Study of Modification of Texture of Zirconium Excel Pressure Tube Materials by Heat-Treatments

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Synopsis: High strength Zr-Excel (Zr-3.5% Sn-0.8%Nb-0.8%Mo) has been suggested as PT materials in the CANDU Generation-IV Super Critical Reactor (SCWR). In order to increase the thermal efficiency up to 45%, a significant structural change has been proposed in the conceptual design of SCWR [1]. The proposed design requires a substantial improvement in the deformation behavior which critically restricts axial elongation as well as diametral strain of the PT. The anisotropic in-reactor deformation behavior strongly depends on the texture, therefore to control or to minimize the preferential deformation, it is required to have a less pronounced crystallographic texture.

Motivation: Life extension of current reactors and advanced nuclear reactor designs will push materials to unprecedented levels of radiation dose and operation temperature. The severe radiation environment present inside the reactor core gradually changes the microstructure of the alloys, eventually altering the mechanical properties and thus the deformation behavior of the structural components. Experimental research directed at understanding the microstructure property relations under these operating conditions is required to realize the benefits of advanced nuclear reactors.

Texture inherited through a phase transformation has a direct correlation with the parent phase texture. It can be significantly affected by variant selection during the transformation of phases. The transformation of zirconium α and β phases is through the Burgers relation as $\{110\}_\beta // \{0002\}_\alpha$, and $<111>_\beta // <11\text{-}20>_\alpha$ (fig. 1). Due to this transformation, the inherited texture of the final product can be significantly affected by heat treatments.

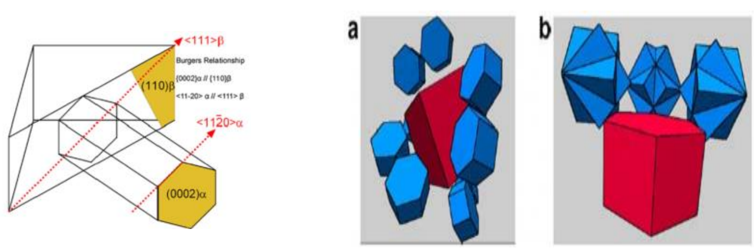


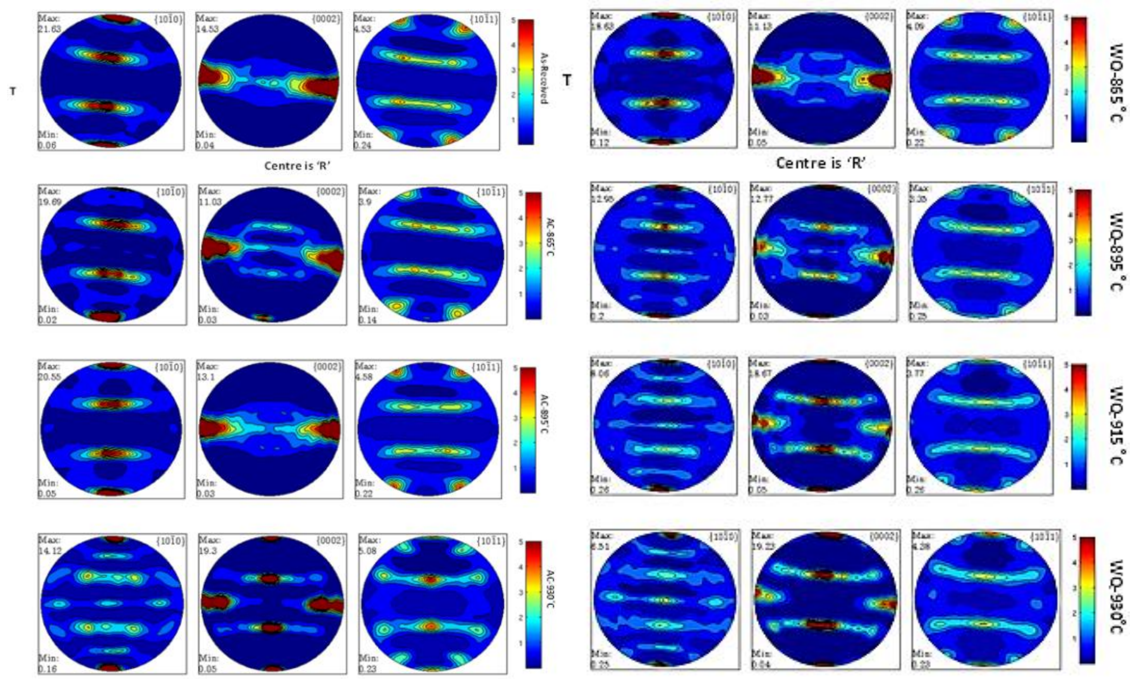
Figure 1. (a)Burgers orientation relationship between hcp α and bcc β [2]; (b) Schematic showing different variants for a) β to α; b) for α to β [3]

