Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Effects of the manufacturing parameter and chemical composition on properties of HANA-4 cladding tube

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1. Introduction

KEPCO NF conducted some researches to improve workability of HANA-4 cladding tube[1]. It was changed to TREX outer diameter for increase Q-factor in first pilgering process related to the workability of cladding tube. In general, a increasing Q-factor leads to improvement yield of tubing manufacture in zirconium alloys[2]. And decreasing of amount of alloying element changed cladding properties. Therefore, this study was conducted in the conformity assessment of cladding tube in modified HANA-4 alloy that was changed chemical composition and TREX outer diameter.

2. Experimental procedures

The alloys used in the study were three different manufacture conditions of HANA-4, a chemical composition and TREX outer diameter as shown in Table 1. The secondary phase particles analysis was observed using transmission electron microscopy (TEM). TEM samples were prepared by using pickling, in a solution of 10 ml HF, 30 ml H_2SO_4, 40 ml HNO_3 and 40 ml H_2O, and jet polishing. The chemical composition of precipitates observed from energy dispersive X-ray spectroscopy (EDS). The texture properties were analyzed by using XRD diffraction and confirmed Kearn's parameter. And corrosion test was performed in PWR simulated loop at 360^{o}C. Texture test and corrosion test specimen were pickled in a solution of 5~10 ml HF, 45 ml HNO_3 and 50 ml H_2O.

Table 1. Chemical composition and TREX outer diameter

Alloying Elements	Chemical Composition (wt%)		
	HANA-4	Modified HANA-4	
Nb	1.4~1.6	1.3~1.5	
Sn	0.3~0.5	0.2~0.4	
Fe	0.18~0.22	0.16~0.20	
Cr	0.08~0.12	0.06~0.10	
O	0.08~0.12	0.06~0.10	
Zr	Bal.	Bal.	
TREX OD (Q-factor in 1st step pilger)	63.5 mm (1.13)	63.5 mm (1.13)	50.8 mm (2.07)

3. Results

Figure 1 shows the TEM microstructure of the modified HANA-4 cladding tube which has 63.5 mm and 50.8 mm TREX outer diameters. Precipitates were identified by using EDS in these alloys. The HANA-4 alloy had two types of precipitates, that is β-enriched phase and $Zr(Nb,Fe,Cr)_2$ phase, composition is known by previous research[3]. The average chemical com positions are 62.73 wt% Zr – 37.27 wt% Nb, and 50.98 wt% Zr – 29.62 wt% Nb –11.76 wt% Fe –4.78 wt% Cr for β-enriched phase and $Zr(Nb,Fe,Cr)_2$ precipitates. The β-enriched phase precipitates were more frequently observed compared to $Zr(Nb,Fe,Cr)_2$. Changing TREX outer diameter was not affected to precipitates size and distributions as first step pilgering Q-factor increasing from 1.13 to 2.07 as shown in table 2.

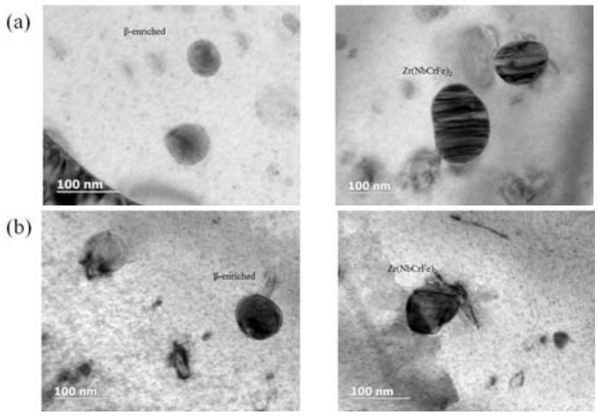

Figure 1. Precipitates observed in modified HANA-4 cladding tube which has (a) 63.5 mm and (b) 50.8 mm TREX OD

Table 2. Characteristics of precipitates in HANA-4 cladding tube which has 63.5 mm and 50.8 mm TREX OD

TREX OD	63.5mm	50.8mm
Precipitate type	β-enriched, $Zr(Nb,Fe,Cr)_2$	β-enriched, $Zr(Nb,Fe,Cr)_2$
Average particle size	84nm	77nm

Result of corrosion test by using PWR simulated loop with test conditions were 360^{o}C and 19 MPa as shown in figure 2. The corrosion resistance was increased with decreasing of amount of alloying element, but regardless of changing TREX outer diameters in 90 days. The corrosion test and investigation will be continued to long time in this condition. Table 3 shows (0002) the Kearn's parameters of basal pole for each fabricating step in 63.5 mm and 50.8 mm TREX outer diameter. The change of TREX outer diameter in first step pilgering process affected Kearn's parameters for each fabricating step and final tube. The Kearn's numbers of final tube are changed from f_r = 0.58, f_c = 0.37, f_n = 0.05 to f_r = 0.60, f_c = 0.35, f_n = 0.05. The stress orientation and the hydride orientation in respect to the texture of the zirconium alloy component, which plays also an important role for tubing process [4]. The change of TREX outer diameter exerts a beneficent influence on texture of cladding tube.

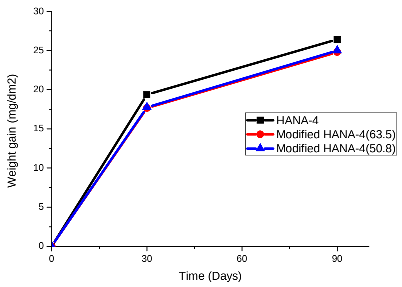

Figure 2. Corrosion behavior of HANA-4 tube

Table 3. Kearn's number of HANA-4 alloy which has 63.5 and 50.8 TREX outer diameters.

TREX OD	63.5 mm			50.8 mm		
Kearn's # / Process	f_r	f_c	f_n	f_r	f_c	f_n
1st pilger	0.45	0.50	0.05	0.53	0.39	0.08
2nd pilger	0.54	0.40	0.06	0.60	0.34	0.06
3rd pilger	0.58	0.37	0.05	0.60	0.35	0.05

4. Conclusion

The secondary phase particle analysis, the corrosion behavior and the texture were examined for HANA-4 alloys with adjustments of chemical compositions and TREX outer diameter for the purpose of enhancement formability. The precipitate type, size, and distribution of HANA-4 alloy were not changed as the chemical composition and the manufacturing parameters. The corrosion weight gain was decreased with reducing alloying elements, which considered the beneficial effect of reduced tin. And TREX outer diameter change exerts a benefit influence on texture of cladding tube. The modified HANA-4 alloys, which are proposed this research, are reasonable for application of cladding tube.

5. Acknowledgements

This research has been carried out as a part of the nuclear R&D program of the Korea institute of Energy Technology Evaluation and Planning funded by Ministry of Trade, Industry and Energy in Korea.
(No. 20121510100010)

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