

# Comparative metallographic analysis of the structure of St3 steel after being exposed to different ways of work-hardening

**A E Balanovsky<sup>1</sup>, M G Shtayger<sup>2</sup>, M V Grechneva<sup>1</sup>, V V Kondrat'ev<sup>1</sup>  
and A I Karlina<sup>1</sup>**

<sup>1</sup>Irkutsk National Research Technical University, 83 Lermontov street, Irkutsk, 664074, Russia

<sup>2</sup>MC Mechel Steel, 1 Krasnoarmeysky street, 125167 Moscow, Russia

E-mail: kvv@istu.edu

**Abstract.** Results of the study of the change in the microstructure of St3 steel using different methods of heat treatment are presented. Comparison of hardness during bulk quenching and quenching by a highly concentrated heat source (plasma arc) is given. Description of the obtained microstructures is presented.

## 1. Introduction

Quenching can significantly increase the hardness and wear resistance of machine parts and tools. Moreover, the degree of increasing of hardness after quenching depends mainly on the carbon content in it. This is because the hardness of martensite depends on the degree of distortion of the crystal lattice. The smaller the content of carbon in the martensite, the less distorted its crystal lattice is and, consequently, the lower the hardness of steel is [1].

In this paper, the possibility of increasing the microhardness of low-carbon St3 steel by means of various technological methods of hardening is considered: bulk hardening, ultrasonic hardening [4], use of highly concentrated energy sources – plasma arc [5,6].

## 2. Methods and materials of research.

To study structural transformations in St3 steel, bulk hardening and surface hardening by plasma were carried out. Bulk hardening was performed in the furnace at various temperatures from 800 to 1000°C, holding time is 15 minutes, cooling in water. Plasma hardening was carried out on a plate with dimensions of 80x20x10 mm of St3 steel. Plasma surface quenching was carried out with the following parameters: plasma arc current 90A, argon flow rate 8 l/min; gap between the cut of the nozzle of the plasmatron and the detail is 5 mm; speed of movement of samples is 5-30 mm/s. With the given parameters, quenching process proceeds without metal surface flash [7,8]. Chemical composition of the material St3nc in percent GOST 380 - 2005 (table 1).

To carry out ultrasonic processing, a device consisting of an ultrasonic generator and a tool in the magnetostrictive transducer and indenter was used. Ultrasound processing of materials is based on the energy of mechanical oscillations of the instrument-indenter. The oscillations are made with an ultrasonic frequency (18-24 kHz) and an amplitude of oscillations (0.5-50) of 10<sup>-6</sup> m. Energy is introduced in the cutting zone by means of the static pressing force of the tool to the surface of the workpiece.



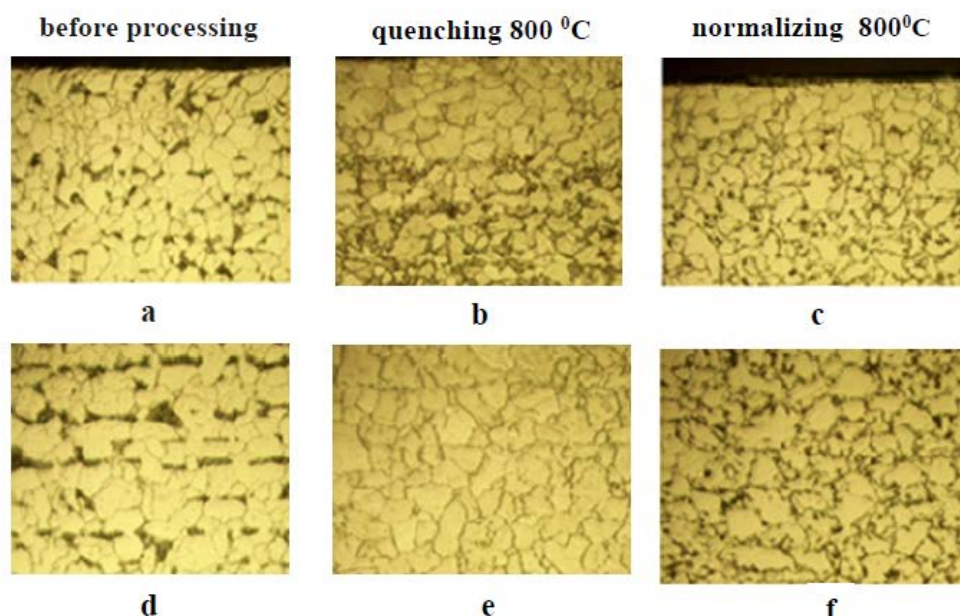
**Table 1.** Chemical composition of the material St3пс in percent.

