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MASTER

THE APPLICATION OF THE CHIP AND SHOT METHODS
TO THE PREPARATION OF HOMOGENEOUS ALLOYS

D. S. Kneppel

nuclear metals, inc.
concord, massachusetts

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The Application of the Chip and Shot Methods
to the Preparation of Homogeneous Alloys

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I. INTRODUCTION

The chip method was developed to obtain homogeneous alloys in systems where other homogenizing techniques were inadequate. In essence, it is a quasi powder metallurgical technique which can be used when powders are not obtainable in pure form or when the powders are unstable. The nonhomogeneous alloy casting is completely machined into chips which are blended and then cleaned before cold compacting in a can. This compact is then hot extruded. In certain cases, it may be desirable to hot compact the canned chips prior to the final extrusion. Homogeneous alloys of Al - 15 ^{w/o} U [1] and U - 10 ^{w/o} Nb [2] have been obtained previously by means of the chip method.

In a modification of the same method, shot produced directly from the alloy melt was used as the starting material instead of chips machined from a casting. The use of shot was a much closer approximation to powder metallurgy and appears to have some economic advantage as well.

II. SUMMARY OF RESULTS

Chip method experiments were performed with Th - 9 ^{w/o} U, U - 10 ^{w/o} Nb, and Al - 16 ^{w/o} U - 0.2 ^{w/o} B. The work done on Th - 9 ^{w/o} U indicated that the technique was applicable with only slight impairment of mechanical properties and slight increase of oxygen content. Extension of the work done on U - 10 ^{w/o} Nb in order to produce a more corrosion-resistant alloy was not successful. The potential use of the chip method in fabricating alloys with a burnable poison such as boron appears feasible. An aluminum alloy containing 16 ^{w/o} U and 0.2 ^{w/o} B showed good homogeneity.

The shot method was used on an alloy of Al - 25 ^{w/o} U. The homogeneity and the mechanical properties of this alloy, when extruded, were superior to those of similar alloys produced by conventional melting and casting. In addition, preliminary work on the blending of master alloys of a burnable poison (i.e., boron) with an aluminum-uranium alloy has indicated the feasibility of obtaining a homogeneous alloy with good mechanical properties.

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III. SYSTEMS STUDIED

A. Th - 9 ^W/o U - Chip Method

1. Introduction

In the Th - 9 ^W/o U system adequate homogeneity is obtained by conventional melting and casting. The advantage of the chip method is that it offers a means of consolidation of material without the necessity for remelting which increases oxygen content and generates scrap. In handling enriched materials, the latter is an important economic consideration.

2. Procedure

A solid, cast ingot of thorium-uranium weighing about 62 pounds was machined into chips without the use of a coolant. Approximately 6.6 pounds of chips, taken at random, were used for each run. A batch of this size, after extrusion, yielded a rod of 1/2-inch diameter and about 80 inches length.

The thorium-uranium chips were cold compacted in a 2-inch OD, 16-gage copper can having a conical 45° nose containing a solid 45° cone of a Cu - 14 ^W/o Ni alloy. The internal copper-nickel cone served to increase the ram pressure necessary to start the billet flowing through the die; in this way, the cold compacted chips, in transmitting the pressure from the ram to the nose plug, received additional compaction at high temperature even before entering the die. After cold compacting, a cover with an evacuation tube was welded on the can, the can was evacuated, heated to 1200°F to degas, and then sealed. This assembly was heated to 1550°F and extruded from a 2-inch liner through a 0.500-inch die, a reduction of 16:1. In certain cases a 0.400-inch die was used to give a reduction of 25:1.

3. Discussion

One of the main concerns in the use of the chip method for thorium-uranium was the possibility of excessive oxygen contamination of the fabricated rod. The chips as received analyzed 1.78 ^W/o ThO₂ (acid insoluble residue). During compacting of the first batch of chips it was noted that oil was being squeezed out; apparently they had become contaminated

during machining. In all subsequent runs the chips were degreased prior to use, and in the second run, degreased and pickled* chips were used. As a result of pickling, approximately 0.2% of the weight of the chips was lost, and the oxygen content decreased from 1.78% to 1.14% ThO_2 . From Table I, it would appear that pickling of the chips prior to compacting results in decreased oxygen content in the extruded rod. The desirability of pickling was very evident when comparing the micro-structures of the rods made from pickled and unpickled chips (see Figs. 1 and 2). The original chip boundaries were much less pronounced in the rod extruded from pickled chips.

