

UNCLASSIFIED

AD 408 607

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. 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.

63 4.2

408607

AMC TR 7-866 (V)

AMC INTERIM REPORT 7-866 (V)

Western Gear Report No 635-214

MAY 1963

CATALOGED BY DDC

AS AD No.

408 607

HIGH ENERGY RATE FORGING DEVELOPMENT

J. M. Palsulich

Western Gear Corporation
Systems Management Division
&
Precision Forge Co.
(Forging Subcontractor)

Contract: AF 33 (600)-42523

AMC Project: TR 7-866

Fifth Interim Technical Progress Report

10 October 1962 - 10 May 1963

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

DDC
RECEIVED
JUL 17 1963
JISIA D

Western Gear Report No. 635-214

AMC TR 7-866 (V)
May 1963

HIGH ENERGY RATE FORGING DEVELOPMENT

J. M. Palsulich

WESTERN GEAR CORPORATION
Systems Management Division
and
Precision Forge Company
(Forging Subcontractor)

Contract: AF 33(600)-42523
AMC Project: TR 7-866 (V)
ASD Project Engineer: L. C. Polley

Fifth Interim Technical Progress Report
10 October 1962 - 10 May 1963

AMC Aeronautical Systems Center
United States Air Force
Wright-Patterson Air Force Base
Dayton, Ohio

ABSTRACT - SUMMARY

Successful high energy rate forging of unwrought refractory materials is highly dependent upon the forging configuration and die design. Good forgings are possible when working stresses are compressive in nature. Tensile and shear stresses during forging generally result in fracturing of the billet if the refractory metals have received little or no plastic work.

Data for forging conditions and results of metallurgical examinations are presented.

FOREWORD

This Interim Technical Progress Report covers a portion of the work on Phase III performed under Contract AF 33(600)-42523 from October 1962 to May 1963. It is published for technical information only, and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This program is being conducted by the Systems Management Division of Western Gear Corporation, Lynwood, California. It is under the direction of Mr. L. C. Polley of the ASD Basic Industry Branch, Wright-Patterson Air Force Base, Ohio. Mr. J. M. Palsulich, Research Metallurgist is project engineer and technical supervisor. Mr. M. L. Headman, Manager of Research is program manager.

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.

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

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
Program Objective	1
Phase I - State-of-the Art Analysis	2
Phase II - Forging of Low and Medium Temperature Alloys	2
Phase III - Forging of Two Refractory Metals	2
DISCUSSION OF PHASE III	3
Results	3
I. Billet Material Examination	3
II. Closed Die Forging	5
III. Micro-Examination of Forgings	8
CONCLUSIONS	11

LIST OF TABLES

<u>Table Number</u>		<u>Page</u>
I	Analysis of Tungsten and TZM Molybdenum Billets	4
II	Forging Conditions for TZM Molybdenum Alloy Rocket Nozzle Inserts	7
III	Forging Conditions for Tungsten Rocket Nozzle Inserts	9

LIST OF FIGURES

<u>Figure Number</u>		<u>Page</u>
1	Macroetch arc-melted tungsten billet	12
2	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	13
3	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	13
4	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	14
5	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	14
6	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	15
7	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	15
8	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	16
9	Photomicrograph of forged, pressed and sintered TZM molybdenum alloy	16
10	Photomicrograph of as-received TZM pressed and sintered billet	17

LIST OF FIGURES - (Continued)

<u>Figure Number</u>		<u>Page</u>
11	Photomicrograph of as-received tungsten pressed and sintered billets	17
12	High energy rate forged TZM molybdenum rocket nozzle insert	18
13	Arc melted TZM rocket nozzle insert	19
14	Pressed and sintered TZM rocket nozzle insert	19
15	Macroetched section of arc melted TZM billet in blocked condition	20
16	Typical example of failure in arc melted TZM molybdenum alloy.	21
17	Typical example of failure in arc melted TZM molybdenum alloy	22
18	Macroetched section of the forging illustrated in Figures 16 and 17	23
19	Macroetched section of blocked tungsten forging	24
20	Top view of forging seen in Figure 19	25
21	Example of intragranular type cracking	26
22	Example of intragranular type cracking	26
23	Photomicrograph of banded area	27
24	Photomicrograph of as-forged, Group I, arc melted TZM forging	27
25	Photomicrograph of as-forged, Group I, arc melted TZM forging	28
26	Photomicrograph of as-forged, Group I, arc melted TZM forging	28
27	Photomicrograph of pressed and sintered TZM billet forged in Group III	29

INTRODUCTION

The refractory metals are a group of materials which generally include those metals whose melting points are equal to, or higher than, 3400°F. There are many refractory metals with widely varying properties and availability. At the present time, these metals are the subject of intensive investigation because their high temperature strengths and high melting points are required in space vehicles, advanced aircraft, and nuclear energy applications. For various economic and technological reasons the refractory metals currently of most importance are tungsten, tantalum, molybdenum, niobium and chromium.

The production, fabrication and machining of the refractory metals present major problems which result in elevated costs. Using presently accepted forging and manufacturing techniques, as much as 350 pounds of material are required to make a 35 pound part. Therefore, any improvement in forging technique that can provide better material utilization will result in greater efficiency of the forging process and provide substantial cost savings. These cost savings are possible through reduction of initial material costs and substantial reduction in the cost of machining to finished dimension.

This investigation of high energy rate forged refractory materials was prompted by the demonstrated ability of the high velocity forging process to produce close tolerance precision forgings while providing better material utilization. Effective utilization of the process is also enhanced by the fact that forging temperature for a given material can be reduced to within the furnace capabilities of most companies in the metalworking field.

All forging in this program is being performed on a 1220 B Dynapak high energy rate forging machine manufactured by the Advanced Products Department of General Dynamics Corporation. This report discusses the experimental results obtained during the reporting period from 10 October 1962 to 10 May 1963.

Program Objective

The objective of this program is to determine the suitability of the high energy rate forging process using a Dynapak machine for the production of aerospace hardware. The investigation includes a variety of materials of current interest. Emphasis is placed on evaluating the metallurgical structure and the mechanical properties of the materials when forging parameters are varied. Information on die design, forging temperature, mechanical properties, hardness, microstructures and other pertinent material and manufacturing data will be developed.

Phase I - State-of-the Art Analysis

During this phase, a state-of-the art survey was conducted to determine current activity in high velocity pneumatic forging. During this phase, a satisfactory procedure for subsequent phases was established.

Phase II - Forging of Low and Medium Temperature Alloys

Under this phase, high velocity forging of the following materials was studied: 6 Al-4V alpha-beta titanium alloy; AISI 4340 medium alloy steel; type H-11 tool steel; and PH 15-7 Mo precipitation hardening stainless steel. Phase II was divided into two sections: upset forging billets to approximately 80% reduction, and the forging of specific geometries.

Phase III - Forging of Two Refractory Metals

This phase is to investigate the possibility of forging commercially pure tungsten and TZM molybdenum alloy to close tolerances and to determine the various forging parameters necessary to insure high quality forgings. After forging parameters have been established, subsequent forging of specific geometries will be accomplished.

DISCUSSION OF PHASE III

Materials and Procedure

Two materials are currently being investigated under Phase III of the program, i. e., commercially pure tungsten and the TZM molybdenum alloy. Pressed-and-sintered and arc melted-and-centrifugally cast billets of both tungsten and TZM molybdenum alloy are used as starting material. All billets have the nominal dimensions of two inches in diameter by two inches long. The arc melted billets were ultrasonically inspected and all were sound. Both the pressed and sintered and arc melted billets were found to be free from any surface cracks when examined by the dye penetrant inspection method. Chemical analysis of the billets as supplied by the vendors is shown in Table I.

