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PHALANX CIWS PENETRATOR ROUNDS,(U)

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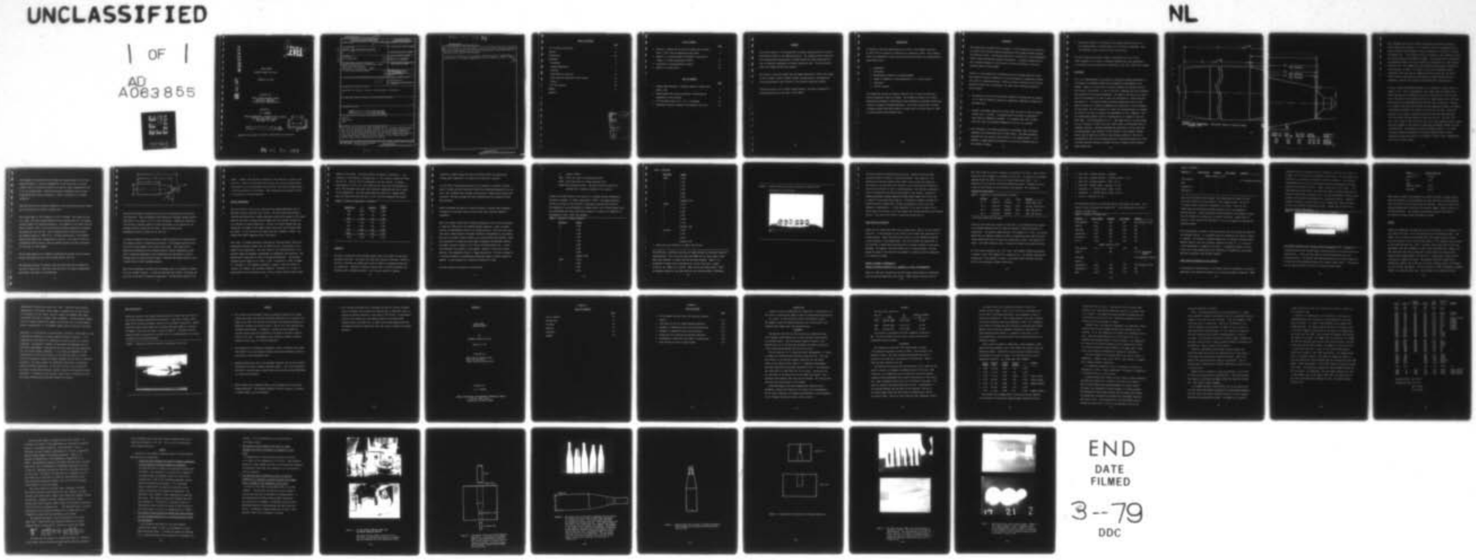

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FINAL REPORT

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FEBRUARY 28, 1978

Prepared for

NAVAL SURFACE WEAPONS CENTER
WHITE OAK LABORATORY
SILVER SPRING, MARYLAND 20910

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The central purpose of this program was to develop forging know-how on U-2% Mo specifically related to the Phalanx penetrator. The forging process studied was one concerned with producing near net shape penetrator blanks which would reduce raw material requirements and reduce machining costs. The factors which affect the forging process were studied.

The results of this work showed that net shape penetrators of 90%

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of the volume of the penetrator could be forged, thereby reducing material requirements by 17% and eliminating a major portion of the precision machining required.

U-2% Mo was found to be an easily forged material, relatively insensitive to forging temperature in the range of 700° - 1100°F.

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ABSTRACT

The central purpose of this program was to develop forging know-how on U-2% Mo specifically related to the Phalanx pentrator. The forging process studied was one concerned with producing near net shape penetrator blanks which would reduce raw material requirements and reduce machining costs. The factors which affect the forging process were studied.

The results of this work showed that net shape penetrators of 90% of the volume of the penetrator could be forged, thereby reducing material requirements by 17% and eliminating a major portion of the precision machining required.

U-2% Mo was found to be an easily forged material, relatively insensitive to forging temperature in the range of 700°-1100°F.

INTRODUCTION

A feasibility study has demonstrated the U-2% Mo in the annealed condition, Rc 28/32 could be forged at a relatively low temperature, 700°F. This research effort was undertaken to study the many factors which affect the forging process. These factors were:

1. Temperature
2. Die design
3. Metallurgical condition of forging material
4. Effect of chemistry of starting material, i.e., carbon content
5. Lubricants
6. Surface condition

The program was carried out using an induction coil to heat the blank and a vertical mechanical press for forging. The program was guided by an overall philosophy and purpose of developing as much information as possible specifically related to forging the Phalanx penetrator. The initial concept was to develop a forging process which would produce a forged blank to near net shape in order to reduce material and machining costs.

DISCUSSION

This program was concerned with the forging of U-2% Mo penetrators and therefore all efforts were directed toward determining how the forging variables affected that specific product. The Phalanx penetrator is unique with its own dimensional, surface finish and Rockwell hardness requirements. A research program with an aim of studying forging of U-2% Mo would be entirely different in scope and technique than was this program.

Implicit in this program was the expectation that the forged penetrator would have superior ballistic properties or could be produced by forging more economically than by a machining process. There are several attributes of the Phalanx penetrators which have a significant cost impact when considering machining versus forging.

1. The material in rod form is relatively expensive which may make the savings of .3" (16%) of length per penetrator significant, depending on swaging and grinding costs.

2. Uranium is extremely abrasive and causes rapid tool wear of even the hardest carbide (3% Co - 97% WC). If forging reduces the amount of machining it could result in significant savings. It is assumed that, with a proper lubricant, wear of the carbide forging dies will not be a problem.

3. The tolerances of the Phalanx penetrator are extremely tight and several dimensions are interrelated with the taper angle. This makes machining expensive but also requires close control of the forging process. It is possible to forge oversize and machine, but this would eliminate much of the potential savings.

4. The surface finish of 32 required by the drawing requires the use of a fine grinding wheel or requires great care to obtain by machining. This care manifests itself as high cost due to finer cuts.

The First Phase Interim Report (FPIR) is incorporated as part of this report (Appendix I) in order to eliminate redundency and, more importantly, to illustrate how the concepts and conclusions of this final report were reached.

DIE DESIGN

For a full understanding of the problems of forging the Phalanx penetrators it is necessary to thoroughly understand the dimensional requirements of the drawing. Figure 1 is a 10X scale of the part showing the tolerances and how they relate to the problem. It can be seen that, depending upon the A dimension, the tolerance for B is *almost* eliminated. The angle of the taper is not specified by the drawing but in order to meet the requirements it cannot vary more than about 30'. In practical terms the tapered length (B-A) must be fixed exactly because the A tolerance eliminates the availability of the B tolerance. In other words, the full tolerance of B cannot be utilized because its termination point at the flat is fixed by the requirements of the C dimension (.274"). The relationship between C and B-A is determined by the tangent of half the taper angle. This relationship is 1:2.6. This means that as C varies through its full tolerance of .006" B will vary .0156", which is 50% greater than its allowable tolerance. Therefore machining the penetrator is not an easy task and forging might prove ecnomical if the surfaces of the straight cylinder portion and the taper can be left in the as-forged condition. This can be accomplished by the use of starting stock with a reasonable finish and a lubricant which prevents scoring of "pickup" and can be removed from the forging without high costs.

