Experimental characterization of tungsten monoblocks exposed to pulsed high heat loads

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Experimental characterization of tungsten monoblocks exposed to pulsed high heat loads

V.D. Shah, J.A.W. van Dommelen and M.G.D. Geers

V.Shah1@tue.nl

1. Introduction

In future tokamak based nuclear reactors (such as ITER), the divertor performs the vital function of extracting heat and ions from the plasma. Furthermore, the divertor design for ITER consists of tungsten (W) monoblocks, equipped with a CuCrZr heat sink. Under normal operating conditions, the presence of pulsed high heat flux (HHF) loads of 10 to 20 MWm^{-2} will result in a steep temperature gradient along the monoblock depth, ultimately evolving the bulk microstructure due to recrystallization and grain growth, in addition to degradation of the surface via melting, roughening, erosion and crack nucleation. These microstructural changes will adversely influence the thermal fatigue lifetime of the monoblocks, and are a major concern for the reactor lifetime. Thus, an in depth understanding of the damage mechanisms under HHF loading is necessary. As a first step, a thorough macro to micro scale characterization of the W monoblocks exposed to several thousand cycles of pulsed HHF loads is performed in this work.

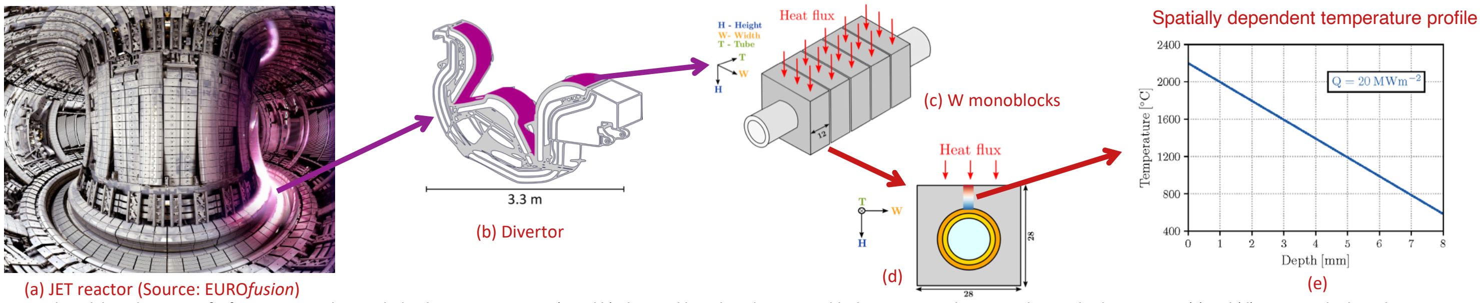


Figure 1: Tokamak based concept of a fusion reactor along with the divertor component (a and b), designed based on the W monoblock geometry with a CuCrZr heat sink. The images in (c) and (d) respectively show the isometric and the front view of the monoblock geometry. The temperature gradient along the monoblock depth due to the HHF load of 20 MWm^{-2} (highlighted in d) is depicted in (e).

2. Method

HHF exposure:

- Electron beam exposure at ITER divertor testing facility (IDTF), Russia.
- Loading scheme: 10 MWm^{-2} (5000 cycles) + 20 MWm^{-2} (1000 cycles).

Post exposure characterization:

- Roughness: Interferometry.
- Microstructure:
  1) Light microscopy.
  2) EBSD.
- Hardness: Micro-indentation.

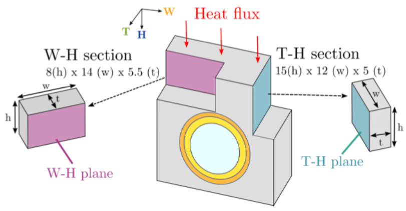


Figure 2: The investigated cross-sections (W-H and T-H) following HHF exposure of W monoblock.

3.1 Results: Macrostructure characterization

- Transition in surface reflectivity (red lines) indicating the extent of the HHF assisted microstructural changes due to recrystallization and grain growth (Figure 3).
- Substantial barreling of the monoblock geometry due to high temperature and internal stresses (Figure 4a).
- No macro/micro-crack formation.