During this reporting period work continued on developing forging techniques to forge these materials into a rocket nozzle insert as shown in Figure 12. All billets were heated to forging temperature in a Lindberg recirculating gas-fired furnace. Heating was accomplished without the use of a protective atmosphere since it was previously established that metal losses due to oxidation were relatively low (under 3%).

Subsequent to forging, all parts were placed in lime to prevent rapid cooling and cracking. Stress relieving and recrystallization was performed under an argon atmosphere in a Pereco glo-bar furnace.

The rocket nozzle inserts were forged in two stages. Blocking was performed using a flat punch and the finisher bottom die. Finishing was performed with the bottom die used in the blocking operation and a punch that conformed to the I. D. dimensions of the finished part.

It should be noted that both the TZM molybdenum arc melted and centrifugally cast billets and the TZM alloy pressed and sintered billets used in this program had never been produced before and were considered experimental by the suppliers.

Results

I. Billet Material Examination

Many problems occurred during the development forging of the rocket nozzle configuration. Generally speaking, the blocking operation presented very few difficulties. However, in most cases, severe cracking occurred during finish forging of the blocked parts. The following procedures were observed:

TABLE I
ANALYSIS OF TUNGSTEN AND TZM MOLYBDENUM BILLETS

Element	<u>Pressed and Sintered Billets</u>		<u>Arc Melted Billets</u>	
	Tungsten (ppm)	TZM Molybdenum (ppm)	Tungsten (ppm)	TZM Molybdenum (ppm)
C	*30	40	40	230
O ₂	*50	2300	*20	50
Ti		4400		5000
Zr		1250		650
N ₂	*30	25		
H ₂	1.5	4.4		
Al	*20	*20		
Co	*20	*20		
Cr	*20	*20		
Cu	*40	*40		
Fe	*100	*100		
Mg	*20	*20		
Mn	*20	*20		
Ni	*25	60		
Pb	*20	*20		
Si	*100	100		
Sn	*50	60		
V		25		
Mo		Remainder	2800	Remainder
W	Remainder		Remainder	650

* Less than

A. Macro-Examination

Macro-examination of the arc melted tungsten and TZM billets disclosed a columnar grain structure at one end of the billet and the equi-axed grains at the other end (Figure 1). Most of the billets had been forged before this fact was discovered. Upon checking with the supplier, it was learned that seven tungsten and seven TZM molybdenum alloy billets could have been in this condition. All of the TZM alloy billets with the columnar structure and all but one of the tungsten billets were forged.

Grain size of the as-received pressed and sintered billets ranged between 4 and 6 on the ASTM ferrous grain size charts (Figures 10 and 11). The arc melted tungsten grains were between 1/16 inch and 1/32 inch in diameter and some of the columnar grains were 3/4 inch long. Grains in the arc melted TZM molybdenum billets were slightly smaller than those in the arc melted tungsten billets.

B. Micro-examination

An extensive micro-examination of the forged pressed and sintered TZM alloy parts showed a large number of inclusions and many areas of porosity (Figures 2-9). Hardness of the inclusions was determined on a Wilson microhardness tester utilizing a 100 gram weight. The average Knoop hardness of the particles was 900. This roughly corresponds to a Rockwell C hardness of 67. It is thought that these particles may be a titanium carbide. However, no analysis was performed to verify this.

II. Closed Die Forging

A. TZM Molybdenum

In the previous reporting period, the program had met with a large degree of success. Sound forgings having a wall thickness of approximately 0.090 inch were produced from both arc melted and pressed and sintered billets (Figures 12, 13 and 14). These forgings were produced in the following manner.

Blocking was performed in one blow using a fire pressure of 900 psi, 6-3/8 inch stroke, and 2200°F forging temperature. The blocked forgings (Figure 15) were then cooled in lime to room temperature. Next, the forgings were heated to 2050°F and struck two to three blows in the finisher dies with a fire pressure of 400 psi. Reheating was performed between each blow. This procedure resulted in sound forgings approximately 80% of the time (Figures 12, 13 and 14).

During the present reporting period, a new approach was taken. It was decided to lower the forging temperature during the blocking operation to 2100°F and use two to three blows of low energy to block the parts.

Group I. Three arc-cast billets were struck three blows in the blocker die with a fire pressure of 450 psi and a forging temperature of 2100°F.* There was no evidence of cracking after the first, second or third blows. The same procedure was repeated for three pressed and sintered billets. One of the pressed and sintered billets cracked on the third blow. The part that cracked bounced out of the die as it was being struck.

The finisher die was placed in the machine and one of the pressed and sintered billets was struck at 1950°F with a fire pressure of 500 psi. It exhibited severe radial cracking through the flash zone and into the body to the forging. Next, the forging temperature was increased to 2050°F keeping the fire pressure at 500 psi. This forging cracked in the same manner as the previous one. Maintaining the 2050°F forging temperature, the next three forgings were struck blows at 400 psi. One of the three cracked radially through the flash (Figures 16, 17 and 18).

Two forgings out of the original six were sound at this time. Using a forging temperature of 2050°F and a fire pressure of 400 psi, both parts were struck. The wall thickness at this time was approximately 0.120 inch. It was decided to give each part one final blow at 500 psi fire pressure in order to reduce the wall thickness to 0.100 inch. Both forgings severely cracked during this operation.

Group II. Two arc cast and two pressed and sintered TZM molybdenum alloy billets were struck three blows in the blocker die using a fire pressure of 600 psi and a forging temperature of 2100°F. All blocked forgings were sound. The forgings were then stress relieved at 2500°F for one hour. All of the stress relieved forgings were struck in the finishing dies utilizing a forging temperature of 2100°F and a fire pressure of 500 psi. Two of the forgings cracked. One of the remaining two was restruck under the above conditions. This forging also cracked. The other forging was struck on another day using an incorrect bottom die. This incorrect die was identical to the one being utilized on this program except that the diameter was approximately 3/4 inch smaller. Five tungsten and three TZM molybdenum alloy billets were blocked in this small die. The results of using this small die are discussed elsewhere in this report.

Group III. Two arc melted and one pressed and sintered were blocked using two blows at 750 psi fire pressure at 2100°F. The forgings were subsequently stress relieved for one hour at 2500°F under an argon

* Reheating is performed between blows in all cases.

TABLE II
FORGING CONDITIONS FOR TZM MOLYBDENUM ALLOY ROCKET NOZZLE INSERT

Billet Designation	Blocking Operation						Finishing Operation						Remarks			
	First Blow			Second Blow			Third Blow			Second Blow				Third Blow		
	FP psi	Temp °F	Temp °F	FP psi	Temp °F	Temp °F	FP psi	Temp °F	Temp °F	FP psi	Temp °F	Temp °F		FP psi	Temp °F	Temp °F
TZMC-1	1100	2200					700	2200								Flash cracked in blocking. Cracked areas removed and forgings struck in finisher. Incomplete fill in some areas.
	1100	2200					700	2200								
	1100	2200					700	2150								
TZMP-1	1000	2200					700	2200								Some parts edge cracked in final blow - two excellent forgings.
	1000	2200					700	2150								
	1000	2200					700	2150								
TZMC-4	900	2200					400	2050								Part cracked final blow
	900	2200					400	2050								
	900	2200					400	2050								
TZMP-9	450	2100					400	2050								Cracked severely
	450	2100					400	2050								
	450	2100					400	2050								
TZMP-10	450	2100					400	2050								Flash cracked into part
	450	2100					400	2050								
	450	2100					400	2050								
TZMP-11	450	2100					400	2050								Cracked in blocking
	450	2100					400	2050								
	450	2100					400	2050								
TZMP-12	600	2100					400	2050								Flash cracked into part
	600	2100					400	2050								
	600	2100					400	2050								
TZMC-13	600	2100					400	2050								Cracked at flash line
	600	2100					400	2050								
	600	2100					400	2050								
TZMP-14	750	2100					400	2050								Severely cracked
	750	2100					400	2050								
	750	2100					400	2050								

atmosphere. Next, the blocked forgings were struck with the finisher dies. The pressed and sintered part cracked and the arc melted ones held together. When the arc melted parts were restruck they fractured on one side. The fire pressure for both blows was 500 psi and the forging temperature was 2100°F.