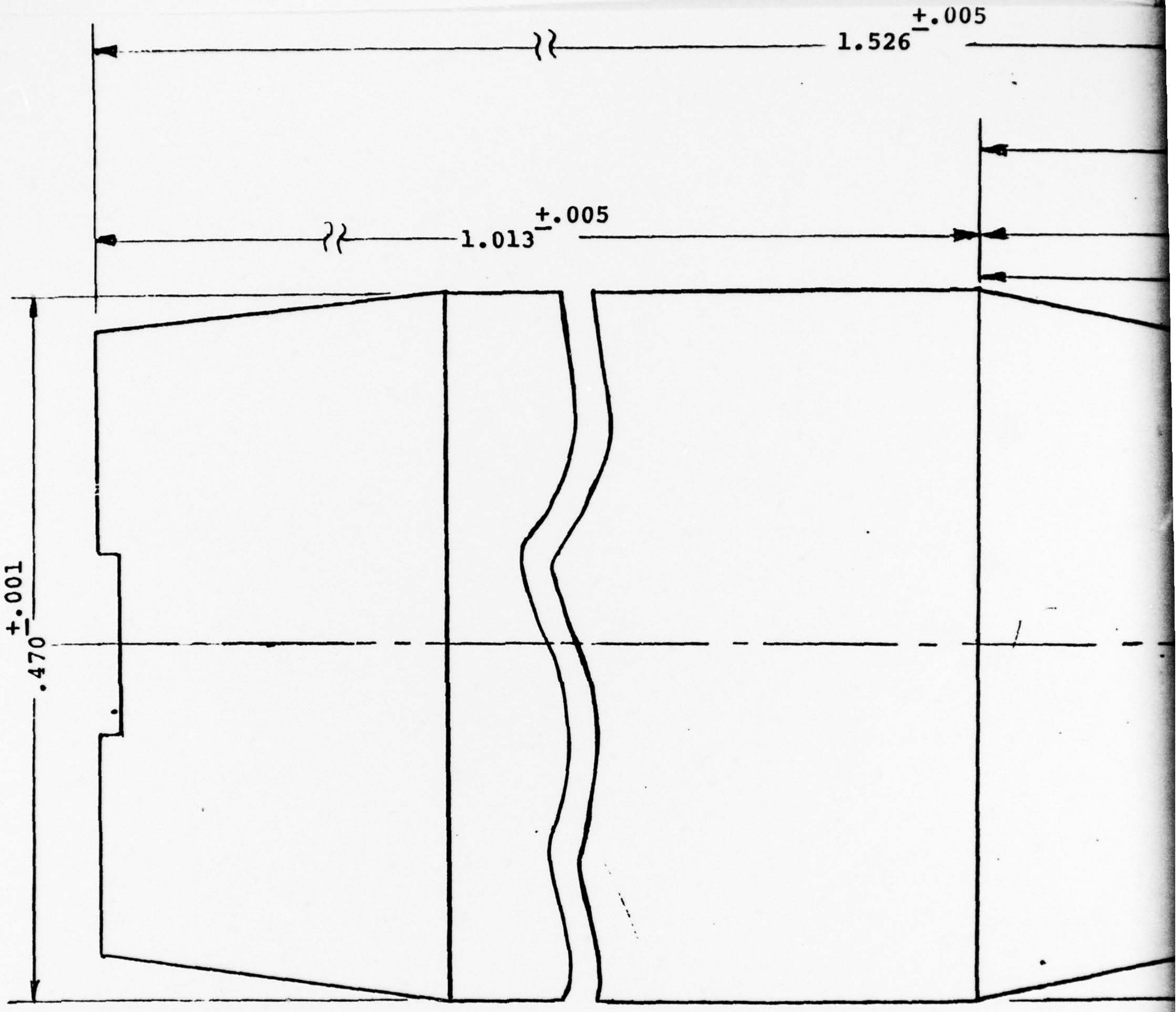
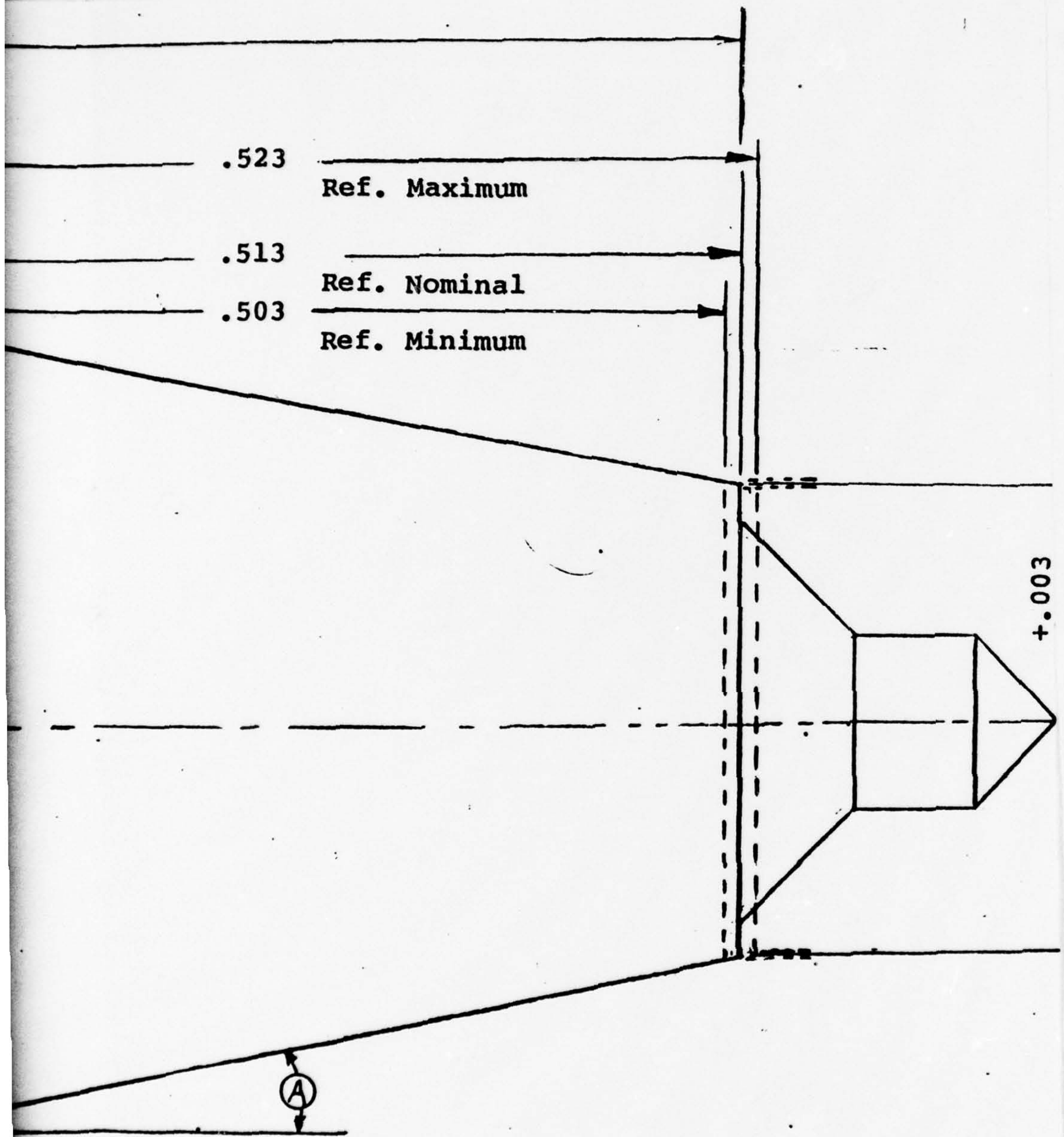


Figure 1.
PHALANX CIWS PENETRATOR - Tolerance Range of Forward Taper
Approx. 10X

Len
Tap



Length of Taper -in	Body Dia -in	Fwd Step Dia -in	Angle (A) -deg	Tolerance Range
.513	.470	.274	10° 48' 54"	Nominal
.503	.471	.271	11° 14' 38"	Maximum
.523	.469	.277	10° 24' 04"	Minimum

Work performed since the First Phase Interim Report has made the forging process appear more favorable. It is important that the A dimension be held within tolerance during forging in order to eliminate the necessity of milling the spinner slot. If the spinner slot is not forged in, the cylindrical section can be made oversize and machined to length. It was found that by reducing the starting blank length, very little material was forged into the .200" diameter extrusion land. The elimination of the extrusion process greatly reduced the force necessary to forge. As a result of this, the A dimension could be consistently held even when the temperature varied between 700° and 1050°F. Previous work on upsetting had shown relatively slight differences due to temperature variation but extrusion involves different characteristics.

In order to forge the Phalanx penetrator it is necessary to forge a part to a length of 1.8". This is approximately .035" longer than the finished part. A concept described in the FPIR was the use of a second blow to form the small flat at the end of the B dimension and the 45° angle leading to the .100" nose. This process can be performed and will produce a part to the print. However, it is possible that this process cannot be used commercially unless the problem of lubrication packing of the corners in the die can be solved. Parts were produced by this method using MoS_2 lubricant but the lubricant eventually fills the corner juncture between the taper and the flat. The print calls out a .010" radius at this point which will allow some packing of the die corner. One other drawback to this process is machining requirements between the first and second blow. The machining required is minimal, however, it is a manufacturing operation and therefore an economic analysis based on actual machining of parts would have to be performed in order to make a determination that this is a viable concept.

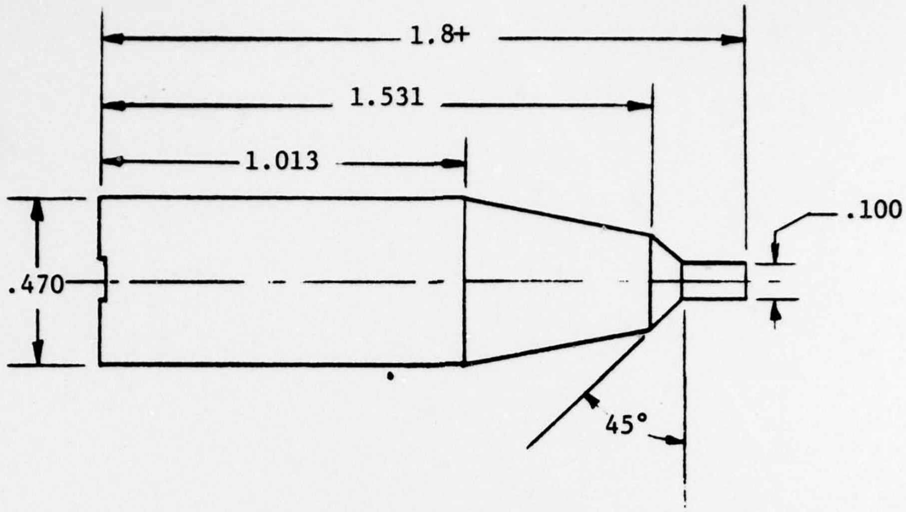
This program was concerned with die design and forging sequence for the most optimum production. Dies were designed and it was proven that a two blow concept could be a production method but it was not clearly demonstrated that it is the optimum method. Further work based on machining costs on actual forged penetrators would be necessary to reach a conclusion as to optimum production.