The results of the oxygen analyses of the solid (casting) extrusion were somewhat anomalous (see Table I), so that a comparison could not be made with the extruded chips. Vacuum melted Th - 9 w/o U ordinarily contains 0.7 - 0.8 w/o ThO_2 , and it is very unlikely that fabrication by hot extrusion would result in any but very slight additional increase in oxygen content. In any case it would appear that the chip method resulted in a small increase in oxygen content.

From a comparison of the mechanical properties of the Th - 9 w/o U alloys, shown in Table II, it would appear that the use of the chip method resulted in some loss of mechanical strength. The solid extruded rod showed a low uranium content; consequently if all the alloys were put on the same basis the loss of strength resulting from the use of the chip method would be somewhat greater.

The impact strength of the rods fabricated by the chip method was good in a qualitative test, also, a sample was cold rolled to 72.5% reduction in thickness before the first indication of edge cracking was noted.

The densities of the rods of extruded chips were measured and compared with the density of solid as-cast Th - 8.9 w/o U alloy. Values of 98.51 and 99.50% of theoretical density were obtained for an extruded chip alloy analyzing 8.81 - 9.07 w/o U; the value of the solid alloy was used as theo-

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*Pickled for 3 minutes in a solution containing 35 v/o concentrated HNO_3 - 3 v/o concentrated HF and remainder water. The reaction is very rapid³ so that care had to be taken that the solution did not overheat.

retical density. Examination of all thorium-uranium alloy rods produced by the chip method showed the presence of voids in varying amounts. Samples from rods extruded at a reduction ratio of 25:1 showed fewer voids than those at the usual 16:1 reduction. In Fig. 3(a), a photomicrograph of a polished sample of an extruded chip Th - 9 ^w/o U alloy, the outer layer is the extruded copper can and the outline of the original chip boundaries is plainly visible. This sample had been prepared for the detection of voids by the Zyglo method.* The same sample, photographed with ultra-violet light [Fig. 3(b)], shows the presence of voids as white spots. In the solid extrusion, no voids were detectable by this method.

4. Conclusions

The use of the chip method on Th - 9 ^w/o U appears feasible, even though the alloy is slightly inferior in mechanical strength. Increase of the oxygen content can be minimized by pickling the chips prior to use. Voids can be minimized to some extent by increasing the extrusion reduction ratio but it is doubtful whether they can be completely eliminated in this way.

B. Uranium-Niobium Alloys - Chip Method

1. Introduction

When compared to pure uranium, uranium alloys containing 6 ^w/o or more of niobium, and properly heat treated to stabilize the gamma phase, show relatively good corrosion resistance in water up to 680°F. In spite of this, the uranium-niobium alloy still requires a more corrosion resistant cladding, such as Zircaloy-2, for use in a reactor in which coolant water temperatures will approach 680°F. In case of cladding failure, the fuel alloy itself must have maximum corrosion resistance.

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*In this method, the sample is first soaked in penetrant oil, the excess oil is washed off, and the sample is dusted with a fluorescent powder. The sample is then heated to about 85°C and the surface is wiped gently. Upon heating, the oil that has penetrated the cracks or voids is driven up to the surface where it fixes the fluorescent powder for observation under ultra-violet light.

Uranium alloys containing about 10 ^w/o Nb appear desirable for this purpose, but a difficulty with the uranium-niobium system is the problem of obtaining a homogeneous alloy. Various melting techniques have been attempted but the segregation problem has not been completely solved. It was demonstrated that U - 10 ^w/o Nb alloys with superior homogeneity could be obtained by the use of the chip method, [2] and it was assumed that with increased homogeneity the corrosion resistance would also improve. This was not the case; material produced by the chip method showed inferior corrosion resistance, and attempts were made to determine the causes and remedies. The results obtained were discouraging in that the uranium-niobium alloys fabricated by the chip method, in spite of all efforts, continued to show relatively poor corrosion resistance.

2. Procedure

The fabrication procedure followed was essentially the same as that developed by Gilliland, [2] in which the details were in general the same as in the preparation of the Th - 9 ^w/o U alloy previously described.