Methods: Zr-Excel PT materials (annealed) were heat-treated in their transformation range at different cooling rates (water-quenched and air-cooled). Investigation on these heat-treated materials showed significant changes in their microstructural features. Primary α-phase were significantly transformed into β-phase at higher solution temperatures and transformed into martensitic or acicular structures in water-quenched and air-cooled treatment respectively during cooling. Crystallographic texture of these modified structures then aimed to measure at Chalk River Laboratories. Texture measurements were conducted through neutron diffraction [4] at the National Research Universal (NRU) reactor in Chalk River Laboratories (CRL). These measurements were made at a nominal wavelength of 2.075 Å obtained from the {220} reflection of a Ge single crystal monochromator, on the E3 spectrometer at NRU. Three distinct pole figures for both the [(0002), $(10\bar{1}0)$ and $(10\bar{1}1)$] and β phase [(200), (110) and (111)] in each sample have been constructed and can be compared for the different solution temperatures as well as for the two cooling rates. The resolved fractions of basal plane normal in each (002) pole figures were calculated and analyzed to compare their quantitative modification.

Results: It has been noticed that the basal pole figures of differently heat-treated samples has significantly modified compared to the highly as-received texture. Transverse components have been substantially shifted towards axial direction. Axial components of the basal pole figures progressively increased with increasing solution temperature. Cooling from ~930˚C (about 80-85% of β_{Zr} and 15-20% α_Z) generated strong axial components in the basal pole figure). An overall changes or modification in texture components (f_T, F_R and f_A) at different solution temperature has been estimated and shown in figure 2. This illustrates the fact how a different degree of randomness has been achieved after heat-treatment.

This modification of texture components has resulted from the texture inheritance from high temperature β_{Zr} through Burgers relationship and driven by internal strains [5]. Significant variant selection might have occurred during the transformation (β_{Zr} to α) which led to transfer of initial transverse (0002) intensity to

(0002) axial intensity. Despite some variant selection, randomization has been noticed in both treatments. The slower air-cooled treatment is comparatively less effective than a water-quenching process in causing randomization.



(a) (b)

Figure 2: Pole figures of α-phase (a) After-AC and (b) after WQ treatment (compared with as-received PT materials).

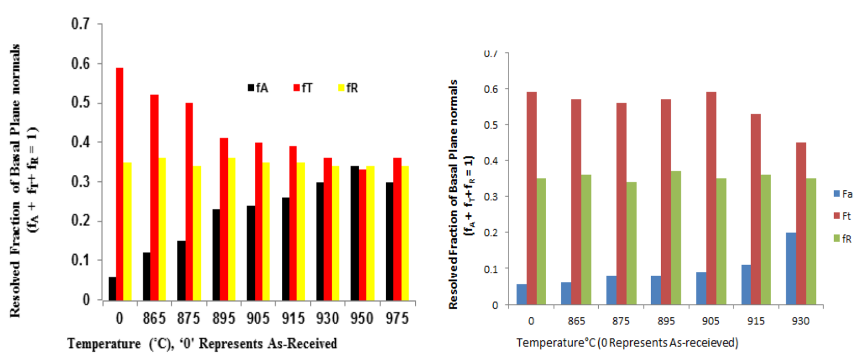


Figure 3. Comparison of Resolved fraction variation of basal plane normal in (a)WQ; (b) AC treatment.

The β-phase texture in both ASR and WQ is found to be quite similar (shown in fig. 3). During heating epitaxial growth of pre-existing β might be occurring in contrast to the nucleation or growth of new grains.

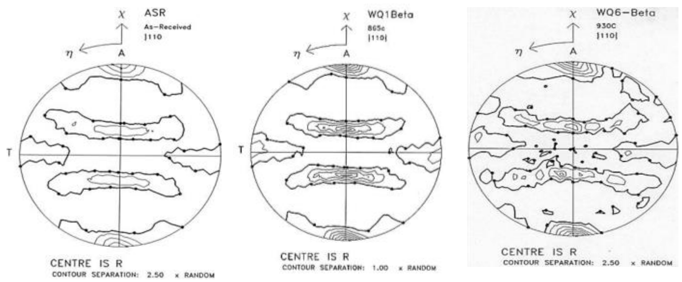


Figure4. β-phase (110) pole figure at different heat-treatment conditions

Conclusion: Heat-treatment in annealed Zr-Excel pressure tube materials shows significant responses in texture modification. A linear correlation has been observed in increase of solution temperature and the extent of this modification. Modification is predominant in water-quenched treatment over air cooled treatment. Interaction between martensitic constituents, cooling rate, phase region from where cooling was done as well as the phase constituents presents at that temperature could be the factors which influence the variants to be selected or not.

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