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Surface damage of tungsten by heat and particle loadings
タングステンの表面損傷

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In this presentation, present knowledge and issues of tungsten surface damage caused by transient heat pulses and plasma (hydrogen isotopes and helium) loadings are reviewed. Since tungsten materials are brittle, surface damage could also cause large scale cracks penetrating throughout tungsten blocks. Surface damage could cause enhanced erosion and dust formation, which need to be limited below acceptable levels in terms of W material lifetime, safety and core plasma performance.

Tungsten is foreseen as a plasma facing material for ITER and DEMO because of its low sputtering yield, high melting point and high thermal conductivity. But the surface damage of tungsten caused by transient heat loadings unmitigated disruption/VDE with high stored energy plasmas as well as by unmitigated ELMs are of great concerns for enhanced erosion and impact of core plasma performance. In addition, hydrogen isotopes and helium mixed plasmas would also affect surface morphology changes such as blisters and He induced structure.

In terms of transient heat loadings by major disruptions (MD), vertical displacement events (VDE) and edge localized modes (ELM) could be applied to the divertor surfaces (mainly MD and ELM) and the baffle surfaces (VDE). Although there still remain large uncertainties in estimation of deposition energies, surface melting of tungsten might occur without mitigation. Melt layer motion driven plasma pressure and JxB forces could cause surface unevenness which enhances further melting and ejection of droplets, which could be serious concerns for core plasma contamination and mobilizing tungsten dusts. For DEMO reactors, significant melting of tungsten must be avoided due to these reasons. In order to avoid melting of tungsten, appropriate measures for disruption and ELM mitigation, which will be the most important subjects for ITER using full W divertor from day one.

Even with success of mitigation of transient heat loadings, thermal fatigue by high cycle transients caused by mitigated ELM's is another concern. High cycle heat pulses with pulse energy density even much below a melting threshold (~1MJ/m^2 for ~0.5 ms pulse length) might bring about surface cracking, local melting and droplet and grain ejection. We still do not know how these processes have impacts on stable operations of DEMO reactors. Surface protection and/or surface repair/refurbishment might be necessary.

Particle loadings (hydrogen isotopes and helium), in general, cause thin damaged layers containing trapped and solute atoms whose mechanical and thermal properties are degraded by solution of these atoms, nanometric bubbles (by both hydrogen and helium), blistering (mainly by hydrogen in fusion environments at low temperatures), large holes (by helium at elevated temperatures), and nanostructure (W fuzz, by helium at medium temperatures). Hydrogen blistering could not be an issue in a fusion environment due to mainly engineering surfaces of W monoblocks and plasma impurities (Be and He). W fuzz could bring about enhanced release of tungsten through unipolar arcing, but more studies on the formation, erosion, and disappearance of W fuzz by pulsed heat are necessary to correctly evaluate this effect on core plasma performance [1].

Combined effects of heat and particles could enhance surface damage and erosion by pulsed heat only in some cases. But some other experimental results showed alleviation of surface damage (e.g. W fuzz and He holes) by ELM-like pulsed heat. Therefore, there still remain some uncertainties of surface morphology changes by combined loadings. Although transient heat loadings should be reduced to some acceptable level, effects of occasional modest transients on surface damage alleviation should also be examined [1].

Reference

[1] Y. Ueda et al., “Research status and issues of tungsten plasma facing materials for ITER and beyond”, Fusion Engineering and Design, Vol. 89, October 2014, Pages 901–906.