Comparison of Crystallographic Texture of Domestic Zirconium Alloy Tubes by Using X-ray Diffraction Method

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1. Introduction

Zircaloy cladding tube produced by pilgering process has been used for many years in chemical and nuclear engineering [1]. The zirconium alloy is hexagonal structure which crystallographic texture is formed by pilgering process [2]. Since the crystallographic texture influences durability of the tube, texture control is very important technique in industry [3]. In this study, crystallographic texture of a zirconium alloy cladding tube fabricated in a domestic company was carried out to give information about an optimum fabrication condition.

2. Experimental methods

Zirconium alloy tubes fabricated by Korea Nuclear Fuel Co. LTD (KNFC). Fig. 1 is geometric direction of the zirconium alloy tube in this study. The tubes were sectioned to several pieces with 1.8x2.0x200 mm, respectively. Microstructure of the tube was observed by polarizing microscope (Nikon Epithot 200). Micro-hardness of the tubes was determined (Buehler micro-Vickers). Texture of the tube was analyzed by X-ray diffraction (Bruker-08) at room temperature.

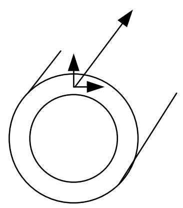

Fig. 1. Geometric direction on zirconium alloys tube.

3. Results and Discussion

Table 1 is a micro-hardness change of the zirconium tubes with pilgering. The hardness of TREX (tube reduced extrusion), 1st , 2nd and final pilgered tubes for longitudinal and cross-sectional directions are 210, 203, 260, 270 and 265, 272, 268 and 274 [Hv], respectively. As shown in Table 1, the hardness mainly increased after 1st pilgering.

It is interesting why the hardness rapidly increased after 1st pilgering. This mechanical behavior can be explained by strengthening mechanisms. Among eight kinds of strengthening mechanisms, grains-size refinement and work hardening mechanisms look plausible effects on the zirconium alloys. In previous study, the average grain sizes of the zirconium alloy tubes were 22, 11, 8 and 2 μm, respectively [4]. Hall-patch equation about the hardness change with grain size variation estimates that the ratio of hardness change from TREX to 1st and from 1st to 2nd pilgering are 165% and 200%. However, the real values are about 30% and 1 %, respectively. This means that Hall-patch evaluation is not well fit to the pilgering process of zirconium. Accordingly, the hardness change after 1st pilgering may include grain-size refinement and work hardening, however, it is more dependent upon work hardening than grain-size refinement mechanism. It is related that work hardening effect is lower in HCP structure than in FCC structure because the HCP structure has less slip system than FCC for a same atomic packing factor.

Table 1. Micro-hardness change of zirconium tubes

	TREX	1st	2nd	3rd
longitudinal	210	260	265	268
cross-section	203	270	272	274

Fig. 2 is X-ray diffraction spectra to show (002) pole of TREX with pilgering process. As shown in Fig. 2, TREX has relatively random pole distribution. The (002) pole tended to be parallel to the direction after 2nd pilgering. After final pilgering, most of (002) poles exist between tangential and longitudinal directions.

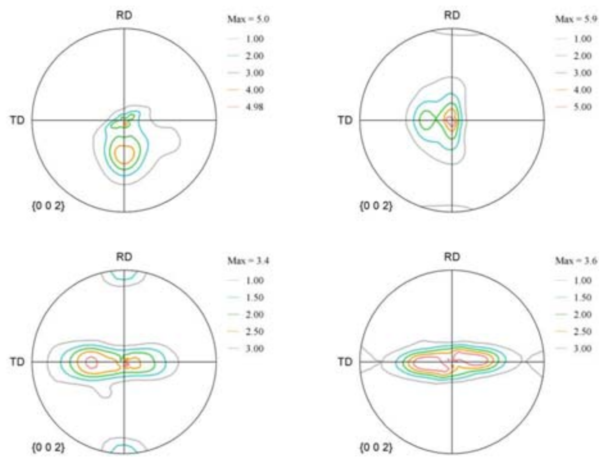

Fig. 2. (001) pole change with pilgering process determined by X-ray diffraction : (top-left) TREX, (top-right) 1st pilgering, (bottom-left) 2nd pilgering, (bottom-right) final pilgering.

It is necessary to verify crystallographic texture of the zirconium alloy tube and commercial one, which is prepared in other bath or company. Fig. 3 is (002) poles of commercial zirconium tube determined by the X-ray diffraction. As shown in Fig. 3, most of (002) poles of the commercial TREX has already well aligned to the angle of 45 degrees between tangential and longitudinal directions. The (002) poles figures are not absolutely changed and kept in the direction after following pilgering processes. Fine difference of the (002) pole contour were observed. The difference between Fig. 2 and fig. 3 may be caused by different analysis S/W or equipment. However, similar crystallographic texture between the commercial TREX and 2nd pilgered tube in Fig. 2 was clearly observed. This supported that the (002) poles of both tubes after 2nd pilgering are similar orientation although the TREXs of as-received or domestic alloys have initially different crystallographic texture.

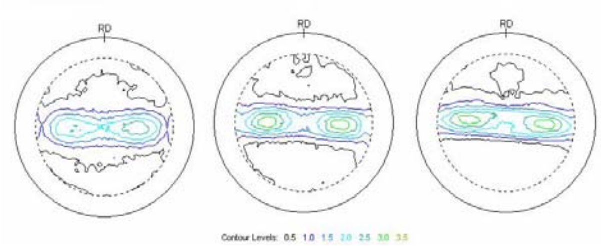

Fig. 3. (002) poles of commercial zirconium tubes : (left) TREX, (middle) 1st pilgering, (right) 2nd pilgering.

4. Summary

Crystallographic texture of a zirconium alloy tubes produced by KNFC was analyzed by X-ray diffraction and is compared with as-received one. The hardness increases from 210 to 274 Hv after pilgering. Both grain size refinement and work hardening mechanisms are effective after 1st pilgering process. The work hardening becomes predominant for the change of hardness after 1st pilgering. Comparing (002) poles of zirconium alloy tubes with commercial tubes, both TREXs have initially different crystallographic texture. The (002) poles of both tubes after 2nd pilgering are similar orientation.

5. Acknowledgements

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