Estimation of dust production rate from tungsten armour after repetitive ELM-like heat loads

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13th PFMC WORKSHOP and 1st FEMaS CONFERENCE ROSENHEIM 9-13 MAY 2011

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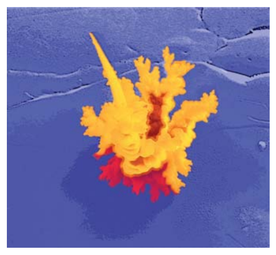


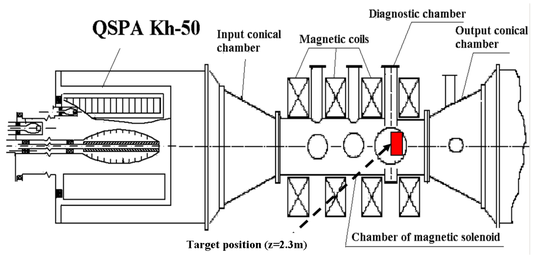
Abstract

- Simulations for erosion rate of tungsten targets under ITER ELM-like surface heat load have been performed in the QSPA-Kh50 plasma accelerator
- Analysis of the experimental results allows to conclude that the erosion mechanism is solid dust ejection during surface cracking under action of thermo-stress
- W influx into the ITER confinement of $N_W > 10^{20}$ per one medium size ELM of 0.75 MJ/m^2 and 0.25 ms time duration has been predicted
- Such influx of tungsten is intolerable: it should terminate the ITER discharge within a second

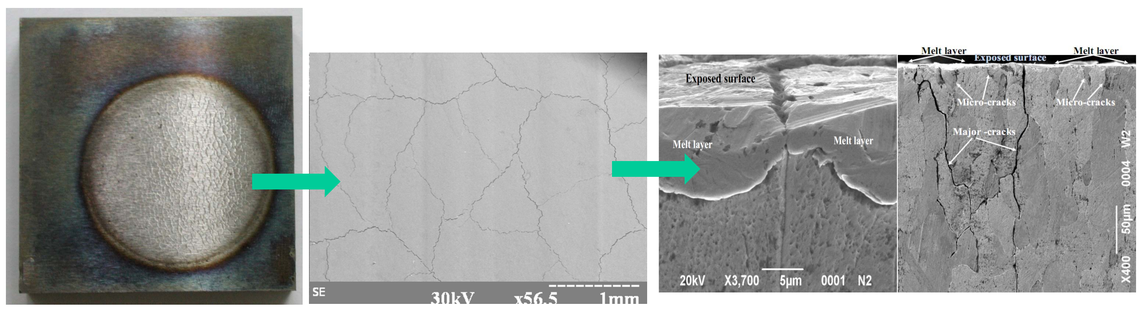
Introduction

- The edge localised modes (ELMs) of plasma instabilities produce short periodic pulses of heat flux at the divertor armour, the most heat loaded part of tokamaks
- The ELMy H mode is the ITER reference operational scenario
- Heat loads during ELMs has the energy density of 0.1–5 MJ/m^2 and time duration 0.1–0.5 ms, causing the divertor armour cracking or even melting
- Simulations of the tungsten armour cracking due to the large type I ELMs has been successfully performed earlier using the PEGASUS-3D code
- The cracks propagating along the tungsten grain boundaries do not deteriorate the thermoconductivity
- The only possible danger of the tungsten armour for the ITER discharge would be the dust produced during its cracking and the droplets ejection from the layer melted under action of most powerful ELMs.
- The dust production rate due to ELM-like heat load is investigated in this paper

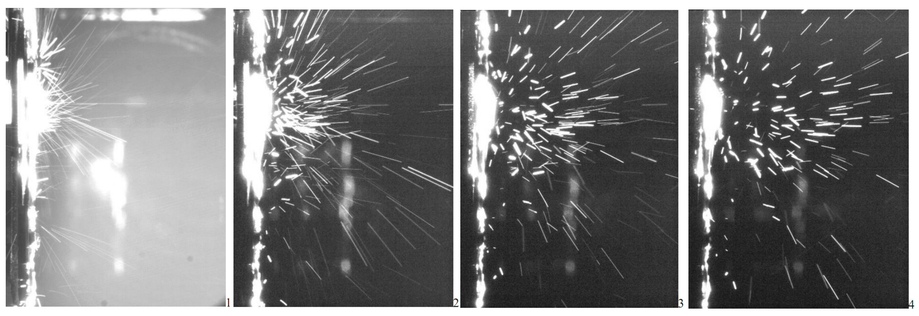
QSPA Kh-50 plasma gun



E_i ~ 0.4 keV,
P_{max}= 3.2 bar; $P_{average}$~1.6 bar
n = (2-7) 10^{15} cm^{-3}
Plasma stream diameter 18 cm.
Pulse duration 0.25 ms
Q=0.2; 0.3; 0.45; 0.75 MJ/m^2



