TRANSFORMATIONS IN AUSTENITIC MANGANESE STEEL

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The isothermal transformation of high-manganese austenite was studied in [1-3]. In the present work the autoradiographic method was used to study the distribution of carbon in austenitic manganese steel (1.25% C, 13.0% Mn, 0.35% Si, 0.02% S, and 0.07% P) in relation to the heat treatment conditions, and the phase transformations.

Radioactive carbon was added to the metal by diffusion saturation from a gaseous medium [4]. The autoradiographs (on NIKFI film) were made from the polished surfaces of the samples at different exposures. The autoradiographic data were supplemented by metallographic, magnetic, and x-ray structural analysis.

After austenitizing (1050°C, water) the samples were held 24 h at 200-800°C (50° intervals). The data from metallographic and autoradiographic analysis are shown in Fig.1. At temperatures below 250°C no
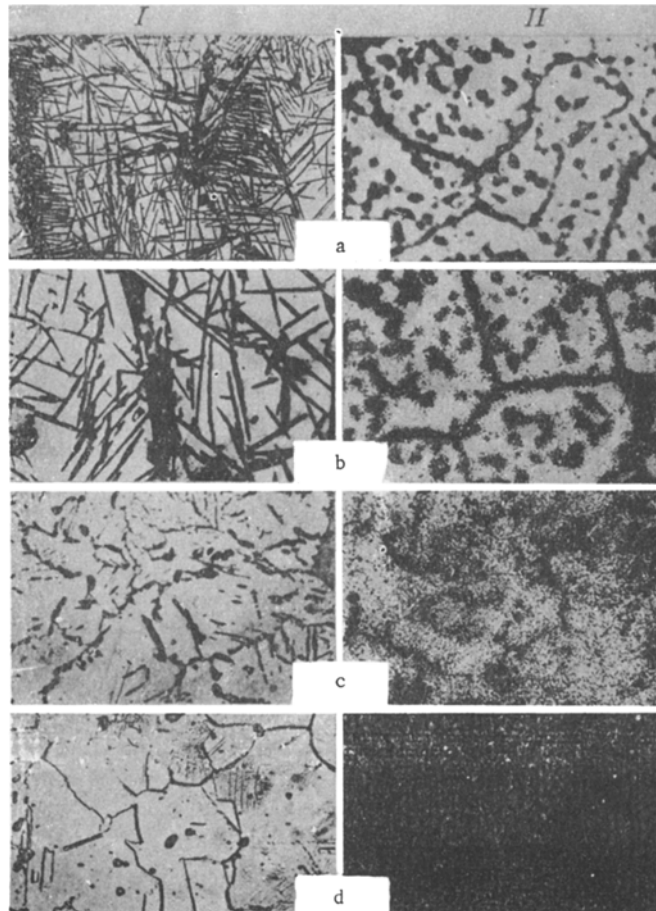

Fig. 1. Effect of temperature on the isothermal decomposition of manganese austenite (held 24 h). a) 250°C; b) 550°C; c) 750°C; d) 850°C. I) Microstructure (× 85); II) autoradiograph (× 55).
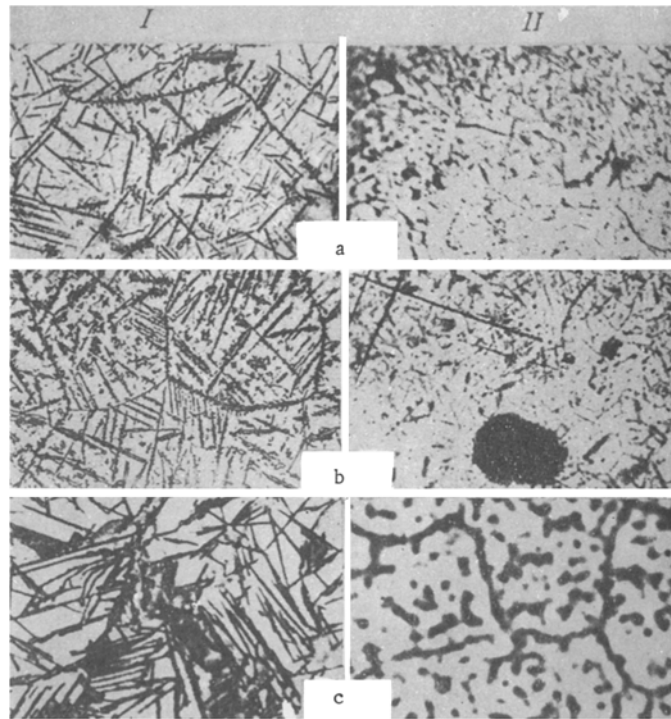
Fig. 2. Effect of holding time at 550°C on the isothermal decomposition of manganese austenite. a) 15 min; b) 30 min; c) 24 h. I) Microstructure (× 85); II) autoradiograph (× 55).

