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# The effect of temperature and cooling rate on hydride reorientations of high burnup claddings under interim dry conditions

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## 1. Introduction

Interim dry storage of spent nuclear fuel has been considered as an potion for increasing spent fuel storage capacity in South Korea. It is generally known that hydride reorientation from the circumferential to radial direction may reduce the critical stress intensity that accelerates radial crack propagation.[1-4] In this work, the integrity of high burnup spent fuel during the interim dry storage was investigated, simulating interim dry storage and high burnup fuel conditions and using unirradiated Zr-Nb alloy claddings. First of all, mechanical property degradations of the hydrogen-charged Zr-Nb alloy claddings were generated at various temperature conditions. Then, the effects of cooling rate under the tensile hoop stress of 150MPa on hydride reorientation were investigated. It is found that the mechanical properties of the Zr-Nb claddings are strongly related to temperature and cooling rate.

## 2. Methods and Results

### *2.1 Methods*

Stress-relief annealed Zr-Nb alloy claddings with an outside diameter of 9.5mm and a wall thickness of 0.58mm were employed. Its chemical composition is given in Table 1. Two cladding tubes, cut into 100mm length, were first uniformly hydrogen-charged by a mixed gas of 150torr $H_2$ and 200torr He at 400$^{o}$C. The target hydrogen levels ranged from 250 and 500 ppm. Typically hydrides were oriented in the circumferential direction and homogeneously distributed across the cross-section of the cladding specimens.

Table 1. Chemical composition of Zr-Nb alloy cladding (wt%)

| Nb | Sn | Fe | Zr |
|---|---|---|---|
| 1.0 | 1.0 | 0.1 | Balance |

The first mechanical tests were carried out for the 250ppm and 500ppm hydrogen-charged Zr-Nb alloy cladding specimens at temperatures of room temperature(RT), 200 $^{o}$C, 300 $^{o}$C and 400$^{o}$C at a strain rate of 0.12mm/min to examine the effect of temperature and hydrogen content on the cladding mechanical properties. The specimens were heated at a heating rate of 1$^{o}$C/min with no stress applied. The second mechanical tests, as shown in Fig.1, were done for the hydrogen-charged specimens of 250 and 500ppm at RT, 200$^{o}$C, 300 $^{o}$C after holding for 2hrs at 400$^{o}$C under a tensile hoop stress of 150MPa and then cooling at RT, 200$^{o}$C, 300$^{o}$C at a cooling rate of 2$^{o}$C/min(SC), 7 $^{o}$C/min(AC) maintaining the same hoop stress to evaluate the effect of hydrogen content on the amount and morphology of radial hydride formed during the cooling and subsequently on the mechanical property degradation.

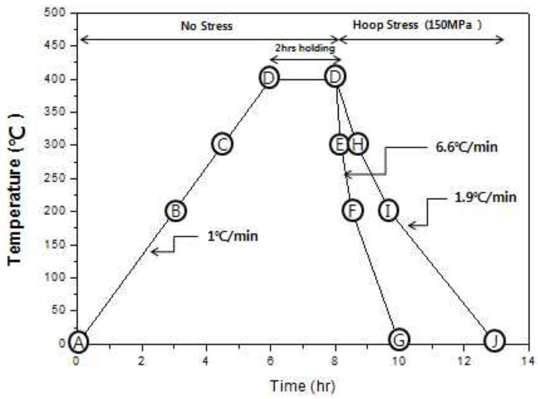


Fig 1.Temperature and Hoop Stress histories for ring specimen cooling tests.

### *2.2 Results*

The first mechanical tests were carried out for the 250ppm and 500ppm hydrogen-charged Zr-Nb alloy cladding specimens at temperatures of RT, 200, 300 and 400$^{o}$C. The test results are shown in Fig.2 and Fig.3

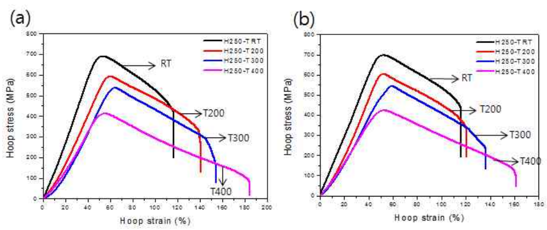


Fig 2. Temperature-dependent Hoop stress-strain curves of 250ppm-H(a) and 500ppm-H(b) Zr-Nb claddings.

