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Effects of Critical stresses on Hydride Reorientation and Mechanical Properties of Zirconium Alloy Claddings under Interim Dry Storage Conditions

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1. Introduction

As being closer to high burn up long period operation, the amount of hydrogen and corrosion increases. Compressive stress is applied when nuclear fuel is manufactured and it burns under the circumstance of 350 degrees and 150 atmospheric pressure, which make internal pressure approximately 60 atmospheric pressure at this point. After the burning task is completed at nuclear power plant, the nuclear fuel gets moved to fuel pit from nuclear reactor, and then it gets cooled underwater. Here, tensile strength, which has 2 atmosphere of external stress and 60 atmosphere of internal stress, is applied to a cladding. Wet storage method has a limited storage capacity because additional radioactive waste gets produced. Dry process storage is considered as a strong alternative to resolve such problems. In the dry storage method, we store nuclear fuel for more than 50 years under the condition of noble gas. At this process, tensile strength, which has 1 atmosphere of external stress and 60 atmosphere of internal stress, is applied to the cladding. Hydrogen concentration is known to be between 300~600 ppm according to burning condition inside a nuclear reactor. When tensile stress is applied to cladding in circumferential direction, making tensile stress bigger than 75~80, as cooling process of cladding progresses, hydride in circumferential direction gets rearranged to hydride in radial direction, causing fire. Also, it is reported on one hand that the temperature of cladding decreased by the rate of 100 degrees in 10 years when using dry storage; however, the rate of temperature decrease by storage time is expected to have a substantial difference, depending on the insulation design of storage container, spent fuel's degree of burn up, length of wet storage and temperature of cladding at an early phase of dry storage.

Therefore, the goal of this study is to find critical stresses for hydride rearrangement and the effect of following mechanical characteristics.

2. Experimental

2.1 Specimen Preparation

On this study, we used domestically manufactured Zr-Nb alloy for zirconium alloy cladding. The compositions, textures and specifications are shown in table 1. We processed the cladding with an external diameter of 9.5mm and thickness of 0.57mm into dog-bone shape by using wire as shown in Fig. 1. For hydrogen charging, we used vacuum heat treatment equipment. Then, we vacuum-sealed the cladding, fully charged with hydrogen, and we applied homogenization treatment by heat-treating it under 420^{o}C for 24 hours so that hydrogen can be evenly distributed in cladding matrix. We then analyzed the hydrogen concentration of as-received cladding and hydrogen-charged cladding by using LECO hydrogen analyzer. The concentration was found to be 250 for as-received and 50 for hydrogen-charged.

Table I: Chemical Compositions of Zr-Nb Alloy (wt %)

Nb	Sn	Cr	Fe	Zr
1.0	1.0	-	0.1	Bal.

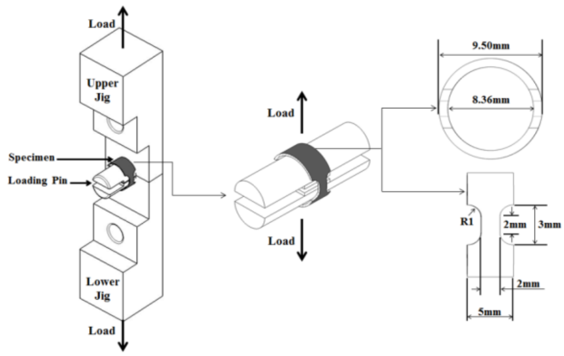

Fig.1. Zr Specimen size and jig

2.2 Experiment Procedure

We conducted an experiment to find critical stresses of hydride rearrangement, which was sealed in zirconium alloy cladding, under the stress of 80MPa, 85MPa, 90MPa by using creep tester (KLES 500-S). Fig. 2 is the graph of temperature related to the experimental process. After raising the temperature to

400^{o}C in 1^{o}C /min without applying stress in the early phase of heating, we had 2 hours of holding time for stabilization at 400^{o}C. We then cooled them to 200^{o}C with the rate of 2^{o}C/min, 8^{o}C/min in certain stress, and water quenched. In order to find mechanical strength following hydride rearrangement, we checked hydride rearrangement through OM from tensile test conducted at room temperature with the strain rate of 0.12mm/min.

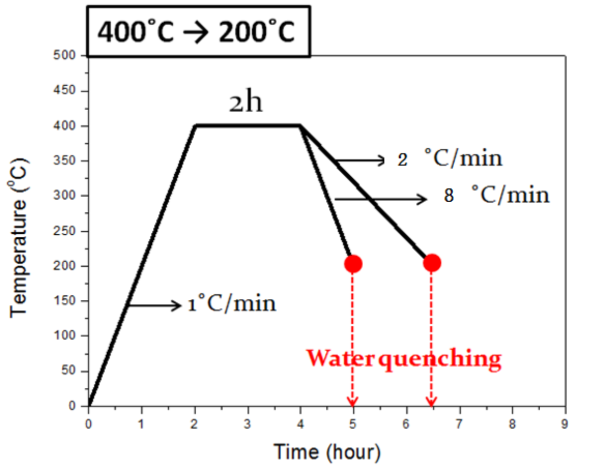

Fig.2. Graph of temperature related to the experimental process

3. Results and Discussion

Fig. 3-8 is the graph and OM picture from the result of tensile test conducted after the experiment to find at what critical stress, hydride sealed in zirconium alloy cladding gets rearranged. We could observe, when 2^{o}C/min, much hydride were rearranged at 85MPa regardless of cooling rate. The result of tensile test also shows that it is vulnerable at 85MPa. Furthermore, much hydride were rearranged at 90MPa regardless of cooling rate when 8^{o}C/min. The result of tensile test also shows that it is vulnerable at 90MPa. As the cooling rate lowered, the proportion and length of precipitated radial hydride increased. due to the speed of hydrogen expansion into basal plane in accordance with hysteresis of cooling rate during cooling period, tensile stress in circumferential direction and the number of the proportion of basal planes in radius direction and in circumferential direction.

