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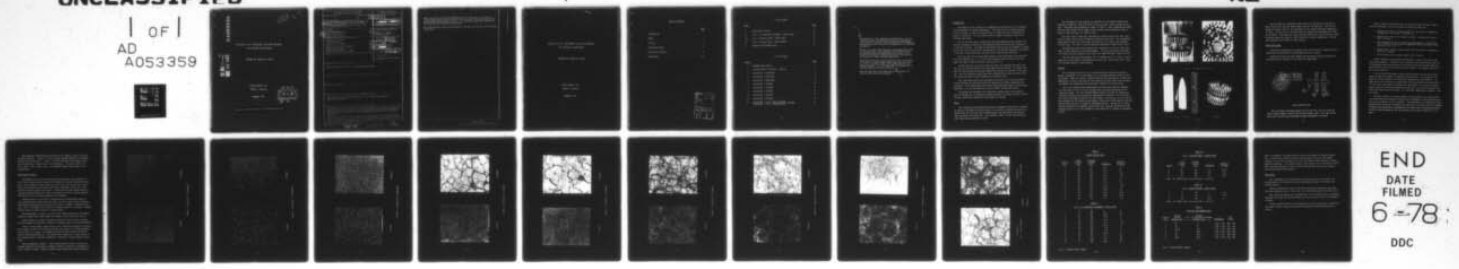

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FEASIBILITY OF INVESTMENT CASTING PREFORMS FOR PHALANX PENETRATORS

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Nuclear Metals, Inc.

Edmund J. Tenerini

November 1977

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Investment Casting of Depleted Uranium - 2 w/o molybdenum preforms for the Phalanx Penetrator

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program was to demonstrate, in a preliminary fashion, that depleted uranium2 w/o molybdenum alloy Phalanx penetrators can be produced by the investment casting process and to provide cast penetrators for ballistic evaluation.

Results of the work have shown that sound penetrators, free of internal voids, can be produced by investment casting. As-cast penetraitors and penetrators heat treated to the specification hardness (28-32Rc) have ductility equal to, or superior to, that of wrought penetrators. Over

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Under the melting and casting conditions used in this work, an increase in carbon content beyond specification limits occurred in sequential melts using approximately 50 w/o recycle material. It is believed that this problem can be solved by adjusting melting conditions.

Over 200 penetrators have been provided to the Navy for ballistic and corrosion evaluation.

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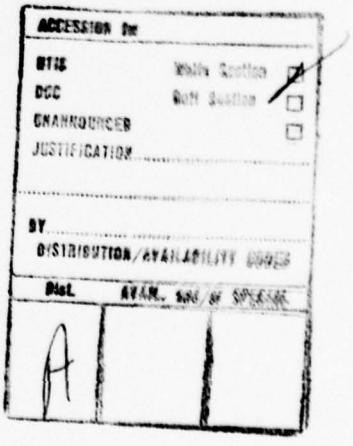

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The objective of this program was to demonstrate, in a preliminary fashion, that depleted uranium 2 w/o molybdenum alloy Phalanx penetrators can be produced by the investment casting process and to provide cast penetrators for ballistic evaluation.

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INTRODUCTION

The purpose of this program was to demonstrate the feasibility of investment casting preforms for Phalanx penetrators. The scope of work involved producing six (6) castings, of which a minimum of four (4) would be used to establish the effect of recycling. Two (2) castings were to produce a minimum of 100 finish machined penetrators.

The six (6) molds were purchased from Hitchiner Manufacturing, Milford, N.H., and each contained a maximum of 187 penetrator preform cavities and a minimum of 13 test bar cavities. The shape of the preform cavities was not intended to closely follow the final size and exact configuration of the Phalanx penetrator, but merely to provide a simple blank which could be easily machined and evaluated.

The first and fifth castings were produced using 100 percent virgin material, while the remainder (2, 3, 4, 6) utilized 50 percent recycle material from the gates and runners removed from the casting prior to it.

Following melting and casting into each mold, and allowing sufficient time for cooling, the mold material was broken away from the casting. All blanks were then cut from the gating system and identified according to location in the casting. Four (4) penetrator blanks were then selected from various positions within the casting and used to obtain chemistry and hardness data.

Heat treat experiments were conducted utilizing the cast test bars and material from each of these experiments was machined into tensile specimens and evaluated. It was determined that solution heat treating at 850°C for 40 minutes, quenching in oil and overaging for 8 hours at 582°C yielded good results.

Two hundred and seventeen (217) penetrator preforms taken from castings one (1) through four (4) were heat treated according to the above process, finish machined into Phalanx penetrators and shipped to the Navy.

MOLDS

The investment casting process utilizes an expendable mold which is produced by coating a wax model of the part which is to be cast, including the gating system and pour cup to direct flow of molten metal, and then melting out the wax after the outer coating has set. This provides a shell or mold, containing the exact shape which you desire to cast.

For the purpose of our program, wax patterns for the Phalanx preform were produced in quantity, along with waxes for the test bars, gating system and pour cups. These were then assembled, as shown in Figure 1, into a completed wax model, which was then dipped into a number of wet slurries and fluidized dry sands to produce, layer by layer, our ceramic molds.

The first layer of each mold consisted of zirconia-zircon flour plus 5 percent colloidal silica slurry followed by fluidized zircon sand. All intermediate layers were zircon-silica flour plus colloidal silica in slurry, then aluminosilicate sand. The final or outside layer was potassium silicate-zircon slurry.

The penetrator waxes were produced with a minimum of 1/4" extra length and .040" of extra material on the major diameter. The nose configuration followed a 10° angle with the exception of the front 1/4" where the angle increased to 30°.

Test bar waxes were approximately 1/2" in diameter and 2 1/2" long. Figure 2 shows the as-cast shape of the penetrator and test bar, and also the entire casting following removal of mold material.

CASTING

All casting was carried out in a vacuum induction furnace with the mold packed in preheated silica sand (468°C) in an evacuated container below the melting chamber. When the charge of depleted uranium and molybdenum had reached pour temperature, a plug in the bottom of the graphite crucible, which lines the melting chamber, was removed and the molten metal flowed into the mold below.

