3 - 5 Sink Effect of Second-phase Particle on Cavity Swelling in RAFM Steel under Ar-ion Irradiation at 773 K

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The second-phase particle intentionally introduced by prior thermal treatment in complex structural alloys is very important to application of the candidate structural materials for advanced nuclear reactors, because the precipitate particles are used to strengthen the matrix and grain boundaries in structural alloys[1]. A good understanding on the stable second-phase particle behavior under irradiation in structural alloy is necessary to develop new radiation swelling resistance candidate structural alloys for advanced nuclear reactors. In present study, the precipitates behavior on cavity swelling in Chinese RAFM steel irradiated with 792 MeV Ar-ions at 773 K were examined by using a transmission electron microscope (TEM).

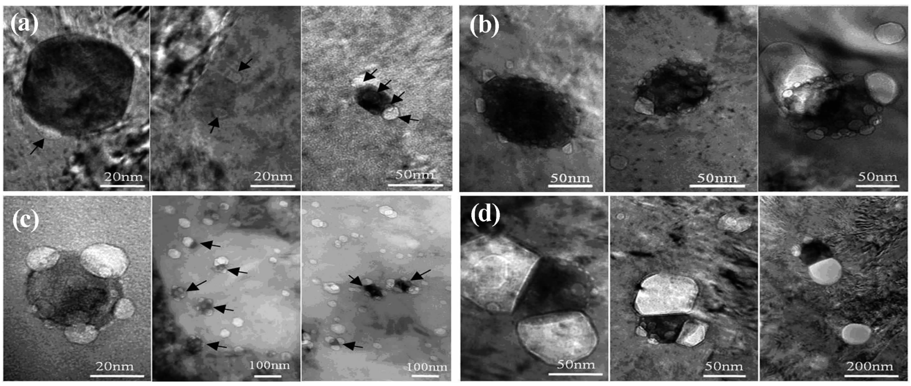

Fig. 1 Preferential nucleation and growth of cavities at the interface of MC precipitates at different damage level: (a) 2 dpa; (b) 6 dpa; (c) 9 dpa; (d) 18 dpa.

The typical bright field (BF) images present the cavity formation in association with metallic carbide (MC) phase particles at different irradiation damage levels in Fig. 1. As shown in Fig. 1(a), at the dose of 2 dpa, preferential formation of small cavities occurred at the interface between MC particle and matrix. Slightly smaller cavities could also be observed in matrix. Thus it can be inferred that the dose threshold for cavity formation at the interface between MC particle and matrix is lower than that in matrix. As the displacement damage dose is increased, as shown in Fig. 1(b), the interface of MC particle, as a region of rapid defect transport sink similar to large angle grain boundary, can provide favorable sites for the nucleation of cavity and result in the number density of cavity increasing significantly. At the same time, the cavity embryo located at the interface can absorb a sufficient number of vacancies introduced by irradiation and then the diameter of attached cavities reach a maximum of approximate 50 nm. It is also observed that the attached cavities are significantly larger than those in the matrix and approximate 80 cavities were associated with each particle, as shown in Fig. 1(b). These observations suggest that the attached cavities at the interface of the MC particles grow or coarsen faster than those in the matrix.

Fig. 1(c) shows the typical microstructures of developed cavities attached to MC particle and unattached cavities in the peak damage region irradiated to the dose of 9 dpa at 773 K. The results indicate that significant increase of both attached and unattached cavity size with an increase of the dose is apparent. According with the migration and coalescence mechanism (M & C)[2], the number of cavities associated with each particle falls rapidly and the size of them obviously increased. Furthermore, careful observation reveals that the size of unattached cavities reaches a maximum value of ~70 nm and the maximum size of attached cavities is only ~40 nm in diameter. It should be mentioned that dense unattached cavities have larger size in diameter than the attached cavities. However, for the attached cavity at the interface of the MC particles, although the interface acts as an efficient collector for point defect and result in preferential nucleation and enhanced growth of cavities occurred, the growth rate of the MC particle nucleated cavities reduce sharply as the cavity approaches the MC particle size due to the limitation of free volume at the MC interface.

With increasing irradiation dose to 18 dpa, an important feature of cavities-particle complexes is the second-phase particles changing their shape by attached cavities. Typical microstructures of the cavities attached to MC particle are shown in Fig. 1(d). On one hand, the observed shape changing of MC particle by attached cavities suggests that there is a strong binding between particles and cavities[3]. On the other hand, when argon is injected, migrating argon is trapped at particle-matrix interfaces where it stabilizes cavity embryos against shrinkage in the early stages of nucleation[4]. The attached cavity can grow subsequently under argon supply and accumulation of supersaturated vacancies and then it results in the MC particle become truncated by the cavities containing argon under high internal pressure. The observed trapping of both argon and vacancies at the interface of MC particles at 773 K indicates that these MC particles may be able to reduce high temperature helium embrittlement at grain boundaries in a similar way to the effect of Y_2O_3 particles in oxide dispersion strengthened (ODS) steels.

References

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3 - 6 Microstructure in Martensitic Steels Chinese RAFM and T91 Irradiated with 196 MeV Kr Ions

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Martensitic steels offer some advantages over austenitic stainless steels and are proposed as candidate structural materials in advanced nuclear reactors because of their low activation, superior swelling resistance, excellent mechanical properties, and good microstructure stability. The irradiation of Kr-ion with a kinetic energy of 196 MeV was performed on the high temperature & stress (HTS) materials research terminal of the HIRFL-SSC (IMP, Lanzhou). The materials used in the present irradiation are Chinese reduced activation ferritic/martensitic(RAFM) and Japan T91 steels. After irradiation, the irradiated specimens were prepared with the cross-sectional specimen technique and then thinned for TEM by ion beam milling, so that damage level as a function of depth could be obtained directly. The TEM observation was performed with an FEI TECNAI G^2 F30 TEM at Lanzhou University and all micrographs were taken at 300 keV.

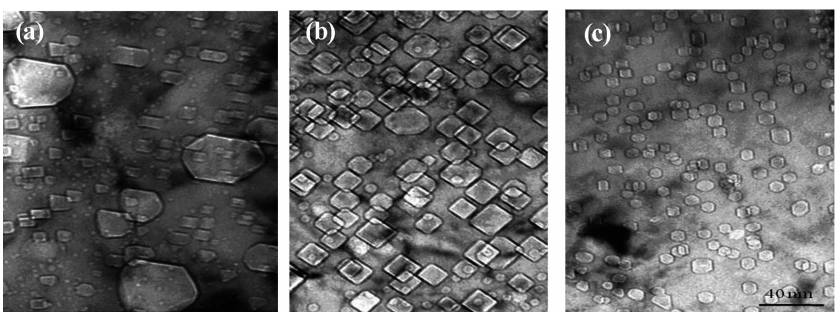

Fig. 1 Microstructure of cavities in Chinese RAFM steel at different irradiation conditions: (a) 31 dpa, RT; (b) 28 dpa, 450 ℃; (c) 31 dpa, 550 ℃.

Figs. 1 and 2 show the microstructure of cavities induced by irradiation at peak damage region in Chinese RAFM and T91 steel at different irradiation temperature, respectively. It is found that dense cavity produced by irradiation mainly located in the martensite lath boundaries, dislocation network and precipi-