

Hot radial pressing: An alternative technique for the manufacturing of plasma-facing components

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Abstract

The Hot radial pressing (HRP) manufacturing technique is based on the radial diffusion bonding principle performed between the cooling tube and the armour tile. The bonding is achieved by pressurizing the cooling tube while the joining interface is kept at the vacuum and temperature conditions.

This technique has been used for the manufacturing of relevant mock-ups of the ITER divertor vertical target. Tungsten monoblock mock-ups were successfully tested to high heat flux thermal fatigue (20 MW/m² of absorbed heat flux for 1000 cycles).

After these good results the activity is now focused on the developing of a manufacturing process suitable also for the CFC monoblock mock-ups.

A FE calculation was performed to investigate the stress involved in the CFC tiles during the process and to avoid the CFC fracture.

The results obtained by the FE calculation and by the test performed in air simulating a HRP manufacturing process for a CFC monoblock mock-ups is reported in the paper.

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1. Introduction

ENEA is involved in the ITER-R&D activity aimed at the development of basic manufacturing solutions for high heat flux plasma-facing components, such as the divertor targets, the baffles and the limiters. Within

this R&D programme [1] ENEA during the last years has been manufacturing actively cooled mock-ups by using different technologies, namely brazing, diffusion bonding and HIPping [2,3].

The activities have been now focused on simplifying the manufacturing technique and on improving the process reliability. This target was achieved by combining the diffusion bonding and HIPping technologies into a new technique: the Hot Radial Pressing (HRP) [4].

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2. Tungsten monoblock mock-ups by HRP

We would remind that the principle of the HRP manufacturing process is to perform a radial diffusion bonding between the cooling tube and the armour monoblock tile by means of the small deformation of the tube due to the internal pressure applied. The internal isostatic pressure also transmits the load needed for the bonding. The results obtained in our previous experimental activity [4,5], in which small tungsten monoblock mock-ups were manufactured and tested to thermal fatigue, confirmed that the HRP is suitable to manufacture such plasma-facing components.

The overall length of the 13 tile W mock-ups was 74 mm with a gap of 0.5 mm between each tile.

The copper alloy tube was machined from a CuCrZr rod that had been supplied solution annealed, quenched and cold-drawn, according to the ITER-grade specifications. The final dimensions of the tubes were 12 mm external diameter and 1 mm thickness.

The armour tiles used for the mock-up consisted in 24 mm × 22 mm × 4 mm tungsten blocks with a 14 mm central hole. The basic material composition was: W-1% La₂O₃. A pure Cu interlayer of about 1 mm, acting as a soft material, is previously cast into the tile hole.

This mock-up finally reached 1000 cycles at 18 MW/m² without suffering any joining damages [5].

Another mock-up was tested at 20 MW/m² for 1000 cycles.

3. CFC monoblock mock-ups by HRP

In the ITER tokamak divertor will be used two different armour materials according to the incident heat flux that is foreseen in that region. The CFC graphite composite should be used for zone where the heat flux can reach the power of 20 MW/m². Several mock-ups were manufactured and tested by associations and firms [1]. The conclusion was that the most reliable geometry is the monoblock one.

The HRP manufacturing process was qualified for the W monoblock mock-ups and the next step was to test this technique on CFC monoblock mock-ups.

The using of CFC armour tiles has some issues to be take into account. The reference ITER grade



Fig. 1. Picture of the compressive rig with the CFC tile in the center.

CFC, that is the material used in our experimental activity, is the NB31 three-dimensional matrix composite manufactured by SNECMA Motor (France). This material has rather different mechanical properties compared to W. It is an non-isotropic material and the tensile strength is variable in the three directions: 130 MPa in the (X) direction (ex-pitch), 40 MPa in the (Y) direction (ex-Pan) and 10 MPa in the (Z) direction (needing).

In the HRP process the tube is pressurized up to 60–70 MPa and the stresses are transmitted to the CFC that is unable to withstand to such stresses. Therefore, the CFC tiles have to be mechanically contained in order to leave the CFC material in a compression status in at least two directions: the X and the Y.

To obtain this compression status an ‘ad hoc’ rig was studied for each tile. This rig have to keep into account that the coefficient of thermal expansion (CTE) of the CFC is almost zero for a wide range of temperature. For this reason every single material puts around to compress the tile after the heating finally has a gap between the tile and the material.

The rig was designed and a FE analysis was performed to choose the best dimensions of the rig and in particular to define the best shape and thickness of the insert components.

The rig (Fig. 1) consists of a low coefficient of thermal expansion material ring and four compliant inserts.

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