The six (6) molds weighed approximately 63 pounds each and were preheated for 20-24 hours at 927°C in an air furnace prior to being transferred to the induction furnace. The time required between removal from the air furnace and initiation of melting and casting was approximately 30 minutes. All molds were cast using 250 pounds of material for each charge. Castings one (1) and five (5) were charged with 100 percent virgin material consisting of 245 pounds of depleted uranium derby and five (5) pounds of molybdenum pellets. Charges for all other castings consisted of 50 percent recycle (125 lbs), which was obtained from the casting previous to it, 122.5 pounds of virgin derby and 2.5 pounds of molybdenum pellets.

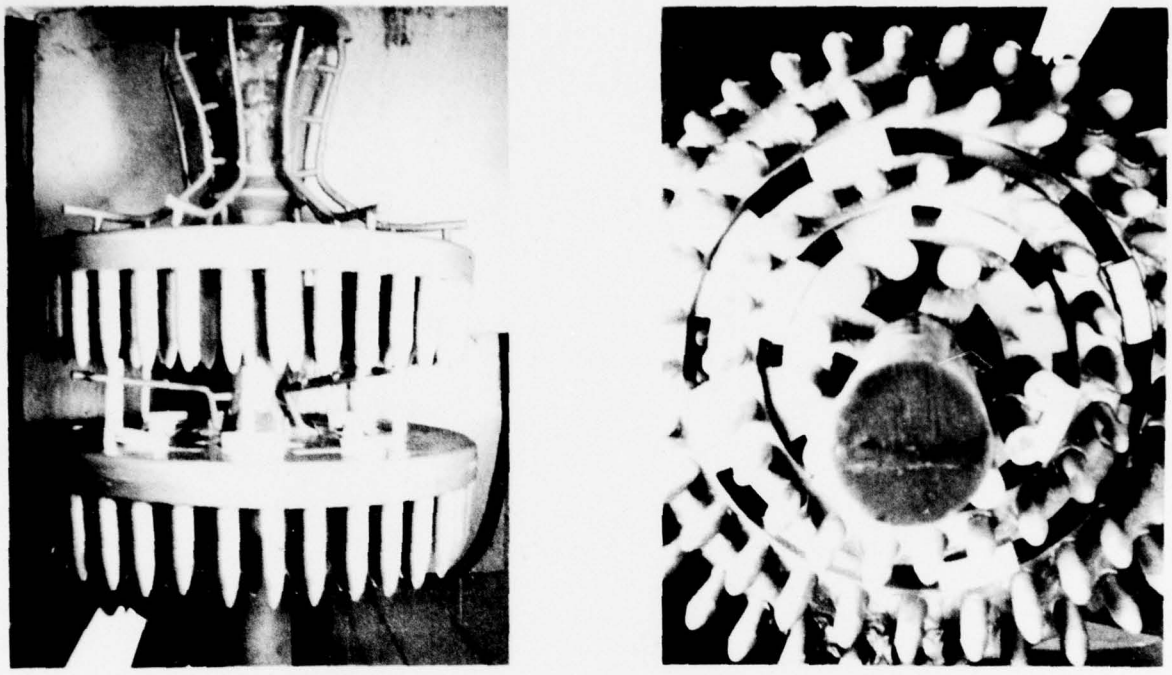
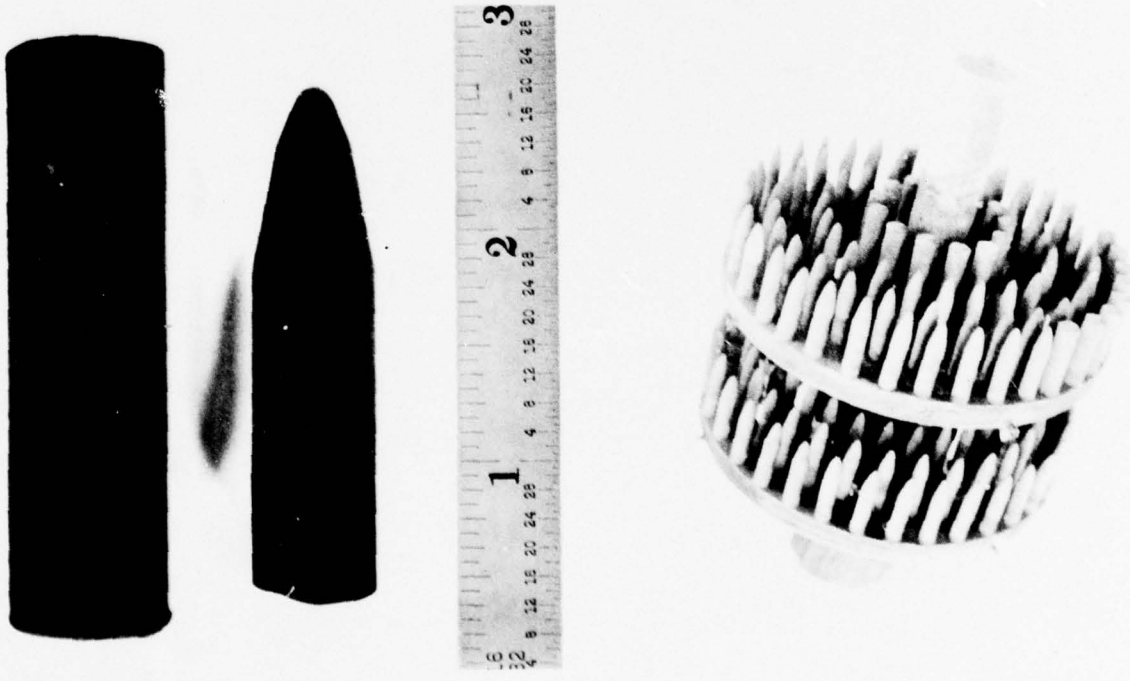


