Corrosion and Mechanical Properties of HANA-6 Strip

Myung Ho Lee[1], Jun Hwan Kim[1], Sang Yoon Park[1], Byoung Kwon Choi[1], Yong Hwan Jeong[1], Yoon Ho Kim[2], Jin Gon Chung[2]
Mhlee2@kaeri.re.kr
[1]*Advanced Core Materials Lab., KAERI, P.O.Box 105, Yuseong, Daejon, 305-353, Republic of Korea*
[2]*Materials Development Group, R & D Center, KNFC, 493, Deokjin-dong, Yuseong, Daejon, 305-353, Republic of Korea*

1. Introduction

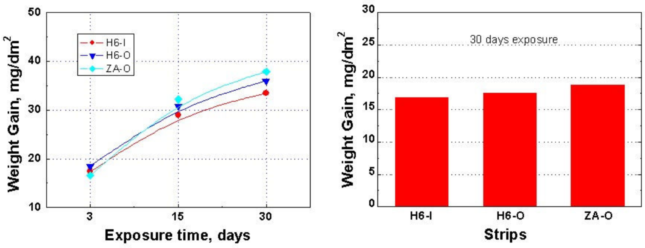
The Zircaloy-4, one of zirconium alloys, has been used as a nuclear fuel and structural material because it has a satisfactory mechanical strength and corrosion resistance. As in many plants it was attempted to increase their discharge burn-up and power level, the development of new zirconium alloys for a high burn-up fuel material has been required. In response to these needs, in 1997 KAERI started the development of some Zr-based new alloys, called HANA alloys, for high burn-up fuel cladding material and has tested the out-of-pile and in-pile performance of these HANA claddings after manufacturing the claddings with HANA alloys. [1] The sample specimens of the HANA cladding tubes showed a good performance for both corrosion resistance and creep properties at an irradiation test up to 12GWD/MtU in Halden test reactor as well as at various out-of-pile tests. [1] It is also scheduled to start the verification test of the in-pile performance of the HANA claddings in a commercial reactor by the end of 2007. KAERI and KNFC are also trying to extend the applicability of these alloys to the spacer grid for PWR nuclear fuel. As one of these attempts, KAERI has tested the properties of HANA-6 strips of 241.3 mm in width, and both 0.457 and 0.667 mm in thickness manufactured with a larger scale in width than a laboratory scale. The same test is scheduled to carry out for HANA-4 strips with a time lag. This paper summarized the results of the corrosion test, tensile test and bending test for the HANA-6 strips up to now.

2. Methods and Results

The chemical composition of the HANA-6 strips for this study is Zr-1.11Nb-0.08Cu-0.140O with some impurities such as 110ppm Si, 20ppm H, 35ppm N. The HANA-6 strips are manufactured in accordance with the applicable requirements, and the ZA strip was equivalent to a commercial grade one. The corrosion behavior of the strips was investigated both in a 360^{o}C 18.6MPa PWR simulated loop system containing 2.2ppm Li and 650 ppm B and in 400^{o}C steam in a manner consistent with the ASTM G2. The mechanical tests were carried out both at room temperature and 316^{o}C in accordance with the ASTM E8 and ASTM E21, respectively. The strain rate was 0.007mm/mm/min. through a 0.2 % offset yield stress and 0.05mm/mm/min after yield stress. The strips with 20mm in width and 100mm in length were also bent 180^o around a radius of 10mm with a strain rate of 3mm/mm/min. in accordance with ASTM E290. The other procedures such as the composition analysis grain size measurement, Rockwell hardness test, and surface roughness measurement were conducted in accordance with the requirements in the characterization test matrix of HANA Strip.

2.1 Corrosion behavior

Figure 1 shows the corrosion behavior of the HANA-6 inner strip(H6-I) and outer strip(H6-O) with the outer strip of ZA(ZA-O) in the 400℃ steam and PWR loop environment. As shown in the Fig. 1, the corrosion resistance of the HANA-6 strip is better than that of the ZA strip. The corrosion resistance of the HANA-6 inner strip is better than the outer strip because the reduction ratio of the inner strip at the 3rd rolling step was two times larger than that of the outer strip.



(a) 400^{o}C steam environment (b) PWR loop environment

Fig. 1 Corrosion properties of strips in steam and PWR loop environment

2.2 Tensile properties

Figure 2 shows the tensile properties of the HANA-6 inner strip(H6-I) and outer strip(H6-O) for the rolling and transverse directions at room temperature and 316℃. Figure 3 shows the stress-strain curves of the HANA-6 strips for the rolling and transverse directions at the same temperatures.

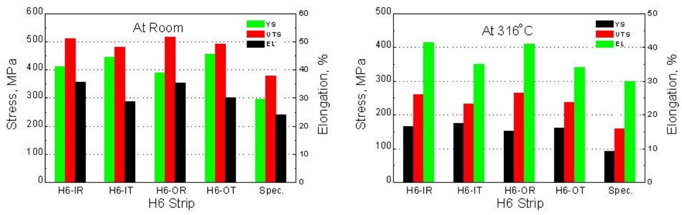


Fig. 2 Tensile properties of HANA-6 strips at room temperature and 316℃

As shown in Fig. 2, the yield stress (YS), ultimate tensile stress (UTS) and elongation (EL) of the HANA-6 inner and outer strips are higher for both rolling and transverse directions than those defined in the specification.