All three billets were struck in blocking and finishing using the incorrect small diameter bottom die. It would be expected that the billets would rupture with the small die especially when the finisher punch was used.

The billet material was subject to extremely high shear loading at the entrance to the die due to the action of the punch and the under-size die.

Most of the other failures that were noted previously were located in the flash area and at the top of the forging. All of the failures occurring in conjunction with the under size die went well into the body of the forgings.

B. Commercially Pure Tungsten

For the most part, the tungsten closed die forging was unsuccessful. Blocking could be successfully carried out without any external signs of rupturing. All blocking of tungsten billets during this reporting period was carried out at 2600°F using a fire pressure of 1000 psi and a stroke of 8-1/2 inches.

Some of the blocked forgings were sectioned and macroetched. Both intracrystalline and intercrystalline cracks were evident (Figure 19). This was found to be true in both the pressed and sintered and arc melted materials.

Recrystallization of the blocked forgings made little difference in the forging characteristics of the materials. As long as the billets are subjected to compressive stress, little or no surface rupturing is observed. Once the parts are subjected to tensile or shear stresses, however, severe rupturing occurs in almost every instance.

It is believed that the use of wrought billet stock made little difference in this forging program. The presence of columnar grains (Figure 20) in some of the arc melted billets were also detrimental to the forging characteristics. In the majority of cases, the tungsten forgings had many cracks whereas the TZM forgings had only one or two cracks of limited length.

III. Micro-Examination of Forgings.

Samples for micro-examination were taken from most of the forgings. All specimens were removed using an abrasive cut-off saw with copious

TABLE III
FORGING CONDITIONS FOR TUNGSTEN ROCKET NOZZLE INSERTS

Bill D. S. ratio	Blocking Operation						Finishing Operation						Remarks
	First Blow		Second Blow		Third Blow		First Blow		Second Blow		Third Blow		
	F ₁ psi	Temp °F	F ₂ psi	Temp °F	F ₃ psi	Temp °F	F ₁ psi	Temp °F	F ₂ psi	Temp °F	F ₃ psi	Temp °F	
WP-14	100	2500											Bottom end and top cracked
WP-15	1000	2500											Bottom end and top cracked
WP-16	1200	2600											Bottom end and top cracked
WP-17	1200	2600											Bottom end and top cracked
WC-1	1200	2600					800	2400					Bottom stuck in die - tip reworked
WC-2	1200	2600					800	2400					Completely fractured
WC-3	1200	2600					800	2400					Small crack in flash area
WC-4	1000	2300					800	2400					Bottom broke off
WC-5	1000	2600					800	2400					Completely fractured
WP-18	1000	2600			Recrystallized at 2500°F for one hour		1000	2600					Completely fractured
WP-19	1000	2600			Recrystallized at 2300°F for one hour		800	2500					Severe fracturing
WC-5	1000	2600			Recrystallized at 2300°F for one hour								Part sectioned
WC-6	1000	2600			Recrystallized at 2300°F for one hour		800	2500					Severe fracturing
WC-14	1000	2600			Recrystallized at 2300°F for one hour		800	2500					Severe fracturing
WC-8	1000	2600			Recrystallized at 2300°F for one hour		800	2500					Severe fracturing
WC-10	1000	2600			Recrystallized at 2300°F for one hour								Only slight edge cracking
WC-12	1000	2600			With Blocking Die								Only slight edge cracking
WC-18	1000	2600			With Blocking Die								Only slight edge cracking
WC-19	1000	2300			With Blocking Die								Only slight edge cracking
WC-20	1000	2600			With Blocking Die								Only slight edge cracking
WC-1	1000	2600			With Blocking Die								Only slight edge cracking

amounts of water for cooling. Both the tungsten and the TZM molybdenum alloy samples were etched subsequent to final polishing with a modified Murakami's Reagent (25% glycerol - 75% Murakami's Reagent).

Figures 21 and 22 illustrate the intragranular type cracking noted in many of the failures. The material is forged arc melted TZM molybdenum alloy. It should be noted that the grain boundaries were very fine and did not present any obstacle to cracking. The banding that is visible was not observed in all forgings, nor was it in any of the as-received billets that were sectioned. Figure 23 is a view of the banded areas at 1000 X. In any given crystal, there are banded areas as well as non-banded areas.

Specimens were removed from one of the Group I arc melted TZM forgings. The specimens were forged at 2100°F and heat treated at 2300°F and 2350°F in some recrystallization primarily around the grain boundaries for three hours resulted in some recrystallization primarily around the grain boundaries and a small amount in the center of the crystals.

The pressed and sintered TZM billet forged in Group III was given a 2500°F heat treatment after forging. Only a small amount of recrystallization was observed and this was principally in the grain boundaries (Figure 27). All the forgings made from pressed and sintered billets showed very little, if any, evidence of recrystallization.

CONCLUSIONS

High energy rate closed die forging of unwrought refractory metals appears feasible providing the working stress in the part is compressive in nature. When the forging configuration is such that the principal stresses are tensile and/or shear, the forging of unwrought refractory metals is not practical. This conclusion is in conflict with the one contained in Interim Report IV in which it was stated that it would be practical to manufacture rocket nozzle inserts using unwrought arc cast materials.

It is believed that the compressive working of unwrought billets prior to forging would eliminate the problem of cracking due to tensile or shear working stress. This alternative could be evaluated with the die configuration utilized in this program.

The columnar grain structure found in some unwrought arc cast materials is very detrimental in the forging process. The use of extruded or rolled billets would obviate this condition. It is believed that high inclusion content and porosity in the pressed and sintered TZM molybdenum contribute to rupturing of the forgings. The use of arc cast and extruded billets should help to eliminate this problem.

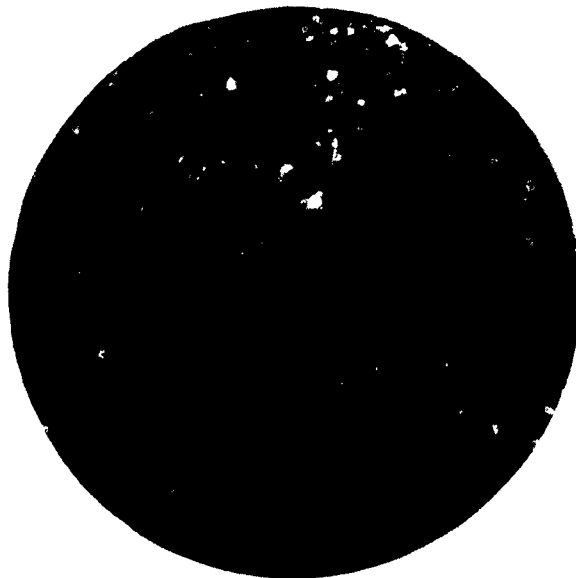


Figure 1 - Macroetch arc-melted tungsten billet showing equi-axed structure at one end and columnar grains on the other end. Approx. 1.5 X mag.

