Oxide Scale Fracture-accelerated Creep-to-Rupture of T91 Steel in Liquid Lead-Bismuth Eutectic

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Abstract The incompatibility between coolant and structural materials poses a critical challenge to the deployment of advanced Lead-cooled fast reactors. The long-term operational performance of T91 steel in Lead-Bismuth Eutectic (LBE)-cooled reactors is critically impacted by creep deformation and the integrity of protective oxide scales. The present study investigates the creep-to-rupture behavior of T91 steel in static LBE, focusing on the effects of cyclic thermal conditions and oxygen levels. The results demonstrate that cyclic thermal conditions, oxygen deficiency, and elevated stress levels accelerate creep deformation, significantly reducing the creep-to-rupture lifetime of T91 steel. While the protective oxide scale delays crack initiation and propagation by isolating LBE from the steel surface, its integrity is compromised under thermal cycling and low oxygen environments, leading to premature failure. Microstructural analyses reveal the mechanisms of oxide scale damage and self-healing, which are essential in understanding the material's long-term performance. These findings underscore the need to account for oxide scale integrity and its failure mechanisms when designing and evaluating the operational longevity of advanced LBE-based reactors. The study offers valuable insights into improving the safety and durability of structural materials in next-generation nuclear systems.

Keywords lead-bismuth eutectic, T91 steel, creep-to-rupture, cyclic thermal, oxide scale