Improving Wear Resistance Of Steel Products To Unconventional Heat Treatment Methods

Darob Berdiev, Abdulaziz Yusupov, Makhmuda Umarova, Tuychi Ibodullaev

Abstract: Application of heat treatment in order to increase wear resistance is considered on the example of samples from steels 35, 45, 40X, 65G, U8 and U12A in comparison with a reference sample made of Armco-iron. It is proposed that, before the final heat treatment of carbon and low alloy steels, a preliminary hearing is carried out with an extreme temperature, when, after cooling, structures are formed with an increased level (after normalization) of the dislocation density or with its high level (after quenching).

Index Terms: Alloy steels, carbon and low, density, dislocation, hardness, heat treatment, wear resistance.

1 INTRODUCTION

The most important problem of modern engineering and repair enterprises should be considered a reduction in metal consumption and energy. However, the service life of metal products is determined mainly by their wear resistance. Depreciation is the most destructive and therefore a large amount of metal is spent annually for the manufacture of spare parts. Conventional, standard modes of heat treatment of metal products, as a rule, provide a sufficiently high level of mechanical properties. However, in some cases this is not enough. In particular, this concerns the viscosity of the metal of the product [1,2], which ensures its high reliability. In recent years, considerable attention has been paid to structural heredity, since it was not always possible to get rid of the presence of large grains in harvesting [3,4]. The aforementioned even concerned a uranium alloy [5], questions of the dependence of the mechanical properties of low-carbon martensitic steels on the degree of manifestation of structural heredity during heat treatment [6]. The review article [7] considers heredity in phase transformations. Based on the studies, it was found that all non-traditional modes of heat treatment of steel are based on the fundamental laws of phase transformations [8].The essence of non-traditional heat treatment modes is that by means of preliminary high-temperature heat treatment a high level of defectiveness of the crystal structure of steel is achieved. This allows for repeated heating, depending on the completeness of repeated structural transformations, to greatly grind steel grain [7]. Grinding grain increases the viscosity of steel while increasing strength. While maintaining a high level of dislocation density, an increase in wear resistance occurs [9].

- *Darob Berdiev, Doctor of technical sciences at Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan.*
- *Abdulaziz Yusupov, Senior lecturer at Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan.*
- *Makhmuda Umarova, Senior lecturer at Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan.*
- *Tuychi Ibodullaev, Senior lecturer at Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan.*

However, there are a number of unresolved issues in the direction of research relating to the phase transformations of steels, theoretical and practical plans, without which the use of non-traditional heat treatment modes is very difficult:

- how does the heating time affect the temperature and the extremum of the dislocation density after the γ - α transformation during quenching cooling, in air, and after annealing of steel;
- how does the increase in the density of dislocations during cooling with an extreme heating temperature depend on the composition of the steel;
- what is the relative difference in the density of steel dislocations after quenching or normalization with an extreme and usually accepted heating temperature;
- that during repeated phase recrystallization with heating at a generally accepted temperature (Ac3 (or Ac1) + 30 ÷ 50 ° C) it affects the extremum of the growth of the dislocation density taking into account the temperature of the preheating. There is no clear enough explanation for this phenomenon;
- there is no experimental data on the effect of the duration of heating during repeated phase recrystallization of preheated steel on the state of the thin and microstructure of steel.

In this work, the mechanism of α - γ - α transformations is considered in detail, but it is also noted that at high heating temperatures there is an extreme temperature when atoms of refractory impurity phases transition into a solid solution (austenite). In this case, upon cooling (γ - α transformations), a high density of dislocations in the α phase is obtained. Upon repeated phase recrystallization, part of these dislocations is retained. A detailed analytical review of works published in the field of high-temperature heat treatment with double phase recrystallization showed [7] that they have received sufficient application to increase wear resistance. However, the theoretical justification for the implementation of various modes of unconventional technologies was not enough [9]. The solution to the problem of an additional increase in the wear resistance of products from carbon and low alloy steels was possible when conducting research simultaneously in two directions in the field of heat treatment:

1. Determination of the features of the formation of structures of the studied steels during their overheating to extreme temperatures;
2. Development of heat treatment technologies that maximize the potential capabilities of steels in increasing wear resistance.

