CRYSTALLOGRAPHIC TEXTURE OF NUCLEAR REACTOR CLADDING TUBES

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Crystallographic texture is one of parameter that plays a crucial role in the performance of nuclear reactor cladding tubes, as it directly determines the anisotropy of their physical and mechanical properties upon irradiation. In zirconium alloys used to produce VVER-1000 reactor cladding tubes with a hexagonal close-packed (HCP) lattice, texture control is crucial to minimize radiation growth, creep, and preventing failure due to hydride embrittlement [1]. An error in texture can cause the cladding tube to bend in an "arc".

Texture is also important for steel cladding tubes of fast neutron reactors, although steel with a cubic lattice (BCC or FCC) is often considered more isotropic on a macroscale. The texture created during the rolling process influences microstructural stability and the balance of strength and ductility, which is important for fast reactors cladding tubes. Texture determines how the tube will perform under extreme loads in the reactor core [2]. It affects how much the tube deforms under the pressure of the coolant and gases inside. Controlling the crystal orientation makes the cladding tubes more rigid and resistant to deformation. Unlike zirconium, where texture controls the orientation of hydrides, in steels the main challenge is dimensional stability (swelling minimizing) under high irradiation doses. Not optimal crystallographic texture of the cladding tubes could lead to worse sodium flow.

Information about texture of cladding tubes can be obtained from experimentally measured pole figures. Pole figures characterize the relative volume of specific crystallographic direction

measured in a sample coordinate system on the unit sphere. The most common method to measure pole figures is X-ray diffraction. However, due to the small X-rays penetration depth into substance, pole figures can only be measured in reflection mode. This makes impossible direct measurements of complete pole figures. The EBSD (electron backscatter diffraction) method is implemented in a scanning electron microscope (SEM). This method allows one to construct orientation maps of the microstructure, see the texture distribution in specific zones and analyze grain boundaries. However, in the case of X-ray diffraction, the penetration depth is approximately 100 µm; the EBSD technique provides information for only a few atomic layers. So, X-ray and EBSD can characterize the sample only locally (typical gauge volume is 0,01 cm^3 and 0,01 mm^3 respectively). Due to the high penetrating power of neutrons, texture can be examined in bulk samples (up to 100 cm^3) or entire tube fragments in transmission mode without destruction or any special sample preparation.

The complete pole figures of the Zr-1%Nb alloy and austenitic steel samples were extracted from the time-of-flight patterns measured at the SKAT spectrometer (Spectrometer for the Quantitative Analysis of Textures). SKAT is situated at the 7A-2 beamline of the high flux pulsed nuclear reactor IBR-2 (FLNP, JINR). The samples were glued together from seven sections of the original cladding tubes. Since the complete pole figures are measured, they can be normalized by integrating the pole density over the sphere. The complete normalized pole figures (0002), (10-10), (11-20), and (10-11) were obtained for cladding tubes made of the Zr-1%Nb alloy and pole figures (111), (200), (220), (311) for cladding tubes made of the austenitic steel. Some of the pole figures are shown in the figs. 1, 2. The Zr-1%Nb alloy texture is axial, with the texture axis coinciding with the tube axis. The crystallographic direction [0002] lies in the plane perpendicular to the tube axis. The maximum of normalized basal pole figure (0002) is 3.78 mrd.

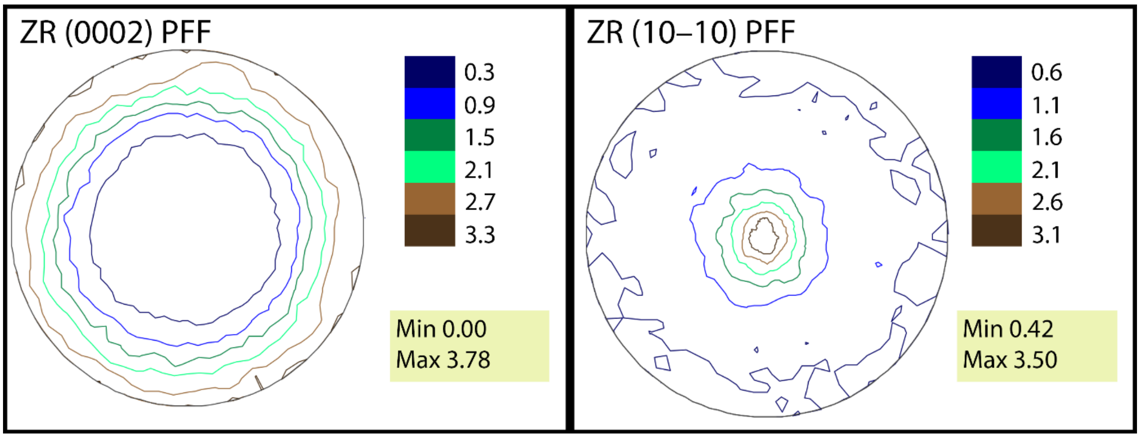

Fig.1 The complete normalized pole figures for the Zr1%Nb alloy cladding tube

During operation, zirconium absorbs hydrogen that leads to hydrides formation. This texture ensures that the hydrides will be oriented tangentially (along the tube's circumference), without creating dangerous "notches" in the wall.

The steel tube has two component axial texture with texture axis coinciding with the tube axis.

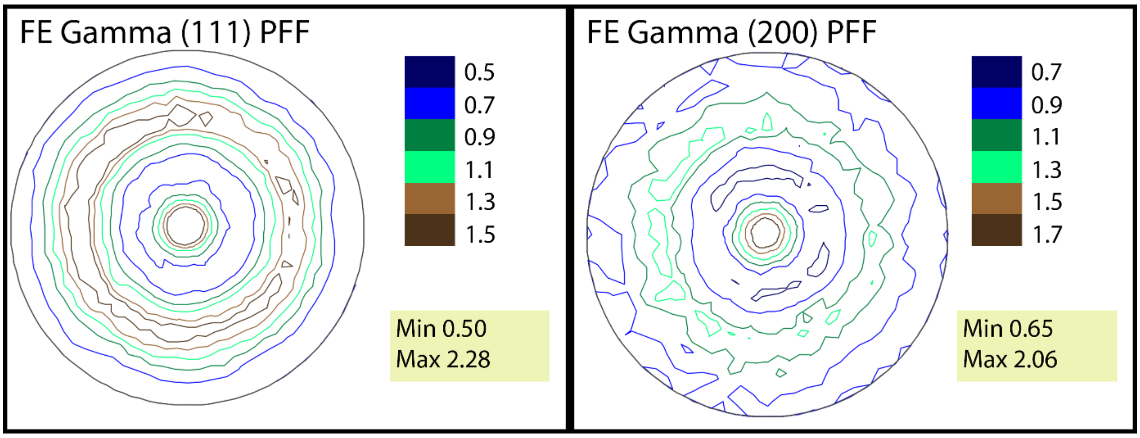

Fig.2 The complete normalized pole figures for the austenitic steel cladding tube

In this case the normal to (111) and (200) planes coincide with tube axis. The maximum pole density 2.28 mrd at the pole figure (111), whereas one is 2.06 mrd at the pole figure (200).

The optimization of texture of the steel cladding tubes to improve resistance to radiation swelling need further investigations.

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