Corrosion and Mechanical Properties of HANA-4 Inner Strip

Myung Ho Lee[*a], Yang Il Jung[a], Jun Hwan Kim[a], Sang Yoon Park[a], Byoung Kwon Choi[a], Jeong Yong Park[a], Yong Hwan Jeong[a], Kyong Bo Eom[b], Nam Gyu Park[b]

[a]*Fusion Technology Development Div., KAERI, P.O.Box 105, Yuseong, Daejon, 305-353, Korea*
[b]*Nuclear Fuel Development Team, R & D Center, KNF, 493, Deokjin-dong, Yuseong, Daejon, 305-353, Korea*
[*]*Corresponding author: mhlee2@kaeri.re.kr*

1. Introduction

Since 1997 KAERI (Korea Atomic Energy Research Institute) has carried out a program for the development of some advanced Zr-based new alloys, called HANA (High performance Alloy for Nuclear Application) alloys, for an extended burn-up fuel cladding. After manufacturing different kinds of claddings with HANA alloys on the basis of extensive researches, the claddings were subjected to a variety of out-of-pile tests including corrosion, creep and LOCA tests as well as in-pile tests in the Halden research reactor [1,2]. The HANA cladding tubes showed a good performance for their corrosion resistance, creep and LOCA properties, especially for their corrosion resistance at an irradiation test up to 32MWD/kgU in the Halden test reactor [2]. The verification test of the in-pile performance of the HANA cladding tubes in a commercial reactor was also started in November of 2007. KAERI in collaboration with KNF (Korea Nuclear Fuel) undertook a research for the applicability of HANA alloys to the spacer grid for a PWR (Pressurized Water Reactor) nuclear fuel in 2007. As a part of the research, KAERI tested the mechanical and corrosion properties of a HANA-6 strip [3]. The effect of the final heat treatment on the properties of the HANA-4 strip was studied in this work to extend the research on the HANA-4 strip.

2. Methods and Results

The chemical composition of the specimens for this study was Zr-1.47Nb-0.38Sn-0.20Fe-0.11Cr-0.12O with some impurities such as 98ppm Si, 21ppm H, 10ppm N. The HANA-4 inner strip specimens were specially manufactured in accordance with the applicable requirements. The ZA inner strip specimens for the reference test were equivalent to a commercial grade. All the tests and available observations were done on the specimens which had a nominal thickness of 0.46mm. The tensile tests on the specimens were carried out at room temperature in accordance with the ASTM E8 and E352. The strain rate was 0.005mm/mm/min. through a 0.2 % offset yield stress and 0.05mm/mm/min after a yield stress. The corrosion behaviors of the specimens were investigated in a 400^{o}C steam environment in a manner consistent with the ASTM G2.

2.1 Tensile properties

The tensile tests were carried out on the specimens in both the rolling and the transverse directions after they had been finally heat-treated from 580℃ to 700℃ for 10minutes, respectively. Figure 1 shows the effect of the final heat treatment on the mechanical properties.

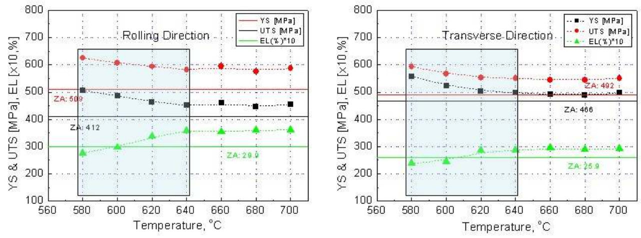

Fig.1. Effect of final heat treatment on the mechanical properties of HANA-4 strip

The YS of the HANA-4 strip is higher in the transverse direction than that in the rolling direction while the UTS and EL of the strips are higher in the rolling direction than those in the transverse direction as shown in Fig. 1 since the anisotropy of Zr alloy on the mechanical properties would contribute to a directional difference [3]. The yield stress (YS) and ultimate tensile stress (UTS) and elongation (EL) of the HANA-4 strip were better than those of the ZA strip at a temperature higher than 600℃. The temperature range from 580℃ to 640℃ was selected to further investigate the effect of the final heat treatment on the microstructure and corrosion property of the HANA-4 strip by taking the mechanical properties of the ZA strip into consideration.

2.2 Microstructures

Figure 2 shows the optical microstructures of the HANA-4 strip which is normal to the rolling direction. The strips were heat-treated at a different temperature from 580℃ to 640℃. They indicate a partial re-crystallization although it is not clear. However, the TEM microstructures of the strip reveal a partial re-crystallization as shown in Fig. 3. It was reported that in a Zr-Nb alloy system, β-Nb phase precipitates would retard the corrosion of the alloy but the β-Zr phase precipitate would rather accelerate its corrosion [4]. No β-Zr phase precipitates were found by the TEM observation of the HANA-4 strip which had been heat-treated at 620℃.

