Strain Rate Dependent Mechanical Properties of Textured Beryllium

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Abstract

In this work, the evolution of mechanical properties, microstructure and texture of beryllium were observed during compression at varying strain rates from 0.0001/sec to 5000/sec to compressive strains of ~20%. Because of their low symmetry, hexagonal metals, such as beryllium, cannot deform solely by dislocation emission and motion, but may accommodate enforced deformation through activation of twinning under certain conditions. We expect deformation twinning to be favored at high strain rates, and this assumption is borne out. By monitoring the texture evolution on the Spectrometer for MAterials Research at Temperature and Stress (SMARTS), the switch of parent to daughter grains is seen through the changes of diffraction peak intensities corresponding to each crystallographic plane normal (pole). Multiple parent directions (distinct grain orientations) are possible, and the data clearly shows that grains with (100) crystallographic plane normals parallel to the straining direction preferentially twin first.

Objectives

- To develop a physics based model for predicting enforced deformation behavior in beryllium.
- Find a connection between strain rate and deformation twinning and slip.
- Determine the effect of strain rate on the tendency for grains to twin. We expect deformation twinning to be favored at high strain rates.
- Seek to better understand micromechanics of twinning.

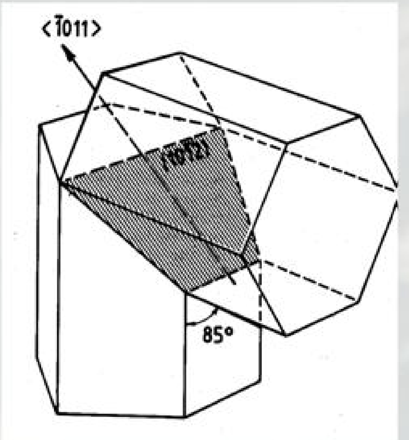

Figure 1: Twinning is a discrete reorientation of crystal symmetry

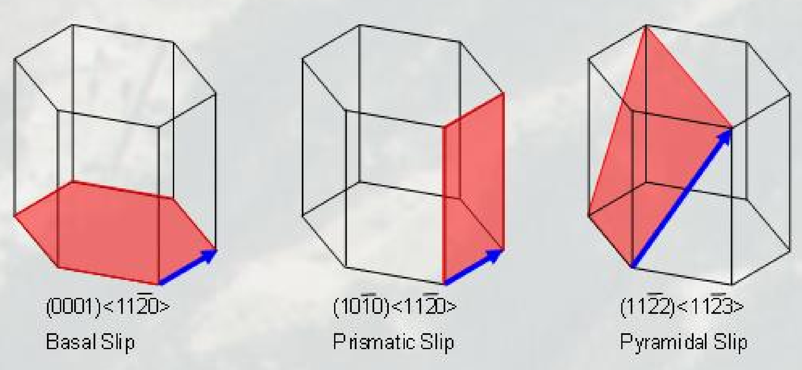

Figure 2: There are three different slip planes. Basal slip is preferred in beryllium, but depending on how the texture changes, prismatic slip could also occur.

Experiment

- Beryllium samples were analyzed with in situ neutron diffraction using Spectrometer for MAterials Research at Temperature and Stress (SMARTS).
- Samples from a rolled plate were compressed at room temperature along directions perpendicular to the plate normal (in-plane direction).
- The crystallographic texture dictates that grains with plane normal of the form (hk0), i.e. prism plane normals were parallel to the straining axis.

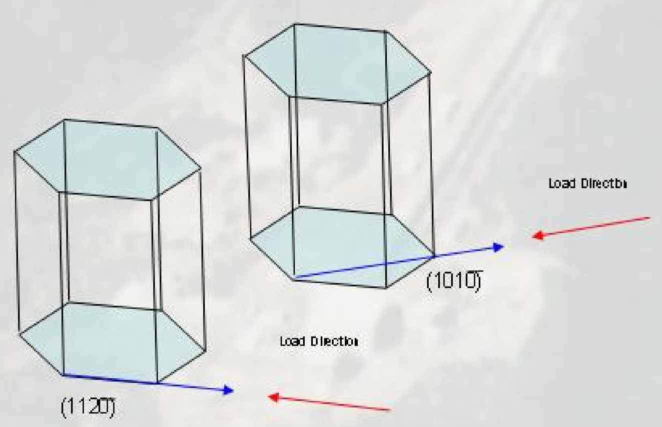

Figure 3: Loading directions of beryllium samples.

