Complex metallographic researches of 110G13L steel after heat treatment

A E Balanovs'kyi, M G Shtayger, V V Kondrat'ev, S A Nebogin and A I Karlina

1Irkutsk National Research Technical University, 83 Lermontov street, Irkutsk, 664074, Russia
2MC Mechel Steel, 1 Krasnoarmeysky street, 125167, Moscow, Russia
E-mail: kvv@istu.edu

Abstract. Complex studies with the use of modern methods of metallographic analysis with manganese steel were carried out. The mechanism of phase and structural transformations in the temperature range of heating of 110G13L steel samples for quenching from 920 to 1100 °C is considered. The optimal heating temperature for saving energy was determined.

1. Introduction
At the present time, as before, the main place in the production of cutting tools for earthmoving machinery is occupied by manganese steels, most of which are 110G13L steel or Gatfield steel [1]. The usual mode of heat treatment of such steel is quenching in water with a temperature of 1100-1150 °C, while the heating rate to quenching temperature is limited to 70-150 °C/h [1,2]. This is because the carbides of cement type formed during crystallization of the casting have different thermodynamic activity of carbon [1]. Such low heating rates, coupled with a sufficiently high quenching temperature, as well as with often required long exposures, make the process of heat treatment of 110G13L steel sufficiently long and energy-intensive.

One of the ways to reduce the time of heat treatment, in our opinion, is to reduce the quenching temperatures to some reasonable theoretically justified values. Reasonability of quenching of all castings with one temperature of 1100 °C is not entirely justified, because according to the Fe-Mn-C diagram, for example, for a steel with a carbon content of 0.90%, structure of pure austenite can be provided by heating to 860 °C [4]. For the experimental verification of the proposed assumption, castings from 5 different meltings were selected in the foundry of the heavy engineering plant (Irkutsk) and investigations were carried out. In castings of different meltings, the carbon content varies from 0.90% to 1.25%.

2. Optical microscopy
Figure 1 shows the results of optical microscopy of samples heated to different temperatures. Figure 1a shows the microstructure of austenite grains of samples heated to a temperature of 920 °C, with scattered carbide particles, both in the grain volume and along the grain boundaries. Figure 1b – to a temperature of 980 °C, it can be found less carbide particles, i.e. the process of dissolution of carbides proceeds.
Figure 1. Distribution of carbides in 110G13L steel samples heated to different temperatures.

In figure 1, the samples were heated to a temperature of 1050 °C, dark spots appear, the austenite grain increases, the carbide particles dissolve. After being heated up to a temperature of 1100 °C, multiple depressions appear in the area of the grain under investigation.

3. Electron microscopy
Figure 2 shows the photomicrographs of the surface of the steel after quenching. Structural studies have shown that against the background of the austenite structure, small carbide inclusions located along the grain boundaries are observed. This structure leads to a decrease in the strength properties of the metal. Such a structure is associated with incorrectly selected heat treatment regimes, i.e. the temperature differences, appeared during carrying the basket with castings from the furnace to the quench tank were not taken into account, temperature of the charge was lowered, which caused the carbides to fall out again. In austenite grains, traces of plastic deformation by sliding and twinning are visible. There are no obvious defects in the structure. It should be noted that the etched surface of the sample in figure 2a has traces of nonmetallic inclusions, as well as traces of darkening of the individual places in figure 2b and the depressions of the spherical shape in figure 2, c. The austenite grains are large and have the classical boundaries, figure 2, d (triple junction). The body of the grain is literally strewn with spherical depressions – figure 2, c, d, e. It's not possible to identify these spherical depressions as carbides, - with a larger zoom there is nothing in these places figure 2, d.

A large number of shear deformation bands were observed in the structure of the samples under study (figure 2, f). It is known that in 110G13L steel, toughness is approximately four times greater than in samples in whose structure these bands are absent. At the same time, a detailed analysis of the
grain boundaries showed that the “loose ones” are eaten by spherical depressions. Can we consider them (spherical depressions) as the location of carbides that were artificially removed during mechanical polishing of the sample? The issue is debatable, i.e. the analysis of the literature shows that despite the preparation (mechanical polishing) of the samples, the carbide phases in 110G13L steel are retained on the surface, and they are clearly visible in the microscope (optical and electronic). In our case, it is impossible to speak unambiguously about the presence of a carbide phase in the austenite with the result of electron microscopy, as the spherical depressions can only theoretically be the locations of the carbides and which may have been removed as a result of polishing. A characteristic of the microstructure of all microsections was the presence of polygonal austenite grains, within which there were lines of shear (twinning). These lines were approximately parallel within each grain and had a definite orientation. Traces of plastic deformation lines of various degrees were observed in an overwhelming number of grains, regardless of place of study of the microstructure.

