Characteristics of HANA-4 tube shell with different manufacturing process

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1. Introduction

Zr-based alloys have been used as a fuel cladding material for several decades since these alloys have revealed a good corrosion resistance and mechanical properties in reactor operating conditions [1]. More advanced Zr-Nb alloys are used instead of Zircaloy-4 to satisfy more severe operating condition such as higher burn-up and increased operation temperature. Because of their good mechanical and corrosion properties, Zr-Nb alloys such as ZIRLO, M5, and E635 etc. have been studied for improved fuel cladding [2-4]. Among the Zr-Nb alloy claddings, HANA (High-performance Alloy for Nuclear Application) alloys, have been developed in order to achieve excellent corrosion resistance.

It is well known that the mechanical properties and corrosion resistance of zirconium alloys are dependent on the microstructure from manufacturing process of the tube. The microstructural characteristics of Zr-based alloy were determined at the tube shell manufacturing stage. The purpose of this study is to compare the microstructure and hardness of the HANA-4 tube shell with different manufacturing sequences by manufacturers.

2. Experimental procedure

Tube shell used in this study is HANA-4(Zr-1.5 Nb-0.4 Sn-0.2 Fe-0.1 Cr). To evaluate the characteristics of HANA-4 tube shell, samples were collected at each process.

ICP(Inductively Coupled Plasma) analysis and combustion method have been performed to identify the chemical composition of HANA-4 tube shell. Metallographic studies have been performed with optical microscope and TEM. For optical microscopy, electropolishig and electroetching were performed. The electroetching solution was containing 10% of oxalic acid, and the electrolytic voltages between 0 and 53 V were applied. Thin foils for TEM were prepared by electropolishing using double-jet thinning in a solution of 10% perchloric acid in methanol maintained below –40°C. Measurement of hardness of each process has been performed by Vickers hardness test.

3. Results and discussion

The chemical composition of HANA-4 ingot was analyzed by ICP. Also the H, N and O compositions of the billet were analyzed by combustion method. The results show that requirement of the alloying element contents in the tube specification are satisfied .

The microstructure of HANA-4 tube shell at each manufacturing process was investigated with optical microscope, as shown in Fig. 1. The manufacturing process of HANA-4 tube shell consists of ingot melting, beta-forging, beta-quenching, extrusion, cold working, and annealing. Among the tube manufacturing processes, cold working process is different between two manufacturers; cold pilgering (A) and cold forging (B), respectively.

After ingot melting process, large grains are observed. Forged specimen produced by hot working has a lamellar microstructure consisting of α-Zr and β-Zr phases. The lamellar microstructure of the forged material is transformed into a martensitic structure after quenching of billet. During the hot extrusion in α-region of quenched billet, a structure consisting of primary α-Zr phase in the form of fibers and grains, β-Zr phase is observed. Tube shells produced by strong deformation at cold working have the microstructure such as deformed lengthwise structure with high level dislocations. Final heat treatment was performed in the temperature range of 570 to 580°C for 3 hours after cold workings. Therefore the similar fine-grained microstructure of tube shell was formed in both A and B's final annealed specimens.

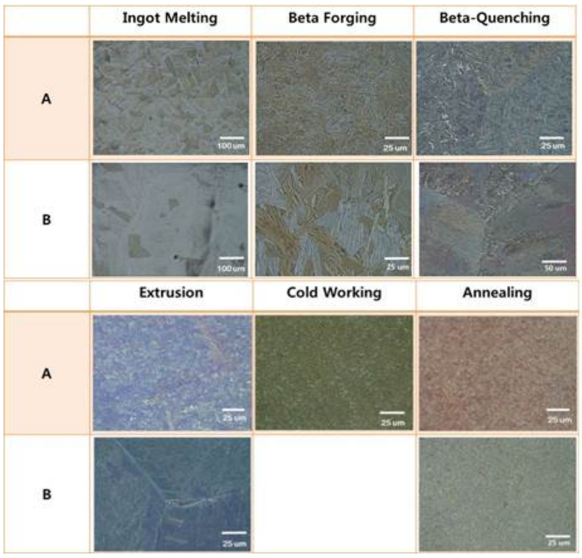
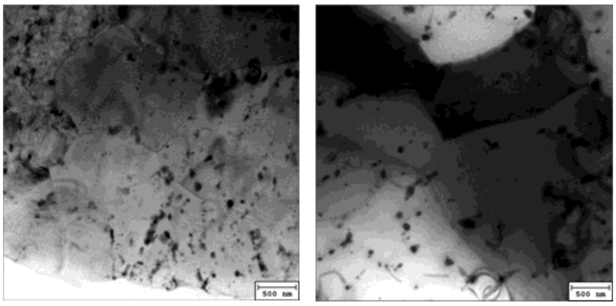


Fig. 1. Microstructures of HANA-4 tube shells different with manufacturing process between two manufacturers.

TEM was used to detect the difference, which can be caused in the manufacturing process, in the tube shell. As shown in the Fig. 2, the microstructure of final annealed tube-shell consists of α-Zr, β-Nb, and $Zr(Cr,Fe,Nb)_2$ precipitates, and there is no significant difference between manufacturers A and B.



(a) (b)

Fig. 2. TEM images of final annealed tube shell,
(a) Manufacturer A, (b) Manufacturer B

Fig. 3 shows results of the hardness measurement of the HANA-4 tube shells during manufacturing processes. The change of hardness was similar between two manufacturers. Due to the change in structural-phase state of the material after quenching, hardness of quenched specimen is higher than that of forged one. After extrusion step vacuum annealing was performed in order to remove residual stress, the hardness was slightly decreased. The hardness of cold worked specimen increased whereas that of annealed specimen was decreased. Even though the manufacturing process was slightly different, the hardness of final annealed tube shells shows no difference by the same final heat treatment.

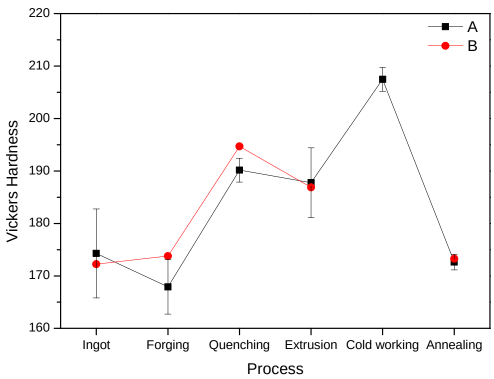


Fig. 3. Changes in hardness of HANA-4 tube shells with the manufacturing process

3. Conclusions

To compare the properties of HANA-4 tube shell with the manufacturing process, chemical, microstructure, and hardness analyses were performed.

ICP analysis revealed the requirements of chemical composition of the HANA-4 tube shell in specification are met. The microstructure was slightly different during the cold working stage, it has the same characteristics for the finished tube shell by the same final annealing. The hardness of the both tube shells is also decreased to the similar extent by the cold working.

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REFERENCES

[1] Ramos C, Saragovi C, Granovsky M.S., Some new experimental results on the Zr-Nb-Fe system, J. Nucl. Mater., 366, 198-205 (2007)

[2] D.G. Franklin and P.M. Lang, ASTM-STP 1132, 3 (1991)

[3] V.F. Urbanic, B.D. Warr, A. Manolescu, C.K. Chow and M.W. Shanahan, ASTM-STP 1023, 20, (1989)

[4] G.R. Kilp, D.R. Thornburg and R.J. Comstock, IAEA Technical Committee Meeting on Fundamental Aspects of Corrosion of Zirconium-Base Alloys in Water Reactor Environments, IWGFPT/34, paper 10, Vienna, (1990)