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FABRICATION OF URANIUM-ALUMINUM ALLOYS

D.E. HAMBY

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METALLURGY DIVISION

FABRICATION OF URANIUM-ALUMINUM ALLOYS

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Fabrication of U-Al Alloys

Abstract

Fuel elements of uranium-aluminum alloys have been prepared both by extrusion and by casting. Fuel elements for the CP-3 Heavy Water Reactor at Argonne National Laboratory and some P-10 slugs for use at the Hanford Engineer Works were made by the extrusion process. It was found that with relatively small changes in composition, different extrusion conditions were required to produce satisfactory results. The optimum conditions have been determined for aluminum alloys containing 2%, 6% and 7.5% uranium.

A number of P-10 size slugs were prepared for use in the development of reprocessing procedures. Cast slugs and extruded slugs were made, thus permitting a direct comparison of the two types of slugs. The cost of reprocessing P-10 slugs may be greatly reduced by the use of extruded slugs in preference to the cast slugs since the extruded slugs may be dissolved much more readily. The initial cost of producing P-10 slugs also may be materially less when done by extrusion methods rather than by casting and machining to final size. A preliminary cost estimate, based upon the known production rate of the equipment used to make these slugs, places the cost at about $0.97 per slug.

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CONTENTS

I. Abstract - 2

II. Introduction - 4

III. Summary - 4

IV. Conclusions - 5

V. Experimental Procedure and Discussion - - - - - - - 5

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Introduction

The Metallurgy Division of ORNL has been requested on several occasions to prepare rods and slugs of U-Al alloys by various methods. This necessitated a certain amount of development work in each case in order to be reasonably certain of performing satisfactory work. The specific alloys used in this work were 2% U-98% Al, 6% U-94% Al and 7.5% U-92.5% Al.

The fuel elements for the CP-3 Heavy Water Reactor at Argonne National Laboratory (2% U-Al) were made by extruding a rod oversize, followed by a rolling operation to bring them to the required size. The P-10 slugs for Hanford (7.5% U-Al) were prepared by extruding oversize and drawing to size on a 20,000 lb. draw bench. About 200 P-10 type slugs were prepared for Chemical Technology Division both by extrusion and by casting. This work permits a comparison of production costs and relative quality of slugs produced by the two different processes.

Summary

Fuel elements have been manufactured successfully both by extrusion and by casting. The most expedient method is the extrusion process since a large number of rods or slugs may be made very rapidly. It was found that satisfactory extrusions could be made from billets of a 2% U-98% Al alloy under the following conditions:

(1) Flat face die at 200°C.
(2) Container temperature of 205°C.
(3) Billet of U-Al 3-1/8 inches in diameter, 6 inches long.
(4) Temperature of 300°C.
(5) Extrusion pressure of 300 - 390 tons and speed of 38 ft./min.
(6) Dummy blocks of steel 3.145 inches in diameter by 2 inches long at a temperature of 75°C.

The 6% and 7.5% U-Al alloys required progressively higher temperatures to yield satisfactory extrusions. The identical dies and extrusion conditions were used but it was necessary to increase the billet temperature to 360°C in the case of the 6% U-Al alloy and to 480°C for the 7.5% alloy.

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Extruded and cast slugs of 7.5% U-Al alloy were prepared for the Chemical Technology Division of ORNL who found that the extruded slugs dissolved much more readily than did the cast slugs. This is thought to be due to the difference in distribution of the UAl_4 compound in the alloy. The cost of producing a slug by extrusion and drawing is considerably less than the cost of the same size slug made by casting and machining to the final size.

Conclusions

1. The satisfactory extrusion of U-Al alloys is highly dependent upon the billet temperature and die design. The most satisfactory die design is one having a flat face with a very small radius. The following extrusion temperatures were found to be satisfactory:

2% U - 98% Al - 300°C

6% U - 94% Al - 360°C

7.5% U - 92.5% Al - 480°C

2. The observed differences in rate of dissolution of cast slugs and extruded slugs is probably due to the distribution of UAl_4 in the alloy.