phase transformations were observed. At 250°C a carbide film is precipitated in the austenite grain boundaries; thin carbide platelets grow from this film (a, I, Fig. 1). The autoradiograph (a, II, Fig 1) also shows carbon agglomerates in the boundaries and locally within the grains. Isothermal decomposition at the temperature of the maximum instability of manganese austenite (550°C) results in the formation of a more substantial carbide network in the boundaries and plates within the grains. Troostite nodules are formed in the grain boundaries (b, I, Fig. 1). The autoradiograph shows substantial accumulations of carbon in the grain boundaries as plates and troostite nodules (b, II, Fig. 1). At 750°C the carbides in the grain boundaries and within the grains coalesce. The austenite decomposes slowly (c, I, Fig. 1). The autoradiograph shows a somewhat discontinuous accumulation of carbon in the grain boundaries and a substantial concentration in the γ solid solution. At 800°C the coalescence of the carbide phase continues gradually, and on holding 24 h at 850°C no phase transformations are observed (d, I, Fig. 1). The carbon is completely retained in the austenite, which is indicated by the uniform blackness of the autoradiograph (d, II, Fig. 1).

The decomposition of manganese austenite is most intense at the temperature of its least stability, and after 15 min holding the carbide is concentrated in the boundaries and has formed platelets within the grains (Fig. 2a). The phase transformations continue with longer holding time (Fig. 2b) and prolonged holding (over 2 h) induces almost complete redistribution of the carbon between the γ solid solution and the phases formed — carbide and ferrite (Fig. 2c).

The variation of the magnetic properties is shown in Fig. 3. The occurrence of the magnetic phase after holding 4-6 h is more intensive at 500-600°C due to the profound structural changes in the manganese austenite. At higher and lower temperatures the reaction is slowed down, and below 400°C and above 700°C no magnetic phase was observed. The change in the austenite lattice constant with the holding time at 550 and 600°C indicates that decarburizing of the γ solid solution is most intense in the initial period (Fig. 4). With increasing holding time the martensite point M_s increases and the Curie point decreases, which indicates impoverishment of the γ solid solution in manganese. This process is also most intense in the initial holding period (Fig. 5).
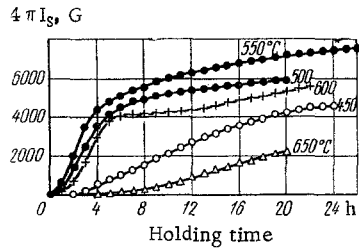
Fig. 3

Fig. 4

Fig. 3. Variation of the magnetic properties of austenitic manganese steel with holding temperature and time.
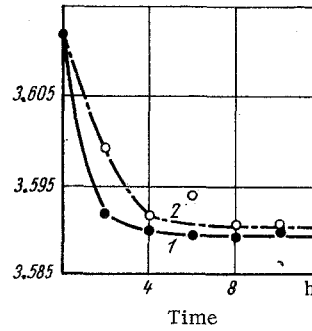
Fig. 4. Variation of the lattice constant of the γ solid solution with the holding time and temperature. 1) 550°C; 2) 600°C.

After prolonged holding at 500 and 550°C additional magnetic phases can be formed as the result of cold treatment (below M_S) (Fig. 6).

Atoms of carbon in the austenitic manganese steel concentrate preferentially in the grain boundaries, creating an interphase heterogeneity. The transformation begins with precipitation in the grain boundaries. X-ray structural, metallographic, and autoradiographic analysis indicates that the carbides precipitated are of the cementite type $(Fe, Mn)_3C$. As the variation of the lattice constant shows (Fig. 4), the formation of the carbides substantially decarburizes the austenite matrix. At the same time, the carbide is enriched in manganese and the Curie point drops sharply (Fig. 5). Carbide formation occurs at 250-800°C. At lower and higher temperatures no phase transformations were observed, although the formation of carbide phase is possible at 950°C according to [5].

