Feasibility Study on the Sodium Compatibility Test for Fuel Cladding of SFR

Jun Hwan Kim[a*], Sang Hun Shin[a], Sang Gyu Park[a], Woo Seog Ryu[a], Sung Ho Kim[a],
[a]*Advanced Fuel Development Division, Korea Atomic Energy Research Institute, Daejeon, 305-353, Republic of Korea*
**Corresponding author: junhkim@kaeri.re.kr*

1. Introduction

A Sodium-cooled Fast Reactor (SFR), a reactor that uses fast neutrons as a fission process, is considered one of the most probable candidates in next-generation reactors because it can maximize the uranium utilization when compared to conventional water reactor. Liquid sodium is used as a coolant in a SFR, because it has superior efficiency of fast neutron economy and high thermal conductivity, which enables a high power core design. However, previous research reported that fuel cladding materials like austenitic and ferritic-martensitic steel (FMS) 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 [1].

Fuel cladding, a seamless tube which has approximately 0.5mm in thickness and 3m in length is the component which covers fuel to protect radioactive species from being released. Because of its smaller thickness, the mechanical properties of the cladding are easily affected by the small changes of material property. Previous study revealed that FMS cladding, which has relatively smaller thickness (0.44mm) is likely to suffer the decrease in the mechanical property under a long time exposure to the 650^{o}C liquids sodium mainly by the decarburization process, whereas duct, which has relatively larger thickness (3.09mm), reduces in the mechanical property owing to the thermal aging process [2].

Thus, it is necessary to investigate the mechanical property of the fuel cladding under the long-term liquid sodium exposure. The objective in this study is to describe the status of sodium-material compatibility facility and propose the optimal option in the case of the SFR fuel cladding.

2. Technical Status

Sodium-material compatibility test has been conducted over HT9 and Gr.92 steel since 1960's for securing necessary database to construct LMFBR in United States. Argonne National Laboratory (ANL) has constructed sodium loop (ALEX) to evaluate the integrity of the component and the material property, whose operating temperature was below 550^{o}C. ANL has performed the corrosion test of FMS coupon and tensile, creep, fatigue, and creep-fatigue tests over the specimen during and after exposure to sodium [3,4].

CEA has conducted sodium compatibility study of 9Cr steel and ODS, where laboratory-scale loop (CORRONA) has been installed since 2009 [5]. Rotating-type electrode has been applied in the loop in order to investigate the effect of hydraulic parameter. Parameters of the facility were 500~625^{o}C in temperature and 0.7~38ppm oxygen contents.

Material compatibility test under liquid sodium has been extensively studied by FZK (former form of Karlsruhe Institute of Technology) since 1980 [6], where it has now been converted into liquid lead-bismuth facility for MYRRHA project.

Japan Atomic Energy Agency (JAEA) has operated thermal-hydraulic loop for liquid sodium (PRANDTL, CCTL) and creep-fatigue property of structural material under steady state and thermal transient condition. JAEA performed long-term creep-rupture life of PNC-FMS cladding under the liquid sodium by pressurized tube specimen, which revealed that significant reduction of life, which results from the decarburization on the cladding surface has observed in 650^{o}C sodium even above 1000 hours [7].

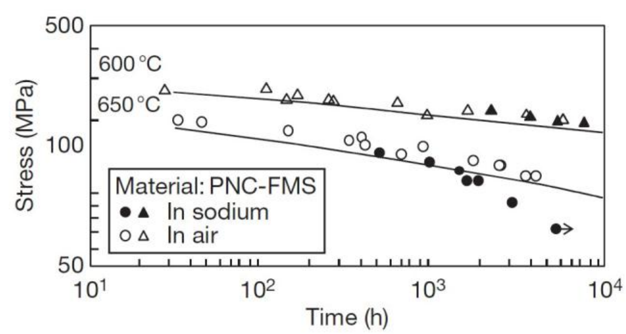

Fig. 1 Creep-rupture property of PNC-FMS cladding tube under liquid sodium environment [7]

IGCAR has operated liquid sodium test loop (INSOT) for verifying PFBR component and testing material property which performs creep, low-cycle fatigue, and creep-fatigue interaction, whose operating temperature ranged between 550~600^{o}C [8].

CIAE has constructed material test loop for establishing database used for the construction of Chinese Experimental Fast Reactor (CEFR) [9]. Corrosion test loop having test temperature 600°C at a maximum as well as test loop for mechanical test which performs creep-fatigue interaction and tube creep has been operated since 1980's.

KAERI has experienced sodium compatibility study on the cladding materials as a preliminary stage [10]. Quasi-dynamic loop caused by natural convection has been constructed. Corrosion test over FMS coupon and mechanical property test over Gr.92 cladding tube [11] have been performed at 650°C liquid sodium environment.

3. Feasibility Analysis

As described at the previous section, migration of dissolved carbon in the cladding plays a great role in the mechanical property of fuel cladding. Because such migration phenomena greatly depends on the solubility, which is influenced by the temperature and flow rate, testing loop which enables sodium flow and purifies dissolved impurity (e.g., dissolved oxygen and carbon) is needed. From the previous study, modified 9Cr-1Mo steel is expected to undergo decarburization behavior under EBR-II sodium chemistry containing 0.16~0.28 ppm of dissolved carbon at above 620~650°C [12]. This indicates that most of the FMS cladding is expected to behave decarburization in PGSFR environment, leads to the decrease in mechanical strength under the long-term exposure.

Since creep (both thermal and irradiation) acts as one of the most important parameters in the performance of the cladding, it is desirable for the sodium-cladding compatibility test to perform pressurized creep test under the controlled sodium environment. From this standpoint, liquid sodium loop for material testing has been designed conceptually. Manufacturing technology for pressurizing creep specimen is underway and is going to be finalized at the end of 2015.

4. Conclusion

This paper summarizes the status of sodium-material compatibility facility and proposes the optimal option in the case of the SFR fuel cladding. Previous researches revealed that assessing in-situ mechanical property is important in the case of cladding material owing to its dimensional characteristic. Optimal test method for assessing sodium compatibility of the cladding tube can be proposed that pressurized creep test under the controlled liquid sodium environment is desirable to evaluate the long-term life of the fuel cladding more actually.

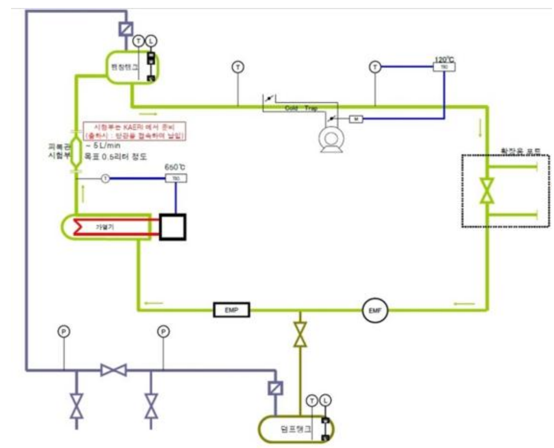

Fig. 2 Conceptual design of liquid sodium loop for material testing.

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