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Examination of C/C flat tile mock-ups with hypervapotron cooling after high heat flux testing

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Abstract

Two C/C flat tile mock-ups with a hypervapotron cooling concept, have been successfully tested beyond ITER specification (3000 cycles at 15 MW/m^2, 300 cycles at 20 MW/m^2 and 800–1000 cycles at 25 MW/m^2) in two electron beam testing facilities [F. Escourbiac, et al., Experimental simulation of cascade failure effect on tungsten and CFC flat tile armoured HHF components, Fusion Eng. Des., submitted for publication; F. Escourbiac, et al., A mature industrial solution for ITER divertor plasma facing components: hypervapotron cooling concept adapted to Tore Supra flat tile technology, Fusion Eng. Des. 75–79 (2005) 387–390]. Both mock-ups provide a SNECMA SEPCARB® NS31 armour, which has been joined onto the CuCrZr heat sink by active metal casting (AMC) and electron beam welding (EBW). No tile detachment or sudden loss of single tiles has been observed; a cascade-like failure of flat tile armours was impossible to generate. At the maximum cyclic heat flux load of 25 MW/m^2 all tested tiles performed well except one, which revealed already a clear indication in the thermographic examination at the end of the manufacture. Visual examination and analysis of metallographic cuts of the remaining tiles demonstrated that the interface has not been altered. In addition, the shear strength of the C/C to copper joints measured after the high heat flux (HHF) test has been found to be still above the interlamellar shear strength of the used C/C material. The high resistance of the interface is explained by a modification of the C/C to copper joint interface due to silicon originating from the used C/C material.

Keywords: Hypervapotron; Flat tile; Divertor; CFC

1. Introduction

One of the most challenging components in ITER are the vertical target (VT) in the divertor. During normal operation a heat flux of 5–10 MW/m^2 is deposited

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onto the bottom segment of the VT. However, the capability to remove up to 20 MW/m^2 during 300 transient events each lasting for 10 s has also to be provided [3,4].

The reference design of the VT provides an array of units having a heat sink made of CuCrZr onto which the plasma facing material is joined [5,6]. Carbon fibre reinforced carbon composite (C/C) monoblocks joined onto a CuCrZr tube are envisaged for the lower part of the VT, where the highest heat flux is expected.

An alternative to the reference design could be the replacement of the monoblocks in the lower part of the VT by a flat tile armour, which is joined onto a heat sink with hypervapotron cooling structure [3]. This leads to a full flat tile component and allows to profit from experience has been obtained since the early 1990s with respect to series-like manufacture, quality assurance and performance in experiments [10].

Under ITER operating conditions flat tile components are assumed to suffer from reduced fatigue life time under cyclic heat fluxes and so-called cascade failure of tiles [4,6]. However, in recent testing campaigns these concerns have not been confirmed either for tungsten or for C/C flat tile armours [1,2]. These tests show that the design values for cyclic heat flux loads expected for ITER can be reached with margins. Both mock-ups have been analysed after the HHF tests. The obtained results are summarized in this paper.

2. Features of the mock-ups

Two flat tile mock-ups (Fig. 1) which consist of a CuCrZr (grade CRM16 from Le Bronze Industriel) heat sink with hypervapotron cooling concept and a 6 mm thick C/C flat tile armour (grade SNECMA SEPCARB® NS31) have been manufactured by PLANSEE SE. The overall length of the mock-ups is 741 mm, of which 500 mm are armoured with 25 C/C flat tiles, each of them having a width of 27 mm. A gap of 0.8 mm has been machined between the single tiles. As indicated in Fig. 1 the ex-pitch fibres of the armour tiles have been oriented perpendicular to the heated surface, the ex-PAN fibres along the axis of the mock-up and the needled direction has been across the width of the mock-up. In order to mitigate the joint interface stress due to thermal expansion mismatch between CuCrZr and C/C, a ∼2 mm thick copper compliant layer is introduced by active metal casting

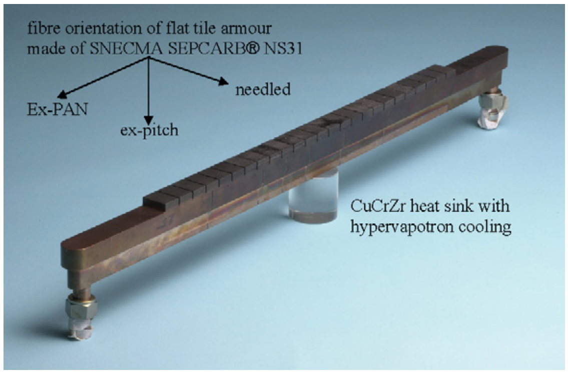

Fig. 1. C/C flat tile armoured high heat flux mock-up with hypervapotron cooling concept. The overall length of the mock-up is 741 mm with a width of 27 mm [2].

(AMC) of pure copper in the presence of titanium onto the LASER treated C/C surface [4–6]. A typical view of this interface is given in Fig. 2.

After AMC all tiles have been inspected by means of radiography and then electron beam welded (EBW) onto a rectangular CuCrZr bar, followed by an ultrasonic testing of the EBW-joint. Finally, the hypervapotron cooling channel (thin fins perpendicular to the flow direction) has been machined and closed by EBW with a rear cover plate made of CuCrZr. Ultrasonic testing, transient thermography as well as helium leak and water pressure tests have finalized the manufacturing and quality inspection. The HHF testing of both mock-ups, which is described in Ref. [2], started with a screening at 5 MW/m^2 followed by cyclic HHF tests at 15 and 25 MW/m^2, respectively. A critical heat flux (CHF) test up to 30 MW/m^2 and a final screening at 5 MW/m^2 completed the testing campaign. Every tile of both mock-ups has been exposed to the screenings at 5 MW/m^2, whereas each level of the cyclic HHF tests and the CHF has been performed on five separate tiles. In addition to the test sequence described in Ref. [2] 10 tiles including 2, in which the ex-PAN fibres have been oriented perpendicular to the heated surface, have been tested in FE200 for 300 cycles at 20 MW/m^2.

3. Description of the inspections

After the HHF tests the examination was focused on the interface between the C/C and the AMC copper. Areas of special interest have been defined by using the