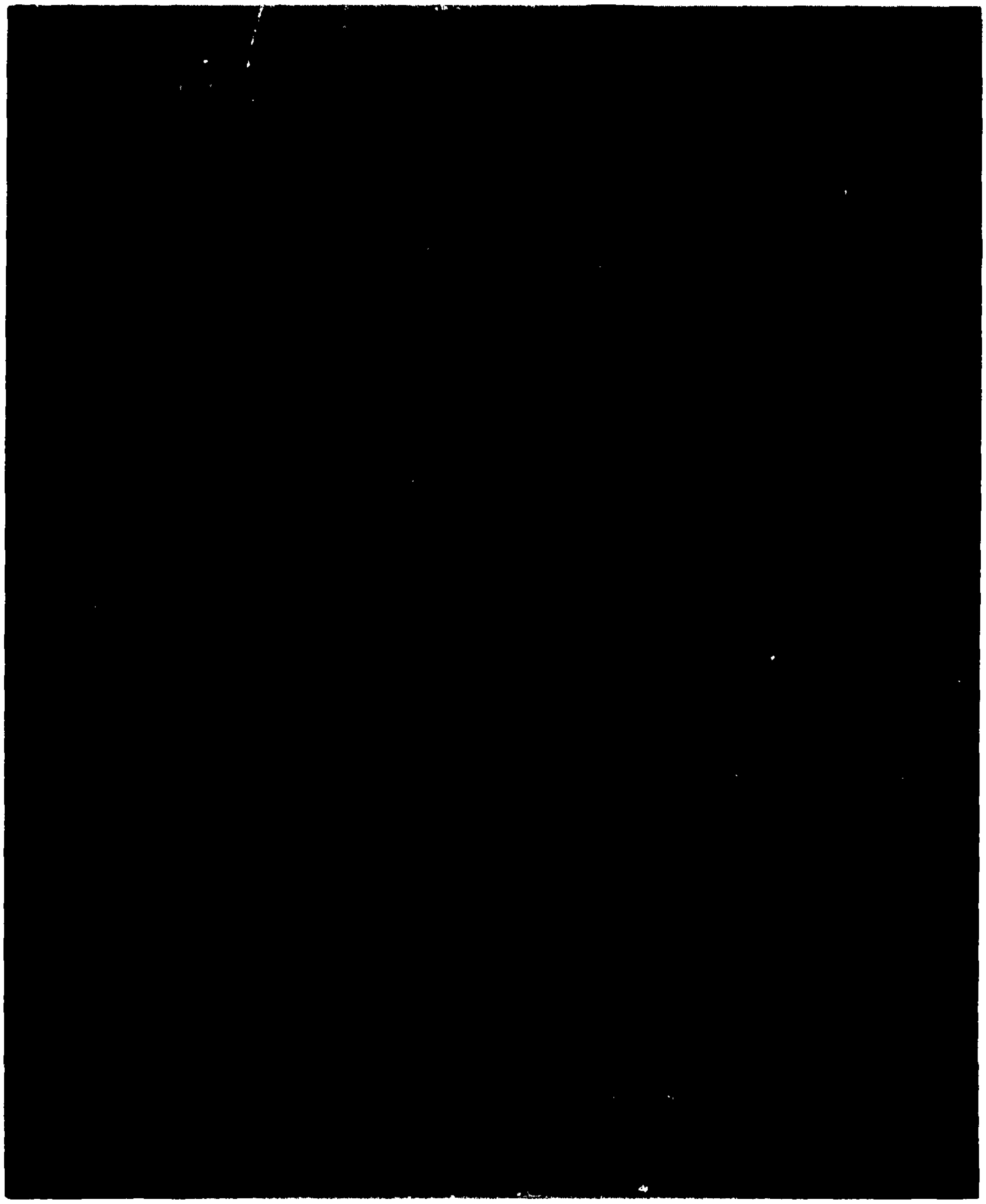

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Fig. 1 - CHANCE-VOUGHT PART SELECTED FOR FORGING TESTS.