Figure 1. Assembled Wax Pattern



As-Cast Preform & Test Bar

Casting

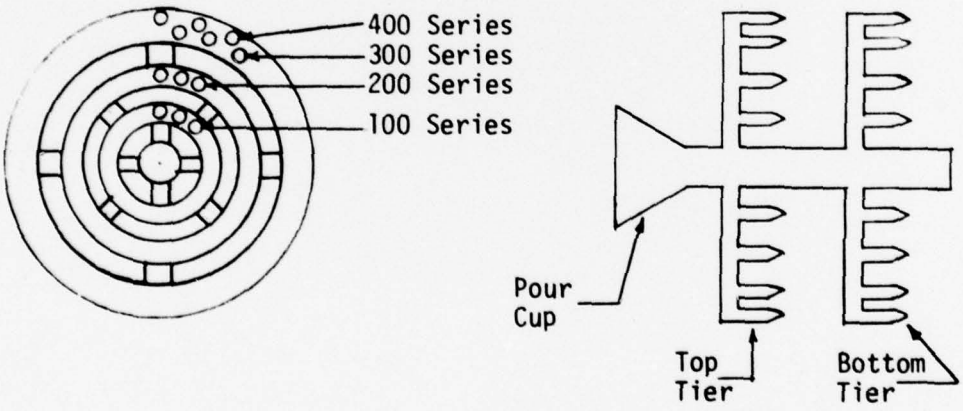
Figure 2

From initiation of pump down of the furnace, to the point of switching on power to the coils required approximately one hour for each melt. This was followed, 40 minutes later, by the attainment of the required superheat temperature of 1420°C. At this point a 20 minute hold was begun with the temperature remaining at 1420°C. Following this hold, power was switched off and 6-12 minutes later the molten metal had cooled to 1300°C, which has the pour temperature. Pouring time required 10-15 seconds for each casting.

PROCESSING BLANKS

Following an appropriate cool down period, the casting was removed from the furnace and the mold material broken away using an air hammer.

Penetrator blanks were then removed from the gating system and identified according to their location on the casting as shown below.



Blank Identification

Four (4) blanks from each casting, two (2) per tier, were set aside and used to obtain chemical analysis and as-cast hardness data. All other blanks and as-cast test bars were processed through radiographic evaluation.

Blanks selected from castings one (1) and two (2) were utilized in heat treating experiments carried out under the following conditions.

1. Solution heat treat in vacuum at 844°C for 30 minutes at temperature followed by a fast quench in agitated oil.

2. Solution heat treat and oil quench as above. Overage for 8 hours at 582°C in vacuum.

3. Seal penetrator blanks in a copper can and evacuate. Solution heat treat at 844°C for 30 minutes at temperature and allow blank and copper can to cool in air.

4. Solution heat treat in vacuum at 844°C for 30 minutes at temperature, then cool in vacuum.

5. Solution heat treat as above, except cool in helium.

Tensile specimens were machined from material in each of the above conditions except number 3. Condition 2 was selected as the standard heat treat for all penetrators which were provided to the Navy and tensile specimens were produced from each casting using test bars heat treated in this manner and also in the as-cast condition.

A Tinius-Olsen 60,000 pound tensile testing machine was used and an atmosphere of argon surrounded all specimens during testing. The purpose of the argon was to help maintain a constant test temperature and low humidity. The gage area of each specimen was coated with a bluing substance and scratch marks, 1/2 inch apart, were made to represent the gage length. As an extra precaution against corrosion, specimens produced from castings 5 and 6 were coated with oil after machining and during testing. All tests were conducted at a speed of .005" per minute.

The yield strength (.2 percent offset) was calculated from a stress-strain curve electronically produced by attaching an extensometer to each specimen which was in turn connected to an X-Y recorder. The extensometer was removed from each specimen after sufficient information was obtained to calculate the yield strength. Elongation was determined by reassembling the broken tensile specimen and measuring the distance between the two scratch marks, which were originally 1/2 inch apart.

Metallographic examination was carried out for samples in the as-cast and overaged conditions. Figures 3, 4 and 5 display photomicrographics of unetched samples from castings No. 2, 3 and 4. Figures 6 through 10 show samples which were etched using a chromic acetic acid electroetch. (50 grams chromic acid +60 cc water + 100 cc acetic acid.) All photomicrographs were taken at 100 x magnification.

DISCUSSION OF RESULTS

Radiographs of each casting indicated all blanks to be very sound and in only a few instances surface porosity or incomplete filling of mold cavities was seen. This incomplete filling always occurred at the nose and was due to small pieces of mold material which had fallen into a penetrator cavity or to a disfigured wax prior to mold construction. Surface porosity was shallow enough to clean-up during machining and a yield of 95 percent or better could be expected from each of the six castings produced on this program.

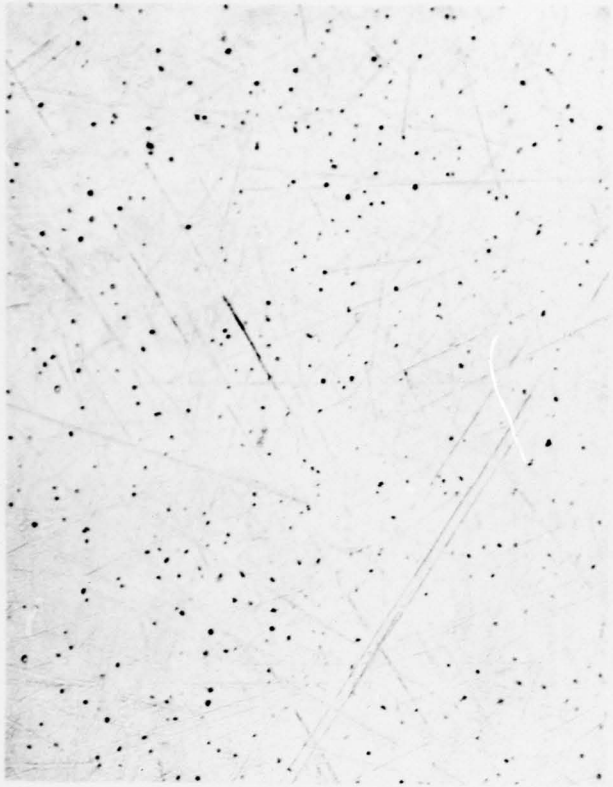
Chemical analysis (see Table V) indicated that the molybdenum content of each casting was well within specified limits, but the carbon content increased rapidly when 50 percent recycle material was used on a number of sequential castings. This is evidenced by the results of chemical analysis on castings 1 through 4 which shows the steady increase in carbon content.

Photomicrographs in Figures 3, 4 and 5 give a good indication of the carbon content as shown by the larger number of carbides in each successive casting.

Etched samples in Figures 6 through 10 show the as-cast acicular structure and the overaged structure which displays a secondary phase in the grain boundaries.

Figure 11 shows samples from castings 1 and 2 which were overaged by solution heat treating to 850°C for 40 minutes and then cooling one in a helium atmosphere and the other in a vacuum. Each sample displays the same structure previously noted in the overaged material. The vacuum cooled sample has a larger amount of the secondary phase in the grain boundaries, indicating a greater degree of overaging.

