Performance Estimation of Beryllium under ITER Relevant Transient Thermal Loads

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The employment of beryllium as armor material in ITER ensures a high level of plasma performance at the cost of a high erosion rate and the risk of melting during transient events. To assess the possible impairment of the beryllium armor by these events, a series of transient thermal load tests was carried out. The electron beam facilities JUDITH 1 and JUDITH 2 located at Forschungszentrum Jülich were used to exert transient thermal loads with ITER relevant edge localized mode and massive gas injection (MGI) like characteristics onto S-65 grade beryllium specimens. The test campaign covered a broad range of loading parameters, i.e. heat flux factors in the range of 3 – 32 $MWm^{-2}s^{0.5}$, pulse durations of 1 – 10 ms, base temperatures from room temperature up to 300 °C, and numbers of pulses of $1 – 10^7$. This comprehensive dataset was used to map the damage behavior of beryllium. The results indicated that the loading conditions causing no damage on beryllium after 100 pulses are limited to a heat flux factor of $\leq$ 6 $MWm^{-2}s^{0.5}$ at base temperatures below 300 °C. For higher heat flux factors or base temperatures, the yield strength of the investigated beryllium becomes too low to compensate the thermally induced stresses fully elastically. Despite the fact that inflicted damage in the form of plastic deformation/roughening/cracking seems to be hardly avoidable under operational conditions, beryllium showed a promising long term performance under transient thermal loads. Tests with high numbers of pulses of up to 10^7 indicated that the induced damage saturates after 10^5 pulses as long as the applied heat flux factor does not exceed 9 $MWm^{-2}s^{0.5}$.

MGIs in ITER are intended to reduce the severe local damage caused by plasma disruptions in the divertor region by transforming the stored plasma energy to radiation, which is spread homogeneously across the reaction chamber wall. This radiation leads to transient thermal loads on the beryllium tiles capable of melting them [1]. The experimental simulation of these heat loads pointed out that, under the conservative assumption of 1000 full power disruptions mitigated with MGIs, the affected beryllium armor thickness is about 340 µm.

Overall, the post mortem analysis of the carried out transient thermal load tests revealed numerous surface morphology changes such as roughening, cracking, and melting but also the formation of pits, elongated filaments within cracks, and the detachment of the melt layer from the bulk material under repetitive melting. The pit formation and the detachment of the melt layer under repetitive melting were linked to the formation/segregation of beryllium oxide at the surface and at the grain boundaries, respectively. The oxygen partial pressure in the experiment was limited to 2×10^{-5} mbar, which is the lowest accessible value in JUDITH 1. Further investigations are planned to examine whether the beryllium oxide formation/segregation significantly affects the performance of beryllium under transient thermal loads at lower oxygen partial pressures, closer to the value of 10^{-9} mbar anticipated in ITER.

[1] M. Lehnen, et al., J. Nucl. Mater. 463 (2015) 39–48