Full-field kinematic characterisation of fusion divertor armour under high heat flux conditions

A. Tayeb[1a], L. Fletcher[1], M. Gorley, C. Hamelin[1] and A. Harte[1]

[1]UK Atomic Energy Authority, Culham Science Centre, Abingdon, OX14 3DB

[a]email: adel.tayeb@ukaea.uk

Abstract. Plasma facing components in a fusion reactor are subjected to extreme environments including high heat flux, strong magnetic fields, and neutron irradiation. In this work, a full kinematic field characterisation of a Divertor design subjected to high heat flux is carried out by using Digital Image Correlation (DIC). The tested design is composed of four tungsten mono-blocks, a copper-chromium-zirconium (CuCrZr) pipe and pure copper (Cu) interlayer. The heat flux was applied by induction under vacuum using an induction coil on the top surface of the four mono-blocks. The findings of this work will be used to validate thermo-mechanical simulations considering both experimental and modelling uncertainties.

Introduction

The validation of component performance under a spectrum of fusion-relevant loadings relies on FE simulations and experimental data [1]. In this work, we propose a full-field characterisation of a plasma facing component subjected to high heat fluxes. The heat flux was produced by using induction heating under vacuum. The full kinematic fields were measured by DIC, blue filters were used to minimise image saturation through IR glow and heat haze was avoided by way of the vacuum [2]. We start by presenting the experimental set up and sample preparation. Then, we briefly show some results including measured displacements and temperatures when the heat flux reached steady state regime. The full results, including measurement uncertainties quantification and comparison to the FE simulations will be shown at the conference.

Experimental procedure and sample preparation

Fig. 1 shows the experimental setup and the main preparation steps for the sample. The tested sample is a mock-up of the reference adopted design for the ITER divertor [3] composed by four 12 × 23 × 28 mm^3 with a 15 mm diameter CuCrZr pipe and a 1 mm thick Cu interlayer. Before the test, a set of three thermocouple were point welded to the back of the sample to track the surface temperature during the heat flux pulses (see, Fig. 1. a). Then, a random white and black speckle pattern was applied to the opposite surface of the four mono-blocks by using of an airbrush, see Fig. 1. b. High temperature paints were used in this study, which can nominally withstand temperatures up to 1100º C. The average size of the speckle pattern was ~4 pixels (10.96 µm). After that the sample was carefully placed facing the stereo DIC system, i.e., attached to the water-cooling loop inside the vacuum vessel facing its front port, see Fig. 1. c. The distance between the coil and the top surface of the sample was set to the minimum allowed by the current design in order to achieve efficient induction heating, see Fig. 1. d.

Once the sample was placed inside the vacuum vessel, the stereo calibration was performed by using a 3D printed holding system for the calibration target, designed to be used through a port in the vacuum vessel. Before applying the heat induction pulses, the coolant water at 100º C was introduced into the pipe and a stabilised temperature was measured in all thermocouples. The maximum power available in the current system is 28 kW. If no losses occur in the system, an equivalent maximum heat flux of 25.36 MW/m^2 is obtained. Ramps of 1 kW were carried out and a set of static images was captured once the steady state temperature was reached in all thermocouples. Note that a rigid body motion was detected after introduction of the coolant water. Therefore, the reference image was taken once the sample temperature was stabilised to the coolant temperature before applying the heat flux pulses.

Results and discussion

Results reported below are obtained from the pulse at 22 KW, which corresponds to a maximum heat flux of 19.92 MW/m^2 if no losses occur. All DIC analysis was performed using MatchID with a subset of 25 px, a step of 10 px, an affine shape function and the ZNSSD correlation criterion. First a noise floor analysis was performed by correlating static images after introduction of coolant water. The displacement resolution was about 0.66 µm, 0.81 µm and 4.7 µm for in-plane horizontal, vertical, and out of plane displacements. Fig. 2 shows the displacement fields once the steady state is reached and temperature recorded by the two thermocouples. Note that in this case the steady state was reached within 6 s and held for ~20 s, see the blue curve in Fig. 2. d.

