Thermal and mechanical properties characterization of the surface damaged layer of tungsten

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As the potential divertor material of future fusion devices, the structure of tungsten (W) surface is modified by plasma irradiation. Thermal and mechanical properties of the damaged layer degrade and the melting and cracking thresholds decrease. The material can therefore fail more easily by transient events such as edge localized modes (ELMs), which produces extremely fast and powerful cyclic heat loads. Quantified criteria and parameters are needed to estimate the damaged level and to predict the potential failure rather than simply observing the damaged microstructure and analyzing the total fluence.

In the present study, the thermal and mechanical properties of the W and selective laser melted tungsten alloys surface layer irradiated by hydrogen (H) plasma with ion energy of 50 eV and fluence of 1.6×10^{26} $m^{-2}s^{-1}$ on Magnum-PSI, by helium (He) plasma with ion energy of 40 eV and fluence of 10^{25}-10^{26} $m^{-2}s^{-1}$ on PSI-II, and by He ions with energy of 30-190 keV and damage of 0.2-1 dpa were characterized. The transient thermoreflectance technique [1] was employed to test the thermal conductivity (TC) of W samples irradiated by He plasma/ions. Results show that the TC values of the W damaged layer dropped 1-2 orders of magnitude compared to the W bulk and decreased as the irradiation temperature and fluence increased. The serious degradation was due to the formation of He-bubbles and the damaged crystalline structure. Additionally, we utilized Berkovich/Spherical nanoindentation to test the mechanical properties changes induced by H plasma and He ion irradiation. Berkovich nanoindentation results indicate that irradiation hardening occurred and the hardness increased with increasing damage dose and exposure temperature. Moreover, the stress-strain curves extracted from Spherical nanoindentation reveal that yield stress increased with increasing dose and working hardening rate decreased after irradiation. Finally, the irradiated samples were loaded by ELM-like head fluxes with a pulse width of 1 ms and peak power density of 1.7 $GW\cdot m^{-2}$ produced by electron beam on EMS-60. Melting occurred and the grain size of the resolidified structure, as well as the depth of the molten bath increased as the TC of the damaged layer decreased. Obvious rounded cracks were observed around the molten baths of the He ions irradiated samples and became more severe as the TC decreased, which can be explained by the modified temperature field resulting from different TCs and the decreased ductility induced by the irradiation hardening [2]. The damage behaviour caused by the ELM-like heat load after previous irradiation is consistent with the results of the characterization of the thermal and mechanical properties.

[1] S. Qu, et al., J. Nucl. Mater. 382-385 (2017) 484
[2] M. Roedig, et al. J. Nucl. Mater. 766-770 (2004) 329