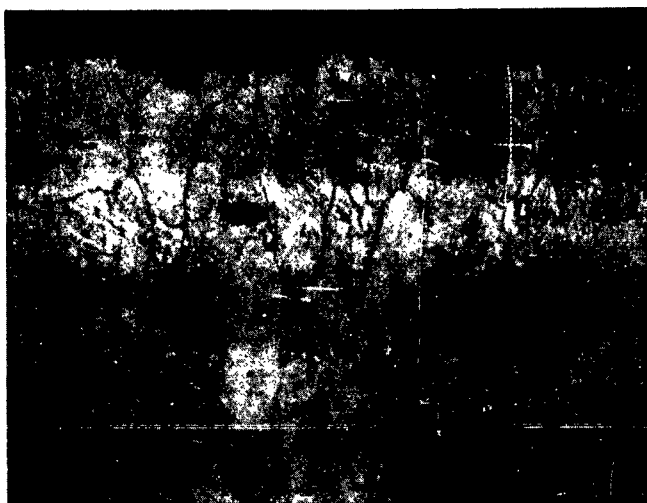


Figure 2 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100X mag. Etched with modified Murakami's Reagent



Figure 3 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100X mag. Etched with modified Murakami's Reagent

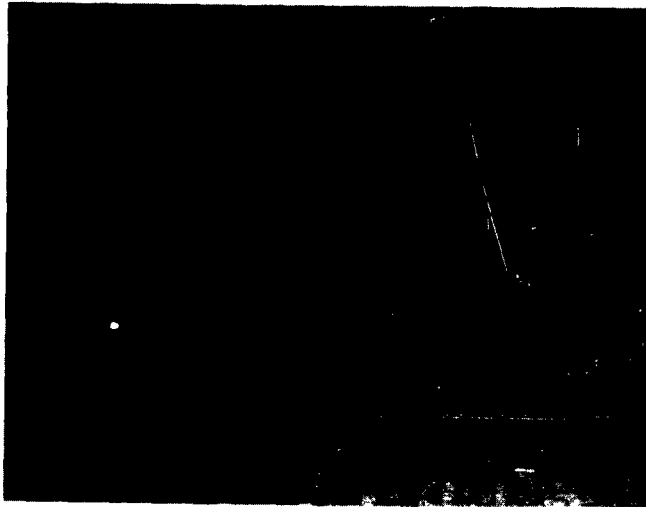


Figure 4 - Photomicrograph of forged, pressed and sintered TZM molybdenum alloy illustrating area of concentrated porosity. 100X mag. Etched with modified Murakami's Reagent.

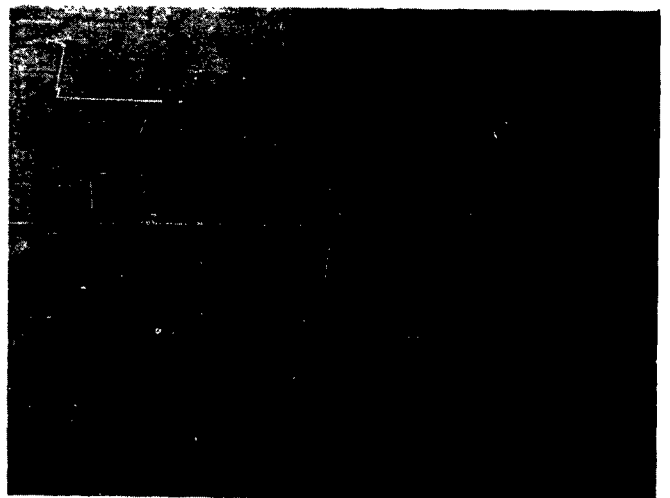


Figure 5 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100X mag. Etched with modified Murakami's Reagent.



Figure 6 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100 X mag. Etched with modified Murakami's Reagent.

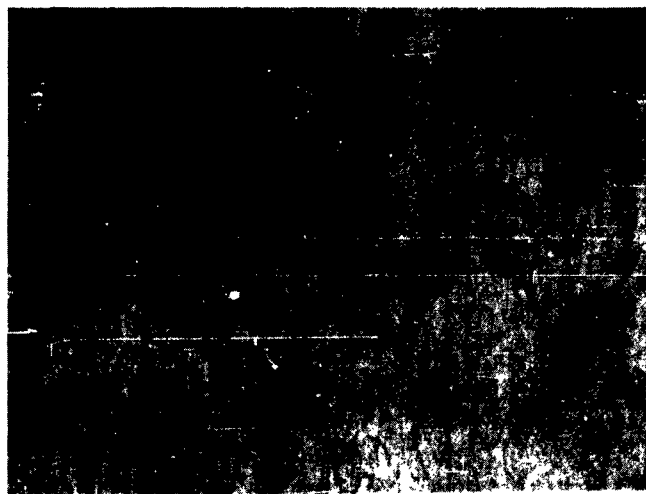


Figure 7 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100 X mag. Etched with modified Murakami's Reagent.

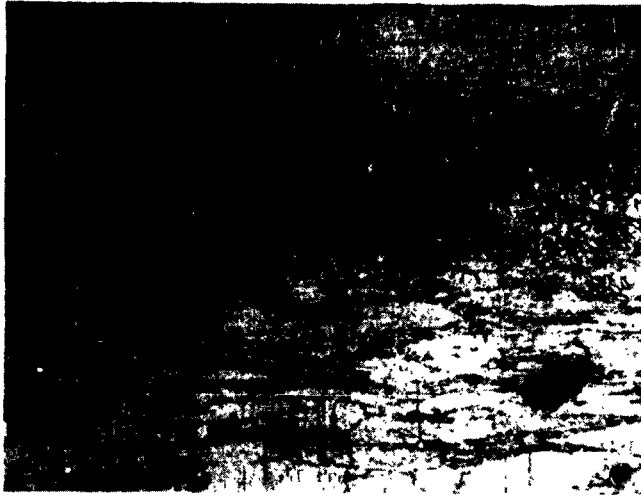


Figure 8 - Photomicrograph of forged, pressed and sintered TZM molybdenum alloy illustrating area of concentrated porosity. 100 X mag. Etched with modified Murakami's Reagent.

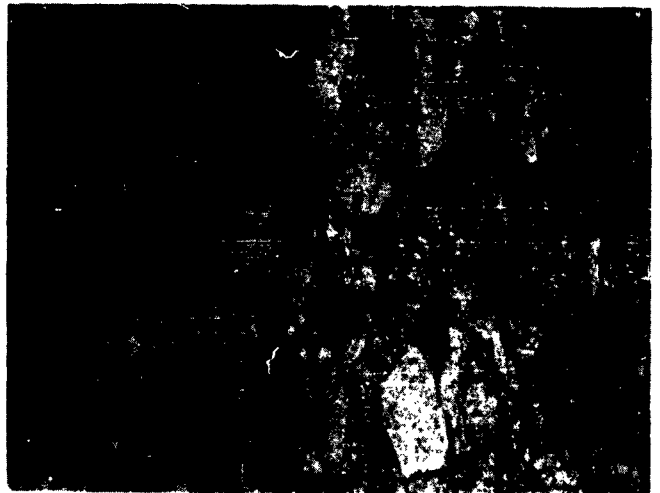


Figure 9 - Photomicrograph of forged pressed and sintered TZM molybdenum alloy. Note inclusions. 100 X mag. Etched with modified Murakami's Reagent.

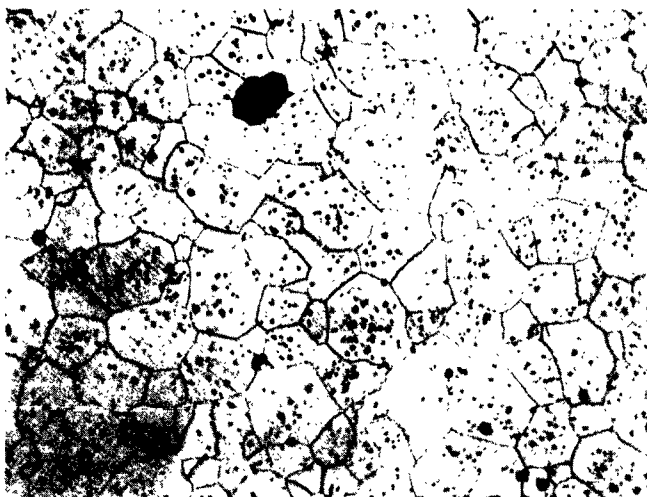


Figure 10 - Photomicrograph of as-received TZM pressed and sintered billet. 100 X mag. Etched with modified Murakami's Reagent.

