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Casting of Continuous Wide U-7wt.%Mo Alloy Foil for Advanced Research Reactor Fuel

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1. Introduction

Generally, the conventional fabrication method for uranium foils [1-2] has the disadvantages of complicated processes. In the conventional method, the U-Mo must be heated and rolled under a vacuum or in an inert atmosphere because it is a reactive material. The hot rolling is repeated several times to obtain a suitable thickness of the U-Mo foil. As the hot-rolling process takes a long time, productivity is relatively low. A washing/drying process must be done to remove the surface impurities after hot rolling. 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 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 hot-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 the cooling-roll casting method. The fabrication and the characterization of the U-Mo foils with various thickness by the cooling-roll casting method have been carried out.

2. Experimental procedure

U-7wt.%Mo alloy is introduced into a ceramic nozzle with a longish slot, and a vacuum is formed within the cooling-roll casting apparatus by the operation of an exhaust pump. When the vacuum degree in the apparatus reaches upto 10^{-3} torr, the nozzle is heated by a high frequency induction coil. When the molten alloy is super-heated at a proper temperature, it is discharged at a high pressure from the nozzle slot to the outer circumference of the cooling roll rotated at a high speed. The discharged melt through the longish nozzle slot is rapidly cooled by a rotating cooling-roll under an inert atmosphere. A wide and continuous U-7wt.%Mo foil is cast in a collection container. The obtained foils are measured for their thickness and widths at several positions and observed in the surfaces of the U-7wt.%Mo foils.

3. Results and Discussion

3.1. Wide U-7wt.%Mo Foil

In order to make wide foils, in the case of using a narrow nozzle slot, the U-7wt.%Mo melt is split into several pieces of foils during a discharging from the nozzle. U-7wt.%Mo melt should be properly super-heated in the ceramic nozzle and a longish nozzle tip should be pre-heated at a suitable temperature, by a control of the discharging temperature of the melt. Fig. 1 shows the U-7wt.%Mo foils cast with narrow nozzle slot (a) and the large nozzle slot (b), respectively. In the case of using a nozzle with a narrow slot tip, the width of the cast U-7wt.%Mo foil is much smaller than the width of the nozzle slot; however, in the case of using a nozzle with a wide slot tip, the width of the cast U-7wt.%Mo foil is almost equal to the width of the nozzle slot. It is indispensable to feed the U-7wt.%Mo alloy melt into a rotating cooling-roll through a wide nozzle slot with a high injection pressure.

(a)

(b)

Fig. 1. U-7wt.%Mo foils cast with narrow nozzle slot (a) and large nozzle slot (b).

3.2. Continuous U-7wt.%Mo Foil

U-7wt.%Mo alloy has a low ductility and a high strength, in contrast to pure uranium. Excessive revolution speed of the cooling roll should be avoided to make a continuous U-Mo foil, as the U-Mo foil collides severely collided with a high sliding speed at the wall of the collection chamber, and then it is damaged with cracks and fragments in the U-Mo foils. In the case that the revolution speed is so low, the feeding rate of the melt from the nozzle to the cooling roll is much larger than the casting rate of the U-Mo foil on the surface of the cooling roll, resulting in a non-uniformity of the thickness due to traces of a melt flow on the free surface. Thin U-Mo foil made with a high revolution speed, is damaged with cracks and fragments by a high sliding speed in the collection container; however, a continuous U-Mo foil is fabricated with an appropriate revolution speed of the cooling roll. Excessive injection pressure of the melt should also be avoided to make a continuous U-Mo foil, as the U-Mo alloy melt tends to be atomized or fragmented under a high injection pressure, resulting in the inhibition of the formation of a continuous U-Mo foil.

3.3 Uniform U-7wt.%Mo Foil

As the thickness of the U-7wt.%Mo foils increases, a lack of a uniformity of the U-Mo foil generally increases. It is important to control the revolution speed of the cooling roll and the injection pressure of the melt appropriately, in order to make uniform U-Mo foils with regards to the thickness. In the case of being cast by a low revolution speed of the cooling roll and an excessive injection pressure, the feeding rate of the melt from the nozzle to the cooling roll becomes much larger than the casting rate of the U-Mo foil on the surface of the cooling roll. It resulted in a non-uniformity of the thickness due to traces of a melt overflow and droplets of melt on the free surface of the U-Mo foil. Fig. 2 shows the effects of the revolution speed of the cooling roll on the thickness of the U-7wt.%Mo foils. As the revolution speed of the cooling roll decreases, the thickness of the U-Mo foil increases.

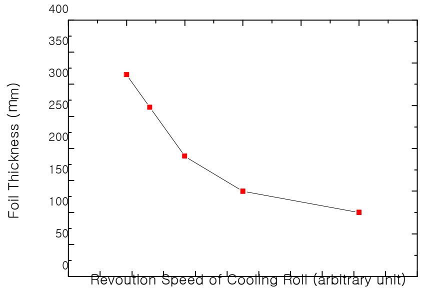

Fig. 2. The effect of the revolution speed of cooling roll on the thickness of the U-7wt.%Mo foils.

U-Mo foil is apt to have various defects such as cracks, tears, foldings, etc. in the edges of the U-7wt.%Mo foil, especially in the case of fabricating U-Mo foils larger than about 200㎛ in thickness. In the case of being cast with a narrow nozzle slot, a tearing phenomenon of the edge part occurs, while the alloy melt passes the longish nozzle slot.

4. Conclusions

1) Continuous U-7wt.%Mo foils with a width of about 50 mm and a thickness ranging from 100 to 250 microns were fabricated, by adjusting the process parameters of a single roll casting method apparatus. 2) 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.

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