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Tungsten Alloys with Enhanced Stability and Manufacturability Through Integrated Alloy Design and Microstructural Engineering

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Of the many significant materials challenges for future fusion reactors, the susceptibility of tungsten to recrystallization above 1200°C and its stability under thermal transients continues to plague the development of stable divertor armor. Additionally, the need for geometrically complex components to control strike point interactions has driven interest in laser additively manufactured (AM) tungsten, which suffers from cracking during solidification. In this presentation, two computationally designed tungsten alloys are introduced for addressing the intrinsic limitations of unalloyed tungsten in terms of thermal stability and manufacturability. The first material is a grain boundary stabilized ultrafine grained W-Ti-Cr alloy. Constructed using computational thermodynamics, alloy design maps are used to identify compositional complexities that stabilize fine-grained microstructures via synergistic thermodynamic and kinetic mechanisms. The resulting W-Ti-Cr (>95 wt.% W) compositions are synthesized through high energy ball milling and field assisted sintering with stable microstructures demonstrated up to 1500°C, well above the common recrystallization point for unalloyed tungsten.

The second W-Ti-Fe (>96 wt.% W) alloy was developed through a CALPHAD-based alloy design strategy to fabricate laser AM tungsten materials free of process cracking and with improved fracture properties. Microstructures are first contrasted with pure laser AM tungsten and demonstrate an effective "crack-healing" mechanism attributed to the presence of a solute-rich phase during solidification, which simultaneously enhances the alloy's capacity for plastic strain accumulation relative to pure laser AM tungsten. A second comparison is made with tungsten processed through electron beam (e-beam) melting. Densities are reported up to 99.98% with process parameter − texture correlations identified. Mini tensile test samples extracted in build and perpendicular directions were tested up to 800°C and revealed exceptional strength and ductility, but unsurprisingly anisotropic properties. A reduction of preheat temperature and accelerated build times were achieved by using a W-3Re alloy, which are contrasted to the laser AM W-Ti-Fe alloys in terms of microstructure and properties. Collectively, we show that all these novel classes of tungsten alloys provide a basis for enhancing plasma facing armor performance relative to unalloyed tungsten in terms of thermal stability and manufacturability.