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Abstract

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THE EFFECT OF NEUTRON IRRADIATION ON THE MARTENSITIC TRANSFORMATION

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The use of neutron irradiation as a new effective means of acting upon the state of matter ([1]-[4]) is of interest not only as a means of changing the structural state, which brings about a definite change in the properties of metals and alloys ([5]-[8]), but, evidently, to no lesser degree as a method for investigating the nature of phase transformations (a method of preliminary action on the state of the initial phase, producing a definite change in its stability and in the kinetics of subsequent phase transitions). It seems to us promising to use this method for studying transformations of the martensitic type. The regular, strictly oriented displacement of atoms during a martensitic transition ([9]) accounts for its exceptionally high sensitivity to all kinds of disturbances in the structure of the crystal lattice of the initial austenitic phase. The occurrence of the transformation in the region of comparatively low temperatures should make it possible to study the kinetics at temperatures ensuring, as far as possible, complete preservation of the acquired radiation defects.

The general picture of radiation defects arising in the crystal lattice of metals and alloys under elastic collisions of fast neutrons with atomic nuclei is very complex. During irradiation, defects of various character and of unequal stability may arise simultaneously. It is assumed that defects possessing relatively low stability are large and equal, in magnitude, concentrations of interstitial atoms and vacancies. Structural changes exhibiting relatively high stability are associated with the formation of defects of a more macroscopic and complex character, appearing as a result of local melting and recrystallization of individual rather large zones ([3], [10]-[12]).

In the present investigation, the first attempt was undertaken to apply neutron irradiation to the study of martensitic transformations. Steels and alloys were studied for which the effect of prior plastic deformation on the martensitic transformation had previously been investigated in detail ([13], [14]): medium-carbon manganese steel 50G8 (0.48% C; 7.7% Mn; 2.2% Cu; $T_m = -10°$); high-carbon manganese steel 140G4 (1.40% C; 4.0% Mn; $T_m = -94°$); medium-carbon nickel steel 50N21 (0.50% C; 21.0% Ni; $T_m = -28°$) and iron–nickel–manganese alloys:

Fig. 1

Figure 1: Fig. 1

N23G3 (0.025% C; 22.7% Ni; 2.88% Mn; $T_m = -20^\circ$) and N22G3 (0.020% C; 22.4% Ni; 3.48% Mn; $T_m = -39^\circ$).

Irradiation of the specimens ($2 \times 3 \times 24$ mm) was carried out in the active zone of an experimental heavy-water physical reactor ([15]), near uranium rods* after preliminary heat treatment, consisting in—

* During irradiation the temperature of the specimens rose by no more than to 40°.

annealed in vacuum at 1100° for 10 h. One batch of specimens was irradiated for 100 h, another for 200 h. The total neutron flux was of the order of 10^{17} n/cm^2. The change in the stability of austenite was evaluated from the course of magnetometric curves of deep cooling and heating.

As a result of the investigation it was established that preliminary neutron irradiation has a substantial influence on the stability of austenite with respect to martensitic transformation.

Fig. 1. Different character of the effect of irradiation on martensitic transformation:
a —activating effect (steel 50G8), *b* —retarding effect (alloy N22G3); 1 —without irradiation, 2 —irradiation for 100 h, 3 —irradiation for 200 h, 4 —irradiation for 200 h, annealing at 100° for 5 h.

This change in stability (expressed in a change in the position of the martensitic point and in the final effect of the transformation) has a different character in different materials.

In steels, regardless of carbon content and the character of alloying, irradiation increases the intensity of the martensitic transformation occurring during subsequent deep cooling. Thus, in steel 50G8 irradiation raises the temperature of the start of transformation by 15° and increases the effect of deep cooling by 10% (Fig. 1a). In nickel steel 50N21 the activation of austenite caused by irradiation is expressed, in addition, in an increase in the amount of martensite arising during the initial "burst." In manganese steel 50G8 (having the highest martensitic point) an indication was also obtained of the possibility of a phase transition austenite → martensite directly under the influence of irradiation.

A different character of the action of irradiation is observed in carbon-free iron-nickel-manganese alloys N23G3 and N22G3. In these alloys, irradiation in both variants (for 100 and 200 h) always exerts a stabilizing influence on the γ-phase—it lowers the martensitic point and decreases the intensity of the transformation (Fig. 1b).

