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EXTRUSION OF 2% U-AL ALLOY FUEL RODS FOR THE ARGONNE CP-3 REACTOR

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EXTRUSION OF 2% U-AL ALLOY FUEL RODS FOR THE ARGONNE CP-3 REACTOR

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ABSTRACT

The procedure for the preparation of 140 2% uranium-aluminum alloy fuel rods was divided into two parts--billet preparation and extrusion. Billets 3-1/8 inches in diameter and 6 inches long were prepared by melting aluminum and adding metallic uranium to the superheated aluminum bath prior to casting in graphite molds. The billets were extruded through a 0.861 inch diameter die and then rolled to 0.850 inch diameter, the final dimension. Recommended changes in procedure are given for future work.

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INTRODUCTION

The Metallurgy Division of Oak Ridge National Laboratory was asked to fabricate 140 fuel rods for the CP-3 heavy water reactor at Argonne National Laboratory. These fuel rods were to be 2% uranium and 98% aluminum; the uranium enriched to 93.2% U^{235} and the aluminum to have a cross section less than 0.22 barns. The finished rods were specified as 66-3/4 inches long with a diameter of 0.850 inch with one end threaded for 3/4 inch with 5/8 inch--18 NF Class 3 fit threads.

The preparation of these rods is divided into two parts: the melting and casting of the alloy and the extrusion of the alloy billets into rods. Preliminary work using natural uranium alloys was performed to develop techniques for melting, casting and extrusion; it also served as a guide for the accountability procedures. The preliminary work is presented in the Metallurgy Division Progress Report for period ending April 21, 1950.

EXPERIMENTAL PROCEDURE AND DISCUSSION

A. Melting and Casting

As a result of the experimental runs using natural uranium, the following procedure was developed for melting and casting. Aluminum of 99.9% purity was melted in a graphite crucible in a high frequency induction furnace. When the temperature of the aluminum bath reached 850°C, the uranium wrapped in aluminum foil was added to the molten bath. The power was turned off and as the furnace cooled the metal was stirred with a graphite rod for ten minutes or until the temperature had fallen to 725°C. The metal was then cast into preheated graphite molds. A continuous temperature record was kept of the melting cycle by means of a strip chart recorder.

If the alloy solidified without a hot top, an excessively large shrinkage cavity was formed. A calrod resistance heater was wound around the top position of the mold to control the rate of solidification and minimize shrinkage cavities.

The ingots produced were 3-1/8 inches in diameter and 13 inches long. The shrinkhead was removed and the ingot was cut into two extrusion billets. The billets were then faced off on the ends prior to extruding. These machining operations were done in the 101 Research Shops under the direction of Mr. C. W. Wright, Jr.

Control analyses were made from dip samples taken immediately before casting. In Table II is a list of the finished rods and their composition as

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determined from the dip samples. One of the natural uranium ingots was sectioned longitudinally and samples for analyses were taken from various points to check the homogeneity of the ingot. The analytical results were not consistent but there was no evidence of segregation. The analytical work was performed by Mr. L. T. Corbin's section of the Analytical Chemistry Division of Oak Ridge National Laboratory.

A total of 69 melts of the 2% uranium alloy and one of 6% uranium were made. It was necessary to remelt only two ingots; one because of an error in composition, and one due to excessive pipe caused by the failure of a heater on the mold. After the 139 billets were extruded, eleven faulty rods were returned for remelting. The compositions after remelting remained within the specified limits of 2% $\pm$ 0.1% uranium.

B. Extrusion

The test extrusions using natural uranium-aluminum alloys led to the optimum extrusion conditions which were used in the production of the 140 rods for Argonne National Laboratory.

The optimum extrusion conditions were as follows:

A. Die:

(1) Flat face with 1/32 inch radius fillet, 1/8 inch bearing with 0°30' relief through bearing.
(2) Temperature 200°C
(3) Throat cleaned by hand with steel scraper after each extrusion to remove excess alloy.
(4) Cleaned after 4-7 extrusions with NaOH solution.