C,%	Si,%	Mn,%	Ni,%	S,%	P,%	Cr,%	N,%	Cu,%	As,%
0.14–0.22	0.05–0.15	0.4–0.65	to 0.3	to 0.05	to 0.04	to 0.3	to 0.008	to 0.3	to 0.08

### 3. Results of research and discussion.

Microstructure of St3 steel before and after quenching is shown in figure 1-5, structure of the initial metal consists of ferritic and pearlitic grains with an average hardness of 1900 - 2100 MPa.

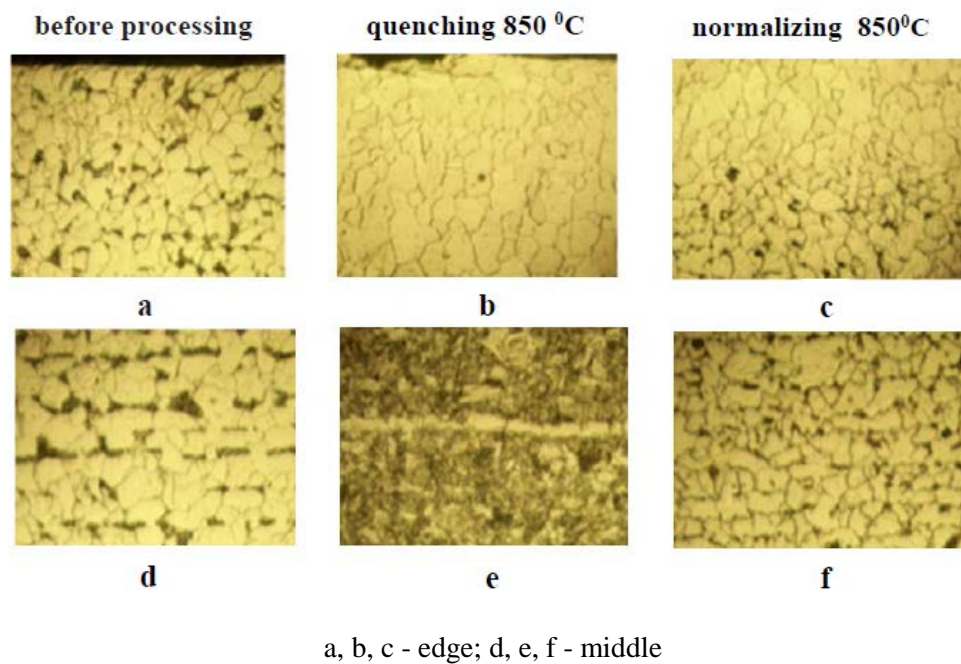
Analysis of the microstructures shown in Figure 1, St3 steel is heated to a temperature of 800 °C. It is impossible to obtain a pure ferrite-martensitic structure even using water quenching of sample with a cross section of 15x15 mm. During water quenching, a small amount of excess ferrite is released from the austenite, and the remaining austenite decomposes into a martensitic-bainitic mixture. Investigations carried out showed that when heating in the intercritical temperature range of Ac1-Ac3, the formation of the first portions of the austenite in samples with the initial ferrite-pearlite structure takes place in pearlitic grains. Further increase of the amount of austenite is due to the migration of its boundaries into ferrite grains.