Comparison of the data obtained with the results of investigations of plastic

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

deformation ([13,14]) shows that the influence of each of these two factors has much in common: the particular attitude that a given material exhibits toward the action of preliminary plastic deformation coincides in its main features with the peculiarities of its behavior found after irradiation (the stability changes in one direction).

Does a retarding effect exist in steels under relatively strong irradiation effects, similar to that which occurs under plastic—

tic deformation; or else does irradiation, in contrast to plastic deformation, always cause in steels only activation of austenite? Some data have been obtained on this question indicating the correctness of the first supposition: in steel 50G8 the existence of a maximum of activation as a function of irradiation duration was observed (an increase in irradiation time from 100 to 200 h led to a decrease in the activating effect by more than a factor of two).

Fig. 2

Fig. 3

Fig. 2. Removal of the activating effect during holding and low-temperature annealing of steel 50G8.
1 —without irradiation; 2 —irradiation for 100 h, holding for 90 days; 3 —irradiation for 100 h, holding for 330 days; 4 —irradiation for 125 h, holding for 162 days, annealing at 100° for 10 h.

Fig. 3. Additional increase in the stability of the γ-phase during holding of the irradiated alloy N23G3.
1 —without irradiation; 2 —irradiation for 100 h, holding for 130 days; 3 —irradiation for 100 h, holding for 334 days; 4 —irradiation for 200 h, holding for 234 days.

Prolonged holding of irradiated specimens at room temperature leads to an increase in the stability of austenite. This retarding influence of prolonged holding is expressed in steels in the gradual elimination of the activating effect of irradiation (Fig. 2), and in iron-nickel-manganese alloys in an additional increase in the stability of austenite (Fig. 3). An analogous, but still stronger, influence is exerted by annealing at 100° (Fig. 2). Consequently, the influence of low-temperature annealing in irradiated steels is analogous to that observed after relatively small, activating deformations [^16]: in both cases the activation effect is gradually eliminated.

Consideration of the entire body of data obtained, comparison of these data with the picture of the change in austenite stability under the influence of plastic deformation [^13,^14,^16], and also the existing ideas concerning the nature of radiation defects [^1–^8,^10–^12] lead to the following conclusion. It would hardly be correct to suppose that the activation effect caused by irradiation is in principle inherent only in steels, and the retarding effect only in alloys. Evidently, during irradiation, structural changes develop simultaneously in metals and alloys that affect the stability of austenite in opposite directions. The total effect of the action, i.e., the detection of an activating or retarding effect, depends on the total neutron flux (which determines the degree of radiation damage) and on the characteristics of the material (elasto-plas-

···of the plastic properties of austenite, etc.). At earlier stages of irradiation, disturbances evidently arise predominantly that favor the transformation; at later stages, structural changes come into play that exert the opposite influence. The appearance of a maximum of activation in steel indicates the validity of this assumption.

The low temperature stability of the activating effect (its elimination in the course of aging and annealing at 100°) indicates that it is due to the formation of defects of the vacancy-interstitial type, which, as is known, are capable of being restored at very low temperatures (beginning at 50° K) (12). The favorable influence of such disturbances on the martensitic transformation must be connected with the appearance of elastic deformations of the crystal lattice around sites with an increased concentration of interstitial atoms and vacancies (5, 10, 12), since it is known that stresses in the general case exert a stimulating influence on the martensitic transformation (they reduce the potential barriers that must be overcome by atoms during the phase transition). The probability of the development of considerable local stresses must be the greater, the higher the elastic properties of the initial austenitic phase. It is precisely for this reason, evidently, that the activation effect is clearly expressed in steels.

The stabilizing effect of irradiation is apparently due to the formation of defects of a more complex character (3), which, as is known, possess high temperature stability (8, 10). Such defects, according to existing views, appear during irradiation as a result of the development of processes of fragmentation and disorientation of crystals and constitute complexes of the smallest differently oriented crystallites, formed in zones of local melting and recrystallization. The disordered state of such regions and the small size of each crystallite entering into the complex must limit the possibilities for the formation and growth of martensitic crystals. The elimination of these defects and, correspondingly, the elimination of the stabilizing effect of irradiation are possible only at temperatures that ensure the occurrence of recrystallization processes.

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Note: Figure translations are in progress. See original paper for figures.