4.4 FABRICATION OF FUNCTIONALLY GRADED, TUNGSTEN STEEL LAMINATE - L.M. Garrison, E. Ohriner (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this project is to create functionally graded tungsten to steel laminate composites for use in plasma facing components in fusion reactors.

SUMMARY

Tungsten foils in thicknesses 250, 100, and 25 µm and grade 92 steel foils in nominal thicknesses 250, 100, and 76 µm were obtained. The foils were alternately stacked within a stainless steel container and then hot rolled at 1000°C to approximately 80% reduction of the original height to induce bonding. A sample of the rolled composite material was polished for metallographic analysis. Metallographic analysis of the foils is ongoing. Samples of the foils and the rolled composite will be tensile tested.

PROGRESS AND STATUS

Introduction

Tungsten's thermal and plasma-interaction characteristics have made it the chosen material for plasma-facing components in fusion reactors. However, tungsten's low toughness and small thermal expansion compared to structural steels are remaining challenges for using tungsten in a reactor. Creating a tungsten-steel graded composite would simplify the joint between the two materials in a plasma-facing component and would reduce the stresses induced by their different thermal expansions.

Results

Foil metallography

Tungsten foils in thicknesses 250, 100, and 25 µm were purchased. Grade 92 steel foils in nominal thicknesses 250, 100, and 76 µm were fabricated by cold rolling. In the as-rolled state, the foils' surfaces had striations from the rolling, but individual grains could not be identified (Figure 1). To understand the foil properties, it is necessary to examine the grain structure and texture in the initial state. Because of the thin nature of the foils, attempts to mount them in resin in the traditional way for polishing were unsuccessful. Instead, foils were attached to resin discs with double sided tape and then polished to a 1 µm diamond paste and colloidal silica finish. For the steel foils (Figure 2a and 2b) this polish was successful in removing the surface texture from rolling. However, it appears individual particles of the polishing media were trapped in the sample surface, seen as the dark spots with trails in the figure. For the thicker tungsten samples, Figure 2c and 2d, the polishing appears to have removed the directional striations from the rolling, but a finer texture remains on the surface that obscures the grains. For the thinnest tungsten sample, Figure 2e, some of the rolling texture is still visible after polishing. Alternate ways of preparing samples to reveal the grains for crystallographic texture analysis are being explored.

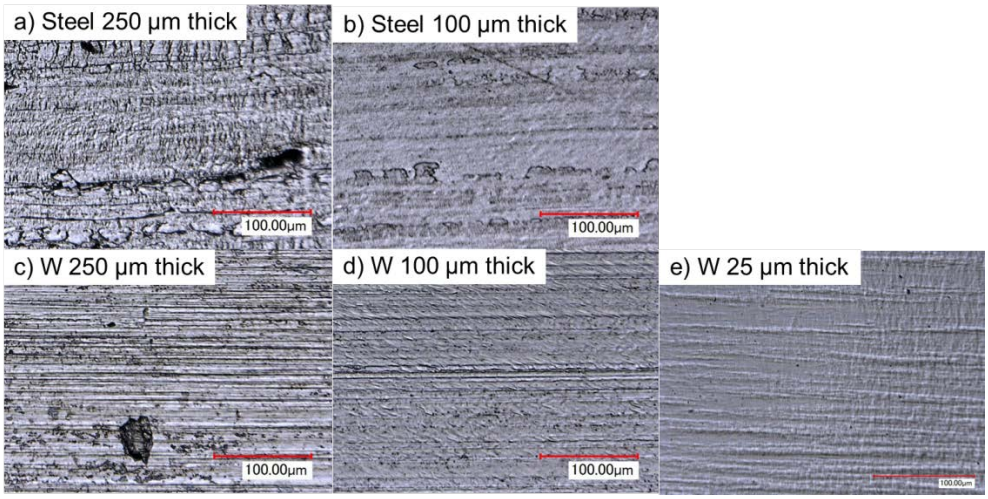

Figure 1. Surfaces of as-fabricated steel and tungsten foils imaged in a digital optical microscope using the HDR mode to enhance the texture.

