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The Synergistic Effects of Plasma and Heat Loads on Dispersion-Strengthened Tungsten in DIII-D

Chase Hargrove[1], Matthew Parsons[2], Ashrakat Saefan[1], Jonathan Coburn[3], Florian Effenberg[2], Ryan Hood[3], Dmitry Rudakov[4], Tyler Abrams[5], Xing Wang[1]
[1]The Pennsylvania State University, [2]Princeton Plasma Physics Laboratory, [3]Sandia National Laboratories, [4]University of California-San Diego, [5]General Atomics
Email(speaker): cqh5778@psu.edu

Dispersion-strengthened tungsten (DSW) alloys exhibit improved mechanical properties compared to pure tungsten (W), making them promising candidates for fusion pilot plants. It is essential to investigate DSW's surface stability under reactor-relevant conditions. The behavior of 1 wt% transition metal carbide (TaC, TiC, ZrC) reinforced DSW was investigated under H-mode plasma conditions in DIII-D using the Divertor Materials Evaluation System (DiMES). The results indicate that TiC dispersoids provide superior surface resilience against heat and plasma exposure, providing a down-selection within the class of DSW materials suitable for fusion pilot plant applications. Previous studies on hydrogen retention in Ti DSW suggest additional studies are needed on the interplay between grain refinement and H trapping.[1] For each DSW type, samples were mounted both flush with the divertor floor and at a 10° angle towards the incident plasma flux to achieve higher thermal loads. The outer strike point was rastered across the DiMES location to uniformly distribute heat fluxes across the samples, as shown in Fig. 1.

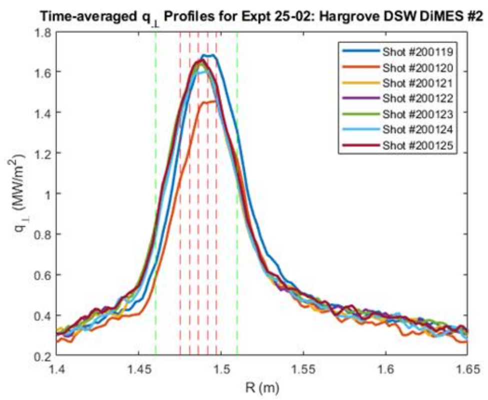

Figure 1. Time-averaged heat flux profile across the DiMES sample holder for DSW samples.

Identical exposures and analyses were repeated for as-received samples, and samples pre-implanted with 10^{18} cm^{-2} helium at 200eV to an implantation depth of 2.5nm. As DSW samples have been shown to be more resilient to surface cracking than IGW under transient heat loads[2], ITER grade W was concurrently exposed as a control. A micron-scale fiducial marker was placed on each sample before plasma exposure as shown in Fig. 2a. The evolution of dispersoids is characterized by energy-dispersive spectroscopy (EDS) and x-ray photoelectron spectroscopy (XPS). Post-exposure analysis by scanning electron microscopy (SEM) found no evidence of melting or cracking on the flush-mounted samples, regardless of composition, demonstrating excellent surface stability of DSW. Micron-scale Ta deposits were seen on flush-mounted ITER W, in addition to macroscopic melting on the angled W-TaC. The location of melted deposits with respect to the ITER W and W-TaC samples is consistent with J x B forces moving Ta. Further analysis of the angled samples revealed surface damage variations among as-received, helium implanted, and heated samples, ranging from dispersoid sublimation (Fig 2) to microscale cracking. In W-ZrC and W-TaC angled samples, the damage was significant enough to destroy the fiducial marker in addition to large, melted regions of Ta and Zr. In contrast, the fiducial marker was visibly evident on the surface of all three W-TiC angled samples, regardless of the initial condition.

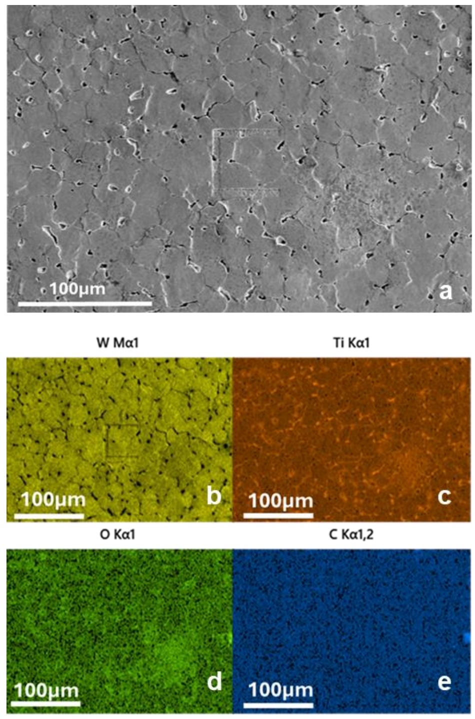

Figure 2. Post exposure SEM and EDS map of the Angled W-1TiC sample showing dispersoid sublimation.

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