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Zirconium Alloy Cladding Tube Characteristics Made by KNF

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1. Introduction

The characterization tests for the Zr alloy cladding tubes have been conducted for the KNF products followed by several qualification tests through the joint R&D program to develop the nuclear grade zirconium alloy tube manufacturing technology with WEC (Westinghouse Electric Co.) since 2004. To compare the properties of cladding tube produced by KNF and WEC, more than 20 round robin tests were performed [1]. The compared test results are described herein, in the point of cladding tube properties with relation to tube manufacturing process.

2. Methods and Results

The representative cladding tubes were selected by the consideration of reduction passes, its production quantity and tube size. For the cladding tube production by KNF and WEC, the serial TREX(tube reduced extrusion) of same lot was used for the elimination of chemical composition effect. After production completed, the cladding tubes were exchanged each other and independently tested for more than 20 test items including room temperature tensile test.

2.1 Mechanical Properties

The appropriate international standard methods were used for the mechanical test. The room temperature tensile test was summarized in Fig. 1. The dotted lines represented reference accepted range specified in the specification of the cladding tubes. This showed the yield strength, ultimate tensile strength and elongation had the equivalent values each other. This is attributed to the same reduction schedule and intermediate/final annealing condition. Also, the tensile properties at 385℃ as shown in Fig. 2 would be equivalent.

2.2 Metallurgical Properties

The metallurgical properties of cladding tubes could be roughly classified into the texture parameter, second phase particle size and degree of recrystallization due to its final stress relief annealing.

As shown in Fig. 3, the (0002) basal pole figure had the same shape and amplitude, and the texture parameter of the cladding tubes made by both companies was nearly identical. This is attributed to the same three reduction pass schedule and its same die/mandrel design. The slight changes of feed rate, turning and stroke during pilgering did not change the texture parameter.

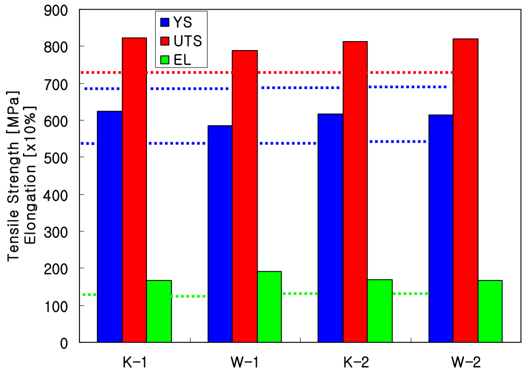


Fig. 1. Room temperature tensile properties for the cladding tubes manufactured by KNF and WEC

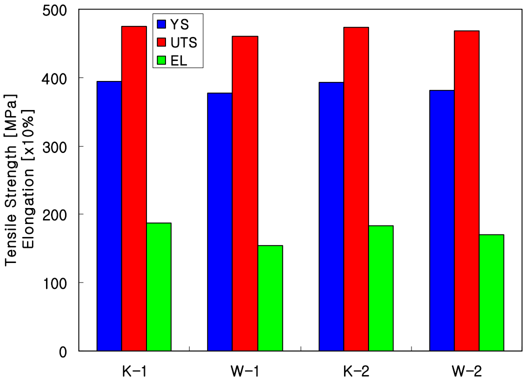
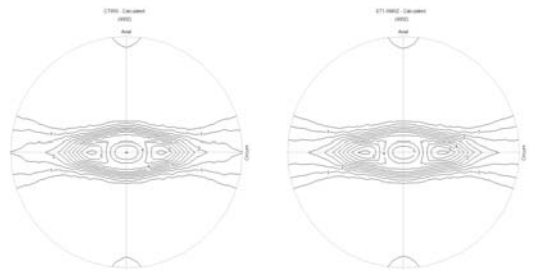