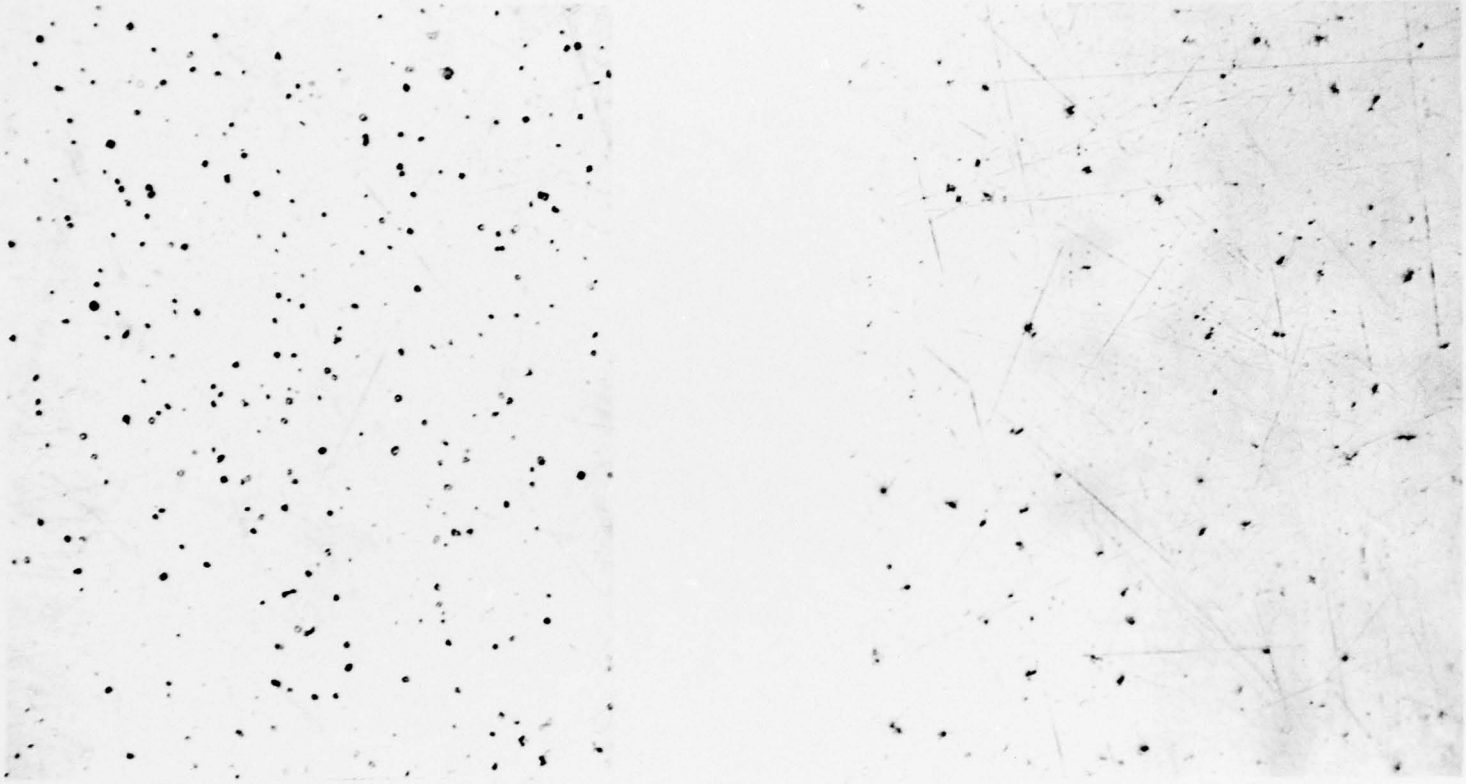
Tensile properties (Tables I - IV) of solution heat treated, quenched and overaged material from castings 1 through 4 indicate a decrease in elongation as carbon content increases. Material solution heat treated and vacuum cooled was



As-Cast

Overaged

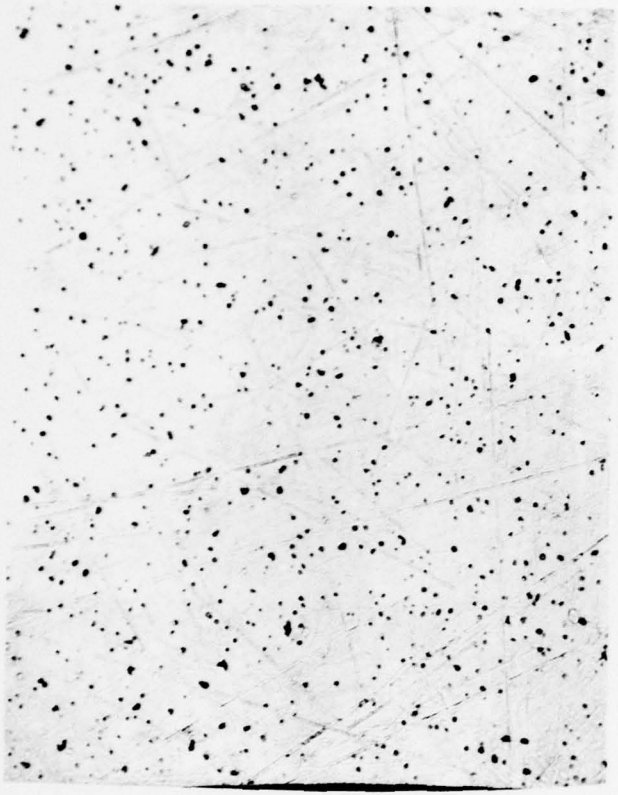
Figure 3. Casting No. 2 (Unetched)