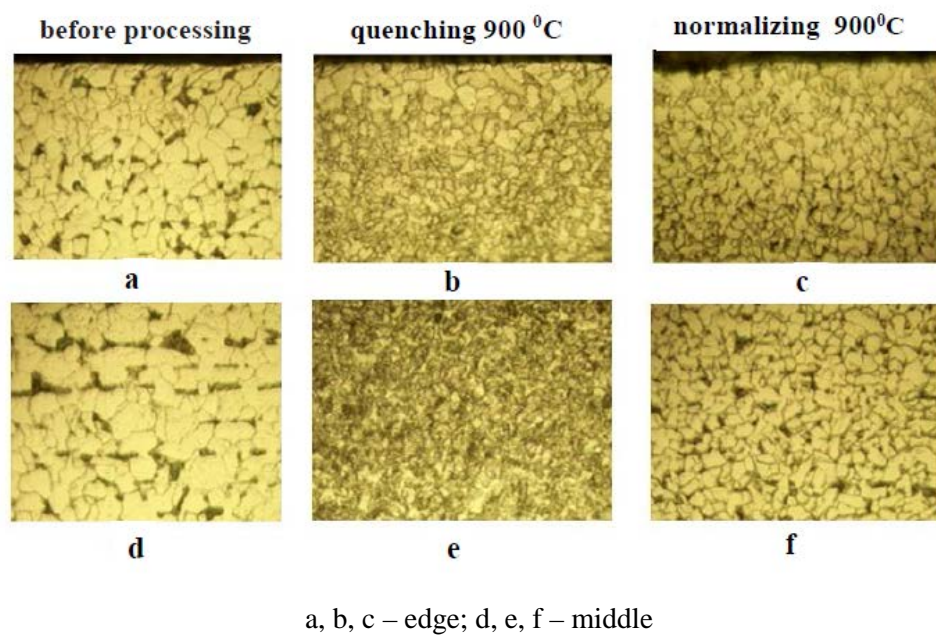
a, b, c – edge; d, e, f – middle

**Figure 1.** Microstructure of St3 steel after being heated to a temperature of 800 °C.

After cooling, low-temperature decomposition products of austenite (martensite-bainite), surrounded by new ferrite precipitates, are located along the boundaries of the old ferrite, which did not undergo transformation upon heating (figure 2). At the same time, figure 1 shows that the microstructure of the surface and the core differ from each other. On the surface, decarburization of the surface layer is seen both for the quenching regimes and for the normalization regimes. An increase in the heating temperature in the intercritical interval to 850 °C is accompanied by a decrease in the stability of the austenite, and after the excess ferrite is isolated, supercooled austenite is almost fully converted to bainite. With this heat treatment, quenching with the temperatures of the two-phase field ensures the formation of a ferrite-bainite structure (figure 2). During the cooling process, in air, from the lower half of the intercritical interval, mainly a ferrite-bainite structure with a small pearlite content is formed. The amount of pearlite increases with increasing of the heating temperature in the intercritical interval.



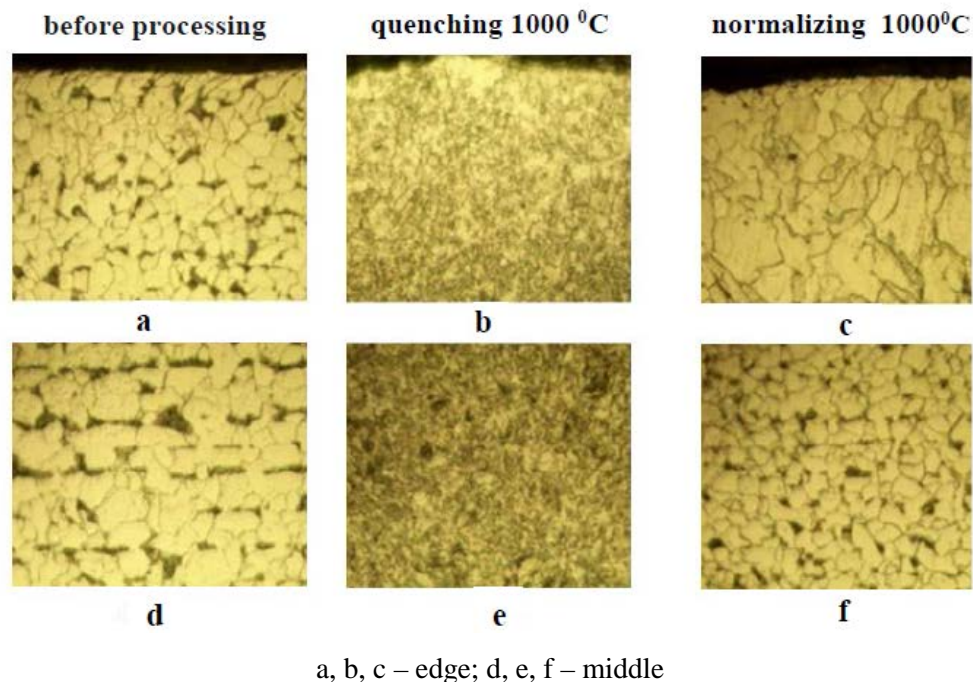
**Figure 2.** Microstructure of St3 steel after being heated to a temperature of 850 °C