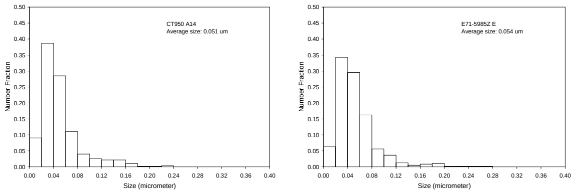
Fig. 2. 385℃ tensile properties for the cladding tubes manufactured by KNF and WEC

The result of second phase particle size and distribution measured by TEM was shown in Fig. 4. The mean size was 0.051 ㎛ and 0.054 ㎛ for KNF and WEC cladding, respectively. With the second phase particle size range, the good corrosion resistance of cladding tube is anticipated [2].



(a) KNF cladding (b) WEC cladding

Fig. 3. Basal (0002) pole figures of cladding tubes manufactured by KNF and WEC.



(a) KNF cladding (b) WEC cladding

Fig. 4. Second phase particle size and distribution of cladding tubes

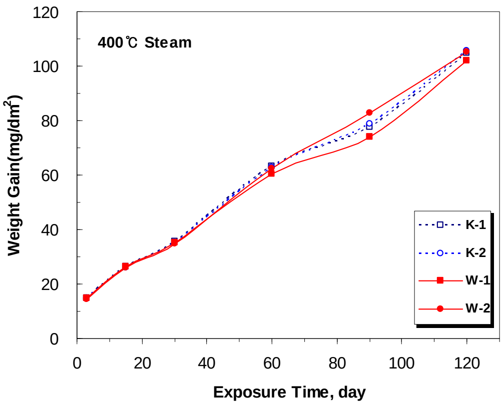
After the final stress relief annealed, the degree of recrystallization defined as the area fraction of recrystallized grains was measured on low magnification TEM. The degree of recrystallization was 1.2% and 2.3% for KNF and WEC cladding tube, respectively, though both cladding had the same cumulative annealing parameter.

2.3 Corrosion Properties

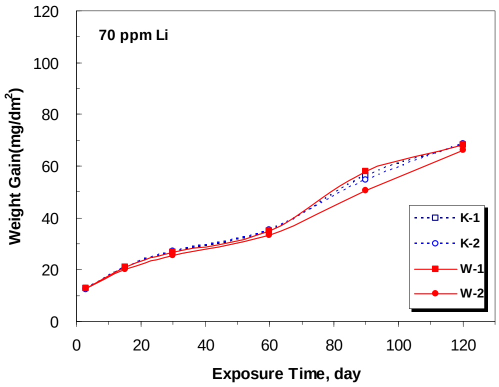
The long-term corrosion behavior of both claddings at 400℃ 10.3 MPa steam and at 360℃, 18.7MPa pressurized 70 ppm lithiated water environment had the equivalent weight gain for both claddings as shown in Fig. 5. From the results, the manufacturing process, especially tube finishing process parameter of KNF would be suitably set-up.

2.4 Creep Properties

The creep strain with the mid-wall stress of 130 MPa, 400℃, 240 hrs was 4.6±0.7% and 4.7±0.6% for KNF and WEC cladding tube, respectively. The same creep strain was attributed to the same final annealing condition. Therefore, the thermal creep model could be used for performance analysis without any change.



(a) 400℃, 10.3 MPa steam



(b) 360℃, 18.7MPa pressurized 70 ppm lithiated water

Fig. 5. Corrosion behavior of the cladding tubes manufactured by KNF and WEC

3. Conclusions

The characterization tests for the cladding tubes made by KNF and WEC was performed for approving the equivalent properties. With the comparison of more than 20 test items including the tensile properties, cladding tube made by both companies had the equivalent mechanical and metallurgical properties.

Acknowledgement

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[2] Sabol, G.P. et al., In-Reactor Corrosion Performance of ZIRLO™ and Zircaloy-4, Zirconium in the Nuclear Industry: Tenth International Symposium, ASTM STP 1245, 1994, p. 724.