SIMULATION OF Be ARMOUR CRACKING UNDER ITER-LIKE TRANSIENT HEAT LOADS

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ABSTRACT

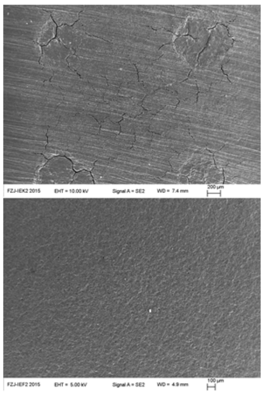
- Simulation of beryllium cracking under action of multiple severe surface heating has been performed
- Used are the PEGASUS-3D code and experiments in the JUDITH 1 facility
- Beryllium thermoconductivity degradation is at least 4 times due to accumulation of the cracks after 100 pulses has been revealed
- An analytical model for Be cracking threshold under action of arbitrary heat pulses has been developed.

INTRODUCTION

- Disruptions are unavoidable crashes of the tokamak discharges
- They deposit plasma energy onto the plasma facing components of the tokamak vacuum vessel
- Disruptions happen regularly in modern tokamaks, but the first wall damage due to the disruptions is negligible because of moderate energy content in the hot core of these tokamaks
- Beryllium cracking under action of ITER-like transients have been investigated earlier
- However, understanding of the cracking mechanism and its implications for Be armor lifetime are not
- This investigation is devoted to the mechanisms and influences of cracking on Be properties as well as for experimental validation of the results obtained
- Be armour cracking has been investigated using the PEGASUS-3D code and JUDITH 1 facility

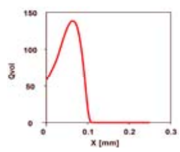
SIMULATION OF TRANSIENT LOADS ON Be IN THE JUDITH 1 FACILITY:

- Experimental simulation of the thermal shocks has been performed in the electron beam facility JUDITH 1
- The electron beam:
  - Diameter ~ 1 mm (FWHM)
  - Swept with frequencies of 40 kHz and 31 kHz
- All tested samples were polished with 1 μm diamond suspension

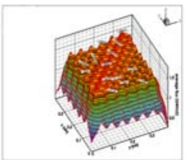


melting starts at 900 MW/m², after 100 pulses of 1 ms duration. At 800 MW/m², cracks only

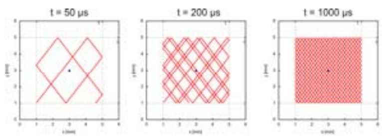
$$\int_0^{\infty} Q_{vol}(x)dx = 1$$



Power deposition from JUDITH 1 with 120 keV eln. $Q_{vol}(x)$ maximum is at 64 μm

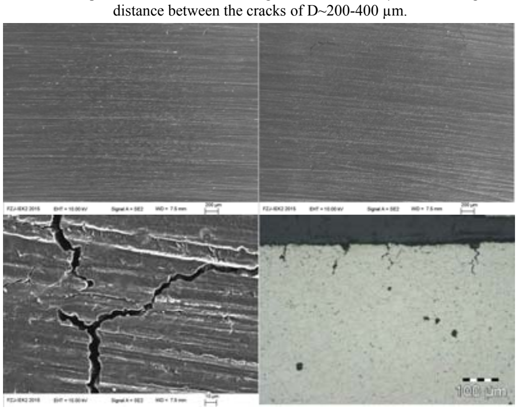


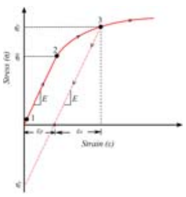
Averaged over 1 ms heat flux from JUDITH 1 facility



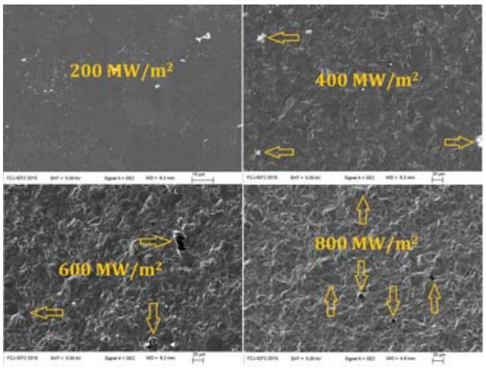
Scanning beam trajectory.
The frequencies of 40 kHz and 31 kHz

900 MW/m², 1 ms duration: no cracks after 1 pulse (upper left panel). After 10 pulses the cracks with average width of W~5-7 μm and average distance between the cracks of D~200-400 μm.

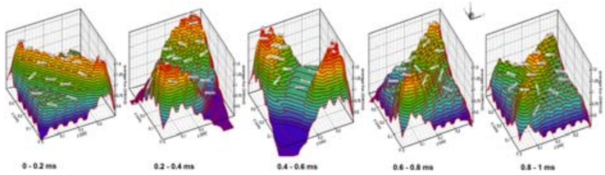




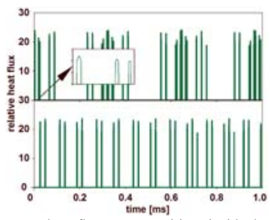
Tensile residual stress development under action of compressive thermostress



100 pulses, 1 ms duration. Separate cracks arises at 400 MW/m², at 200 MW/m² the cracks are absent at the sample surface.



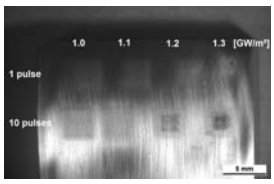
Heat flux from the JUDITH 1 electron beam averaged over sequential time intervals of 0.2 ms. The ratio of the heat flux maxima (at the corners) and the flux minimum reaches up to two times



JUDITH heat flux at two positions inside the spot of 4×4 mm.
Upper (x=1mm, y=1mm): melting starts;
Lower (x=1mm, y=2mm): no melting
The average heat flux is 900 MW/m².

CONTRADICTION:

- Simulations has predicted surface melting at 1100 MW/m²
- Experimental observation of the melting at 900 MW/m².
- Suggestions:
  - flux inhomogeneity due to the scanning
  - thermoconductivity degradation due to cracks
- Verification: melting threshold under 1 shot



CRACKING THRESHOLD FOR Be

- Cracking is due to compressive plastic deformation.
- Heating ⇒ compressive stress $\sigma > \sigma_y$ ⇒ plastic deformation ε_p,
- Cooling ⇒ residual deformation $\varepsilon \approx \varepsilon_p$ ⇒ residual stress $\sigma_r = -\varepsilon E$,
- After n pulses $\sigma_r = -n\varepsilon E$ ⇒ if $\sigma_r \geq \sigma_y + \sigma_u$ then cracks are developed

$$T_{th} - T_0 \cong \frac{\sigma_y(T_{th}) + \sigma_u(T_{th})}{E(T_{th})\alpha(T_{th})}$$

CONCLUSIONS

- Simulation of beryllium cracking under action of multiple severe surface heating has been performed
- PEGASUS-3D code + verification by the dedicated experiments in the JUDITH 1 facility.
- Thermoconductivity degradation after 100 pulses of 900 MW/m² has been found to be at least 4 times due to accumulation of the cracks
- An analytical model for the Be cracking threshold under action of arbitrary heat pulses predicts the threshold of ~160 MW/m².
- The threshold in the interval 200-400 MW/m² has been measured in JUDITH 1 after 100 pulses
- Experimental verification by large pulse number

Acknowledgements: This work was supported by Fusion for Energy agency and carried out within the framework of the contract F4E-OPE-584. The views and opinions expressed herein do not necessarily reflect those of F4E.