One of the first investigations concerning possible causes of inferior corrosion resistance was contamination of the starting chips. The chips were spread out on a piece of paper and a powerful magnet was moved over them. A small amount of material was separated out by this procedure.

Furthermore, during blending of the chips by rotating in cans the chips became contaminated with iron as a result of the abrasive action of the chips on the walls of the can. Pickling of the chips in a dilute 5% solution of HCl appeared to eliminate the iron. However, all subsequent blending was done by hand to eliminate this contamination. In addition all chips were thoroughly degreased before use by three successive soakings in trichloroethylene followed by two dips in acetone. In spite of all these precautions, the corrosion resistance was not significantly improved.

Attempts were made to improve by heat treatment the corrosion resistance of samples from rods of extruded chips. Samples were heated for about a week in dynamic vacuum of 1000°C followed by rapid cooling to retain

the gamma phase. Other samples were cycled between the alpha and gamma phases and then quenched from the gamma phase. It was thought that the poor corrosion resistance of extruded chips was due to poor bonding among them as a result of a thin oxide film surrounding each chip. Cycling of the metal between alpha and gamma would tend to break up the film and thus improve the corrosion resistance of the metal. No significant improvement was observed as a result of any of these heat treatments. In other tests, samples which had been quenched from the gamma phase were aged at 750°F for one hour before corrosion testing. This treatment resulted only in a very slight improvement.

The corrosion behavior of uranium-niobium alloys in 680°F water shows a loosely adherent corrosion product in the initial stages. Continued exposure results in cracking and finally, complete disintegration. It is believed that at 680°F the gamma phase slowly transforms to the less corrosion resistant gamma phase, leading ultimately to cracking and disintegration. For this reason it is difficult to make quantitative comparisons of corrosion results on the basis of weight changes. The corrosion behavior of the material can be better evaluated on the basis of the time it takes for severe cracking to take place.

3. Discussion

The corrosion resistance of uranium-niobium alloy produced by the chip method was compared with that of a rod produced from an extrusion of a solid casting. Samples from both rods were given identical heat treatments for retention of the gamma phase. Both materials, as seen from the analyses in Table III, showed excellent homogeneity, but their corrosion resistance was relatively poor when compared to corrosion lives of 21 to 28 days reported in the literature. [3] The solid extrusion shows only slightly better corrosion resistance than the extruded chips. This slight improvement may have been due to the slightly higher niobium content and/or the lower carbon content. [3] Thus it might appear that the use of chips was not the cause of the lowered corrosion resistance in extruded uranium-niobium alloys.

Metallographic examination of both materials showed no detectable differences in the microstructure. However, in both instances close examination of polished longitudinal sections of the rods revealed the presence of numerous voids in the metal. These voids, in most cases difficult to detect, were present in all samples of extruded chip alloys examined. Figure 4 shows a void in the solid extruded rod and Fig. 5 is an example of a void in an extruded chip alloy. In both cases the samples chosen for photographing contained an unusually large void, indicated by arrows.

The presence of voids in the solid extrusion can be accounted for only by the probable presence of porosity in the as-cast metal. In the chip extrusions, the voids are undoubtedly due to imperfect consolidation of the chips during fabrication, as shown by low temperature (500 to 525°F) water corrosion tests. The shape of the original chips was detected by the slightly different corrosion rates presumably the result of different orientation. The contrast between behavior of adjoining chip revealed the chip boundary. Where a void was present, low temperature water corrosion tests showed that corrosion attack proceeded from the void along the chip boundary and resulted in raised corrosion product. However, it should be pointed out that in the absence of voids, accelerated attack of the metal in most cases did not initiate at the chip boundaries. It would appear that the presence of voids contributes at least in part to the poor corrosion life of extruded uranium-niobium alloys.

At first, it was believed that the inferior corrosion resistance of the extruded alloy chips might be due to poor bonding as a result of oxide film on each chip. No good evidence of the original chip boundaries could be found in the micro-structures of extruded chips. Furthermore, heavily tarnished chips when heated in vacuum to 1200°F or even lower resulted in clean bright metal, indicating that the oxide film (tarnish) had diffused into the metal. Thus at 1650°F (the temperature of extrusion), the presence of an oxide film on the chips, which would interfere with bonding, appears unlikely.

