Recent Results on Compatibility of Structural Materials in Liquid Lead Alloys

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The use of heavy liquid metals (HLM), namely Pb or Pb-based alloys, in energy-related applications, is under consideration, due to their favourable thermal and neutronic properties. However, concerns are related to their compatibility with structural steels in terms of corrosion and mechanical resistance. To protect the steels from direct contact with HLM, the formation of an oxide layer is aimed at. Thermally grown protective oxide scales on steel surface, exposed to HLMs, can be achieved in operando by dissolving a suitable level of oxygen into the HLM. Structural materials, envisaged to be used in HLM environment, are austenitic steels (AS), ferritic-martensitic steels (FM) and ODS steels. Experiments have shown that, below 500°C, the AS - 15-15Ti steel and the FM - T91 steel are protected by stable, relatively thin FeCr-based oxide scales. However, above 500°C, AS steels suffer severe dissolution attack, while FM steels form thick, fast growing oxide scales, which reduce heat transfer from the fuel pins and may break off, eventually blocking the coolant channels. The improvement of corrosion resistance has been attempted by alloying the steels with strong oxide-forming elements (e.g. Al). Aluminum has shown its potential to protect steel surfaces in contact with HLM (containing small amounts of oxygen) forming slowly growing Al-rich oxide scale. However, the development of a thin, continuous, dense, stable, adherent Al2O3 layer, providing an effective corrosion barrier in HLM, requires a minimal Al-level, which unfortunately affects negatively the mechanical properties of the steel. Therefore a surface alloying process, using intense pulsed electron beam (GESA-process), was developed and optimized in KIT. The procedure consists in two steps: (i) coating the steel surface with an Al-containing alloy layer and (ii) melting the deposited layer and the steel surface to form an homogeneous, well bonded coating. In order to find the suitable composition for the formation of Al2O3 protective scale, oxide maps, for the oxidation of pure Fe-Cr-Al bulk alloys in oxygen-containing HLM, were drawn using grazing incidence synchrotron X-ray diffraction, electron microscopy, X-ray photoelectron spectroscopy and thermo-gravimetric measurements. It was found that an Al content of at least 8 wt.% guarantees the formation of a thin Al2O3 scale on coatings containing also 12-16 wt.% Cr. Based on these results, FeCrAl-based layers were deposited on flat and tube specimens (T91) and then exposed to HLM. The corrosion experiments showed the good protective behavior of Al scales (<0.001 mm thickness) in HLM with 10−6 wt.% oxygen up to 650°C and for exposure times up to 10,000 h. Creep test in HLM, at 550°C, show strain, 2nd creep rates and creep-to-rupture times comparable with those of non-coated T91, tested in air. The Al surface alloying by GESA process improves the fretting resistance up to a factor of 5 between 450°C and 550°C, compared with non-coated T91.

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