Described below are the critical dimensions of the first and second blow blanks and the machining and forging procedures used.

The forging blank is .460" diameter by 1.455" in length. The length can vary by at least .045" since excess material will be extruded past the 1.8" minimum required length for a finished penetrator. The diameter of the blank should be held to within ± .002" to avoid the problem of thermal expansion not allowing the heated part into the die. The die diameter must be within the finish part dimension which is .469"/.471". The punch should have a .468" diameter and have the spinner slot configuration on the tip. The corners of this tip configuration must be held as sharp as possible because the print requirement for the radii is .005" maximum.

The as-forged blank can be finished by machining the boattail and the forward section containing the flat, the 45° angle and the .100" tip.

The machining necessary to produce a part for the second blow is simple and can vary in minor ways. After much trial and error, one simple configuration, shown below, was found to be satisfactory.



This part was forged by heating only the top 1/2" and placing the cold end in the bottom die. This was necessary since heating the straight cylinder section would make it too large to fit in a .470" bottom die. Forging this blank was easy and only a moderate amount of flash was produced at the juncture of the straight cylinder section and the taper. This was removed when machining the final 45° angle on the .100" tip.

It should be understood that the forging concept described above departed from the original concept of forging near net shape. The procedure described (both one and two blow) produces a part which is net shape. This means that no machining is performed on the as-forged surfaces, thereby eliminating a great deal of precision machining but also eliminating the opportunity to correct forging errors and improve surface finish. Therefore the forged blank must have a finish close to the 32 maximum required.

There was an experiment concerned with die design which is of technical interest but of no economic interest. A punch was made which was capable of forging the boat tail at the time of forging the penetrator. Two parts were forged in this manner. However, the load was too severe for the punch and it failed on the third try. There is little doubt that the boat tail could be forged during the second of a two blow operation since the boat tail would be formed within a thick die and not by a thin punch. This concept was not pursued but could be utilized in a two blow operation.

FORGING TEMPERATURE

The initial work on this project indicated that forging temperature was an important variable requiring close control. The First Phase Interim Report contains data showing that forging temperature affected the length of the forged blank and the work on forging buttons showed that the resultant hardness was also affected by forging temperature. However, the button forging data also showed that the length of the forged button varied very little between 500°F and 1200°F. At the low end of the range there was a tendency to split. But between 700°-1000°F temperature has little effect.

Later work, on forging penetrators using shorter starting blanks, showed that temperature variation between 750° and 1050°F had very little effect on the length of the forged blank. The final length of the forged penetrator is an excellent means of obtaining a measurement of forgeability and lubricity. The length must be understood in terms of the Phalanx penetrator. The straight cylinder section length (A) is 1.013" ± .005". A variation of .010" in length of a cylinder of .470" diameter represents a length of .055" in length of a cylinder .20" diameter (the extrusion diameter). Therefore, if the part is forged deeper into the extrusion land, A will be shorter and the overall blank length will be longer. Two factors offset the amount of extrusion: 1. the resistance of the material to movement and, 2. the lubricity between the blank and the die. Lubricity will be discussed in the next section. By using a blank length of 1.455", very little material was forced into the extrusion die and it was determined that under this condition, temperature had little effect on the forgeability. The table below shows the results of a forging series where the blanks were uniformly short (1.455") and the temperature was varied.

TABLE 1. Effect of temperature on forging.

Temperature	A	Diameter	Final Length
975°	1.012	.470	1.800
975°	1.015	.470	1.800
975°	1.015	.470	1.790
925°	1.011	.470	1.807
925°	1.013	.470	1.788
925°	1.007	.470	1.824
800°	1.015	.470	1.764
700°	1.020	.470	1.742

LUBRICITY

The bulk of forging work was performed using a MoS_2 in an organic solvent manufactured by Kal Gard. The reason for using this particular lubricant, called AI, was that a lubricant was needed which could be applied by dipping and which was not hydroscopic. Spraying a lubricant requires care to achieve uniformity and therefore adds an unwanted variable. The AI easily applied by dipping, required no lengthy drying time and was therefore ideal for applying and forging almost immediately or forging can be delayed if required.

For the task of evaluating lubricants it was necessary to prepare a uniform group of blanks and have them spray coated by an experienced sprayer all at one time. Four different MoS_2 coatings and one group of copper plated blanks were evaluated. The MoS_2 coatings that were evaluated were all sprayed on by Kal Gard personnel.

Before discussing the results it would be helpful to provide some background information on lubricants and how factors other than lubricity should be considered.

MoS_2 in an organic solvent has a potential advantage in that it may be possible to leave the lubricant on the finished Phalanx penetrator. MoS_2 in organic solvents is nothydroscopic and will not absorb moisture. MoS_2 in a water base does tend to absorb moisture and might therefore be detrimental if not removed. The use of an organic solvent, however, can cause problems with the EPA. Large scale spraying on a production basis might discharge an unacceptable quantity of organic solvents (toluene et al) from the building exhaust vent. A water base lubricant will present no such problem. However, a water base solvent requires a low temperature bake or a longer drying cycle. The use of copper as a lubricant presents no contamination problem and copper is easily plated and removed. It was evaluated as a potential alternative to MoS_2.

The MoS_2 lubricants evaluated are listed below.

AI - Organic solvent

WL88 - Water base used for extruding zirconiun

WL99D - Water base used for forging stainless steel

WL99D with conversion coating. The same lubricant as above but, applied over a chemical treatment of the uranium.

Listed in the table below are the results of a forging sequence performed on one group of blanks, 1.5 inches long heated to 950°F. The lengths reported indicate the effect of the lubricant, long blanks indicate high lubricity. The forging set up was established by forging some of the AI coated blanks first and establishing the punch penetration necessary to produce an A dimension of approximately 1.023" (.005" over maximum).

TABLE 2. Results of forging sequence.

Lubricant	Length
AI	2.058
"	1.979
"	1.962
"	1.984
"	1.964
"	1.982
"	1.986
"	1.966
	Average 1.985
WL88	2.030
"	2.008
"	2.012
"	2.013

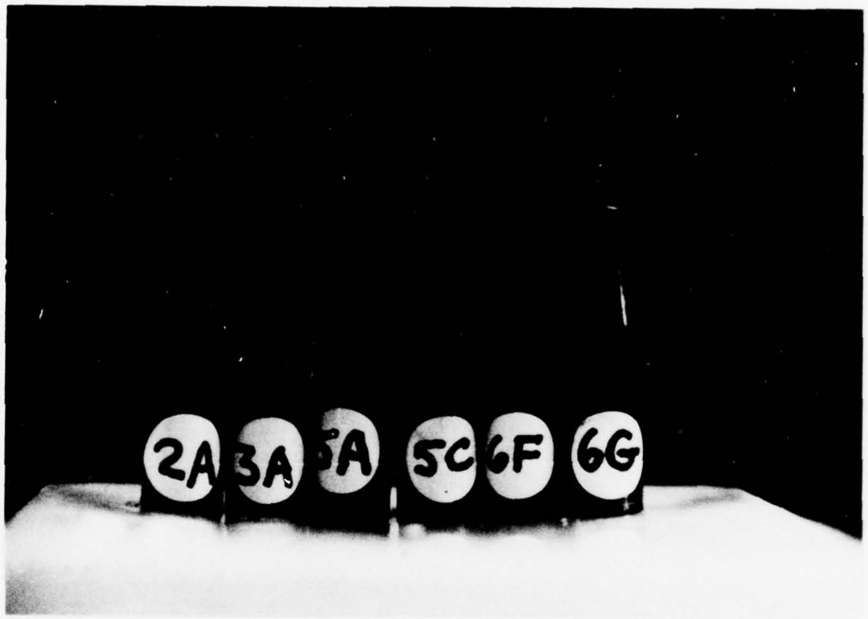
TABLE 2 CONTINUED.

Lubricant	Length
WL88	2.030
"	2.046
"	2.019
"	1.971
"	2.038
"	2.003
	Average 2.017
WL99D	1.754*
"	1.744*
"	2.023
"	1.916
"	1.810*
"	1.743*
	Average 1.832
Cu Plate	1.764*
"	1.767*
"	1.744*
	Average 1.758

* - These parts were difficult to remove from the die.

