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Analyzing the Static Corrosion of T91 in Liquid Lead and Bismuth Eutectic at the Atomic Scale

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A potential design for GenIV nuclear fission reactors is the lead-bismuth-cooled fast reactor (LBEFR), with the lead-bismuth eutectic (LBE) chosen as a coolant due to its favorable properties [1, 2]. T91 steels are proposed as structural components of these reactors. However, the effects of corrosion and its dependence on concurrent irradiation remains a major concern for LBEFR designs. Also, LBE is known to be more corrosive to structural steels than pure lead [3]. As a result, the operation temperature has to be restricted to approximately 550℃ which limits the power density and thus economic benefits promised by LBEFR [4, 5].

There has been only a limited amount of previous research on the corrosion mechanisms of steel in lead in atomic scale. The corrosion of materials in LBE is driven more by diffusion. Hence, understanding how different elements behave in the vicinity of the lead-steel interface and the mechanisms underpinning the resulting processes will be essential to mitigate the effect of corrosion. To this end, high resolution characterisation methods are required. Atom probe tomography (APT) as an atomic scale characterisation technique can provide nano-scale compositional information. Combined with energy-dispersive x-ray spectroscopy (EDX) and transmission electron microscopy (TEM), investigation of the static corrosion of T91 steel in LBE can be conducted across multiple length scales.

As-received T91 steel has been analyzed as a reference material. Electron backscatter diffraction (EBSD) has been used to confirm that the main grain structure is martensitic. EDX shows numerous precipitates in the matrix. Using APT, three types of precipitates were detected in as-received T91: Vanadium-enriched precipitates, Chromium-enriched precipitates, and Niobium-enriched precipitates, in agreement with previous reports [6]. EBSD further showed the existence of secondary phases along the grain boundaries. Grain boundaries have been selected and incorporated into site-specific APT samples by the use of transmission Kikuchi diffraction (TKD) analysis. TKD also can be used to target precipitates for incorporation into the specimen for APT characterisation (Fig. 1).

Next T91 samples exposed to static corrosion in liquid LBE for various lengths of time (70, 245, or 506 hours) in either reducing or oxidizing environments at 715℃ and 700℃ respectively is considered. From the EDX results of static corrosion for 506 h at 715 ℃ in reducing environment, an obvious depletion of Cr is observed over a significant depth beneath the original T91 surface. Furthermore, within this Cr-depleted region, the Cr-enriched precipitates disappeared, as shown in Fig 2. However, EDX alone cannot provide further insights into the mechanism by which these precipitates disappear and how Cr leaves the matrix, for example, if there exist fast diffusion paths. APT with complementary EBSD and TKD is applied to build up a detailed picture of how the distribution of precipitates changes in the static

corroded samples from the matrix to the LBE corroded surface. Furthermore, we also study how different types of precipitates behave. The same analysis is also conducted on samples corroded under in an oxidizing environment. These results give a detailed picture of how LBE corrodes T91 under different conditions.

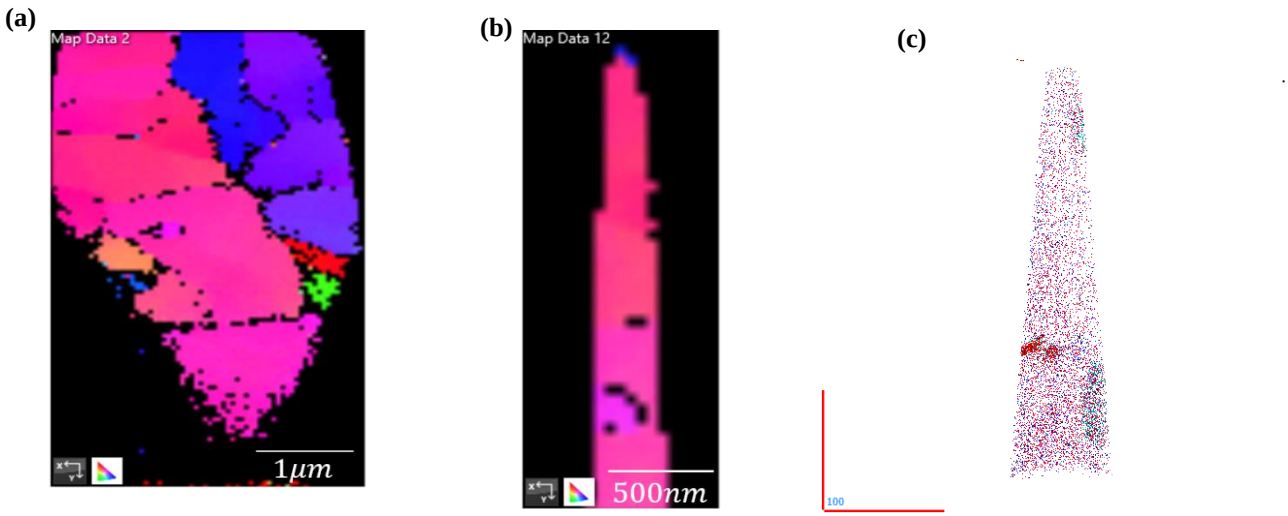

Figure 1. Method of selecting grain boundaries and precipitates for APT analysis of as-received T91 steel. (a) TKD map showing different grains in the liftout; (b) TKD map confirming the presence of grain boundaries in APT needle; (c) APT reconstruction with the segregation of elements to grain boundary and precipitates.

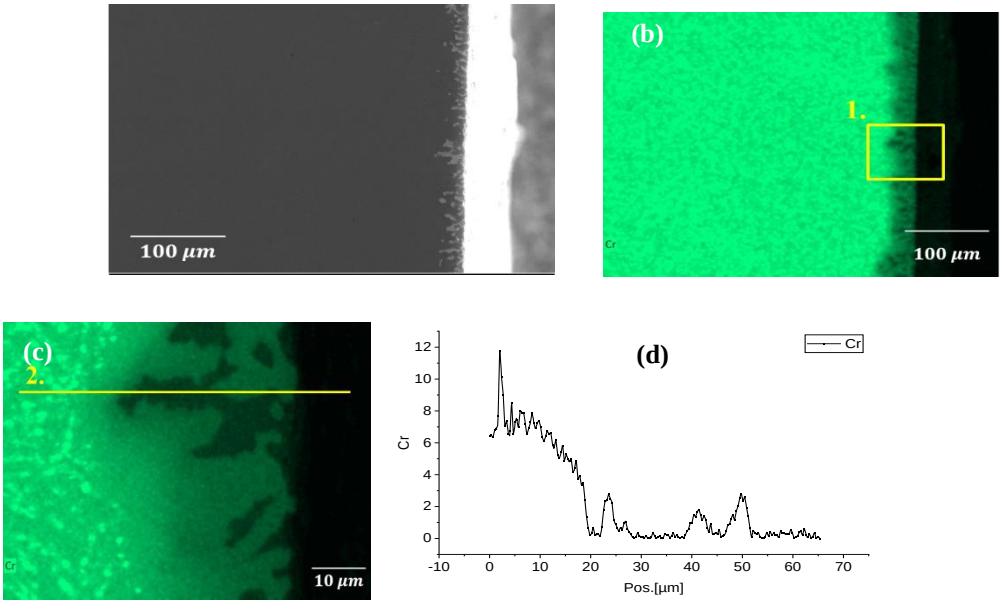

Figure 2. The depletion of Cr in static corroded T91 (506h, reducing environment, 715℃) showed by EDX. (a) The cross-section SEM; (b) The Cross-section EDX; (c) The EDX for the select region in (b); (d) The Cr content following the line in (c).

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