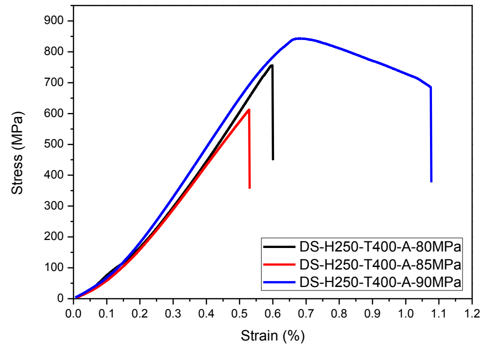

Fig.3. Stress-strain when hydrogen concentration is 250ppm with the cooling rate of 2^{o}C /min.

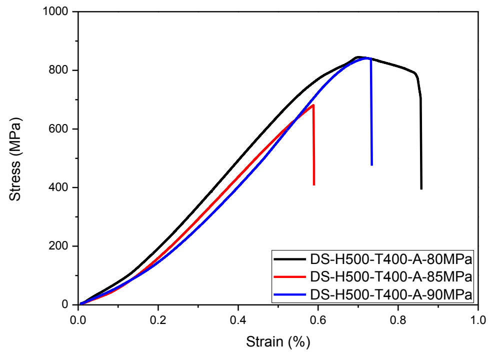

Fig.4. Stress-strain when hydrogen concentration is 500ppm with the cooling rate of 2^{o}C /min.

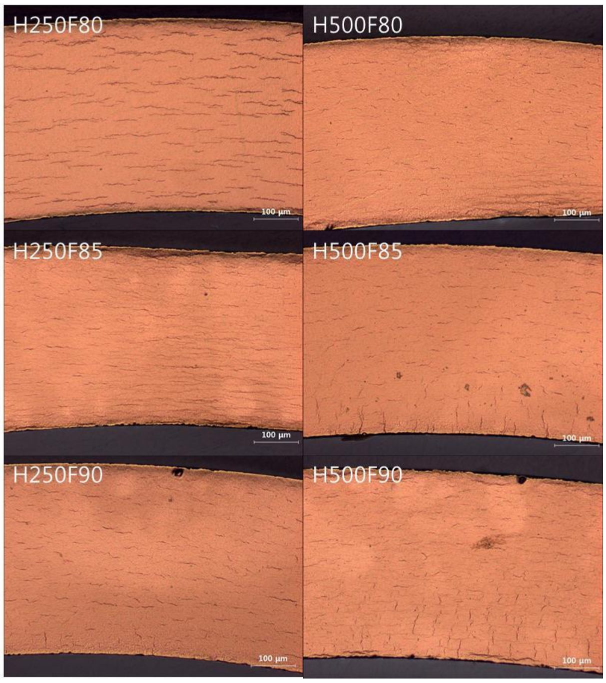

Fig.5. OM picture when hydrogen concentration is 250ppm and 500ppm with the cooling rate of 2^{o}C /min.

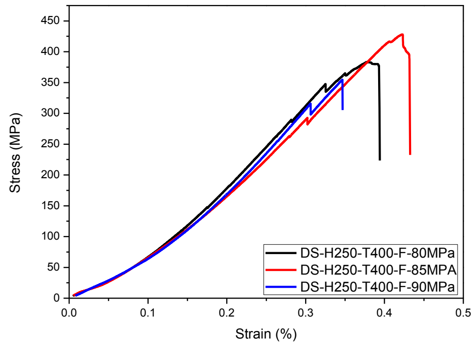

Fig.6. Stress-Strain when hydrogen concentration is 250ppm with the cooling rate of 8^{o}C /min.

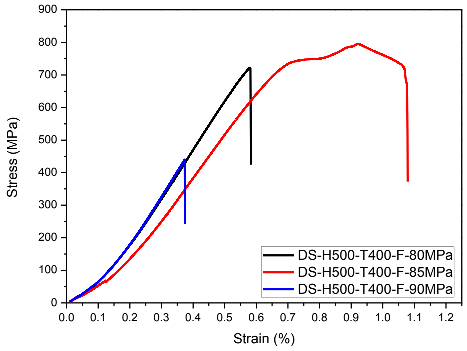

Fig.7. Stress-Strain when hydrogen concentration is 500ppm with the cooling rate of 8^{o}C /min.

Fig.8. OM picture when hydrogen concentration is 250ppm and 550ppm with the cooling rate of 8^{o}C /min.

3. Conclusions

We conducted an experiment to find critical stresses of hydride rearrangement, which was sealed in zirconium alloy cladding, under the stress of 80MPa, 85MPa, 90MPa and the hydrogen concentration of 250ppm, 660 ppm at the cooling rate of 2C/min and 8C/min by using creep tester. We could observe, when 2C/min, much hydride were rearranged at 85MPa regardless of cooling rate. The result of tensile test also shows that it is vulnerable at 85MPa. Furthermore, much hydride were rearranged at 90MPa regardless of cooling rate when 8C/min. The result of tensile test also shows that it is vulnerable at 90MPa. This means Critical stress is 85MPa for 250ppm-H and 90MPa for 550ppm-H. The result shows that, at similar temperature, as hydrogen concentration increases, ductility decreases, but tensile strength is similar.

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