**Figure 3.** Microstructure of St3 steel after being heated to a temperature of 900 °C.

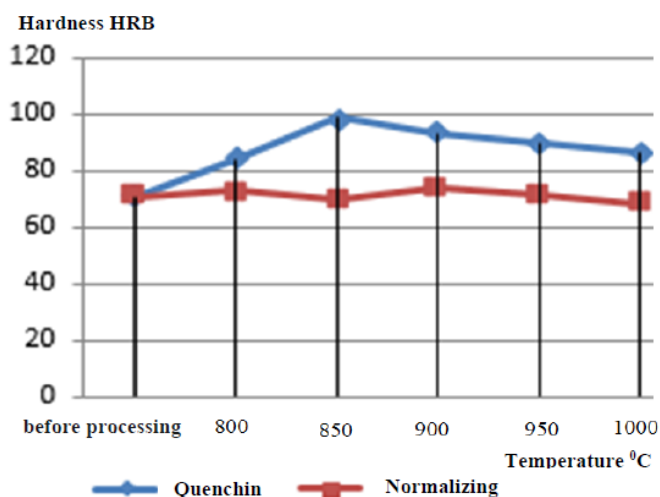
With increasing temperature of heating in the intercritical interval figures 3, 4. stability of the over-cooled austenite decreases, Mn rises, which is due to a decrease in the carbon content in the forming austenite, appearance of heterogeneity in chemical composition between the microvolumes of the sample and inside the grains.