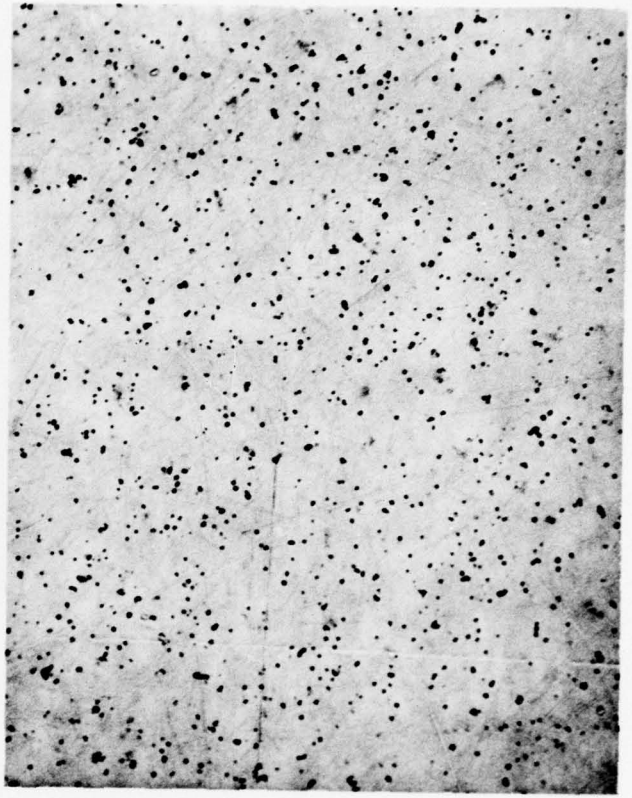
As-Cast

Overaged

Figure 4. Casting No. 3 (Unetched)

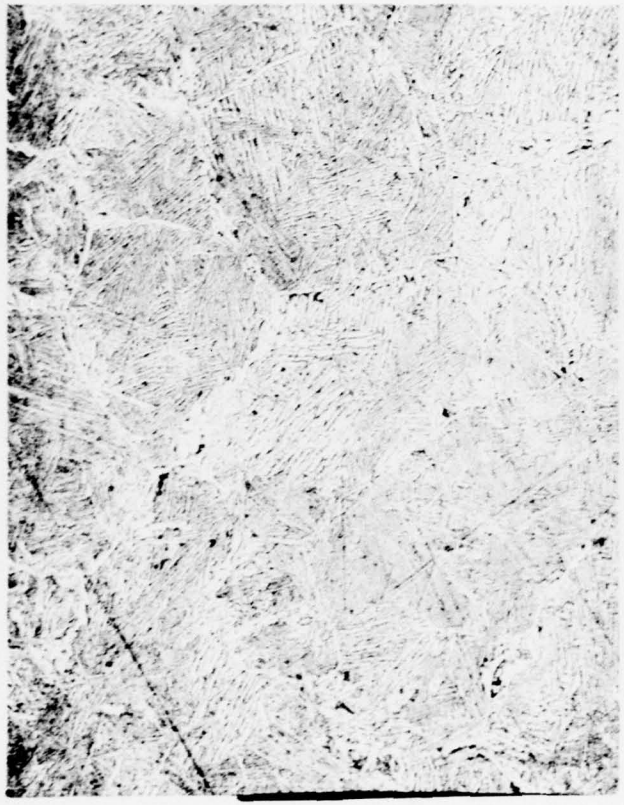


As-Cast

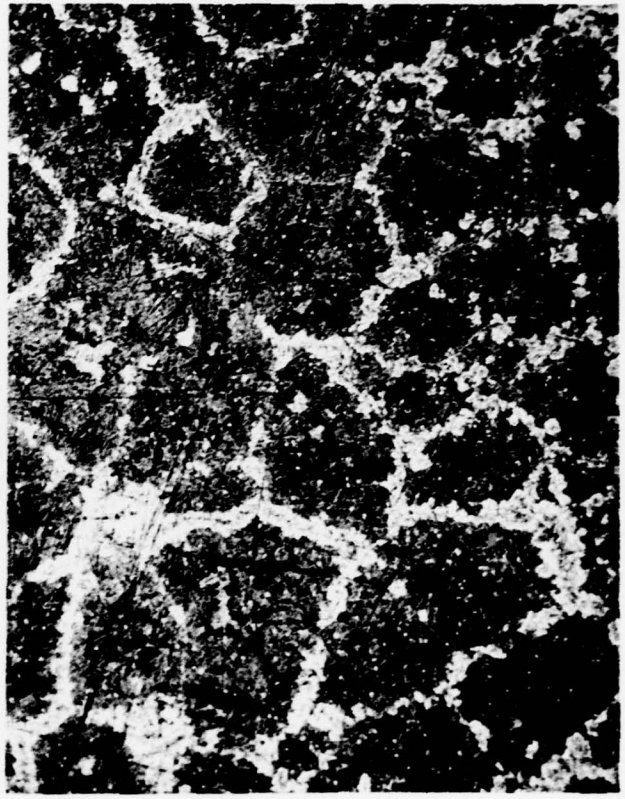


Overaged

Figure 5. Casting No. 4 (Unetched)