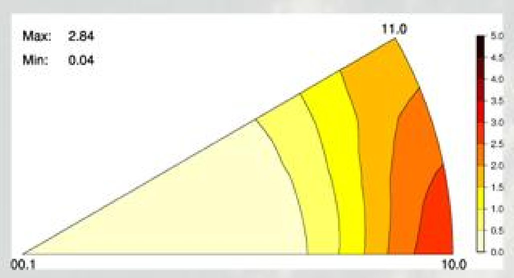

Figure 4: Inverse pole figure of the as received microstructure of the beryllium samples.

Data

- Rietveld texture analysis was completed using General Structure Analysis System (GSAS) software developed at LANSCE.
- GSAS was used to calculate Orientation Distribution Functions (ODF's).
- Inverse pole figures were drawn from the ODF's calculated in GSAS.

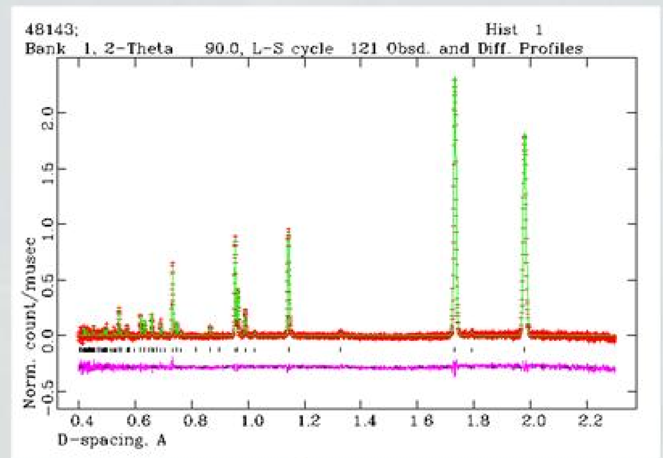

Figure 5: Diffraction data taken from a single run and analyzed using GSAS.

Repeatability

- Two distinct samples (repeats) were deformed to the same strain at strains rates of both 0.001/sec and 5.5/sec . The repeatability of the experiments is demonstrated by the similarities between the repeated mechanical tests and texture determinations.