The application of the chip method to a ternary alloy containing U - 9 ^W/o Nb - 1 ^W/o Zr was tried in another attempt to improve corrosion behavior. Analyses of this alloy are shown in Table IV. It was evident that the homogeneity of both the niobium and the zirconium was quite good, but its corrosion life in 680^oF water was three days or less. The poor corrosion behavior of this alloy can be attributed only in part to the somewhat higher carbon content.

About 1% of zirconium hydride was blended in with the chips of the same alloy. The hydride was to act as a getter for oxygen, which might prevent bonding of the chips. The compacted blend of chips and hydride powder was heated to 1400^oF in a vacuum to decompose the hydride and remove the hydrogen. After extrusion, samples were heated in dynamic vacuum at 1000^oC to remove the last traces of hydrogen, and then quenched to retain the gamma phase. Again, tests in 680^oF resulted in a life of three days or less. The presence of voids were in much greater evidence in this material, as shown by the large black areas in Fig. 6, a transverse section of the as-extruded rod.

Compacting of the chips was done in a Zircaloy-2 can, since the welded copper cans might leak when heated to 1650^oF for extrusion. This innovation, too, showed no improvement in corrosion resistance of the extruded chips.

4. Conclusions

In spite of superior homogeneity, the corrosion resistance of extruded chips of the uranium-niobium alloys is considerably worse than that of similar alloys produced by other techniques. The cause for this is unknown but evidence has been obtained that the presence of voids in the extruded chips is at least partly responsible.

C. Al - 16 ^W/o U - 0.2 ^W/o B - Chip Method

1. Introduction

The addition of a burnable poison, such as boron, to aluminum-uranium alloy fuel elements would reduce flux perturbations during

the initial stages of reactor operation and at the same time enhance fuel element life. In the Al-U-B alloy system there are two problems of major importance which have not been satisfactorily solved by conventional melting and casting techniques. The first is poor boron recovery during casting of the alloy and the second is the lack of homogeneity in the casting. It was hoped that increased recoveries would result from the chip method since a greater portion of the ingot could be converted to chips than could be used directly from the ingot for further fabrication. The second problem, non-uniform distribution of uranium and boron, is ideally suited for application of the chip method.

2. Procedure and Results

Attempts were made to obtain a casting containing Al - 16 ^{w/o} U with 0.2 ^{w/o} B. The addition of boron powder directly to the aluminum-uranium melt, as well as the use of an aluminum-boron master alloy, were both unsuccessful. The use of nickel-boron master alloy containing about 12 ^{w/o} B gave an ingot with fair boron recovery. The nickel-boron alloy was made by blending powders of elemental nickel and boron, cold compacting, sintering and double arc melting. Analyses of the arc-melted button showed 12 ^{w/o} B. From chemical analyses obtained at various points on the circumference along the length of the ingot (Table V), it can be seen that boron tended to segregate at the bottom of the casting. The uranium content was also greater at the bottom.

The ingot was machined into chips which were then thoroughly blended; a random sample analyzed 0.12 ^{w/o} B and 15.10 ^{w/o} U. The fines resulting from blending and handling analyzed 0.52 ^{w/o} B, but these represented only about 0.5% of the total weight of the ingot.

A portion of the blended chips was compacted in a 3-inch steel can, and a cover with an evacuation tube was welded on. The billet was evacuated, heated to 400°F to degas the chips and then sealed. The sealed assembly was hot compacted at 850°F by means of a penetrator ram at a pressure of 85,000 psi.

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The first hot compacted billet broke while its steel can was being machined away; in the second attempt, with a billet cold compacted under a pressure of 170,000 psi, the evacuation tube broke off during degassing, and again, during machining of the steel can, part of the billet broke. The remainder of this billet was painted with a slurry of alumina, before canning in 2S-Al, so that the aluminum can could be stripped from the extruded alloy rod. Extrusion was carried out at 950°F at a reduction ratio of 32:1. A pressure of 75,000 psi was required. The alloy rod produced was relatively short, so that only samples from front and rear were taken. Analyses of the rod showed 0.14 ^{w/o} B, 15.66 ^{w/o} U at the front and 0.13 ^{w/o} B and 15.81 ^{w/o} U at the rear. It seems apparent that the chip method is capable of producing a homogeneous alloy in this system. Figures 7(a) and 7(b) show that microstructure of the resulting alloy, which was similar in appearance to melted and as-cast alloys of the same composition. It was assumed that the black particles are borides and they appear to be reasonably well dispersed throughout the matrix.