The WL99D with a conversion coat was not forged because the lubricant flaked off during heating. Four of the six parts with WL99D and all three copper plated parts were difficult to remove from the die after forging. Figure 2 is a photograph of sample parts representing the various lubricants. Sample 2A had AI, 3A - WL88, 5A, 5C and 6F - WL99, and 6G was copper plated. While the lengths reported in the table show that the lubricant makes a difference,

FIGURE 2. Forged blanks with various lubricants illustrating the importance of die lubricant.



the picture makes the differences more obvious. Sample 3A which had WL88 lubricant showed no evidence of lubricant distress. This lubricant is an excellent one and will probably prove itself to be the best for production. The purpose of the lubricant is to provide a low friction barrier between the work piece and the die in order to prevent galling. The U-2% Mo is especially prone to galling and will attach itself (weld) to the carbide. During this forging development program numerous extruded blanks jammed into the die and no amount of force would drive them out. Drilling was required to remove the forged blank and following that, honing was required to clean up the last remnants of uranium metal. A close inspection of the parts in Figure 2 will show a faint line parallel to the line between the cylinder section and the tapered section. This line is the result of previously honing the die.

OXIDE EFFECT ON LUBRICITY

During all the forging work there was no evidence that oxide in any way affected lubricity. If the lubricant is poor there is little doubt that oxide would not prevent galling. Where oxide may have an effect is on the adhesion properties of the lubricant to the forging blank. This would require the application of the lubricant to blanks which had been held for various intervals of time after grinding. For example, one month periods over a 12 month program. This was beyond the scope of this work but the problem, if operative, would be important in a production program.

EFFECT OF CARBON ON FORGEABILITY

EFFECT OF MATERIAL CONDITION (i.e. ANNEALED vs. STOA) ON FORGEABILITY

These two tasks were discussed in the First Phase Interim Report but additional work has been performed since that report. NETCO returned some bar stock of

Heat 3798 to NMI for solution treating to a hardness of Rc 39/41. Half of these blanks were then overaged to a hardness of Rc 30.5/33. In addition, we purchased annealed blanks (Rc 28/32) of an out of specification heat (8267). The chemistry of this heat was 2.2% Mo and 560/670 ppm carbon. Although it was not a task of this contract we also evaluated cast material. The castings we received are shown below.

TABLE 3. Evaluation of casting material received.

Casting	Mo	C	Rc	Remarks
No. 1	1.98/2.07	330/460	27	STOA* virgin melt
No. 2	1.90/1.98	250/470	23/25	As Cast, 50% recycle
No. 3	1.95/2.08	500/580	30/31	STOA, 50% recycle
No. 4	1.98/2.06	930/960	29.5	STOA, 50% recycle

* Solution treated and over aged.

During the work previously reported in the FPIR, it was determined that forging of the Phalanx penetrator was not sensitive enough to discern differences in forgeability. We therefore forged buttons .470" diameter by 1" long. The results showed that all materials forged very well at temperatures above 500°F and small cracks appeared only when the upset was exceptionally severe: 60% reduction in length - over 300% increase in area. Hitting the blanks cold stalled the press.

For this latter evaluation, the 1 1/2" long, .460" diameter blanks was machined to produce a nose .250" diameter for a length of 1/2". By severely reducing the forging area it was possible to forge a cold blank without stalling the press. The test was performed on blanks listed below.

1. Heat 3798 - original material - annealed.
2. Heat 3798 - original material - solution treated - Rc 40.
3. Heat 3798 - original material - STOA - Rc 31.
4. Heat 8267 - 560/670 carbon - annealed - Rc 30.
5. Casting No. 3 - 500/580 carbon - STOA - Rc 30.
6. Casting No. 4 - 930/960 carbon - STOA - Rc 29.5.
7. U-3/4 Ti - Extruded - Rc 32.

The blanks were placed in a bottom die and hit cold using a flat punch. After a series of tests, the punch was lowered .040". Three series were run and the results are shown below.

TABLE 4. Results of forging tests.

Material	Final Length	Diameter	Nose Length	Comments
3798 annealed	1.391	.280	.397	26% increase in area
3798 ST	1.412	.272	.410	18% "
3798 STOA	1.407	.280	.410	26% "
Casting No. 3	1.406	.280	.410	26% "
Casting No. 4	1.391	.275	.395	21% "
3/4 Ti	1.408	.274	.410	21% "
		Hammer Lowered $\simeq$ .040"		
3798 annealed	1.347	.295	.355	39% "
3798 ST	-	.297	-	41% 45° compression failure
3798 STOA	-	-	-	45° Compression failure
U-3/4 Ti	-	-	-	"
Casting No. 3	1.346	.310	.345	54% Increase in area
Casting No. 4	1.345	.280	.355	26% "
8267	1.348	.290	.355	35% "

TABLE 4 CONTINUED.

Material	Final Length	Diameter	Nose Length	Comments
		Hammer Lowered $\simeq$ .040"		
3798 annealed	-	-	-	45° Compression failure
8267	-	-	-	"
Casting No. 3	-	-	-	"
Casting No. 4	-	-	-	"

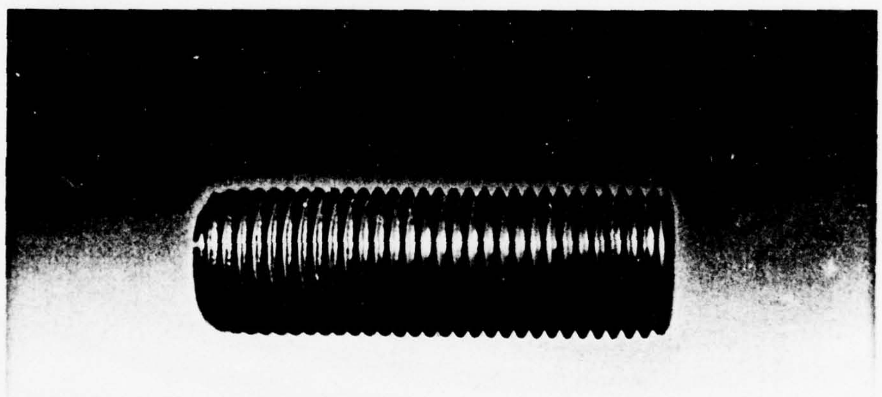
This test illustrated several things. Most importantly it showed that even high carbon content is not detrimental to the forging process. The effect of carbon content on ballistic properties is not known. This test also showed that cast U-2% Mo has excellent ductility and is as forgeable as extruded material. We had previously forged penetrators from castings, however, this test showed that casting can be severely cold upset. Another point of interest is that extruded and STOA material is not as forgeable as extruded and annealed material.

More investigation is needed in this area because the cast material was STOA and was extremely ductile. It is possible that the forgeability is directly related to hardness. The Rockwell C hardness numbers are as reported by Nuclear Metals. Hardness seems to vary with technique, machines and loads and is in addition a poor measurement of toughness or ductility. A compression impact test such as was run in this program may be more indicative of forgeability (and perhaps ballistic properties) than Rockwell hardness.

OTHER TASKS NOT REQUIRED BY THIS CONTRACT

In discussions of problem areas of the Phalanx round the fastening of the plastic windscreen to the penetrator seemed to be an area which might be improved. NETCO considered that the windscreen could be attached to the nose by the means of threads, if U-2% Mo could be successfully thread rolled. We investigated this possibility by attempting to thread roll several conditions. The technique investigated was two die flat rolling and the work was performed cold using standard 1/2-20 thread roll dies. Figure 3 shows one of the 1/2-20 x 1 1/2" long blanks which was rolled. We rolled cast blanks, extruded blanks and one solution treated blank of Rockwell C 40. All were successfully rolled and this technique can obviously be developed into a production process. Uranium is extremely abrasive on cutting tools so it is assumed that thread rolling is far more cost effective than thread cutting. Threads can be rolled at the rate of at least 30 per minute.

FIGURE 3. U-2% Mo thread rolled cold - 1/2" - 20 threads.



The Phalanx penetrator has a surface finish requirement of 32. A number of forged penetrators were checked using a surface analyzer and all were within the specification. A check was then made on the starting material which was centerless ground. The results were surprising because the surfaces appeared to be less than 32 and grinding normally will provide a good surface. Listed below are the results obtained on several as-received ground blanks.

Blank	Surface Finish AA
Casting No. 3	85-100
8267	55-65
3798 Solution Treated	65-70
3798 STOA	60-65

These results indicate that grinding cast material produces a rougher surface than that obtained in extruded material and also show that the harder material does not provide a better surface than soft material. There is no doubt that a coarse grinding wheel, while better for material removal, cannot be used for a finished penetrator. The forging process greatly improves the finish of as-received bar stock thereby providing an economy.

