Study on Eutectic Melting Behavior of Control Rod Materials in Core Disruptive Accidents of Sodium-Cooled Fast Reactors
(40) Eutectic Melting and Relocation Behavior of B_4C Pellet-Stainless Steel Using Numerical Approach

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Moving Particle Semi-implicit (MPS) method is used to model the eutectic reaction between stainless steel (SS) cladding and boron carbide (B_4C) to a severe accidents scenario. The study measured the boron concentration in the solidified eutectic melt due to B_4C ingress. Increased temperature enhances boron diffusion into SS, causing cladding penetration and melt flow, with a 13% boron concentration rise closely matching experimental results.

Keywords: Severe accident, B_4C, SS, Eutectic reaction, MPS method, Boron concentration

1. Introduction

In Sodium-cooled Fast Reactors (SFRs), eutectic reactions between stainless steel (SS) cladding and boron carbide (B_4C) can cause the failure of control-rod cladding, resulting in B_4C-SS eutectic melt relocation and control-rod breakup. Simulation is essential for assessing boron diffusion and control rod dynamics. Numerical analyses specific to SFRs are limited; existing methods like SIMMER III/IV have limitations. We enhance the Moving Particle Semi-implicit (MPS) method to address this, improving models for surface tension, viscosity, density, and heat transfer. Our simulations reproduce the "candling" phenomenon observed in experiments. This study is intended to enhance understanding of eutectic reactions in SFRs, crucial for reactor safety analysis.

2. MPS methodology and results

In MPS simulations, 2D and 3D cases validated experimental findings and studied boron diffusion in eutectic melt. Busby et al. [1] diffusion rate coefficient enabled B_4C to SS diffusion. 2D simulations mimicked experimental steps with B_4C-SS using symmetry for preliminary analysis and 3D simulations scaled real geometry, both with dummy walls as heat sources. Thermal conditions aligned with experimental settings. Melting SS layers showed boron diffusion, resulting in a 13% rise in boron's atomic composition in the eutectic melt, closely matching a 15% increase observed in SEM/EDS analysis [2]. The boron mass concentration in the eutectic melt increases with temperature, accelerating the diffusion process. However, it's important to note that the modified code achieves slower boron diffusion, thereby reducing the overestimation of boron mass concentration in the eutectic melt and producing results closer to experimental values.

3. Conclusion

Previous studies had difficulty accurately modeling B_4C-SS relocation and the candling effect. Our MPS simulations confirmed the candling and relocation phenomenon, along with B_4C ingress in the solidified eutectic melt, aligning with experimental findings. The enhanced MPS code, with temperature and concentration-dependent thermophysical properties, prevent boron mass overestimation, and closely replicate melt geometry, matching experimental results.

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References

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