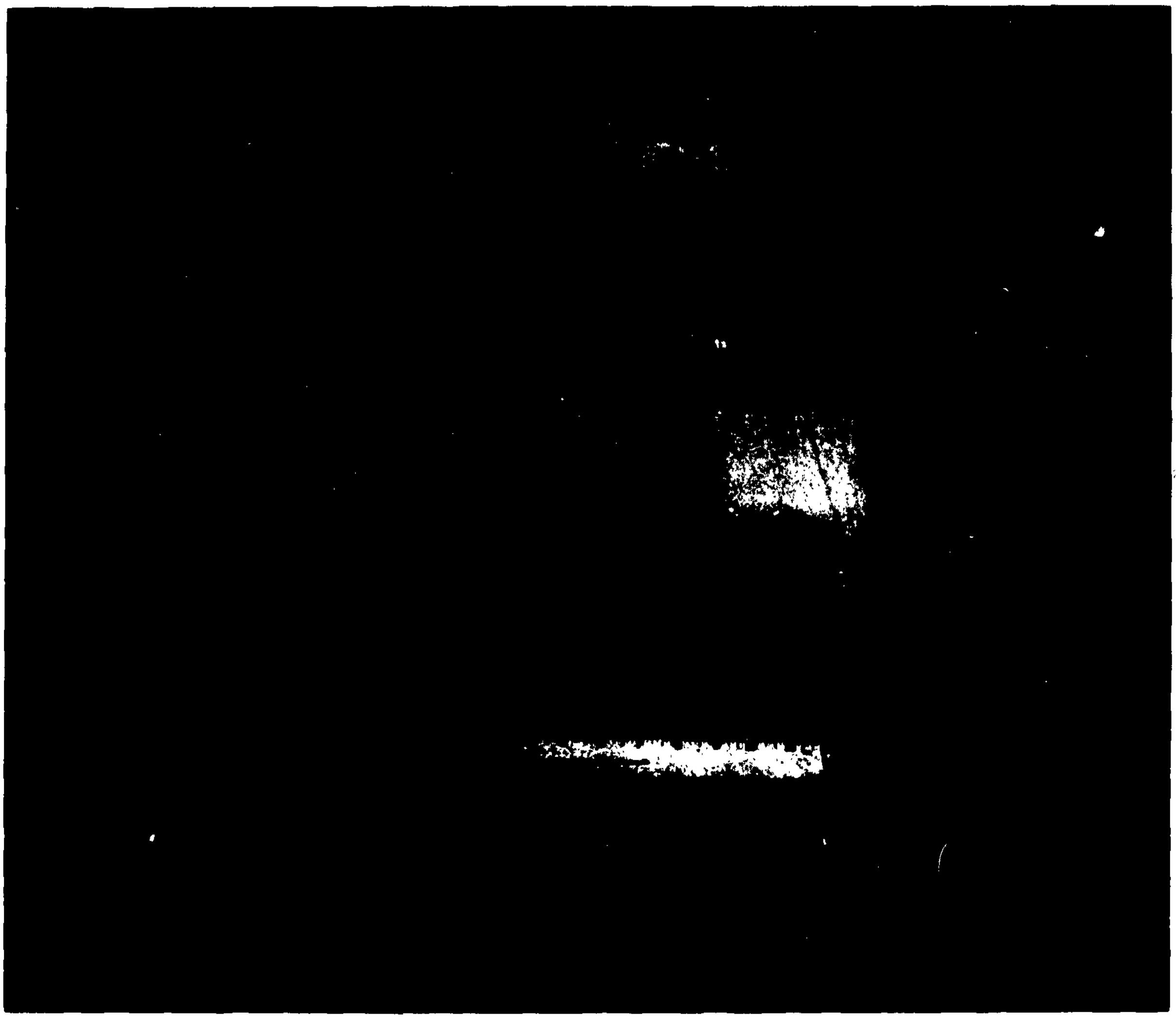

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Fig. 2 - Drag Pattern For Experimental Hot Dies.