TEXTURE

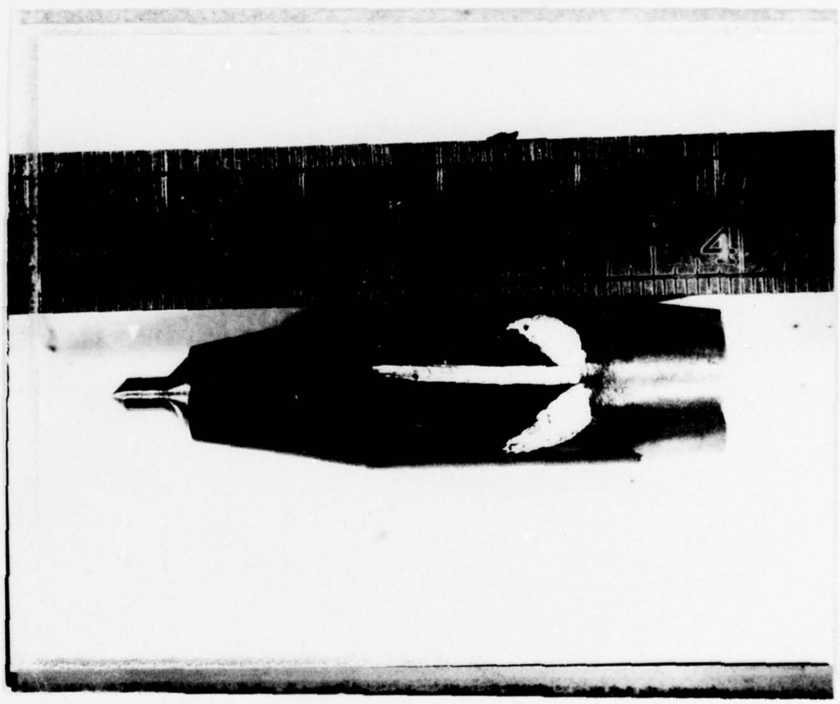
During the experiments concerned with the two blow concept, in an attempt to fill the corner of the flat, one of the blanks was struck exceptionally hard. This blank, like all others, was not heated along the straight cylinder section. This was necessary so that the first blow blank of .470" diameter could be placed in the bottom die which was .4707". All parts, during this portion of the die development work, had a diameter of .4707" after the second blow. However, the part which was struck with a great deal of force came out of the die with a diameter which ranged between .472" and .473". A great deal of difficulty was encountered in removing the blank. The hydraulic knockout cylinder was of insufficient capacity and it was only by the use of impact blows on the knockout pin that the part was removed. The die is press fit (.006" interference) tungsten carbide in a heavy H13 steel case. After removal of the blank the die was dimensionally inspected and found to be .4707". There are three possible explanations for obtaining a piece larger in diameter than the die opening. It is possible, but not likely, that the carbide die expanded under impact and allowed the blank to increase .002" in diameter. Another possible explanation is a volume increase after removal from the die due to a stress induced partial transformation, or the diameter change could be related to texturing.

Texturing is a characteristic of uranium which could have a severe impact on the processing of penetrators to achieve improved ballistic properties. It is recognized that the modulus of a penetrator can have an effect on ballistic properties. The modulus of uranium can vary almost 50% depending upon the direction of measurement. Texturing can occur not only from mill working but also from simple thermal treatments. It is strongly recommended that this characteristic of U-2% Mo be studied in a very practical manner concerned with mill processing, forging and thermal treatment and the effect on ballistic properties. This might prevent the inadvertant fabrication of penetrators with poor ballistic properties. On the positive side it may be practical to obtain a process which produces a specific texture with enhanced ballistic properties. A program with this specific intent could be dovetailed in with the current Manufacturing Technology Program as an adjunct.

BAR STOCK QUALITY

During the course of this program several sections of ground bar were found to have severe visually detectable surface defects. This type of defect, which might be due to heavy inclusions, would not be a problem in production. Smaller subsurface defects which might not be visually detectable might be a problem. An example of this type of defect is shown in Figure 4. This defect was not observed during the machining of the boat tail, but became apparent as corrosion occurred and the inclusion darkened.

FIGURE 4. Subsurface inclusion revealed by machining of boat tail.



SUMMARY

1. This research and development program successfully developed the forging concept and showed that the U-2% Mo Phalanx penetrator can be forged to net shape of over 90% of the surface area and meet the drawing requirements of dimensions, hardness and surface finish. The die is of the simpliest most straight forward design. In addition, a unique two blow concept was developed which forges the penetrator to net shape in the most intricate portion of the part. The forging process reduces the amount of material required by more than .3" (17%) per penetrator.

2. The temperature for forging was determined to have a relatively wide range (700°-1050°F) with only residual stresses and surface hardness as potential restrictions on the temperature used.

3. Forging lubricant was found to be extremely important and two dry film MoS_2 lubricants were found to produce excellent results. One of the lubricants, Kal Gard AI, uses an organic solvent while the other was Kal Gard WL88 which is a water base lubricant.

4. Carbon content has no apparent effect on the forgeability of the U-2% Mo Phalanx penetrator. The potential problem of stress corrosion, as related to carbon content, was not evaluated.

5. Prior thermal processing such as extruding followed by solution treatment, solution treatment and overaging and annealing has no observable effect on forging the Phalanx penetrator in the range of 700°-1100°F. No differences could be found between cast and annealed blanks and extruded blanks. Forging studies, performed cold, on simple upset blanks demonstrated that the annealed condition forges better than the solution treated and overaged condition.

APPENDIX I

FIRST PHASE
INTERIUM REPORT

ON

CONTRACT N60921-76-C-0287

August 22, 1977

Prepared for

Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, Maryland 20910

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INTRODUCTION

A previous contract established the feasibility of forging DU-2% Mo bar stock in a manner which might be used to produce Phalanx penetrators. As a result of that work this contract was granted to study die designs to make the Phalanx penetrator and to study some of the variables which might effect the forging process.

PROCEDURE

The material available for this contract was centerless ground .470" diameter random length bars of three different heats obtained from Nuclear Metals. From the reported chemical analysis it was believed that one of the heats was extremely low carbon (40 ppm) but it has since been determined that this was an error.

The bar stock was cut to length and pieces approximately 1.5 inches in length were lubricated with Kal-Gard AI MoS_2 dry film. The slugs were heated in a 20 KW high frequency induction coil and forged using a 60 ton Minster Press (Figure 1). Temperature measurements were made using Temp Lag and when reported are ±25°F. The temperature was controlled by a timer which cut off the power. The heated slug was then moved to the bottom die and the hammer was tripped. This operation would normally take less than two seconds. The heating times used were from three seconds to ten seconds.

Following forging, parts were dimensionally inspected with a micrometer, caliper, dial indicator (for concentricity measurements) and an optical comparator for angles and measurement of such dimensions as the straight cylindrical portion, herein called A.

MATERIAL

The three heats used were:

Heat No.	C PPM	Mo 90	Rockwell Hardness R_c
3798	190/200 (200)	2.18 (2.20)	32 (30)
3808	210/230 (380)	2.08 (2.14)	31 (29)
3811	320/330 (40)	2.20 (2.09)	30 (30)

The results in parentheses are those originally certified by NMI. The results shown are those from a recent retest and are considered the more accurate.

DISCUSSION

The feasibility study used a die large enough to accept a .470" diameter slug heated as high as 1200°F. This required a die diameter of about .482" thus necessitating machining the entire surface of the blank with the exception of the back end. Figure 2 shows the basic design of the die.

The lower die is placed in the bottom portion of the press and the punch is placed in the hammer or movable portion of the press. When setting up, it is imperative that the punch and the die be properly aligned and fine adjustments can be made in the position of the bottom die. This is normally done by the use of "blueing" on the punch. The punch is carefully and slowly moved into the die. A disturbance of the blueing indicates that the punch is not centered. The die is then moved toward center and the process is repeated until the two are exactly right. The die is then carefully fully tightened in place.

The punch stroke can be precisely adjusted to travel to a desired vertical height. This is part of the set up procedure and in the case of the Phalanx penetrator, this adjustment is used to produce the dimension A. With a large excess of force and a material with little resistance, once this adjustment is made the A dimension will always be the same even with variation in starting blank length. However, from a practical standpoint variation in lubricity and blank temperature will affect A. Generally in this work, at any given temperature, A can be held within the tolerance required by the penetrator drawing.

Since we had as variables, temperature, punch adjustment, blank length and blank diameter, quite a few blanks were forged to gain the knowhow we needed. Listed below are some results obtained during the forging of a series of blanks. The time reported is actually temperature variation. All blanks were .460" diameter.

	Blank Length	Heating Time	Forged Length	Forged Diameter	A	Remarks
1.	1.480	5.0 sec	1.850	.470	1.033	
2.	1.460	4.5 sec	1.595	.471	1.070	
3.	1.460	5.5 sec	1.810	.4685	1.010	spiral cracks
4.	1.470	6.0 sec	1.765	.469	1.032	spiral cracks
5.	1.515	5.2 sec	2.080	.470	1.013	hammer lowered
6.	1.515	5.0 sec	1.860	.470	1.032	
7.	1.515	5.0 sec	1.920	470	1.019	hammer lowered

This series (all forgings made in this series are not reported in the interest of brevity and understanding) illustrates several things which have an effect. Cutting back .020" in blank length between 1 and 2 and reducing temperature results in a shorter blank but a larger A. This meant the blank resisted the hammer more and did not move as far into the die. Raising the temperature on #3 produced a part to the proper A length.