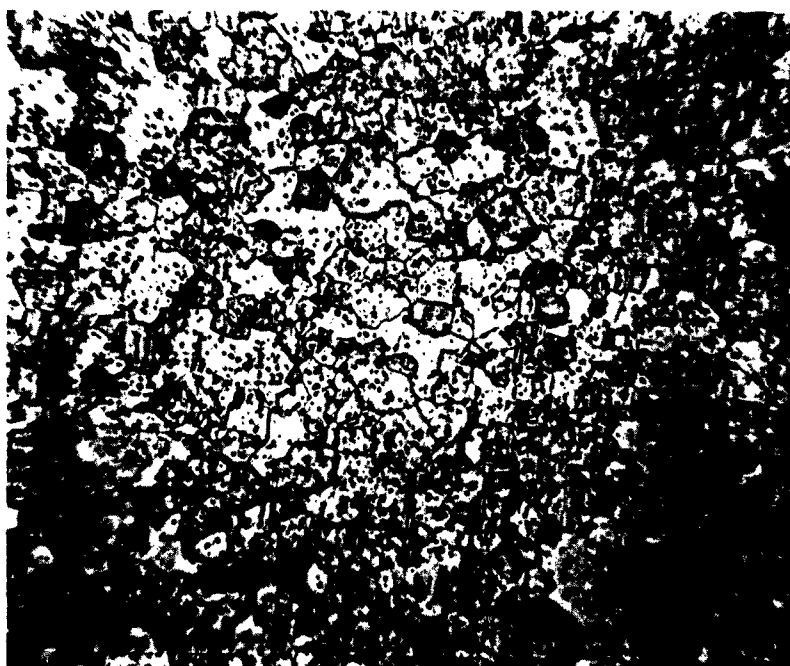


Figure 11 - Photomicrograph of as-received tungsten pressed and sintered billet. 100 X mag. Etched with modified Murakami's Reagent.



**HIGH - ENERGY - RATE - FORGED
TZM MOLYBDENUM
ROCKET NOZZLE INSERT**

Figure 12

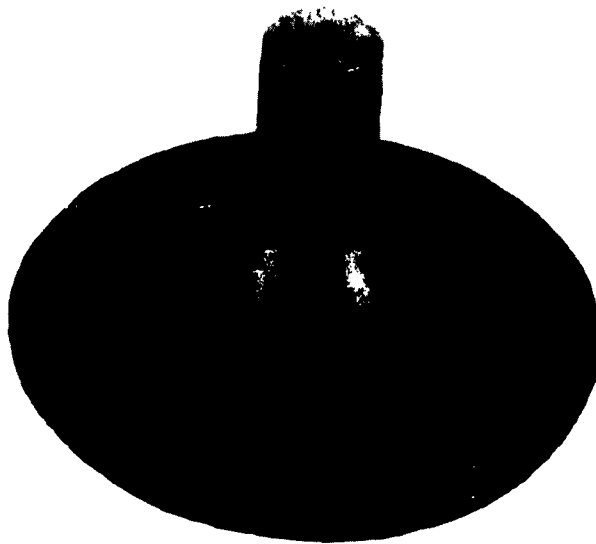


Figure 13 - Arc melted TZM billet
forged into rocket nozzle insert shown
in the as-forged condition.

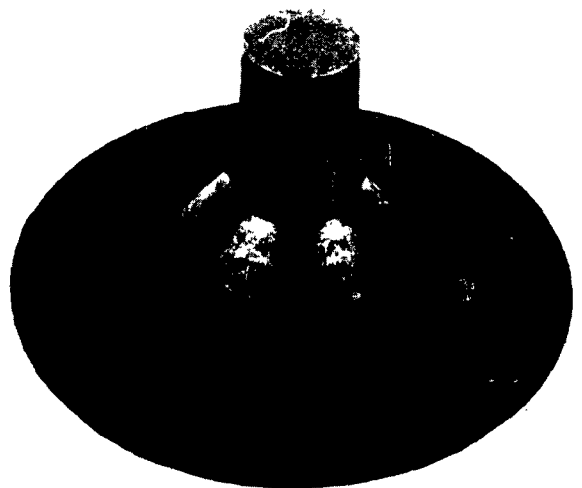


Figure 14 - Pressed and sintered TZM
billet forged into rocket nozzle insert
shown in the as-forged condition.

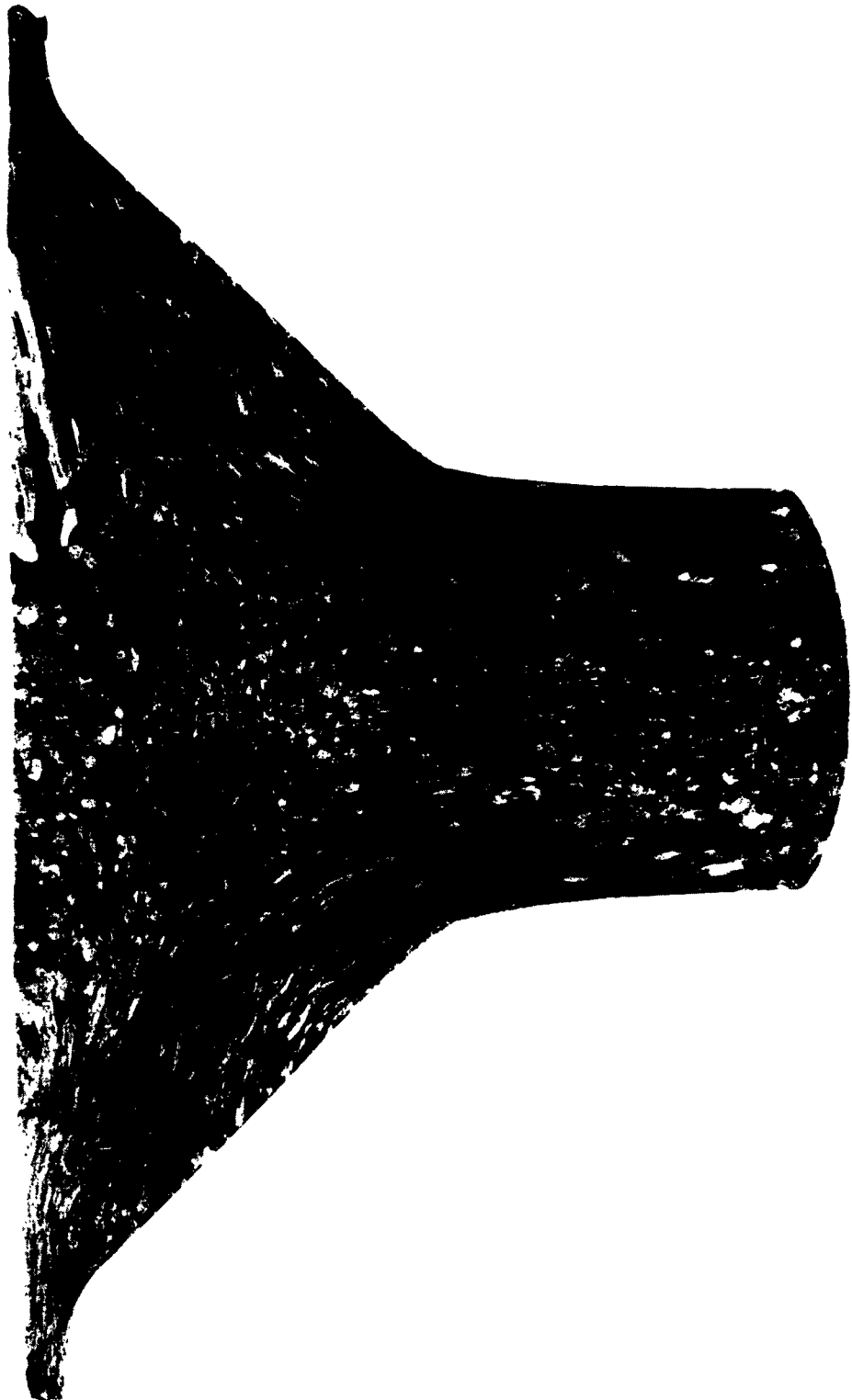


Figure 15 - Macroetched section of arc melted T'ZM billet in blocked condition. Crack occurred upon sectioning.



