## 4.2 FABRICATION OF FUNCTIONALLY GRADED TUNGSTEN STEEL LAMINATES — L. M. Garrison (Oak Ridge National Laboratory)

### OBJECTIVE

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

### SUMMARY

Analysis is underway of the tungsten-steel laminate composites. The composite was fabricated from tungsten foils in thicknesses 250, 100, and 25 µm and grade 92 steel foils in nominal thicknesses 250, 100, and 76 µm. The fabrication was by forging and hot rolling at 1000°C. Shear punch tests were completed on the tungsten foils. Tensile and shear punch samples are being machined from the composite.

### PROGRESS AND STATUS

#### Introduction

For the plasma-facing components of fusion reactors, tungsten will be the interface between the plasma and the underlying structural component because tungsten has a low sputtering yield, high melting temperature, and relatively high thermal conductivity. However, because tungsten is brittle and has low fracture toughness, it is impractical to fabricate the entire plasma-facing component out of tungsten. Current divertor designs utilize various methods to bond the tungsten surface layer to the underlying structural part of the component that contains the cooling channels, but for future divertors where the operating temperature will be higher, more robust solutions are needed. Advanced steels are being developed for structural components in future fusion reactors. Unfortunately, tungsten and steel have vastly different coefficients of thermal expansion, so a direct joint would be subjected to intense thermal stresses. A tungsten-steel functionally graded material would ideally both improve the fracture toughness as compared to tungsten alone as well as reduce the thermal stresses between the tungsten and steel parts of the plasma-facing component.

#### Results

Previously, tensile tests were completed on the individual tungsten and steel foils. Because of the delicate nature of the foils, the results were sensitive to any slight misalignment of the foil in the fixture and any machining defects on the gauge section. This led to a wide scatter in the collected data and a high proportion of the tensile tests being invalid because of premature failure. Additionally, digital image correlation is not well suited to observing tensile tests of the tungsten materials at room temperature because of the limited plastic deformation before failure.

As an alternative to tensile tests, shear punch tests are a way to obtain mechanical property information about the materials. The advantages of the shear punch test are that they do not require a specific sample geometry, are insensitive to sample loading alignment, and are insensitive to edge defects on the material. Shear punch testing was completed on the tungsten foils of thicknesses 250, 100, and 25 µm. In the shear punch tests, the medium tungsten foil performed the best with more uniform and total elongation than the two other foil thicknesses (Figure 1). It is postulated that the thickest foil had low elongation because it may behave as bulk tungsten would. This is supported by the previous crystallographic texture analysis on the foils that revealed an almost uniform spread of grain orientations in the 250 µm foil as compared to the highly textured thinner foils (Figure 2). At the other extreme, the 25 µm foil may have few options for plastic motion because of the small number of grains present through the thickness. The 100 µm foil may have the benefit of the foil texture and foil effect of dislocations being able to annihilate on the surface, while still having enough grains through the thickness to allow for plastic

deformation.

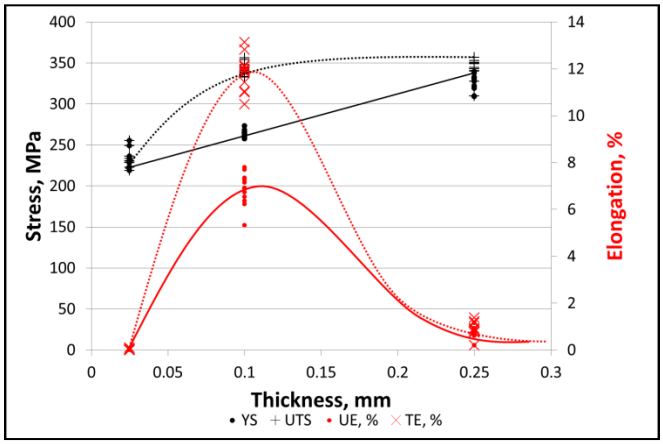


**Figure 1.** Shear punch yield stress (YS), ultimate tensile strength (UTS), uniform elongation (UE), and total elongation (TE) for the tungsten foils in thicknesses 250, 100, and 25 µm.

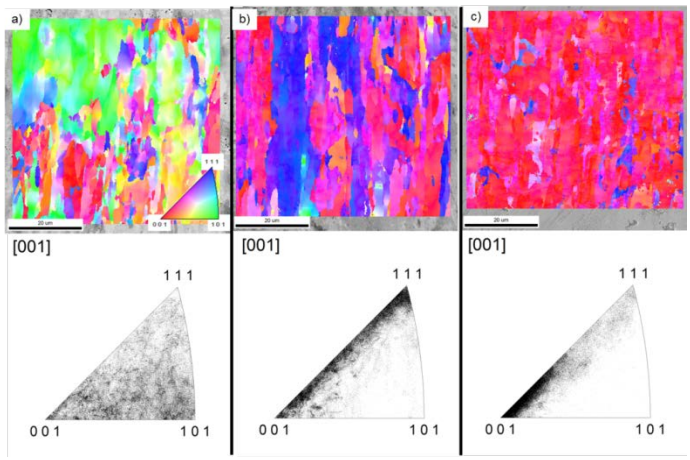


**Figure 2.** EBSD analysis of the a) 250 µm thick tungsten foil surface, b) 100 µm thick tungsten foil surface, and c) 25 µm thick tungsten foil surface. Rolling direction is vertical on the page.

The tungsten-steel composite was fabricated using an 80% overall reduction in thickness from the combined forging and rolling. The stresses present in the material during fabrication were more than the 250 µm tungsten foils could withstand, which caused several cracks to form in the tungsten layers (Figure 3). The largest crack had propagated throughout the entire tungsten layer in the composite, such that essentially Section 1 was separated from Sections 2 and 3. The consequence of this crack was that samples could not be fashioned from the whole thickness of the composite material. Instead, tensile samples with their tensile direction aligned to the composite rolling direction and flat face parallel to the foil faces are being fabricated from each of the three sections of the composite. These tensile samples will allow tensile testing followed by shear punch testing using the tab sections.

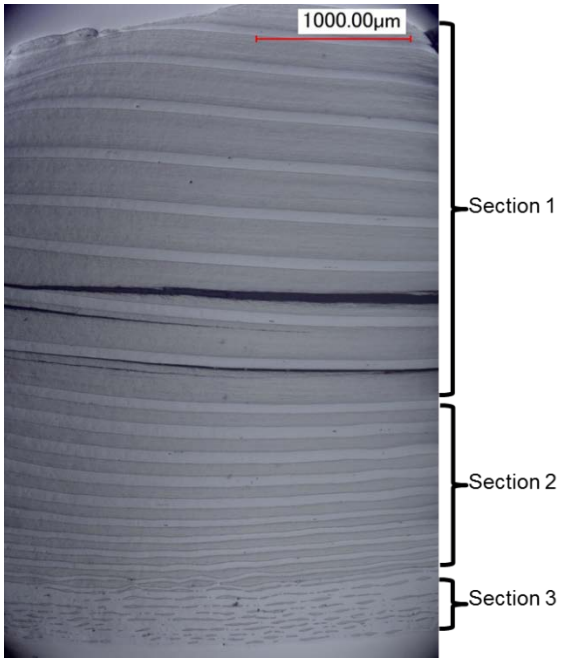


**Figure 3.** Cross-section of the tungsten-steel composite fabricated with 80% overall reduction in thickness. The flat planes of the foils are into the page as is the foil and composite rolling direction.