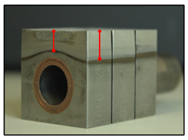


Figure 3: The HHF assisted change in the reflectivity of the top 5–5.5 mm of the monoblock.

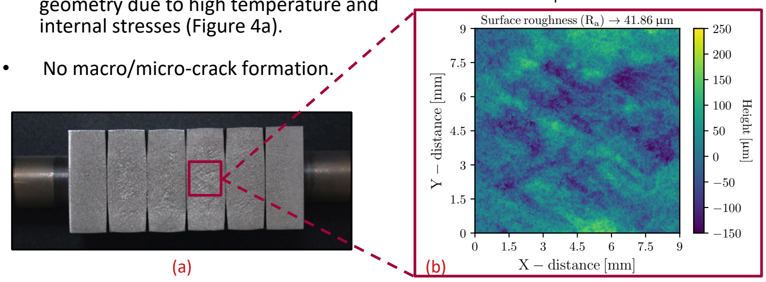
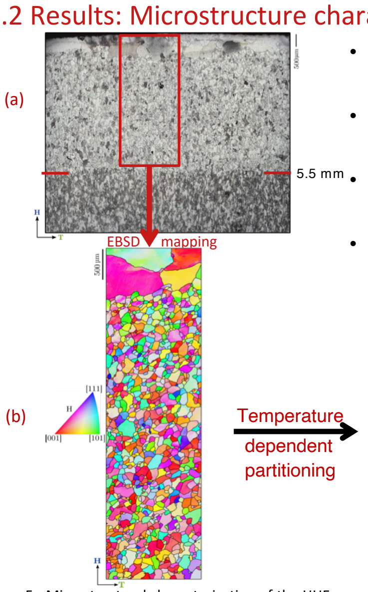


Figure 4: Macrostructural changes in the monoblock geometry following HHF exposure with (a) a significant barreling of the geometry, and (b) the surface topography with a mean roughness of 41.8 μm as compared to 0.72 μm in the unexposed state (not shown here).

3.2 Results: Microstructure characterization



- Recrystallized grain structure up to depth levels of 5.5 mm.
- Depth greater than 5.5 mm: Initial grain structure (deformed state).
- Abnormal grain growth near surface, due to high temperature.
- Surface to bulk: Transition from low angle to high angle ($\geq 15^o$) type grain boundaries

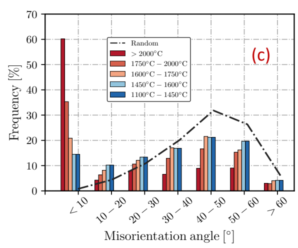


Figure 5: Microstructural characterization of the HHF exposed monoblock (T-H plane), (a) optical micrograph (b) Height direction IPF map of the recrystallized region (c) Temperature/depth dependent grain boundary character distribution corresponding to the map shown in (b).

3.3 Results: Structure – Property

- The hardness varies over the depth due to temperature variations.
- Significant loss of hardness in top region following HHF exposure.
- Two stage hardness profile:
  1) Recovery and partial recrystallization (T: 920-1100 °C).
  2) Full recrystallization (T > 1100 °C).

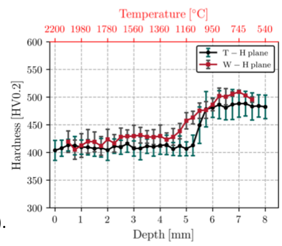


Figure 6: Temperature/depth dependent hardness profile in the HHF exposed W monoblock.

4. Conclusion

Substantial roughening of the monoblock surface was observed along with barreling of the monoblock geometry following the HHF exposure. Additionally, significant changes in the grain structure occurred up to 5.5 mm along the monoblock depth due to recrystallization. However, no recrystallization assisted macro-crack formation was observed. The inhibition of the macro-crack formation can be attributed to the higher fraction of low angle grain boundaries near the surface, thereby enhancing the strain compatibility between the grains and aiding in ductile behavior of the recrystallized W.

materials innovation institute

research instruments