B. Container:

(1) Temperature 205°C
(2) Not cleaned until completion of job

C. Ram:

(1) Initial Pressure - 390 tons
(2) Running Pressure - 390-300 tons
(3) Speed - 38 ft/minute

D. Billet:

(1) Size 3-1/8 inches in diameter x 6 inches long
(2) Unscalped, machined ends
(3) Temperature 300°C

E. Dummy Block:

(1) Steel 3.145 inches in diameter x 2 inches long
(2) Temperature - approximately 75°C
(3) Cleaned after each extrusion with NaOH solution

The dies, with a throat diameter of 0.861 inch, produced rods with an average diameter of approximately 0.854 inch under the above conditions. (See Table III.) The rods were then straightened and rolled to 0.850 inch diameter in a 6 inch x 12 inch two high mill roll. Since the tolerance on the finished rod was ± .002 inch on the 0.850 inch diameter, it was not advisable to try to extrude to size. Therefore, the rods were extruded oversize and rolled to the final dimension using a specially ground pass in the rolls. After rolling, the rods were shipped in lots of 20 to the 9212 area of Y-12 where they were cut to size and threaded on one end as per specifications.

An extrusion of 6% U-Al alloy using the same die and identical extrusion conditions, produced a very rough rod. The billet temperature was increased to 350°C and a satisfactory extrusion was produced with only a few seizure lines on the rod from the die. It is believed that the billet temperature should be increased still more for higher percentage alloys in order to produce a good finish on the rods.

An interesting difference in the extrusion characteristics of the top billet and bottom billet made from the same ingot was found. In all, eleven bad extrusions were made. Of these nine were top billets of 2% U, one was a bottom billet of 2% U and one was a 6% U billet extruded at too low a temperature for this alloy. It is believed the difficulty in extruding "A", or billets from top of the ingot, is caused by a combination of large grained structure present near the hot top and secondary pipe that was not prevented by the hot top. This difference was quite apparent since a good extrusion was made through the same die without thorough cleaning when a "B" or bottom billet followed an "A" or top billet through the die. The "B" rod was good and the "A" rod was rejected.

C. Metallography

The photomicrographs in the appendix illustrate the way the structure of the 2% uranium-aluminum alloy was altered during the extrusion. The as-cast structure of Fig. 1 and 2 was slightly changed in the leading end of the rod Fig. 3 and 4; while in the middle and trailing end of the rod no remnant of the as-cast structure can be seen. This can be explained by the relative amounts of deformation the different portions of the rod received; the leading end was slightly deformed while the middle and trailing end of the rod has undergone more deformation.

In the as-cast structure Fig. 1 and 2 the eutectic of Al and $U\text{-}Al_5$ (now identified as $U\text{-}Al_4$) is seen surrounding the primary aluminum grains. The photomicrograph of the extruded rod does not show the lamellar eutectic since the magnification was not high enough to resolve this fine structure.

The metallographic work was performed by the Metallographic Section of the Metallurgy Division under the supervision of Mr. R. J. Gray.

D. Accountability Procedure

The work using natural uranium alloys showed that some simple type of flowsheet for keeping a continuous record of each melt would be needed for handling the enriched uranium. The record seen in Table IV was maintained for each melt made.

The melting loss is due to oxidation loss, spatter and crucible pickup of the metal. At the conclusion of the melting all the crucibles, stirring rods, molds and dip sample molds were sent to Y-12 to recovery any uranium that had impregnated the graphite. It can be seen in Table V that melting loss was actually a weight gain. This was due to graphite pickup in the dross.

The pickling solution figures were placed in the table to account for the material that was picked up on the dummy blocks and dies. After each extrusion the dummy block was cleaned by placing it in a concentrated NaOH solution. The dies were cleaned in this solution after 4-7 extrusions. The dies and dummy blocks were weighed before and after immersion in the NaOH solution so the amount of alloy could be determined.

The extrusion loss is due to the following: cropping the rod, "loading" of the interior of the container of the extrusion press, scaling and splintering of small slivers around the die. At the end of the work the container was broached and then honed to remove the uranium-aluminum alloy. In Table V the extrusion loss figure also shows a gain in material. This can be explained by the introduction of foreign material in the pickling solution from the cuttings obtained while cleaning the container.

CONCLUSIONS

In future work it would be advisable to change the pouring procedure and the design of the hot top in order to prevent secondary pipe. The solidification time should be shortened to decrease the formation of large grains in the region of the hot top. In extrusion the billet should be placed in the container so the bottom of the billet will be the leading end of the rod. This will minimize the "loading" of the die caused by the portion of the rod containing the secondary pipe.

