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THE MECHANISM OF PEARLITIC TRANSFORMATION IN CARBON STEEL

The paper describes the dislocation mechanism of pearlitic transformation in carbon steel. Genesis of lamellar pearlite is determined by flat-polygonal walls from dislocations, which are formed during thermoplastic deformation caused by austenite cooling process. Lamellar pearlite crystallization is shown to occur primarily due to the end (longitudinal) growth of lamellar cementite nuclei and secondarily – due to transverse crystallization of cementite and ferrite lamellae, which apparently occurs by the mechanism of separate crystallization of the cementite and ferrite lamellae through carbon transfer from austenite to cementite via ferrite lamellae within the interlamellar distance.

Keywords: *pearlitic transformation, dislocation mechanism, carbon steel.*

There exist many theories of pearlite formation [1]. It should be noted that these theories include, mainly, physical-mechanical models of the processes of austenite pearlitic transformation into steel.

It should be emphasized that pearlite is a bicrystal [1], consisting from ferrite and cementite crystals. At present, however, the mechanism of lamellar pearlite formation has not been sufficiently studied. Dislocation mechanism of pearlite formation is known [2, 3]. Lamellar morphology of cementite and ferrite in pearlite is determined by the following special features of the transformation mechanism: by thermoplastic deformation of overcooled austenite, caused by the cooling process, and formation of a polygonized structure in the form of flat dislocation walls, perpendicular to the planes of easy slip; regular arrangement (distance) of flat dislocation walls in austenite, determined by thermodynamics of the process, which is the smaller, the more overcooled austenite is; elastic interaction of dislocations, forming flat walls, with the atoms of carbon, which results in the formation of flat cementite nuclei.

According to [4], dependence of interlamellar distance in pearlite on overcooling degree obeys the parabolic law, in accordance with which the biggest values of interlamellar distance in pearlite correspond to small overcooling degree while the lowest values correspond to greater overcooling, i.e. interlamellar distance change rate decreases with increased overcooling. With increased austenite cooling rate at temperature $A_{1,}$ interlamellar distance in pearlite decreases. This could be explained by less intensive development of dislocation annihilation processes with growing thermoplastic deformation rate, determined by the cooling rate [5]. It would be logical to assume that interlamellar distance in pearlite is determined by the distance between flat-polygonal walls in austenite, which were formed prior to its transformation into pearlite.

Dislocation mechanism of pearlite transformation in steel У8А is confirmed by the fact that in the process of thermoplastic deformation, caused by cooling from 950 °C to 670 °C with average rate of 40 ° C / hour and then with a furnace, austenite has different structure depending on the size of adjacent samples, taken off from the square 10×10 mm: in a massive sample (7…8 мм) there is a small amount of structurally free ferrite and pearlite while in a thin sample there is a continuous cementite network and pearlite [6]. This is explained by the fact that in thin samples there is an easier drain of the crystal lattice to the surface and, consequently, smaller amount of carbon is associated with defects and greater amount of it (as compared with a massive sample) is in a solid solution, facilitating austenite oversaturation with carbon and cementite network formation along the boundaries of pearlite colonies.

According to [7], homogeneous austenite is always transformed into lamellar pearlite while inhomogeneous austenite is transformed into granular pearlite for all overcooling degrees.

Scientific-engineering developments on high-speed electro-patenting (HSEP) of carbon steels [8, 9] could also be interpreted with the application of dislocation mechanism of pearlitic transformation as follows: homogeneous austenite of hypoeutectoid steel should be cooled to the temperature in the range of 300 – 600 °C without its decomposition. After overcooling a part of samples was cooled in the air during the period, necessary for the complete austenite decomposition, and then – in water; the other part, after a certain pause, was subjected to high-speed electric heating at the overcooling temperature. Austenite of the first part of samples was shown to decompose with the kinetics, which is close to the corresponding isothermal diagram, and austenite in the samples of the second part – at the temperature in the range of 500 - 670 °C, the time of austenite transformation into pearlite in the second case being 1 – 2 s. Microstructure of the electro-patented steel 60 is presented in Fig. 1 [8].

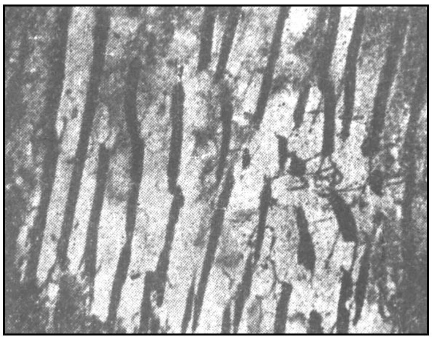

Fig. 1. Microstructure of the electro-patented steel, ×30000

Taking the obtained data into account, the proposed mechanism of lamellar pearlite crystallization would be expedient to be considered after description of the regularities of homogeneous austenite decomposition into granular pearlite.

According to [10], homogeneous austenite is transformed into granular pearlite only after thermocyclic treatment (TCT) at the temperature in the range, limited by A_1 and M_s, and isothermal exposure at the upper level of the cycle temperature.

In [11] it is shown that after one thermal cycle of homogeneous austenite in isothermal environments (from 300 to 700 °C), followed by exposure within 10 and 20 s and water hardening, the structure of steel У8 has the form shown in Fig. 2.

