Effect of an Intermediate Heat-treatment on a Change of the Corrosion Resistance and Hardness of a HANA-4 Outer Strip

Myung Ho Lee[*a], Yang Il Jung[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], Yoon Soo Lim[c]
[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*
[c]*Department of Advanced Materials Engineering, Hanbat National University, San 16-1, Yuseong, Daejeon 305-719, Korea*
[*]*Corresponding author: mhlee2@kaeri.re.kr*

1. Introduction

KAERI (Korea Atomic Energy Research Institute) in collaboration with KNF (Korea Nuclear Fuel) undertook some researches on the applicability of HANA-4 and HANA-6 alloys for the spacer grid for a PWR (Pressurized Water Reactor) nuclear fuel [1, 2]. As a part of the research, KAERI studied the effect of the final heat-treatment on the mechanical and corrosion properties of a HANA-4 inner strip [2]. The strip was manufactured with a sheet which had been intermediately heat-treated at about 580℃ for 2.5-4 hours after each cold rolling before being processed into the final strip product. It was mentioned that the process with the intermediate heat treatment needed reviewing to establish an improved manufacturing process for the cold rolling. So, this work tried to check the effect of an intermediate heat-treatment on the properties of a HANA-4 strip using a specimen that was taken from a second hot rolled material before a cold-rolling. The manufacturing processes, with three different kinds of annealings, were introduced to investigate the applicable intermediate heat-treatment process. After all the cold-rolling processes, the Vickers hardness was measured for the final annealed specimens and 60 days of corrosion tests were carried out to check on the effect of the intermediate heat-treatment. Finally, an appropriate intermediate heat-treatment was proposed to improve the manufacturability of the HANA-4 strip.

2. Methods and Results

The chemical composition of the HANA-4 alloy for this study was Zr-1.49Nb-0.38Sn-0.20Fe-0.11Cr-0.15O with some impurities such as 98ppm Si, 90ppm C, 21ppm H, 10ppm N. The original specimen for the tests was taken from the second hot-rolled sheet of a HANA-4 alloy which had a 4.75 mm thickness. The test specimens were prepared with three different kinds of annealing processes as shown in Table 1. All the tests and available observations were done on the final cold-rolled specimens that had a nominal thickness of 0.66mm and finally heat-treated with Final Annealings 1 or 2 as in Table 1. The superficial hardness of the specimens was measured by a Vickers indentation at a 980 mN load. The average value of 10 measurements was taken for a review of the ductility for a cold rolling. The weight gain of the specimens was also measured for the ones tested in a 400°C steam environment in a manner consistent with the ASTM G2.

Table 1. Manufacturing process of the test specimens

Manufacturing Process	Thickness t(mm) or Intermediate Annealing		
	Process A (580℃ x 4hrs)	Process B (600℃ x 2hrs)	Process C (620℃ x 1hr)
1st Hot-rolling	20t		
2nd Hot-rolling	4.75t		
1st Cold-rolling	3.2t		
1st Annealing	580℃ x 4hrs	600℃ x 2hrs	620℃ x 1hr
2nd Cold-rolling	2.05t		
2nd Annealing	580℃ x 4hrs	600℃ x 2hrs	620℃ x 1hr
3rd Cold-rolling	1.4t		
3rd Annealing	580℃ x 4hrs	600℃ x 2hrs	620℃ x 1hr
4th Cold-rolling	0.8t		
4th Annealing	580℃ x 4hrs	600℃ x 2hrs	620℃ x 1hr
Final cold-rolling	0.66t		
Final Annealing 1	580℃ x 4hrs	600℃ x 2hrs	620℃ x 1hr
Final Annealing 2	600℃ x 2hrs	600℃ x 2hrs	600℃ x 2hrs

2.1 Microstructures

Fig. 1 shows the sheets after the second cold-rolling and the optical microstructures of the normal plane cuts for the sheets with Process A, B and C after Final Annealing 1.

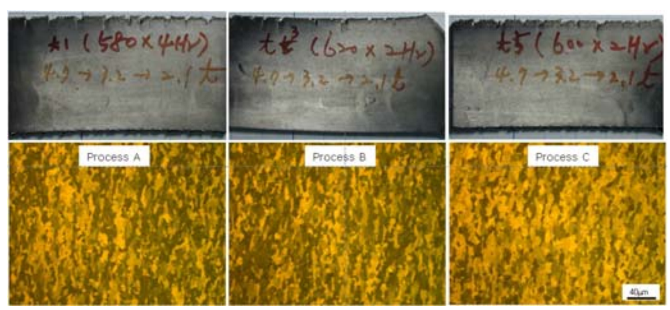

Fig. 1 Appearance of the sheets after the second cold-rolling and optical microstructures after Final Annealing 1

It seems that all the rolled surfaces on the specimens have a similar appearance and greater recrystallization occurred on the sheet with Process C than on the other ones with Process A and B. Fig. 2 shows the TEM microstructures after Final Annealing 2. The β-Zr phase precipitates were not found in the TEM microstructures of the specimens with Final Annealing 2. It was reported that the β-Zr phase precipitates contribute to an acceleration of their corrosion [3].

