Fabrication of Zr-U/Zr-Nb Rod using Coextrusion Processs

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1. Introduction

The use of material consisting of two different materials is increasing in many industries such as electronics, nuclear engineering, and chemistry. It has material properties that cannot be obtained from a single material.[1,2] During the coextrusion process, non-homogeneous deformation tends to occur because the billet consists of materials with different mechanical properties. Recently, the coextrusion process has provided the fuel element fabricator with a relatively economical means to clad a uranium core with a zirconium alloy. This process not only clads the Zr-U with Zr-Nb and forms the fuel into its final shape but also forms a metallurgical bond between the two.[3-5] The metallic bond is a definite requirement for high power, high temperature operation of metallic fuel element.

For the present study, a coextrusion process was applied to fabricate an Zr-U/Zr-Nb rod. In order to analyze the effect of extrusion temperature in the fabrication of Zr-U/Zr-Nb rod using coextrusion process, four extrusion temperatures were applied. Hardness distribution of the fabricated Zr-U/Zr-Nb rod under different processing conditions were determined. The bonding characteristics at the interface between Zr-U and Zr-Nb alloy was studied by SEM and EDS analyses.

2. Methods and Results

Hot extrusion of Zr-U/Zr-Nb billets was performed at various temperatures using a horizontal extruder. The pressure medium is important because it transmits pressure and lubricates the interface between the billet and die. It should have properties of low compressibility and good lubrication under high pressure. In this study, Rocol dry molybdenum spray was used as a high pressure medium. The billet was composed of a copper can, Zr-U and Zr-Nb alloy. After surface treatment, uranium was inserted into the zirconium can and copper can. The rear/front end of the billet was sealed by electron beam welding in a vacuum atmosphere. The hardness variation across the interface between Zr-U and Zr-Nb clad was determined by means of the Micro Vickers hardness test.

2.1 Extrusion pressure

Extrusion pressure is important factor in the coextrusion process because it is dependent on flow stress of the material, the extrusion ratio, lubrication, die condition, extrusion speed, extrusion temperature. Extrusion pressures of three extrusion temperatures were determined experimentally and compared against each other to investigate the effect of the extrusion temperature in the fabrication of the Zr-U/Zr-Nb rod. Figure 1. shows the relationship between extrusion pressure and temperature. The extrusion pressures decreased as the extrusion temperatures increased because the deformation strength decreases with an increase of extrusion temperature.

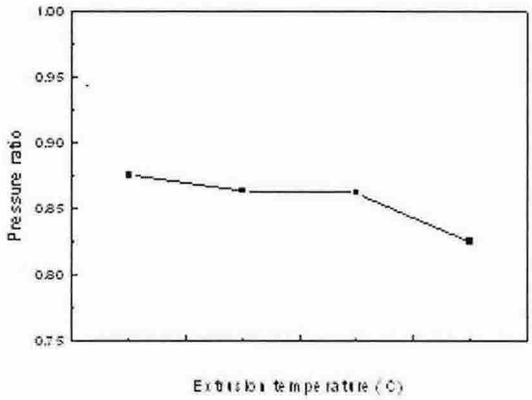

Fig. 1. Extrusion pressure of an Zr-U/Zr-Nb rod as a function of extrusion temperatures

2.2 Hardness

In order to determine the effects of the extrusion temperature on the hardness of an extruded Zr-U/Zr-Nb, Vickers hardness was measured across the cross section of the Zr-U/Zr-Nb rod. Hardness was measured at the same place six times. The measured values of the hardness were then averaged. Figure 2. shows the distribution of average hardness across the cross section of the uranium core at various temperatures. First, hardness decreases with an increase of extrusion temperature. Second, hardness of cross-sectional lines becomes more uniform as the extrusion temperature increases. Third, hardness decreases as the distance from the center increases. This is in line with the findings of another research's study. The strain at the outer surface is greater than that at the center due to plastic flow of billet during the extrusion.[2] The uniform distribution of hardness with an increasing temperature is not sensitive to changes in strain.

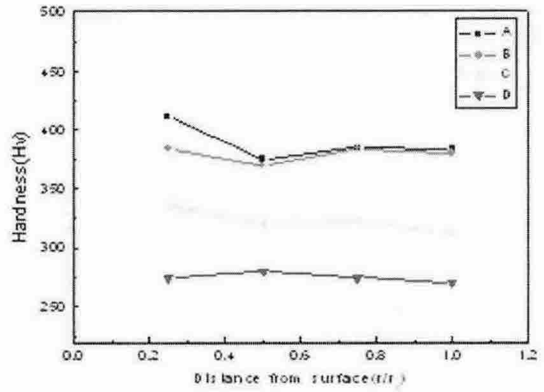

Fig. 2 Hardness distribution of an Zr-U/Zr-Nb rod at various extrusion temperatures.

2.3 Interface

Mechanical properties of metallic clad rod are dependent on interfacial bonding status and the metallic materials are bonded together by diffusion in the process of hot extrusion. Figure 3. shows the Zr-U/Zr-Nb interface in the extruded rod. The interface between core and cladding was shown to be a metallurgical bond without any gaps. The wave-shaped line was also observed in the core-cladding interface. It was ascribed to the difference of grain size and deformation strength in plastic flows of two-kind materials.[3]

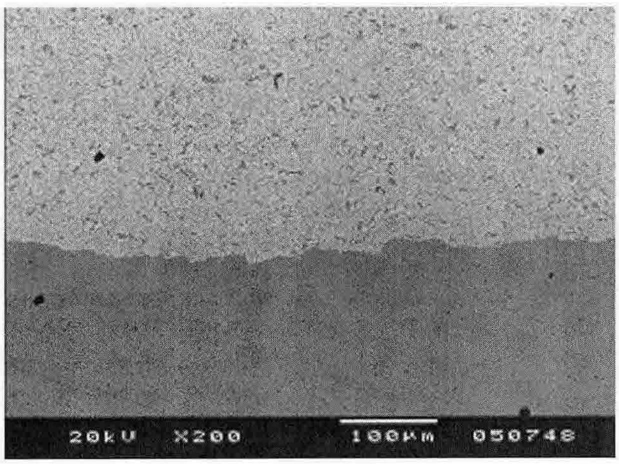

Fig. 3. Micrograph of core-to-clad interface in the extruded Zr-U/Zr-Nb rod.

4. Conclusion

In this study, we applied a coextrusion process to fabricate an Zr-U/Zr-Nb rod at various temperatures. The effect of the extrusion temperature on the process of coextrusion was determined experimentally. The followings are the conclusions obtained in this study. The extrusion pressures decreased as the extrusion temperatures increased. Hardness decreases with an increase of extrusion temperature. Hardness becomes more uniform as the extrusion temperature increases. Hardness decreases as the distance from the center increases. The uniform distribution of hardness with an increasing temperature is not sensitive to changes in strain. The interface line of the Zr-U/Zr-Nb rod was observed to be wavy. The wavy bonded line is due to grain-to-grain differences in material flow.

Acknowledgements

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