Effects of Aging Treatment on Tensile Behavior in Zr-2.5%Nb Pressure Tube Material

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1. Introduction

The pressure tube made of the Zr-2.5% Nb alloy in CANDU reactor forms the primary pressure boundary with the feeder pipe [1]. The pressure tube contains nuclear fuel causing nuclear fission, and heavy water (D_2O) being a coolant and a moderator flow between the pressure tube and the fuel.

Although Zircaloy-2 alloy was initially used for the pressure tube of the heavy reactor, there was a rupture failure during operation due to high ingress rate of hydrogen generated during CANDU reactor operation [2]. On the other hand, the Zr-2.5% Nb alloy has been used as a pressure tube material with relatively high yield strength and low hydrogen absorption.

The change in material that appears when the material is held at the reactor operating temperature is generally referred to as an aging phenomenon. Until now, it was common to study the aging phenomena to confirm the change in strength or toughness according to the aging treatment. However, the material has increased entropy in the manufacturing process and a decrease in entropy during service operation in actual structures. In alloys this process is due to the attraction force between specific atoms. Then, the arrangement of atoms has been changed. Certain atoms are located around another specific atom. If its size is as small as 2 nm, it is called a short range order (SRO) because it does not form a super lattice [3, 4].

Aging in a reactor operating environment inevitably involves an SRO phenomenon. That is, the SRO phenomenon is at least one of the causes of the aging effect. However, to date, the nature of the aging phenomenon is not known to the SRO phenomenon. When the SRO phenomenon occurs during the Aging process, the distance between atoms gets closer, the lattice distance and the length of the structure is reduced. Surprisingly, the SRO phenomenon generates additional stress itself within the structure [5, 6, 7].

Therefore, this study aged a quadruple melt pressure tube material from 300-420**℃** up to 3,000H. The effect of aging on tensile behavior was examined and analyzed. In addition, the effects of strain rate and the effects of short range ordering (SRO) are discussed in detail.

2. Experimental

The pressure tube material used for this experiment was melted four times (quadruple melt), the chemical composition of this pressure tube is shown in Table 1.

To simulate the Aging effect, the material was aged in air at 300, 350, 400 and 420°C up to 3,000 hours, respectively. In order to analyze the effect of aging, the as-received specimens and the aging treated specimens were tested together.

The gage length of tensile specimen in tranverse direction is 16mm due to the limitation of pressure tube with 103mm inner diameter. Strain rate for tensile test is applied to be $1x10^{-6}$/s. Tensile test was carried out at 310±2°C, which is the outlet temperature of the pressure tube in CANDU reactor.

Table 1. Chemical composition of quadruple melt Zr-2.5%Nb (wt%).

elements	Zr	Nb	Fe	Ta	Cr	Ti	W	O	H
composition	Balance	2.6%	980 ppm	100 ppm	<100 ppm	<50 ppm	<50 ppm	1100 ppm	<3 ppm

3. Results and Discussions

Figure 1 compares the change in mechanical properties with aging treatment time at 350°C. Yield strength and tensile strength decreased by about 5% and about 2%, respectively, by aging up to 3,000 hours.

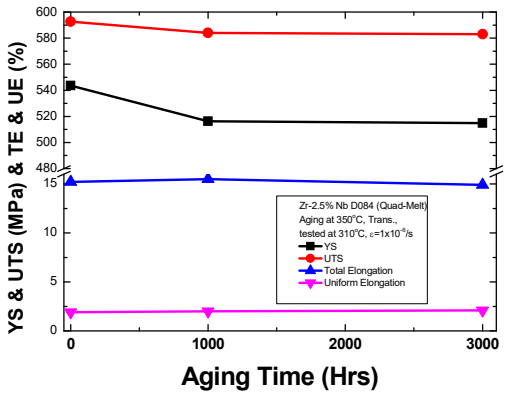

Fig. 1. Variation of mechanical properties at 310°C in Zr-2.5%Nb pressure tube material with aging at 350°C up to 3,000 hours.

Figure 2 shows the changes in the mechanical properties of the specimens aged at 400°C, depending on the aging time. Yield strength and tensile strength decreased about 7-9% with increasing aging time.

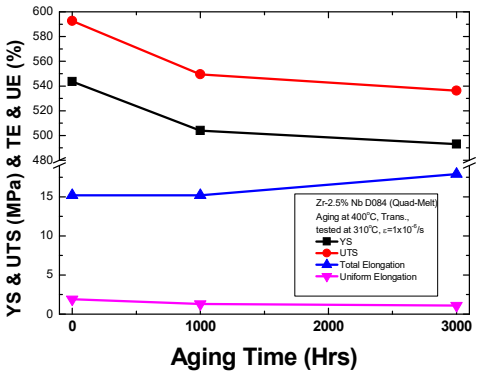

Fig. 2. Variation of mechanical properties at 310℃ in Zr-2.5%Nb pressure tube material with aging at 400℃ up to 3,000 hours.

