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Formation of Nanosize Phases under Thermomechanical Strengthening of Low Carbon Steel

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Abstract**—**A study of the H-beam's nanosize structure phase states after thermomechanical strengthening was carried out by TEM. The following processes were analyzed. 1. The dispersing of the cementite plates by cutting them by moving dislocations. 2. The dissolution of cementite plates and repeated precipitation of the cementite particles on the dislocations, the boundaries, subgrains and grains. 3. The decay of solid solution of carbon in the α-iron after "self-tempering" of martensite. 4. The final transformation of the retained austenite in beinite with α-iron particles and cementite formation. 5. The implementation of the diffusion mechanism of $\gamma \Rightarrow \alpha$ transformation.

Keywords**—**nanosize, phase, steel, strengthening

I. Introduction

PRODUCTION of rolled steel uses thermo-mechanical hardening technology, providing enhanced mechanical properties without the use of expensive alloying additives. Targeted management of the rolled steel operational properties, and development of optimal modes of its hardening should be based on knowledge of the structure-forming process under various technological operations.

II. Materials And Study Methods

The aim of this study was to investigate the formation of nanosize structural-phase states of 09G2S steel (0.1%C, 2%Mn, 1%Si) H-beam subjected to thermomechanical strengthening (accelerated cooling). Analysis of structure phase states and dislocation structures were performed by transmission electron microscopy of thin foils on the different distances from cooling surface.

III. Results and their Discussion

Accelerated cooling of the surface is accompanied by formation of the gradient of the structure phase states.

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Quantitative relationships that characterize the gradient nature of the organization of the defect substructure of H-beam subjected to forced water cooling are shown in Fig. 1. Analysis of the results presented in this figure confirms the conclusion about the gradient nature of the defected substructure. Namely, the closer to the cooling surface the scalar density of dislocations in the ferrite grains (Fig. 1a, curve 2) and ferritic interlayers of pearlite grains (Fig. 1a, curve 1), are increasing and the average size of fragments of the ferrite (Fig. 1b, curve 1) and particle size of cementite (Fig. 1b, curve 2) are reducing.

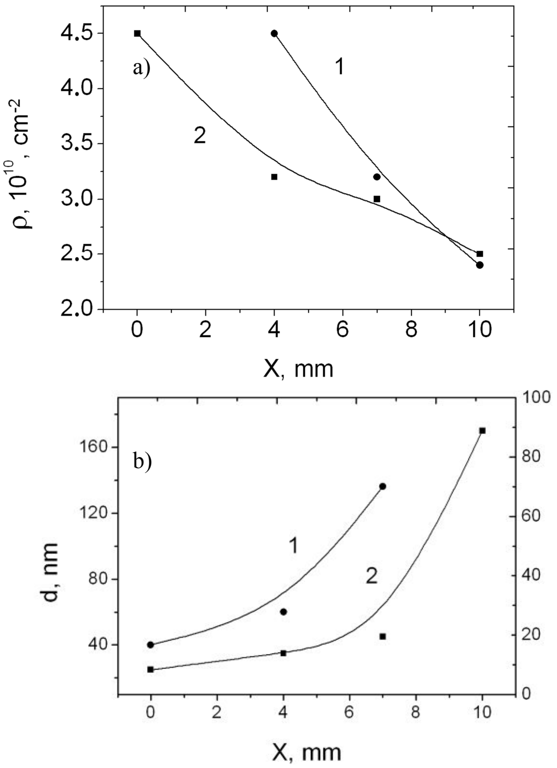

Fig. 1 Dependences on the distance to the surface of treatment a) the scalar density of dislocations located in the ferrite component of the pearlite grains (curve 1) and ferrite grains (curve 2), b) cementite fragments average size (curve 2) and ferrite fragments D average size (curve 1)

It can be seen that in the surface layer of H-beam the state is formed, which based on the average size of fragments of α-phase and cementite particles can be regarded as a nanostructure.

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Analysis of the obtained results [1-3] gives us grounds to conclude that the formation of nanoscale phase in the studied steel under thermomechanical processing and subsequent accelerated cooling of rolled products is possible with the implementation of such a processes.

A. Dispersion of the pearlite colonies cementite plates by cutting them by moving dislocations

Fig. 2 shows electron microscopy images of the pearlite colony, the cementite plates which are divided into separate fragments (the blocks). Sizes of fragments vary from 5 to 30 nm. Simultaneously, cementite particles are found in ferritic interlayers of the pearlite colony, the sizes of whose particles vary from 5 to 10 nm (Fig. 2, the particles are indicated by arrows).