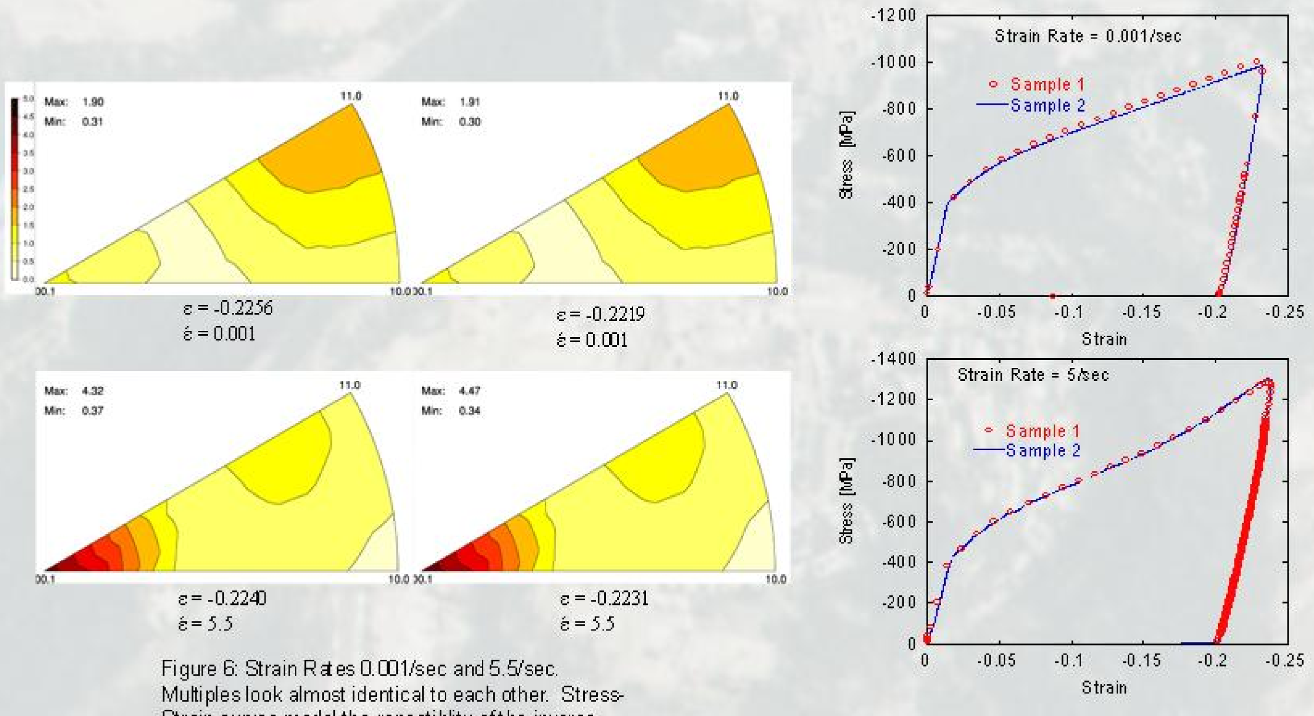

Figure 6: Strain Rates 0.001/sec and 5.5/sec. Multiples look almost identical to each other. Stress-Strain curves model the repeatability of the inverse pole figures.

Deformation twinning initiates in grains with {100} plane normal parallel to the straining direction.

- As strain increases on the samples, density of the (002) poles increases.
- The inverse pole figures show the distinction between the {100} and {110} poles and the presence of twins.
- The data clearly shows that grains with {100} crystallographic plane normals parallel to the straining direction twin first.
- The difference that we see between the {100} and {110} plane normals can be modeled with theoretical analysis

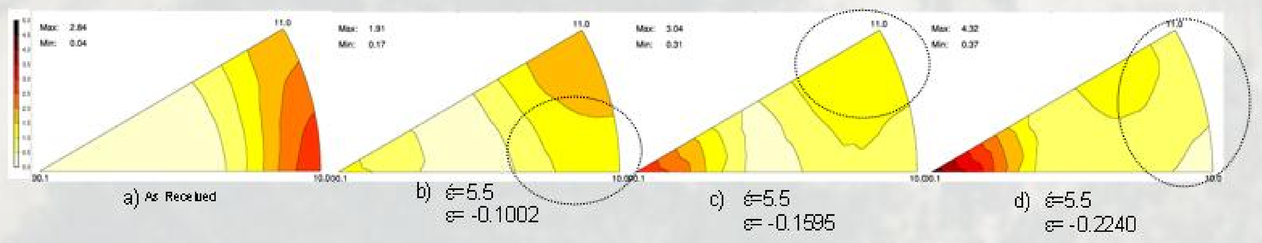

Figure 7: a) The orientation of the poles in the as received sample. b) At 10% strain, the pole density from the {100} direction decreases with respect to the AR sample as strain increases. c) At 15% strain, the {110} poles decrease later than the {100}. d) At 20% strain, the pole density of both the {110} and {100} plane normals have decreased.

Analysis

- The Schmid factor (SF) (m=cosλcosχ) can predict which grains will twin first. The higher the SF, the lower the stress at which twinning initiates.
- In beryllium's case, the SF when loading along to {100} crystallographic plane normal is ~0.49 while for {110} it is ~0.37.
- The {100} plane normal which has a higher SF shows a decrease in plane normals before the {110} plane normal.

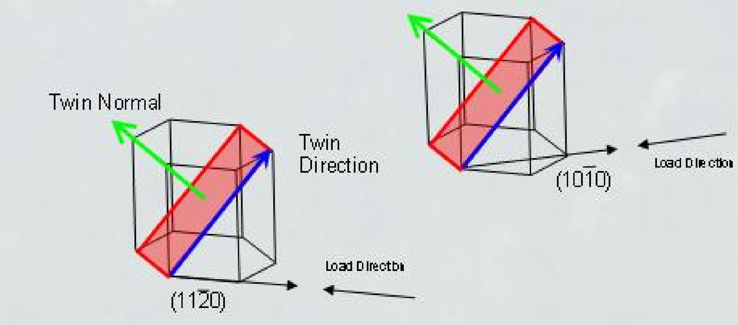

Figure 8: Shows where the twin normal and twin directions are with respect to the loading direction. The loading direction was anywhere between (1120) and (1010) crystallographic directions.

