TESTING TUNGSTEN PLASMA FACING COMPONENTS IN WEST AND AUG TOKAMAKS : LESSONS FOR ITER

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Next step fusion devices will face unprecedented heat loads and particle fluence with thousands of hours of plasma exposure on plasma-facing components (PFC). These components must guarantee acceptable lifetime, reliable heat exhaust capabilities (10-15 MW/m^2 power fluxes in steady state) and a high level of resilience after multiple thermal stresses generated by transient events, such as ELMs or disruptions. An extensive tungsten (W) PFC testing work-program has been conducted in the WEST (Tungsten Environment in Steady State Tokamak) and ASDEX Upgrade (AUG) tokamaks, taking advantage of key capabilities and strengths of the two machines. WEST is currently equipped with an ITER-grade actively cooled divertor [1], including shaped monoblocks (MB) with a toroidal bevel as foreseen for ITER, while AUG allows the exposure of dedicated tile-sized samples (with different geometries such as PFC gap size, slopes and materials) in high power ELMy H-mode discharges using its divertor manipulator DIM-II system [2]. The results reported here provide new information on W material response (e.g. heating, cracking or melting) of direct relevance to ITER.

Several damage mechanisms have been investigated in both devices under nominal and extreme heat loading conditions. Multi-physics numerical tools have been developed to simulate and predict thermal emission/reflection on highly reflective PFCs (photonic modelling [3]), thermally activated processes such as softening (restoration/recrystallization), cracking (TREX code [4]), thermoionic emission and melting (MEMENTO code [5]). The input data for the codes - PFC temperature and power load distributions - are measured by various diagnostics in both machines. A very high spatial resolution (VHR) infrared (IR) camera (0.1 mm/pixel) and radially distributed Fiber Bragg grating (FBG) thermal sensors are used in WEST to derive the heat load distribution with high accuracy. The steady state heat load measured on the ITER-grade MBs ranges from 4 to 6 MW/m^2

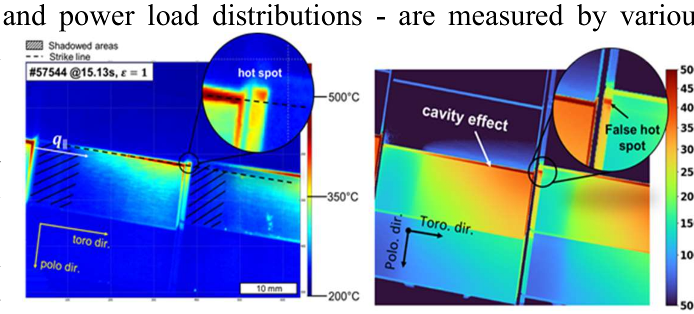

Figure 1 : Experimental (left) and synthetic (right) IR temperature maps on WEST lower divertor MBs.

during standard L-mode plasma operation up to ITER relevant values of 11 MW/m^2 during dedicated "high power" experiments for PFC testing. The experimental heat flux poloidal profile exhibits a shape with 2 decay lengths, with a narrow feature on top of a wider heat flux decay length [6]. The VHR-IR measurements show high apparent temperatures in the toroidal and poloidal gaps of the MB stacks (figure 1). The reflections on the W surfaces lead to an enhanced local apparent temperature inside the gaps, called the cavity effect, and to the appearance of a "false" hot spot on the poloidal chamfer in front of the toroidal gap [7].

A high fluence campaign with attached plasma conditions, was performed in the early phase of WEST Phase 2 to assess the performance of the ITER-grade MB under ITER relevant particle fluence (445 repetitive discharges were performed over a ~1 month campaign, cumulating ~3 hours of plasma operation). Although the divertor did not show any sign of degradation in terms of heat exhaust capability, W deposited layers of a few tens of micrometer thickness and crack networks were observed on some of the MB top surfaces. In subsequent operation, long pulses were also used with different plasma parameters. A total of 11h of accumulated plasma exposure with more than 10^{27} D/m^2 particle fluence on the divertor has been achieved in WEST Phase 2, corresponding to a few ITER pulses. To test component ageing on an accelerated basis, a few selected MBs were pre-damaged in a controlled way at various damage levels (crack network, melted droplets and macro-crack) in the FZJ JUDITH-2 high heat flux test facility and then exposed in the WEST tokamak [8]. Figure 2-(a) shows the macro-crack damage generated by a few steady state thermal cycles above 20 MW/m^2. IR data and preliminary surface analyses show no evidence of significant degradation damage or progression under WEST plasma conditions.

Dedicated new melting experiments have been performed to further benchmark melt code simulations. Samples made of poor (iridium) versus efficient (niobium) thermionic emitter materials were simultaneously exposed to 5 Type-I ELMing H-mode discharges in AUG. The MEMENTO code was able to reproduce the thermal responses and melt deformation profiles of the two different materials (Figure 2-b) under the same heat flux. Shallow melting under stationary (without ELMs) was also investigated on an actively cooled WEST MBs at two different locations on the MB leading edge: in the centre of the MB and, more recently, near the toroidal gap, to investigate the melt displacement though the toroidal gap (Figure 2-c).

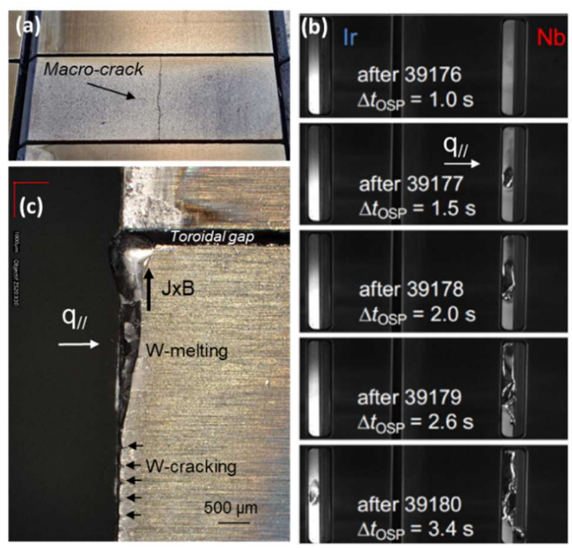

Figure 2: (a) predamaged MB with macro-crack. Controlled melt experiments in AUG (b) and WEST (c) tokamaks.

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