Figure 16 - Typical example of the type of failure experienced during the current reporting period. Material is arc melted TBM molybdenum alloy. Cracking was along grain boundaries.

Figure 17 - Typical example of the type of failure experienced during the current reporting period. Material is arc melted TZM molybdenum alloy. Cracking was along grain boundaries.



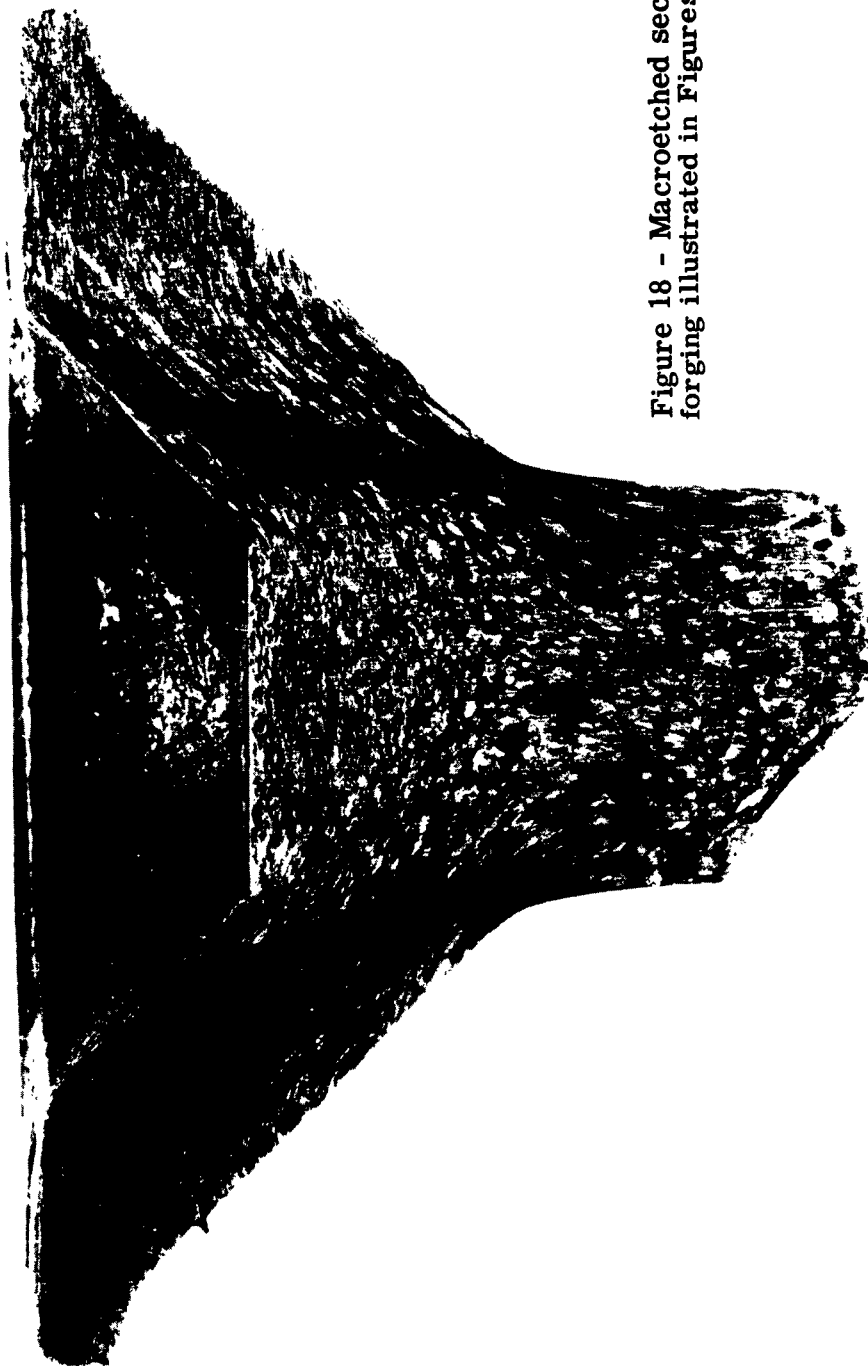


Figure 18 - Macroetched section of the forging illustrated in Figures 16 and 17.



Figure 19 - Macroetched section of blocked tungsten forging made from arc melted billet. Note crack on left side of forging. Cracks are both intra- and trans-granular in nature.



Figure 20 - Top view of forging seen in Figure 19. This forging was made from billet having columnar grain structure.



Figure 21 - Example of intragranular type cracking. Material is arc melted TZM molybdenum alloy. 100 X mag. Etched with modified Murakami's Reagent.



Figure 22 - Example of intragranular type cracking. Material is arc melted TZM molybdenum alloy. 100 X mag. Etched with modified Murakami's Reagent.

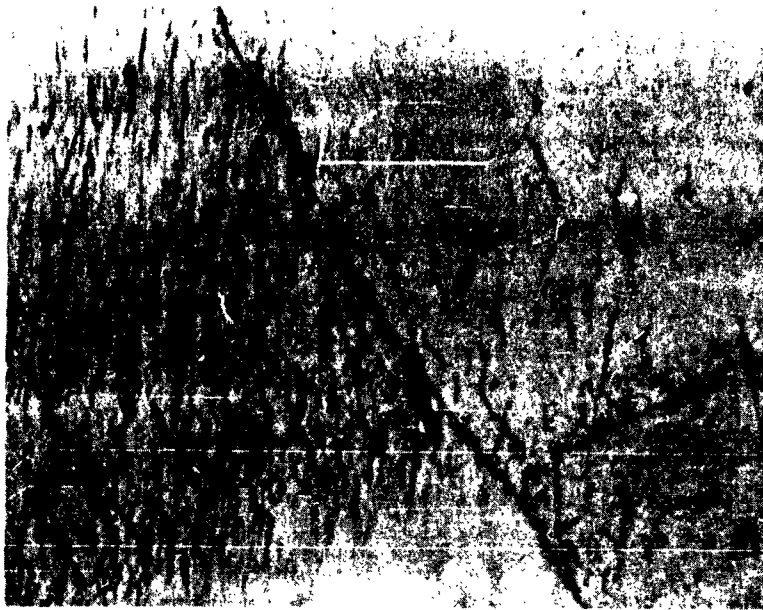


Figure 23 - Photomicrograph of banded area in forged TZM arc melted material. 1000 X mag. Etched with modified Murakami's Reagent.

