ASSESSMENT OF B_4C AS FIRST WALL COATING FOR THERMONUCLEAR REACTOR

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1. ABSTRACT

The new ITER baseline includes tungsten (W) as first wall (FW) material. This increases the risk of increased plasma contamination by W (and other metallic impurities) and the associated plasma radiation that may decrease the achievable Q. Together with ITER Organization (including activities in the frame of TA IO/24/TA/4500000207) R&D is performed for study B4C coating that can be applied to first wall panels and other metallic areas in line of sight of the plasma in ITER to reduce influx of high-Z metallic impurities in ITER to prevent this risk from materializing.

2. MAIN RESULTS

For all presented study and testing ITER grade tungsten with a fine-grained elongated structure oriented along the heat flow direction in the plasma facing components is used. Boron carbide (B_4C) coating was applied by detonation spraying (DS) on a computer-controlled detonation spraying facility CCDS2000 (Fig. 1) developed at the Lavrentyev Institute of Hydrodynamics, Siberian Branch of the Russian Academy of Sciences.

Fig. 1. Detonation spraying facility CCDS2000 with a manipulator

The possibilities of DS using this facility are described in detail in [1]. The material for spraying was boron carbide powder (GOST 5744-85) with an average particle size of 20 microns. To investigate the functional properties of B4C coatings, 50 and 1000 μm thick layers were deposited on tungsten substrates of different sizes. Optimal DS modes were selected experimentally taking into account the previously obtained experience in producing coatings from tungsten and chromium carbides without metal binders. Previous studies have shown that the microhardness of a 200 μm thick B4C coating on tungsten substrate is 1422 ± 162 HV0.1, with a porosity determined by cross-sectional optical image analysis of 1.4 ± 0.2%. Adhesion tests by the adhesive method (ASTM C633 standard) showed a value of 12.4 ± 0.6 MPa, with fracture within the coating. This means that the bond strength of the coating with the substrate exceeds the tensile strength of the coating itself. W samples with different dimensions and with applied B4C coating were used for exposure by:

- high heat flux (HHF) on the «Tsefey-M» testing facility, which has an e-beam gun with a power of 800 kW as mock-ups surface thermal heating source. By adjustment and selection of optimal parameters of the beam current and accelerating voltage of the e-beam gun, it is possible to achieve a penetration depth of the e-beam in B4C of no more than a few microns in order to ensure predominantly surface heating. HHF tests carried out in the heat load cycling mode (heating - cooling) at absorbed power density from 1 to 5 MW/m2. HHF tests also include combined tests, where in addition to cyclic stationary loading at a power density of 5 MW/m2, periodic powerful short-pulse impacts were carried out at absorbed energy densities of up to 100 MJ/m2 with a duration of no more than 300 ms. The mock-up thermometric diagnostics system on the «Tsefey-M» testing facility allow monitoring B4C surface condition during testing and detecting areas of local overheating due to possible detachment of the coating.

- transient thermal loads (heat fluxes of ~ 1 – 10 GW/m^2, with durations of ~ 0.1 – 1 ms relevant to mitigated disruptions (MD)). Experimental simulations of such loads are performed using laser radiation and an electron beam. A key feature of the experimental setups is the integrated in situ diagnostics, allowing real-time monitoring of sample conditions during heating. To characterize the resistance of boron carbide coatings deposited on tungsten via the detonation spraying method, the corresponding samples were tested with multiple pulsed thermal loads expected during the operation of the ITER tokamak. During the experiments, ~ 10^4 pulses were applied. Depending on the heat flux of each pulse and the total number of pulses, the coating erosion was characterized.

- by plasma streams under conditions relevant to unmitigated (UD) and MD disruptions in ITER were performed at plasma guns QSPA [2] and MKT [3] at JSC SRC RF TRINITI. During UD experiments samples with a "thick" (1 mm) B_4C coating are irradiated with powerful deuterium plasma streams thermal load on the surface varies from 1 to 2.4 MJ/m^2 with a duration of exposure t = 1 ms (Fig. 2a). During MD experiments targets with a "thick" (1 mm) and "thin" (50 µm) coating are exposed to a photonic heat loads from a vapor-shielding plasma formed near the surface of "sacrificial" target (Fig. 2b). In this case, thermal load on the sample surface is at least 0.4 MJ/m2, t = 1 ms. 50 impacts were performed on each sample. After 1, 3, 9, 27, and 50 irradiations damage of B_4C coating was studied and integral erosion of the coating was determined. The ionic composition, temperature, and electron plasma concentration were determined by spectral measurements in the visible, AXUV and soft X-ray ranges also were determined for experiments at MKT plasma gun.

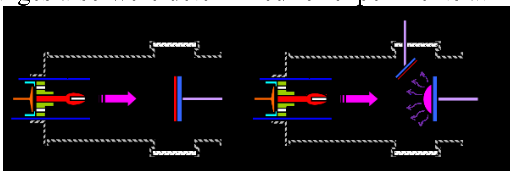

Fig. 2. Unmitigated (a) and mitigated (b) disruptions experiment schemes

- low energy plasma flux (~ 10's eV plasma temperature) for imitation conditions of stationary process. Exposure under D, D+He+Ne plasmas with concentration representative to the range of He and Ne as expected at the ITER far SOL for Q = 10 plasmas (namely ~ 5% He and ~ 1% Ne) was used for B_4C coating up to 50 µm thickness with two different doses and two different substrate temperatures. During irradiation of the coatings, the sputtered material was deposited on tungsten and boron carbide substrates. The following studies were performed: measurement of the sputtering rate of the coating, gas trapping during coating irradiation, and analysis of the change in composition and morphology of the coating surface during irradiation. Thickness, adhesion, composition and gas trapping in redeposited layers on tungsten and boron carbide catchers were also measured.

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