§95. Characterization of Cascade-Induced Defect Production by Microstructural Analysis Based on Rate Theory Modeling

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Microstructural and microchemical changes as consequences of defect migration and accumulation are generally understood to be responsible for the irradiation-induced property degradation in fusion reactor materials. Therefore, the defect production characteristics and effective flux of freely migrating point defects under cascade damage conditions are among the key issues to assess the materials behavior under fusion environment by mechanistic modeling.

Attempts to clarify the defect production efficiency have been made for years both by experiments and computation. Computer simulations of cascade events by means of molecular dynamics has shown 10 to 20 percent of surviving defect fractions (SDF) in typical fcc metals at elevated temperatures. SDF here is number of cascade-produced Frenkel pairs, which survived in-cascade recombination by the end the cascade cooling phase, relative to the number of displacements determined by the NRT definition. Since the produced defects are localized within or at the periphery of cascade core regions at the end of atomic process simulations, the SDF quoted above should be the maximum value of the cascade-escaping defect fraction, which must be more or less smaller. Stochastic annealing simulations have provided some quantitative information on this issue, however, understanding of the effect of localized defect production is still insufficient. Results from the maximum swelling rate measurements are generally consistent with the calculated SDF at high temperatures, however, effective free defect production rates derived from other experiments including loop growth measurement and radiation induced segregation or radiation induced diffusion analyses yielded to as low as several tenth percent. This discrepancy is most likely attributed to the effect of fine defect structures in part due to the complexity of defect production behavior particular to high energy cascade. Such microstructural effect should influence swelling rates as well but have never been assessed systematically.

In the present work, using a rate theory model of defect evolution in irradiated materials, issues related to characterization of cascade - induced defect production by microstructural analysis, including swelling rate analysis in reactor - irradiated austenitic alloys and loop growth rate analysis in electron - and heavy ion - irradiated austenitic model alloy, are studied.

The summary of this work follows: determination of cascade-produced defect characteristics, such as surviving defect production efficiency and cascade cluster configuration, was attempted by means of swelling analysis based on rate theory modeling. A temperature dependence study suggested that CVC in austenitic alloys relax into stacking fault tetrahedra or similar lowest energy configurations during their early life and then act as effective sinks of point defects below certain temperature. Effects of surviving defect fraction and dislocation-interstitial bias on temperature dependence of swelling rate appeared dissimilar when CVC effect is significant.

In addition, the influences of SDF and CVC production on dislocation loop growth rate were investigated. The CVC production is likely to be the major cause of loop growth rate suppression at relatively low temperatures. Steady-state vacancy cluster concentration was estimated from loop growth analysis, and the contribution of cascade-overlapping was discussed in terms of interaction radius.