Texture Gradient Effects on the Mechanical Response of a Rolled Tantalum Plate

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Introduction

OIM measurements were used to understand the unusual mechanical behavior observed in tantalum plate. The material used in this study was rolled and annealed vacuum arc-re-melted tantalum plate. Cylindrical compression specimens were machined from the plate in the orientations shown in figure 1. While all of the samples exhibited differences from each other, the through-thickness sample showed an unexpected shape after compression to strains near 0.3 as shown in figure 2. The sample exhibited an hourglass type shape instead of barreling or remaining cylindrical as is normally expected during a compression test. This is not to say the midsection of the compression sample "shrunk" during the compression test, rather the ends of the sample expanded more rapidly than the mid-section during compression. The degree of the hourglass effect was measured in two samples and found to be 94.7% and 95.4% respectively. This was calculated by dividing the cross-sectional area at the center of the deformed sample by the cross-sectional area at the end of the sample.

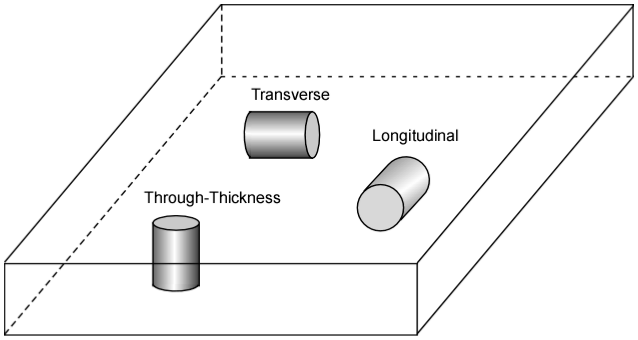

Figure 1 – Schematic of compression samples cut from rolled tantalum plate.

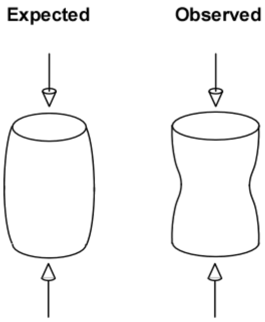

Figure 2 – Schematic of hourglass effect.

Originally, it was supposed that this effect could be due to a difference in grain size. The grains at the surface of the plate were generally larger (100µm on average) than the grains near the centerline of the plate (23µm). Large grained materials are generally softer than small-grained materials. Thus, the larger grains at the ends of the compression sample could have accommodated the strain more than the smaller grains at the center section of the sample. This would account for the hourglass shape. However, the Hall-Petch constant, which describes the relationship between softening and increasing grain size, is very small for tantalum. Calculations based on the Hall-Petch constant predict an hourglass effect of only 99.3%.

OIM Measurements

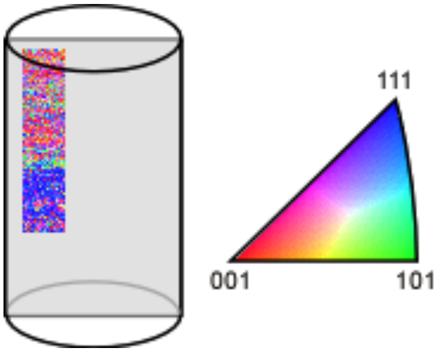

Figure 3 – Schematic showing location of OIM measurements.

Since the hourglass effect could not be explained by differences in grain size, we thought perhaps the effect could be due to differences in the local texture (i.e the distribution of crystal orientations in a polycrystal) between the surface and center of the plate. The cylinder was cross-sectioned lengthwise and OIM measurements made as shown in figure 3. The scan was relatively coarse, 11,000 measurements were made on a hexagonal grid with 20 micron spacing between measurements. The inscribed map shows the alignment of crystal directions with the compression direction of the sample. Grains colored blue have <111> crystal directions aligned with the compression direction and grains in red have <001> directions aligned with the compression axis. Deformation in tantalum occurs by slip on {110} planes primarily in the <111> direction. The propensity of a given grain to yield is a function of the orientation of the {110} plane and <111> direction relative to the compression axis. The <001> grains are oriented in such a way that slip more easily occurs. In fact, during compression many grains re-orient themselves toward the <111> orientation.

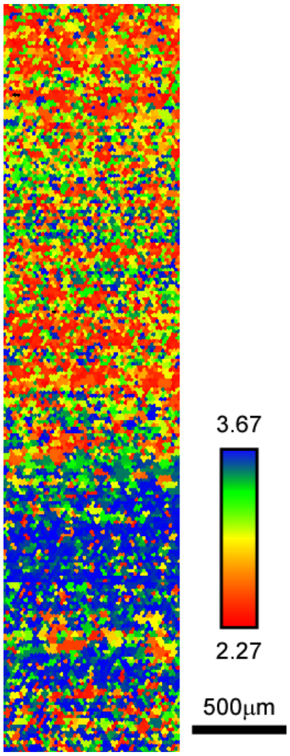

Figure 4 – A color OIM map based on the Taylor Factor. The blue denotes hard grains, the red soft.