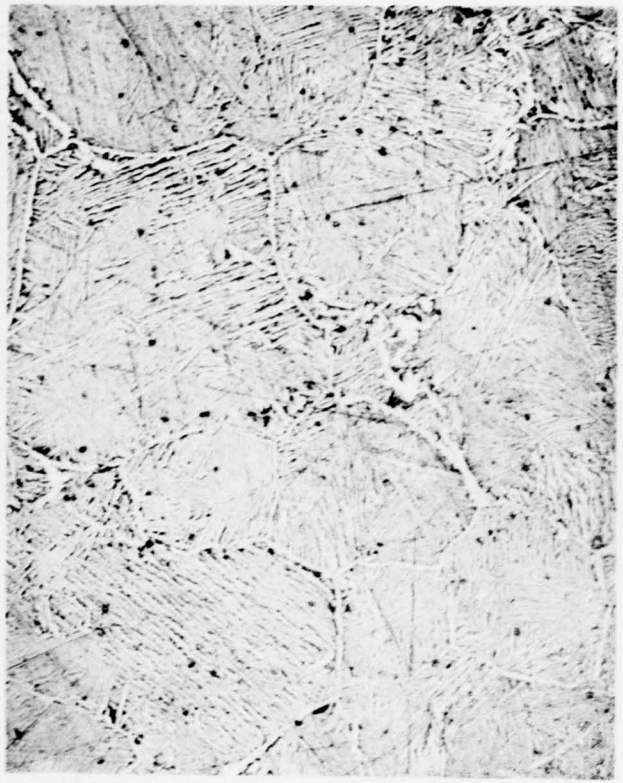


As-Cast

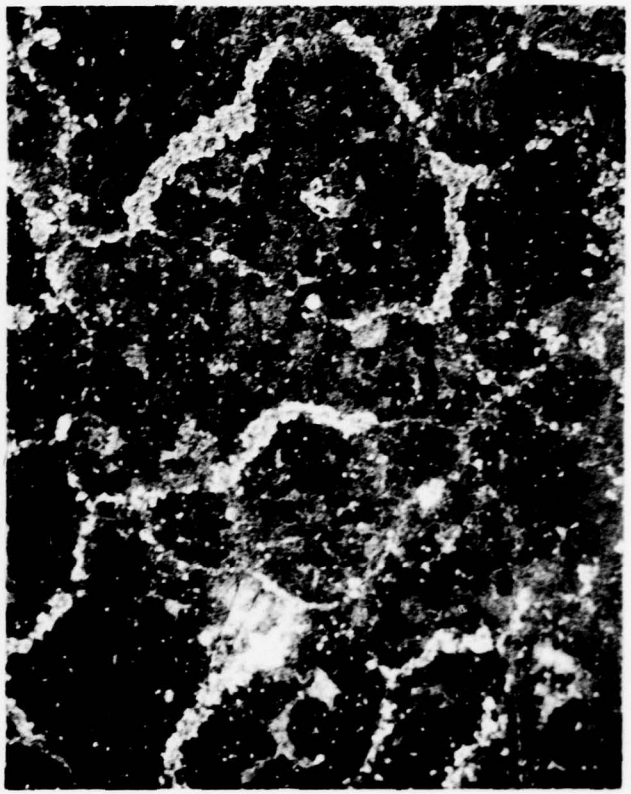


Overaged

Figure 6. Casting No. 2 (Etched)

