Development of Preliminary HT9 Cladding Tube for Sodium-cooled Fast Reactor (SFR)

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1. Introduction

Sodium-cooled Fast Reactor (abbreviated as SFR) is considered as one of the most probable candidates in the next generation reactor because it enables to recycle the spent fuel from the conventional light water reactor [1]. Because of its superior dimensional stability against fast neutron irradiation, ferritic-martensitic steel (FMS) has preferred to the SFR fuel cladding in Korea, where prototype SFR is going to be built in 2028. To achieve manufacturing technology of the fuel cladding tube in order to keep pace with the predetermined schedule in developing SFR fuel, KAERI has launched in developing fuel cladding tube in cooperation with a domestic steelmaking company. After fabricating medium-sized 1.1 ton HT9 ingot, followed by the multiple processes of hot and cold working, preliminary samples of HT9 seamless cladding tube having 7.4mm in outer diameter, 0.56mm in thickness, and 3m in length were fabricated. The objective of this study is to summarize the brief development status of the HT9 cladding tubes. Mechanical properties like axial tension, biaxial burst, pressurized creep and sodium compatibility of the cladding tubes were carried out to set up the performance evaluation technology to test the prototype FMS cladding tube which is going to be manufactured in next stage.

2. Development of HT9 cladding tube

2.1. Manufacture of HT9 mother tube

Table 1 showed the chemical composition of the HT9 cladding tube. Material was manufactured as a 1.1 ton scale ingot using vacuum induction melting by POSCO Specialty Steel Ltd. Ingot was fabricated into the mother tube having 19.05mm in outer diameter, 1.24mm in thickness, and 6m in length followed by the hot forging, making hollow billet, hot extrusion, cold pilgering and subsequent heat treatment.

2.2. Manufacture of HT9 cladding tube

Manufactured mother tubes were moved at Iljin Steel Corp. and they were made into the final form of seamless tubes having 7.4mm in outer diameter, 0.56mm in thickness, and 3m in length by the multiple processes of cold drawing and heat treatment. Cladding was finally heat-treated in 1038°C for 5 minutes as a normalizing and 760°C for 30 minutes as a tempering process.

Table 1 Chemical composition of HT9 cladding tube

element	C	Mn	Si	Cu	Ni	Cr	Mo	W	Al	Nb	V	P	S
HT9	0.18	0.59	0.25	-	0.59	11.99	1.00	0.54	0.01	0.008	0.30	0.005	0.003

Fig. 1 Fabrication of preliminary HT9 cladding tube

3. Performance evaluation

3.1. Microstructure

Dimensional parameters of the fabricated HT9 cladding tube like inner and outer diameter, ovality, straightness and roughness were fitted quite well in the range of conventional LWR cladding. Microstructure of the HT9 cladding tube showed a typical tempered martensite structure where approximately 2% of the delta ferrite contained inside the matrix measured by the image analysis. Cr and Ni equivalents were respectively 13.38 and 6.36, which contains approximately 2~3% of delta ferrite according to the Schaeffler diagram [2]. Fine $M_{23}C_6$ type carbides were uniformly dispersed along the martensite lath boundary.

3.2. Mechanical property

In order to evaluate the performance of the manufactured HT9 cladding tube, various kinds of mechanical test were carried out, like tension, burst, creep, and sodium compatibility test. Tension test was carried out in accordance with the ASTM E8 specification from room temperature to 700°C. Biaxial burst test was performed in accordance with the ASTM E764, E453 and B353 specifications, where the test was conducted from the room temperature to 650°C. Pressurized creep test of the HT9 tube was also performed. End of the cladding tube was sealed by the welding and the argon gas was injected to the desired pressure after the tube reached the temperature of 650°C.

Fig. 3 showed the uniaxial tensile property of the HT9 cladding with the test temperature. Trends of the tensile property showed a good accordance to the previous published data [3]. Fracture appearance of the cladding tube showed that typical ductile cup and cone fracture dominated at all temperature, as shown in Figure 5. Biaxial burst property of the HT9 cladding tube also showed a similar manner to the uniaxial tensile data.

