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Electron Irradiation Effects on the 316 Stainless Steel

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1. Introduction

The void-swelling resistance of austenitic stainless steels is determined by the change of the microstructure and phase composition under irradiation. The electron beam used in a transmission electron microscope (TEM) can cause temporary or permanent change in the surface or bulk structure of a specimen.

Fig. 1 classifies radiation damage according to the type of electron scattering and according to the effects produced in a specimen.

Elastic scattering means electrostatic deflection of incoming electrons by the Coulomb field of each atomic nucleus. It causes electron-diffraction patterns and diffraction and phase contrast in TEM images, but in some circumstances it can result in atomic displacement within a crystalline specimen or electron-beam sputtering of atoms from its surface.

Inelastic scattering means Coulomb interaction of incoming electrons with the atomic electrons that surround each nucleus. It causes the secondary-electron production, the emission of X-rays used for elemental analysis (EDS), and electron energy-loss spectra (EELS) in the TEM. But inelastic scattering can also produce radiolysis effects, which change the structure of a specimen or remove material (mass loss). Under certain conditions (the presence of ambient hydrocarbons), electronic excitation also causes hydrocarbon contamination.

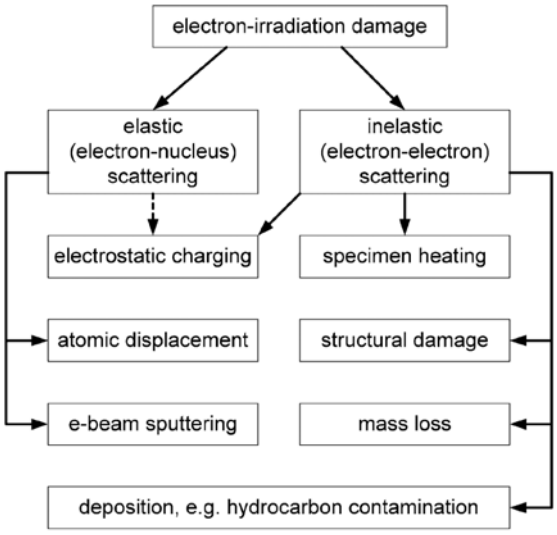

Fig. 1. Categorization of radiation damage according to the type of electron scattering and according to the effects produced in a specimen [1]

We have obtained specimens in which the microstructure was changed by using the high-voltage TEM, and analyzed the change of EELS peaks for characterizing the electron irradiation damage.

2. Methods and Results

Fig. 2 represents EELS peaks obtained from a 316 stainless steel at room temperature against the time of electron irradiation by the HVEM in KBSI. The intensity of EELS peaks was reduced as the electron irradiation time increased. They undergo changes in the specimens during electron irradiation carried out with the HVEM.

The intensity distribution can be expressed as a function of t/λ

$$I_0/I = \exp(t/\lambda) \quad (1)$$

where t is the true sample thickness, and λ is the mean free path of electron for inelastic scattering. As shown in Fig. 3, the relative thickness calculated from the change of relative EELS intensity for the electron irradiated area was almost not changed for several minutes, but after time (7 min) it approximately linearly decreased as the irradiation time increased. This relative thickness change can be attributed to a real thickness variation due to a true mass loss and/or a change of the mean free path λ at the irradiated area. The latter can be caused by a change in atomic density, inversely proportional to λ. The present relative reduction of thickness should accompany a net mass loss because the upper limit of the change in λ was estimated from the plasmon shift to be only ~2% [2-3].

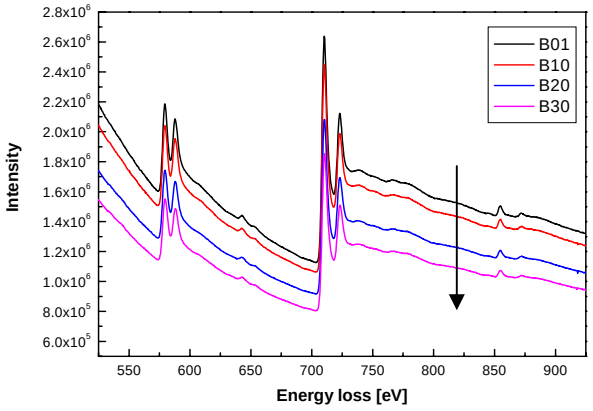

Fig. 2. EELS peaks obtained from 316 stainless steel at room temperature against the time of electron irradiation by the HVEM in KBSI.