The proper extrusion procedures have been developed for the extrusion of 2% uranium-aluminum alloys, but additional experimental runs will be necessary to extrude rods of different uranium contents. The preparation of extruded pieces to a close tolerance could be accomplished much easier by following the extrusion with a drawing operation in which the rod is drawn through a sizing die. In this work the 140 fuel rods were rolled to final size since a draw bench was not available at that time.

TABLE I

Composition of Starting Materials

Aluminum:

Nominal analysis from Reynolds Aluminum was as follows:

Al - 99.9%

Si - 0.04%

Fe - 0.06%

Spectrographic analysis performed by C. W. Feldman at Oak Ridge National Laboratory gave the following results: Be, Cu, Fe, Si--very faint trace, Ca and Mg--faint trace.

Enriched Uranium:

Two lots of uranium were used in making the alloys.

Element	Lot #1 93.176% U^{235} Parts per million	Lot #2 93.24% U^{235} Parts per million
Al	13	5
B	.2	1.1
Fe	48	35
Si	45	125
C	90	150
Mn	6	8

These analyses were furnished by Mr. W. H. Hoose of the 9212 Area at Y-12.

TABLE II

Chemical Analysis of Extruded Rods for the CP-3 Reactor

Rod Number	Per Cent Uranium
338 A and B	2.06
339 A and B	2.02
340 A and B	1.98
341 A and B	1.92
342 A and B	2.03
343 B	1.96
344 A and B	2.03
345 A and B	2.00
346 A and B	1.99
347 A and B	2.05
348 A and B	2.03
349 A and B	1.90
350 A and B	2.04
351 A and B	2.04
352 A and B	2.02
353 A and B	2.05
354 B	1.98
355 A and B	1.98
356 A and B	1.97
357 A and B	2.07
358 A and B	2.03
359 A and B	1.99
360 A and B	1.95
361 A and B	2.02

Table II (continued)

Rod Number	Per Cent Uranium
362 A and B	1.97
363 A and B	1.97
364 A and B	1.99
365 A and B	1.97
366 A and B	1.98
367 A and B	1.92
368 A	1.98
369 A and B	2.00
370 A and B	2.00
371 A and B	2.01
372 A and B	2.01
373 A and B	1.98
374 A and B	2.00
375 A and B	1.98
376 A and B	1.98
377 A and B	1.99
378 A and B	1.97
379 A and B	1.97
380 A and B	2.02
381 A and B	1.99
382 A and B	1.90
383 B	2.01
384 B	2.01
385 A and B	1.91
386 B	2.01

Table II (continued)

Rod Number	Per Cent Uranium
387 A and B	2.03
388 A and B	2.06
389 A and B	2.01
390 A and B	2.04
391 A and B	2.03
392 B	2.03
393 A and B	2.01
394 B	2.00
395 B	2.07
396 B	1.96
397 A and B	1.98
398 A and B	2.01
399 A and B	2.07
400 B	1.97
401 B	1.98
402 A and B	1.91
403 A and B	1.96
404 A and B	2.01
405 A and B	2.02
406 A and B	1.97
408 A and B	1.98
413 A and B	2.02
343 R	2.00
354 R	1.83
368 R	2.07
383 R	2.06

Table II (continued)

Rod Number	Per Cent Uranium
384 R	2.10
386 R	1.99
392 R	1.98
394 R	2.06
395 R	2.01
407 R	5.89

A - Is the top billet from the ingot

B - Is the bottom billet from the ingot

R - Is a rerun melt only one billet was made per melt.

Note:

In melts 338-376 inclusive the uranium used was enriched 93.176%. All the ingots from 377 on were made with 93.24% enriched uranium. In reruns 343R, 354R, and 368R uranium of both enrichments were used so the average enrichment for each ingot is as follows: 343R - 93.182%; 354R - 93.183%; and 368R - 93.183%. The remaining reruns were all made with uranium enriched 93.24%.