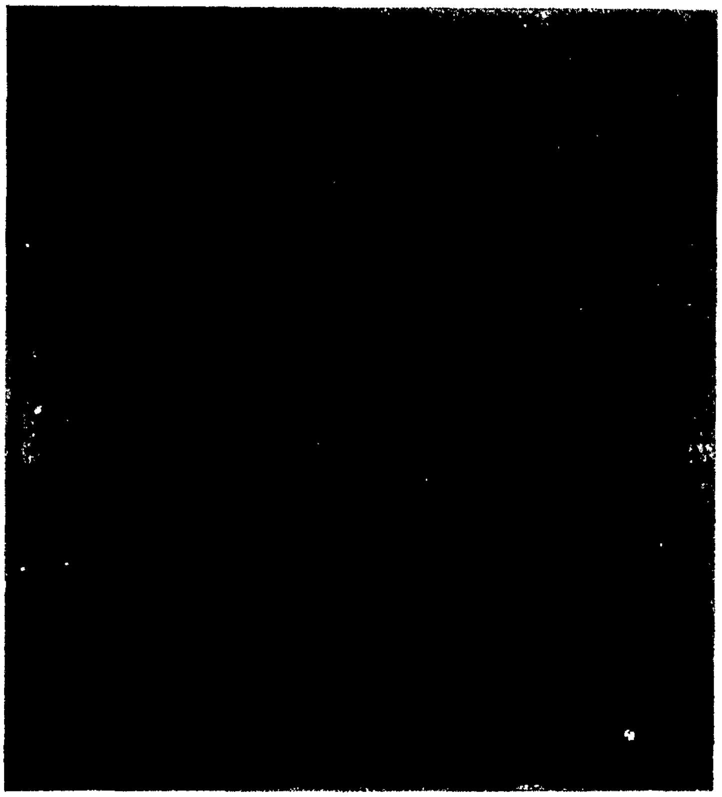

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Fig. 3 - Pattern For Upper Punch For Experimental Extrusion Forging Die.

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Fig. 4 - Various Steps in Manufacture of Chance-Vought Forging.

in both the conventional hot die and the experimental "extrusion-forging" hot die.

B. Production of Hot Dies

The hot dies have been produced in Inconel 713C with BB4 graphite as the mold material. The graphite bonded with 4% GD sodium silicate powder, 4% bentonite, and 6 to 8% water was used for the die cavity, or drag portion, of the various molds. The upper portions, or copes, were produced from Wedron 7030 silica sand bonded with sodium silicate. Both parts of the various molds were baked at 450°F for 6 hours, after which they were coated with a silica flour base wash wherein alcohol was the suspension or carrying agent.

The Inconel 713C was melted in a 600 lb capacity, 3000 cps, 100 kw induction furnace. To reduce losses of titanium and aluminum a heavy slag cover, made up mainly of calcium fluoride, and an argon blanket were employed. The metal was cast in the temperature range 2920°-2960°F. Figure 5 illustrates the lower experimental "extrusion-forging" hot die after removal of heads and light sand blasting. This casting will be suitable for service as a hot die after the horizontal seating and mating surfaces are ground flat.

C. Alternative Hot Die Materials

Several newly developed alloys have some interest as alternative die materials. One of these, IN-100, developed by International Nickel Company, may have better hot mechanical properties than the 713C alloy employed thus far for the hot dies. To obtain a comparative evaluation of the mechanical properties of these two alloys, after air melting rather than the conventional vacuum melting, a series of test bars have been investment cast. These test bars were typical of those normally used for evaluation of investment cast alloys, having threaded ends and a 1 inch gauge length with a diameter of 0.250 inch. To ensure that tensile fracture occurred within the gauge length a 1/2-inch center portion was reduced by grinding from 0.250 inch to 0.200 inch diameter.

