Western Nanofabrication Facility

Investigation of the Mechanical Anisotropy of the Zr-2.5%Nb Pressure Tube using micro-pillars at 25 °C

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The safe operation of nuclear power plants is of paramount importance to nuclear power generating organizations worldwide. This necessitates the use of highly effective methods for characterizing the mechanical properties of reactor materials and components. This is important since all components located in a nuclear reactor core experience high levels of neutron irradiation which cause defects to be formed in the metals' crystal structure. The density of these crystal defects increases with increasing exposure to neutrons and causes the crystalline metal to become harder and simultaneously more brittle. This change in mechanical properties is potentially detrimental to the safe performance of the nuclear reactor.

To evaluate the mechanical anisotropy of extruded and cold-drawn Zr-2.5%Nb pressure tube material used in CANDU nuclear reactors, two sets of micro-pillars of 5 μm diameter and 5 μm height were fabricated from polished surfaces of the pressure tube in the axial, radial and transverse direction of the tube. The micro-pillars were made by Focused Ion Beam (FIB) milling with a LEO (Zeiss) 1540XB FIB/SEM located at the Western Nanofabrication Facility of Western University (London, ON, Canada). One set of the micro-pillars were then irradiated with 8.5 MeV Zr^+ to simulate neutron irradiation. The ion-irradiated and non-irradiated micro-pillars were then subjected to uniaxial compression testing using a 10 μm diameter flat diamond punch attached to a nano-indentation platform [1].

The yield stress and degree of strain localization of the micro-pillars at the testing temperature of 25 °C increased with ion irradiation and it was observed from the results obtained that the extent of increase was largest in directions containing low (0001) basal pole fractions. Since prismatic dislocation glide is regarded as the primary mode of axial and radial deformations along directions of low (0001) basal pole fraction and the pyramidal dislocation glide is the primary mode of transverse deformation along directions of high (0001) basal pole fraction, this suggested that Zr^+ irradiation inhibits prismatic dislocation slip more than pyramidal slip in this material.

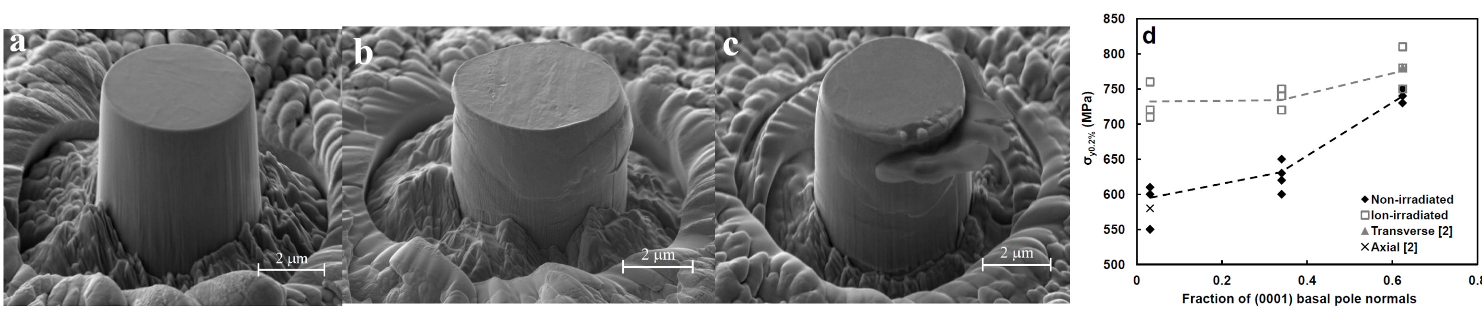

Figure caption: SEM images of FIB machined 5 μm diameter Zr-2.5%Nb (transverse normal) micro-pillars (a) before compression, (b) after compression testing (non-irradiated condition), (c) after compression testing (Zr^+ irradiated condition). The increased strain localization leading to splitting of the micro-pillar at the final stages of the compression test on the Zr^+ irradiated sample is clearly shown in (c). (d) Plot of 0.2% offset yield stress versus resolved fraction of (0001) basal poles parallel to the direction of compression for the non irradiated and Zr^+ irradiated micro-pillars. The data from ref. [2] in (d) are from previously published uniaxial tensile tests performed on non-irradiated Zr-2.5%Nb material.

[1] R.O. Oviasuyi, R.J. Klassen, J. Nucl. Mater. 421 (2012) 54.

[2] N. Christodoulou, P.A. Turner, E.T.C. Ho, C.K. Chow, M.R. Levi, Metall. Mater. Trans. A 31A (2000) 409.

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