Between 4 and 5 the blank was lengthened, the temperature lowered and more force was used (hammer lowered) and a perfect part was produced. For 6, the temperature was lowered and A dimension was too long. Using the same temperature for #7 and more force, the A dimension was decreased almost to within tolerance. The temperature was lowered in this series because #3 and #4 showed spiral cracks in the nose indicating we were probably in the gamma field. These cracks could always be eliminated by lowering the temperature.

The final diameter of the forged blanks also show the effect of temperature. Numbers 3 and 4 were .001" to .002" smaller in diameter due to greater thermal contraction.

In a production operation it will be necessary to control the temperature in order to control dimensions. The effect of temperature is discussed later on in this section.

It became evident that blanks could be forged to finish dimensions, including the spinner slot, of 90% of the surface area, Figure 3. Many of these blanks were finished machined for various reasons, including some furnished to General Dynamics for firing purposes. The machining of these blanks, however was not quickly done because the dimensional tolerance and concentricity requirements required a great deal of care. The transition from the long tapered section, through the little flat, to the 45° cone leading to the tip was especially difficult to machine.

While this machining operation could be speeded up in a large scale production program, nevertheless, there is a substantial potential savings if the front end could be forged. A die was designed to form this front end on a second blow. The tip of the Phalanx is only .100" in diameter and is therefore too small to use as a place to force excess metal during forging. It was, therefore, decided that the first blow blank would require machining before it could be hit again. This operation would have to be kept simple (inexpensive) and after trial and error a blank as shown in Figure 4 was found to be satisfactory. Figure 5 shows the die concept.

There was considerable doubt whether the sharp edge at the flat would stand up but since the operation does not force metal to "flow" past this corner the die withstood the blow. What is not known is how long the die will stand up in production. This is critical since a $300 die has to produce 3000 parts to keep die costs to $.10 per part.

Figure 6 shows a sequence of parts from original cut off blank to first blow to second blow to machined part. The second forging blow causes a flash where the hammer (upper die) meets the holding die. This flash is easily removed.

An attempt was made to form the boat tail on the second blow but this caused unacceptable difficulties in maintaining dimensions. The boat tail is too easily machined to burden a critical forging operation with unnecessary problems. An attempt will be made to forge the boattail in the first blow but the chances of success are not considered high.

The effect of temperature on the forgeability of DU-2% Mo was determined along with a comparison of the forgeability of the three heats of material. In order to get meaningful data a simple upset forging was made. The heated blank was placed in a bottom die with a 1/8" deep (slightly tapered) hole in the middle and a hammer punch was used to hit the blank. This increased the diameter and decreased the length of the blank. The hammer could be adjusted to any height and the only limiting factor was the press power (60 tons). The most severe upset was one which brought the hammer to a point less than .4" above the bottom die. A piece of cold rolled steel heated to 1800°F had a length of .390" after being struck. All uranium blanks were 1" long before forging. This means the length was reduced to less than 40% and the cross sectioned area was increased more than 300%. Figure 7 shows upset blanks. In the table below are listed the results of 35 tests. The results are grouped for various hammer settings and show the effect of temperature. The area number reported is a ratio of the original area to the largest final area. This means that if the area of the blank after forging was twice, the number reported would be 2.00.

Heat #	Temp. °F	Hammer Setting	Length	Area Ratio	Hardness Rc	Remarks
3798	500	.428	.445"	2.85	32	
3798	1100	.428	.428	3.08	29/31	
3798	500	.390	.407	3.18	32/33	Cracked
3808	500	.390	.407	3.19	32/33	Cracked
3811	500	.390	.407	3.19	33	
3798	600	.390	.403	3.27	31/32	Slight burning
3798	775	.390	.399	3.31	32	Cracked
3798	775	.390	.399	3.36	31/33	Cracked
3808	775	.390	.398	3.32	32	Cracked
3811	775	.390	.400	3.32	31/32	Cracked
3798	900	.390	.393	3.38	31	Cracked
3798	1000	.390	.391	3.42	30	Cracked
3798	1150	.390	.387	3.46	28	
3808	1150	.390	.389	3.46	27/28	
3811	1150	.390	.389	3.46	27/28	
3798	1300	.390	.388	3.43	27/31	
3798	1200	.598	.600	2.01	28	
3798	1075	.598	.603	2.05	28/30	
3808	1075	.598	.603	2.12	28/29	
3811	1075	.598	.604	2.12	29/30	
3798	800	.598	.612	1.91	31	
3808	800	.598	.612	1.91	30	*
3811	800	.598	.612	1.91	31	
3798	800		.808	1.31	29/30	
3811	800		.808	1.32	29/30	
3798	1075		.799	1.37	26/27	
3808	1075		.798	1.38	26.5/28.5	
3811	1075		.800	1.39	28/29	
3798	1075		.863	1.23	28/29	**
3798	70	.598	.777	1.34	31/32	Press Stalled
3808	70	.598	.813	1.28	29/31	Press Stalled
3811	70	.398	.831	1.25	31/32	Press Stalled

*Superficial Test 30 N ≅ Rc37

**Superficial Test 15 N ≅ 32

30 N ≅ 33/35

45 N ≅ 29/30

There are many things of interest from the above results. It is evident that except at room temperature, all three heats of material behave in a strikingly uniform way. From these data it can be concluded that small chemistry differences will not have a significant impact on warm forging of the Phalanx penetrator. There is an increase in hardness due to work hardening at temperatures up to 1000°F. The hardnesses reported in the above table are only a relative guide since there are differences in hardnesses depending on the type of test run. Apparently uranium acts more like a stainless steel than an alloy steel. The Rockwell hardness test is a reasonable test for alloy steel but is used only as a guide for some stainless steels. Since the Phalanx penetrator drawing calls out Rc 28/32 this might cause problems in future procurement.

One of the results in the table shows a hardness of Rc 28/29 when 150 KG load and a brale indentor was used. However, the same specimen, when tested with a lighter load (superficial hardness) showed an equivalent Rockwell C hardness ranging from 29/30 to 33/34. Another upset blank, forged at 800°F, showed an even greater difference; Rc 30 to Rc37 for a superficial test. The superficial test, of course, measures more of the surface hardness and in a forged blank it is reasonable to expect more work hardening on the surface.

The hardness discrepency is also illustrated by the results shown below. These results were obtained by NMI on an automatic Rockwell Tester, testing the O.D. and face of several bar blanks.

Heat No.	OD Rc	Face Rc
3811	19.9, 26.2, 25.0, 26.3	29.9, 29.8, 29.4, 31.4
3808	23.6, 23.4, 25.4, 26.2	30.6, 30.7, 30.8, 31.3
3798	21.0, 23.2	32.1, 31.8, 31.9

The fact that the surface of a forged blank might be 7 Rockwell C points higher than the body may provide superior ballistic properties.

Surface hardening may provide more erosion resistance while still maintaining toughness in the core. This can only be determined by firing forged penetrators.

SUMMARY

Section F, of the contract required a number of tests and determinations and are listed below.

1. Contractor shall determine the effect of forging temperature on the formability and work hardening of penetrator.

   The penetrator can be forged at any temperature between 500° and 1300°F. The limitation on the high side is apparently the gamma transus and manifests itself as cracks on the extruded nose. Some of the overheating apparently results from self heating during extrusion. In a temperature range of 1025°/1125°F the penetrator forms very easily without cracking and only moderate work hardening. The penetrator can be forged at lower temperatures by applying more force. This results in more work hardening which may prove beneficial. The DU-2% Mo is extremely ductile at temperatures as low as 500°F but upsets of 300% increase in area cause cracks on the O.D. at temperatures up to 1000°F.

2. The contractor shall develop die design and forging sequence for most optimum production (i.e., one die-two blow or multi-die requirement).

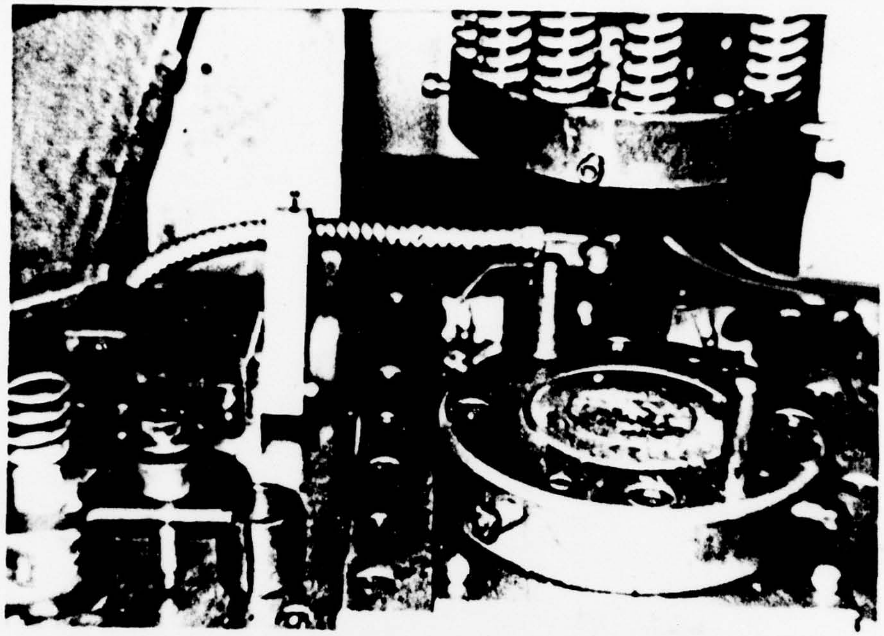
   A die design was developed for a one blow forging operation which might be able to be performed on a high speed horizontal header. A further die design was developed for a second blow which has the potential of reasonable cost savings. It is not believed this can be performed on a horizontal header.