3. The cost of producing an extruded slug is approximately $0.97 whereas a cast slug is more expensive because of the increased machining operations required.

4. Extruded rods may be drawn to size and held within tolerance limits of + 0.001" and - 0.002" on the diameter.

Experimental Procedure and Discussion

A. Melting and Casting

The method of producing U-Al slugs consists of a melting and casting operation followed by fabrication. The melting and casting procedure is constant regardless of the subsequent fabrication and is summarized below.

Aluminum of 99.9% purity was melted in a graphite crucible in a high frequency

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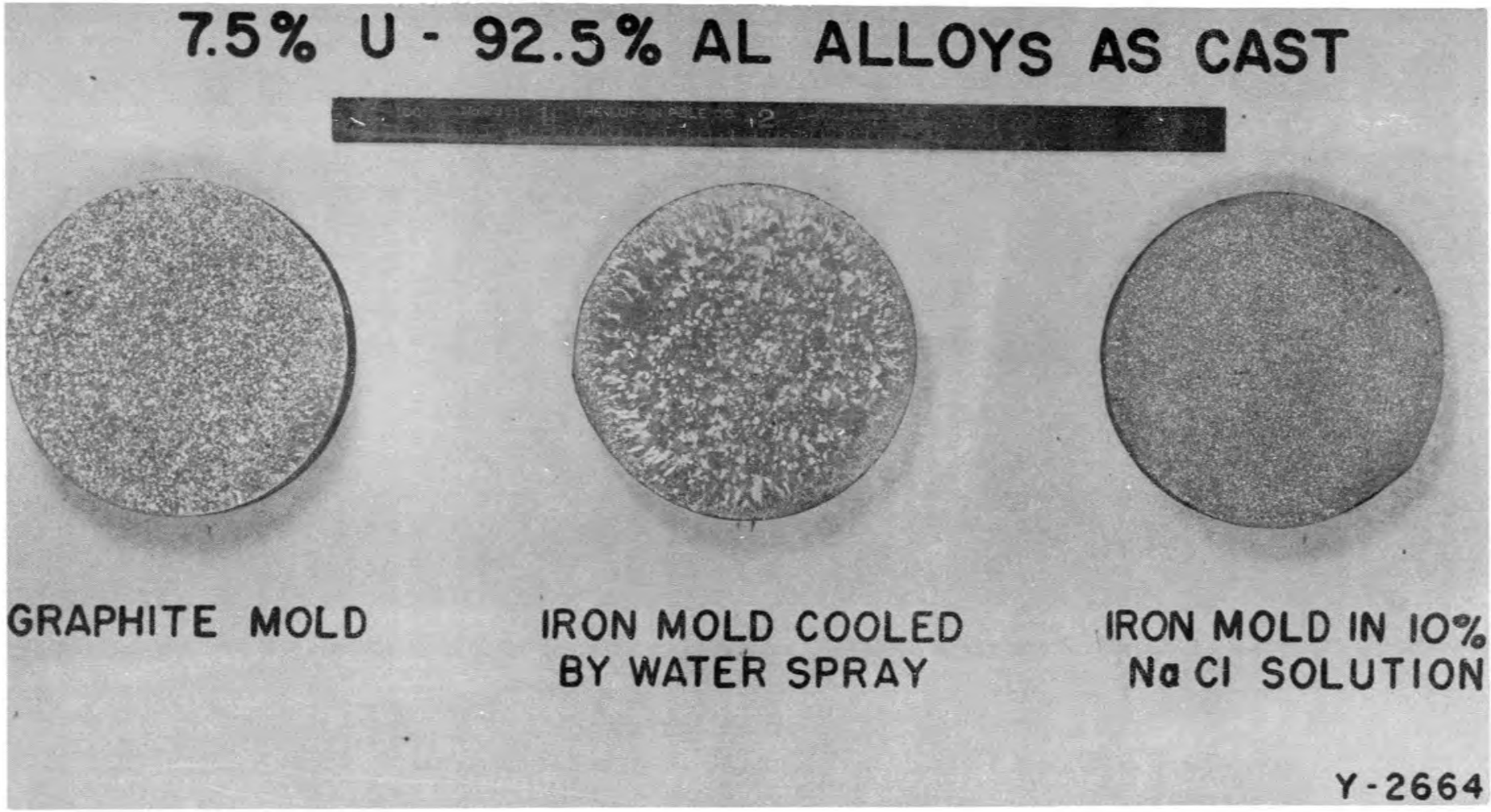
induction furnace. When the aluminum was completely melted, the metallic uranium wrapped in aluminum foil was added to the molten bath. The power was turned off when the temperature of the metal reached 850°C and the bath stirred with a graphite rod for 10 minutes. In addition to this stirring, the melt was violently agitated by induced currents and the uranium appeared to go into solution very rapidly. A continuous record of the melting cycle was obtained with a strip chart recorder and when the temperature of the alloy dropped to 725°C, the metal was sampled for a control analysis and cast into graphite molds of the proper size. If extrusion billets were desired, the metal was cast into a mold 3 to 4 inches in diameter and 8 to 14 inches long. If cast slugs were needed, the molds were 1.5 inches in diameter and 9 inches long. The usual size melt will make one extrusion billet to produce ten extruded slugs or eight cast ingots for machining into eight slugs.