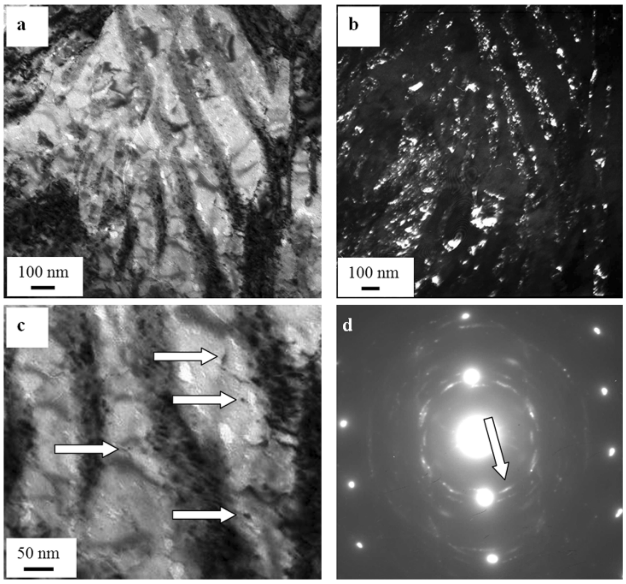

Fig. 2 The fragmentation of the cementite plates of perlite grains, a, c – light-field image, b - dark field image obtained in the reflection [121] Fe3C; d - electron diffraction pattern image, the arrow indicates the reflection, in which a dark field image was obtained. On c) the arrows indicate cementite particles located in the plates of ferrite

Dissolution of cementite plates of the pearlite colonies and repeated precipitation of the cementite particles on the dislocations, the boundaries of the blocks, subgrains and grains

Removal of carbon atoms from destructed particles of cementite is possible and at large distances. Studies of the block (subgrain) structure of α-iron grains by methods of dark-field analysis revealed the cementite particles in the body of the blocks on the dislocations and block boundaries (Fig. 3). Particles have a rounded shape, particle sizes vary from 5 to 15 nm.

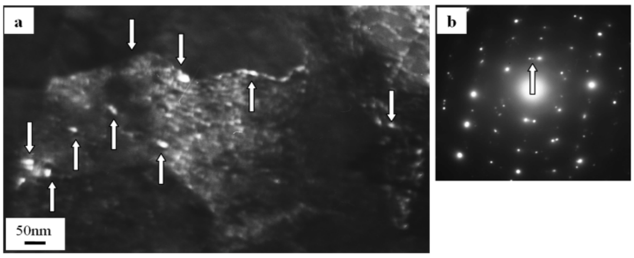

Fig. 3 Precipitations of second phase particles (cementite) within the body and at the boundaries of α-phase subgrains: a - dark field image, obtained in the reflections [012] Fe_3C + [110] α-Fe (particles indicated by arrows), b - electron diffraction pattern image, the arrow indicates the reflection, in which a dark field image was obtained

B. The decay of solid solution of carbon in the α-iron, formed under the conditions of accelerated cooling of steel ("self-tempering" of martensite)

Accelerated cooling of the H-beam leads to the formation of the martensitic structure in the surface layer. Subsequent "self-tempering" of the steel under the influence of the residual heat is accompanied by relaxation of the dislocation substructure, which manifests itself in reducing the scalar density of dislocations, the destruction of low-angle boundaries of martensite crystals, precipitation on dislocations within the body of martensite crystals (Fig. 4, a) and along the boundaries of cementite particles (Fig. 4, b). The sizes of particles located on dislocations, vary between 5 ... 10 nm (Fig. 4, a), located on the borders - in the 10 ... 30 nm range.

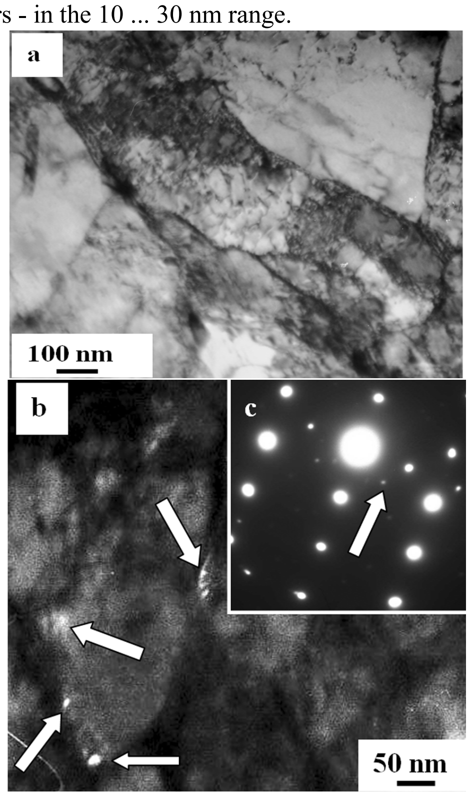

Fig. 4 The microstructure of the hardened layer of the H-beam, a - bright-field image, b - dark field image obtained in the reflection [120] Fe_3C; c - electron diffraction pattern image, the arrow indicates the reflection, in which a dark field image was obtained. On (b) the arrows indicate cementite particles

