Improvement of the HANA^{TM}-4 Tubing Workability

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1. Introduction

HANA^{TM} cladding has been developed for high burn-up fuel cladding exceeding 70,000 MWD/MTU. HIPER fuels using HANA^{TM}-6 material are currently being conducted in-reactor test in commercial nuclear reactors.

HANA^{TM}-6 was produced successfully for the fuel tubing by KEPCO NF. However, the production of fuel tubing of HANA^{TM}-4 has not reached to target yield due to cracking during tube pilgering. The purpose of this study has been carried out to improve workability of HANA^{TM}-4 tubing.

2. Production history of HANA^{TM} Tubing

Table 1 shows the manufacturing results of HANA^{TM} tubing fabricated by KEPCO NF with different TREX suppliers. HANA^{TM}-6 tubes were produced successfully but, HANA^{TM}-4 failed to manufacture tubing by current pilgering process due to transverse crack occurred on the surface.

Table 1. Manufacturing results of HANA^{TM} tubing

TREX supplier	Alloy	Results
A	HANA-4	T-Crack happened
	HANA-6	No problem
B	HANA-4	T-Crack happened
	HANA-6	No problem

3. HANA^{TM}-4 Workability Improvement Tests

3.1 Alloy Compositions Control

HANA^{TM}-4 containing Nb, Fe, and Cr elements which are beta stabilizing alloy elements. These alloying elements induce strength increase due to precipitate hardening and solid solution strengthening in the matrix. Also, alpha stabilizing elements, Sn and O, act as a solid solution strengthening in the Zr matrix[1]. Precipitate hardening and solid solution strengthening are the major factors making it difficult to work with increasing the strength.

Therefore, it is possible to reduce the amount of HANA^{TM}-4 alloying elements within a range that does not affect the corrosion and mechanical properties. Modified alloy composition and hardness test results of HANA^{TM}-4 TREX are shown in Table 2.

Table 2. Modified alloy composition of HANA^{TM}-4 TREX

		As of	Modified
Alloy element (wt%)	Nb	1.4~1.6	1.3~1.5
	Sn	0.3~0.5	0.2~0.1
	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.
Hardness(HRB)		88~90	83~84

3.2 Manufacturing Parameter Control

Q-factor and heat treatment temperature are the most important parameters in determining cladding workability. Q-factor is closely related to the workability of the cladding and important factor in determining the texture of the cladding tube[2]. According to a study by Abe[3], increasing the Q-factor of zirconium alloys in the manufacture, the tube is easy to fabricate. And another research results reveal that surface cracks are decreased in the zirconium tube by the increasing Q-factor[4]. Therefore, the TREX OD size was changed to 50.8mm from 63.5mm in order to have higher Q-factor than current one in pilgering.

The intermediate annealing temperature was established at the range of 570~600^{o}C, which minimizes weight gain in corrosion test[5]. Therefore, the intermediate annealing temperature was changed to make more ductile pilgered products within the range not to impact its microstructure.

3.3 Results

The adjustments compositions and manufacturing parameters for HANA^{TM}-4 make tube yield to the commercial values in tube deforming state, and the follow-up tests are currently being evaluated.

4. Conclusions

An improvement on the manufacturing parameters and the alloy compositions adjustments in order to improve workability HANA^{TM}-4 tubing was performed in the producing HANA^{TM}-4 cladding successfully without cracking. However, it is necessary to minor change the design of Mandrel and Die to improve the surface quality. The effects on corrosion properties and microstructure by an adjustment in manufacturing parameters and alloy compositions are currently being evaluated.

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