Insights into fatigue crack propagation mechanism of T91 steel in liquid lead-bismuth eutectic at 150–450ºC

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Abstract: Liquid Pb-Bi embrittlement of alloys can cause catastrophic brittle fracture, which is a critical issue for the development of lead-cooled fast reactor (LFRs) [1]. However, the micromechanism of liquid Pb-Bi embrittlement for alloys has remained absent in the past decades. The key equipment materials of LFRs are used in high temperature liquid lead-bismuth eutectic (LBE) environment, and corrosion fatigue is one of the main potential failure forms, and also the focus of design, safety review, operation and life evaluation [2]. T91 steel is one of the preferred structural materials with excellent radiation damage resistance and good medium and high temperature properties [3]. Here we conducted fatigue crack propagation tests of T91 steel in liquid LBE at 150-450ºC. The FCG rate increased gradually with the increase of temperature at 150–350ºC, is firstly low at 450ºC and then comparable with that at 350ºC. The macroscopic trans-granular cracks preferentially propagated along the deformation-induced low-angle grain boundaries (LAGBs) near the crack tip at the microscopic scale. We use aberration-corrected transmission electron microscopy to directly capture the segregation of Pb and Bi atoms ahead of the crack tip. Intergranular precipitation-enhanced wetting of matrix by liquid LBE results in the reduction of atomic bonding force and formation of micro-cracks along the LAGBs, which triggers brittle cracking.

Keywords: Steel; Lead-bismuth eutectic; Fatigue; Embrittlement

Reference

[1] Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies - 2015 Edition (NEA–7268). Nuclear Energy Agency of the OECD (NEA).

[2] X. Gong, M.P. Short, T. Auger, E. Charalampopoulou, K. Lambrinou, Environmental degradation of structural materials in liquid lead- and lead-bismuth eutectic-cooled reactors, Prog. Mater. Sci. 126 (2022) 100920.

[3] K.L. Murty, I. Charit, Structural materials for Gen-IV, Nucl. React.: Chall. Oppor., J. Nucl. Mater. 383(1-2) (2008) 189–195.