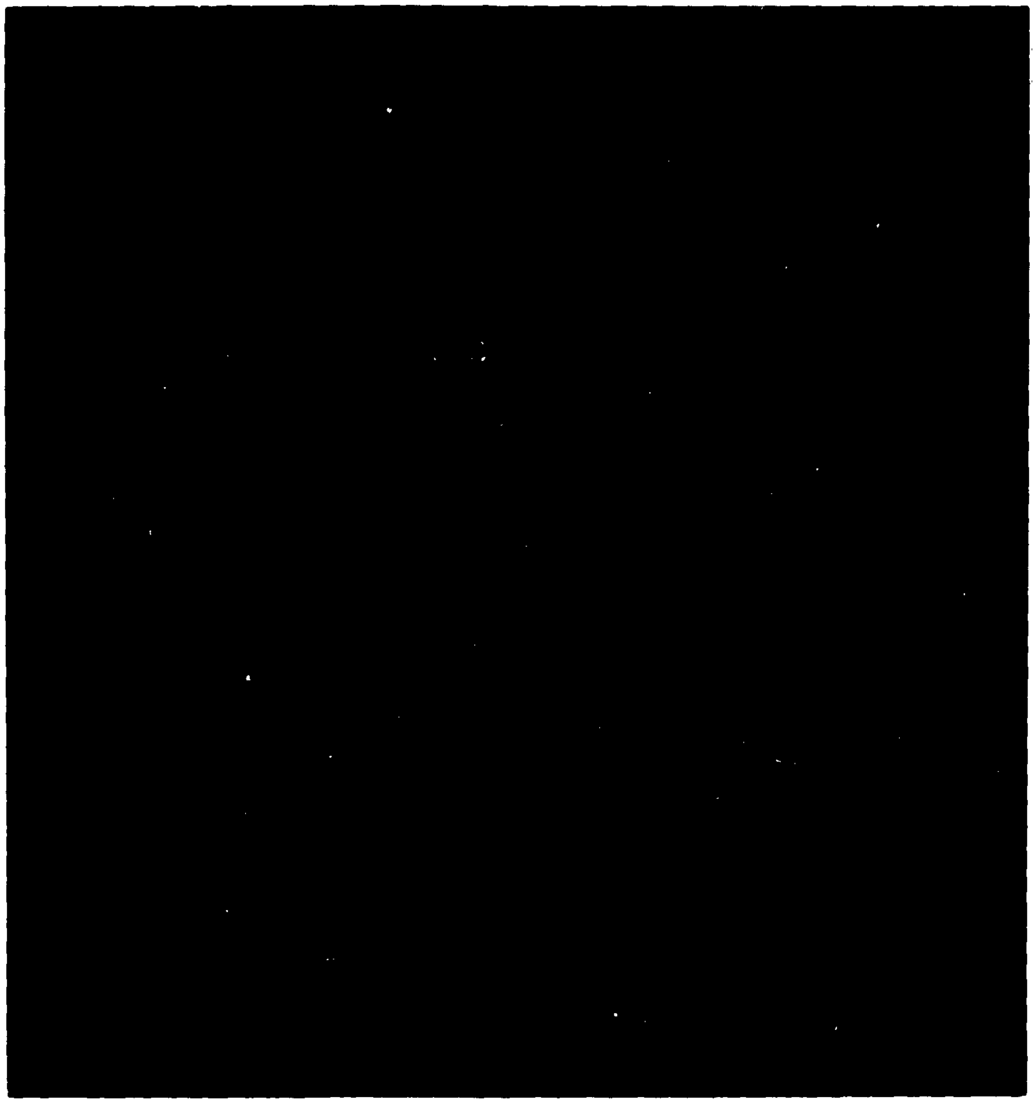

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Fig. 5 - Inconel 713C Experimental Extrusion Forging Die Block Casting.

The tensile properties of the air-melted IN-100 alloy and Inconel 713C are exhibited in Tables III and IV, respectively.