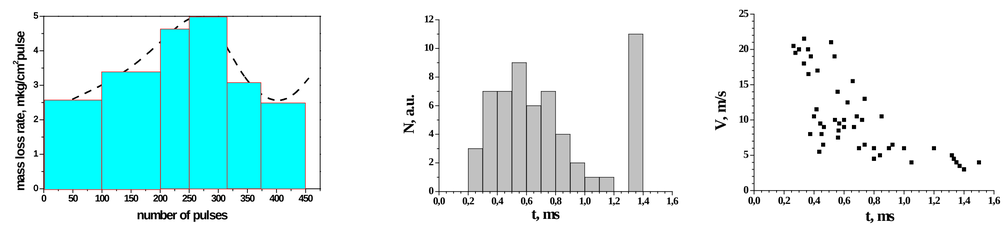
General view of the tungsten target and SEM image of the target cross-section after exposition of 20 plasma shots in the QSPA-Kh50 facility



4 frames of the digital camera with the traces of erosion products corresponding to 1.2 ms, 3.6 ms, 6 ms and 8.4 ms after start of plasma-surface interaction ($t_{exposure}$= 1.2 ms).

Experimental results from QSPA Kh-50

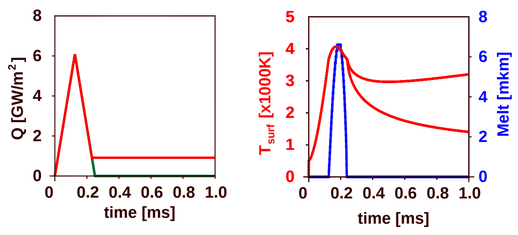
- In the dedicated series of experiments the erosion products flying from the tungsten target have been registered using high-speed 10 bit CMOS digital camera pco.1200 s with spectral range 290…1100 nm and space resolution of 1280×1024 pixels
- Special ITER-like targets of pure tungsten designed and manufactured by Plansee AG (Austria) with the sizes 5×5×1 cm have been used for these experiments
- Particles velocity and the time moment when it started from the target surface has been calculated from several camera frames of 1.2 ms duration with traces of particles flying from the tungsten surface
- mass loss of the target was measured after several shots.
- All the targets were exposed to plasma streams perpendicular to the target surface.
- The surface energy load of 0.45 MJ/m^2, without surface melting, 0.75 MJ/m^2, produces melt layer of ~7 μm



Dynamics of the target mass losses and the distributions for particles number and particles velocities on the start time from the target surface

Analysis of the experimental results

- Extrapolation of the results on tungsten erosion rate measured in the QSPA-Kh50 on ITER conditions depends on erosion mechanism
- If the particles are droplets, ejected from the melt (Kelvin-Helmholtz or Rayleigh-Taylor), then the erosion rate should be much smaller in ITER and their velocities are smaller and the erosion rate must be zero if the ELM does not cause surface melting
- If the particles are solid dust, split during the tungsten surface cracking then the erosion rate and their velocities spectrum should be the same as in QSPA-Kh50 facility and the erosion for ELMs without surface melting is nonzero
- The measured in QSPA-Kh50 distribution of W particles allows conclusion that the particles are dust, produced due to cracking of solid tungsten surface
- Simulation for the QSPA-Kh50 shot of 0.75 MJ/m^2 performed using PEGASUS-3D code, proves that the melt at the tungsten surface re-solidifies after 0.23 ms
- At least more than 95% of particles started from solid surface



Simulation of the QSPA-Kh50 shot. Even a ‘tail’ on the power density does not changed time of the melt existence

Conclusions

- Simulations for erosion rate of tungsten targets manufactured by Plansee AG under ITER ELM-like surface heat load have been performed in the QSPA-Kh50 plasma accelerator
- The erosion rates of 3-5 μg/cm^2/pulse have been measured for regime with surface melting and 1.5 μg/cm^2/pulse without melting.
- From analysis of the experiment it has been concluded that the erosion mechanism is solid dust ejection during cracking at least for 95% of registered particles
- W influx into the ITER confinement of $N_W > 10^{20}$ per one medium-size ELM of 0.75 MJ/m^2 and 0.25 ms time duration has been predicted assuming 3 m^2 of wetted area
- Such influx of tungsten should terminate the ITER discharge within one second

Acknowledgements: This work, supported by the European Communities under the EFDA Task Agreement WP10-PWI between EURATOM and Karlsruhe Institute of Technology, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.