Effective corrosion and Tritium barrier coatings in PbLi WCLL-BB

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In the present communication, we report promising results about a class of efficient functional ceramic coatings based on alumina, acting as a protective layer against PbLi corrosion and as a tritium permeation barrier in WCLL-BB operating condition.

In the conceptualization and development of the WCLL BB, particularly for both the DEMO and ITER TBM, material properties play a crucial role in optimizing the reactor's lifespan, efficiency, and overall safety. Specifically, the EUROFER alloy currently considered as the reference structural material for HCLL, WCLL and DCLL tritium BB concepts for the future DEMO reactor must withstand the corrosive conditions posed by the high-temperature liquid PbLi eutectic alloy that serves as a coolant, breeder fluid and neutron multiplier. At the same time, this material must retain the tritium generated inside the reactor environment by the lithium-neutron nuclear reaction.

Indeed, the PbLi molten alloy is inherently corrosive towards steels leading to the dissolution of the main alloying elements of RAFM steels (Fe, Cr) with increasing intensity at higher PbLi temperature and flow velocity. Besides the wall thinning and possible liquid metal embrittlement of structural steel, PbLi corrosion might lead to severe operative problems such as clogging effects in the blanket due to the deposition of corrosion products in colder regions of the system where their solubilities drop down. Moreover, EUROFER is not able to effectively limit the dispersion of the generated tritium outside the reactor facility. Therefore, to ensure critical properties such as corrosion resistance and reduced tritium permeation, it is essential to protect the exposed surfaces of the blanket with functional coatings. These coatings act as anti-corrosion and anti-permeation barriers mitigating the magnetohydrodynamic (MHD) effect on the PbLi pressure drop.

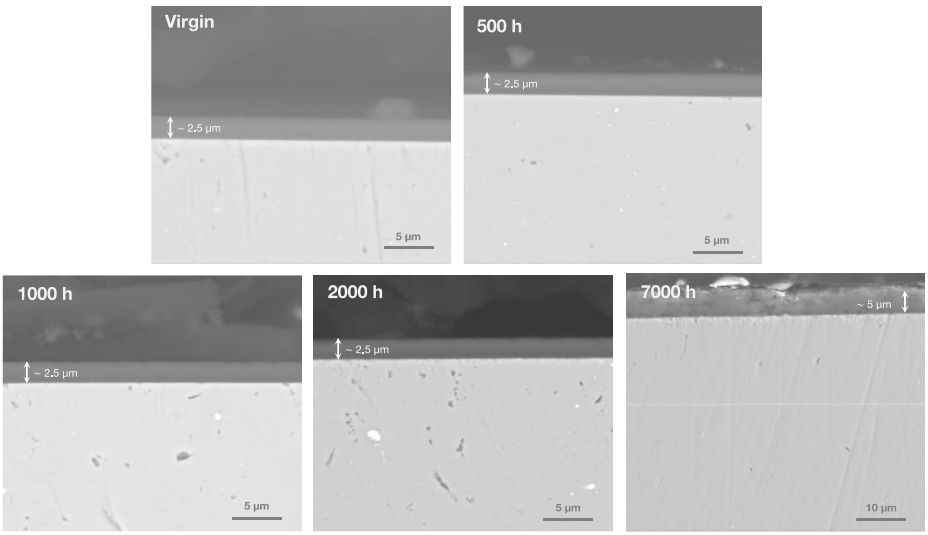

Figure 1: Electronic micrographs showing cross-section morphology of PbLi exposed coatings at 550 °C for 0 h (virgin), 500 h, 1000 h, 2000 and 7000h.

Recent research in EUROfusion has identified aluminium oxide ceramic as a promising barrier coating material, demonstrating a good resistance against PbLi corrosion and tritium permeation.

This communication focuses on the development and characterization of Pulsed Laser Deposited alumina coatings on EUROFER presenting results on their effectiveness in preventing corrosion during liquid PbLi exposure at WCLL BB operating condition as well as on their deuterium (mimicking tritium) permeation barrier properties.

Coatings developed have been exposed to liquid PbLi at 550 °C for different time duration up to 7000 h. Then they have been investigated using scanning electron microscopy (SEM) to study the corrosion resistance and by measuring deuterium permeation to evaluate their effectiveness as tritium diffusion barrier. Figure 1 represents the electron micrographs of alumina coatings (3 µm and 5 µm thick) both virgin and exposed to the corrosive action of PbLi. SEM images clearly indicate that coatings resisted quite well to the PbLi harsh environment and succeeded in protecting the underlying Eurofer from corrosion, maintaining their thickness constant and a good interface adhesion.

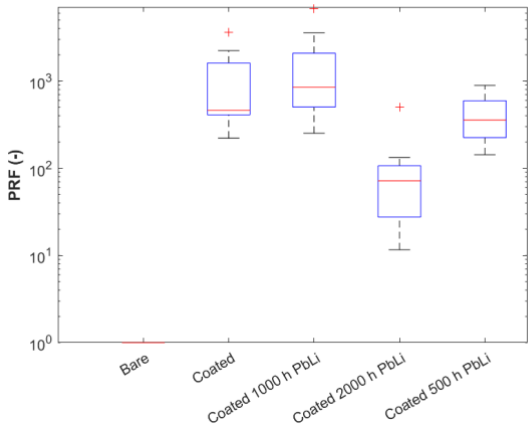

Figure 2: Cumulative Box-plot of PRF values with respect to bare Eurofer, measured at different temperature and D_2 partial pressure on coatings exposed to liquid PbLi at 550 °C for 0 h (virgin), 500 h, 1000 h, 2000 h.

Moreover, Figure 2 reports a box plot of Permeation Reducing Factors (PRF) values at different measuring temperature and partial D_2 pressure on virgin and liquid PbLi exposed coating at 550 °C and different time duration. The obtained results are quite promising since most of the points are in the range 10^2 - 10^3, exceeding in many cases 10^3 with peaks up to 7 x 10^3. In average, the PRF values recorded at all PbLi exposure time investigated is always larger or approximately equal to 10^2 which is considered the minimum threshold for a functional coating in the WCLL.

Finally, a last open issue concerns the observed diffusion of Lithium inside the coating. Indeed, although the coating structure and its tritium-permeation/PbLi-corrosion barrier properties seem to remain unaffected, x-ray diffraction crystallography and x-ray photoelectron spectroscopy depth profiling (not shown here for brevity) evidenced the formation of Li-Al mixed oxides. Since Lithium atoms could cause issues during neuronic irradiation within the BB, the planning of an experimental neutronic irradiation campaign starting within 2025 is already undergoing.