

Carbon Distribution in the Martensite Structure of Structural Steel

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Abstract—The martensite structure of a hardened pseudosingle crystal of grade 37KhN3A medium-carbon structural steel (0.37 wt % C, 1.50 Cr, 3.0 Ni, 0.33 Mn) had the form of coarse packets with dimensions of to 1 cm in the cross section. Every packet was composed of six-orientation martensite crystals arising on one common austenite plane of type {111}. The position of three texture maximums was determined using an X-ray diffractometer for every orientation. In addition, the position of four maximums of retained austenite was found. The periods of martensite lattices and retained austenite as well as the carbon concentration in martensite lattices and near the boundaries are determined.

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By martensite transformation in steels, a solid α -iron solution supersaturated by carbon was formed. However, one cannot consider that overall carbon atoms are located in interstitial sites of the crystalline lattice. Carbon atoms of steels containing C less than 0.5 wt% with a high martensite point may leave bcc lattice interstitial sites occupied by them already during quench cooling and when holding at room temperature [1]. The analysis of the behavior of carbon with martensite transformation is important to understand the mechanism of transformation and the nature of the strength of hardened steel. L.M. Utevskii supposed that carbon can be distributed when growing a martensite crystal at transformation temperatures of 523–623 K [2]. I.A. Tananko revealed that the martensite fraction in medium-carbon hardened steels is depleted with carbon with respect to their grade composition [3]. Production of pseudosingle crystals of structural steel [4] opened additional possibilities for study of the carbon distribution in the martensite structure. The aim of the present research is investigation of the carbon distribution in hardened steel with packet martensite. It gave fresh data on the carbon concentration in lattices of martensite and retained austenite and on lattice defects.

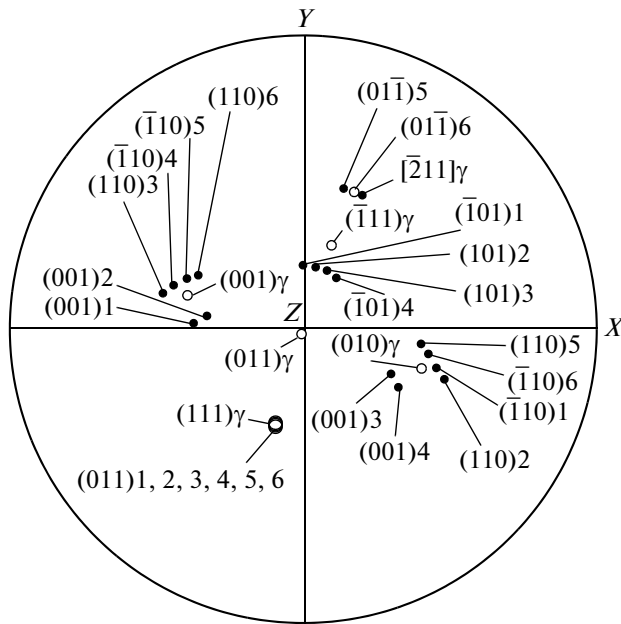
A single crystal of grade 37KhN3A medium-carbon structural steel (0.37 wt % C, 1.50 Cr, 3.0 Ni, and 0.33 Mn) in the austenite state was grown with the Bridgman method from a melt of commercial steel and oil-quenched. The martensite structure of the

pseudosingle crystal produced had the shape of coarse packets with dimensions of up to 1 cm in the cross section. The retained amount of austenite was about 6.5% [4]. In [4] it was found that every packet was composed of six-orientation martensite crystals arising on one common austenite plane of type {111}. The orientation ratios between martensite and austenite were irrational and intermediate between the Kurdjumov–Zaks and Nishiyama ratios. Furthermore, they proposed a bunching scheme of crystals-rods within the coarse packet that demonstrated “practically complete compensation of bainite and shear deformations” [5]. The present research was carried out using a quenched single crystal, which was at room temperature for 45 years. Therefore, the carbon concentration distribution in the martensite structure can be considered to be quasi-equilibrium.

It is known [4, 5] that the austenite plane being common for overall martensite crystals of one packet has indices (111) $_{\gamma}$. Martensite crystals in the packet are formed by the shear mechanism according three austenite shear systems of (111)[11–2], (111)[1–21], and (111)[–211][6, 7]. Two equivalent variants for martensite deformation with the invariant lattice act for every shear system. As a result, six orientation crystals form in the packet [4, 5, 7]. These orientations form three pairs, and every pair has the close axes of martensite tetragonality.