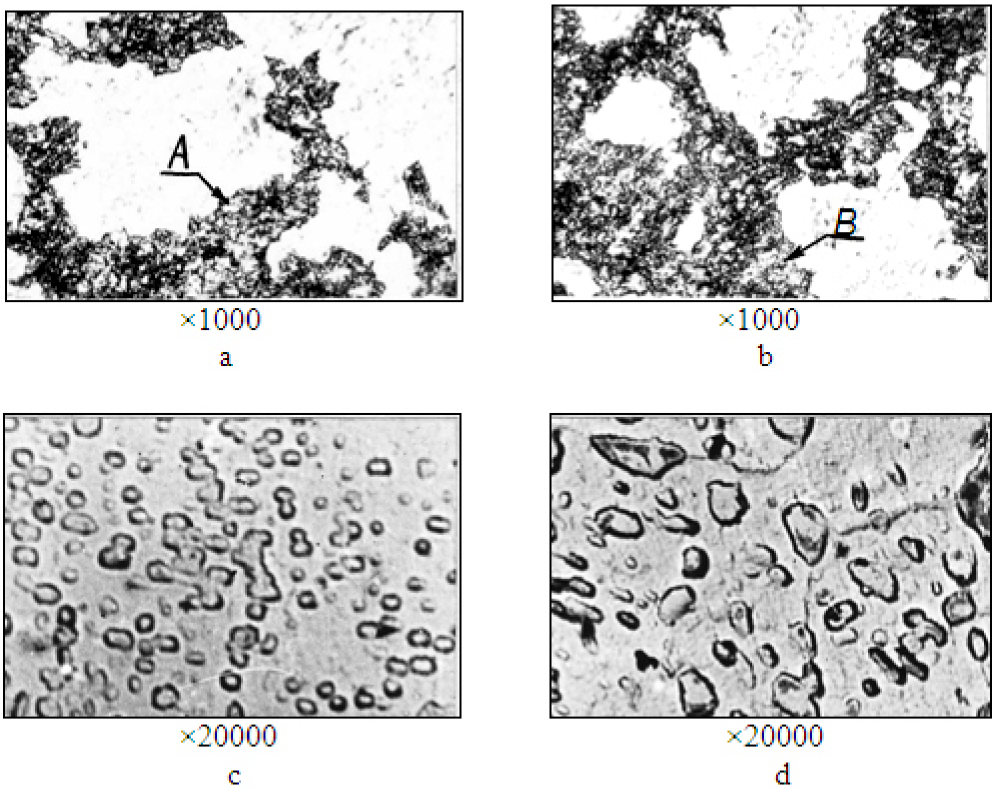

Fig. 2. Microstructure of high-carbon steel after cooling to 300 °C and heating up, followed by exposure within 10 (a, b) and 20 (c, d) seconds at 700 °C and water hardening; b, d – microstructures of areas A and B respectively

As it is evident from this figure, steel microstructure consists from light areas of strutureless martensite and dark areas of finely dispersed granular pearlite. In [11] obtaining of such microstructure is explained by the fact that granular pearlite formation occurs directly after homogeneous austenite decomposition and not due to the lamellar pearlite formation followed by its transformation into granular pearlite.

It was discovered later, however, that pearlite morphology (lamellar or granular) depends on the duration of carbon steel austenite exposure at the upper level of the cycle temperature after its preliminary overcooling to the lower level of the cycle temperature.

This scientific fact could be explained as follows. For short duration of exposure (3 s at 700 °C) of the preliminary overcooled austenite of steel У8А, followed by its cooling in the air, lamellar pearlite is formed (Fig. 2, a), while after exposure within 10 s spheroidization of the structure begins, which is fully completed after exposure within 140 s. Under this logic it could be supposed that in the process of TCT lamellar cementite nuclei are formed, which are later spheroidized due to formation of cellular dislocation substructure in the process of full TCT cycle.

Thus, the proposed mechanism of lamellar pearlite crystallization process can be described in the following way:

1. In the process of thermoplastic deformation, caused by cooling of homogeneous austenite, flat-polygonal dislocation walls are formed, which interact with the atoms of carbon in γ-phase and at the temperature below A_1 become the centers of cementite lamellae nucleation.
2. Lamellar pearlite crystallization occurs primarily due to longitudinal growth of lamellar nuclei of cementite and then – due to transverse crystallization of the cementite and ferrite lamellae, which were formed within interlamellar distance.

Transverse crystallization of the lamellae of cementite and ferrite is associated with diffusion transfer of carbon from austenite to cementite via the ferrite layer (lamellae). It should be noted that at practically equal temperatures diffusion coefficient of carbon in ferrite is by two orders of magnitude higher than that in austenite [12]. In the process of carbon diffusion in ferrite from austenite to cementite lamellae thickening of cementite lamellae is observed, followed by repacking of γ → α lattice. Therefore, pearlite transformation of austenite occurs according to the mechanism of separate crystallization of cementite and ferrite lamellae [13].

At the temperature of minimum stability of overcooled austenite (500…530 °C) maximal rate of its transformation into a lamellar pearlite is determined by minimal distance between lamellar cementite nuclei, which results in significant reduction of carbon diffusion paths if the proposed mechanism of its transformation is realized.

Conclusions

Genesis of lamellar pearlite is determined by flat-polygonal walls from dislocations, which are formed during thermoplastic deformation caused by austenite cooling process.

At the austenite temperature below point A_1 flat polygonal dislocation walls become the centers of cementite lamellae nucleation.

Interlamellar distance in pearlite is determined by the distance between flat-polygonal walls in austenite, formed prior to its transformation into pearlite.

Lamella pearlite crystallization occurs, primarily, due to the end (longitudinal) growth of lamellar nuclei of cementite and, secondarily, due to transverse crystallization of the lamellae of cementite and ferrite, which, most probably, occurs by the mechanism of separate crystallization of the lamellae of cementite and ferrite through carbon transfer from austenite to cementite via ferrite lamellae within the interlamellar distance.

At the temperature of minimum stability of overcooled austenite (500…530 °C) maximal rate of its transformation into a lamellar pearlite is determined by minimal distance between lamellar cementite nuclei, which results in significant reduction of carbon diffusion paths, if the proposed mechanism of its transformation is realized.

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