It can be seen that IN-100 is generally superior to Inconel 713C insofar as strength is concerned but somewhat poorer in ductility. In both instances mechanical properties obtained from the air-melted test bars compare quite favorably with those obtained from the vacuum-melted stock, with the exception of ductility as measured by elongation. However, in this hot die application it is considered that this factor is not necessarily detrimental to service utility.

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

A. Selection of Materials

The properties required of a die material which will operate at 2400°F and forge molybdenum stock at 3000°F are principally as follows:

1. High flow stress at temperature
2. Toughness under non-axial loading at temperature
3. Oxidation resistance in service.

In addition, availability in large section sizes and material cost have to be considered. Several of the refractory alloys possess reasonably high tensile yield stresses at 2400°F. Selected tests have been performed upon candidate die materials to evaluate some of their applicability in this proposed service. The following tests have therefore been performed:

(a) Simple hot compression test
(b) Resistance to oxidation

The compression test specimens are 3/8 inch diameter by 3/4 inch high, and testing is performed in vacuum. The compression yield stress results for refractory metal systems obtained during the current work period are contained in Table V.

These data show the superiority of TZC alloy as a die material, for highly stressed conditions, when compared to the other candidate refractory metal materials. P1 would also appear to have considerable merit as a die material.

TABLE III

MECHANICAL PROPERTIES OF AIR-MELTED AND VACUUM-MELTED IN-100 ALLOY

Testing Temperature, °F	UTS, kpsi	0.2% Yield Stress, kpsi	Elongation, per cent
	Air-Melted		
1400	148.0	140.0	3.0
1900	49.5	43.0	3.0
2000	37.0	33.0	3.8
2100	20.5	19.0	4.3
	Vacuum-Melted		
1400	139.0	120.0	6.0
1900*	60.0	43.0	6.0
2000*	40.0	29.0	6.0
2100*	24.0	16.0	6.0

* Extrapolated data.

TABLE IV

MECHANICAL PROPERTIES OF AIR MELTED AND VACUUM-MELTED INCONEL 713C ALLOY

Testing Temperature, °F	UTS, kpsi	0.2% Yield Stress, kpsi	Elongation, per cent
		Air-Melted	
1400	118.0	113.0	2
1600	94.0	84.0	6
1600*	99.5	91.0	7.6
1700	73.5	64.0	13.0
1800	54.0	45.0	13.0
1900	>35.0	>31.5	Broke outside gauge length.
2000	>15.0	>12.5	Broke outside gauge length.
2100	5.0	4.0	72
		Vacuum-Melted	
1600	92.0	81.0	8.0

All test bars except* heat treated by heating to 1700°F for 16 hr followed by air cooling.

* Heated to 2150°F - 2 hr - air cool - reheat to 1700°C for 16 hr - air cool.

TABLE V

COMPRESSION TEST DATA ON CANDIDATE REFRACTORY METAL DIE MATERIALS TEST TEMPERATURE 2400°F

Material	Prior Heat Treatment	Compressive Yield Stress, psi
TZM (Mo Alloy)	Heated to 3000°F for 1/2 hr, Cool to Room Temp.	17,211
Cross Rolled W	None	16,555
15% Recryst.	90 hr at 2400°F	15,486
P1 (85W-15Mo)	None	27,629
	None	36,054
	90 hr at 2400°F	33,155
P4 (97W-3Mo)	None	23,462
	None	24,184
	90 hr at 2400°F	24,277
F48 (Cb Alloy)	None	36,235
	None	26,044
	90 hr at 2400°F	24,365
TZC (Mo Alloy)	None	39,580
	None	38,952
	90 hr at 2400°F	38,319

The experimental materials ordered earlier in the program were received at the Foundation, and elevated temperature compression data were determined for this series of candidate ceramic and graphitic materials. Cylindrical test specimens were utilized, 3/8 in. diameter x 3/4 in. long; the specimen ends were squared off by grinding to minimize the effects of nonaxial loading. The tests were performed in an atmosphere of helium under reduced pressure at a temperature of 2400 °F using the apparatus and techniques described previously. The results of this work are presented in Table VI. In the initial testing sequence one sample of each material listed in the table was evaluated. A 2400 °F compression strength of 30,000 psi was selected as representing the minimum acceptable value for this application, and the second test series was limited to materials which exceeded this criterion. Four of the ceramic materials exhibited strengths greater than 30,000 psi at 2400 °F, and duplicate tests were performed accordingly (Table VI). KT silicon carbide and titanium diboride appeared to merit special consideration as they indicated elevated temperature compression strength values in the 50,000 to 60,000 psi range.

