Assessment of Low Cycle Fatigue Behaviour of OFHC Copper at Room & High Temperatures

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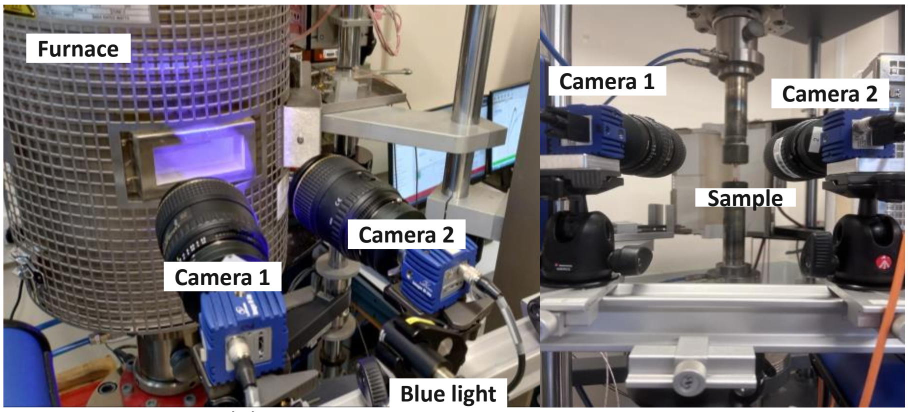
Abstract

The European DEMOnstration Fusion Power Plant DEMO is a crucial step in advancing sustainable fusion energy, bridging the gap between ITER and commercial fusion reactors. Copper and its alloys are the main candidates for high heat flux components, specifically for divertor monoblock components. Oxygen-Free High Conductivity (OFHC) copper (Cu) is used as an interlayer material to join Tungsten (W) used as the first wall material and Copper-Chromium-Zirconium (CuCrZr) alloy is used as a cooling pipe. These components endure significant thermomechanical stresses, and severe damage due to high thermal load cycles, combined with high electromagnetic loading, irradiation damage and complex cyclic loading as a result of the plasma pulsed mode operation in service [1]. Therefore, the knowledge of the impact of cyclic loading is crucial to assess its effects on the fatigue lifetime of the component.

In this study, the Low-Cycle Fatigue (LCF) regime is investigated to simulate the in-service large disruptive events in a fusion reactor. LCF has a high loading amplitude that is dominated by plastic deformation and therefore the number of cycles is expected to be low, resulting in the component failing due to the accumulation of plastic strain. To characterise the fatigue behaviour under the LCF regime, the first initial stage of fatigue deformation, the cyclic hardening and further softening will be identified through the cyclic response of the specimen during tension and compression loading conditions until failure. This cyclic stress-strain behaviour of OFHC Cu will be coupled with microstructural analysis and a comparison will be made to reveal the impact of the variation of loading conditions.

A series of strain controlled LCF experiments have been conducted at room temperature and 400°C at different strain ranges (0.4 and 0.6 %) until the complete failure of the specimens. These tests are carried out in a Zwick-Roell Kappa 100 machine. The testing procedure is guided using the standard E606/E606M-21 [2] with triangular waveform at a constant strain rate of 10^{-3} s^{-1} under fully reversed loading, R=-1 where R is the strain ratio of the minimum and maximum strain values. To gain further insight into the localised strain measurement, Digital Image Correlation (DIC) is used to calculate the strain values on the surface of Cu and quantify the plastic strain during the cyclic fatigue test from displacements on specific points of several subsets corresponding to unloaded state and deformed images that monitored during the test. This will be useful for result analysis for the calibration and validation of the crystal plasticity simulation model. An extensometer is also used to measure the axial strain and compare the capability and accuracy of the DIC system. The experimental setup is represented in Fig 1. The specimen before the test was cycled for twenty cycles at fixed stress-controlled to stabilise the material properties and produce a consistent cyclic test.

Scanning Electron Microscope (SEM) and Electron Backscattered Diffraction (EBSD) characterisation are conducted on the fractured surfaces that are cut from the tested specimen. EBSD characterisation enables to assess the local damage failure by quantifying the misorientations induced by Geometrically Necessary Dislocation (GND). Therefore, the EBSD data is processed using the open-source toolbox MTEX and comparison of the GND Density maps will be presented in this work.



(a) (b)

Figure 1: Experimental set-up of fatigue testing using Zwick-Roell Kappa 100 Machine with 3D-DIC system (a) at high temperature (b) room temperature.

Reference

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[2] 'Standard Test Method for Strain-Controlled Fatigue Testing'. ASTM Standards. [Online]. Available: https://www.astm.org/standards/e606