

Review on the Control of the Direction of Hydride in Zirconium Clad Tube in Terms of Manufacturing Process

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1. Introduction

Coolant serves as an oxidant and the zirconium cladding corrodes and absorb hydrogen atoms at the same time in nuclear reactors. The absorbed hydrogen atoms precipitate as hydrogen compounds (zirconium hydride) in the region below the solubility [1]. The deterioration of robustness of the cladding due to precipitated zirconium hydride is a major issue in the dry storage [2,3], accident conditions [4], and high burnup fuel [5,6].

Specifically, zirconium hydride differs not only in its precipitation fraction, but also in the mechanical performance deterioration along its direction of in the cladding tube [7]. The tensile stress in the circumferential direction is generated not only by the internal pressure but also by the action of UO₂ pellets pushing out of the cladding tube. Therefore, hydrogen compounds precipitated in the radial direction are of greatest interest [3,7].

In this study, we review the factors that can control the directionality of zirconium hydride which are inevitably formed in a zirconium cladding tube during burnup from the perspective of cladding manufacturing.

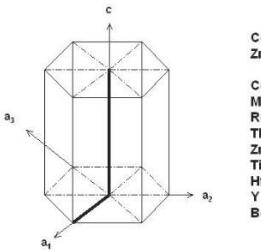
2. Clad Tube Manufacturing Factor

2.1 Pilgering Factor

Tube reduced extrusion (TREX) is subjected to three times cold pilgering to reach the final product dimensions and to be able to reach basal pole within 30 to 40° from the radial direction as shown in the Fig. 1 (a1). Therefore, the preferential formation and growth of the hydride can be achieved on the plane 10-17 which is inclined by 15° on the 0002 plane.

However, without proper adjustment of the tube reducing ratio (R_w / R_d , R_w : Reduction length of wall thickness, R_d : Reduction length of diameter) in the process of cold pilgering, perpendicular texture is formed as shown in the Fig. 1 (a3). The reason for this is that the change in texture is determined by the ratio (c/a) in crystallography of hexagonal crystal structures.

The cladding composed of zirconium atoms has an aspect ratio of 1.593, which is smaller than 1.633 of the hard sphere model [9]. Therefore, it is necessary to perform cold working at a ratio of R_w/R_d over 1 to develop the desired texture [8,9]. In practice, nuclear fuel manufacturers adjust the ratio using the Q factor.



Cd = 1.886	above normal
Zn = 1.856	hard sphere model
Co = 1.628	
Mg = 1.624	
Re = 1.615	below normal
Ti = 1.598	
Zr = 1.593	
Ti = 1.587	
Hf = 1.581	
Y = 1.571	
Be = 1.568	

Deformation process	Deformation element	Strain ellipse in the plane perpendicular to the direction of elongation	Deformation texture		Annealing texture	
			(0002) pole figure	{1010} pole figure	(0002) pole figure	{1010} pole figure
a1	Tube reducing $R_w/R_d > 1$	RD, TD, AD	RD	AD	AD	AD
a2	TD, TD, AD $R_w/R_d = 1$	TD	RD	AD	AD	AD
a3	TD, TD, AD $R_w/R_d < 1$	TD	RD	AD	AD	AD

Fig. 1. c/a axial ratio for hcp metals (left) and deformation process for cold deformed and annealed conditions (right) [8].

2.2 Heat Treatment Factor

After the cold pilgering, the strongly formed texture is slightly changed by the heat treatment, but the angle of the basal pole does not change. As shown in the Fig. 2 which is the result of measuring zirconium alloy cladding tube annealed for 8 hours on 520°C, only (10-10), the primary prism plane, perpendicular to the basal pole rotates about 30° around the basal pole. The measurement was performed using electron backscattered diffraction (EBSD) technique.

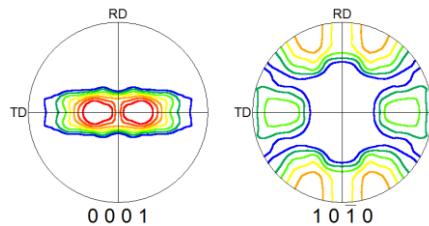


Fig. 2. Inverse pole figure (IPF) in zirconium alloy.

tube at 30 ~ 40° in the direction of the radial direction from the production stage.

ACKNOWLEDGMENT

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3. Conclusions

In order to control the precipitation direction of the hydride precipitated in zirconium cladding, R_w/R_d ratio is set over 1 in the cold pilgering step. In addition the heat treatment does not cause a large change in the texture. As a result, it is possible to suppress the embrittlement of the cladding due to the formation of hydrogen compounds in circumferential direction by forming the texture of zirconium clad