3. The contractor shall determine the effect of carbon, hydrogen and impurity inclusions on forgeability of the alloy.

At temperatures of 500°F and above chemistry had little or no effect on the forgeability of the alloy. Three different heats with carbon ranging from 200 to over 300 ppm were evaluated. An additional fourth heat with chemistry out of specification will be evaluated.

4. The contractor shall determine the effect of material condition (i.e. annealed or solution treated and overaged) prior to forging on the forgeability of the alloy.

A portion of heat #3811 was provided by NMI in the STOA condition. This material was used in the early stages of the work and there was no difference in forging quality. It was believed that the STOA condition might forge better but the alloy is so forgible, no difference could be noted. Additional material is being obtained and upset tests will be run. In addition, finished blanks will be made so that ballistic tests can be performed; if desired.



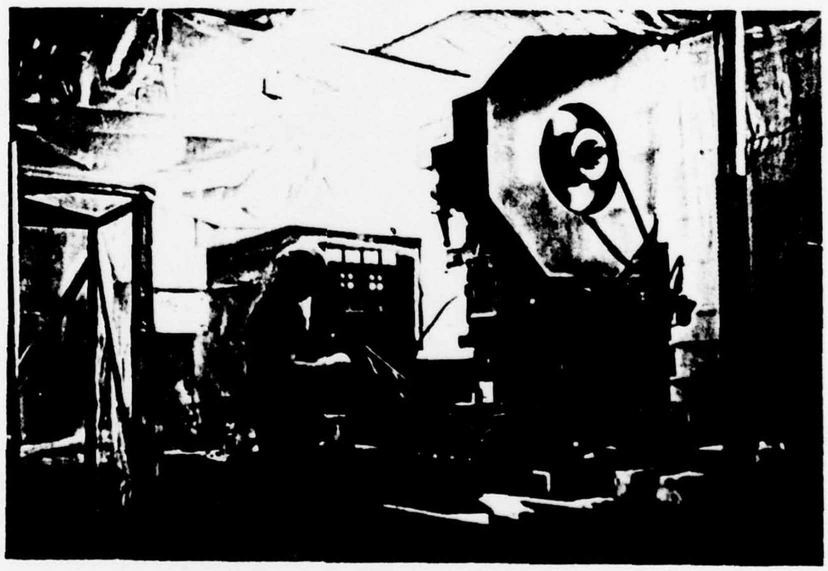


Figure 1. 60 TON MINSTER VERTICAL PRESS AND TOCCATRON INDUCTION HEATER

The upper picture shows a close up of the lower die, the sping loaded upper die (hammer) and the induction coil for heating the blank.

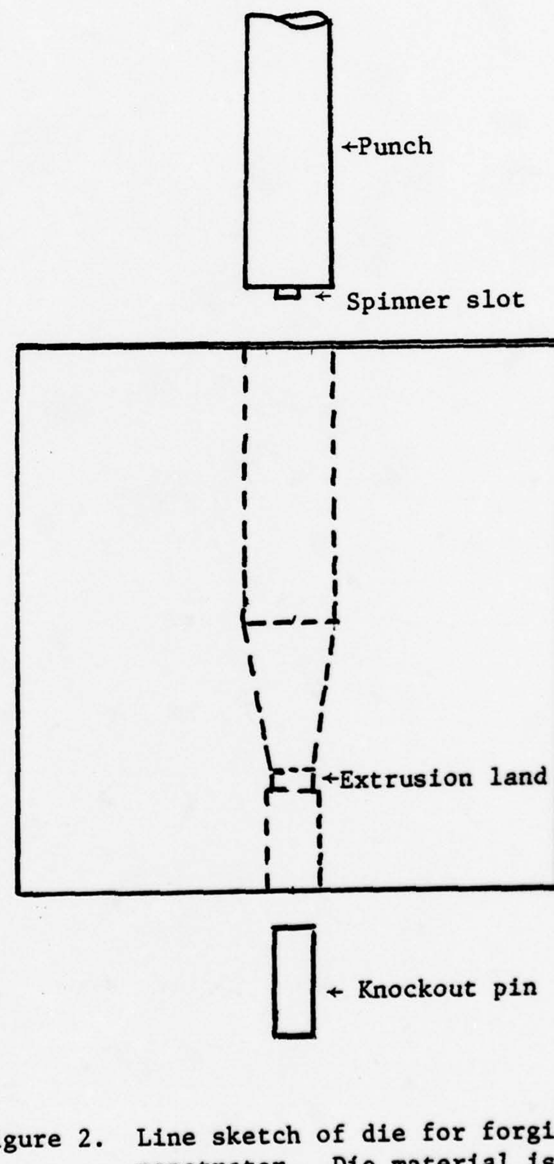


Figure 2. Line sketch of die for forging Phalanx penetrator. Die material is carbide. Heated, lubricated blank is placed in die, punch attached to movable head of press, is lowered a controlled amount and withdrawn. Knock out pin forces part out of die

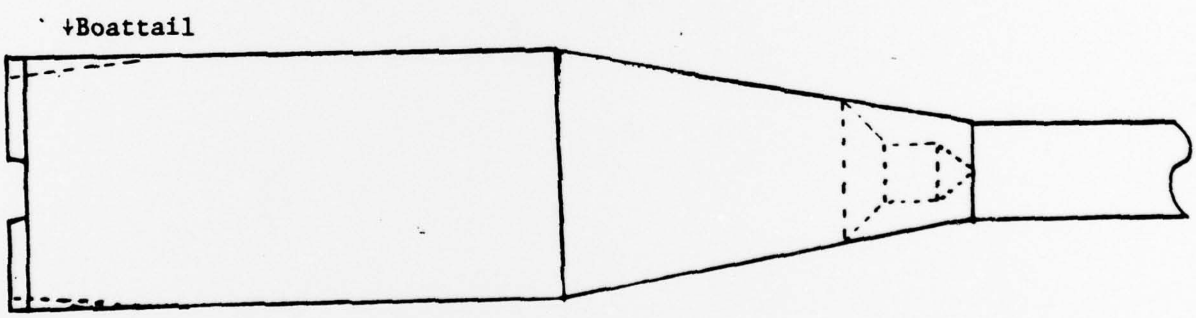


FIGURE 3. The solid lines of the sketch represent the first blow of forgings currently made by NETCO (The photograph is of an actual part). The dashed lines represent the finished Phalanx penetrator. This figure shows that over 90% of the surface area and a greater percentage of the volume can be formed to net shape. The material to the right of the point of the penetrator represents excess material extruded beyond the extrusion land on the die and show that a reasonable amount of excess starting blank can be accommodated. The photograph shows the variations obtained from different length blanks, forged with variations in force and in temperature.

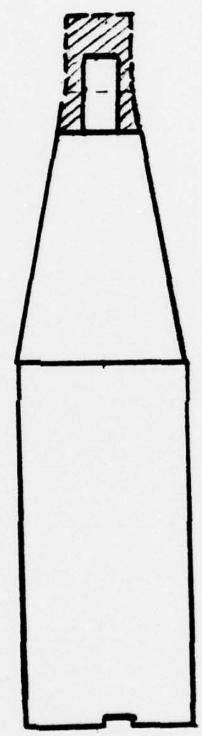


Figure 4. Machine Blank for 2nd Blow of Phalanx Penetrator. Cross Hatched area represents machined portion from 1st blow.

