FORMING MODIFIED LAYERS ON THE SURFACE OF STEEL DURING ULTRASONIC FINISHING


Tomsk Polytechnical University, Tomsk
*Yurga Technological Institute of TPU, Yurga
**Institute of High Current Electronics (IHCE) SB RAS, Tomsk
***Institute of strength physics and materials science SB RAS, Tomsk
E–mail: klimenov@tpu.ru

The authors investigated the way ultrasonic finishing influences structure and properties of the surface layers of ferrite and pearlite grades of carbon steels. Ultrasonic modification was assessed according to the results of metallographic, electron microscopic analysis of samples. The surface and near – surface structure changes were accomplished by means of splitting up the microstructure into fragments and blocks with the formation of microdistortion of crystal lattice. During the ultrasonic treatment, all steels revealed the maximum level of microhardness on their surface which was steadily decreased in depth.

Based on a number of carbon proeutectoid steels, we have studied the effect of ultrasonic surface treatment on the microstructure and microhardness of the obtained modified layer. The surface treatment of specimens was carried out by an ultrasonic device that allows alternating compressive and shear deformation. The deformation was induced by the action of the moving indentor normally oscillating with ultrasonic frequency [1-3].

Optical metallographic analysis and microhardness measurements were performed with the use of transverse metallographic sections cut out of the obtained specimens. Diffraction electron microscopy was used to examine a thin surface layer of the specimens.

Specimens of steels 20, 45 and 60 (in the Russian designation) in the annealed state have a ferrite-pearlite structure. The ratio of the ferrite and pearlite constituents is known to vary depending on the carbon content in the alloy. In steel 20 the ferrite constituent dominates, while in steel 60 — pearlite one.

Optical and scanning electron microscopy is applied to examine the structure of the main structural constituents of these steels. In the initial state steel 20 consists of ferrite grains 10…25 \( \mu m \) in size and pearlite grains of 3…5 \( \mu m \) in size. Pearlite grains are located at junctions of ferrite grain boundaries and occupy 20…25 vol. %. Ferrite has a polycrystalline structure. Within grains there is the structure of dislocation chaos with the scalar dislocation density \( \rho \sim 3 \times 10^9 \) cm\(^{-2}\) (Fig. 1a).

![Electron microscopic images of the structure of steel 20](image)

**Fig. 1.** Electron microscopic images of the structure of steel 20: a — ferrite; b — pearlite.
Pearlite in the initial state is lamellar, ferrite grains are located between cementite plates (Fig. 1b). The ferrite constituent has a chaotic dislocation substructure with $\rho \sim 1 \times 10^9$ cm$^{-2}$. In steels 45 and 60 in the initial state the both structural constituents have the same structure.

After ultrasonic surface treatment of all the studied steels, the initial equiaxial grains of the both structural constituents are elongated in the direction of indenter motion and are fragmented (Fig. 2).

![Fig. 2. Microstructure of steel 45 after ultrasonic surface treatment](image)

The depth of the plastically deformed layer for the studied steels is 15…25 µm. In steel 20 the shape change mostly takes place in ferrite grains, while in steels 45 and 60 the shape of both structural constituents changes similarly.

Electron microscopic analysis reveals that ultrasonic treatment gives rise to the following changes in the thin surface layer of steel 20. Ferrite grains are fragmented (Fig. 3a). The fragmented structure is misoriented, which is manifested in the smearing of $\alpha$-Fe reflections (Fig. 3b).

![Fig. 3. Electron microscopic images of the ferrite structure of steel 20 after ultrasonic treatment: a — light-field image; b — microdiffraction pattern for a.](image)

By the presence of the dislocation substructure subgrains are divided into two types: almost no dislocations are observed in subgrains smaller than 0.1 µm in size, while in larger subgrains of size 0.1…0.7 µm there is a cellular dislocation substructure with scalar dislocation density $\sim 5.5 \times 10^{10}$ cm$^{-2}$. One more characteristic feature of ferrite grains is the presence of a large number of bend extinction contours that point to high bending-torsion of the material lattice.

Cementite plates that have earlier had a block structure are divided into single particles (Fig. 4a). The particles are misoriented relative to each other, which is manifested in interferences in microdiffraction patterns obtained from carbide precipitates (Fig. 4b). In ferrite interlayers a fragmented substructure with fragment size $\sim 0.4$ µm is formed. With the fragments there is a grid-cellular dislocation substructure with scalar density $4 \times 10^{10}$ cm$^{-2}$. 


Fig. 4. Electron microscopic images of the pearlite structure of steel 20 after ultrasonic treatment:
a — light-field image; b — microdiffraction pattern for a.

In steel 60, where the major constituent is pearlite and ferrite grains are located as interlayers along their boundaries, at ultrasonic treatment on the specimen surface the material of the both structural constituents is mixed. In a thin surface layer 2-3 μm thick a nanocrystalline structure is formed, which consists of the mixture of α-Fe crystallites and chaotically spaced cementite particles (Fig. 5) [4].

Fig. 5. Electron microscopic images of the structure of steel 60 after ultrasonic treatment: a — light-field image; b — dark field in the [121] Fe₃C reflection; c — microdiffraction pattern for b (the arrows point to the dark-field reflection)

The formation of all the enumerated defects of the crystal structure leads to surface layer hardening of the studied steels. With pearlite content growth in steel one can see an increase in the hardened layer depth and degree of cold work calculated by the microhardness value growth. In steel 20 the degree of cold work on specimen surfaces is 39 %, while in steel 45 — 54 %. In case if a nanocrystalline layer is formed on the surface of steel 60, the degree of cold work reaches 100 %. The hardened layer depth in steel 20 is about 50 μm, while in steel 60 — no less than 300 μm. For all the studied steels the hardened layer depth is larger than the depth of the plastically deformed layer. This is due to the fact that the growth of microhardness values is also observed in the layer where only elastic-plastic stress fields are present.

Thus, based on the performed investigation it is found that at ultrasonic treatment of carbon proeutectoid steels both the ferrite and pearlite constituents undergo significant structural changes: the substructure is formed, dislocation density increases, and high internal stresses arise. The formation of all the enumerated defects of the crystal structure leads to surface layer hardening. In steel 60 where the main structural constituent is lamellar pearlite the structure is fragmented up to the formation of a nanosized ferrite-cementite mixture, which gives maximum hardening.
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Bibliography: