**Y-12 DEVELOPMENT ORGANIZATION
TECHNICAL PROGRESS REPORT**

Part 3 - Metal Processing (U)

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HIGHLIGHTS

RHEOCASTING AND SEMISOLID FORGING URANIUM-6 WEIGHT PERCENT NIOBIUM ALLOY

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METAL PROCESSING

RHEOCASTING AND SEMISOLID FORGING URANIUM-6 WEIGHT PERCENT NIOBIUM ALLOY

R. L. Bridges

Summary

Rheocasting is a method to eliminate skull and arc melting from the uranium-6% niobium (U-6Nb) alloy production stream. Rheocasting is also a viable method to reduce niobium segregation in production of U-6Nb alloy material. Semisolid forging (SSF) of rheocast U-6Nb alloy could be used to produce near-net-shape components. A U-6Nb ingot was melted and stirred in the rheocasting furnace. Although the U-6Nb ingot is still being evaluated for composition, homogeneity, and microstructure, initial inspection gave no indication of a shrinkage cavity. After the ingot was sectioned, some discontinuous center-line porosity could be observed.

Introduction

Static casting of U-6Nb alloy ingots results in unacceptable segregation in the as-cast microstructure. Flemmings et al.¹ defined rheocasting or slush casting as "the stirring of an alloy melt while cooling into the semisolid or mushy zone." Rheocasting cools the molten alloy into the two-phase, liquid-plus-solid regime and vigorously stirs the semisolid material to improve homogeneity and to provide a microstructure conducive to semisolid forging (Fig. 1). Semisolid forging of rheocast U-6Nb is also being evaluated as a potential method of producing near-net-shape components (Fig. 2).

Fig. 1. Rheocasting involves stirring the melt in the (liquid + solid) phase field.

Fig. 2. Semisolid forging of rheocast material.

Prior Work

Spencer studied semisolid processing, or rheocasting,² at the Massachusetts Institute of Technology in the early 1970s. He recognized that by stirring an alloy when it was cooling into the liquid-plus-solid regime the flow resistance was comparable to a viscous fluid. The continuous stirring during solidification produced a liquid/solid mixture of equiaxed solid particles that flowed easily in a liquid matrix, much like marbles suspended in mineral oil. Because of the formation of these equiaxed solid particles, no dendritic microstructure exists to impede movement (Fig. 3); therefore, complicated molds can be filled using very little force.

Fig. 3. Schematic illustration of structure evolution during solidification with vigorous stirring. (a) Initial dendritic fragment, (b) dendritic growth, (c) rosette, (d) ripened rosette, and (e) spheroid.

Rheocasting offers a number of advantages over conventional casting, including improvements in alloy homogeneity and forming behavior. The mechanical stirring or blending in the semisolid state reduces macro- and possibly microsegregation that is inherent to the U-6Nb alloy. Some of the improvements in forming behavior are due to the lower operating temperatures, which result in less shrinkage of the material during solidification and increased die life. Other improvements are due to the higher viscosity of the semisolid material, which fills the die more evenly at laminar flow. As the material fills the die at laminar flow, gas entrapment is less likely to occur, thus reducing the formation of voids and porosity.³

Rheocasting. Although rheocasting is considered a high-risk technology, it could be a practical alternative to the very large and expensive process now used for U-6Nb production. After a vacuum arc remelted (VAR) alloy ingot is produced, it must be thermomechanically processed into plate form. Plates formed in the current processing stream have a wide niobium variation from the center to the edge of the plate (Fig. 4). Because the niobium distribution is more uniform at the center of the plate, common practice is to make parts from the center portion and discard the edge material. If rheocasting is successful, it could provide a homogeneous ingot and a uniform forming plate. The ultimate goal, however, is not only to provide a homogeneous U-6Nb alloy but also to melt, blend, and semisolid forge to near net shape in a single operation.

Fig. 4. Microprobe niobium traces show the inherent segregation in VAR U-6Nb alloy plate.

