Microstructural Characteristics of HANA-6 Tube Shell Manufacturing

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1. Introduction

Zr alloys have been widely used in nuclear power reactor since it has good mechanical properties, corrosion resistance and low neutron absorption [1]. Zircaloy-4 has been successfully used as fuel cladding in light water reactor environments for many years.

However, as light water reactors tend to be operated in more severe environments, that is, increased burn-up, high operation temperature, and high pH in first loop, higher corrosion resistant alloys have been continuously developed as a substitute for Zircaloy-4. Because of their good mechanical and corrosion properties, Zr-Nb alloys have been studied as candidate materials for improved fuel cladding [2-4]. Several new Nb-containing zirconium alloys such as ZIRLO (Zr–1.0Nb–1.0Sn–0.1Fe), M5 (Zr–1Nb–O), E635 (Zr–1.0Nb–1.0Sn–0.4Fe), and N18 (Zr–0.3Nb–1.0Sn–0.3Fe–0.1Cr) were developed and/or are being tested in-reactor. Also, new zirconium alloy claddings, HANA (High-performance Alloy for Nuclear Application) alloys, have been developed in order to achieve excellent corrosion resistance at discharge burn-up in excess of 60 GWd/MTU. It is well known that the mechanical properties and corrosion resistance of zirconium alloys are dependent upon the microstructure developed during manufacturing process of the tube. Therefore, the observation of microstructure with manufacturing steps is necessary to establish the tube manufacturing process.

The purpose of this work is to initially investigate the microstructural characteristics of HANA-6 tube shell with the manufacturing process from the ingot to tube shell.

2. Experimental procedure

Tube shell used in this study is HANA-6 (Zr–1.1Nb–0.05Cu) alloy. The manufacturing steps of the HANA-6 tube consist of ingot melting, beta-forging, beta-quenching, hot extrusion, cold-pilgering, and annealing. During the manufacturing processes, samples for microstructure observation were collected at each manufacturing process as summarized in the Table 1.

To evaluate microstructure characteristics of each process, specimen was taken by wire cut machine. The sampling plan is listed in the Table 1, and position of the specimen is shown in Fig. 1. Billet is divided into five tube shells, and each tube shell was cut into two tube shells as shown in Fig. 1. The microstructure with the manufacturing process was observed using an optical microscope. For optical microscopy, electropolishig and electroetching were performed. The electroetching solution contained 10% of oxalic acid. The electrolytic voltage between 0 to 53 V was applied.

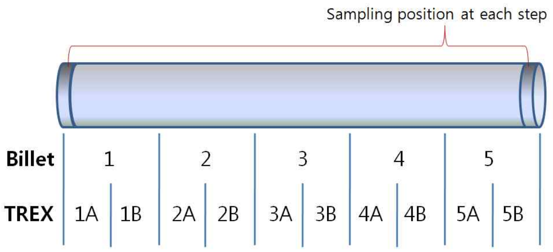

Fig. 1. Sample preparation of the HANA-6 alloy.

Table 1. Sampling processes for HANA-6 tube shell

Process	Condition of Specimen
Ingot melting	After machining
Beta -forging	After conditioning
Beta- quenching	After conditioning
Extrusion	After annealing
Cold-pilgering	After pilgering
Shell annealing	After annealing

3. Results and discussion

Fig. 2 shows results of the optical microscope observation of the HANA-6 specimens. After ingot melting process, large grains are observed as shown in Fig. 2(a). Fig. 2(b) presents the microstructure after beta forging process. It contains aligned α phase plate obtained after the sample was forged from β phase region. To improve mechanical properties and corrosion resistance of zirconium alloy, beta-quenching is typically performed. For beta-quenching, the specimen is annealed in the β phase region for one or two hours, and then quenched at room temperature.

After beta-quenching, plate-like structure, typical Widmannstatten structure, is observed as shown in Fig.

2(c). It was reported that two kinds of microstructure are manifested depending on the cooling rate during beta-quenching. One is basket-weave structure with lower cooling rate, the other is parallel plate-like structure with faster cooling rate. Fig. 2(c) shows typical basket-weave structure.

To reduce wall thickness as well as diameter of the extruded tube, cold-pilgering was performed. After extrusion and cold-pilgering process, the structure is elongated as shown in Fig. 2(d) and (e). Fig. 2(f) shows the microstructure after shell annealing. The grain size of HANA-6 tube shell after annealing was ASTM No. 7 or finer.

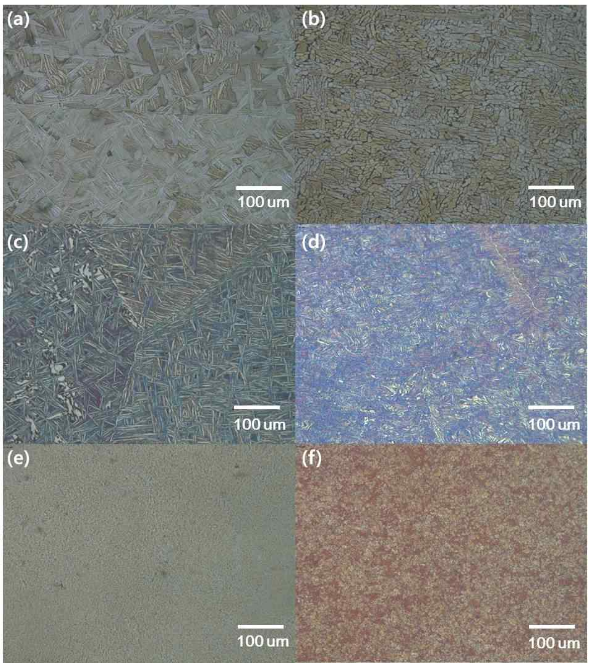

Fig. 2. Observation of HANA-6 specimens by optical microscope; (a) Ingot, (b) beta-forging, (c) beta-quenching, (d) extrusion, (e) cold-pilgering, (f) shell annealing.

3. Conclusions

The microstructural characteristics of HANA-6 alloy from the ingot melting to the tube shell manufacturing was investigated. At each process of tube shell manufacturing, the characteristic microstructure was well developed. From the tube shells with optimum final grain size and shape can be processed to the cladding tubes.

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