Microstructure and Hardness in the Fracture Region of Coextruded Zr-U/Zr Rods

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1. Introduction

As it provides a relatively economical method, the coextrusion process has been used to clad a uranium core with a thin Zr-alloy. This coextrusion process was chosen because it could effect in a metallurgical bond between the Zr-U core and Zr cladding. It is considerably required that the metallic fuel should have a metallic bond in the interface between fuel and clad for high power and high temperature operations [1].

During the extrusion process of clad materials, fracture of the clad or core materials frequently occurs because of the discontinuity of deformation caused by the differences in the flow stress of the clad and core materials. Therefore, to predict the fractures strain of clad/core materials, it is necessary to investigate the theory on the ductile fracture. The beginning of ductile fracture depends on the paths of stress and strain, therefore, most criterion equations of ductile fracture are expressed as an integral formation. In a clad material, the fracture phenomenon has occurred by the bending, fracture in clad material, and lack of interface bonding force among different kinds of materials during coextrusion process. Kinds of lubricating materials, die semi-angle, and initial shapes of billets in coextrusion are very important.

In this study, the microstructural behavior and mechanical property in the fracture region of a coextruded Zr-U/Zr rod were examined.

2. Methods and Results

2.1 Experimental procedure

Hot extrusion of Zr-U/Zr billets was performed at high 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 the properties of both low compressibility and good lubrication under high pressure. In this study, Rocol dry molybdenum spray was used as lubricant for a high pressure medium. The billet was composed of Zr-U core, Zr alloy and Cu cans. After surface treatment, Zr-U alloy was inserted into the Zr and Cu cans. The rear/front ends of the billet were sealed by an electron beam welding method in a vacuum atmosphere. The variation of hardness across the interface between Zr-U core and Zr clad was examined by means of the Micro Vickers hardness test. Hardness was measured six times in a region. The measured values of the hardness were then averaged. The microstructural observation was performed using a OM and SEM/EDS.

2.2 Hardness

In order to determine the effects of the microstructural behavior on the hardness of an extruded Zr-U/Zr, Vickers hardness was measured across the cross section of the Zr-U/Zr rod. Figure 1 shows the distribution of hardness across the cross section of the Zr-U matrix and Zr-rich precipitates in the core of Zr-U/Zr rod. The hardness revealed an uniform distribution in the core region. This observation coincided well with another results [1-2]. 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 is not sensitive to change in strain. Hardness of the Zr-rich precipitates was measured higher than that of the Zr-U matrix. It is considered that the Zr-rich precipitates in the core would be made during the sintering and coextrusion processes.

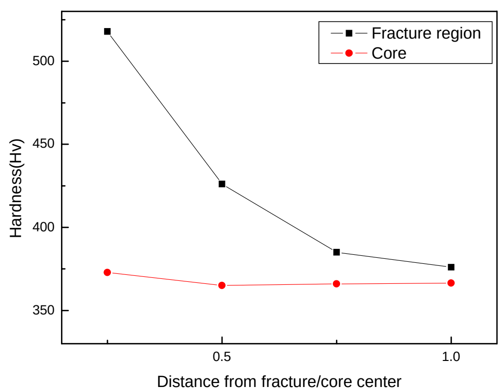

Fig. 1. Hardness distribution of coextruded Zr-U/Zr rods.

2.3 Microstructure

Figure 2 shows microstructures in the longitudinal and transverse sections of coextruded Zr-U/Zr rod.

No Zr-rich precipitates in the coextruded Zr-U/Zr rod were observed(Fig.2a, b). The core and clad interface was shown to be a metallurgical bond without any gaps. The wave-shaped line was also observed in the core-cladding interface. It is ascribed to the difference in the grain size and deformation strength in plastic flows of two-kind materials [3-4]. Mechanical properties of metallic clad rod are dependent on the interfacial bonding status, and the metallic materials are bonded together by diffusion in the process of hot extrusion. In the fracture region (Fig.2c, d), the crack and void were observed near the Zr-rich precipitates in the core. The result of SEM/EDS study showed that fracture regions contained much amount of zirconium component(95.6wt.%). As shown in this figure, the fracture regions exhibited much cracks near Zr-rich precipitates. It is attributed to the Zr-rich precipitates having brittle behavior during deformation, resulting in the cause of cracks. This result shows good agreement with hardness data (Fig.1). During plastic deformation due to external force on billet, the difference in metal flow both Zr-U matrix and Zr-rich precipitates occur and a void is created in the matrix-precipitates interface simultaneously. When this void is propagated, it creates cracks in the core during coextrusion process.

3. Conclusion

The effects of the microstructural behavior and hardness on the process of coextrusion were experimentally observed. In the coextruded Zu-U/Zr rod, The hardness revealed an uniform distribution in the core region The uniform distribution of hardness is not sensitive to change in strain. Hardness of the Zr-rich precipitates was measured higher than that of the Zr-U matrix. The interface line of the Zr-U/Zr rod was observed to be wavy. The wavy bonded line is due to grain-to-grain differences in material flow. The fracture regions exhibited much cracks near Zr-rich precipitates. It is attributed to the Zr-rich precipitates having brittle behavior during deformation, resulting in the cause of cracks.

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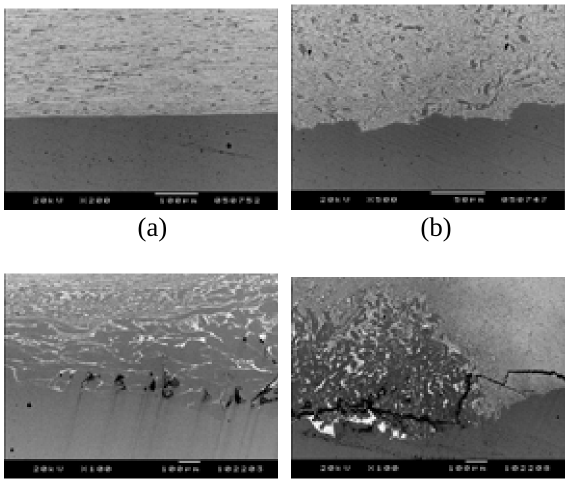

(a) (b) (c) (d)

Fig. 2. Micrographs in the core-to-clad interfaces of the extruded Zr-U/Zr rod.

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