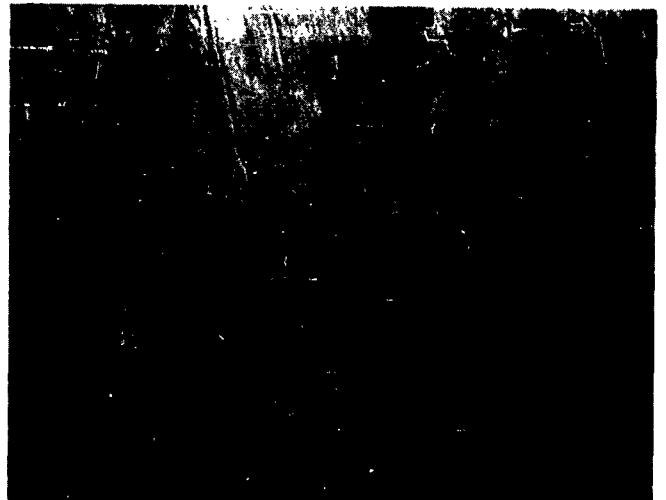


Figure 24 - As-forged, Group I, arc melted TZM forging. 100 X mag. Etched with modified Murakami's Reagent.



Figure 25 - As-forged, Group I, arc melted TZM forging heated at 2350°F for two hours subsequent to forging. 100 X mag. Etched with modified Murakami's Reagent.

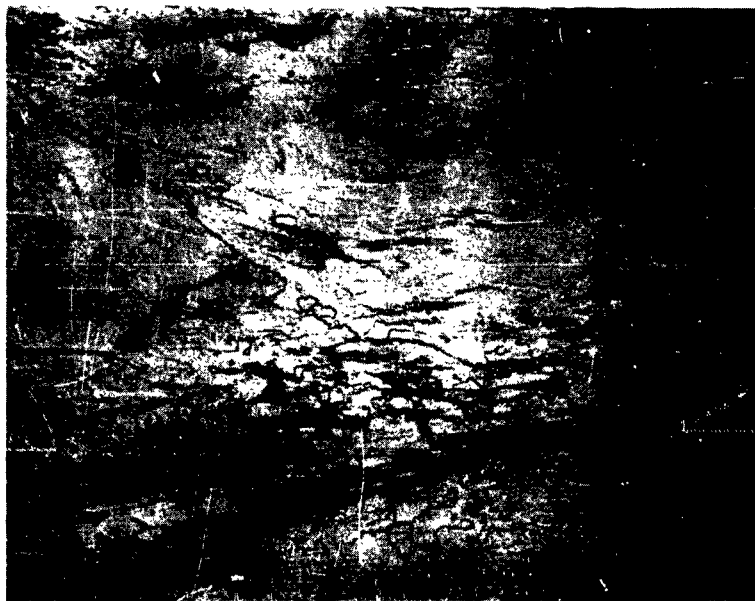


Figure 26 - As-forged, Group I, arc melted TZM forging heated at 2350°F for three hours. Small amount of recrystallization observed primarily along grain boundaries. 100 X mag. Etched with modified Murakami's Reagent.



Figure 27 - Pressed and sintered TZM billet forged in Group III. Heated to 2500°F for one hour. Very small grains detected along grain boundaries. 1000X mag. Etched with modified Murakami's Reagent.

DISTRIBUTION LIST
Contract AF 33(600)-42523

ASD (ASCRT-1)
Wright-Patterson AFB, Ohio (6)

ASD (ASAPT)
Wright-Patterson AFB, Ohio

ASD (ASRCM-1A, Mrs. N. Ragen)
Wright-Patterson AFB, Ohio (2)

Aerojet-General Corporation
Attn: Chief Engineer
P.O. Box 298
Azusa, California

Allegheny Ludlum Steel Corporation
Attn: Works Manager
Brackenridge, Pennsylvania

Arcturus Manufacturing Corporation
Attn: Chief Engineer
4301 Lincoln Boulevard
Venice, California

ASTIA
Arlington Hall Station
Arlington 12, Virginia (10)

Baldwin-Lima-Hamilton
Attn: Mr. George Lessie
111 Fifth Avenue
New York 3, New York

Bell Aerospace Corporation
Attn: Manager, Production Engrg.
P.O. Box 482
Fort Worth 1, Texas

Bendix Utica Division
Bendix Aviation Corporation
Attn: Director of Engineering
211 Senard Avenue
Utica, New York

The Boeing Company
Materials Mechanics & Structures
Branch - Systems Mgmt. Office
P.O. Box 3707
Seattle 24, Washington

ASD (ASRCEE, Mr. J. Teres)
Wright-Patterson AFB, Ohio

ASD (ASRC, Dr. A. L. Lovelace)
Wright-Patterson AFB, Ohio

ASD (ASRCMP-4, Mr. S. Inouye)
Wright-Patterson AFB, Ohio

Aircraft Industries Association
Attn: Mr. H. D. Moran
7660 Beverly Boulevard
Los Angeles 36, California

Alloyd Research Corporation
Attn: Mr. Louis Mager, General Mgr.
202 Arsenal Street
Watertown 72, Massachusetts

Armour Research Foundation
Attn: Metals Research Department
10 West 35th Street
Chicago 16, Illinois

Babcock & Wilcox Company
Attn: Chief Metallurgist
Beaver Falls, Pennsylvania

Battelle Memorial Institute
Defense Metals Information Center
505 King Avenue
Columbus 1, Ohio

Bendix Products Division
Bendix Aviation Corporation
Attn: Director of Engineering
401 N. Bendix Drive
South Bend, Indiana

Beryllium Corporation of America
Attn: Mr. John D. Carr, Librarian
P.O. Box 1462
Reading, Pennsylvania

Buehler Corporation
Attn: Works Manager
9000 Precision Drive
Indianapolis 28, Indiana

Cameron Iron Works
Attn: Manager, Special Products Div.
P.O. Box 1212
Houston 1, Texas

Chance Vought Corporation
Attn: Chief Librarian
P.O. Box 5907
Dallas, Texas

General Dynamics Corporation/Pomona
Attn: Chief, Mfg. Engineering
P.O. Box 1011
Pomona, California

General Dynamics Corporation/Convair
Attn: Manufacturing Development
Zone P-46
Fort Worth, Texas

Curtiss-Wright Corporation
Wright Aeronautical Division
Attn: Manager, Metallurgy
Wood Ridge, New Jersey

Curtiss-Wright Corporation
Metals Processing Division
Attn: Chief Engineer
760 Northland Avenue
P.O. Box 15
Buffalo, New York

Douglas Aircraft Company, Inc.
Attn: Plant Engineering Supervisor
3855 Lakewood Boulevard
Long Beach 8, California

Douglas Aircraft Company, Inc.
Attn: Works Manager
2000 North Memorial Drive
Tulsa, Oklahoma

Dresser Industries, Inc.
Security Engineering Division
Attn: Mr. Ralph H. Hughes
Vice President - Manufacturing
3400 West Illinois
Dallas 11, Texas

Canton Drop Forging & Mfg. Company
Attn: Quality Control Manager
2100 Wilett Avenue
Canton 2, Ohio

The Cleveland Twist Drill Company
Attn: R. D. Leshner, Development Engr.
1242 E. 59th Street
Cleveland 14, Ohio

General Dynamics Corporation/Convair
Attn: Manufacturing Development
General Office
San Diego 12, California

General Dynamics Corp/Astronautics
Attn: Materials Research Group
Mail Zone 595-20
San Diego 12, California

Curtiss Division
Curtiss-Wright Corporation
Attn: Chief, Engineering Materials
U. S. Route 46
Caldwell, New Jersey

Defense Automotive Supply Center
Attn: DASC-PSB, Mr. W. Sutherland
1501 Beard Street
Detroit 9, Michigan

Douglas Aircraft Company, Inc.
Attn: Works Manager
3000 Ocean Park Boulevard
Santa Monica, California

Dresser Industries, Inc.
Attn: Mr. George H. Pfefferle
Republic National Bank Building
Dallas, Texas

Firth Sterling, Inc.
Attn: Manager, Powder Metals Research
3113 Forbes Avenue
Pittsburgh 30, Pennsylvania

Ford Motor Company
Aeronutronics Division
Attn: Mr. R. L. Shanower
1406 Talbott Tower
Dayton 2, Ohio

Grumman Aircraft Engineering Corp.
Attn: Manufacturing Research
Coordinator Plant 12
Bethpage, Long Island, N. Y.