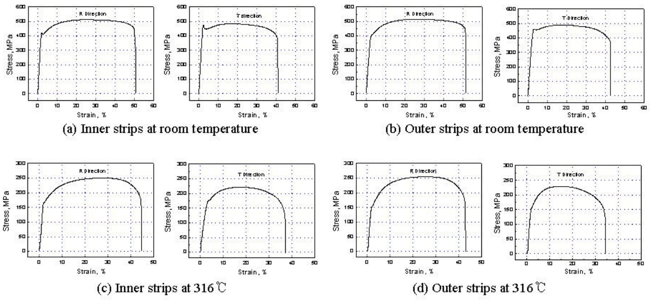


Fig. 3 Stress-strain curves of HANA-6 strips in the rolling (R) and transverse (T) directions at room temperature and 316℃

The YS of the strips is higher in the transverse direction than those 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. 3, the yield drop of the HANA-6 strip is larger at room temperature than at 316℃, also it is larger in the transverse direction than in the rolling direction. The anisotropy on the mechanical properties would contribute to the directional difference. [2]

2.3 Bending properties

Figure 4 shows the diagram for the maximum bending yield force for the displacement of the HANA-6 outer strips in both the rolling and transverse direction.

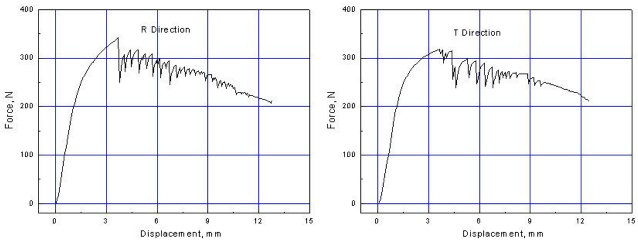


Fig. 4 Maximum bending yield force to displacement of HANA-6 outer strip in the rolling direction and the transverse direction.

The maximum bending yield force in the rolling direction is higher than that in the transverse direction as the UTS in the rolling direction is higher than that in the transverse direction because the strain hardening rate is higher along the rolling direction than the transverse direction. [2] Figure 5 shows the surface condition of the HANA-6 inner and outer strips in the rolling direction (IR, OR) and transverse direction (IT, OT) after they had received a 180° bending at room temperature. There were no visual findings about surface defects on the bent areas.

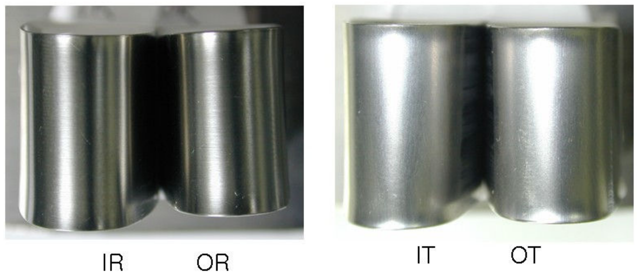


Fig. 5 surface condition of HANA-6 inner and outer strips in the rolling direction (IR, OR) and transverse direction (IT, OT) after 180° bending

3. Conclusion

In order to evaluate the properties of HANA-6 inner and outer strips, various characterization tests were carried out. The test results of the HANA-6 strips for the corrosion, tensile and bending properties met the specification requirements. The corrosion resistance of the HANA-6 strips was better than that of the ZA strip. The corrosion performance of the HANA-6 inner strip was better than the outer strip. There is a directional difference in the tensile and bending properties of the HANA-6 strips due to the micro structural anisotropy of zirconium. That is, the YS of the strips were higher for the transverse direction than those for the rolling direction while the UTS and EL of the strips were higher for the rolling direction than for the transverse direction. The yield drop of the HANA-6 strip was also larger at room temperature than at 316℃, and it was also larger in transverse direction than in the rolling direction. There were no visual surface defects on the bent areas of HANA-6 strips in the rolling direction and the transverse direction when the strips were bent 180° around at room temperature.

Acknowledgement

This study was supported by Korea Institute of Science & Technology Evaluation and Planning (KISTEP) and Ministry of Science & Technology (MOST), Korean government, through its Nuclear R&D Program.

Reference

[1] Yong Hwan Jeong, Sang-Yun Park, Myung-Ho Lee, Byung-Kwon Choi, Jonh-Hyuk Baek, Jeong-Yong Park, Jun-Hwan Kim, Hyun-Kil Kim, J. of Nucl. Sci & Tech, 43, 9, 983 (2006)
[2] K. Linga Murty, Ravi Jallepalli, S.T.Mahmood, Nucl. Eng. & Design, 148, 1-15 (1994)