SWELLING IN COLD-DEFORMED OKhI6NI5M3B STEEL ON IRRADIATION
IN A HIGH-VOLTAGE ELECTRON MICROSCOPE


Previous cold deformation greatly reduces the swelling of austenitic steel on neutron irradiation at 400-650°C. Conflicting results have come from research on the mechanism of this. For example, it has been found that the reduced swelling in cold-deformed steels of types 316 [1, 2] and OKhI6NI5M3B [3] is due to reduction in the growth rates of the pores, whose mean size decreases as the degree of deformation rises. However, cold deformation of type 304 steel reduces the rate of pore generation, which reduces the pore concentration and therefore the swelling [4]. The effects of cold deformation on the swelling of type 316 steel indicates [5] that the reduced swelling is due to reduction in the size and concentration of the pores, and the extent of the fall is dependent on the irradiation temperature.

These data indicate that there are several factors influencing the development of radiation porosity in austenitic steels. The contribution from each of the factors is dependent on the structural state and the irradiation conditions. Also, experiments within reactors are complicated and time-consuming.

In a high-voltage electron microscope, the electron energy exceeds the threshold needed to produce the radiation damage in the form of displaced atoms, and this enables one to perform the experiments much more quickly under strictly controlled conditions with continuous recording of the structure changes.

We have examined the effects of previous cold deformation on the development of radiation porosity in an austenitic steel of type OKhI6NI5M3B by exposing the steel to 1000 keV electrons in a JEM 1000 high-voltage electron microscope fitted with a heating attachment.

The specimens were prepared by jet electrolytic polishing [6]. The electrolyte was a mixture of 23% perchloric acid and 77% glacial acetic acid. The cell voltage was 200 V at 160-180 mA, while the electrolyte temperature was 20°C.

In neutron irradiation, the temperature dependence of the swelling of OKhI6NI5M3B steel is bell-shaped, with its maximum around 500°C [7], so the specimens were heated to this temperature, which was measured from the calibration curve with an error of not more than ±25°C (±5%). The electron flux density was determined with correction for the beam divergence by means of a Faraday cylinder as about 10^{19} electrons/cm²·sec. The diameter of the irradiated part was about 3 μm. The vacuum in the microscope column during the experiment was about 3·10^{-6} Pa. The threshold displacement energy and, therefore, the displacement cross section are very much dependent on the crystallographic orientation of the specimen with respect to the beam, so the specimen was placed in such a way that the beam passed along the (110) direction. The maximum dose attained in 12 h was 4·10^{23} electrons/cm², which corresponded to about 20 displacements per atom if one assumes that the overall displacement cross section for iron at 1000 kV is about 50 b [8]. During the experiment, the irradiated part was photographed every 30 min during the first 4 h of irradiation and then every hour.

The usual method [9] was used to determine the quantitative parameters characterizing the porosity, but the local thickness of the irradiated parts of the foil was found from the change in length of projections of dislocations on stereoscopic photographs with differences in angle of 5-10°. The distribution of the pores is distorted by the effects of the free surfaces in very thin parts of the foil [10], so we chose parts of thickness not less than 0.7 μm. We determined the total volume of the pores ΔV(ΔV), which was taken as equal to the swelling of the steel, as well as the pore concentration. We also examined the pore size distribution and calculated the mean size.

Fig. 1. Electron micrographs of a specimen with 5% cold deformation after 1 (a), 7 (b), and 12 (c) hours of irradiation.

Fig. 2. Electron micrographs of a specimen with 15% cold deformation after 1 (a), 7 (b), and 12 (c) hours of irradiation.

Figure 1 shows electron micrographs for a specimen that had undergone previous 5% cold deformation after 1, 7, and 12 h of irradiation. It is clear that even after 1 h (Fig. 1a) there are distinguishable pores with clear-cut facets. The pore distribution is nonuniform in size and in disposition within the metal. The size and concentration increase with the irradiation time. After 12 h of irradiation (Fig. 1c) it is clear that the pores have the form of slightly truncated or even perfect polyhedra.

The length of the incubation period increases with the degree of cold deformation, this being the time for extinguishable pores to appear. Figure 2 shows that steel previously deformed by 15% even after 7 h produces pores that are smaller (Fig. 2a) than those in steel deformed by 5% after 1 h. As in the case described, the size and concentration of the pores increase with the irradiation time (dose). However, the distribution remains uneven. The concentration is maximal in steel previously cold deformed by 10%. This can be seen by comparing Fig. 3, which shows the distribution in such a specimen after 12 h of irradiation, with Figs. 1c and 2c.

The size distribution is symmetrical with a single peak (Fig. 4) in specimens with various degrees of preliminary cold deformation irradiated to a maximum dose of 20 displacements per atom. One obtains more complicated curves for specimens of steel of this type irradiated in a reactor [7], evidently because there are various additional factors. The centers of the distribution shifts to smaller sizes as the degree of cold deformation in-