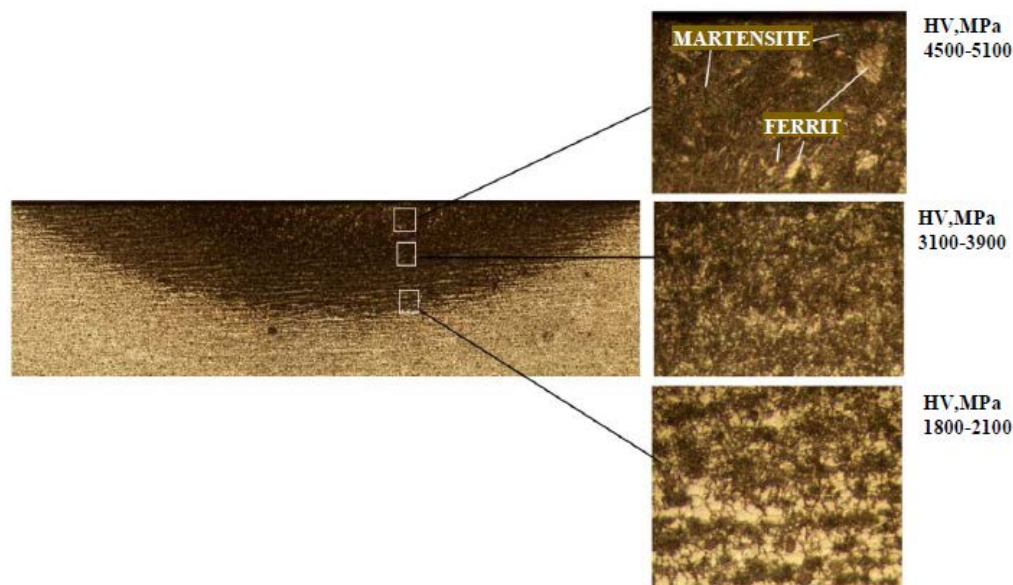


**Figure 4.** Microstructure of St3 steel after being heated to a temperature of 1000 °C.

During quenching the samples after its heating at 30 °C above Ac1 (figures 3, 4), lath martensite is formed with an “indirectly” located midrib with a high density of microtwins and dislocations, which binds to a low Mn because of the highest concentration of carbon in the first portions of the austenite formed from perlite. Decrease of the carbon content in austenite, along with increase of its amount and temperature of formation, leads, during the water quenching, to the occurrence of high-temperature martensite, in which individual laths with a high density of dislocations are assembled into piles. During the cooling process from the upper region of the intercritical interval, austenite decomposes according to the bainite mechanism. Figure 5 shows the values of the macrohardness of the samples after being heated to different temperatures. For comparison, plasma surface quenching of St3 steel at a processing speed of 15-30 mm/s was carried out. Figure 6 shows a macro image of a hardened zone and a microstructure along the depth of a hardened layer with hardness values.

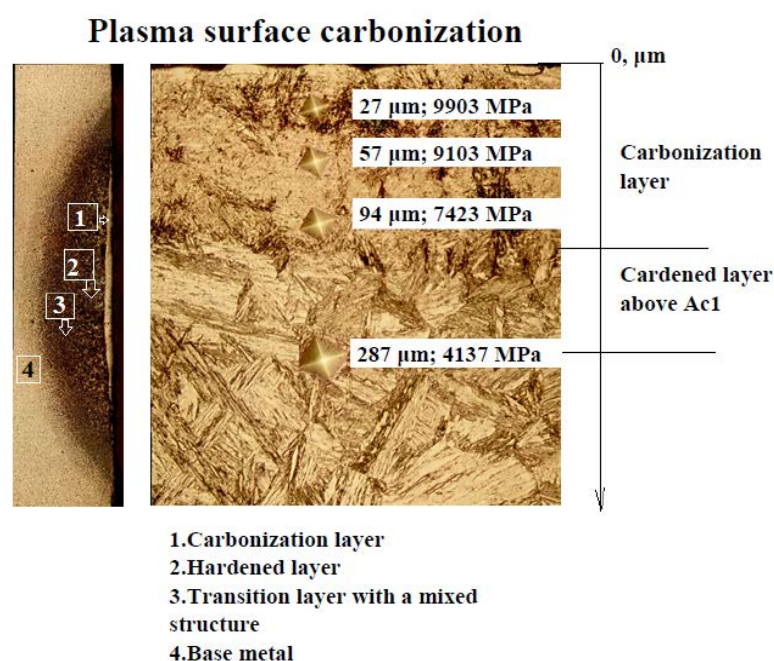


**Figure 5.** Quantitative values of macrohardness on the surface of samples of St3 steel after heat treatment.



**Figure 6.** Microstructure of St3 steel after plasma quenching in arc mode.

This is due to the fact that in the process of plasma surface heating, there are different stages of austenization [3-7]. During the plasma quenching of St3 steel, previously subjected to quenching and tempering, tempering zone is identified at the boundary with the initial structure. The entire quenching zone is a region of homogeneous martensite with a microhardness of 500650 HV, which is higher than the hardness of martensite obtained by quenching. A transition zone is observed at the boundary with the original structure. A significant increase in the hardness of the surface layer in comparison with the results presented above is possible with the help of plasma surface carburizing [8,9]. Figure 7 shows the results of the plasma surface carburizing of St3 steel. The proposed treatment allows the formation of various gradient-phase states in the surface layer of low-carbon steels.



**Figure 7.** Plasma surface carburizing of St3 steel.

With the combined treatment of St3 steel in the regimes of: bulk quenching and subsequent ultrasonic treatment, microhardness of a thin surface layer is increased to 500 HV. The depth of the plastic deformation zone is (0.05–0.1 mmV), microhardness of ferrite grains is 380 ... 450. The increase in microhardness is associated with phase hardening.

#### 4. Conclusion

Thus, comparative studies have shown the prospectivity of new methods for treating low-carbon steels with the use of a plasma arc and in the quenching and surface cementation regime and, also, for combined hardening by the example of St3 steel. Further studies in this direction will be continued with an aim to clarify the shape and dimensions of the martensitic and bainitic crystals during surface quenching, mechanism of saturation of the surface layer in the process of plasma carburizing.

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