TABLE III

Extrusion of 2% Enriched U-Al Alloy Fuel Rods

Die No	9	10	11	12
No. of Extrusions	32	37	42	39
Extruded Rod Size				
Average Maximum	0.855	0.855	0.854	0.852
Average Minimum	0.851	0.851	0.851	0.849
Billet Temperature (°C)	290	290	290	290
Container Temperature (°C)	200	200	200	200
Original Die Temperature (°C)	200	200	200	200
Ram Pressure				
Average Maximum (psi)	1610	1625	1630	1625
Average Minimum (psi)	1275	1320	1330	1335
Billet Pressure				
Average Max. (Tons/sq. in)	51.5	51.9	52.1	51.9
Average Min. (Tons/sq. in)	40.8	42.2	42.5	42.7
Reduction Ratio	13.5/1	13.5/1	13.5/1	13.5/1
Approximate Extrusion Rate (Ft/min)	42	42	42	42

TABLE IV

Accountability Record for Each Melt

Melt No. A-345 (Ref. p. 9, SNB #284)

Melting Process	Material in Process, gms.	Material Lost to Process, gms.
Starting Materials		
Al	4523.954	
U	92.3256	
Total Charge	4616.28	
Analysis Sample		5.625
Dross		129.80
Ingot	4480.8	
Melting Loss		- 0.06
Machining Operation		
Machining Loss		93.4
Shrinkhead		133.0
Billets	A-2129.8	
	B-2124.6	
Extrusion Process		
Butt and Croppings		A- 44.22
		B- 38.87
Pickling Solution		A- 4.876
		B- 4.076
Extrusion Loss		A- -1.703
		B- 4.147
Finished Rod	A- 2079	
	B- 2085.8	

[redacted]

TABLE V

Disposition of Material at the Completion of the Work

	Wt. in Grams.
Al *	336,115.13
U *	6,759.31
Analysis Sample	524.76
Melting Loss	+ 22.15
Ingots *	342,371.89
Machining Loss	7,591.58
Shrinkhead	13,002.7
Billets *	321,777.61
Butt and Croppings	5,999.56
Pickling Solution	229.2
Extrusion Loss	+ 18.92
Finished Rods	315,567.77

*These items were consumed in other stages of the process, all other material existed as listed at the completion of the work.

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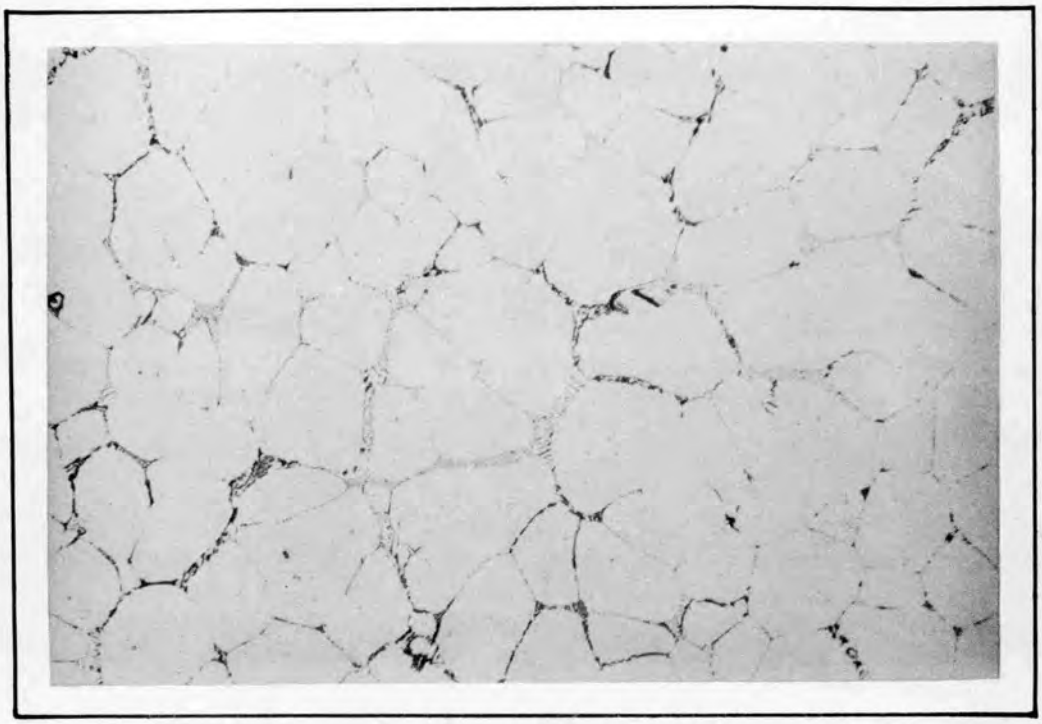
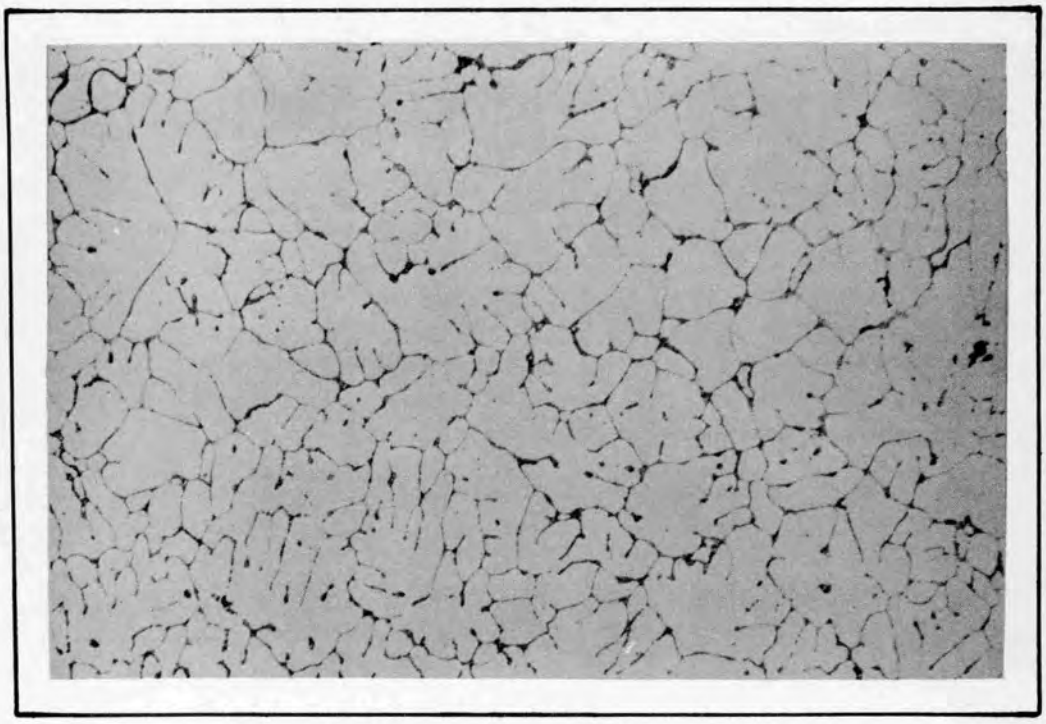


Top of ingot

Mag. 100x (Y-1797)

Fig. 1



Bottom of ingot

Mag. 100x (Y-1798)

Fig. 2

AS CAST 2% URANIUM-ALUMINUM ALLOY

1% HF Etch Y-1843

R. S. Crouse

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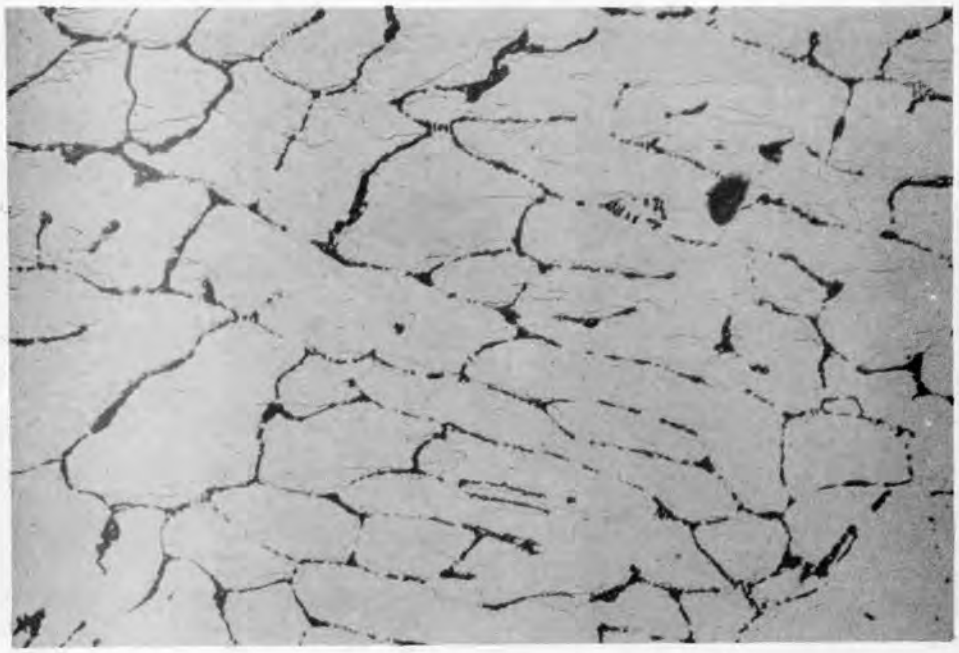
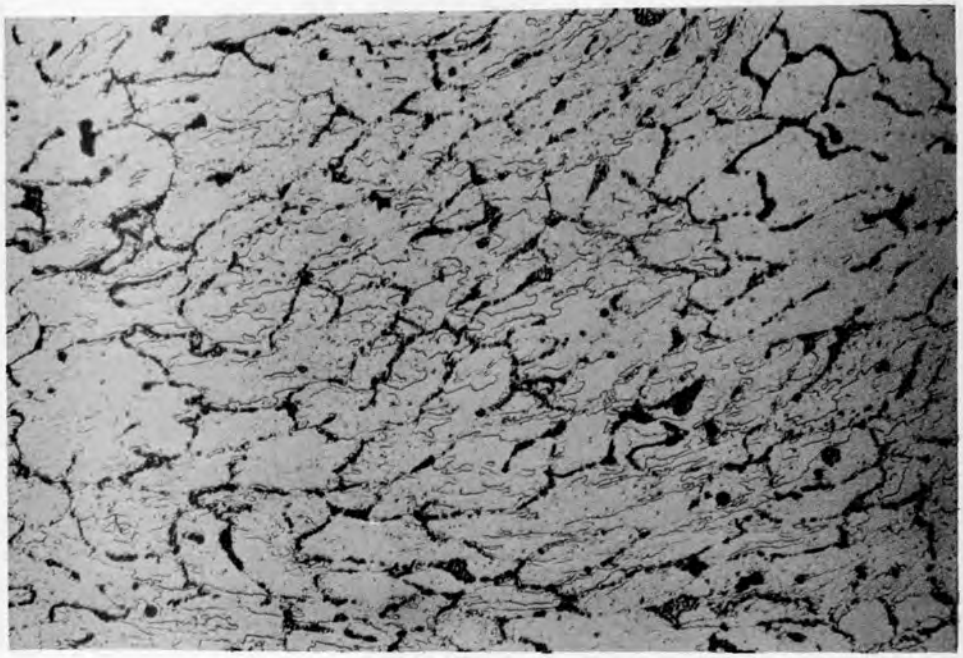


Transverse view of center of leading end
Mag. 100x (Y-1801)

Fig. 3



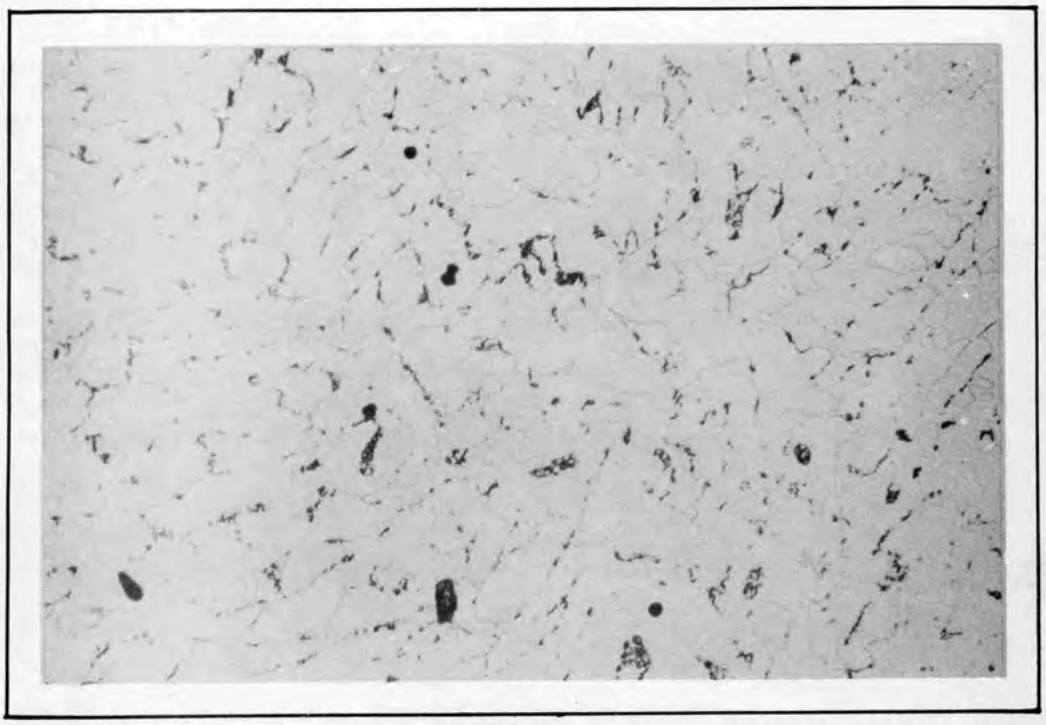
Transverse view of surface of leading end
Mag. 100x (Y-1802)