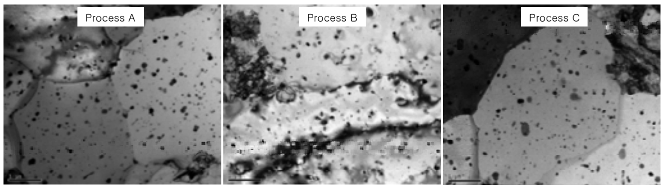

Fig. 2 TEM microstructures after Final Annealing 2

2.2 Ductility review of the cold-rolled sheets

Ductility or formability of the sheet during a rolling can be improved by lowering its hardness. Figure 3 shows the Vickers superficial hardness for the normal cuts to the rolled sheets with Processes A, B and C after Final Annealing 1 and 2. The hardness of the specimen sheets was lower when they were heat-treated with Processes A and C after Final Annealing 2 than that after Final Annealing 1. From Fig. 3, it can be interpreted that the intermediate heat-treatment temperature governed the change of the hardness in Process A while the intermediate heat-treatment time governed it in Process C.

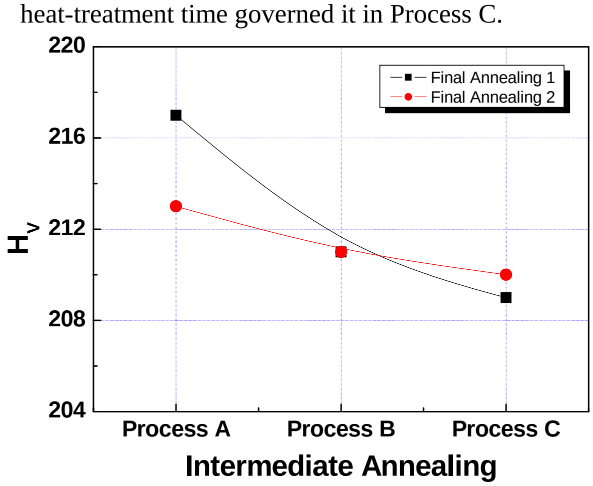

Fig. 3 Vickers hardness on the normal cuts to the rolled sheet with each process

2.3 Corrosion behavior

Fig. 4 shows the weight gain of the tested sheets from the corrosion test for 60 days in the 400℃ steam environment. The samples were cold-rolled and heat-treated by different final annealing processes. It was confirmed that the weight gain of all the specimens increased with an increasing heat-treatment temperature. In an equilibrium Zr-Nb alloy system, β-Zr phase precipitates at 610℃. The greater weight gain of the HANA-4 strip will result from corrosion at a higher temperature over 610℃ due to the β-Zr phase precipitation [3].

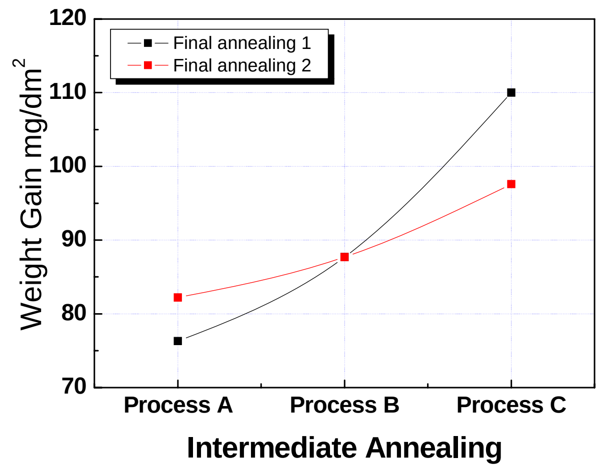

Fig. 4 Corrosion of the sheets depending on the different intermediate annealing

3. Conclusion

In order to evaluate the effect of an intermediate heat treatment on the formability of rolled specimens and on the corrosion property of a HANA-4 strip, Vickers hardness tests and corrosion tests in a 400℃ steam environment were carried out for three kinds of intermediate annealing processes with an observation of the optical and TEM microstructures. The results showed that the 600℃ x 2hrs intermediate annealing could be proposed among the cold rolling processes in order to improve the formability or ductility of the cold-rolled HANA-4 strip before it is used as a final product.

Acknowledgement

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

REFERENCES

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

[2] Myung Ho Lee, Yang Il Jung, Jun Hwan Kim, Sang Yoon Park, Byoung Kwon Choi, Jeong Young Park, Yong Hwan Jeong, Kyong Bo Eom, Nam Gyu Park, Trans. of KNS Spring Meeting, Gyeongju, Korea, May 29-30 (2008)

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