Advanced manufacturing of tungsten for nuclear fusion applications using selective laser deposition: microstructure and properties

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Abstract: Tungsten has been widely used in plasma-facing components for first wall and divertor of future nuclear fusion reactors. However, pure tungsten is difficult to process due to its high melting point and brittleness. As components directly exposed to plasma, tungsten faces the risk of burn-out and cracking during high-temperature plasma operation; therefore, surface repair of tungsten has become a key concern. This study aims at the issue of surface repair by employing selective laser deposition process to fabricate pure tungsten. A novel ring and core beam shaping strategy with a single mode core and a multimode annular ring was utilized to achieve effective keyhole formation using core and a wider and homogeneous melt pool with annular ring. The microstructure and properties of pure tungsten were systematically investigated under constant core power but varying ring powers, substrate and powder size. The element distribution and defects in printed tungsten were also analyzed in depth. Results indicated that optimal surface quality and tungsten properties were obtained at a laser ring power of 320 W and a powder size of 15-25 μm on RAFM (reduced activation ferritic/martensitic) steel. Cross-sectional microstructural observations revealed that the W-steel interface ultimately formed a three-zone gradient material. Cracks predominantly occurred in the transition zone, primarily due to elemental migration and the formation of hard, brittle Fe-W inter-metallic compound. Grains in this transition zone exhibited a dendritic structure. Hardness distribution data revealed exceptionally high Vickers hardness (650 HV3) in the transition zone, closely correlated with microstructure and the brittle second phase. By using the finest powder size and moderate power, tungsten parts with a purity of up to 97% can be obtained, and the crack rate in tungsten is minimized. This work explored an innovative and promising manufacturing method of pure tungsten without vacuum environment, offering new insights for on-site manufacturing of fusion reactor components.

Keywords: Tungsten, Plasma-facing components, Surface repair, Laser deposition

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