The structure of the cast ingot is dependent upon the cooling rate. A very rapid cooling of the melt results in a very fine grain size and consequently very small particle size giving a more uniform distribution of the UAl_4 compound particles. The molds used in the majority of this work were made from high purity graphite whose high thermal conductivity produces a relatively rapid rate of cooling. Other molds which have been used include iron, water cooled iron, copper, water cooled copper and stainless steel. A brine solution has also been used around metal molds to give a still faster rate of cooling. Samples which have been given a macro etch to show the grain size are shown in Figure 1. The initial grain size seems to have a very little effect on the final structure of an extruded slug. However, the grain size is important in the case of slugs which are used in the as cast condition since different properties are encountered with alloys having different distribution of UAl_4 compound particles.



Comparative Grain Size Obtained by Different Rates of Cooling of $7\frac{1}{2}$% U-Al Alloy
Fig. 1

B. Final Fabrication

(1) Cast Slugs

When slugs with an as cast structure are needed, the cast ingot is machined to the final size. The cast ingot and the machined slug are shown in Figure 2. The machining operation consists of cutting off the shrink head, facing both ends and machining about 0.140 inches off of the diameter of the slug. The usual tolerance is +0.001" and −.002" on the diameter.

(2) Extruded Slugs

An extrusion ingot four inches in diameter and 12 inches long is shown in Figure 3. Portions of an extruded rod both in its original condition and after drawing to size are shown also in Figure 3. The top of the ingot is cut off to give an extrusion billet which is heated to the proper temperature in an electric resistance furnace. The billet is extruded into rod of any desired diameter with a 700 ton Lake Erie extrusion press. The optimum extrusion conditions for 2% U-Al alloy which were determined from the fabrication of fuel elements 0.850 inches in diameter were was follows:

A. Die

(1) Flat face with a throat diameter of 0.861 inch, 1/32 inch radius at entrance and 1/8 inch bearing surface with $0^{\circ}30'$ relief through bearing.

(2) Temperature $200^{\circ}C$.

(3) Throat cleaned by hand with a steel scraper after each extrusion to remove excess alloy.

(4) Cleaned after 4 - 7 extrusions with NaOH solution.

B. Container

(1) Temperature $205^{\circ}C$.

