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Fig. 1

Figure 1: Fig. 1

Abstract

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ON THE MECHANISM OF AUSTENITE FORMATION DURING RAPID HEATING OF CARBON STEELS

(Presented by Academician G. V. Kurdyumov, 5 VIII 1963)

For a long time a discussion has been going on in the literature ([1,2]) and elsewhere concerning the mechanism of austenite formation during the heating of steels at high rates (100°/s and above).

According to one of the hypotheses, known as the "diffusion" hypothesis, the mechanism of austenite formation at high heating rates does not differ from the usual mechanism by which austenite formation develops under conditions close to thermodynamic equilibrium according to the Fe–Fe_3C diagram.

Experimental study of the process of austenite formation at high heating rates, begun about 30 years ago, led to the establishment of a number of facts for which at that time no satisfactory explanation was found within the framework of the "diffusion" hypothesis ([1]). This stimulated the construction of an alternative hypothesis, which allowed for the possibility of a phase transformation during rapid heating in accordance with a metastable transformation diagram ([2]). In this view, at the first stage of the transformation, upon reaching the temperature of metastable $\alpha \rightleftarrows \gamma$ equilibrium, the formation of metastable austenite was assumed to be possible as a result of a "diffusionless" (i.e., without a change in concentration) rearrangement. It was assumed that at the second stage the metastable austenite vigorously dissolves the carbide particles, and its composition approaches that required by the equilibrium diagram.

Fig. 1. Oscillogram of heating of quenched U8 steel in the transformation interval. **1, 2** –distribution of x-ray intensity as a function of reflection angle for the (211) α- and (311) γ-phases, respectively; **3** –specimen temperature; **4** –specimen expansion; **5** –marks of the extreme position of the KP slit, relative to which the measurement of parameters is performed; **6** –time marks, $f = 500$ Hz

Figure 2

Figure 2: Figure 2

According to estimates of the "diffusionless" hypothesis, metastable austenite at the moment of its formation contains ([3]) 0.2–0.4 wt.% C (at 760°), whereas according to the "diffusion" hypothesis the composition of austenite at any temperature must correspond to the phase diagram.

Unfortunately, in works devoted to elucidating the mechanism of austenite formation at high heating rates, there are no direct experimental data on the composition of the high-temperature phase directly during the process of its formation. Estimates made by means of indirect methods ([4,5]) led to a large scatter of the data. Thus, for example, in U8 steel ([4]), by measuring the specific electrical resistivity, ···

of quenched specimens showed that, at a heating rate of 100°/sec, the austenite formed at 755° contains less than 0.4% C. Use of the magnetometric method (according to the position of the martensite point during quenching) led to a range of carbon concentrations in austenite from 0.2 to 0.7% C (5).

Accurate data on the composition of the high-temperature phase can be obtained by direct measurement of the lattice parameter of austenite immediately during its formation on heating. The technical difficulties of carrying out such measurements are due to the fact that, at a heating rate on the order of hundreds of degrees per second, the time of the phase transformation amounts to hundredths of a second, while the austenite parameter during its formation and subsequent heating may change continuously.

The solution to the problem was found by us in creating a special X-ray apparatus that made it possible simultaneously to record on an oscillogram the parameters of the α- and γ-phases every 0.03 sec. The recording time for one line was then ~0.003 sec. The use of a BSV-3 tube with (iron radiation), which during the exposure period was operated at 30 kV, 30 mA, made it possible to investigate the process of austenite formation in carbon steels at heating rates up to 600°/sec. The error in determining the parameter of the γ-phase did not exceed $±$0.0002 nm.* Simultaneously, changes in the length of the specimen and its temperature were recorded on the same oscillogram. The method for recording these parameters has already been described in detail (7). A sample oscillogram in the temperature range of the phase transformation is presented in Fig. 1.

Fig. 2. Dependence of the parameters of the α- and γ-phases of steel in the annealed (top) and quenched (bottom) states; triangles—steel U8, 500°/sec; black points—steel 45, 500°/sec; open circles—steel 30, 500°/sec.

The results of processing the heating oscillograms of three carbon steels, presented as the temperature dependence of the parameters of the α- and γ-phases

Fig. 3. Change in the half-width of the (211) line of the α-phase with temperature. a —steel U8, 100°/sec; —steel U8, 500°/sec; —steel 45, 500°/sec; —steel 30, 500°/sec

Figure 3: Fig. 3. Change in the half-width of the (211) line of the α-phase with temperature. a —steel U8, 100°/sec; —steel U8, 500°/sec; —steel 45, 500°/sec; —steel 30, 500°/sec

at a heating rate of 450-600°/sec, are given in Fig. 2. Determination of the carbon content in austenite from Fig. 2 can be performed using the already known dependences of the γ-phase parameter on carbon content and temperature, given in (8).