Only one sample was available for tensile testing. The results, in Table VI, are compared to an as-cast and hot rolled alloy with approximately the same aluminum-uranium composition but containing no boron. It would appear that both of the alloys should have about the same mechanical properties under identical conditions of heat treatment. The presence of 0.14 ^{w/o} B adds or detracts little from the mechanical properties.

The chip method Al-U-B alloy could be cold worked with no difficulty. A sample was swaged down to an 88% reduction in area with no indication of cracking. Another sample was reduced 89.5% by cold rolling before the start of slight edge cracking was noted.

3. Conclusion

The results indicate that a homogeneous aluminum-uranium alloy containing at least 0.14 ^{w/o} B, may be obtained by the chip method. The mechanical properties of this alloy are comparable to as-cast aluminum-uranium alloy with the same uranium content.

D. Al - 25 ^W/o U - Shot Method1. Introduction

In a modification of the chip method for obtaining homogeneous alloys, alloy shot is used instead of chips as the starting material for the fabrication of the extruded alloy. The shot method has an initial advantage over the chip method in that it eliminates machining of the ingot to produce chips. The shot is produced directly from the melt by pouring the molten alloy onto a revolving disc. The molten droplets coming off the disc fall through a helium atmosphere and freeze before they reach the bottom of the tank.

2. Procedure

Fifty pounds of Al - 25 ^W/o U alloy shot was obtained from the National Lead Company of Ohio, where it was prepared essentially as described above in much the same way used for producing uranium shot.[5] The usual method was modified by the use of a helium lance to stir the melt, for better homogeneity, and an increase in the helium atmosphere for faster cooling during the pour, thereby compensating for the lower melting point of the alloy. The vendor's analyses of the blended shot, taken from two locations in the shipping container, were 24.6 and 25.1 ^W/o U. The sieve size analyses were also reported, as follows:

Percentage of Batch	Sieve Size
18.2	-20, +30 mesh
51.4	-30, +40 mesh
30.4	-40, +100 mesh

Fabrication of the resulting shot was similar to that used for aluminum-uranium chips. [1] About 1000 grams of the shot, taken at random, was cold compacted in a 3-inch steel can which was then evacuated, degassed at 400°F, and sealed. The canned shot was hot compacted at 850°F and 450

tons (128,000 psi) by means of a penetrator ram. The steel can was machined off and the compacted billet recanned in 2S aluminum. Just prior to this, the billet was painted with a slurry of alumina to facilitate the stripping of the aluminum from the alloy rod after extrusion. The billet was extruded at 950°F at a reduction ratio of 32:1. The 3-inch billet upset at 270 tons (77,000 psi) and extruded at 220 to 180 tons.

3. Results

After stripping of the aluminum, an alloy rod approximately 0.5 inch in diameter and 72 inches long was obtained. Samples for chemical analyses were taken from the front, center and rear to check the homogeneity. A second rod was made for which the shot was blended prior to compacting, and six samples for analysis were taken along the length of the rod. From the results of these analyses, Table VII, it is obvious that by proper blending of the shot, excellent homogeneity results. By comparison, it has been reported in the literature [4] that for as-cast alloy with an intended composition of 25 W/o U, the actual composition varied from 21.2 to 24.2 W/o U.

The mechanical properties of the two extruded rods made from shot have been compared with cast and hot rolled alloy of the same composition, with the results shown in Table VIII. The extruded shot alloys are stronger and harder and yet at the same time considerably more ductile than the cast and hot rolled alloy reported in the literature. [4] The reason for the variation of some of the mechanical properties, namely, yield and tensile strengths, between the two extruded shot alloys cannot be explained at this time; fabrication procedures for both were apparently identical. The microstructure of the extruded shot alloy is shown in Figs. 8(a) and 8(b). For comparison, see Fig. 7 which is somewhat typical, except for the presence of borides,* of the structure normally obtained in as-cast aluminum-uranium alloys containing 16 to 45 W/o U. The alloy produced by shot method resulted in a relatively fine dispersion of the UAl_4 compound

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*See previous section on Al - 16 W/o U - 0.2 W/o B alloy produced by the Chip Method.

in the matrix; this may account for the difference in mechanical properties. The fine particles of the precipitated UAl_4 compound were the result of the rapid freezing of the molten alloy droplets during production of the shot.