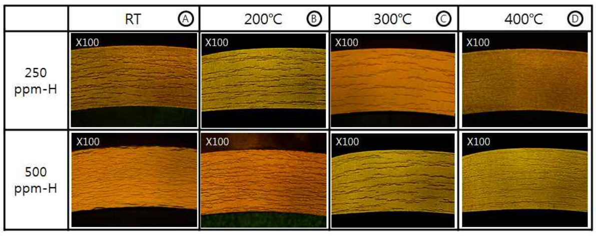


Fig 3. Temperature-dependent microstructure of 250ppm-H and 500ppm-H Zr-Nb claddings

The second mechanical tests were done for the hydrogen-charged specimens of 250, 500ppm at RT, 200°C, 300 °C after holding for 2hrs at 400°C under a tensile hoop stress of 150MPa and cooling rate of 2°C/min(SC),7°C/min(AC) maintaining the same hoop stress in order to evaluate the effect of hydrogen content on the amount and morphology of radial hydride formed during the cooling and subsequently on the mechanical property degradation. The test results are shown in Figs. 4 and Figs. 5

From this figure, it can be seen that effect of cooling temperature on the ultimate tensile strengths and strain is considerable. It was reported that hoop strain will decrease as cooling temperature in the cladding decrease. However, the hoop strain of the 250ppm hydrogen-charged specimens are a little less than those of the 500ppm-H specimens during the cooling.

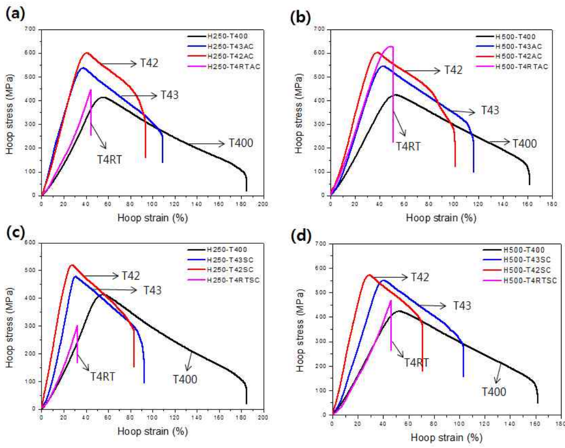


Fig 4. Cooling Temperature-dependent Hoop stress-strain curves of 250ppm-H and 500ppm-H Zr-Nb claddings. (a) H250-AC , (b) H500-AC, (c) H250-SC, (d) H500-SC

This can be explained by the morphologies of the specimens, as shown in Fig. 5. This figure indicates that the fraction of the radial hydrides is largest for the 250ppm specimen during the cooling from 400 to RT. It is noteworthy that the larger fraction and length of the radial hydrides may generate the more brittle cladding materials. Therefore, the 250ppm specimen generated the least elongation. Also, hydride reorientation rate(RR) was calculated using Eq. (1)

$$RR(\%) = \frac{radial}{circumferential + radial} \times 100 \quad (1)$$

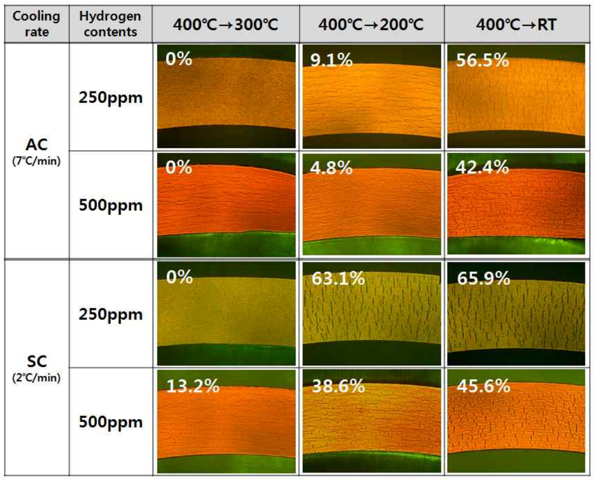


Fig 5. Cooling Temperature-dependent microstructure of 250ppm-H and 500ppm-H Zr-Nb claddings and hydride reorientation rate(RR).

## 3. Conclusions

- When comparing the results before and after cooling, the ductility of cladding after cooling decreased further rather than cladding before cooling. Because circumferential direction hydrides at 150MPa was reoriented in to radial direction hydrides and acted as an crack creation and growth site.
- As cooling rate was slower, the length of hydride was relatively longer and bigger reorientation rate. Because cooling rate is slower, the time for precipitation was sufficient for radial direction hydride to act as a nuclear creation site.
- After cooling test, the length of radial hydride in the 250ppm-H cladding was relatively longer than 500ppm-H cladding, and reorientation rate was higher. The reason is estimated that circumferential hydrides undissolved at 500ppm interrupted the growth of radial hydrides and circumferential hydride acted as a nucleation site.

## REFERENCES

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