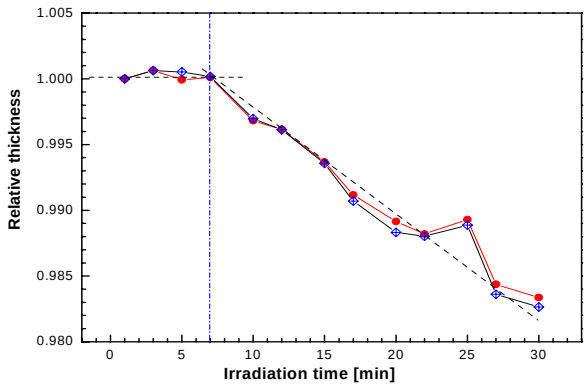

Fig. 3. The change of relative thickness versus the time of electron irradiation carried out by the HVEM.

Fig. 4 shows the relative EELS intensity of the 316 stainless steel normalized with a maximum peak of the Fe L3 edge versus the time of electron irradiation by the HVEM in KBSI. The relative intensity of the EELS peak looks almost the same. But as shown in Fig. 5, both peak position and FWHM of the Fe L3 peak were increased as the electron irradiation time increased.

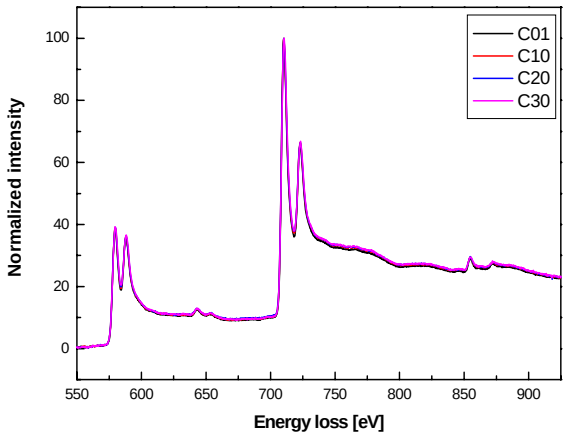

Fig. 4. Relative EELS intensity normalized with the Fe L3 edge peak maximum against the time of electron irradiation by the HVEM in KBSI

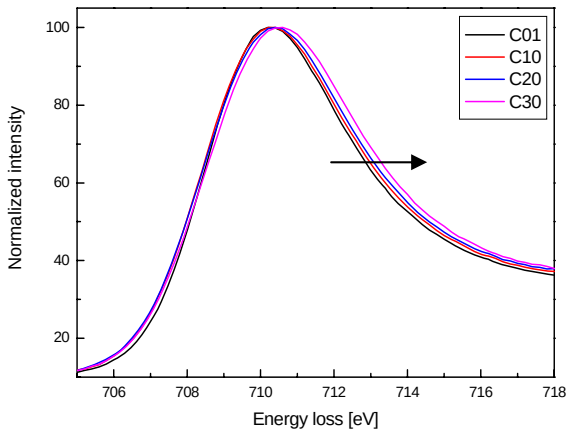

Fig. 5. Peak position and FWHM of the Fe L3 peak were increased as the time of electron irradiation increased by the HVEM in KBSI

Therefore the irradiated area could be stronger and more disordered as the irradiation time increased.

Fig. 6 represents the change of chemical composition in Fe, Cr, and Ni as a function of the electron irradiation time. The trend curve of both Fe and Cr contents is in contradiction with Ni contents fluctuated within 5~10wt% except for Cr contents within 2wt%. The chemical compositions gradually changed for several minutes, but fluctuated after time (10 min). The radiation-induced grain boundary segregation also looks like the same as the chemical compositions of both Fe and Cr are contrary to that of Ni [4].

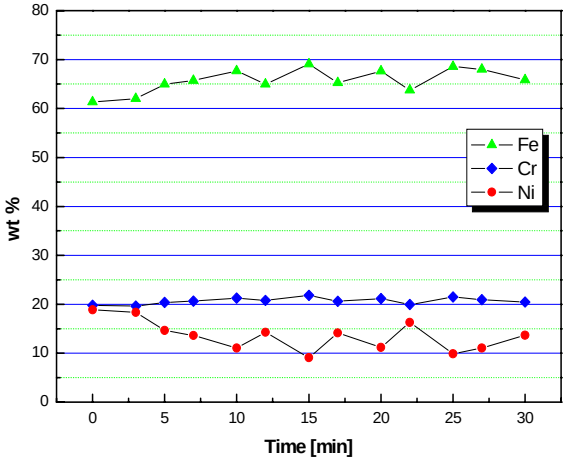

Fig. 6. Chemical composition as a function of the electron irradiation time

3. Conclusions

With an increase in the irradiation time, the intensity of EELS peaks were reduced, and the relative thickness for the electron irradiated area was almost not changed for several minutes. But after time, it approximately linearly decreased as the irradiation time increased. Besides, both peak position and the FWHM of the Fe L3 peak increased. The irradiated area could therefore be stronger and more disordered. The trend curve of both Fe and Cr contents was reverse to Ni contents fluctuated within 5~10wt% except for Cr contents within 2wt%.

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