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Compatibility Behavior of the Ferritic-Martensitic Steel Cladding under the Liquid Sodium Environment

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1. Introduction

Fuel cladding is a component which confines uranium fuel to transport energy into the coolant as well as protect radioactive species from releasing outside. Sodium-cooled Fast Reactor (SFR) has been considered as one of the most probable next generation reactors in Korea because it can maximize uranium resource as well as reduce the amount of PWR spent fuel in conjunction with pyroprocessing. Sodium has been selected as the coolant of the SFR because of its superior fast neutron efficiency as well as thermal conductivity, which enables high power core design. However, it is reported that the fuel cladding materials like austenitic and ferritic stainless steel react sodium coolant so that the loss of the thickness, intergranular attack, and carburization or decarburization process may happen to induce the change of the mechanical property of the cladding [1].

This study aimed to evaluate material property of the cladding material under the liquid sodium environment. Ferritic-martensitic steel (FMS) coupon and cladding tube were exposed at the flowing sodium then the microstructural and mechanical property were evaluated. mechanical property of the cladding was evaluated using the ring tension test.

2. Experimental Procedure

2.1. Sodium-material compatibility facility

To assess the sodium-material compatibility behavior, quasi-dynamic device characterized by natural convection has been designed and installed. Fig. 1 shows the schematic illustration of the sodium-material compatibility facility. It consists of sodium storage tank, test loop, sodium expansion tank, electro-magnetic flowmeter, and glove box. Seven furnaces were independently installed around the test loop so that they can induce natural convection caused by the temperature difference. Vanadium Wire Equilibrium Technique (VWET) as well as hot trap by the zirconium foil used as the measurement and control of the dissolved oxygen content inside the sodium. Detailed specification of the facility is shown at the previous paper [2].

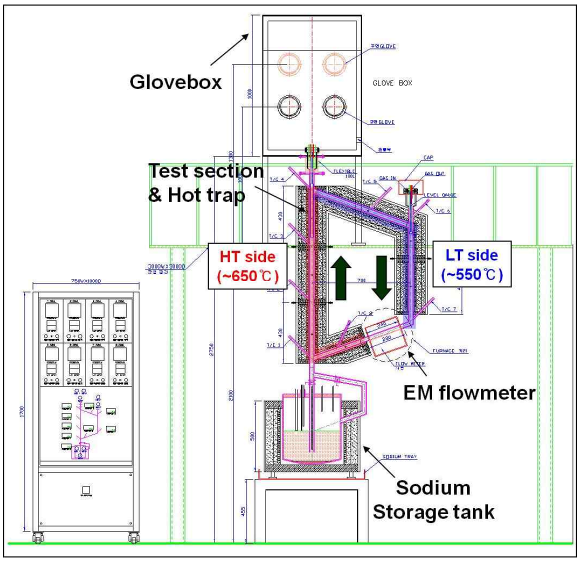

Fig. 1 Schematic illustration of the sodium-material compatibility facility

2.2. Material compatibility test

Compatibility behavior of the FMS coupon (ASTM A182 Gr.92 steel) under the flowing sodium has been performed at the 650^{o}C for 2333 hours. Oxygen content by VWET was measured as 18ppm. After the test, weight change of the specimen was measured after rinsing and ultrasonic treatment. Microstructural evaluation by optical microscopy, scanning electron microscopy (SEM) and nanoindentation has been performed at the tested specimen.

Besides coupon test, compatibility behavior of the FMS cladding tube (ASTM A182 Gr.92 tube, OD 7mm) was performed at the 650^{o}C liquid sodium up to 3095 hours. Oxygen content of the liquid sodium maintained 20ppm during the first 1583 hours. However, oxygen ingressed inside the system after 1583 hours so that oxygen content inside the liquid sodium abruptly increased and reached saturated value at the end of the test. After the test, specimen was cut across the diameter then the ring tension specimen was machined with the 1.84mm gage length and the 1.25mm width. Test was performed in the room temperature at the rate of 0.001/sec. To avoid data scattering due to its small size, identical tests ran at the three times with the same condition, then the each mechanical properties like yield stress (YS), ultimate tensile stress (UTS) and elongation was averaged. To exclude the sodium effect, cladding sample was aged in the vacuum environment at the same temperature up to 2973 hours then the ring tension test at the same condition was performed.