The workability of the shot alloy was good. A cold rolled sample underwent 77.5% reduction in thickness before slight edge cracking began. Another sample was cold swaged with a reduction in area of 88% with no indication of cracking.

The use of blended shot alloy as a method of producing extruded, homogeneous aluminum-uranium alloys appears to be very promising. In addition to the excellent homogeneity, there is an improvement in mechanical properties. The indications are that the method could be successfully applied to aluminum-uranium alloys with uranium contents over 25 ^w/o, and that it may even be capable of solving the problem of producing a fabricable aluminum alloy containing 45 to 50 ^w/o U.

E. Burnable Poison - Shot Method

1. Introduction

The problems involved in making additions of boron to act as a burnable poison have been discussed previously in relation to the chip method. A preliminary study was made on the blending of boron with aluminum-uranium shot to produce extruded homogeneous alloy rods. The use of this technique would eliminate the problem of boron recovery encountered in cast alloys with boron additions and also enable the absolute boron content in the alloy to be more easily controlled.

2. Procedure

The addition of boron for blending with aluminum-uranium shot was made by means of master alloys of boron with nickel or aluminum. The aluminum-boron master alloy was obtained commercially in the form of small "pigs"; these were milled, and the millings in the particle size range of -20, +100 mesh were used for the blending. Analyses of these

millings showed a boron content of 2.66 ^w/o. The nickel-boron master alloy was made by the blending of nickel and boron powders, compacting, sintering and, finally, arc melting. The resulting material was extremely brittle and could be easily crushed. Particles in the size range of -20, +100 mesh were used. Analyses of these showed a boron content of 10.5 ^w/o. After blending the boron master alloys with the shot, the method of fabrication was the same as that used with the pure aluminum-uranium shot described previously.

3. Results

Table IX shows a material balance on two runs made with boron additions. Extrusion 18505 with the aluminum-boron master alloy addition shows that the expected and actual boron values obtained fall within the limits of analytical error. The macro-homogeneity of the extruded rod was good for boron and uranium except for the rear sample which was unaccountably low in uranium. Extrusion 18504 with the nickel-boron master alloy addition also showed good homogeneity with respect to uranium but the boron content showed considerable variation (0.09 to 0.16 ^w/o U). There appears to be erratic correlation of nickel content vs boron content probably because separate pieces were used for analysis of each component.

Figure 9 shows the microstructure of the extruded alloy shot with the nickel-boron addition. The large particles are assumed to be the original nickel boride addition rather than uranium-boron or aluminum-boron compounds since it is unlikely that any reaction would have occurred with the aluminum-uranium alloy in heating to the relatively low temperature of 950°F during fabrication. Measurement of the nickel boride particle size in the extruded rod indicated that some attrition of the nickel-boride particles had occurred. However, in order to obtain improved micro-homogeneity, the particle size of the nickel-boride addition to the alloy shot should be reduced considerably. This would at the same time result in improved macro-homogeneity.

The microstructure of the extruded alloy shot with the boron added as an aluminum-boron master alloy is shown in Fig. 10, in which it is

assumed that the black particles are boron-rich compound (probably AlB_2). As would be expected, the micro-homogeneity in this alloy was considerably better, since a more dilute master alloy of boron was used. Here again it would appear that the micro-homogeneity could be further improved by the use of finer particle sizes of the aluminum-boron master alloy.

The mechanical properties of the extruded alloy shot rods with additions of boron are shown in Table X. Comparing these values with the values in Table VIII for the extruded alloy shot without boron additions, it may be seen that the alloys with the boron addition showed slightly lower strength and ductility. However, these alloys were still superior in mechanical properties to the as-cast and hot-rolled alloys with the same uranium content.