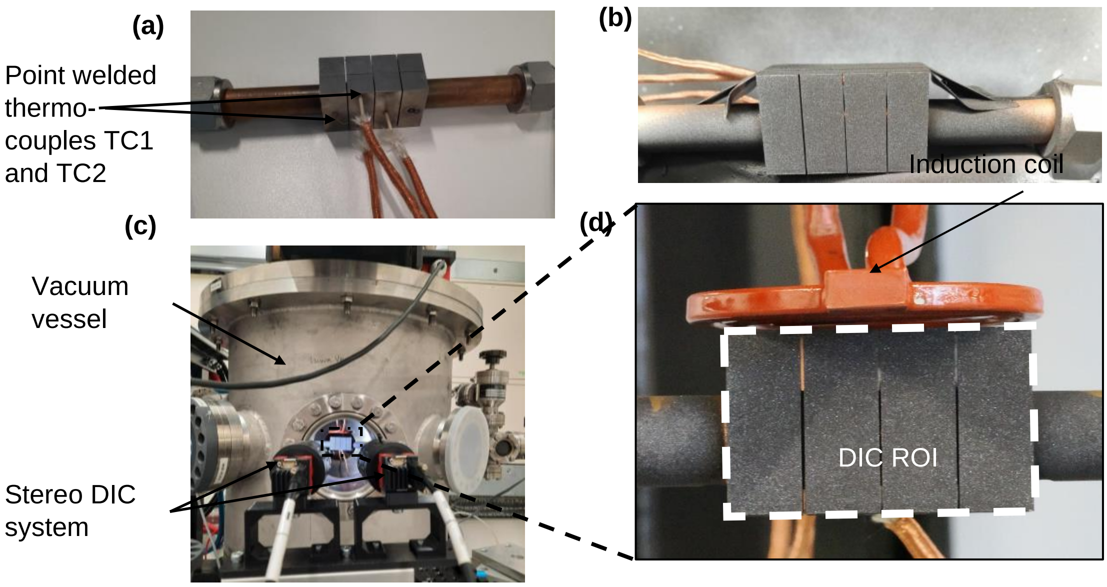

Figure 1:(a) thermocouples placement (b) speckle pattern (c) experimental setup (d) Coil-sample configuration

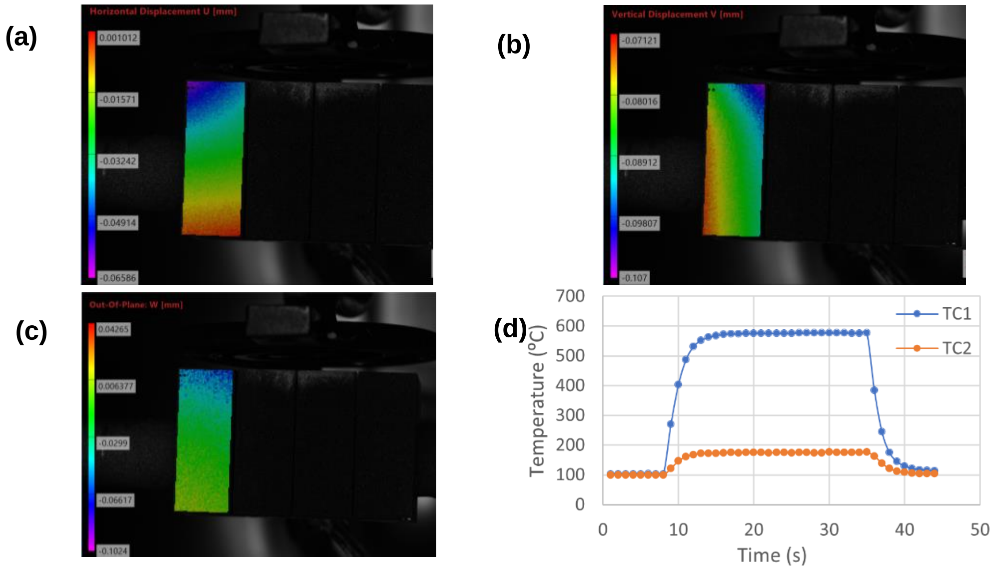

Figure 2:(a) Horizontal (b) Vertical (c) out-of-plane displacements and (d) temperature recorded

Conclusions

In this work we conducted a full kinematic filed characterisation of a plasma facing component under vacuum conditions. The component was subjected to nominal high heat flux loadings up to 25.36 MW/m^2. The kinematic fields, i.e. displacement and strain fields, were measured by DIC. The findings of this work constitute a starting point to a full-field model validation including uncertainty quantification for both models and experiments. In the future we will use the image deformation tool in MatchID coupled to a finite element model of the test to create a validation case, see [4]. This will also allow us to optimise the DIC parameters using a thorough uncertainty quantification.

References

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