On heating annealed steels with 0.3% and 0.45% C in the temperature region of the phase transformation, austenite very inhomogeneous in composition appears

* A detailed description of the apparatus will be given in (6). The design of the apparatus was reported at the XVII Session on the Theory of Heat Resistance of Metals and Alloys in Moscow.

austenite, in which the carbon content fluctuates within the range 0.5-0.6% and, consequently, proves to be close to that expected from the equilibrium diagram. With increasing temperature, a decrease in compositional inhomogeneity is observed, and only at 1000-1050° do the interferences of the γ-phase indicate practically complete homogenization. The results obtained on eutectoid steel U8 are very illustrative. In this case, upon heating

Fig. 3. Change in the half-width of the (211) line of the α-phase with temperature.
a —steel U8, 100°/sec; —steel U8, 500°/sec; —steel 45, 500°/sec; —steel 30, 500°/sec

of quenched specimens (Fig. 2, black points), the temperature at which austenite begins to form proves to be 750°; here the difference between the "diffusional" and "diffusionless" mechanisms of transformation can be traced especially clearly. The composition of the first portions of austenite formation proved to correspond to the "diffusional" mechanism—the lattice parameter of the γ-phase in this case is equivalent to austenite with 0.82-0.9% C. When annealed steel U8 is heated, austenite lines appear at 805-810°, and the parameter of the γ-phase corresponds to a content of 0.9% C. When the eutectoid and hypoeutectoid steels studied are heated, both from quenched and from annealed initial states, carbon-rich austenite forms, the composition of which approaches the equilibrium composition according to the state diagram at the temperature of formation.

Thus, when carbon steels are heated at a rate on the order of 500-600°/sec, the initial composition of austenite in all cases lies within the range of concentrations corresponding to the equilibrium Fe–Fe_3C diagram. The formation of austenite

under these conditions follows the "diffusional" mechanism and differs from transformation under equilibrium conditions only in that, at a high heating rate, the experimentally determined transformation interval is shifted into the region of higher temperatures.

Figure 3 presents data on the change in the half-width of the (211) line of the α-phase during electrical heating of quenched steels at a rate of 100-500°/sec. In accordance with earlier investigations[9], the observed decrease in the half-width of the (211) reflection may be associated with at least three factors: 1) the release of carbon from the α-solid solution; 2) relaxation of second-order distortions; 3) an increase in the size of the regions of coherent scattering.

Not being able at present to assess the specific weight of each of the factors listed in reducing the line width, we must nevertheless note that, regardless of the carbon content in the initial martensite, in the course of rapid heating all the steels studied approach the temperature of the $\alpha \rightarrow \gamma$ phase transformation without any substantial differences in comparison with the ferrite line width of annealed steel.

Similar data, showing that at heating rates up to 1000°/sec the $\alpha \rightarrow \gamma$ transformations proceed by a "diffusion" mechanism, were obtained in heating low-alloy structural steels of the types 15Kh, 40Kh, 45KhN, 45KhNM, 60S2.

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CITED LITERATURE

1. S. S. Shteinberg, *Heat Treatment of Steel*, Moscow, 1945.

2. V. N. Gridnev, Report on research work of the Polytechnic Institute, 7, 1948.

3. Yu. A. Kocherzhinskii, *Problems of the Physics of Metals and Metallography*, No. 10 (1960).

4. Yu. A. Kocherzhinskii, *DAN*, 100, No. 6 (1955).

5. V. N. Gridnev, Yu. Ya. Meshkov, *Dokl. AN UkrSSR*, No. 6 (1960).

6. V. N. Gridnev, V. N. Minakov, V. I. Trefilov, in: *Studies on Heat-Resistant Alloys*, Publishing House of the Academy of Sciences of the USSR, 11, 1963.

7. V. N. Minakov, V. I. Trefilov, *Factory Laboratory*, 2 (1962); V. N. Minakov,

A. P. Rudoi, V. I. Trefilov, *Problems of Physical Metallurgy*, No. 11 (1960).

8. V. D. Sadovskii, M. V. Yakutovich, *DAN*, 57, No. 4 (1947); V. N. Gridnev, V. I. Trefilov, *DAN*, 116, No. 11 (1957); H. Esser, G. Muller, *Arch. Eisenhüttenwesen*, 4, 7 (1933–1934).

9. G. V. Kurdyumov, *Problems of Physical Metallurgy*, No. 2 (1950); V. N. Gridnev, V. I. Trefilov, *Izv. AN SSSR, OTN, Metallurgy and Fuel*, No. 2 (1959).

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