The establishment of 30,000 psi as a minimum strength requirement excluded the three graphitic materials and the aluminum oxide (non-Lucalox type). Although the high-density and siliconized graphites represented a significant improvement as compared to the commercial grade (ATJ), they remained considerably below the 30,000 psi minimum value. As a consequence, graphite and aluminum oxide were eliminated from further consideration as candidate die materials. It was originally intended to test commercial graphite (ATJ) impregnated with difurfuryl alcohol (ASD Interim Report 7-886 (III)); however, the untreated commercial graphite was so weak that this material was also eliminated. Carbofrax, a commercial silicon carbide brick material was not tested either, as it appeared to have too great a degree of porosity for this application.

Pyrolytic graphite was under consideration as a candidate material. Currently, only relatively thin coatings (e.g., up to 0.010 in. thick) deposited on a graphitic base have proven to be practicable. Although pyrolytic graphite has some interesting properties, in its present state of development it does not appear to be applicable to the requirements of this program.

TABLE VI

COMPRESSION STRENGTH OF POTENTIAL HOT DIE MATERIALS AT 2400°F

Material	Compression Strength, psi	
TiB_2	51,700	53,000
KT SiC	60,100	59,100
Refrax	31,400	34,000
Ta_2Be_{17}	47,200	46,300
ATJ commercial graphite	8,000	
ZT 4001 high-density graphite	17,000	
Siliconized graphite	14,900	
Al_2O_3	3,300	

Determinations of oxidation resistance were carried out for KT silicon carbide, Refrax, and titanium diboride. Although the elevated temperature compression strength of tantalum beryllide indicated a good deal of promise, oxidation tests were postponed temporarily for reasons of safety. Tantalum beryllide will be held in reserve as a candidate material, and further work will be initiated, with full safety precautions if the need for an additional material arises. The other materials, positioned in zirconia boats, were tested in flowing dry air at a temperature of 2400 °F. Duplicate tests were performed, and the data are given in Table VII. On the basis of weight loss, the KT silicon carbide was the most oxidation resistant of the three materials. One of the specimens was virtually unaffected while the other indicated some evidence of melting. Discrete globules of melted metal were present in minor amounts on the surface; this did not appear to present a serious problem, however. Refrax, the second most oxidation-resistant material, was glazed on the surfaces exposed to the air in both instances. This may not prove to be a serious disadvantage in service, however. The titanium diboride specimens, which were the least oxidation resistant, developed a brittle skin over the entire surface. This was borne out by the extensive increase in weight accummulated over the 100-hour testing period. Oxidation testing did not appear to influence the over-all adherency of the material, but further investigation will be required to determine the full extent of this effect.

The next step in the development of hot die materials will involve an evaluation of the three ceramics described above in a hot punch set-up. Currently arrangements are being made to obtain these materials in the form of 2 in. diameter tapered punches approximating the male portion of the hot forging die. An experimental approach is being planned in which the punches, heated to 2400°F by a gas burner system, will be applied to hot cupping operations of a tungsten or molybdenum alloy. This type of test will begin to approach the conditions which will occur in an actual forging operation, especially with regard to biaxial loading, and will be expected to provide a better evaluation of the applicability of these materials to high-temperature forging practice.

