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Effect of electron irradiation on microstructural damage in the welded portion of a SUS304 weldment

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Abstract

The matrix and heat affected zone (HAZ) of welded SUS304 steel has been irradiated in an 1250 kV high voltage electron microscope at 673 K to 5.4 dpa (displacements per atom) to study the effect of electron irradiation on microstructure. In situ observation shows the voids formed by electron-beam irradiation coalescence which grew to larger sizes with irradiation dose. Values of void size, void number density and void swelling in HAZ were larger than those of the matrix, and these increased and saturated gradually with irradiation dose. Non-equilibrium segregation phenomenon involving Cr depletion and Ni enrichment at grain boundaries were also observed in both the HAZ and matrix of welded SUS304 steel.

Keywords: Irradiation damage; 304 Stainless steel; High voltage electron microscope; Heat affected zone; Void swelling; Segregation

1. Introduction

An important issue associated with nuclear reactors is how to extend the lifetime of reactor components and structure. To accomplish this, one way is the repair and/or replacement of irradiated materials in reactor. Welding is an available technique for repairing irradiated steels, such as SUS304 and SUS304L, which are popular structural materials for nuclear reactors [1]. However, the heat affected zone (HAZ), which has different physical properties compared to the matrix, is formed by a welding process. Much research has been performed regarding the effect of irradiation on microstructural evolution of austenitic stainless steels [2–13], but the behavior concerning void formation between the HAZ and matrix has not been clarified.

The objective of this study is to investigate the effect of irradiation damage on void nucleation and growth in the HAZ and matrix using electron-beam irradiation for

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welded SUS304 stainless steel in order to simulate the damage process in reactor.

2. Experimental procedure

Specimens for electron-beam irradiation were prepared from a SUS304 stainless steel which was solution-treated at 1323 K for 1 h. SUS304 stainless steel used has the following chemical composition: C: 0.05, P: 0.025, S: 0.004, Cr: 18.25, Ni: 8.27. The disk specimens with 3 mm diameter for electron-beam irradiation were prepared from the HAZ and the matrix portion of SUS304 stainless steel welded by tungsten inert gas (TIG) arc welding.

In order to investigate the effect of irradiation damage on welded portion during the operation of reactor, welded SUS304 stainless steel was aged at 673 K for 1000 h because the atmosphere temperature is about 573 K for structural materials in nuclear reactor.

Electron-beam irradiation was carried out at 673 K to 5.4 dpa in a 1250 kV HVEM. Irradiation-induced segregation analyses were carried out using an energy dispersive X-ray analyzer (EDX) in a 200 kV FE-TEM with beam diameter of about 0.5 nm.

3. Results and discussion

3.1. Microstructure change and void size distribution

Fig. 1 shows the microstructural development of voids formed by agglomeration of vacancies introduced by electron irradiation. Small voids are formed in the early stage of irradiation as shown in Fig. 1a. Both number density and void size increase gradually with irradiation dose as shown in Fig. 1c and d. Arrows in Fig. 1 show two voids coalescing into one larger void.

It is recognized that voids are clearly observable after ∼0.6 dpa. The voids formed in the early stage of irradiation continue to grow, and the nucleation of new voids and their growth are observed with increasing irradiation dose. The voids are effective sinks for point defects so that the void microstructure changes with increasing irradiation as shown in Fig. 1. Long-range migration of point defects also can produce irradiation-induced segregation that will be discussed later (Section 3.3).

Fig. 2 shows the microstructures of void distribution in the (a) HAZ and (b) matrix after irradiation to 5.4 dpa at 673 K in SUS304 steel. The voids are formed

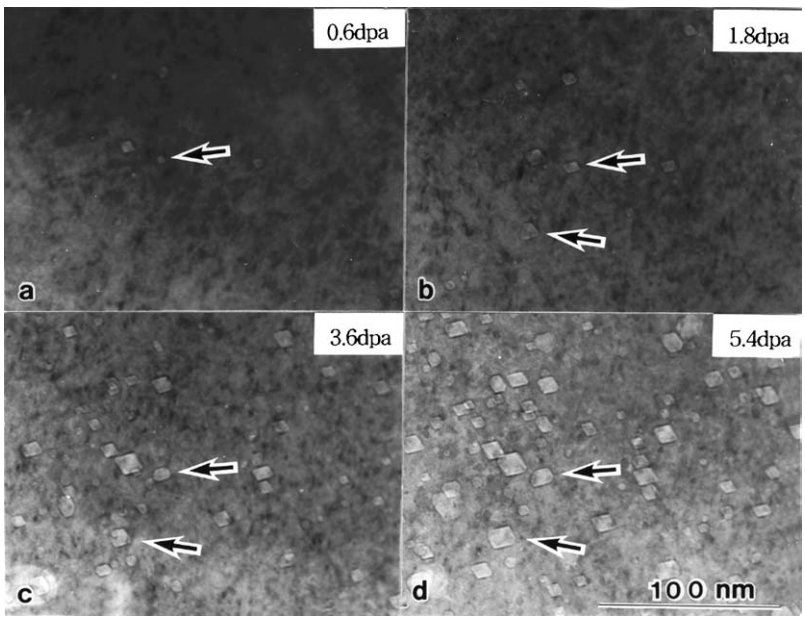

Fig. 1. Void formation changes after electron irradiation to: (a) 0.6 dpa, (b) 1.8 dpa, (c) 3.6 dpa and (d) 5.4 dpa at 673 K in the HAZ of SUS304 steel.