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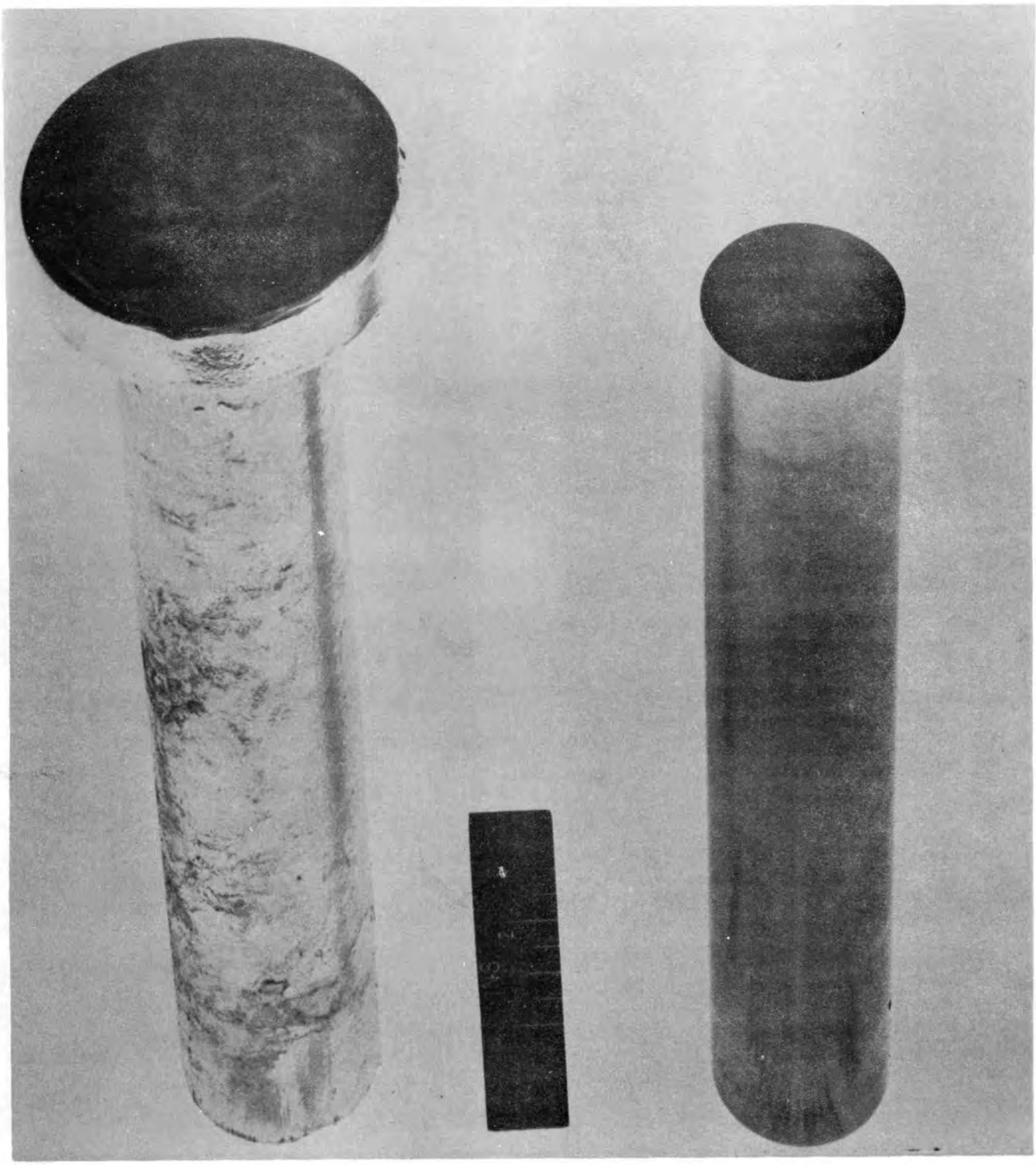


