Casting of Wide U-7wt.%Mo Foils for a Monolithic Research Reactor Fuel by a Single Cooling Roll

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1. Introduction

Generally, the conventional fabrication method for U-Mo foil [1-2] has the disadvantages of complicated processes such as the following: casting the U-Mo ingot after repetitive arc-melting; removing the sprue from the ingot; cold rolling a thick piece of the ingot through many passes to gradually thin it to fabricate U-Mo foil with a thickness of about 100 μm; and finally heat-treatment at about 900 °C and quenching the fabricated uranium foil to produce the required gain size and orientation.

In the conventional method, the cold rolling is repeated several times to obtain a suitable thickness of the U-Mo foil. As the cold rolling process takes a long time, productivity is relatively low. In order to obtain a fine polycrystalline structure which has a more stable behaviour during irradiation, heat-treatment and quenching must be performed. The high hardness and the low ductility of the U-Mo make it difficult to roll the foil. The foil is liable to crack owing to residual stress during the process, resulting in a low yield.

Monolithic fuel has been investigated as a very-high-density fuel candidate for high-performance research reactors since 2000 [3]. Excellent in-reactor results have been obtained from the irradiation of mini-plates containing monolithic LEU U-Mo fuel elements with a uranium density of 15.6 g/cm^3. If an economically viable manner of fabricating the monolithic LEU U-Mo fuel elements is developed, and if the preliminary irradiation tests are confirmed, this fuel holds the promise of enabling LEU operation of all the existing and future research reactors in combination with an unprecedented performance.

As the monolithic U-Mo fuel specimens irradiated in the RERTR-4 were fabricated at a laboratory scale, not at a commercialized scale, by the cold-rolling method due to some problems in foil quality, productivity and economic efficiency, attention has shifted to the development of an alternative technology. In the present study, U-7wt.%Mo foils for a monolithic fuel have been fabricated at KAERI by a single roll casting method. The wide U-Mo foils have been obtained through a rapid cooling directly from a melt. The fabrication of the U-Mo foil by a single roll casting method has been carried out.

2. Experimental procedure

U-7wt.%Mo ingots, melted and cast with a proportioned charge of depleted uranium lumps (99.9 % pure) and molybdenum button (99.7% pure), were charged and induction-melted in a high-temperature-resistant ceramic nozzle. The superheated molten U-Mo alloy was discharged through a small slot in the nozzle onto a rotating cooling-roll under the condition where the slot was located close to the cooling roll. The U-Mo foils were rapidly cooled by contact with the rotating roll driven by an electric motor in an inert atmosphere, so that the fine crystalline grains of the U-Mo foils with the meta-stable γ-U phase are formed. The rapidly solidified foil was collected in a container. The thickness of the U-Mo foils was measured at several positions along each foil using a micrometer. The morphology and the microstructure of the U-Mo foils were characterized with a scanning electron microscope (SEM).

3. Results and Discussion

Fig. 1. U-7wt.%Mo foil fabricated by a single roll casting method.

Fig. 1 shows the typical appearance of U-7wt.%Mo foil of about 50 mm in width and about 100 μm in thickness. The U-Mo foil with a width of 50mm could be continuously cast, using a single roll casting method. The width of the foil was almost the same with the slot width under the stable process condition. The U-7wt.%Mo foils have a relatively good surface state, a high strength and a high stiffness. Since the U-Mo foil is directly fabricated form the melt of U-Mo alloy by rapid cooling, which is difficult to roll due to its high strength and toughness, it may be easily fabricated. The fabrication process of U-Mo foil by a cooling roll is greatly simplified compared to the conventional fabrication method. The melt may be cast at once to fabricate the U-Mo foils of ~1 kg in a few seconds by a single roll casting method, thereby having a high productivity. However, as the U-Mo alloy has a low thermal conductivity and ductility, it is not easy to soundly fabricate the U-Mo foils without deformation and cracks in the collection process of a single roll casting method. The wheel-contact surface has a smooth surface state like the surface of the cooling roll; however, the free surface exhibits a somewhat rough surface state, with some defects. The U-Mo foils exhibited a rough state on the free surface and a fairly smooth state on the cooling-roll contact side.

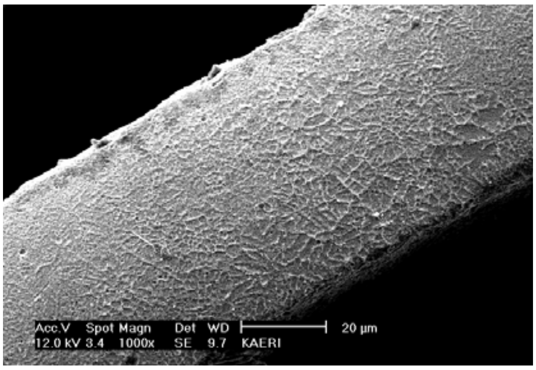

Fig. 2. Scanning electron micrograph of the polished U-7wt.%Mo foil.

Fig. 2 shows the scanning electron micrograph the obtained U-7wt.%Mo foil. The U-Mo foil has homogeneous and fine cells below 30 microns in size irrespective of the foil thickness. The U-Mo foil fabricated by a cooling roll has homogeneous and fine grains with a random orientation so as to prevent the U-Mo foil from excessively growing during irradiation. In addition, all the phases of the rapidly solidified foil are found to be the meta-stable isotropic γ-U (body-centered cubic) phase, irrespective of the foil thickness. It is expected that monolithic fuel with the U-Mo foil may not have a breakaway swelling behaviour but a stable in-reactor behaviour during irradiation, as shown in the monolithic fuel specimens irradiated in the RERTR-4. Therefore, it is not necessary to heat-treat the cold-rolled foil and quench it from about 900 °C to form fine grains with the γ-U phase, as the U-Mo foil having fine grains is directly obtained by the rapid solidification effect. It is seen that the microstructure of the U-Mo foils is polycrystalline, with many non-dendritic γ-U grains. The grain size becomes smaller as the foil thickness becomes thinner. This suggests a more-rapid cooling of the thinner foil owing to the increase of the specific surface area. Because the cooling rate of the thinner foil is higher, the time available for solidification decreases and the tendency to form finer polycrystallines enhances. Despite the rapid solidification, the SEM images reveal some Mo segregation, or cored microstructure, the characteristic of an alloy with a substantial liquidus-solidus gap, such as U-Mo alloy. At extremely high rates of solidification (~ 100 cm/sec), micro-segregation-free alloys may be produced by solute trapping [4]. However, the U-Mo foil fabricated by cooling-roll casting does not impose such high growth rates, and shows micro-segregation.

4. Conclusions

[1] Polycrystalline U-7wt.%Mo foils with a width of about 50 mm were fabricated, by adjusting the process parameters of a single roll casting method apparatus. The U-Mo foils had a good roughness on the surface, with a few impurities.

[2] The U-7wt.%Mo foils had fine and uniform poly-crystalline cells below about 30 microns in size with the γ-U phase. It is expected that monolithic fuel with the U-Mo foils shows a breakaway swelling behaviour but a stable in-reactor behaviour during irradiation.

[3] The fabrication of U-Mo foils by the cooling-roll casting method can be suggested as an alternative process for the fabrication of monolithic U-Mo fuel. for research reactors.

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