$\tau_{RRS} = \sigma \cos \lambda \cos \chi$
σ = Uniaxial stress (load frame)
λ = angle between σ and twin normal
χ = angle between σ and twin direction
Schmid Factor = m = $\cos \lambda \cos \chi$

Deformation twinning increases with increased strain rate.

- The as received microstructure has no (002) poles in the axial direction
- The increased density of (002) poles shows that twinning increases with increased strain rate.
- There is crossover behavior at 0.1/sec strain rate separating the intensity verses strain rate curve into two distinct regimes.

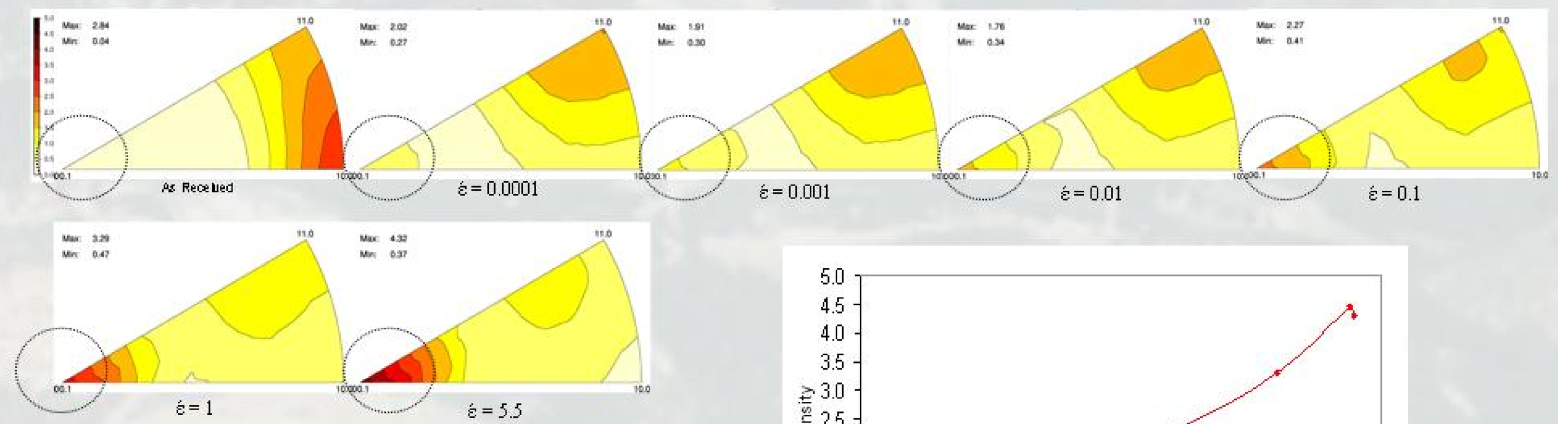

Figure 9: Inverse pole figures show increased (002) poles.

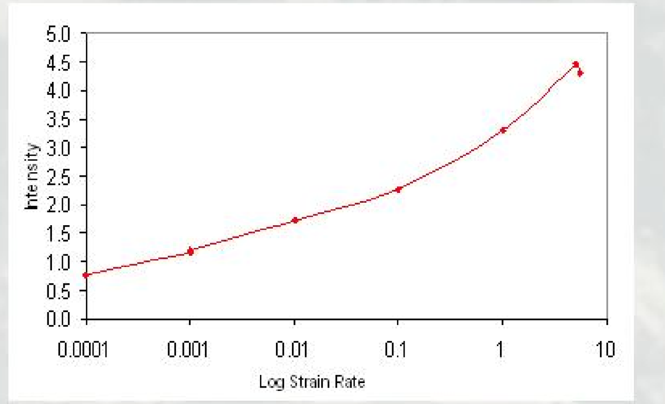

Figure 10: Intensity of (002) direction verses the log strain rate. Shows an increase in intensity as strain rate increases.

Conclusions

- Compressing transverse to the basal poles induces deformation twinning.
- Twins occur at all strain rates but are more prevalent at high strain rates.
- Slip is controlled by thermal processes whereas twinning advances at the speed of sound. Therefore in a high strain rate situation, twins will be more prominent.
- The twins may come from multiple parent directions but the data shows the first grains to twin appear from the {100} crystallographic plane normal while twins from the {110} plane normal come later.

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