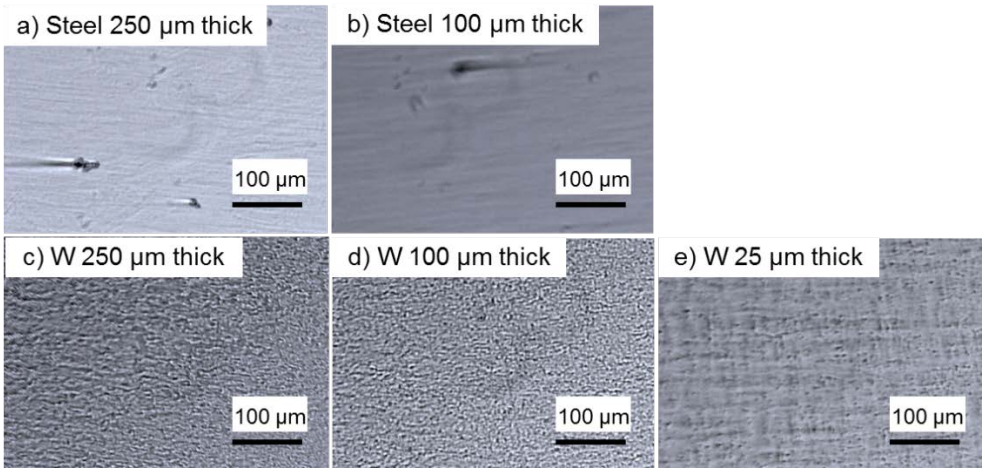

Figure 2. Surfaces of steel and tungsten foils after mechanical polishing, imaged in a digital optical microscope using the HDR mode to enhance the texture.

Rolled laminate composite

The foils were alternately stacked in a stainless steel box and then rolled at 1000°C to approximately 80% reduction. A sample of the resulting laminate composite was cut using electric discharge machining, mounted on its side, and polished to reveal the cross section of the layers (Figure 3). Layers that appear darker in the image are determined to be tungsten and those that are lighter are steel, based on the image contrast of the stainless steel outer layer and the nanohardness results (discussed below). In higher magnification images, contrast from other phases can be seen between the more evident tungsten and steel layers. Energy dispersive spectroscopy is planned to identify these phases.

Several numbered cracks are shown in Figure 3. All of the cracks that are visible are in the tungsten layers, and all of them are in Section 1 of the sample, which has the thickest tungsten pieces. Crack 1 is the widest of the cracks and is visible to the eye throughout the entire laminate material. At the left edge in Figure 3, Crack 1 is on the boundary between the tungsten and steel layer, but the crack moves to the interior of the tungsten layer for the remainder of the image. Cracks 2 and 4 are narrower, are in the

tungsten layer, and do not cross the whole sample. Crack 3 is located on the boundary between a steel and tungsten layer and traverses the whole section that was imaged. To avoid cracks in future laminate samples two strategies are proposed: reduce the processing temperature and increase the reduction per pass of rolling. Tungsten and steel have different coefficients of thermal expansion, so at a lower temperature the difference in expansion will be less, leading to less strain in the sample. An increased reduction per rolling pass also reduces the induced stress in the material. No cracks were observed in Section 2 or Section 3 that had initially thinner pieces of tungsten, so the thickest, 250 µm, tungsten foils may not be optimal for this project.

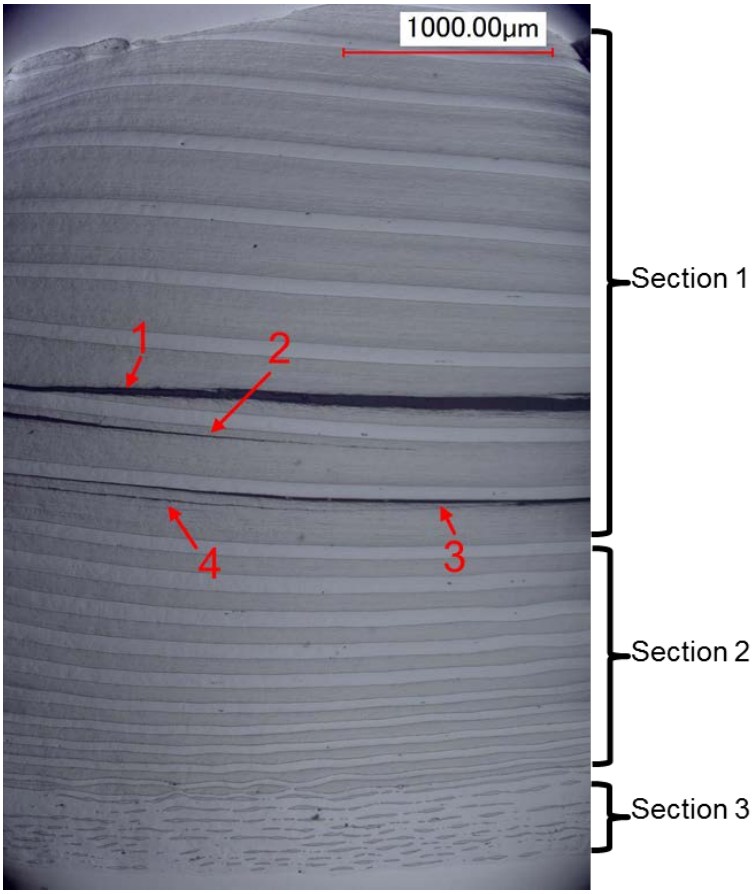

Figure 3. Cross section view of the rolled tungsten-steel laminate composite. The visible cracks are numbered. Layers with darker contrast are tungsten and those with lighter contrast are steel. Sections refer to different initial thicknesses of the foils. The rolling direction was horizontal in the image. Rounding at the edges of the image is an artifact of the optical microscope.

