Effect of Strain Rate on the Mechanical Properties and the Dislocation Substructure of Niobium Single Crystals

High-speed sheet forming of SRF cavities with electro-hydraulic forming (EHF) showed promising results for OFE copper and niobium substrates [1,2]. The use of large-grain disks could significantly reduce the material cost for bulk niobium cavities, but cavities produced with deep-drawing showed forming defects (Fig 1).

The mechanical properties and dislocation substructures of niobium single crystals deformed in tension at strain rates greater than $10^{-1}$ s$^{-1}$ were unknown before this study and essential to understand the effect of high-speed sheet forming.

**Motivation & Objectives**

Tensile tests were performed for different crystal orientations at strain rate of $10^{-4}$ to $10^{3}$ s$^{-1}$ to measure mechanical properties. The deformed microstructure was then characterized with TEM.

**Crystal Orientation Selection for Tensile Tests**

1. Crystal orientation measurement for the 10 largest grains of a large-grain niobium disk.

2. Tensile sample crystal orientation selection based on Schmid law for the (110)<111> and (112)<111> slip systems.

**Methodology**

Tensile tests at quasi-static (1.3x10$^{-4}$ to 1.3x10$^{-2}$ s$^{-1}$), intermediate (1 to 100 s$^{-1}$), and high (~1000 s$^{-1}$) strain rates were performed with mechanical and servo-hydraulic tensile machines, and split Hopkinson pressure bars, respectively. Stress–strain curves are presented in Fig 4.

- Large increase in yield stress with increasing strain rate
- Reduction of anisotropy at high strain rate – likely explained by the activation of multiple slip systems at high strain rate

**Results**

**Tensile Mechanical Properties**

- Tensile tests at quasi-static (1.3x10$^{-4}$ to 1.3x10$^{-2}$ s$^{-1}$), intermediate (1 to 100 s$^{-1}$), and high (~1000 s$^{-1}$) strain rates were performed with mechanical and servo-hydraulic tensile machines, and split Hopkinson pressure bars, respectively. Stress–strain curves are presented in Fig 4.

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**Dislocation Substructure from TEM Analysis**

- Tensile specimens with the same initial crystal orientation deformed at low and high strain rates were prepared for TEM analysis (Fig 5).

**Low strain rate (1.28x10$^{-3}$ s$^{-1}$)**

- Long dislocations
- High dislocation density
- Dislocations often in preferred orientations
- Cell walls close to the fracture surface

**High strain rate (~1000 s$^{-1}$)**

- Short dislocations
- High dislocation dipole density (short loops)
- Homogeneously distributed dislocations
- Effect on superconducting properties?

**Conclusions & Perspectives**

**Conclusions**

- Reduction of anisotropy at high strain rate in tension
- Reduction of ductility with increasing strain rate
- Shorter and more homogeneously distributed dislocations at high strain rate

**Perspectives**

- Crystal plasticity modeling to implement in EHF finite element models – effect of orientation and strain rate
- Effect of the different dislocation substructures on the superconducting properties
- Forming of half-cells at high-speed with electro-hydraulic forming

**References**


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