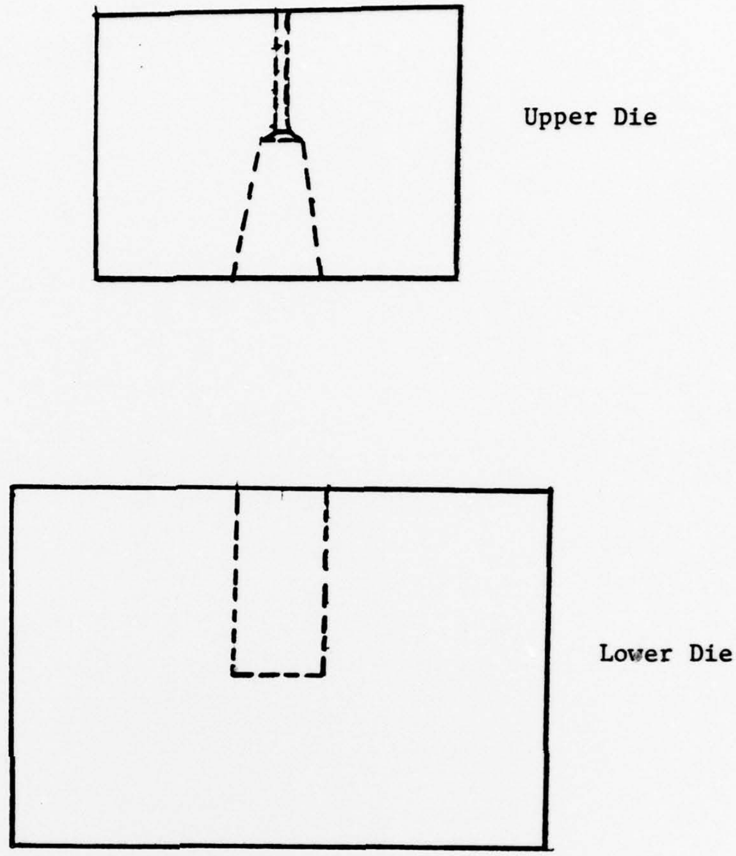
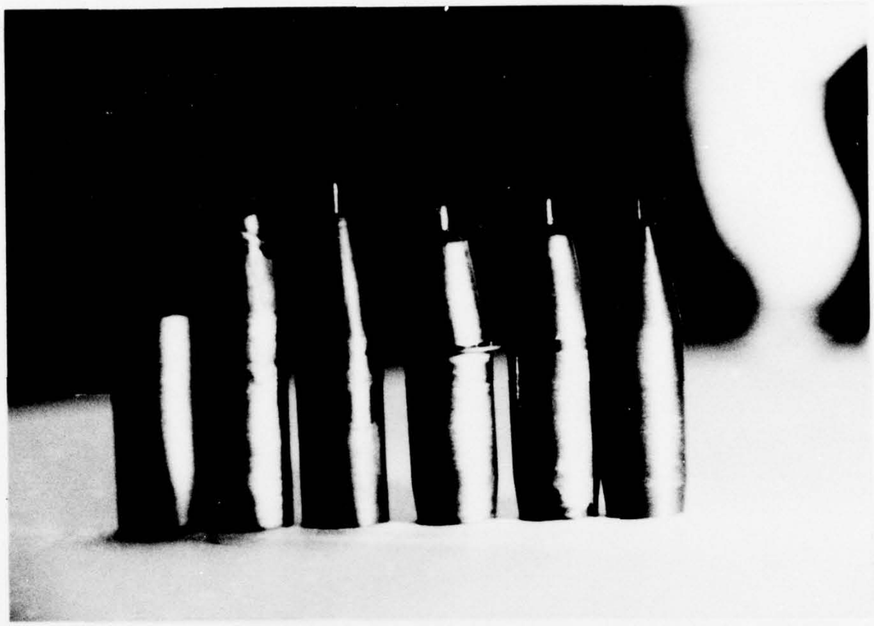


Figure 5. Forging Die for Second Blow of Phalanx Penetrator.



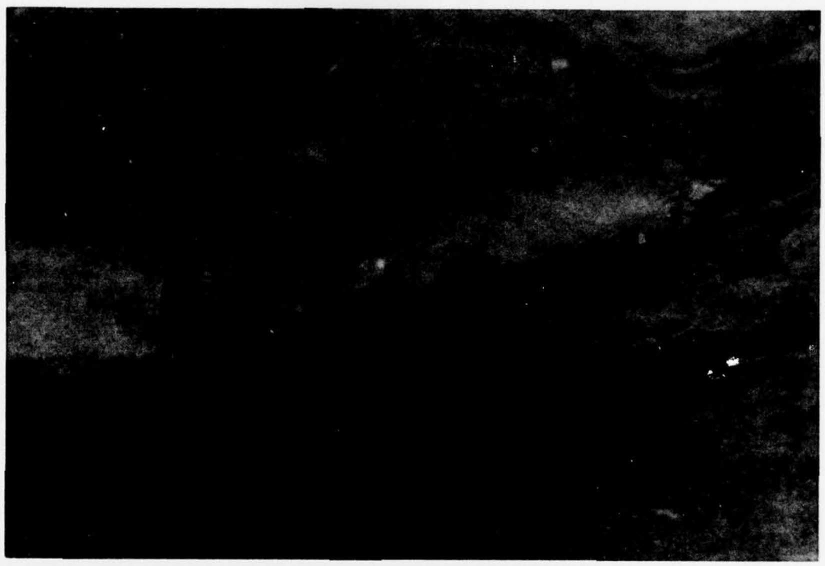


Figure 6. The upper picture shows a cut off blank and a sequence of parts. The lower picture shows the same sequence. The second blank on the left is a first blow part, the next is a machine forged blank, the next is a second blow blank, next is a blank with the flash removed and the last is a finished part.

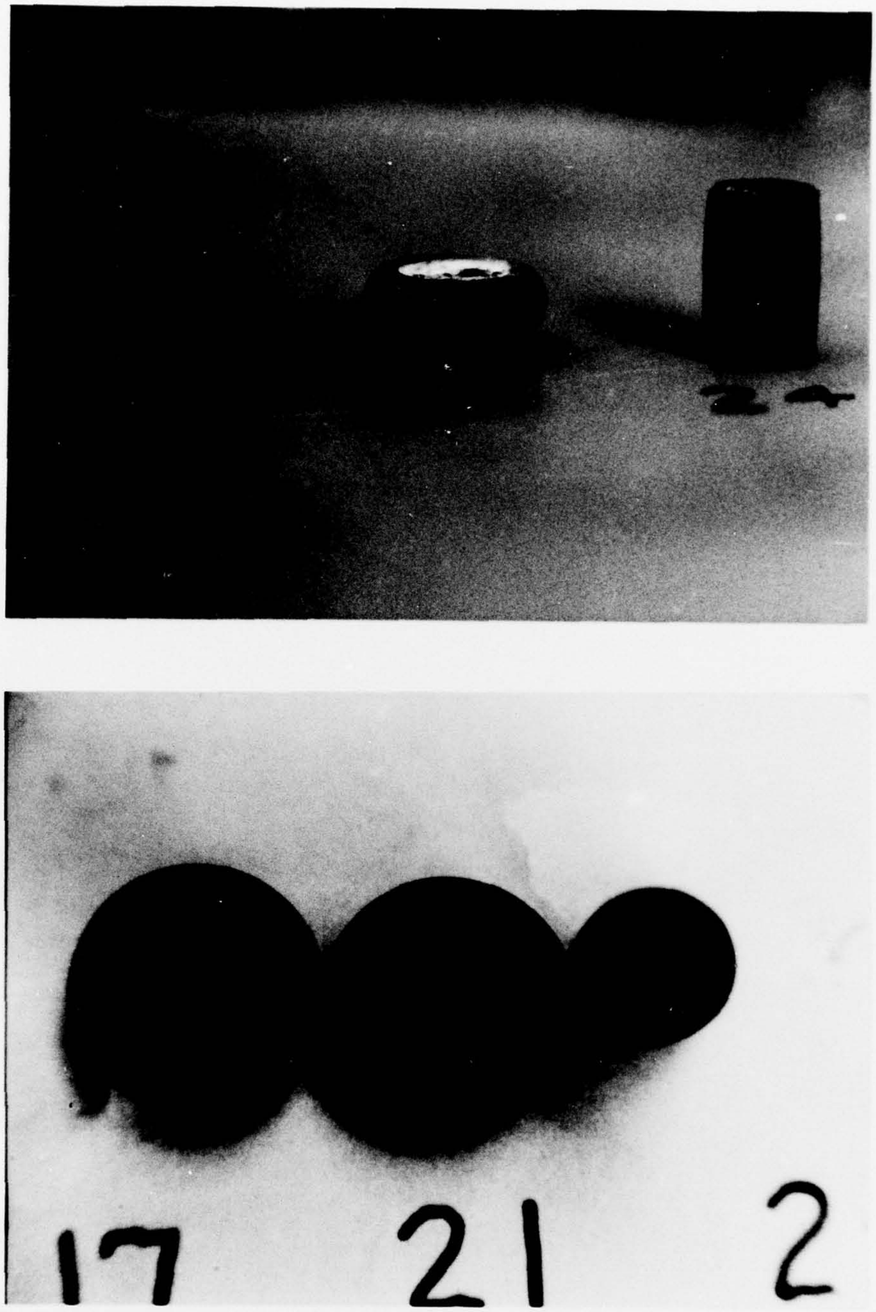


Figure 7. Side view and top view of upset blanks. Number 17 and 21 were reduced to 40% of original length (over 300% increase in area). Number 24 was hit at room temperature and stalled the 60 ton press. It was reduced to 80% of original length and had an increase in area of 28%.