Fig. 4 shows the stress-rupture diagram of the HT9 cladding tube tested at 650°C air environment. From the result, linear relationship was drawn under the log-log coordinate, where the comparison with the other results revealed the similar trend [4]. Sodium compatibility test of the HT9 coupon showed that local decarburization process takes place during the test, where the wall thinning caused by the liquid sodium was negligible.

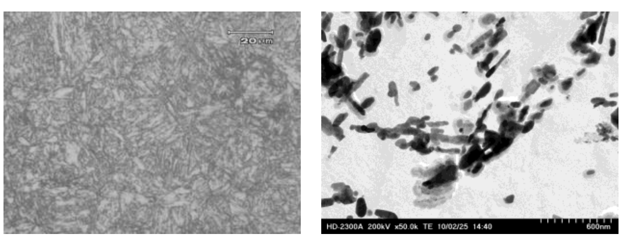

Fig. 2 Optical (left) and transmission electron microscope (right) of HT9 cladding tube

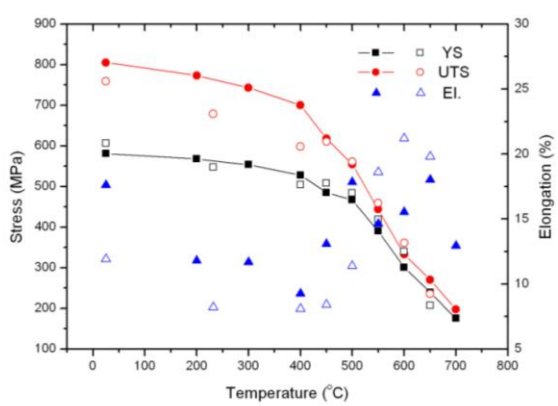

Fig. 3 Uniaxial tensile property of the HT9 cladding tube with the temperature. Open symbols represent previous published data [3].

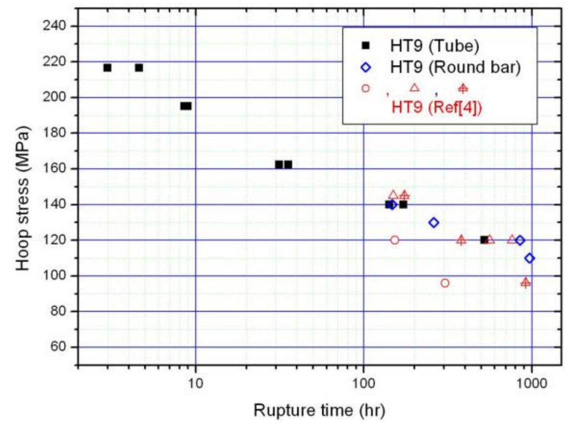

Fig. 4 Creep-rupture test result of HT9 cladding tube.

4. Conclusion

As a part of developing fuel cladding for the Sodium-cooled Fast Reactor (SFR), preliminary HT9 cladding tube was fabricated in cooperation with a domestic steelmaking company. Microstructure as well as mechanical tests like axial tensile test, biaxial burst test, and pressurized creep test of the fuel cladding were carried out. Performance of the domestic HT9 tube was revealed to be similar in the previously fabricated foreign HT9 tube. Further prototype FMS cladding tube is going to be manufactured in next year based on this experience. Various test items like mechanical test, sodium compatibility test, microstructural analysis, basic property, cladding performance under transient situation, and performance under ion and neutron irradiation are going be performed in the future to set up the relevant technology for the licensing of the SFR cladding tube.

Acknowledgement

This project has been carried out under the Nuclear R&D program by SFR development Agency (SFRA)

REFERENCES

[1] Y. I. Chang, Technical Rationale for Metal Fuel in Fast Reactor, Nuclear Engineering and Technology, Vol. 39, No. 3, pp. 161, 2007.
[2] F. B. Pickering, Microstructural Development and Stability in High Chromium Ferritic Power Plant Steels, pp.4, The Institute of Materials, 1997.
[3] T. Lauritzen, W. L. Bell and S. Vaidyanathan, Topical Conference on Ferritic Alloys for Use in Nuclear Energy Technologies, June 19-23, Snowbird, Utah, TMS, pp. 623, 1983.
[4] D. S. Gelles, M, L. Hamilton and G. D. Johnson, European Patent, 0287710A2, 1988.