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重み付きPIC法を用いた蒸気遮蔽シミュレーションによる過渡熱負荷時の金属壁損耗量予測

Estimation of erosion at metallic walls under transient loads by vapor shielding simulations using a weighted PIC method

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In future fusion devices, plasma facing materials suffer extensive heat and particle loads during transient events, ELMs and disruptions. Erosion of wall materials, caused by sputtering, evaporation, ablation, and melting, will shorten the lifetime of the wall components. Lifetime of the first wall can be longer if a thicker first wall is installed. However, the thickness of the first wall is constrained by the operational temperature range of tungsten (tungsten should be below its recrystallization temperature and above the ductile-brittle transition temperature). To keep the tungsten in this temperature range under the steady-state heat loads of ~10MW/m^2, the thickness of the first wall should be a few mm.

Meanwhile, a transient load with 2MJ/m^2 will cause an evaporation loss equivalent to >1μm thickness. If the melted layer motion is taken into accounts, further erosion occurs by a transient pulse.

While there are the pessimistic predictions for the wall erosion as discussed, an inherent erosion suppression mechanism, vapor shielding, is expected. During the massive heat loads, interactions between incoming plasma flux and generated vapor clouds will eventually dissipates incoming plasma energy. Decrease of a total absorbed heat fluence to the wall by this vapor shielding can suppress the wall erosion.

Here, we developed PIXY[1], a simulation tool for the vapor shielding. A PIC code is coupled with a wall model. Plasma flux to the wall surface obtained from the PIC code was used as a boundary condition for the wall model. Vapor ejection rate was calculated in the wall model and returned to the PIC code as atomic neutrals. To treat a wide variation of neutral flux, a weighted PIC model was used.

This novel approach to the vapor shielding reveal importance of neutral-ion collisions as well as the radiation and ionization reactions for the energy dissipation. Plus, erosion estimations including the vapor shielding effects were studied for the beryllium and tungsten walls under various heat flux conditions, different peak heat fluxes, pulse shapes, and pulse lengths.

Calculated vapor shielding efficiencies were summarized to a database. The database is now used for the erosion estimation of ITER first walls under VDE transient loads.

Recent works related to the plasma facing walls and vapor shielding will be summarized. And remaining works for the further studies will be discussed.

[1] K. Ibano et al., Nuclear Fusion 59(2019)076001(13pp)