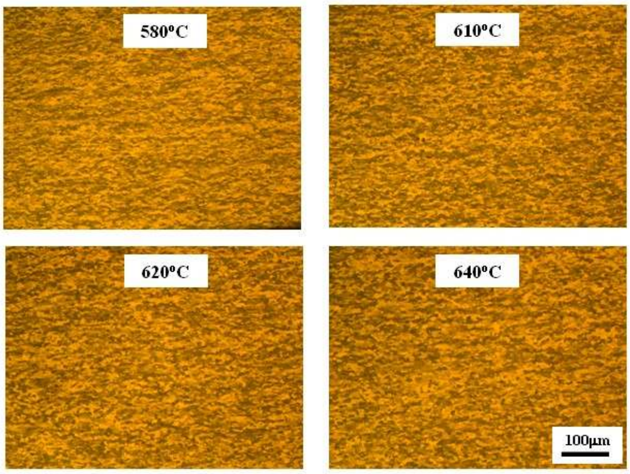

Fig.2. Optical microstructures of HANA-4 strip having different final heat treatment

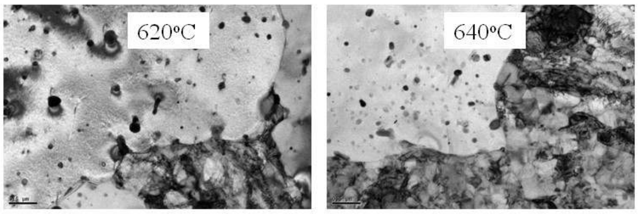

Fig.3. TEM microstructures of HANA-4 strip having different heat treatment

2.3 Corrosion behavior

Figure 4 shows the weight gain from the corrosion test for 3 days in the 400℃ steam environment for the HANA-4 strip which was heat-treated at different temperatures. The weight gains for all samples satisfied the specification requirement. However, the corrosion rate increased as the heat-treatment temperature increased.

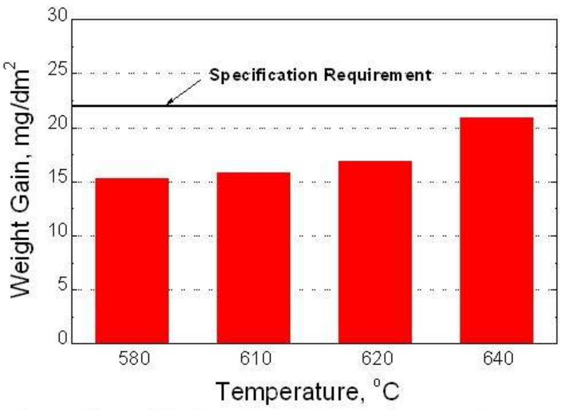

Fig.4. Effect of final heat treatment on the corrosion property of the HANA-4 strip for 3 days in 400°C steam environment

In an equilibrium Zr-Nb alloy system, β-Zr phases precipitate at 610℃. The more weight gain of the HANA-4 strip will result from corrosion at the higher temperature over 610℃ because the β-Zr phase precipitates contribute to the acceleration of the corrosion [4]. Although the β-Zr phase was not found by the TEM observation of the HANA-4 strip which was finally heat-treated at 620℃, it is desirable to undertake a heat-treatment at a lower temperature as shown in Fig. 4.

3. Conclusion

In order to evaluate the effect of the final heat treatment on the properties of the HANA-4 strip, tensile tests and corrosion tests in a 400℃ steam environment were done with an observation of the optical and TEM microstructures. The mechanical properties of the strip were better than those of the reference ZA strip for the samples heat-treated at an elevated temperature of higher than 600℃ in the rolling direction and 620℃ in the transverse direction. Whereas, the corrosion resistance of the HANA-4 strip in the 400℃ steam environment became worse at a temperature higher than 610℃. So it is recommended that the final heat treatment of the HANA-4 strip should be carried out at about 610℃.

Acknowledgement

This study was supported by Ministry of Education, Science & Technology (MOEST), Korean government, through its Nuclear R&D Program.

REFERENCES

[1] Yong Hwan Jeong, Sang-Yun Park, Myung-Ho Lee, Byung-Kwon Choi, Jonh-Hyuk Baek, Jeong-Yong Park, Jun-Hwan Kim and Hyun-Gil Kim, J. of Nucl. Sci & Tech, 43, 977 (2006)

[2] Kun Woo Song, Yong Hwan Jeong, Keon Sik Kim, Je Geon Bang, Tae Hyun Chun, Hyung Kyu Kim and Kee Nam Song, J. of Nucl. Eng. And Tech. Vol.40, 21 (2008)

[3] Myung Ho Lee[*a], Jun Hwan Kim[a], Sang Yoon Park[a], Byoung Kwon Choi[a], Yong Hwan Jeong[a], Yoon Ho Kim[b], Jin Gon Chung[b], Trans. of KNS Fall Meeting, Pyong Chang, Korea, Oct. 25-26 (2007)

[4] Y.H. Jeong, H.G. Kim and T.H. Kim, J. Nucl. Mater., 317, 1 (2003)