Analysis on Mechanical Properties and Textures of Back-end and Front-end Zr-2.5Nb Pressure Tube Materials

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1. Introduction

The Zr-2.5Nb pressure tube (PT) in the fuel channel system of Canada Deuterium Uranium (CANDU) nuclear reactor undergoes irradiation induced deformation during operation. Since the deformation of PT affects the efficiency and safety of the reactor, their prediction and maintenance is one of major interests. It is well known that the metallurgical characteristics of PT before the operation influence on their in-reactor deformation. Even a single PT has different microstructures between front-end and back-end (the front means the first end out of the extrusion process), which leads the anisotropy in the in-reactor deformation behavior [1]. In order to secure the safety and efficiency, the in-reactor deformation of PT should be predictable and controllable. For achieving it, understanding metallurgical properties of pre-operation PT is prerequisite.

Several factors are considered as effective variables for the deformation of PT, such as mechanical properties—strength and hardness, and microstructural features—grain size, grain morphology [2], texture [3], dislocation density [4], hydrides, etc. In the study, the comparisons between the mechanical properties of each end of PT and their texture have been conducted and the results are presented.

2. Methods and Results

For mechanical test and microstructure analysis, specimens were obtained from front and back-end of Zr-2.5Nb PT. The following sections gives more details about each method and result.

2.1. Microhardness

PT has three main axes, axial, transverse and radial direction as shown in Fig. 1(a). Each plane perpendicular to each direction is named following their direction—AP, TP, RP (Fig. 1(b)). Vickers hardness measurement on the planes of the both-ends has been performed with 0.3 kgf of load and 10 sec of dwelling time. Due to strong texture of PT, the highest Vickers hardness values were obtained on TP and the lowest on AP. Back-end material has slightly higher values than front –end.

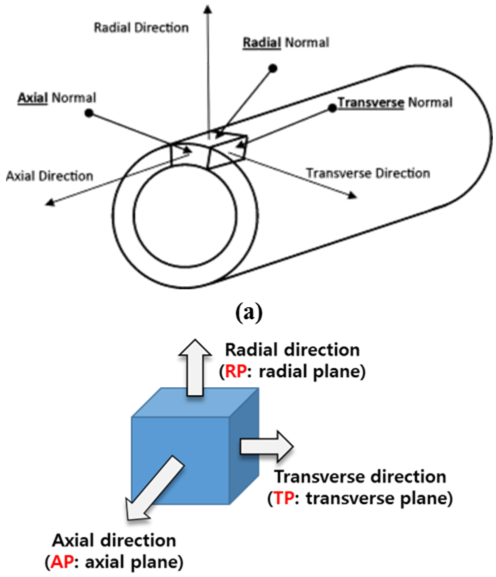

Fig. 1. Schematic diagram of PT. (a) main directions and (b) main planes.

2.2. Tensile tests

Dog-bone shape tensile specimen having 5 mm of gage length and 2.5 mm of width was machined along axial direction. Quasi-static tensile test have been conducted at room temperature and $10^{-3}\ s^{-1}$ of strain rate. For precise strain measurement, digital image correlation (DIC) method was applied during tests using GOM ARAMIS system (Fig. 2).

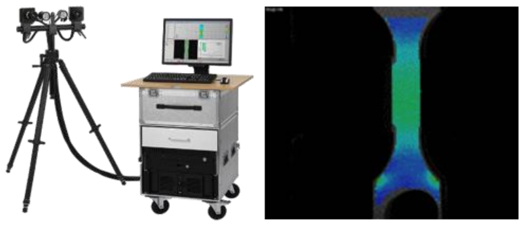

Fig. 2. Digital image correlation (DIC) system and the calculated strain distribution during tensile test.

2.3. Electron backscattered diffraction (EBSD)

To obtain orientation information, EBSD analysis was performed on AP, RP using TSL EBSD system. The points having confidence index lower than 0.09 were deleted for avoiding incorrect orientation information.

2.4. Texture analysis

Based on the orientation information from EBSD analysis, (0001) pole figures have been calculated using free-software MTEX (Fig. 3). Even though two plane, AP, RP, were analyzed, only RP results are shown here because textures calculated from the two planes are microstructurally identical. Both front and back-end materials show strong intensities near the transverse direction. However, it is impossible to distinct the difference between two pole figures.

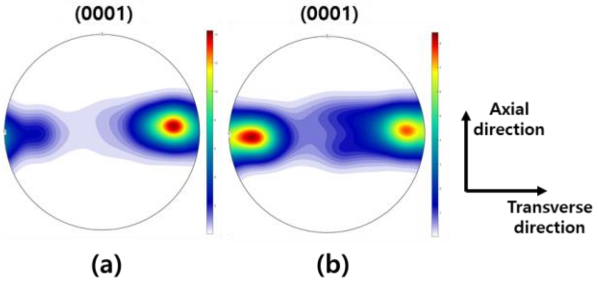

Fig. 3. (0001) basal pole figure of (a) back-end and (b) front-end PT material.

For quantitatively analysis, Kearns factor of each plane were calculated using following equation,

$$f_i = \sum V_i \cos^2 \phi_i \qquad (1)$$

where f_i is the Kearns factor for a given cross-section (‘i': AD, TD or RD), V_i is the volume fraction of the (0001) basal fiber at an angle ϕ_i with the perpendicular direction to ‘i' plane. Fig. 4 shows the comparison of calculated Kearns factors between front and back-end. Notable difference is not found.

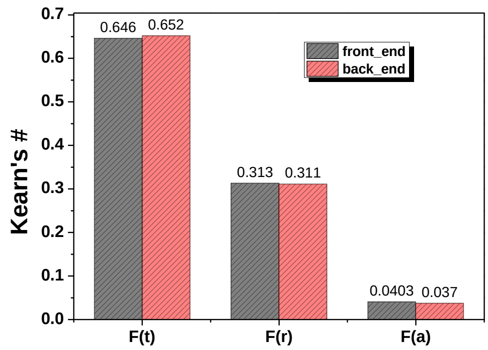

Fig. 4. Comparison of Kearns factor between front-end and back-end PT material.

3. Conclusions

Since in-reactor deformation of PT is influenced on by several metallurgical factors, understanding their effectiveness is pretty important for reactor safety. In the study, we focus on the mechanical properties and texture characteristics of the pre-operation PT. Since PT has anisotropy in microstructure along the axial direction by extrusion process, the front-end and the back-end PT materials from a single PT are compared. Through mechanical tests, it is clearly found that the back-end material has higher strength than the front-end material. It can be inferred that some metallurgical differences make the higher strength for the back-end. As one of candidates, texture analysis has been performed. From the calculated Kearns factors, no clear difference between two materials is found. Therefore, it is concluded that texture does not influence on the difference in the mechanical properties between front-end and back-end, and in-reactor deformation anisotropy along PT because a single PT has very similar texture along the length. Further studies considering other factors, grain size, morphology, etc., are in progress.

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