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学 位 論 文 題 目　Microstructural Change of Oxide Nanoparticles in 9Cr- and 12Cr-Oxide Dispersion Strengthened Steels under High Energy Electron Irradiation（9Cr および 12Cr 酸化物分散強化鋼中の酸化物ナノ粒子に対する電子線照射効果に関する研究）
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論文内容要約

要約

Oxide dispersion strengthened (ODS) steels are one of the candidate materials as fuel cladding for Generation IV fission reactors and blanket module system of DEMO fusion reactors for their superior high-temperature mechanical strength and good radiation resistance. The intelligence is achieved due to the dispersed oxide nanoparticles, which will be called "particles", hereafter, as well as small grain size. However, it is anticipated that the particles are unstable under irradiation, which may greatly influence the radiation integrity of ODS steels. This work is, therefore, aimed at clarifying the mechanism of the radiation response of particles embedded in Fe-Cr matrix. For this purpose, a new method; a focused-electron-beam irradiation technique was developed, which introduces distribution of atomic displacements and enhances vacancy diffusion.

In Chapter 1, the necessity of developing nuclear energy and the importance of the structural materials of the power reactors were deduced. ODS steels, their intelligence in mechanical properties, and their applications were introduced. In Chapter 2, fabrication, mechanical property and radiation integrity of ODS steels, and basic knowledge of radiation effects were reviewed. The discussion extended in Chapter 3, and an intensive review especially focused on the irradiation effects and the characterization techniques of the particles, both of which were the basis of this study, and motivations of this work were given. Finally the research objects of this research, as well as selection of the materials, were deduced.

In Chapter 4, the particles in 9Cr- and 12Cr-ODS steels were characterized by scanning transmission electron microscopy combined with energy dispersion X-ray spectroscopy and high resolution electron microscopy. Most of the particles were either $Y_2Ti_2O_7$ or Y_2TiO_5 whose size smaller than 5nm and ranged from 5 to 15nm, respectively. While, two types of Y_2O_3 (Monoclinic and cubic) having about 10-35 nm in size were also detected but in minor populations.

In Chapter 5, microstructural evolution under electron irradiations at elevated temperature in 9Cr ODS steel using a high voltage electron microscope was summarized. $Y_2Ti_2O_7$-type particles disappeared effectively, besides Y_2TiO_5-type ones did through size shrinkage. The size evolution was statistically analyzed with a parameter of size change rate relevant to dpa and irradiation time. The change in size per dpa tended to be larger at lower dpa rate regime. Under the focused beam irradiation, the size change rate was larger at the periphery of the electron beam, which indicate that the gradient of the dpa rate seemed to have great effect in accelerating the size change of the particles.

Chapter 6 showed the results of high energy electron irradiation experiments with 12Cr ODS steel. Similarly the particles were distinguished by size, and similar disappearance effect of the $Y_2Ti_2O_7$ structure and gradual size change of the Y_2TiO_5 type were observed. Similar trend of the size change of the latter was observed through statistical analysis.

In Chapter 7, kinetics of irradiation-induced instability of the particle was proposed and discussed in detail. The focused beam introduced a distribution of atomic displacements in Fe-Cr matrix, and resulting irradiation-enhanced diffusion from the center to the periphery of the electron beam. The constituent atoms Y and Ti in the particles interact with the incident electrons to generate their Frenkel pairs or chemical disordering (anti-site defects). The displaced atoms may solute into matrix through direct injection into it or irradiation-induced diffusion that replace them with matrix atoms at the particle/matrix interface. Y and Ti atoms in matrix migrate through vacancy mechanism as oversized atoms. The high anti-site defect energy chemical disordering in $Y_2Ti_2O_7$ was considered to destabilize crystalline state.

All the achievements of this work were summarized in chapter 8.