Figure 4 compares the initial thicknesses of the foils to the average thickness of the foils in the composite after rolling. The reduction of the tungsten and steel layers was essentially uniform in Section 1 with both materials experiencing approximately 34% reduction. The thickness of the layers In Section 2 after rolling varied from thicker layers closer to Section 1 and thinner layers closer to Section 3. In the pictured area in Figure 4c, the steel thickness was reduced by approximately 53% while the tungsten was reduced by approximately 44%. Within Section 2, but closer to the boundary with Section 3, the steel was more severely reduced than the tungsten; the maximum reduced layer of steel experienced about 78% reduction while the thinnest layer of tungsten in this section was only reduced by approximately 56%. The layers have a partially sinusoidal character to them, so there is a variation in the thickness of each layer throughout the sample. Because the steel and tungsten layers had different thickness reductions,

they also changed dimensions laterally by correspondingly different amounts to conserve volume, leading the composite to have a non-uniform outer boundary.

Section 3 was initially composed of the thickest steel foils and the thinnest tungsten foils. After rolling, the steel in this section experienced significantly more reduction, an average on the order of 83% reduction, than the steel in the other sections while the tungsten in Section 3 had approximately a 48% reduction (Figure 4d). The tungsten layers do not appear continuous, so the thickness and reduction estimates for the tungsten are taken from the centers of the visible tungsten islands. Because many cracks were found in Section 1, and the tungsten in Section 3 appears segmented, Section 2 appears to be the most successful.

