MICROSTRUCTURAL STUDY OF HELIUM BUBBLE FORMATION AND TRAPPING IN OXIDE DISPERSION-STRENGTHENED STEELS FOR FUSION REACTOR APPLICATIONS

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The management of blanket materials exposed to extreme irradiation and temperature conditions is of critical importance for ensuring the safety and durability of fusion reactors. Helium (He) generation in steels, resulting from nuclear reactions, pose a significant challenge, as it can lead to degradation in the mechanical properties. The high-energy neutrons emitted during fusion reactions have the potential to transmute Fe and Cr atoms into He, subsequently forming bubbles and cavities that compromise the structural integrity of the affected steels. The estimated irradiation damage is approximately 10 atomic parts per million/displacements per atom (appm He/dpa). A very few studies have shown that the oxide dispersion-strengthened (ODS) steels can mitigate the He induced embrittlement. Therefore, the present research work is aimed at comprehensively (i) evaluating the He capture capacity of nano-oxides in 9Cr (martensitic) and 14Cr (ferritic) ODS steels and (ii) establishing the relationship between microstructure of ODS and their He trapping capacity. The martensitic and ferritic ODS steels were subjected to He implantation at room temperature and 400 °C to generate He bubbles at different microstructural features. The concentration and internal pressure of He within the bubbles were determined accurately by a method developed, combining High-Angle Annular Dark Field (HAADF) imaging and Electron Energy Loss Spectroscopy (EELS) techniques in an aberration-corrected atomic resolution microscope (JEOL-neoARM). The determined parameters are of significant importance in understanding the embrittlement mechanism of these steels and can be used to tune and improve the properties of the materials used in the reactor. The current results indicate a significant correlation between the bubble size and the concentration of He and also bubble location within the microstructure such as grain boundary, nano-oxide and its interface. Smaller bubbles exhibited higher He concentrations and thus higher pressures. Bubbles were seen to accumulate more at grain boundaries, dislocations, nano-oxides and also at the matrix-nano oxide interface regions. Dispersed nano-oxides in ODS steels were found to effectively limit the bubble/cavity formation and thereby can mitigate the embrittlement. These results provide insights for enhancing the microstructural stability and durability of the blanket steels under extreme irradiation environments.

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