After the precipitation of carbides in the grain boundaries but before the formation of a continuous film, platelets begin to grow from the cementite precipitates within the grains at all temperatures tested (Figs. 1, 2). Below 400 and above 700°C these platelets (like the precipitates in the grain boundaries) are cementite. The platelets formed at high temperatures lose their acicular form due to coalescence (d, I, Fig. 1).
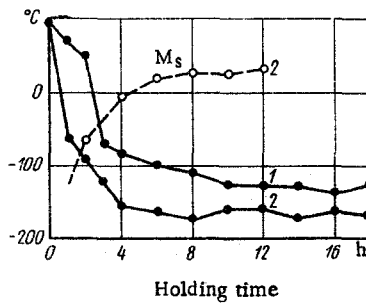

Fig. 5

Fig. 6

Fig. 5. Variation of martensite points M_S and Curie point of carbide $(Fe, Mn)_3C$ with the holding time and temperature of austenitic manganese steel. 1) 450°C; 2) 550°C. - - - -) Martensite point; ————) Curie point of $(Fe, Mn)_3C$.
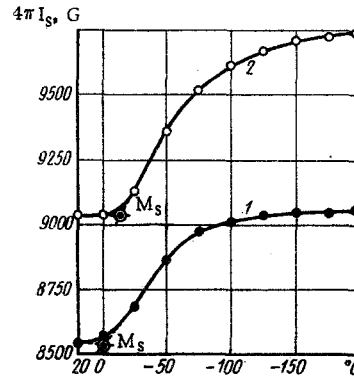
Fig. 6. Variation of saturation magnetization of austenitic manganese steel on cooling after prolonged holding (90 h). 1) At 500°C; 2) at 550°C.

At 400-700°C the platelets appear after a few minutes and have a special character. The x-ray structural analysis showed the lines of the α-phase and cementite, the intensity of the lines increasing. Measurements by means of a magnetic microbalance showed an intense increase of magnetizability in this temperature range (Fig. 3). The platelets are of complex nature and consist of alternate layers of ferrite and cementite. Troostite nodules grow after the platelets are formed. This reaction occurs by the mechanism that is normal for eutectic structures, occurs gradually, and is accompanied by intensive formation of ferrite and cementite. At the same time there is decarburization of the γ solid solution and diffusion of manganese into the carbide, which is indicated by the reduction of the Curie point. The reduction of the lattice constant leads us to conclude that the carbon content of the austenite does not exceed 0.05-0.15%, i.e., practically all the carbon is concentrated in the carbide phase. The amount of manganese in the carbide reaches 18-22%, which agrees with the data in [2]. The manganese diffuses into the carbide from the surrounding austenite, since manganese, unlike carbon, does not diffuse to any substantial distance.

Thus, isothermal decomposition at 400-700°C produces the following reaction:

$$\gamma\,(1.25\% \text{ C}) \rightarrow \gamma\,(0.05-0.15\% \text{C}) + [\alpha + (\text{Fe, Mn})_3\text{C}],$$
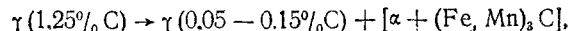
where $[\alpha + (\text{Fe, Mn})_3\text{C}]$ is eutectoid.

During cooling to room temperature, hexagonal close-packed ε-martensite is formed in the decarburized austenite at 100°C [7,8]. This phase has been observed by x-ray structural and dilatometric analysis [7]. The formation of ε-martensite is possible in autstenitic manganese steels with carbon concentrations below 0.7-0.8% [6]. On further cooling, beginning with M_S^ε, α-martensite is formed. The martensite point M_S^α lies below room temperature, its position for untransformed austenite depending on the concentrations of carbon and manganese, which in turn depend on the holding temperature and time. The transformation begins after cooling below M_S^α and gradually ceases toward M_f^α (Fig. 6). After heating to room temperature the samples retain the increase in magnetic phase, which points to an irreversible reaction.

Thus, ε-martensite forms below M_S^ε and α-martensite begins to form below M_S^α. These complex martensite phases, consisting of ε- and α-martensite, are formed from decarburized austenite by the reaction

$$\gamma\,(0.05-0.15\% \text{ C}) \rightarrow \varepsilon + \alpha\ (\text{martensite}).$$
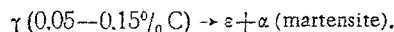
The reaction slows down and ceases toward points M_f^ε and M_f^α. The temperature of these points is below −100°C (Fig. 6) [8].

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