3. Result and Discussion

3.1. Compatibility result of the clad material

Fig. 2 shows the microstructure and the associated analysis of the Gr.92 coupon after the liquid sodium exposure at 650°C for 2333 hours. Weight loss occurred at the rate of 6.7μm/yr, which is comparable from the other study [3]. While the element distribution did not vary across the specimen thickness, decarburization which is characterized by the slight decrease of nanohardness and its associated micropits occurred to the subsurface. Size of the decarburization zone ranged at 41.7μm.

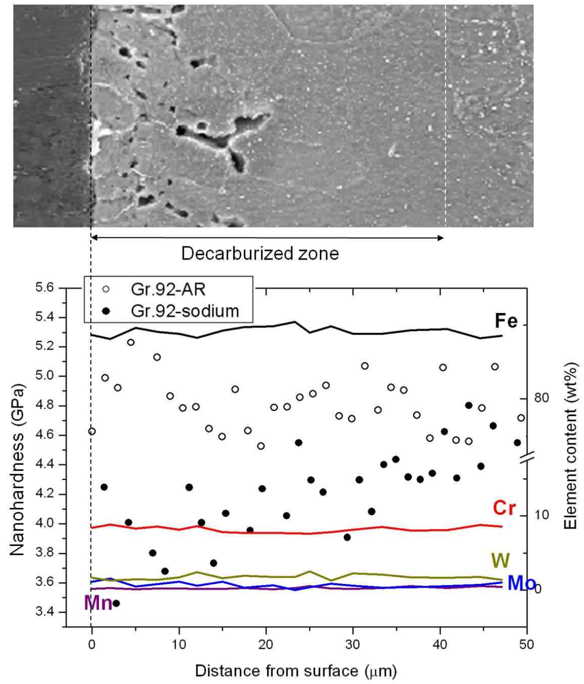

Fig. 2 Element content and nanohardness profile of the Gr.92 coupon after exposure of liquid sodium at 650°C for 2333 hours.

3.2. Mechanical behavior of cladding tube

Fig. 3 shows the change of the mechanical property of the Gr.92 cladding tube with the test time. YS as well as UTS rapidly dropped then showed slight decrease with the aging time, where the similar trends showed in the specimen exposed at the sodium environment. Elongation of the aged specimen showed slight increase in 765 hours exposure then it dropped to the original value. In sodium reacted specimen, elongation steadily increased as the test time elapsed. Further study regarding microstructural analysis which supports the ring tension test result is under progress.

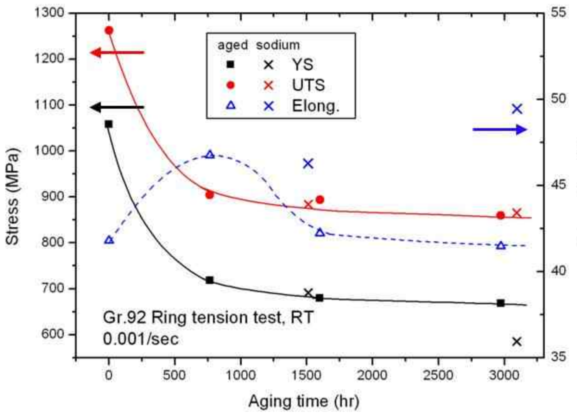

Fig. 3 Change of the mechanical property of the cladding with the test time

4. Conclusion

This paper described the compatibility behavior of the FMS steel in the liquid sodium environment. FMS coupon as well as cladding tube was exposed at the flowing sodium at 650°C, then the microstructural analysis and mechanical property were evaluated. Although weight loss as well as decarburization took place, its effect was negligible when compared to the thermal aging process.

Acknowledgement

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REFERENCES

[1] W. F. Brehem, Materials compatibility in liquid sodium, HEDL-SA-1559, 1978.
[2] J. H. Kim, J. M. Kim, J. E. Cha, S. H. Kim and C. B. Lee, Compatibility Study between 316-series Stainless Steel and Sodium Coolant, Korean Journal of Metals and Materials, Vol. 48, No. 5, pp. 410, 2010.
[3] T. Suzuki and I. Mutoh, Compatibility of high-purity Fe-(5 to 15)Cr-1Mo Ferritic Steels in a Sodium Environment, Journal of Nuclear Materials, Vol. 149, pp. 41, 1987.