§16. Effect of Stress on Radiation-induced Hardening of Fe-Mn Model Alloys

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1. Introduction

Neutron irradiation of steels increases the ductile-to-brittle transition temperature (DBTT) and decreases the upper shelf energy at lower temperature. It was shown that the contribution of dislocation loops to hardening was essential. Pressurized-water (PWR)-PWR type nuclear reactor pressure vessels operate in condition where the pressure vessel is under tension, however, surveillance specimens to simulate irradiation embrittlement are not irradiated under tensile stress conditions. Therefore, consideration of the difference in irradiation embrittlement between a pressure vessel and a surveillance specimen might further our understanding of the mechanical properties involved. However, knowledge about dislocation loops formed at higher dose levels under tensile stress conditions in pressure vessel steels is very limited. Therefore, in this study, a small tensile test machine was newly developed for heavy-ion irradiation experiments using tensile stress conditions; the effect of stress on material properties and dislocation loop nucleation of a A533B steel with low-copper levels and of an Fe–Mn model alloy were studied.

2. Results

Fig. 1 shows the new tensile test machine used in the present study. Irradiation temperature was controlled by an infrared temperature sensor. To adjust the temperature and correct the emissivity of the samples, a thermocouple spot-welded to the specimen was used. This device was inserted and tested in a beam line of the tandem-type accelerator at the Research Institute for Applied Mechanics at Kyushu University. Figs. 2(a) and 2(b) show stress–strain curves of the Fe–1.4 wt%Mn alloy and A533B steel, respectively. In the figure, the test results at room temperature and 563 K are shown. The tensile stress rate was 93 MPa/min. The 2.4 MeV Fe^{2+} ion irradiations were performed at several tensile stress conditions (shown in the figure) at room temperature and 563 K. Hardness tests were conducted before and after the ion irradiations at room temperature using an Elionix ENT-1100 with a load of 1 gf. A triangular pyramidal diamond indentor (Berkovich type) with a semi-apex angle of 65° was used. The indenter load (L) and indenter displacement (d) were continuously monitored by a computer system. L and d are given by

$$L/d = Ad + B, \quad (1)$$

where A and B are dependent on materials but independent of indenter load and displacement. A is proportional to the Vickers hardness (Hv) and is given by

$$A(GPa) = 0.287\ Hv . \quad (2)$$

Without irradiation, the dislocation density of the Fe–1.4 wt%Mn alloy increased with increasing tensile stress. Fig. 3 shows bright-field transmission electron microscopy (TEM) images of the Fe–1.4 wt%Mn alloy at different stress levels at room temperature with the tensile direction shown by arrows in the figure. Measured dislocation densities are also shown in the figure. Room temperature irradiations resulted in a relatively high density of interstitial-type dislocation loops. At 563 K, the number density of dislocation loops decreased and larger loops were formed. In the unstressed condition, formation of small interstitial-type dislocation loops was prominent in the matrix and also in the vicinity of dislocations in the Fe–1.4 wt%Mn alloy.

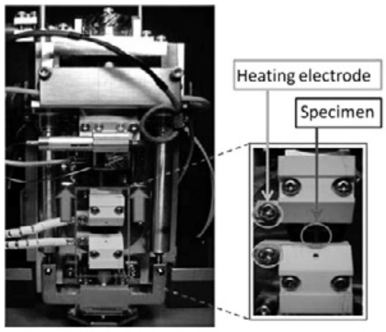

Fig.1. The miniature-sized tensile machine newly developed for the present study.

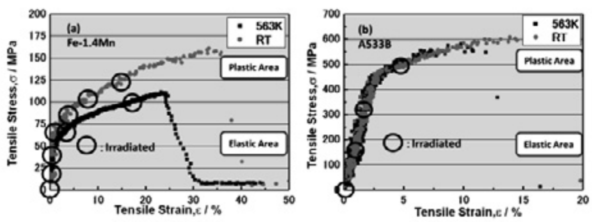

Fig.2 .Stress–strain curves of samples irradiated at room temperature and 563 K. (a) Fe–1.4 wt%Mn, (b) A533B steel.

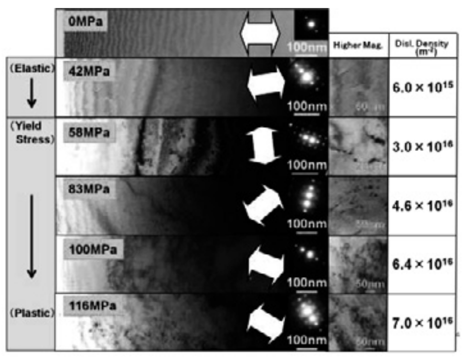

Fig.3. Bright-field TEM images and measured dislocation density of the Fe–1.4 wt%Mn alloy with different loads at room temperature. Tensile direction is shown by arrows. The measured network dislocation density is also shown in the figure.