NUMERICAL SIMULATION OF TUNGSTEN MELT LAYER EROSION CAUSED BY JxB FORCE AT TEXTOR

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INTRODUCTION

Tungsten is foreseen as one of the armour materials for plasma facing components (PFCs) in the ITER divertor and dome and as the main material of DEMO. During the transients expected in tokamaks (disruptions, ELMs, and VDE) the armour will be exposed to hot plasma streams and localized impacts of runaway electrons (RE). The heat fluxes are expected to be so high that they can cause severe erosion of PFCs thereby limiting their lifetime. During the intense transients the melting, melt motion, melt splashing and surface evaporation are seen as the main mechanisms of metallic armour erosion. In case of RE impact and long time transients (VDE) a melt layer can exist up to several seconds [1]. Experiments at TEXTOR [2,3] with long time plasma action at the target surface in the strong magnetic field demonstrated that the JxB force generated by thermo-emission electrons dominates in the acceleration of the melt layer and leads to a high target erosion (up to 1 mm per event).

The expected erosion of W target caused by JxB force in short time transients has been properly estimated using the code MEMOS validated against plasma gun target erosion experiments [4]

EXPERIMENTS at TEXTOR [2,3]

Experiments have been performed by introducing a limiter into plasma at TEXTOR In more detail experiments are described in Refrs [2,3]. The avarage temperature of tangsten rises up to 3500 K with an average heat flux of 10 MW/m^2 . The upper part of the tungsten sample can receive up to 10 MW/m^2 for leading edges. The typical heat flux is 20 MW/m^2 for a duration of 5-6 s. The peak temperatures are 4000 – 6000 K. Vapour shielding leads to a constant temperature level after 2 s, that is confirmed by numerical simulation results. Typical erosion of the tungsten samples caused by the JxB force generated by thermo-emission electrons in the strong magnetic field of B=2.25 T are demonstrated in Fig. 1-3 after single shot. The thermo-emission current is about several tens A/cm^2

Fig.1

Fig.2

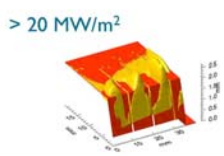

Fig.3

NUMERICAL SIMULATIONS

In this work new MEMOS simulations for the TEXTOR experiments on tungsten targets damage under long time plasma heat loads up to several seconds with heat fluxes in the range 15 – 30 MW/m^2 on the timescale of 5-6 s in a strong magnetic field are performed, with taking into account 3D geometrical peculiarities of the experiments. The melt layer damage is calculated for single shot in 2D and 3D geometry. Main attention is focused on investigation of melt layer erosion caused by the JxB force generated by thermo-emission electrons. Model of space-charge limited thermo-emission current is fitted to be in correlation with the experimental values. In 2D simulations it is assumed that the tungsten sample is have the brush design with D=1cm and gap width between brushes of 0.5 mm. Magnetic field B=2.25 T.
Plasma pressur p=200 Pa. 3D simulation has carried out for the single brush.

References

[1] B. Bazylev et al. Journal of Nuclear Materials ICFRM-13
[2] J.W. Coenen et al. Journal of Nuclear Materials PSI2010
[3] J.W. Coenen et al. Nuclear Fusion IAEA I2010
[4] I.E. Garkusha et al. Journal of Nuclear Materials 363-365, 2007, 1021-1025

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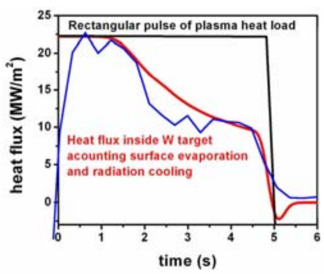
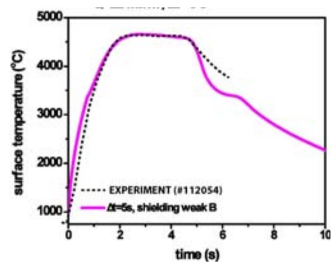
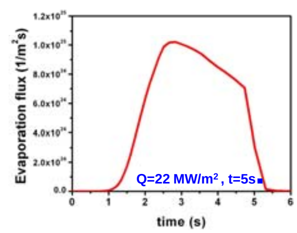
Heat flux and surface temperature: Experimental data vs. MEMOS simulations Q=22 MW/m^2, t=5s. Plasma shielding.



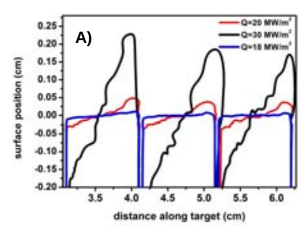


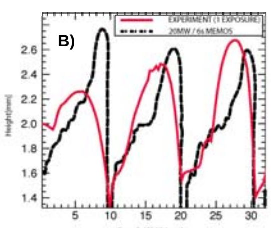
Evaporation flux : MEMOS simulations.



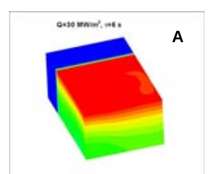
Typical thickness of a melt layer is about 1.3-1.5 mm.
Final thickness of evaporation: - 200 – 400 microns
This fact has demonstrated formation of the plasma shielding above the target surface leading to reduction of the heat fluxes at the target surface and constant surface temperature during rather long time.
Typical maximal amplitude of the thermo-electric current : about 30 A/cm^2 for Q=20 MW/m^2 , 60 A/cm^2 for Q=30 MW/m^2

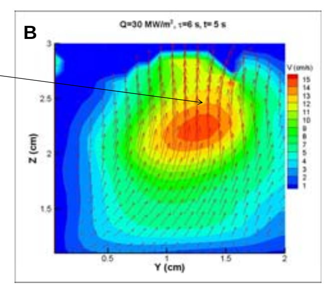
MEMOS simulations. A) Final erosion profiles of macrobrush sample after single pulse for different heat loads. B) Simulations vs experiment

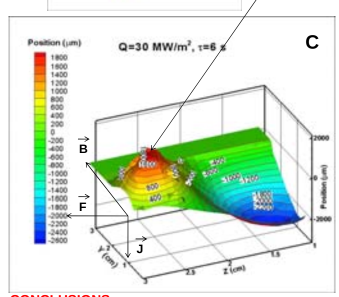




3D MEMOS simulations.







A) Sketch of the single brush in 3D simulations (red – area of plasma-surface interaction)
B) Typical distribution of melt layer velocity along the surface. Contour plot demonstrates velocity values.
C) Final surface profile of the single brush after resolidification

CONCLUSIONS

- To simulate large time scale melt motion in TEXTOR experiments the code MEMOS was significantly updated, in particular accounting for some additional 3D features.
- The thermo-electric current model was improved accounting for space charge limitation.
- Numerical simulations carried out for the heat loads in the range 15 – 30 MW/m^2 on the timescale of 5-6 s have demonstrated a reasonable agreement with TEXTOR experimental data on tungsten target erosion.
- Further numerical simulations of TEXTOR multi-pulse experiments using 2D and 3D version of the code MEMOS have to be performed.

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