The Hermes Corporation
Attn: Mr. R. Q. Parsons, V. P.
1243 Transit
Pomona, California

Kropp Forge Company
Attn: Ray Kropp
5301 Roosevelt Road
Chicago 50, Illinois

Kelsey-Hales Company
Utica Division
Attn: Mr. Phillip E. Munson
Utica 4, New York

Ladish-Pacific
Attn: Mr. G. Shaffer
3321 E. Slauson Avenue
Los Angeles 58, California

Lear-Seigler, Inc.
1700 East Grand Avenue
El Segundo, California

Lockheed Aircraft Corporation
California Division
Attn: Director of Engineering
P.O. Box 511
Burbank, California

The Marquardt Corporation
Attn: Mr. Gene Kline
Manufacturing Engineer
P.O. Box 670
Ogden, Utah

The Martin Company
Denver Division
Attn: Materials Engineering
Mail No. L-8
Denver 1, Colorado

General Electric Company
Alloy Studies Unit
Attn: Manager, Metallurgical Engineering
ARO Building 200, FPLD
Cincinnati 15, Ohio

Harvey Aluminum, Inc.
Attn: Technical Director
19200 South Western Avenue
Torrance, California

Interstate Drop Forge Company
4051 North 27th Street
Milwaukee 16, Wisconsin

Kelsey Hayes Company
Attn: Director of Research
Metals Division
New Hartford, New York

Ladish Company
Attn: Works Manager
5481 Packard Avenue
Cudahy, Wisconsin

Latrobe Steel Company
Attn: Mr. George F. Reuss
Engineering Department
Latrobe, Pennsylvania

Lockheed Aircraft Corporation
Missile Systems Division
Attn: Chief Engineer
Sunnyvale, California

Lycoming Division
AVCO Manufacturing Corporation
Attn: Chief, Manufacturing Engineering
Stratford, Connecticut

The Marquardt Corporation
Attn: Supt. of Manufacturing
16555 Saticoy Street
Van Nuys, California

Materials Advisory Board
Attn: Executive Director
2101 Constitution Avenue
Washington, D. C.

McDonnell Aircraft Corporation
Attn: Chief Industrial Engineer
Lambert - St. Louis Airport
P.O. Box 516
St. Louis 3, Missouri

National Academy of Sciences
National Research Council
Attn: Mary W. Brittain
Secretary to Mr. Arnquist
2101 Constitution Avenue
Washington 25, D.C.

New York University
College of Engineering
Attn: Director, Research Division
New York 53, N.Y.

North American Aviation, Inc.
Attn: Chief Metallurgist
3400 East 5th Street
Columbus, Ohio

Norair Division
Northrop Corporation
Attn: Mr. R. R. Nolan, V.P. Mfg.
1001 Broadway
Hawthorne, California

Pratt & Whitney Aircraft Corporation
Attn: Chief Metallurgist
Engineering Department
East Hartford 8, Connecticut

Precision Forge Company
Attn: Mr. E. C. Rork
2152 Colorado Street
Santa Monica, California

Rocketdyne Division
North American Aviation, Inc.
Attn: Chief Engineer
6633 Canoga Avenue
Canoga Park, California

Ryan Aeronautical Company
3701 Harbor Drive
San Diego 12, California

The Megadyne Corporation
Attn: Chief Engineer
12021 Vose Street
North Hollywood, California

National Bureau of Standards
Mr. A. Brenner
Mr. W. E. Reid
Washington 25, D.C.

North American Aviation, Inc.
Los Angeles Division
Attn: Section Head Materials
International Airport
Los Angeles 45, California

Department of the Navy
Bureau of Naval Weapons
Attn: Mr. N. E. Promisel
Washington 25, D.C.

Pacific Forge, Inc.
Attn: Walter Sebasta, V.P. & Chief Engi
10641 Etiwanda Avenue
Fontana, California

Pratt & Whitney Aircraft Corporation
CANEL, Connecticut Operations
Attn: Chief, Metallurgical & Chem. Lab.
P.O. Box 611
Middletown, Connecticut

Republic Aviation Corporation
Attn: Director of Mfg. Research
Farmingdale, Long Island, N.Y.

Rohr Aircraft Corporation
Attn: Vice President, Manufacturing
P.O. Box 878
Chula Vista, California

Solar Aircraft Company
Attn: Advanced Research Department
2200 Pacific Highway
San Diego 12, California

Southern Research Institute
Attn: Mr. E. J. Wheelaham
2000 Ninth Avenue South
Birmingham 25, Alabama

Special Metals
Attn: Chief Metallurgist
New Hartford, New York

Steel Improvement & Forge Company
970 East 64th Street
Cleveland 3, Ohio

Sundstrand Aviation/Denver
Attn: Mr. Harry Wilson
2380 W. 70th Avenue
Denver 21, Colorado

Sylvania Electric Products Corporation
Attn: Manager, Metallurgy Lab.
P.O. Box 59
Bayside, New York

Taylor Forge & Pipe Works
Attn: Special Products Manager
P.O. Box 485
Chicago 90, Illinois

Thompson-Ramo-Wooldridge, Inc.
Attn: Mr. John L. Haggerty
Talbot Tower
Dayton, Ohio

Transue & Williams Steel Forging Corp.
Attn: Sales Manager
Alliance, Ohio

The Warner & Swasey Company
Attn: Mr. Robert T. Hook
5701 Carnegie Avenue
Cleveland 3, Ohio

Watertown Arsenal Laboratory
Attn: Physical Metallurgy Division
Watertown, Massachusetts

Westinghouse Electric Corporation
Attn: Materials Mfg. Department
Blairsville, Pennsylvania

Westinghouse Electric Corporation
Attn: Works Manager
P.O. Box 228, AGT Division
Kansas City, Missouri

Wyman-Gordon Company
Attn: Chief Metallurgist
North Grafton, Massachusetts

AD	UNCLASSIFIED	AD	UNCLASSIFIED
Western Gear Corporation, Systems Management Division, Lynwood, California	Western Gear Corporation, Systems Management Division, Lynwood, California		
HIGH ENERGY RATE FORGING DEVELOPMENT, by J. M. Palsulich 10 May 1963. 40 p. incl. illus. tables. (Proj. 7-866)(AMC TR 7-866) Contract AF 33(600)-42523.	HIGH ENERGY RATE FORGING DEVELOPMENT, by J. M. Palsulich 10 May 1963. 40 p. incl. illus. tables. (Proj. 7-866)(AMC TR 7-866) Contract AF 33(600)-42523.		
Unclassified Report	Unclassified Report		
Successful high energy rate forging of unwrought refractory materials is highly dependent upon the forging configuration and die design. Good (over)	Successful high energy rate forging of unwrought refractory materials is highly dependent upon the forging configuration and die design. Good (over)	UNCLASSIFIED	UNCLASSIFIED
forgings are possible when working stresses are compressive in nature. Tensile and shear stresses during forging generally result in fracturing of the billet if the refractory metals have received little or no plastic work	forgings are possible when working stresses are compressive in nature. Tensile and shear stresses during forging generally result in fracturing of the billet if the refractory metals have received little or no plastic work.	UNCLASSIFIED	UNCLASSIFIED
Data for forging conditions and results of metallurgical examinations are presented.	Data for forging conditions and results of metallurgical examinations are presented.		
		UNCLASSIFIED	UNCLASSIFIED