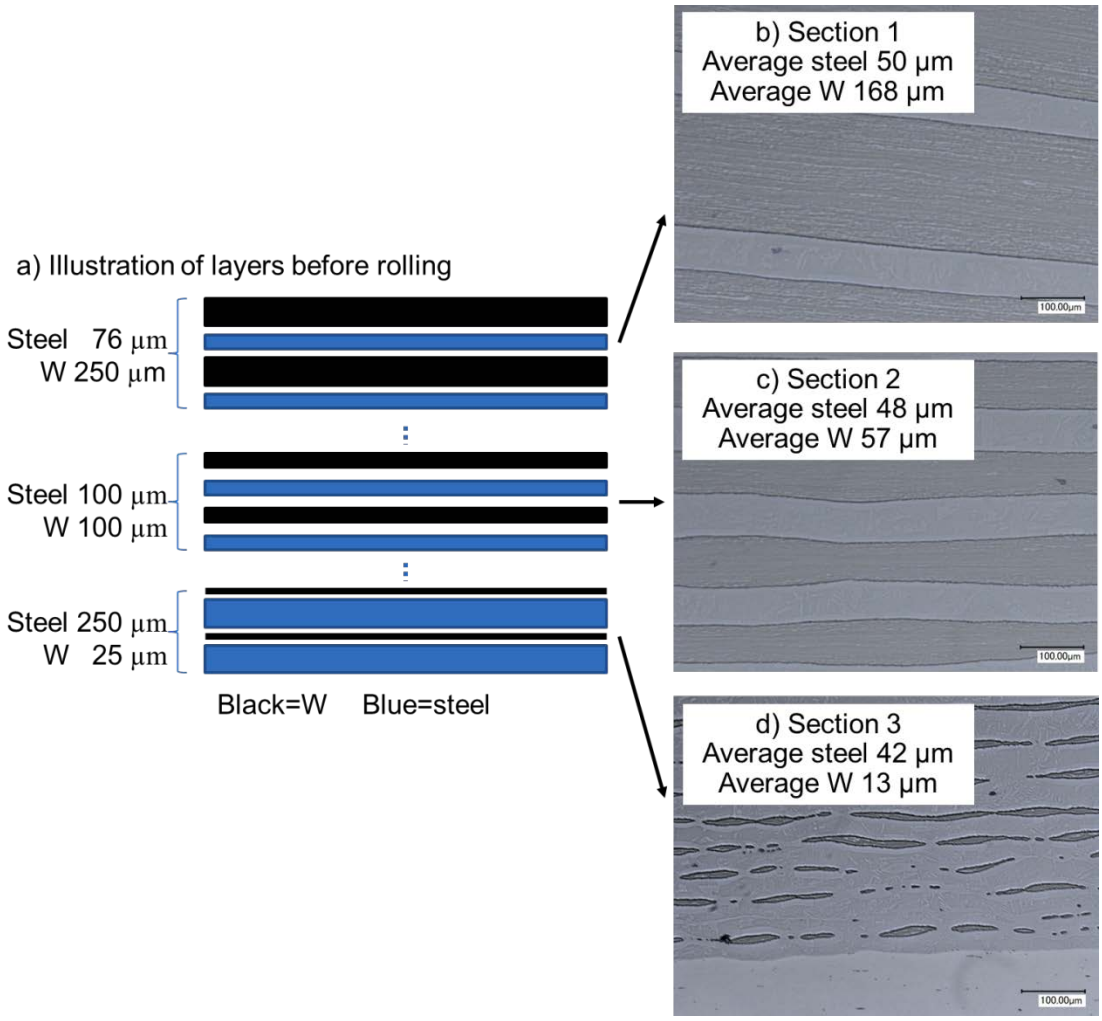

Figure 4. a) The stacking sequence of foils before rolling. Only four of the twenty layers of each of the three sections are illustrated. b), c), and d) are representative optical microscope images from each of the three different sections after rolling

Hardness

The as-received foil hardness measurements are shown in Figure 5; the measurements were taken on the 1 in. by 1 in. surface of the foils. Selected areas of the sample shown in Figure 3 were hardness tested and the results are presented in Figure 6. The hardness values in Figure 6 are of single measurements, and the corresponding indent images show that the indent size is comparable to the

thickness of the layers. Therefore the hardness values may be influenced by the surrounding layers and are only an initial estimate of the hardness. The general features revealed by the hardness tests are that the tungsten layers have higher hardness values than the steel layers, as was the case before roll-bonding the composite. A direct comparison between the hardness values in Figures 5 and 6 is difficult because the measurements were taken on different faces of the foils. It is expected that the foils have highly anisotropic grain dimensions, which may influence the hardness values on the top, as in Figure 5, versus on the cross section, as in Figure 6.

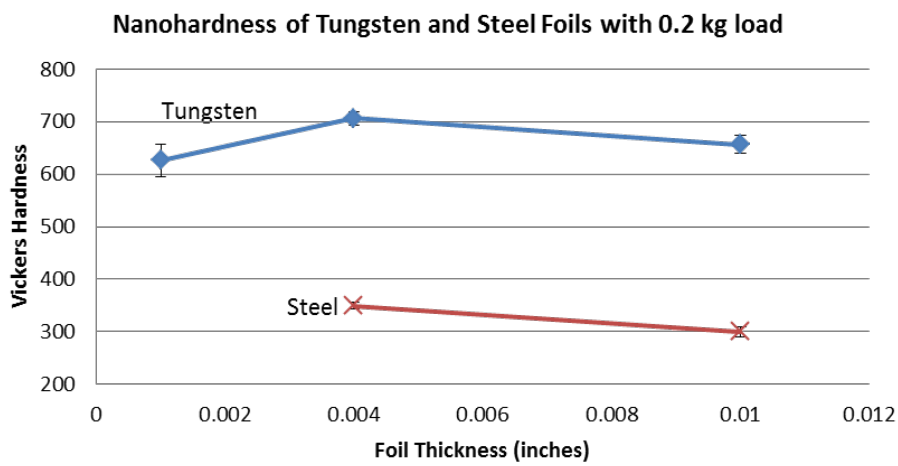

Figure 5. Hardness values for the tungsten and steel foils of various thicknesses.

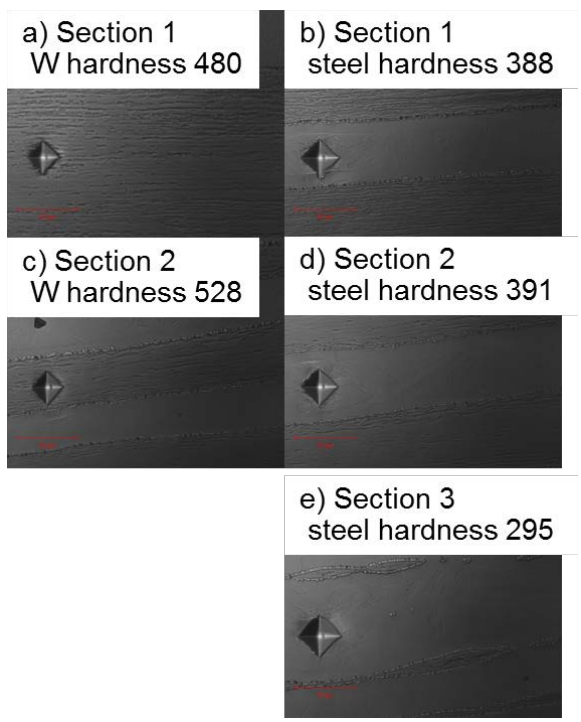

Figure 6. Individual hardness measurements for selected layers on the rolled laminate-composite material.