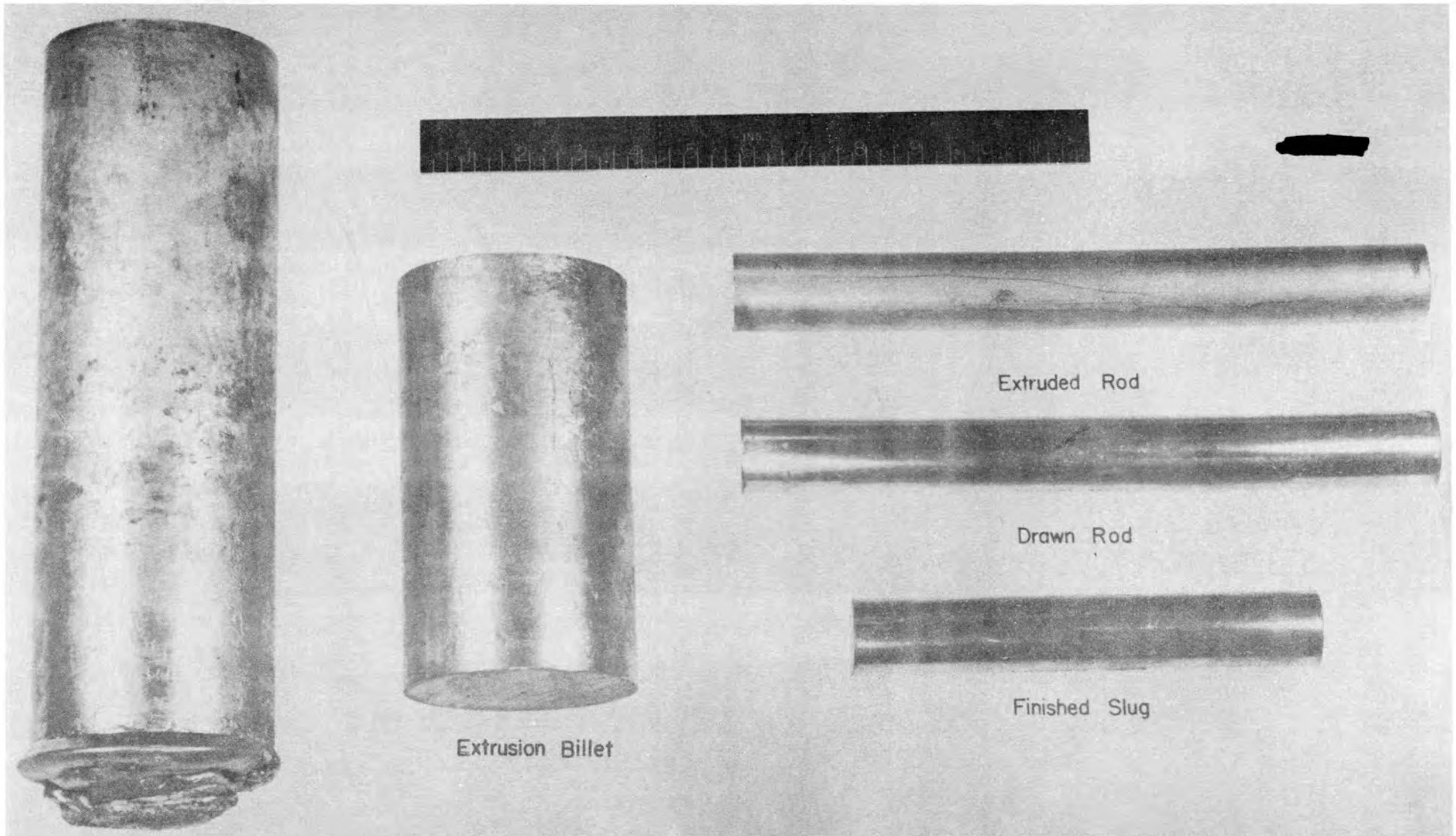
As Cast Ingot

Machined Slug

7½% U-AL ALLOY

Ingot and Slug of 7½% U-Al Alloy

Fig. 2



EXTRUSION PROCESS IN MAKING 7½%U-AL SLUGS

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Fig. 3

C. Ram

(1) Initial Pressure - 390 tons.