4. EBSD analysis
After the electron microscopy, the sample was repolished and underwent an additional ion polishing to conduct the EBSD analysis figure 3, a. As a criterion for small- and large-angle boundaries (SAB and LAB, respectively), disorientation of 15 degrees was used. Grains were understood as crystallites from all directions surrounded by LAB, and for the size of the grain, the diameter of the circle whose area is equivalent to the grain area on the EBSD map was assumed, figure 3b.

![Figure 3](image)

(a) (b) (c) (d) (e) (f)

a – traces of nonmetallic inclusions; b – depressions of spherical form; c, d, e – body of the grain is literally covered with spherical depressions; f – bands of shear deformation

**Figure 2.** Electronic photos of microstructure of 110G13L steel.

The histogram of the distribution of the grain boundaries along the angles of misorientation in the structure of the steel sample is characterized by the presence of an acute peak near the misorientation angle of about 2° and indicates the unconditional predominance of small-angle boundaries whose content in the structure is ~ 90%.
The grain boundaries were superimposed with twin grain figure 3, c. In figure 3a, twin boundaries are represented by a common [111] direction and rotation angle of 600. Analysis of the results, presented in figure 3b, shows that after quenching, in the structure of the 110G13L steel sample, special twin boundaries $\Sigma 3 60^\circ <111>$ with a concentration of 0.813% were formed. The stresses of the 2nd kind, figure 3c, were measured (in austenitic grains the maximum stresses are indicated in red). The visual image, figure 3c, shows that the sample is in a stressed state. Local stresses in the places of spherical depressions are shown in figure 3e. Figure 3e shows the general picture of grain distribution in the sample and their diameter. In the course of the research it has been established that, on the one hand, large grains occupy the entire volume, but this is only at first glance, there are more small grains and, besides having twins within the same grain, the program considers them as a single grain.

![Image](image.png)

(a) (b) (c) (d) (e) (f)

(a) – microrelief of the polished surface, b – grain structure with clear boundaries; c – grains with twin boundaries (rotation angle – 600), special twin boundaries $\Sigma 3 60^\circ <111>$; d – strain of the 2nd kind in austenite grains (red color); e – local stresses in the places of spherical depressions; f – general image of the grain distribution

**Figure 3.** EBSD analysis of samples from 110G13L steel.

5. **Conclusion**

Thus, the complex metallographic studies, carried out by us, made it possible to clarify the mechanism of phase and structural transformations in the temperature range of heating of 110G13L steel samples for quenching from 920 to 1100 °C. This makes it possible to correct the heat treatment regimes of 110G13L steel castings in real production conditions. Quenching temperature can be reduced by at least 50-90 °C, which will save energy.

**References**

[1] Chernyak S S and Broido V L 2001 *Irkutsk* p 352
[2] Mulyavko N M 2001 *Proceedings of the Chelyabinsk Scientific Center* 4(13) 28–30
[3] Balanovsky A E 2015 *Strengthening Technologies and Coatings* 12(132) 18–30
[4] Balanovsky A E 2015 *Strengthening technologies and coatings* 6(126) 27–32
[5] Balanovsky A E 2016 *Strengthening Technologies and Coverings* 1(133) 25–34
[6] Balanovsky A E 2016 *Strengthening Technologies and Coverings* 2(134) 20–30
[7] Gyu V V, Balanovsky A E and Kondratiev V V 2017 *Metallurgy of Machine Building* 1 9–15
[8] Balanovsky A E and Gyu Vu 2017 *Letters on Materials* vol 2 175-9 DOI: 10.22226 / 2410-3535-2017-2-175-179
[9] Fedin V M and Borts A I 2009 *Metal Science and Heat Treatment* vol 51 11-12 544–52
[10] Kargapoltsev S K, Shastin V I, Gozbenko V E, Livshits A V and Filippenko N G 2017 *International Journal of Applied Engineering Research (IJAER)* vol 12 17 6499–503