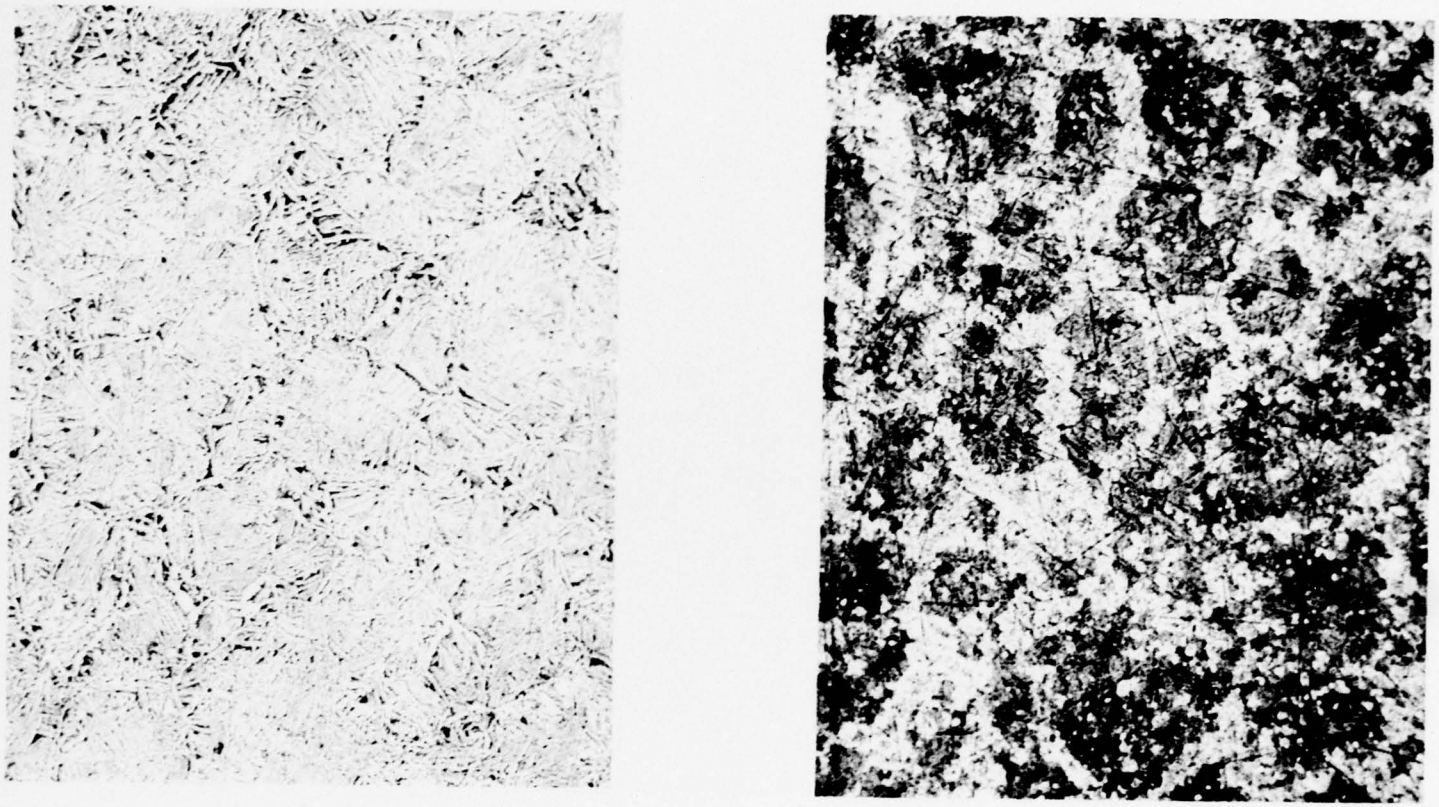


As-Cast



Overaged

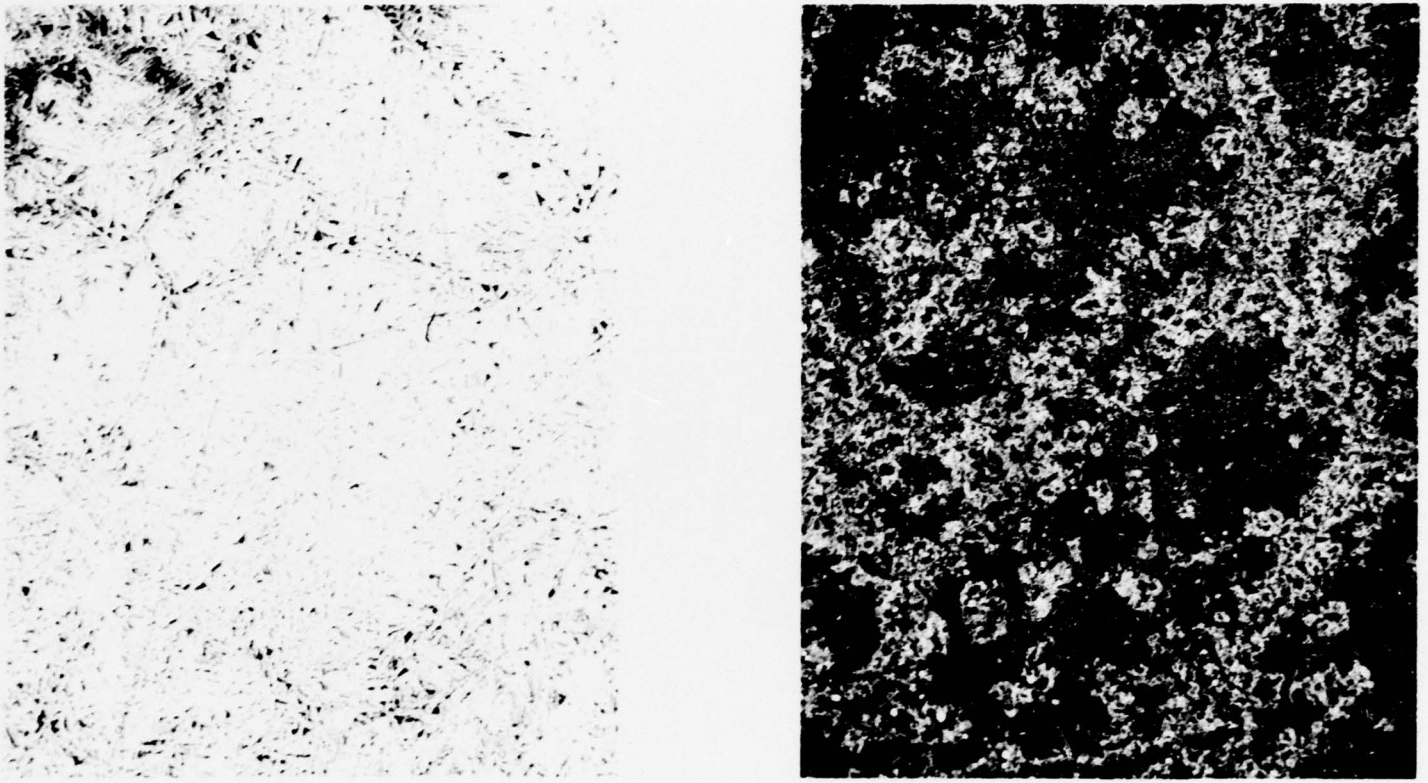
Figure 7. Casting No. 3 (Etched)



As-Cast

Overaged

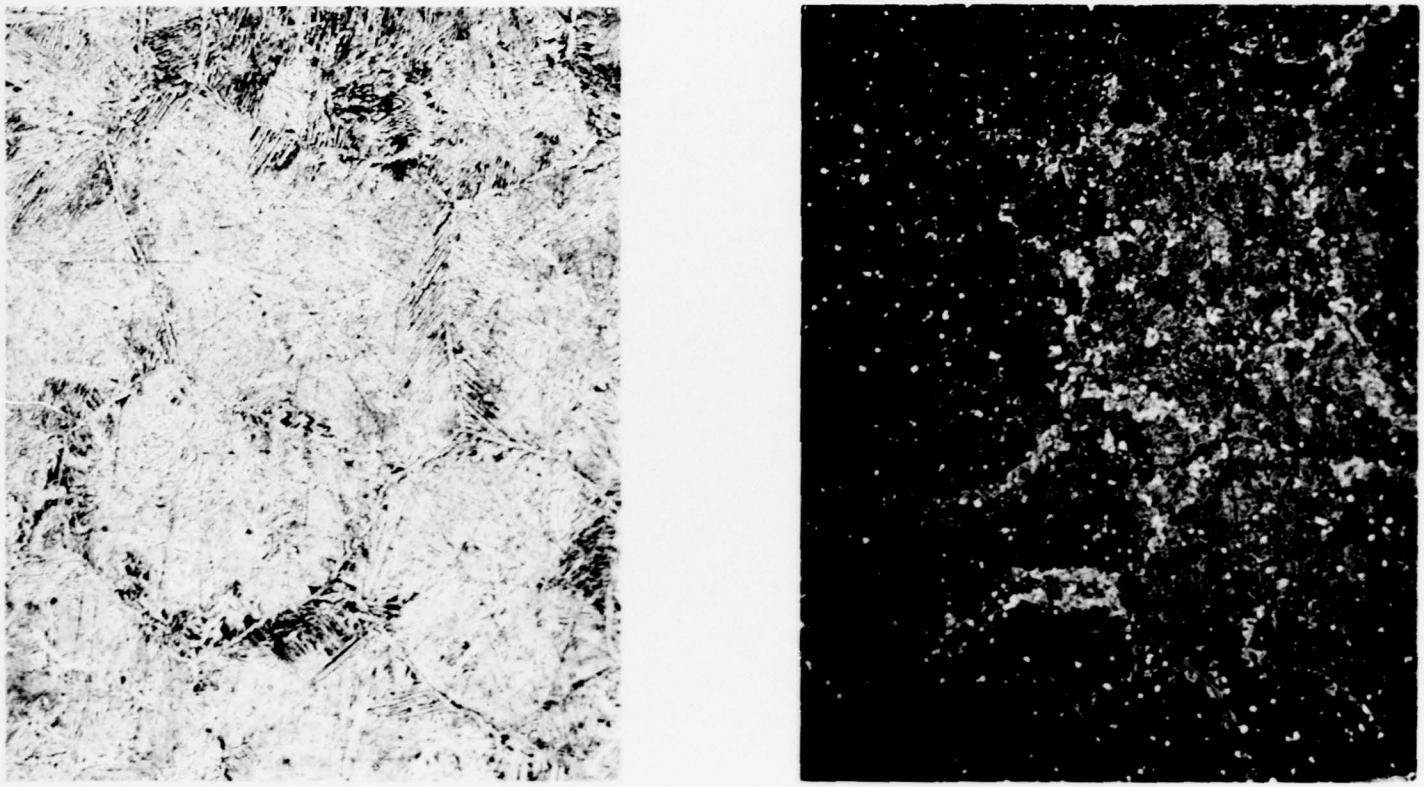
Figure 8. Casting No. 4 (Etched)



