Zirconium Alloy Cladding Tube Properties Made by KEPCO NF

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1. Introduction

KEPCO NF completed development program to provide the nuclear grade Zr alloy tube manufacturing technology. As part of this development program, the characterization tests for Zr alloy cladding tubes were performed in 2008 to demonstrate the equivalency of the KEPCO NF tubular products to WEC products[1]. Results of characterization tests were equivalent and KEPCO NF has been commercially supplying Zr alloy tubing to domestic utility since 2009.

For the purpose of qualifying the KEPCO NF Zr alloy cladding tubing to supply to WEC, characterization test was re-conducted and the results were compared to those of in 2008.

2. Methods and Results

To qualify the KEPCO NF to supply Zr alloy cladding tubing for WEC, three qualification lots of fuel tubing were applied to the manufacturing process. The manufacturing parameters were not changed since last qualification in 2008.

2.1Elevated Temperature Tensile Property

The elevated temperature tensile tests at 385°C were performed and the results are summarized in Figure 1. The Q and K/W represented qualification tubing lots and comparative tubing lots in 2008, respectively. Figure 1 shows that the Q and K/W lots are equivalent to each other for the yield strength (YS), ultimate tensile strength (UTS) and elongation (EL). The tensile test results of 3 qualification lots had similar values to those of comparative characterization lot manufactured by KEPCO NF and WEC at 2008.

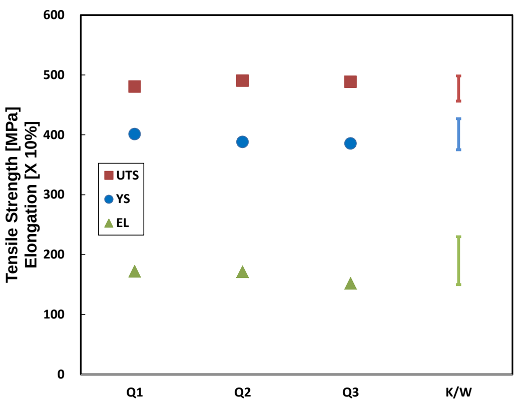

Fig. 1. The elevated temperature tensile test results of qualification lots (Q) and comparative lots (K/W).

One-way ANOVA (Analysis of variance) was performed at the 0.05 level of significance in order to check and confirm the means of tensile properties for the testing lots are equal. The ANOVA result is summarized in Table 1. Based on the results that the computed F value is much lower than F critical value and P-value is larger than 0.05, it can be concluded that all means of the testing lots are equal.

Table 1. Analysis of variance for the elevated temperature tensile test results.

	Computed F	P-value	F critical
YS	0.70	0.60	2.87
UTS	1.09	0.39	2.87
EL	1.03	0.42	2.87

2.2Degree of Recrystallization

The degree of recrystallization was measured by using TEM. Specimens were prepared by punching 3mm diameter disks from the midwall location of the tubing. These disks were mechanically polished down to a 70 μm thickness and then jet polished in a $(90C_2H_5OH:10HClO_4)$ solution at -30 to -40°C. Minimum two foils from each tubing lot were examined at a magnification of 5,000×. The percent recrystallization was determined by measuring the area fraction of recrystallized grains from 38 micrographs.

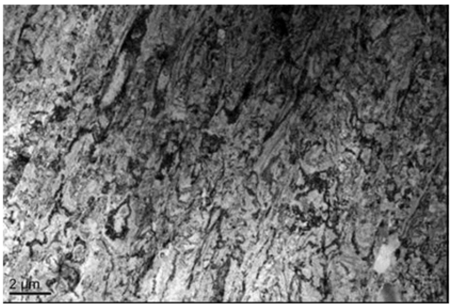

Fig. 2. Representative TEM micrograph from qualification lots (Q).

The degree of recrystallization of qualification lots (Q) is 1.0~1.4%. The degree of recrystallization of comparative lots (K/W) measured by WEC with analySIS software in 2008 was 1.2~2.3%. The difference could be originated from the MATROX INSPECTOR(version 2.1) program for treatment of recrystallized grains.

2.3 Texture

Crystallographic texture for qualification (Q) and comparative characterization tubing lots (K/W) was measured by the direct pole figure technique. The texture samples were axially slit, mounted, and mechanically polished and then chemically polished in ($50H_2O:45HNO_3:5HF$) solution for 10 seconds. The sample area is more than 10×10 mm^2. Complete pole figures were obtained from the orientation distribution function (ODF) for each specimen.

The texture parameters were calculated from the completed basal pole figure. The texture parameter, f_i, is the fraction of all basal poles in a sample that are effectively oriented in a reference direction, i. It is defined by following equation:

$$f_i = \frac{\int_{0^o}^{90^o} I(\phi) cos^2\phi \, sin\phi \, d\phi}{\int_{0^o}^{90^o} I(\phi) sin\phi \, d\phi}$$

The angle ϕ is the angle between the basal pole and the reference direction, i. I(ϕ) is the diffracted x-ray intensity from the basal pole normalized by the diffracted intensity from a randomly oriented sample.

The calculated texture parameters for the three orthogonal tube directions (radial, circumferential, and axial) of qualification (Q) and comparative tubing lots (K/W) were summarized in Figure 3. The qualification and comparative lots commonly showed well developed radial texture.

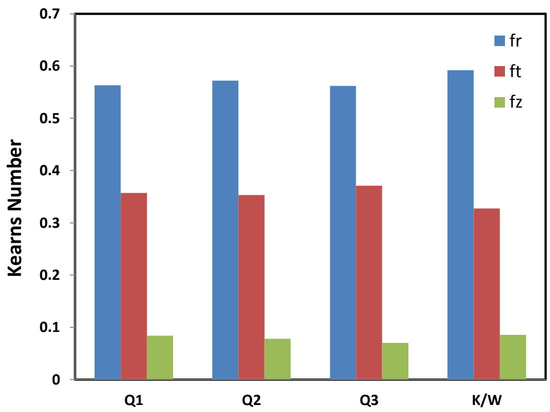

Fig. 3. Texture parameters for tubing lots.

3. Conclusions

As a part of qualification program to supply Zr cladding tube to WEC, the equivalency of Zr cladding tubes by KEPCO NF was demonstrated by comparing the characterization test results with those from comparative lots produced in 2008 by WEC and KNF. Based on the comparison, it can be concluded that the Zr alloy cladding tube properties are consistent with past products.

REFERENCES

[1] Y. K. Mok et al., Transactions of the Korea Nuclear Society Spring Meeting, Jeju, Korea, May 22, 2009.