The relationship between the gradient in local orientation and the mechanical response is evident in the Taylor Factor map shown in figure 4. This map was generated by calculating the Taylor Factor at each point in the scan and assigning the point based on the value calculated. The Taylor Factor describes the resistance of a grain to yielding, the higher the value the greater force required to initiate yielding. It is based on an assumption of deformation by slip along specified planes in a crystal. To calculate the Taylor factor, the slip system, crystallographic orientation and symmetry must be known along with the stress-state. The Taylor Factor is based on the orientation of the slip-system relative to the stress-state (uniaxial tension in this case). Note that to a large extent the Taylor Factor map mirrors the orientation map. This illustrates the ability of OIM to relate crystallographic orientation to a material property such as yielding.

Modeling the Hourglass Effect

An effort was made to model the hourglass effect using a modified Taylor Model as implemented in *LApp*, a polycrystal plasticity code developed at Los Alamos National Lab. This code is used to predict the evolution of texture and it's impact on the stress/strain behavior of a polycrystalline material. The inputs to this code are the boundary conditions (i.e. uniaxial compression in this case), the slip system (both $\{110\}\langle 1\bar{1}1\rangle$ and $\{110\}\langle uvw\rangle$ were used in the experiments) and a set of grain orientations. The output data of these calculations is essentially a stress-strain curve and a set of rotated grain orientations. We were able to use the stress-strain data to predict the degree of the hourglass effect arising from the texture gradient. Three sets of orientation data were derived from the OIM measurements: 1) all of the data, 2) the orientations near the mid-plane of the sample and 3) the orientations at end of the sample. These data were used to simulate the plastic deformation during the compression test. The resulting stress-strain curves are shown in figure 5. These curves show that the <001> oriented grains at the mid-plane are softer than the <111> oriented grains at the surface.

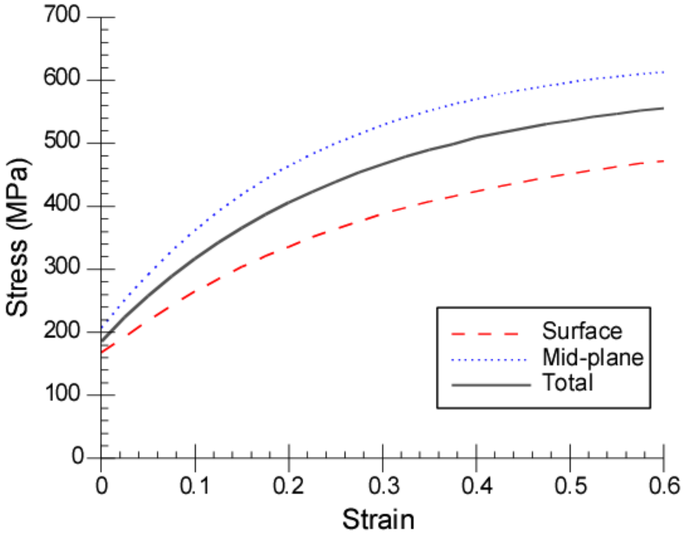

Figure 5 – Simulated stress-strain curves for tantalum plate.

It was assumed that the same amount of work occurred in the surface as in the mid-plane of the sample. We can find the amount of strain in the surface and mid-plane regions using the stress-strain curves. First we find the amount of work applied in the sample as a whole for the strain measured. This is the area under the curve out to the measured strain as shown in gray in figure 6. The strains measured for the two through-thickness samples were 0.273 and 0.261. Second, we determine the strain producing the same amount of work for the surface stress-strain curve (the red area in figure 6.) Third, we do the same for the mid-plane as shown in blue in figure 6. From the strain measurements we are able to calculate the area ratios. We obtained values of 93.6% and 94% respectively. These predicted values compare well with the measured values of 94.7% and 95.4%. The remaining 1% could be achieved by including the grain size-effect.

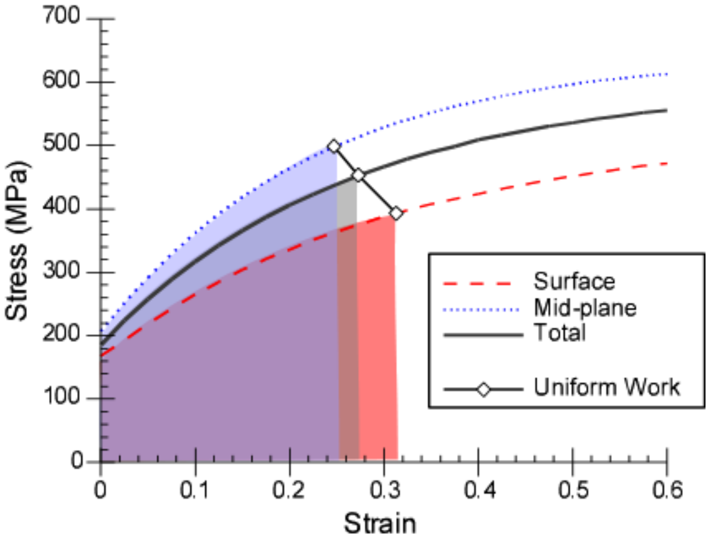

Figure 6 – Application of uniform work assumption to the compression sample strained to 0.273.

Summary

We were able to use the OIM measurements to understand the unexpected behavior of through-thickness compression samples cut from tantalum plate. The OIM data was used as input to a polycrystal plasticity to successfully model the unexpected behavior.

Bibliography

For more details on this work see the following papers:

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