Fig. 4

AS EXTRUDED 2% URANIUM-ALUMINUM ALLOY
1% HF Etch Y-1841

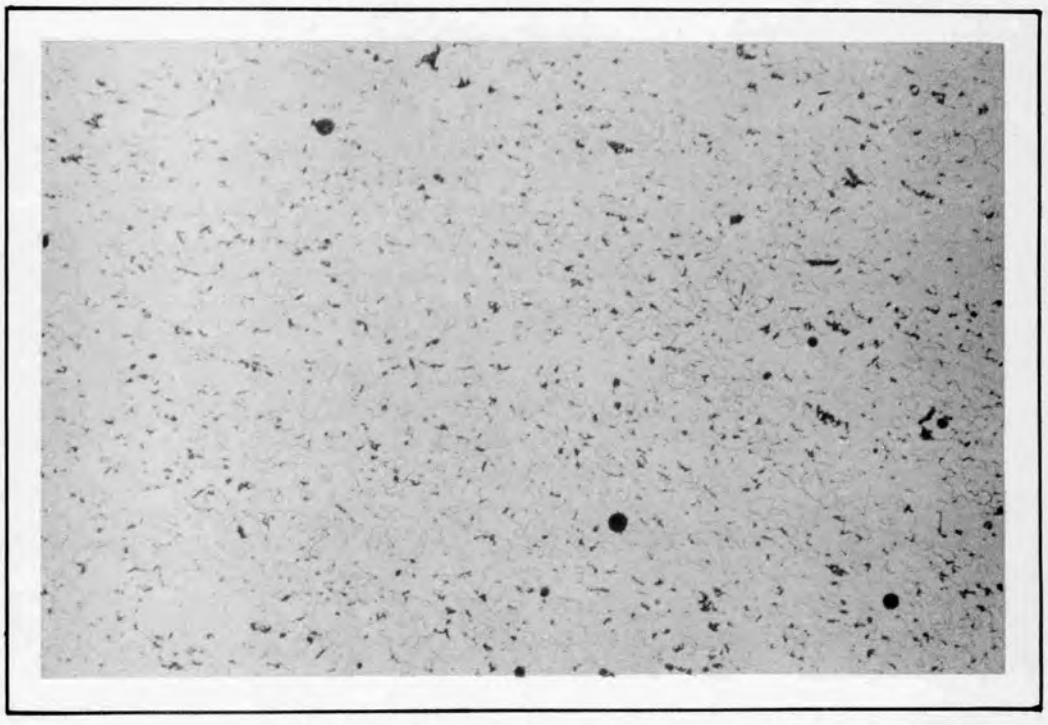
R.S. Crouse

[redacted]



Transverse view of center of middle section
Mag. 100x (Y-1803)

Fig. 5



Transverse view of surface of middle section
Mag. 100x (Y-1804)