As-Cast

Overaged

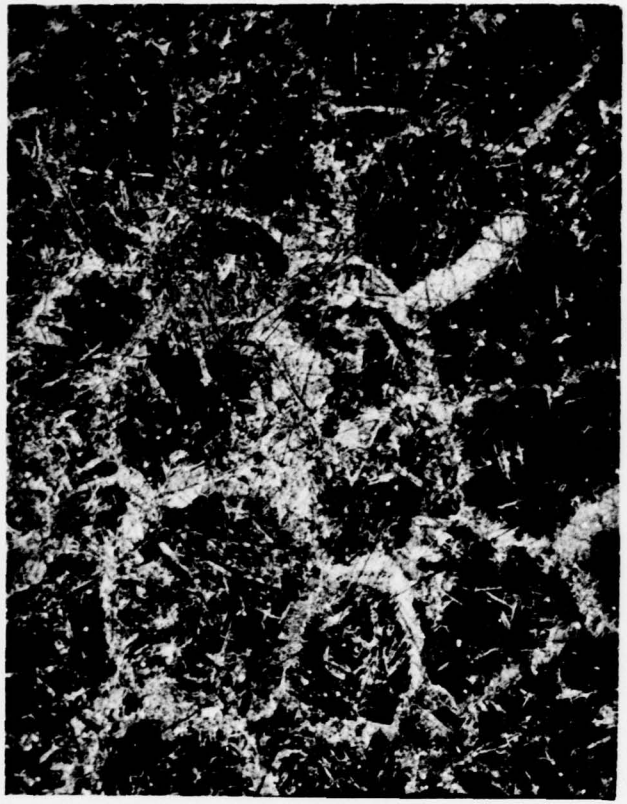
Figure 9. Casting No. 5 (Etched)



As-Cast

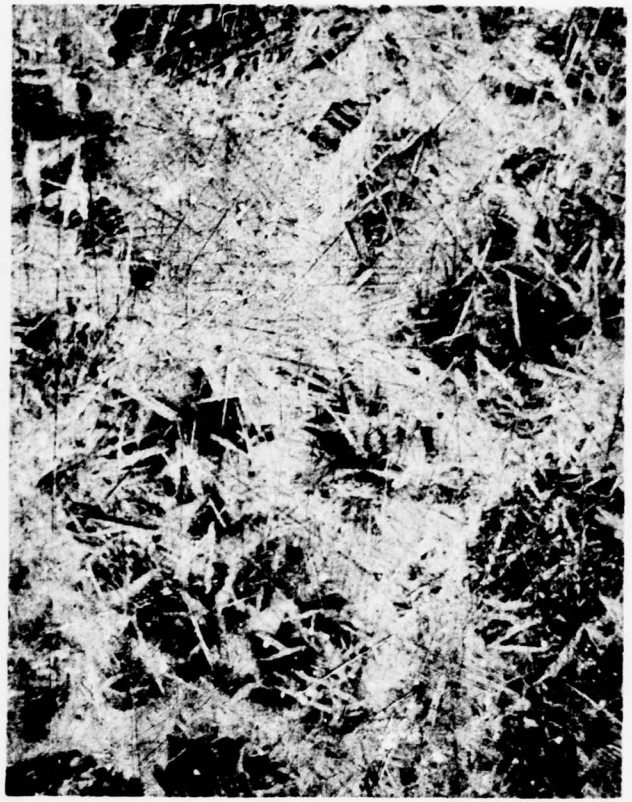
Overaged

Figure 10. Casting No. 6 (Etched)



Casting No. 1

S.H.T. - Helium Cooled



Casting No. 2

S.H.T. - Vacuum Cooled

(Etched)

Figure 11

TABLE I

AS-CAST-TENSILE DATA

Casting No.	Yield Strength KSI	Ultimate Strength KSI	% Elongation	% Reduction of Area
1	67	121	11.6	13
1	60	119	13.2	10
2	63	122	13.7	11.0
2	63	122	14.2	8.5
3	63	134	15.6	11
3	69	133	15.2	10
4	72	122	9.6	8.5
4	68	123	12.8	7.0
5	63	121	14.6	16
5	60	121	35.2	31.5
6	59	122	26.8	29.5
6	63	123	17.2	11.5

TABLE II

S.H.T., OIL QUENCHED, & OVERAGED - TENSILE DATA

1	79	146	21	22
1	75	142	15.6	25
2	72	144	12.4	11
2	77	142	6.8	6
3	82	144	11.2	8.5
3	76	141	10.8	6
4	82	140	6.8	4
4	71	142	7.0	7
5	68	131	18.4	21
5	72	131	17.2	16
6	77	135	26	24
6	71	138	25.6	24

S.H.T. = Solution Heat Treated

TABLE III

S.H.T. & HELIUM COOLED - TENSILE DATA

Sample	Yield Strength KSI	Ultimate Strength KSI	% Elongation	% Reduction of Area
A	84	163	11.4	8.47
B	85	165	9.2	7.24
C	63	160	8.2	5.43

Note: All samples were from Casting No. 1, 29-33 Rc.

TABLE IV

S.H.T. & VACUUM COOLED - TENSILE DATA

X	71	148	7	4.75
Y	76	144	8.6	7.75
Z	76	148	12.6	6

Note: All samples were from Casting No. 2, 32-35 Rc

TABLE V

CHEMISTRY AND HARDNESS DATA

Casting No.	Average As-Cast Hardness (Rc)	Average S.H.T. Oil Quenched & Overaged Hardness (Rc)	% Molybdenum	PPM Carbon
1	23	31	1.98 - 2.07	390 - 460
2	24	31	1.88 - 1.98	230 - 470
3	25.75	31.5	1.95 - 2.08	430 - 590
4	25	29.5	1.98 - 2.06	930 - 960
5	23	28.3	1.93 - 1.97	340 - 420
6	24.4	29.0	1.99 - 2.04	630 - 660

S.H.T. = Solution Heat Treated

equal in strength to the above material but did not exceed 12.6 percent elongation. Solution heat treated and helium cooled material attained the highest strength with the least elongation, but was also noted to have attained a greater degree of hardening. This higher hardness could account for the increased strength which would be unexpected in material which had been more extensively overaged than the previously noted material.

CONCLUSIONS

This investment casting program has proven the ability of that process to provide material of high quality and having properties equal to or better than wrought material.

The cast preforms were readily machined into Phalanx penetrators and could have been produced closer to final size, still maintaining quality and high yield.

Heat treat experiments have indicated that it may be feasible to use alternate processes to achieve the desired hardness of 28-32 Rc, with little or no change in strength.

Further programs which utilize investment casting can be aimed at controlling the carbon content, reducing the machining envelope and optimizing the overall process.