The position of three texture maximums was determined for every orientation using an X-ray diffractometer. In addition, the position of four maximums of retained austenite was found. The given positions of the maximums are plotted in a stereographic projection (figure). Black rings are related to martensite poles; light ones, to retained austenite poles; and figures designate the orientation number. The Z-axis

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Position of investigated texture maximums on the stereographic projection.

coincides with the normal to the microsection plane which is near plane $(011)_\gamma$. X-ray photography was carried out using a DRON-1 modified diffractometer with a BSV22-Co tube at a point focus projection of 0.4×0.4 mm. The primary ray bundle cut by a collimator has a round section with a diameter of about 0.6 mm near the specimen. The X-ray photography was done with the use of a GP-2 improved goniometric attachment which allows for inclination of the specimen and turning of it in its own plane upon bringing the given crystallographic plane into the reflecting position.

The pseudosingle crystal and martensite reflections (002) , (020) , and (200) are placed separately from each other, during X-ray photography from the single packet. Note that these reflections are fused into a single line when photographing the polycrystal. The same is related to martensite reflections (220) , (202) , and (022) . Therefore, to determine exactly periods c by line $(00l)$ and a by line $(hk0)$ is only possible with photography from the single packet. This allows for determining even a small tetragonality. We emphasize that this possibility is absent with X-ray photography of the polycrystal. Martensite lattice period c was determined by reflections (002) , $c = (0.2877 \pm 0.0001)$ nm; and period a , by reflections (220) , $a = (0.2868 \pm 0.0001)$ nm. Period c was calculated for orientations 1, 2, 3, and 4; period a , for orientations 5 and 6 (figure). The scatter of readings was in the limits of the errors mentioned. The lattice tetragonality is $c/a = 1.0031 \pm 0.0009$. Carbon concentration p in the martensite lattice is found using known [1] relationship

$$c/a = 1 + \gamma p, \quad \gamma = 0.046.$$

There is $p = (0.07 \pm 0.02)$ wt % C.

Similarly the retained austenite lattice period was determined using reflections (222) , (-222) , (002) , (020) , and (022) (figure), $a_\gamma = (0.3583 \pm 0.0002)$ nm. The carbon concentration p in the retained austenite lattice is found using the relationship [1]

$$a_\gamma = 0.3555 + 0.0044p.$$

There is $p = (0.64 \pm 0.05)$ wt % C.

Taking into account that the amount of retained austenite is 6.5%, one can find that it contains about 0.04% C. Thus, lattices of martensite and retained austenite include $(0.07 + 0.04)\% = 0.11\%$ C. Because the carbon concentration in steel is greater and is 0.37 wt % C, the greater fraction of carbon atoms, (0.26 ± 0.02) wt % C, is located in no lattice interstitial sites and on crystalline structure defects (dislocations and boundaries of martensite crystals), which corresponds to existing notions [1, 5]. It is not unlikely that dispersed particles of ϵ -carbide form during quenching similarly to those that were revealed with low-temperature tempering of high-carbon steels [8]. The dislocation density in crystals of packet martensite is on the order of 10^{11} cm^{-2} [1, 5]. By the data of [1, 9], packet martensite has $(0.1-0.2)$ wt% C on dislocations. Then, for martensite crystal boundaries, it is $(0.06-0.16)\%$ C.

Most likely, the carbon fraction is driven away by the moving interface into austenite during growth of the martensite crystal. This notion is verified by the observation of the carbon distribution in retained austenite, which was determined using an atomic power microscope [10]. The martensite structure of hardened steel (0.26 wt % C, 3 Cr, 2 Mn, 0.5 Mo, 0.07 Si) had a retained austenite interlayer with a thickness of about 1 nm and an enrichment of up to 0.8 wt% C. The carbon concentration at the martensite/austenite interface reached 2.1 wt %.

Thus, as an example of the pseudosingle crystal of hardened medium-carbon steel, the quasi-equilibrium carbon distribution in the martensite structure was determined at room temperature. With an average concentration in steel of 0.37 wt %, the carbon concentration is only 0.07 wt % C in the martensite lattice and 0.64% C in the retained austenite lattice. The rest of carbon with a concentration of 0.26% C is located at the boundaries of martensite crystals and dislocations, and, it is possible, its fraction is precipitated in the carbide form.

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