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Tungsten Components in Fusion - Power Loading and Melting

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Tungsten (W) is among the main candidate plasma-facing materials (PFM) for a fusion reactor and will be exclusively used in the ITER divertor. Melting is one of the major risks associated with the use of a metal as PFM. Therefore heat load bearing components in tokamaks like JET or ITER are designed such that leading edges and corresponding excessive plasma heat loads due to near normal incidence are avoided. Because of the high stored energies in ITER discharges, shallow surface melting can occur by insufficiently mitigated disruption and Edge Localized Mode (ELM) power load transients. Based on the way components are constructed and exposed in the divertor of fusion devices uncontrolled melting and power loading of edges is a serious lifetime issue and is therefore subject of intense R&D effort.

Experiments have been performed in JET, ASDEX Upgrade and as part of a joint large international effort to elucidate this problem. A focus was set on the study of transient induced melting. Here power loads were used similar to mitigated ELMs in ITER. A dedicated program was carried out at JET to study the physics and consequences of W transient melting. Following initial exposures in 2013 (ILW-1) of a lamella with leading edge, new experiments have been performed on a sloped surface during the 2016 (ILW-2) campaign. Repetitive transient tungsten melting by ELMs has also been studied in recent experiments in ASDEX-Upgrade, using H-mode discharges tailored to produce type I ELMs with the required parallel power flux density ($\sim 1 GW/m^2$) over ms timescales.

First simulations of transient melting at a leading edge facing the parallel power flux were carried out with the MEMOS melt motion code for the JET lamella set-up. The predicted melt pattern is in very good agreement with experimental findings. The model explains the melt motion to be driven mainly by the interaction of the thermionic emission current through the surface with the toroidal magnetic field.

The detailed processes driving melt layer motion during transients are still under investigation as part of the JET and AUG activities. In addition to the melt layer motion one needs also to tackle the issue of obtaining accurate data on the local surface power-load. Here both the IR interpretation of localized heat-fluxes as well as the power load distribution at shaped mono-blocks and edges is of major interest and dedicated studies are ongoing.

In order to allow qualification of materials also e-beam and linear plasma devices such as JUDITH and PSI-2 have been used to study the damage behaviour of materials. It was found that despite staying below the melting point, severe development of crack networks can be expected even at low power loads, comparable to ITER mitigated ELMs.

Potential solutions to these issues can be sought in mainly three directions: mitigation of the incident plasma flux by means of operational actuators such as impurity seeding to increase radiative dissipation in the divertor, applying dedicated shaping of plasma-facing components, and improving material properties such that cracking and subsequent melting is avoided. However, this assumes thus also a high level of suppression of transient headloads such as ELMs by means such as RMP coils.

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