Rheocasting Equipment. The Rheocasting Metal Furnace is a high-vacuum, 100-kW induction-heated, furnace. The crucible is made of niobium with alternating plasma-sprayed layers of yttria. The crucible melt capacity is 85 kg of uranium metal, which is equivalent to a 7-in.-diam by 11-in. ingot. The operating temperature range for the furnace is from room temperature to 1450°C. Temperature is monitored with both a single- and a dual-wavelength infrared thermometry system with a thermocouple backup. Stirring is accomplished with a 15-hp dc motor with a speed range of from 0 to 600 rpm. The stirring motor and associated equipment are designed to stir materials with a viscosity of 2000 cp and a density up to 19 g/cc. (For reference, glycerin at 25°C has a viscosity of 954 cp, and U-6Nb at 50% solid has a viscosity of ~900 cp.) Crucible vacuum is provided by a 12-in. cryopump with a pre-

heatup vacuum of 10^{-7} torr backed up by a mechanical pump. The furnace system is completely computer integrated to control and record all operating parameters for process repeatability.

Rheocasting U-6Nb Alloy. On September 29, 1993, the first experimental melt of U-6Nb alloy was completed in the Rheocasting Metal Furnace. The 31-kg charge consisted of four equal portions of U-6.5Nb, U-5.8Nb, U-6.2Nb, and U-6.6Nb. The charge material was not cleaned before melting because of the unavailability of equipment and resulted in uniformly dispersed uranium oxide (UO_2) contamination throughout the rheocast U-6Nb ingot. Although the UO_2 contamination would be undesirable for casting, it gave visual evidence of how effectively the stirring blended the metal.

With the crucible loaded and a vacuum level in the 10^{-7} -torr range, power was applied. The charge was heated slowly because of the volatiles coming off the dirty charge material and affecting the vacuum. In 90 min, when the crucible temperature was $\sim 1400^\circ\text{C}$, stirring began. Operating parameters were chosen from a previous differential thermal analysis (DTA) study that established transformation temperature as a function of heating and cooling rates for U-6Nb alloy (Fig. 5). Stirring speed was stabilized at 250 rpm (shaft speed) with the stirring motor pulling 7.0 A. Stirring continued for 30 min, until the stirring motor current rose to 8.0 A. The crucible was allowed to cool completely before the rheocast ingot was removed. The ingot was very bright and clean with no oxide; however, some residual metal remained on the crucible wall and the agitator blades. The author observed some discontinuous center-line porosity on the ingot cross section but no evidence of a shrinkage cavity. Metallographic photomicrographs taken from the ingot cross section show microporosity extending from the bottom through the length. The microstructure is typical of slow-cooled U-6Nb alloy (Fig. 6).

Fig. 5. Transformation temperature as a function of heating/cooling rate for U-6Nb alloy.

Fig. 6. U-6Nb alloy continuously cooled while stirring with a low fraction solid, then slow cooled.

Results

The Rheocasting Metal Furnace worked perfectly, and the first U-6Nb alloy ingot showed much promise in this area; however, much work remains to be done before conclusions can be made. The stirring did have a dramatic effect on the dispersion of UO_2 and hopefully on reducing the niobium segregation. To date, no data have been received regarding the chemical analysis. Although the ingot revealed no sign of equiaxed formations in the microstructure, it had not been expected on the first attempt. Solidification was just beginning after 30 min of stirring; therefore, the fraction of solid content was very low, and it is the ripening of these equiaxed solid formations that become a suitable rheocast microstructure.

Conclusion

The rheocasting of U-6Nb focuses on two main experimental questions. First, is the stirring during solidification adequate to produce a homogeneous U-6Nb alloy from depleted, unalloyed uranium and niobium powder? Second, can the formation of equiaxed particles in the microstructure be produced in quantities that could then be suitable for semisolid forging to near net shape? Experiments will be conducted in these areas of interest after evaluation of this first U-6Nb alloy ingot is complete.

References

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