4.7 CHARACTERIZATION OF THERMOMECHANICAL DAMAGE ON TUNGSTEN SURFACES DURING LONG-DURATION PLASMA TRANSIENTS - D. Rivera, A. Sheng, T. Crosby, N.M. Ghoniem (University of California, Los Angeles)

Extended Abstract of an ICFRM-16 paper accepted for J. Nucl. Mater.

Design of plasma facing components for fusion applications requires a detailed knowledge of the damage evolution characteristics of the constituent materials for safe and reliable operation. Tungsten has been declared as a candidate material for many plasma-facing components, and as such, its behavior under simulated fusion conditions must be fully understood before implementation can take place. In an effort to further study the effects mild plasma transients (on the order of 20 MW/m^2) have on plasma facing components, a series of experiments has been conducted in which circular tungsten samples are exposed to cyclic thermal loading. The heat source used is a Praxair SG-100 plasma gun whose output heat flux was measured both by water calorimetry and a specially designed heat flux sensor.

After exposure, samples are subsequently characterized by fabricating micro-pillars on the affected surface as seen in figure 1. These pillars are then tested under compression, and stress vs. strain data is generated as seen in figure 2. Although there is a definite size effect associated with compression of such small pillars, the generated data can be analyzed in a relative sense when compared to the data garnered from pristine pillars. The results indicate the onset of recovery mechanisms within the material as a function of the pulse number. This is evidenced by the reduction of the yield point, and the increase in curvature of the plastic portion of the stress vs. strain curves after exposure. This result is further corroborated by the change in deformation mode of the exposed pillars relative to their pristine counterparts. The deformation mode changed from a barreling type seen in the pristine pillars to one characterized by shear banding typical of well annealed crystals [1] as seen in figure 3. This behavior would indicate that initially the dislocation density in the preferred slip system for tungsten ({110}<111>) was too high for adequate dislocation slip, however after exposure, and the subsequent isothermal anneal, sufficient recovery of the microstructure was able to take place, allowing free dislocation movement in the aforementioned slip system. This is further corroborated by XRD data showing that the material is highly oriented in the <002> direction. Since the shear bands are oriented at 45° from the axis of the pillar, we conclude that the dislocation lines are indeed moving in the (110) planes.

Furthermore, scanning electron microscopy images of the exposed surface reveal the onset of small fractures initiated as a result of thermal cycling; these features can be seen in Figure 4. In order to gain a better understanding of the stress state leading to the surface fracture of the samples during a transient event, a finite element (FE) thermo-elastoplasticity model was developed. The results indicate that upon application of a heat load, compressive stresses build up in the center of the sample, leading to plastic deformation of the surface as can be seen in the von Mises stress map in figure 5. Upon the cooling phase of the cycle, however, the recovered elastic strain of the cooler parts of the sample exceeds that from parts that deformed plastically, resulting in a tensile surface self-stress (residual surface stress), which correlates with the surface fracture seen in the SEM analysis.

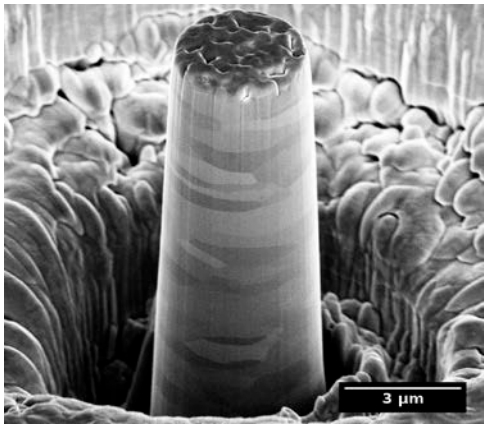

Figure 1. Newly fabricated pillar

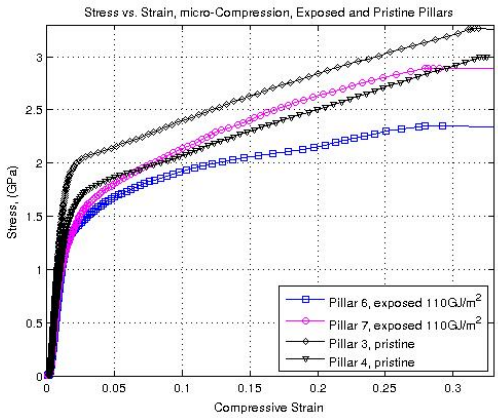

Figure 2. Stress vs. strain data for pillars fabricated from both pristine and exposed material, the stress state is compressive

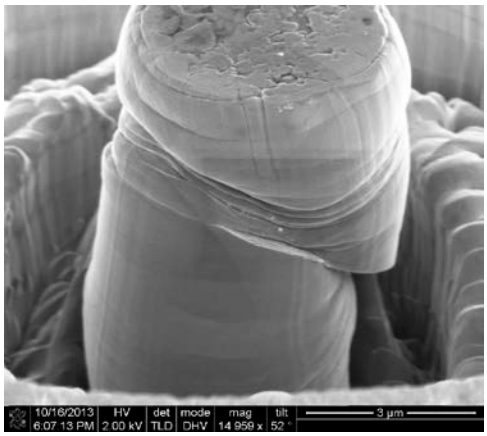

Figure 3. Shearing deformation mode resulting from high exposure to plasma transients.

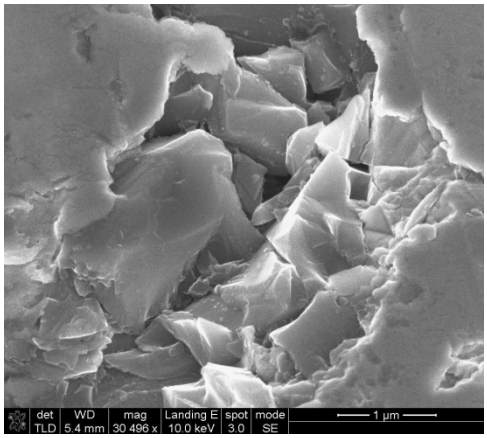

Figure 4. Brittle surface fracture of exposed specimen after 1000 cycles of 25 MW/m^2, each with a pulse duration of 4 s for a total absorbed energy density of 100 MJ/m^2.

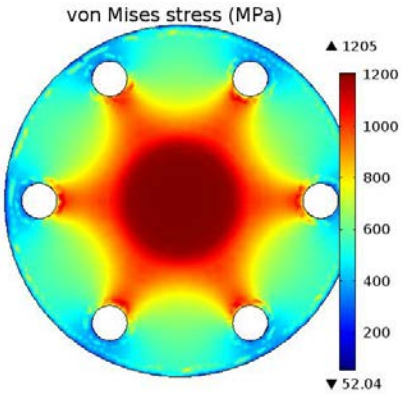

Figure 5. von Mises stress plot of the surface of the test sample during exposure to a 20 MW/m^2 heat pulse.

REFERENCES

[1] Reed-Hill, R. E. and Abbaschian, R, 1994, *Physical Metallurgy Principles,* PWS Publishing Co, Boston, MA, p. 725.