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Abstract

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PHYSICS

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ANISOTROPY OF ATOMIC DISPLACEMENTS

IN THE CRYSTAL LATTICE OF THE α PHASE

OF CARBON STEEL IRRADIATED WITH NEUTRONS

(Presented by Academician G. V. Kurdyumov on 24 VII 1965)

In studies of the nature and properties of radiation-induced defects in crystalline materials, the theory of focusing collisions of atoms is gaining increasing recognition (¹⁻⁶). According to this theory, in the process of formation of radiation damage in the lattice of a crystalline material, the regular arrangement of atoms must be of substantial importance. Elucidating the mechanism of energy transfer from the bombarding particle to the lattice atoms is very important for establishing the type and properties of defects arising in a crystalline body under the action of nuclear radiation. In this connection it is highly desirable to carry out such experiments as would make it possible to establish the dependence of the observed effects on crystallographic orientation.

Earlier (⁷), while studying the change in the integrated intensity of x-ray reflections of metals irradiated with neutrons, we found anomalies in the weakening of the intensity of certain reflections, which could have been a consequence of the anisotropy of atomic displacements in the lattice of the irradiated metal. However, the experimental material obtained in (⁷) was insufficient to draw more definite conclusions about the crystallographic directions in the lattice of the metals studied along which the formation of defects proceeds more intensively than throughout the bulk of the metal.

A more complete study of this question was carried out by us in the present work on specimens of the α phase of steel U-9. The preparation of the specimens, the heat-treatment regime, the conditions of neutron irradiation, and the x-ray method were the same as in (⁷). In order to increase the reliability and accuracy

in determining the effects of changes in the intensity of weak high-order reflections, in addition to recording Bragg maxima with an EPP-09 potentiometer installed on a URS-50I x-ray apparatus, x-ray quanta were also registered with a mechanical pulse counter. Pulses were summed over 2.5-5 angular minutes during a time interval of 4-6 min for each point. For the weakest x-ray reflections, the difference between the background level and the peak of the Bragg reflection was 250-300 pulses. The error in determining the integrated intensity was different for different reflections and amounted to 2-6%.

In order to study the regularity in the change of the intensity of x-ray reflections from different crystallographic planes in the lattice of neutron-irradiated α iron, we measured the integrated intensities of x-ray interferences of a large number of reflections with different and multiple hkl .

Table 1 gives the indices of the crystallographic planes whose integrated intensity was measured.

Figure 1 presents the changes in the logarithm of the ratio of the intensities of x-ray reflections from irradiated (I_{irr}) and unirradiated (I_{unirr}) specimens as a function of the sum of the squares of the indices of crystallographic

crystallographic planes in several orders. Thus, for the plane ($hh0$) the integral intensities of 5 orders of reflections were determined (Fig. 1); for the others the number of reflections was 3-2 (Fig. 1, , , ,). From all the plots presented in Fig. 1 it clearly follows that, after irradiation, the intensity I of the x-ray interferences decreased, although the degree of attenuation of I is not the same for all planes. The change in intensity as a function of $\sum h_i^2$ follows an exponential law.

Table 1

Crystallographic planes of α -iron for which the intensity of x-ray reflections was measured

Sum of squares of indices	Crystallographic plane (hkl)	Reflection order	Sum of squares of indices	Crystallographic plane (hkl)
2	(110)	1	10	(310)
8	(220)	2	40	(620)
18	(330, 411)	3	14	(321)
32	(440)	4	56	(642)
50	(550, 543, 710)	5	20	(420)
4	(200)		26	(510, 431)
16	(400)		38	(611, 532)
36	(600, 442)		46	(631)
12	(222)		58	(730)
48	(444)		62	(732, 651)
6	(211)			

Sum of squares of indices	Crystallographic plane (hkl)	Reflection order	Sum of squares of indices	Crystallographic plane (hkl)
24	(422)			
54	(633, 552, 721)			

In some cases, for example for reflections with $\sum h_i^2 = 18, 50, 36$, and 54, there is superposition of reflections from several planes (see Table 1). This circumstance considerably complicates the determination of the contribution of the intensity from each of the corresponding planes to the total integral intensity of the Bragg reflection (taking into account the possibility of anisotropy of atomic displacements). Thus, the superposition of the reflection from the plane (442) on the reflection (600), $\sum h_i = 36$, has clearly “pulled” the corresponding experimental point upward (see Fig. 1) from the straight line describing the regularity of the change in the intensity of reflections ($h00$). This means that the change in the scattering power for x-rays of the planes (600) and (442) after neutron irradiation occurred to different degrees.

Measurement of the integral intensities of x-ray interferences for different crystallographic planes in several orders makes it possible to establish reliably whether a change occurs in the scattering power for x-rays of a metal irradiated with neutrons, and for which crystallographic planes this change is more significant (i.e., along which directions the radiation damage is greater).

In the present work it was established that after neutron irradiation the intensity of x-ray scattering by the α -phase of carbon steel decreased noticeably; however, the decrease in intensity for a number of planes was stronger than followed from the general course of the intensity-change curve for the remaining reflections. Thus, from consideration of the plots in Fig. 1 it is seen that the angle of inclination of the straight lines in Figs. 1 and 2 is greater than in Figs. 1, 2, 3, 4, which indicates a greater degree of attenuation of the intensity of x-ray interferences from the planes ($h00$) and (hhh) than from the others. This is shown more clearly in Fig. 2. The substantially different slopes of straight lines 1 and 2 (Fig. 2), drawn through a large number of experimental points, convincingly indicate the significance of crystallographic orientation in the process of formation of point defects under neutron irradiation.

It is interesting to note that in the lattice of the irradiated metal there are also such crystallographic planes (for example, (631), $\sum h_i^2 = 46$) whose scattering ability changes very little after irradiation (see Fig. 2).

From the results obtained it follows: the character of the change in the intensity of X-ray reflections for the neutron-irradiated α -phase of carbon steel indicates the presence in the crystal lattice of a considerable number of point defects (displaced atoms), which disturb the periodicity in the arrangement of atoms; moreover, the distribution of these point defects is anisotropic.

From the tangent of the angle of inclination of straight lines 1 and 2 (Fig. 2), representing the dependence of the logarithm $I_{\text{irr}}/I_{\text{unirr}}$ on $\sum h_i^2$, one can determine the magnitude of the displacements of atoms from the lattice sites (8, 9).

Fig. 1. Change in the logarithm of the ratio of the intensities of X-ray interferences of irradiated (I_{irr}) and unirradiated (I_{unirr}) specimens of the α -phase of carbon steel as a function of the sum of the squares of the indices of crystallographic planes of different orders of reflection

Fig. 2. Dependence of $\ln I_{\text{irr}}/I_{\text{unirr}}$ on $\sum h_i^2$ for reflecting planes of the crystal lattice of the α -phase of carbon steel. 1 —planes ($h00$) and (hhh); 2 —planes (hkl) and ($hk0$)

From the expression $\ln I_{\text{irr}}/I_{\text{unirr}} = \bar{A}u^2 \sum h_i^2$, one determines \bar{u}^2 —the mean-square displacement of atoms from lattice sites in the direction of the normal to the reflecting planes (hkl).

For the planes ($h00$) and (hhh) it was obtained: $\sqrt{\bar{u}^2} \simeq 0.04 \text{ \AA}$; for most other planes $\sqrt{\bar{u}^2} = 0.025 \text{ \AA}$.

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