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C. Formation of cementite particles during the process of complete transformation of retained austenite presented in the structure of carbideless bainite

In the surface layer of the steel sample along with grain-subgrain structure the structure of plate type, the so-called carbideless bainite was observed. The plates are arranged parallel to each other and there was an alternation of plates of light and dark contrast. Mottled contrast reminiscent of the contrast from the pre-precipitates of second phase particles (cementite, 5-10 nm size) is revealed within the structure of the darker plates (formed, presumably as a result of the process of complete transformation of residual austenite).

D. Formation of nanosize phases as a result of polymorphic $\gamma \Rightarrow \alpha$ transformation

The high level of steel plastic deformation, which is realized by thermomechanical processing of rolled products, leads to dispersion of structures formed in the process of diffusion of the $\gamma \Rightarrow \alpha$ transformation. Fig. 5 shows electron microscopy images of the structure of lamellar pearlite.

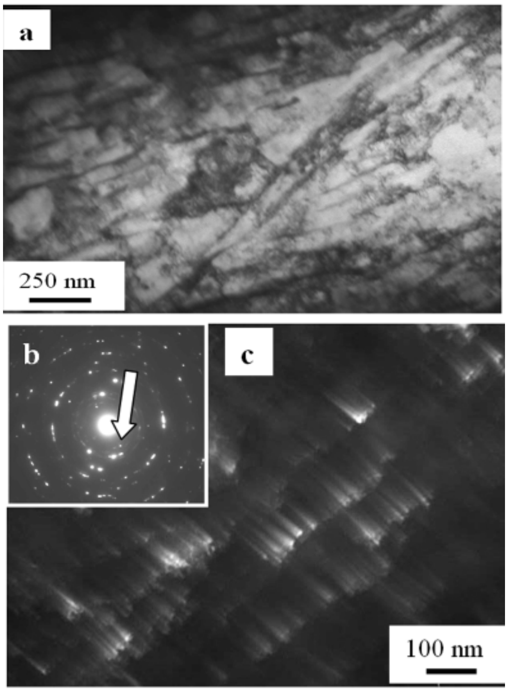

Fig. 5 Electron microscopic image of the structure of the lamellar (plate) perlite: a – light field image, b - dark field image obtained in [021] Fe_3C the reflection; c – electron diffraction pattern image, the arrow indicates the reflection, in which a dark field image was obtained.

The measurements show that the thickness of plates of α-phase, separated by the plates of carbide, is about 70 nm; the thickness of the plates of the carbide phase of ~ 25 nm.Formation of nano-sized particles of the carbide phase, is also observed in the formation of the so-called pseudoperlite, namely ferrite grains, containing particles of cementite of globular morphology (Fig.6). The sizes of particles of cementite in these grains vary in the range 40 ... 60 nm.

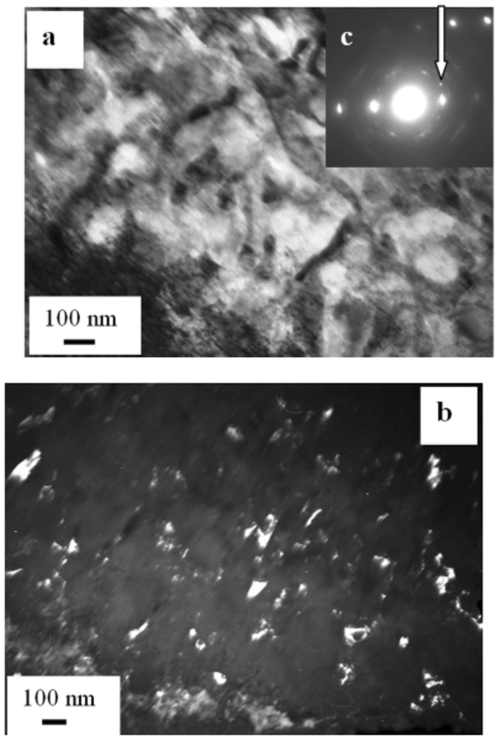

Fig. 6 Electron microscopic image of the pseudoperlite structure: a – light field image, b - dark field image obtained in the reflection [012] Fe_3C; c - electron diffraction pattern image, the arrow indicates the reflection, in which a dark field image was obtained.

IV. Conclusion

Thus, the formation mechanisms of nanosize phases under thermomechanical strengthening of low carbon steel are studied by transmission electron microscopy methods.

The quantitative relationships that characterize the gradient nature of the defect substructure organization are presented.

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