Effect of Texture on Anisotropic Thermal Creep of Pressurized Zr-2.5Nb Tubes

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Outline

- Research motivation and objectives
- Experimental materials and procedures
- Experimental results
- Modeling of creep anisotropy by using self-consistent polycrystalline models
- Conclusions
Crystallographic texture of a standard Zr-2.5Nb CANDU pressure tube

(0002) Pole Figure
Pressure Tube Deformation due to Creep

- Increases in length may exceed the allowances in end hardware, requiring expensive maintenance, or even replacement of the tubes.
- Increases in diameter result in coolant bypassing the fuel and loss of cooling effectiveness, and may require de-rating of the reactor.
- The anisotropic dimensional changes and wall-thickness reduction increase the transverse stress and accelerate the creep of pressure tubes.
- Therefore, there is a strong incentive to understand anisotropic creep and its relationship to crystallographic textures.
Current models – SELFPOLY7
In-reactor creep

Steady-state strain-rate ratio between the axial and transverse direction.

\[
\frac{\dot{\varepsilon}_A}{\dot{\varepsilon}_T}
\]

\((f_T - f_R)\) represents the texture of tubes, i.e., the difference of resolved factors of basal plane normal between the transverse and radial direction.
Objectives

- To provide a database of creep anisotropy of cold-worked Zr-2.5Nb tubes with different textures;
- To investigate the effects of stress, temperature, microstructure, texture and stress state on the creep anisotropy of cold-worked Zr-2.5Nb tubes;
- To assess an existing self-consistent polycrystalline model, SELFPOLY7, by the experimental data, and modify the model to improve the predictions on creep anisotropy of cold-worked Zr-2.5Nb tubes.
Experimental materials

Zr-2.5Nb fuel sheathing tubes (FS)

Zr-2.5Nb Micro Pressure Tubes (MPT) - made with different extrusion conditions to obtain various crystallographic textures
Some of measured textures in cold-worked Zr-2.5Nb tubes

(0002) pole figure
Experimental procedures of creep tests

- Pressurized thin-wall creep capsules
- Stress ratio=1:2 (axial: transverse)

- Tube furnace with argon cover gas

- Laser measurements of length and diameter
Creep test conditions

Based on preliminary tests, regime of dislocation creep is identified, i.e., strain producing mechanism is dislocation slip.

Standard conditions used for subsequent testing:
- Temperature = 350°C
- Transverse stress = 300MPa
- Stress exponent ≈ 6.4
Creep curves

Diameter

Max: 72.8E-06 h^{-1} \sim Min: 2.13E-06 h^{-1}
Over 30 times variation in creep rate at the same stress
Creep curves

Length

Axial strain

Creep time (hrs)

Negative : -2.1E-06 h⁻¹
Creep anisotropy at different textures

Internally pressurized standard FS and MPT capsules
under a transverse stress of 300MPa at 350°C
Existing model SELFPOLY7

Single crystal properties

- prism slip
- basal slip
- pyramidal slip

Crystallographic texture (ODF)

Crystal interactions w/matrix

Macroscopic properties (creep anisotropy)
SELFPOLY7 predictions

Internally pressurized standard FS and MPT capsule

Circled points cannot be manipulated to fit the data
What to change?

We know that grains of different orientations have different dislocation structures. Hence they will have different creep properties.

However, the existing self-consistent polycrystalline model solely based on crystallographic texture, assuming a uniform dislocation distribution.

How to take this into account?

Model the cold work during manufacturing to see the effect of the distribution of pre-existing dislocations on creep anisotropy.
Non-uniform dislocation distribution after cold-work

Shear strains caused by cold work in each slip mode, prismatic \(<a>\), basal \(<a>\) and pyramidal \(<c+a>\), are calculated by using the Elasto-Plastic Self-Consistent model.

Assume that dislocation density is proportional to the shear strain in each active slip system.
Modified model SELFPOLY7-Q

Single crystal properties
+ Dislocation distributions from manufacturing
+ Crystallographic texture (ODF)
+ Crystal interactions w/matrix
↓ Macroscopic properties
Comparison of SELFPOLY7 and SELFPOLY7-Q
Model vs Experimental data

- Model data points:
  - SELFPOLY7-Q (diamonds)
  - SELFPOLY7 (crosses)

- Slope = 1
Conclusions

- A database of anisotropy of thermal creep of cold-worked Zr-2.5Nb tubes with various textures is established;
- The creep anisotropy of cold-worked Zr-2.5Nb tubes is strongly dependent on crystallographic texture;
- Pre-existing non-uniform dislocation structure created after cold-work should be another considering factor to improve the creep anisotropy modeling of cold-worked Zr-2.5Nb tubes.
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