4. Conclusions

The use of the shot method to produce homogeneous boron alloys by blending of boron master alloys with aluminum-uranium alloy shot is very promising. The micro-homogeneity of the material could be improved, probably very simply, by decreasing the particle size of the master alloy addition to the shot. The mechanical properties of the material seems to suffer little, if any, by this fabrication technique.

IV. REFERENCES

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V. TABLES AND FIGURESTable I

Effect of Pickling on Oxygen Content
of Th - 9 ^w/o U Extruded Chips

Extrusion No.	Sample	^w /o ThO ₂		
		Front	Center	Rear
15817	Extruded rod (from A)	1.30	1.22	1.55
15818	Extruded rod (from B)	1.21	1.12	1.25
16054	Extruded rod (from B)	1.25	1.29	1.31
16350	Solid extruded rod (from casting)	0.96	1.41	1.1

A. Chips as-machined (1.78 ^w/o ThO₂).

B. Degreased and pickled chips (1.14 ^w/o ThO₂)

Table IIMechanical Properties of Extruded Th - 9^{W/o} U Alloys

Extrusion No.	Material	W/o U	Rockwell "A" Hardness	Ultimate Tensile Strength	Percent Elongation
15817	Chips as received	Front 9.27 Center 9.64 Rear 9.20	36 35 34	51,800 50,600 49,500	28 28 22
15818	Chips degreased and pickled	Front 8.94 Center 8.81 Rear 9.07	38 38 38	55,000 53,800 54,000	31 28 25
16350	Solid	Front 7.96 Center - Rear 8.33	38 38 38	58,800 59,200 59,900	19 21 21

Table III

Chemical Analyses and Corrosion Life in 680°F Water
of Extruded Chips and Extruded Solid U - 10^w/o Nb Alloys

Extrusion No.	Location of Sample	Nb, w/o	C, ppm	Time to Severe Cracking, Days
14510 (chips)	Front Center Rear	8.79 8.90 8.81	290 250 255	6
15239 (solid casting)	Front Center Rear	9.98 10.10 10.15	170 170 175	8

Table IVAnalyses of Extruded Chips of U-Nb-Zr Ternary Alloy

Location of Sample	Nb, ^w / _o	Zr, ^w / _o	C, ppm
Front	9.40	1.14	335
Center	9.25	1.03	435
Rear	9.20	1.15	445

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Table VAnalyses of Aluminum-Uranium Ingot with Boron Addition(Intended Composition Al - 16 ^w/o U - 0.2 ^w/o B)

Location of Sample (in. from top)	B, ^w /o	U, ^w /o
0 (top)	0.010	15.15
3/4	0.020	15.37
3	0.061	15.51
4-1/2	0.085	15.58
7	0.148	16.02
9 (bottom)	1.93	23.63

Table VI
Mechanical Properties of Al - 16^{w/o} U

	Cast and Hot Rolled at 425°C* Al - 15.9 ^{w/o} U	Extruded Chips at 510°C Al - 15.73 ^{w/o} U - 0.13 ^{w/o} B
Yield Strength 0.2% Offset, psi	12,300	10,000
Tensile Strength, psi	20,300	19,400
Elongation, %	17.0	28.5
Reduction in Area, %	22.6	41.7
Rockwell "H" Hardness	73	69

*Data from reference 3.

Table VIIUranium Content of Extruded Rod of Al - 25% U Shot Alloy

Extrusion No. 18120	
Position	U, ^w / _o
Front	24.19
Center	24.10
Rear	25.29

Extrusion No. 18503	
Location (in. from front)	U, ^w / _o
0 (front)	24.21
20	24.22
33 (center)	24.14
47	24.38
57	24.18
72 (rear)	24.27

200 027

Table VIII

Mechanical Properties of Al - 25 ^W/o U Alloy

	Cast and Hot Rolled	Extruded Shot					
		No. 18120			No. 18503		
		Front	Center	Rear	Front	Center	Rear
Rockwell "F" Hardness	35	72.7	72.3	71.4	74.5	71.7	72.9
Yield Strength 0.2% Offset, psi	16,500	27,600	26,250	25,300	24,750	-	17,800
Tensile Strength, psi	20,500	36,300	36,000	34,600	25,000	21,800	23,000
Elongation, %	7	18.7	16.0	13.0	16.5	17.6	18.4
Reduction in Area, %	15.4	45.7	34.6	27.0	34.1	42.5	39.9