(2) Running Pressure - 390 - 300 tons.

(3) Speed - 38 feet per minute.

D. Billet

(1) Size 3-1/8 inches in diameter x 6 inches long.

(2) Temperature 300°C.

E. Dummy Block

(1) Steel block 3.145 inches in diameter x two inches long.

(2) Temperature - approximately 75°C.

(3) Cleaned after each extrusion with NaOH solution.

It was found that with increasing uranium content in the alloy, higher temperatures were required to produce a satisfactory extrusion. A 6% U-94% Al alloy required an extrusion temperature of 350°C while 7.5% alloys needed a minimum temperature of 480°C. Since the finished slug has little dimensional tolerance, it is not feasible to attempt to extrude to the final size. The die having a 0.861 inch diameter throat produced rods 0.854 inches in diameter, while the 1.4 inch die yielded rods 1.390 inches in diameter. Therefore, the rod is extruded oversize and finished to size by another operation such as rolling or drawing. The fastest and most satisfactory method of finishing to size is by drawing through a die on a draw bench. The extruded rod measuring 1.390 inches in diameter was drawn to 1.360 inches in diameter. Alloys containing 7.5% U have been drawn to the desired size consistently within a tolerance of ± 0.001 inch. To summarize, the optimum conditions for extrusion and drawing of 7.5% U-Al alloy are given below.

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Extrusion

A. Die - hardened steel
Throat diameter - 1.400 inches.
Radius of entrance - 1/64 inch.
Bearing Surface - 1/8 - 3/16 inch.
Bearing Relief - 0.5.
Temperature - 200°C.
Diameter of extruded rod - 1.390 inches.

B. Container Temperature - 400°C.

C. Ram
Speed - 25 - 30 ft./min.
Pressure - 800 - 2100 psi (depending upon length of billet).

D. Billet
Size - 4-1/16 inch diameter x 6 to 12 inches long.

E. Dummy Block
Material - Steel.
Size - 4.045 inches diameter
Temperature - Warm.

Drawing

A. Die
Design - 2 inch radius on bearing.
Size - 1.361 inches diameter.
Lubricant - Sulphonated oil.

B. Speed - 40 ft./min.

C. Finished size of rod - 1.360 inches diameter.

Therefore, no machining of the surface is necessary and the drawn rod may be cut into slugs by simply cutting off to the proper lengths. Since the extrusion and drawing operations are rapid, they are capable of very high production rates.

The melting and casting procedures are identical for the preparation of cast slugs to be machined and for billets to be extruded and drawn to size, so that relative costs of production may be obtained by comparing only the machining and extrusion operations. The machining operations necessary to finish the slug to the required dimension is estimated to be about $2.00 per slug for labor alone when using conventional shop equipment. However, a preliminary estimate of a complete

plant to produce P-10 slugs from start to finish yields a cost of $0.97 per slug. This estimate was based upon production equipment similar to that actually used to manufacture the P-10 type slugs for the Chemical Technology Division. Since this cost is about one half of the cost of labor for machining a slug from a cast ingot, it is obvious that if the manufacture of P-10 type slugs were to be undertaken on a large scale, the most economical and practicable method would be by extrusion.

The results of an investigation of the dissolving rates of both cast and extruded slugs are given in a document by Mr. A. T. Gresky and E. O. Nurmi (ORNL Central Files No. 50-10-44). It was found that extruded slugs dissolved much more rapidly than did the cast slugs. A metallurgical approach to the problem suggests that this is probably due to the distribution of the UAl_4 particles and is treated in detail in a companion memo. (ORNL Central Files No. 50-12-23).