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Compatibility Behavior of Austenitic Stainless Steel under Flowing Sodium Environment

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1. Introduction

Sodium-cooled Fast Reactor (abbreviated as SFR) has been considered as one of the most probable next generation reactors in Korea because it can maximize uranium utilization as well as reduce PWR spent fuel in conjunction with pyroprocessing. Sodium has been selected as the coolant of the SFR on account of the superior fast neutron efficiency as well as thermal conductivity, which enable high power core design. However, lots of previous research reported that fuel cladding materials like austenitic and ferritic stainless steel react sodium coolant so that it results in the loss of the thickness, intergranular attack, and carburization or decarburization process to induce the change of the mechanical property of the cladding [1]. Thus it is necessary to evaluate technology regarding sodium-material compatibility since sufficient mechanical property should be assured at the domestic cladding which will be fabricated in the near future.

The objective in this study is to set up the compatibility technology between material-sodium and evaluate the material property under the flowing sodium environment. Quasi-dynamic device revealed to be effective from the previous study [2] that natural convection facility has been designed, constructed, and compatibility behavior of the austenitic stainless steel has been measured and analyzed.

2. Experimental Procedure

2.1. Specimen preparation

Commercial 316 stainless steel (16Cr-11Ni-0.05C-etc.) has been used as the test material. It treated solution annealing at 1100^{o}C for 45 minute, followed by the water quenching.

2.2. Compatibility test equipment

To assess the sodium-material compatibility behavior, quasi-dynamic device characterized by natural convection has been designed and installed. Fig. 1 shows the construction of the sodium-material compatibility facility. Facility consists of sodium storage tank, test loop, sodium expansion tank, electro-magnetic flowmeter, and glove box. 7-independent furnace was installed around the test loop so that it can induce natural convection caused by the temperature difference. 316L stainless steel (16Cr-11Ni-0.02C-etc.) was used as the material of the test loop. Diameter and the head of the loop were respectively 25.4mm and 1.2m. Previous thermal-hydraulic analysis of the loop [3] revealed that velocity of the liquid sodium could be possible up to 0.25m/sec provided that the temperature difference was maintained up to 100^{o}C.

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, which greatly affects sodium-material compatibility behavior.

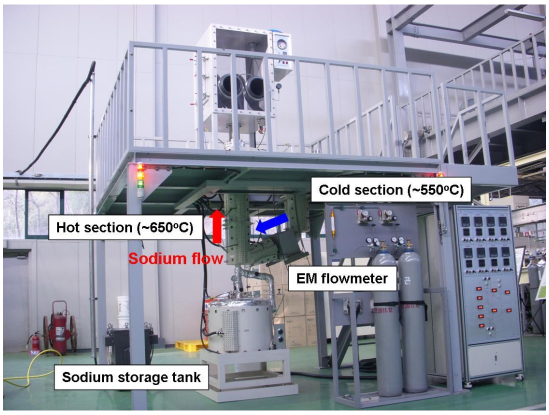


Fig. 1 Construction of the sodium-material compatibility facility

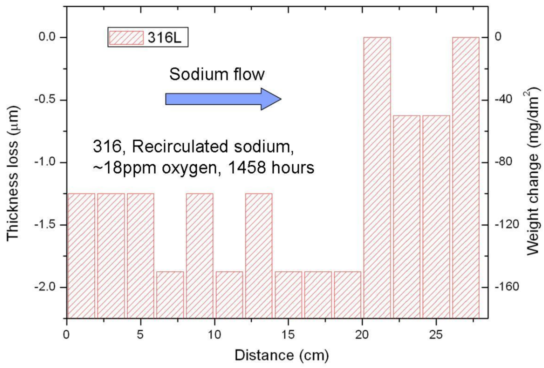
2.3. Sodium-material compatibility test

Compatibility behavior of the austenitic steel under the flowing sodium has been evaluated at the 650^{o}C for 1458 hours. Oxygen content by VWET was measured as 18ppm. Temperature difference during the test period was 70^{o}C so that sodium flow was estimated as 0.2m/sec. Specimens were machined as 13mm x 20mm x 3mm then they were immersed at the top of the test loop for the given testing period. 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.

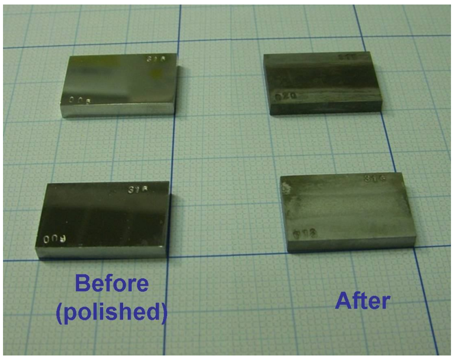
3. Results and Discussion

3.1. Compatibility test result

Fig. 2 shows the compatibility test result of the austenitic stainless steel immersed at 650°C sodium containing 18ppm oxygen for 1458 hours. Weight loss occurred throughout the specimen which indicated that corrosion process took place at the surface of the specimen. Downstream effect where weight loss decreased along the test section was also observed.



(a)



(b)

Fig. 2 Compatibility test result of the austenitic stainless steel under the flowing sodium environment. (a) Weight change, (b) Visual appearance

3.2. Microstructural evaluation

Fig. 3 shows the Cr content measured by Energy Dispersive Spectra (EDS) and the nanohardness value of the tested specimen with different depth. Cr content maintained near a nominal value at the 25 ㎛ depth beneath the surface. However, Cr content decreased to the 15.1% at the surface, indicating that Cr dissolution has taken place during sodium immersion. Nanohardness decreased at the surface when compared to the value at the 25 ㎛ beneath the surface. Decaburization occurred during sodium immersion by the difference of the dissolved carbon content between the liquid sodium and the specimen, which resulted in the decrease of the nanohardness.

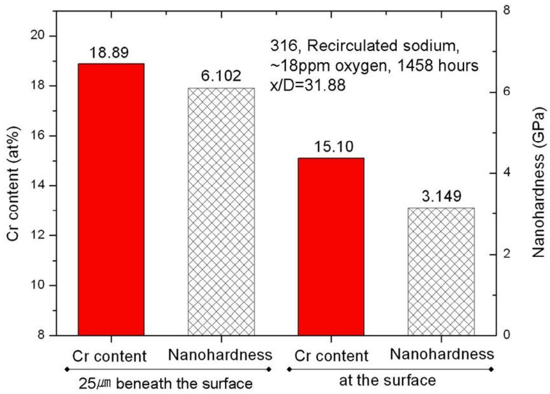


Fig. 3 EDS and nanohardness result of the specimen after compatibility test at 650°C for 1458 hours

4. Conclusions

Study has been carried out to set up the technology regarding sodium-material compatibility. Quasi-dynamic device characterized by thermal convection was designed, constructed, and successively operated. Preliminary experiment on the austenitic stainless steel revealed that weight loss phenomenon by the selective dissolution of Cr as well as decarburization process occurred under the liquid sodium environment.

Acknowledgement

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