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Table IXExpected and Actual Analyses of Extruded Alloy Shot with Boron Additions

		Extrusion				
		No. 18504			No. 18505	
Wt. of Alloy Shot, grams		1000			1000	
Average U Content, ^{w/o}		24.24			24.24	
Boron Master Alloy		Ni-B			Al-B	
Weight, grams		14.7			66.0	
Boron Content, ^{w/o}		10.5			2.66	
		U, ^{w/o}	B, ^{w/o}	Ni, ^{w/o}	U, ^{w/o}	B, ^{w/o}
Expected		23.89	0.15	1.30	22.74	0.165
Actual (at six positions in extruded rod)	1 (Front)	23.93	0.12	1.70	22.85	0.14
	2	24.26	0.16	1.42	22.69	0.13
	3 (Center)	24.50	0.09	1.18	22.70	0.14
	4	24.17	0.11	1.54	22.30	0.15
	5	24.20	0.09	1.71	22.91	0.15
	6 (Rear)	24.15	0.16	1.78	21.72	0.17

250 229

Table XMechanical Properties of Extruded Al - 25^W/o UShot with Boron Additions

	Extrusion					
	No. 18504 (Ni-B Master Alloy)			No. 18505 (Al-B Master Alloy)		
	Front	Center	Rear	Front	Center	Rear
Rockwell "F" Hardness	72.2	73.1	70.6	67.7	65.2	65.4
Yield Strength 0.2% Offset, psi	-	21,500	23,500	24,500	15,650	15,650
Tensile Strength, psi	22,900	21,700	23,700	25,100	24,300	19,700
Elongation, %	12.9	17.7	11.7	20.5	14.5	10.3
Reduction in Area, %	22.9	25.3	22.1	37.8	28.3	24.1

210 500

100X Bt.Lt.

A-1157-1T

Fig. 1 - Extrusion No. 15817. Extruded As-Machined Chips,
Th - 9^{w/o} U. Transverse Section.

100X Bt.Lt.

A-1157-2T

Fig. 2 - Extrusion No. 15818. Extruded, Degreased, and
Pickled Chips. Th - 9^{w/o} U. Transverse Section.

200 331

7X Bt.Lt.

RF-5449

Fig. 3(a) - Extruded Th - 9 ^W/o U Chips. Polished Section of Rod, for Detection of Voids.

7X Bt.Lt.

RF-5560

Fig. 3(b) - Same area as above, photographed with ultra-violet light.

3X Bt.Lt.

RF-5909

Fig. 4 - Longitudinal Polished Section of a Solid-Extruded Rod of U - 10^{w/o} Nb Alloy, Showing a Void.

3X Bt. Lt.

RF-5907

Fig. 5 - Longitudinal Polished Section of a Chip-Extruded Rod of U - 10^{w/o} Nb, Showing a Void.

100X Bt.Lt.

A-2153-5L

Fig. 6 - Voids in Rod of Extruded U-Nb-Zr Chips Blended with ZrH_2 .

500X Bt.Lt.

A-2156-1L

Fig. 7(a) - Transverse Section of Rod of Al - 15.7 ^W/o U -
0.14 ^W/o B Extruded Chips.

500X Bt.Lt.

A-2156-1T

Fig. 7(b) - Longitudinal Section, same as Fig. 7(a).

100X Bt.Lt.

A-2148-1Tb

Fig. 8(a) - Extruded Al - 25 ^W/o U Shot. Transverse Section.

250X Bt.Lt.

A-2148-1La

Fig. 8(b) - Longitudinal Section of Fig. 8(a).

100X Bt.Lt.

A-2178-3T

Fig. 9(a) - As Extruded Rod of Al - 25^w/o U Shot Blended
with Nickel-Boron Master Alloy, Transverse Section.

100X Bt.Lt.

A-2178-3L

Fig. 9(b) - Longitudinal Section of Fig. 9(a).

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100X Bt.Lt.

A-2178-2T

Fig. 10(a) - As-Extruded Rod of Al - 25^w/o U Shot
Blended with Aluminum-Boron Master Alloy,
Transverse Section.

100X Bt.Lt.

A-2178-2L

Fig. 10(b) - Longitudinal Section of Fig. 10(a).

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