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Probing Eutectic Melting and Relocation Behavior of B4C Pellet and Stainless Steel in Sodium-Cooled Fast Reactors through Radiative Heating

The development of Generation IV Sodium-cooled Fast Reactors (SFRs) presents a crucial challenge in the form of Core Disruptive Accidents (CDAs). Boron migration is a significant concern in CDA evaluation since the eutectic reaction between boron carbide (B4C) and Stainless Steel (SS) can lead to forming a molten pool that could potentially relocate widely in the core, increasing the neutron absorption of the disrupted core. This study employs a quantitative and high-resolution method using Radiative heating to visualise the eutectic behaviour of boron migration and subsequent melt structure. The experiments were conducted using a B4C pellet with SS tubes in the temperature range of 1473 K–1645 K to observe the long-duration melting and its relocation behaviour for the first time. Eutectic melting was observed when the interface temperature reached around 1240 ℃. Two melting mechanisms were observed: the SS peeling off the B4C pellet and forming a melting drop containing boride structures. The B4C pellet broke into multiple pieces due to thermal stress, and the entire SS melted during long-duration heating, while a small amount of B4C pellet was absorbed during the eutectic reaction, mixing with the SS melt. A detailed composition analysis using scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDX) revealed the microstructures of the molten drop after cooling at a cooling rate of 50 °C/s. The high atomic boron zone was rich in chromium and iron. It did not contain nickel, suggesting chromium is more likely to coexist with boron in the solidified microstructure. Different crystal phases were confirmed using EDX analysis, which could help determine suitable decommissioning procedures. The study provides a deeper understanding of the behaviour of boron migration and its relocation in SFRs, shedding light on the mechanisms underlying the eutectic reaction between B4C and SS in the event of CDAs.

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