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Aqueous Corrosion of WCLL Breeder Blanket Structural Material Eurofer-97 for Nuclear Fusion Reactors

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The choice of structural materials for nuclear fusion reactor tritium breeder blankets depends on many factors and is critical to the safety and operation of the reactor. Inside fusion reactors, such as ITER and DEMO, breeder blanket components will face high temperatures, high 14MeV neutron flux, and high magnetic fields between 4 - 10 T [1 - 4]. One candidate for breeder blanket design to be tested in ITER and potentially employed in DEMO is the water-cooled lithium-lead (WCLL) breeder blanket, which will add the additional factor of aqueous corrosion for consideration. Here, we present work showing the effects of combinations of fusion-specific factors on corrosion of materials for use in WCLL breeder blanket coolant circuits.

Eurofer-97, Europe's candidate structural material for WCLL breeder blankets, is a reduced-activation ferritic-martensitic (RAFM) steel. Ferritic-martensitic 9Cr steels show a favorable response to neutron irradiation and 'reduced-activation' refers to a compositional change in favor of elements that result in fewer long-lived radionuclides [5, 6]. Eurofer-97 has been subjected to simulated WCLL coolant circuit conditions using an autoclave facility developed through collaboration between the University of Bristol and the National Nuclear Laboratory. Using a Halbach array permanent NdFeB magnet, Eurofer-97 samples are exposed to corrosion experiments both inside and outside of a 0.88 T uniform magnetic field. Magnetohydrodynamic (MHD) effects have been discussed in other work for their effect on corrosion processes [4].

Figure 1 shows scanning electron microscopy micrographs from a low-temperature (70ºC) accelerated-conditions experiment probing the effects of a magnetic field on aqueous corrosion of Eurofer-97 at ambient pressure in a comparatively aggressive pH 2 citric acid solution with 2% Cl for 100 hours. The in-field and out-of-field samples show a significantly different surface morphology with a Cr-rich oxide layer (confirmed via EDX) on the out-of-field sample, which was absent for the in-field sample. Focused ion beam (FIB) microscopy was used to mill cross sections to investigate the surface layers of either sample, Figure 1.c, d.

Using the autoclave flow loop facility, additional samples were exposed to high temperature deaerated water at 310ºC, 124 bar with a flow rate of 10 ml/min for 500 hours with one sample situated within the Halbach array (average temperature 293±1ºC) and two in-series upstream (304ºC) and downstream (280ºC) to account for any temperature or transport effects. Results indicate a similar oxide layer formed on both in-field and out-of-field samples in this experiment. TEM lift-out samples were prepared to probe any subtler differences in the oxide layers. These samples are seen in Figure 2 showing high angle annular dark field (HAADF) images using scanning transmission electron microscopy (STEM). Results

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show a characteristic duplex layer oxide formation as, on all samples, a crystalline layer is seen separated by porosity from a seemingly amorphous inner layer. The oxide layers are the same thickness, within error, for all samples. STEM EDX and TEM are also performed on these samples.

Results for low temperature work show a clear change between in-field and out-of-field samples whereas at conditions closer to those expected inside WCLL coolant circuit there were no distinct differences. These comparatively short duration tests provide an indication that magnetic field effects may be limited for the high purity coolant conditions expected in operational plant circuits, but that MHD effects from the 0.88 T magnetic field may affect Eurofer-97 corrosion in some circumstances, such as with high levels of aggressive impurities [7].

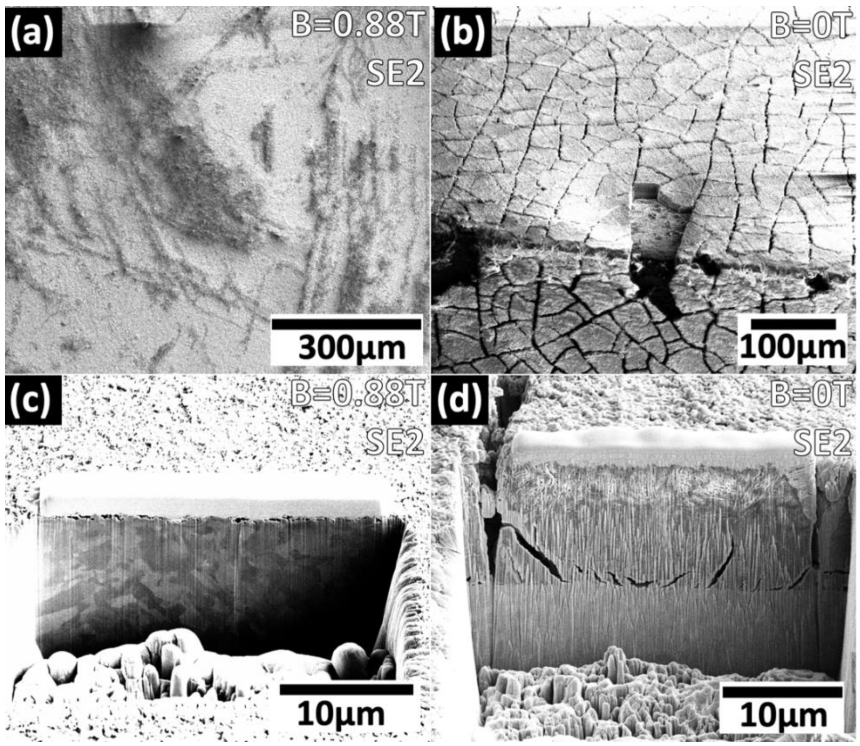

Figure 1. SEM micrographs of Eurofer-97 samples exposed to 70ºC pH 2 citric acid solution for 100 hours (a, c) inside 0.88 T magnetic field, (c, d) outside magnetic field. (a, b) show surface morphology. (c, d) show FIB-milled cross sections through surface layers, with Pt deposited to protect surface features.

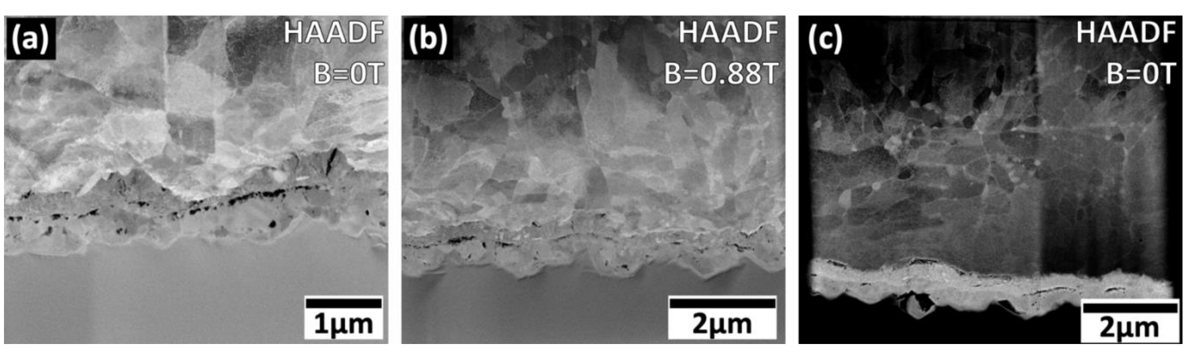

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Figure 2. STEM micrographs of Eurofer-97 samples exposed to high temperature deaerated water at 124 bar with a flow rate of 10 ml/min for 500 hours. (a) outside magnetic field upstream at 304ºC. (b) inside magnetic field 293ºC. (c) outside magnetic field downstream 280ºC.

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