TABLE VII

OXIDATION TESTS OF CERAMIC MATERIALS IN DRY AIR AT 2400°F

Material	Initial Weight, gm	Accumulated Time, hr	Accumulated Weight Loss or Gain, gm
KT SiC	4.517	1	-0.004
		6	+0.001
		24	0.000
		32	+0.001
		50	+0.003
		58	0.000
		74	+0.002
		80	+0.001
		100	+0.004
KT SiC	4.633	50	+0.001
		100	+0.001
Refrax	3.648	1	-0.002
		6	+0.005
		24	+0.009
		32	+0.006
		50	+0.012
		58	+0.008
		74	+0.010
		80	+0.010
		100	+0.014
Refrax	3.683	50	+0.005
		100	+0.002
TiB_2	5.873	1	+0.002
		6	+0.048
		24	+0.102
		32	+0.128
		50	+0.143
		58	+0.188
		74	+0.248
		80	+0.273
		100	+0.326
TiB_2	5.816	50	+0.198
		100	+0.328

B. Die Protection

Work on the protection of the die materials against oxidation has continued. Samples of TZC, P1, P4, and cross-rolled tungsten have been prepared for coating. The Chromalloy Corporation indicated they have developed a new coating, W3, for use on molybdenum alloys. This coating is claimed to be superior to W2 which, within the limits of the ARF evaluation, was better than all other coatings tested. Accordingly, a number of samples of the aforementioned materials will be submitted to Chromalloy Corporation for coating and subsequent evaluation.

A further complementary protection system may also be applied to the hot refractory metal dies. This would involve the coating of the hot dies with a salt or slag with a melting point within the range 2000 to 2300°F. This would contain a reducing agent such as powdered carbon, graphite, aluminum, or titanium. The function of the latter elements would be to act as oxygen getters for any oxygen that might diffuse through the salt or slag layer. The slag or salt would also act as a die lubricant. Experimental apparatus will be assembled during the next work period to investigate the feasibility of this approach toward die protection.

III. SUMMARY

Work has continued on the first three phases of the research, comprising the related objectives of:

a) Extending the upper temperature limit of the present hot die system.

b) Minimizing the required forging sequences by using hot dies.

c) Evaluating new materials for use as a 2400°F forging die.

The ultimate objective is a creation of a true hot working technology for refractory metals.

Forging experiments conducted with the hot die system proved the assembly capable of forging at 1700°F under a 1000-ton load. No die deformation was detected under these conditions. As the temperature of the die was increased, the thermal gradient between heaters and the die surface increased. This increased gradient subjects the supporting heater block to loads near its yield strength at temperature.

A set of dies for use in the extrusion-forging experiments has been successfully cast of Inconel 713C. These dies are being final machined and are scheduled to be installed in the press when the destructive testing of the first die set is completed.

Die materials for use at 2400°F were evaluated by hot compressive testing. This testing was conducted on TiB_2, KT SiC, Ta_2Be_{17}, Al_2O_3, high-density graphite, siliconized graphite, and commercial graphite.

IV. FUTURE WORK

Phase I

Forging experiments to determine the upper temperature limit of the present hot die system will continue.

Phase II

The dies for use in the extrusion-forging experiments will be installed in the forging press upon completion of Phase I work, and experiments to reduce die sequences will start.

Phase III

Design and construct a high-temperature cupping operation for further evaluation of KT silicon carbide, Refrax, and titanium diboride as potential hot forging die materials. Consider approaches for designing a workable high-temperature forging die system based on the materials described above.

V. LOGBOOKS AND CONTRIBUTING PERSONNEL

Data gathered during the research work are contained in ARF Logbooks C 11166, C 11167, C 11168, C 11169, and C 11908. Foundation personnel include:

P. R. Gouwens	T. Watmough	R. Corrado
A. H. Murphy	H. B. Nudelman	
W. Rostoker	R. J. Van Thyne	
J. Dorcic	R. Domkowski	

Respectfully submitted,

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

A. H. Murphy

A. H. Murphy, Associate Metallurgist

T. Watmough, Research Metallurgist

H B Nudelman

H. B. Nudelman, Research Metallurgist

Approved:

Paul Gouwens

P. R. Gouwens, Supervisor
Foundry & Steelmaking Research

Ray J. Van Thyne

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

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