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Development of Lattice Structures of pure Tungsten for Applications in Fusion Energy

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Abstract

Nuclear fusion is a critical element in moving to non-hydrocarbon energy sources where there are advantages to fusion reactors based on reliable shut down capability and significantly reduced half-life of waste materials. However, fusion requires temperatures in the range of 100×10^6 °C consequently the energising plasma must be critically maintained within the reactor to allow the fusion reactions to occur. Tungsten has been defined as the optimal material to line the reactor internal walls. Tungsten is characterized unique material properties; the highest melting point metal (3422°C), high hot tensile strength (350 MPa at 1000°C), large heat capacity and maximal vapor shielding [1]. The use of tungsten as a plasma facing components for reactor wall lining, is enhanced if the tungsten is orientated to present a porous lattice structure to the plasma[2].

To date, attempts to use produce complex lattice-based plasma facing components based on thermal modelling of function and produced using LBPF (laser 3D printing) have resulted in substandard lattices, where the microstructures are characterized by numerous defects consisting of micro-cracks, micro-voids and non-designed pores. These observations indicate that the likely cause of the cracking is through thermal shock due to the rapid cooling (~104 K/s) during printing of the lattice[3].

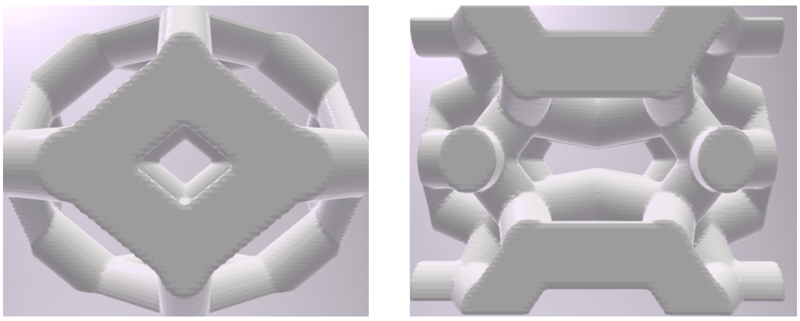

Figure 1 a) base line "C" cell design b) new "W" cell design

In the present study LBPF additive manufacturing (AM) of tungsten lattice structures has been investigated. A new method is proposed to adapt L-PBF process parameters for lattices and alternate lattice unit cell designs are investigated including the baseline C-cell design also known as Kelvin cell – previously developed by the EUROfusion Consortium for higher thermal performance [3]. New lattice designs "W cell" are investigated to reduce manufacturing process induced defects and manage thermal loads during processing in the unit cell structure, figure 1. The unit cell designs were manufactured and mechanically tested to compare with the baseline data, figure 2 &3.

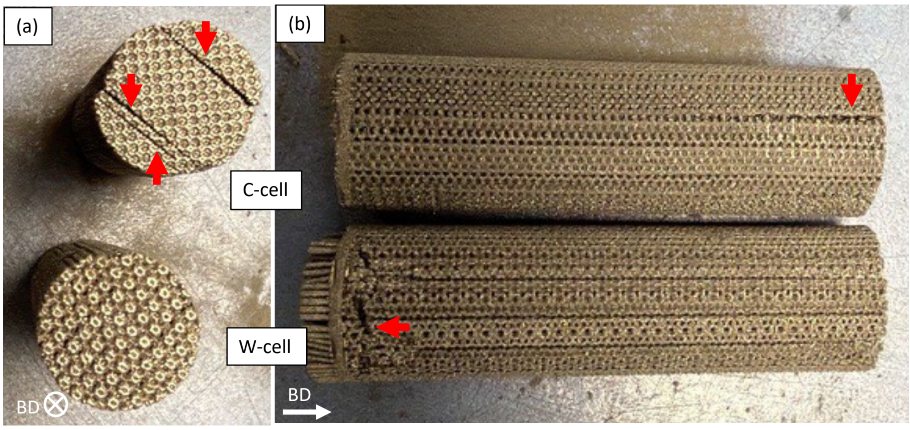

Figure 2 – (a) Top and (b) side views of C-cell (top) and W-cell (bottom) tensile lattice specimens tested without solid caps. Red arrows show location of fractures.

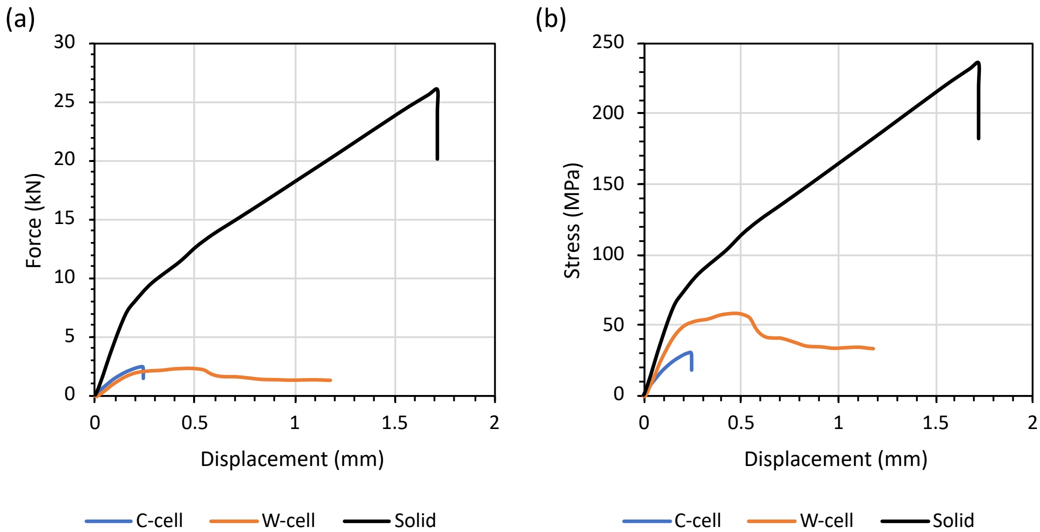

Figure 3 - (a) Force- and (b) stress- displacement curves from tensile testing of C- and W-cell lattice specimens compared to a solid specimen. Cylinder specimens with overall diameter of 11.88 mm was used.

The modified unit cell design denominated the "W-cell" showed improved manufacturability. Crack density, crack length, and crack width in the W-cell were reduced around 67 %, 25 %, and 56 %, respectively, in comparison with the C-cell reference. Preliminary tests indicate that W-cell lattice structures could improve strength and ductility under both compressive and tensile loads, in comparison with C-cell lattice structures with the same mass. Further study is needed to understand the thermal performance of the modified W-cell for limiter plasma facing component application. A compromise between thermal performance and manufacturability is proposed as a critical consideration for new plasma facing component designs.

1 .D Tsuru, M Fukumoto "Design, research and development for plasma facing components" JT-60SA- Physica Scripta N T171
2. J. H. You *et al.*, "Limiters for DEMO wall protection: Initial design concepts & technology options," *Fusion Engineering and Design*, vol. 174, p. 112988, Jan. 2022,
3. J. H. You ., "Limiters for DEMO wall protection: Initial design concepts & technology options," *Fusion Engineering and Design*, vol. 174, p. 112988, Jan. 2022,