Figure 3 shows the comparison of the mechanical properties with the treatment temperature in specimens aged at 420℃ for 3,000 hours. The yield strength and tensile strength decreased with increasing aging temperature.

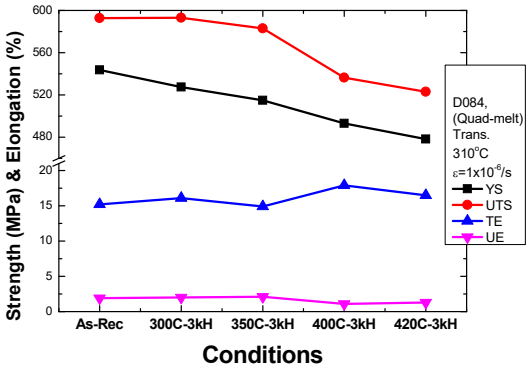

Fig. 3. Variation of mechanical properties at 310℃ in Zr-2.5%Nb pressure tube material with aging at 420℃ up to 3,000 hours

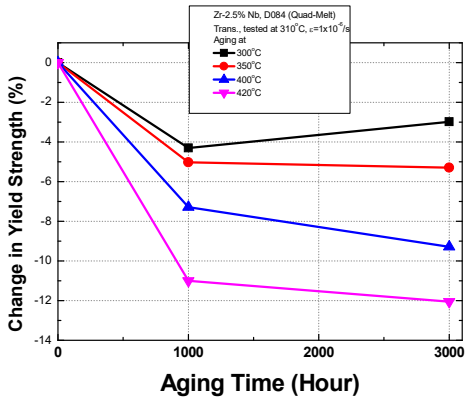

Fig. 4. Variation of yield strength at 310℃ in Zr-2.5%Nb pressure tube material with aging conditions up to 3,000 hours.

Figure 4 shows the comparison of the change in yield strength with aging treatment time at 300-420℃. The yield strength decreases by about 4-11% by aging treatment of 1,000 hours or more, and the decrease rate of yield strength does not change to be low significantly even when the aging treatment time increases to 3,000 hours.

Figure 5 shows the comparison of the change in tensile strength with aging treatment time at 300-420℃. The aging treatment at 300℃ and 350℃. showed little change in tensile strength and reduction rate within 2%. However, aging at 400℃ and 420℃ reduced 7-9% at 1,000 hours and 9-12% at 3,000 hours.

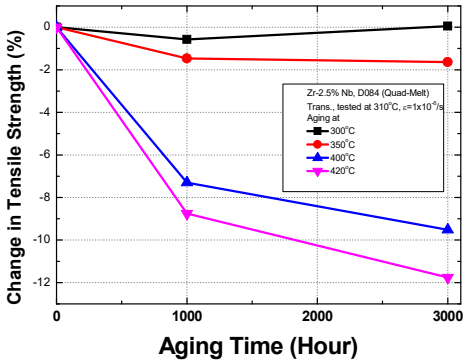

Fig. 5. Variation of tensile strength at 310℃ in Zr-2.5%Nb pressure tube material with aging conditions up to 3,000 hrs.

Yield strength shows a gradual decrease with increasing aging temperature, whereas tensile strength shows a big difference in the rate of change when aging below 350℃ and above 400℃. This study only analyzed the effect of thermal treatment on Zr-2.5% Nb alloy pressure tube. However, since the actual reactor pressure tube is used in a fast neutron irradiation environment, the irradiation effect by the fast neutron irradiation affects the rate of SRO reaction. Therefore, the aging effect in this study is not appropriate to be used directly for the evaluation of the properties of a operating pressure tube, but it is meaningful in terms of studying the aging effect of pressure tube materials in terms of the SRO phenomenon and understanding the nature of the aging phenomenon.

4. Conclusions

1. As-received and aged quadruple melt pressure tube materials show a drop in stress in the region below 50 MPa when tensile strained at a low strain rate of about $1x10^{-6}$/s at 310℃. The width becomes larger. This seems to be because the size or area on the SRO was enlarged by the aging treatment.
2. Evaluation of tensile properties for reactor components such as Zr-2.5% Nb pressure tubes should be evaluated at low strain rates of $1x10^{-6}$/s.
3. The yield and tensile strengths are reduced by 4-11%

and 0-12%, respectively, by 3,000 hours of aging at 300-420℃.

Acknowledgments

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