CLUSTER DYNAMICS MODELING OF DEFECT EVOLUTION IN NEUTRON-IRRADIATED TUNGSTEN FOR FUSION APPLICATIONS

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In magnetic confinement nuclear fusion devices, Tungsten (W) is considered the most promising plasma-facing materials (PFMs) for divertor, which will be exposed to high neutron loads at high temperatures (up to 1200 °C during steady-state operation). Such an extreme environment leads to the production of point defects, dislocation loops, voids, and precipitates consisting of transmutation elements such as Rhenium (Re) and Osmium (Os) in W. As is known to all, these defects will result in the degradation of the mechanical properties and may reduce the duration of the W divertor.

In this study, a cluster dynamics (CD) model is developed to describe the defect production and evolution under neutron irradiation at various temperatures. Defects in size up to several nanometers with different migration dimensions are considered, and the results are compared with the experiments of different devices such as HIFR, JOYO, and BR2.

The simulation results of neutron-irradiated single-crystal W experiments conducted in the BR2 reactor are presented below; the experiment data is available in [1]. To compare with the experiment, only visible defects(>1nm) were considered. Fig. 1 illustrates the variation in total defect concentration of voids and self-interstitial atoms (SIAs) with irradiation dose at different temperatures, showing a decrease in concentration as temperature increases within the studied range. Fig. 2 and 3 compare experimental data with the CD model at 0.2 dpa. While the simulated defect concentration is an order of magnitude lower than experimental values, the average size of visible clusters aligns well with observations. Additionally, the influence of key factors, such as cluster diffusion coefficients and migration dimensions, on defect evolution has been analyzed.

Ongoing work focuses on extending the model to polycrystalline W by incorporating the effects of grain boundaries and dislocation lines as defect sinks. Advanced rate theory approaches are being integrated to refine sink strength calculations and reaction kinetics between defect species.

In summary, the developed model has demonstrated accuracy in predicting defect size in neutron-irradiated single-crystal W. Future efforts aim to extend its predictive capabilities to polycrystalline W, providing insights into microstructural evolution under high-temperature neutron irradiation.

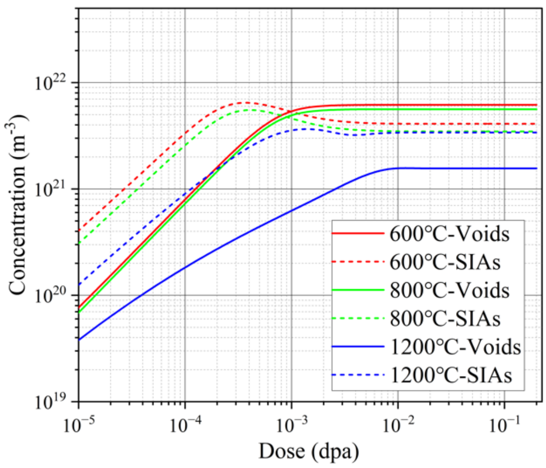

Fig. 1. The relationship between total defects concentration of voids/SIAs and dose for BR2 reactor at three different temperatures

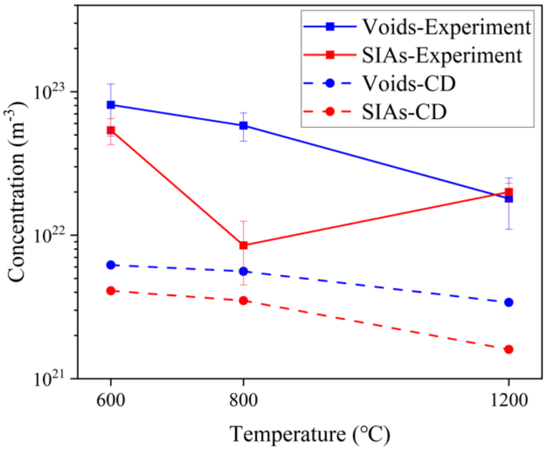

Fig.2. Comparison of visible cluster concentration between experiment and simulation

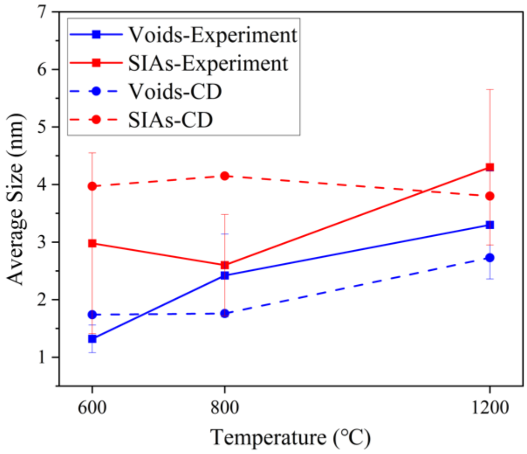

Fig.3. Comparison of visible cluster average size between experiment and simulation

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REFERENCES

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