4.5 IRRADIATION EFFECTS IN TUNGSTEN-COPPER LAMINATE COMPOSITES — L.M. Garrison[a*], Y. Katoh[a], L.L. Snead[a, b], T.S. Byun[a, c], J. Reiser[d], M. Rieth[d], [a]Oak Ridge National Laboratory, [b]Present affiliation-Massachusetts Institute of Technology, [c]Present affiliation-Pacific Northwest National Laboratory, [d]Karlsruhe Institute of Technology

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Tungsten alone is not a suitable structural material for a fusion divertor or first wall. Creating a successful plasma-facing component with tungsten requires lowering the ductile to brittle transition temperature (DBTT) and improving the fracture toughness. A tungsten-copper laminate composite was previously tested in tensile, bend, and Charpy impact tests with much improved properties compared to tungsten plate or rod materials. The present study evaluated the tungsten-copper composite after irradiation in the High Flux Isotope Reactor (HFIR) at temperatures between 410 and 780°C to fast neutron fluences of $0.02\text{-}9.0\times10^{25}$ n/m^2, E>0.1 MeV (0.0064-2.88 dpa in tungsten). Tensile tests were performed on the composites at room temperature and temperatures up to the irradiation temperatures. The fracture surfaces were analyzed with scanning electron microscopy.

At all irradiation conditions and test temperatures, the copper within the composite failed by ductile knife edge failure, so the determining factor for the composite behavior was the tungsten and the interface behavior. Figure 1 summarizes the different zones of behavior observed by fracture surface analysis in the tungsten-copper laminate composite. The boundaries of the different zones, indicated with dotted lines, are not know precisely but are intended to draw the eye to the different failure modes observed in different regions of the parameter space.

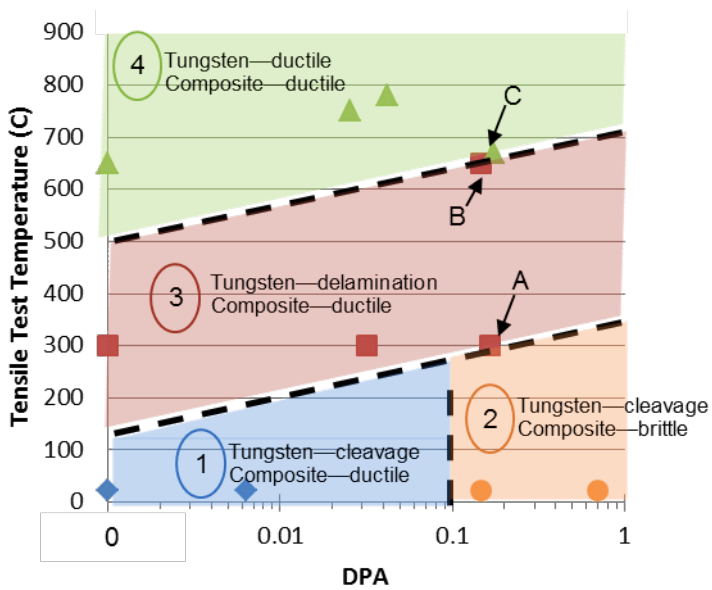

Figure 1. The different fracture modes of the tungsten layers in the tungsten-copper laminate are summarized as they depend on DPA and tensile test temperature.

In the unirradiated state, the composite had 15.5% elongation when tested at 22°C; the tungsten failed by brittle cleavage but the copper had a ductile knife edge failure, indicating that the copper successfully held the composite together after the tungsten layers fractured. In both Zones 1 and 2 in Figure 1, the tungsten layers failed by brittle cleavage. However in Zone 1, up to ~0.1 dpa, the composite as a whole had ductile failure, while after more than ~0.1 dpa, Zone 2, the composite as a whole had brittle failure.

In the unirradiated state, the boundary between brittle cleavage and delamination for the tungsten layers occurs between 22 and 300°C. After irradiation to 0.17 dpa at 420°C and tensile tested at 300°C (SW18, point A in Figure 20) the tungsten layers had mixed mode cleavage and delamination failure, indicating that the irradiation has extended the boundary between cleavage and delamination to a higher temperature. At this irradiation temperature, the primary irradiation defect in the tungsten is expected to be loops and a few voids, which cause the increase in hardness and brittle behavior, while the copper is expected to experience irradiation softening.

The boundary between delamination and ductile failure for the tungsten in the unirradiated state was ~500°C. After irradiation, tungsten in composite SW26 at condition B, 0.15 dpa and tensile tested at 650°C, failed by delamination, while in SW14 at condition C, 0.17 dpa and tensile tested at 670°C, the tungsten layers failed in a ductile fashion, so the delamination-ductile boundary was set between points B and C. All composites tested at 670°C and above had ductile tungsten failure and ductile overall composite behavior.