Fig. 6

AS EXTRUDED 2% URANIUM-ALUMINUM ALLOY
1% HF Etch Y-1842

R.S. Crouse

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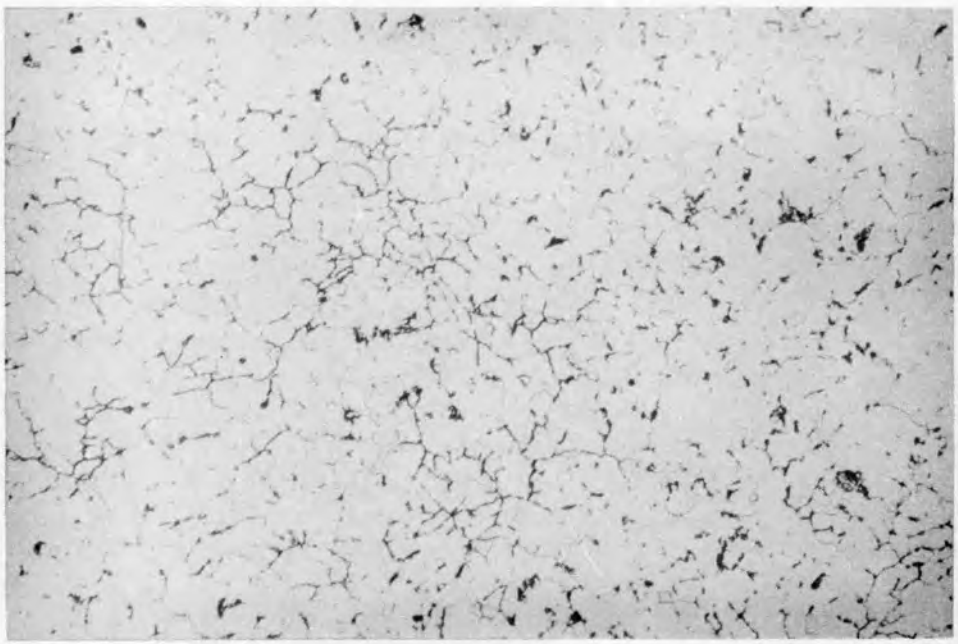
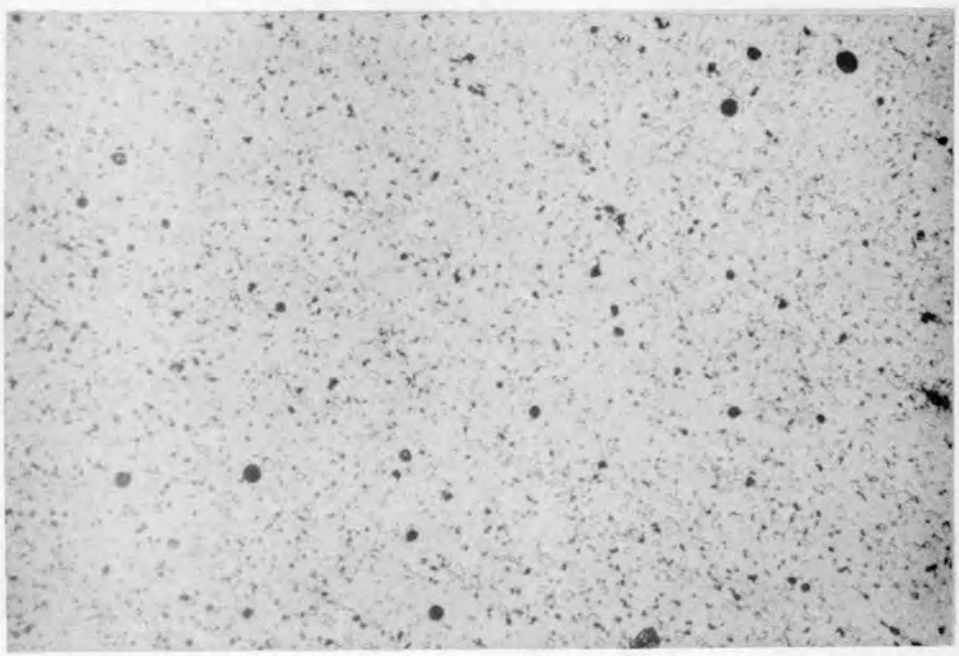


Transverse view of center of trailing end
Mag. 100x (Y-1799)

Fig. 7



Transverse view of surface of trailing end
Mag. 100x (Y-1800)

Fig. 8

AS EXTRUDED 2% URANIUM-ALUMINUM ALLOY

1% HF Etch Y-1840

R. S. Crouse