The purpose of the work is to study the features of steel structure formation when using non-traditional heat treatment modes, which increase the wear resistance of steel products without significant additional costs.

2 METHODS OF RESEARCH

The objects of research were samples of steel for industrial smelting of grades 35, 45, 40X, 65G, U8, U12A. Armco iron samples were used as reference material. Steel grades are regulated by GOST 3541-79. The samples were heat treated by heating to various temperatures, the first of which was selected for each steel from the calculation of Ac3 (or Ac3) + 30 ÷ 50 °C, and then 900 °C, 1000 °C, 1100 °C, 1150 °C and 1200 °C. The exposure time at these temperatures was different: 5 minutes, 20 minutes, 2 hours and 5 hours. Depending on the exposure time, heating was carried out in a salt bath or in a furnace. Some experiments were carried out when heated by high-frequency currents at a heating time of from several to 20 seconds. The samples were cooled in air, in water or oil, and also with cooling of the furnace. Thus, the thermal background of steel was created. Repeated phase recrystallization was always carried out with heating to Ac3 (or Ac3) + 30 ÷ 50 °C for each steel. Metallographic analysis was performed on Neofot-21 and MIM-8M microscopes. X-ray diffraction analysis was performed on a DRON-2.0 apparatus. The state of the fine structure of steel was determined (dislocation density, mosaic block sizes and microdistortion of the crystal lattice), the amount of residual austenite, the lattice period, and the amount of carbon in the phases of hardened steel. The wear resistance tests were carried out during sliding friction on a fixed abrasive material on an X4-B machine, on an unsecured abrasive material on a PV-7 machine, when sliding metal-by-metal on an SMTS-2 friction machine and during rolling friction with slipping on the friction machines MI-1. With an increase in the heating temperature, a known fact of the growth of austenitic grain is observed. However, in all cases, there is an extreme heating temperature of 1100 °C with an austenitization time of 20 minutes, when after cooling it is possible to fix the maximum level of dislocation density (table).

Table 1. *Density of steel dislocations after normalization at various heating temperatures (austenization 20 min)*

Normalization temperature, °C	*Steel grade*							
	Fearmco		*Steel 35*		*Steel 45*		*Steel 40X*	
	$\rho \cdot 10^9$ 1/cm^2	*ρ/ρ_{900}*	*$\rho \cdot 10^9$ 1/cm^2*	*ρ/ρ_{850}*	*$\rho \cdot 10^9$ 1/cm^2*	*ρ/ρ_{850}*	*$\rho \cdot 10^{10}$ 1/cm^2*	*ρ/ρ_{870}*
Ac_3 +30÷50	-	-	-	-	*1,0*	-	*1,13*	-
900	*0,37*	-	*0,51*	-	-	-	*1,13*	*1,0*
1000	*0,88*	*2,38*	*1,76*	*3,45*	*1,73*	*1,73*	*2,31*	*2,0*
1100	*1,40*	*3,78*	*5,85*	*11,4*	*4,5*	*4,5*	*4,54*	*4,0*
1200	*0,73*	*1,97*	*3,46*	*6,78*	*2,99*	*2,99*	*1,26*	*1,08*

Note: ρ / ρ_{st} – is the ratio of the density of dislocations of the current temperature to the first temperature, as to the standard ρ / ρ_{st}). The relative increase in ρ is large, but the absolute difference is not large.

With the normalization of large parts, the exposure time in the austenitic region during heating can be calculated in hours. In this case, the effect of extreme temperature on the state of the fine structure of steel has not been determined. Studies have shown that with an increase in the holding time during heating of steel after the γ - α transformation, the density of α-phase dislocations is lower and the peak of the maximum shifts to lower heating temperatures (Fig. 1).

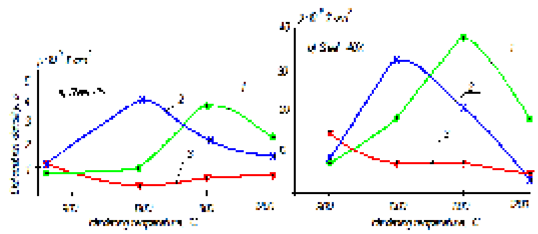
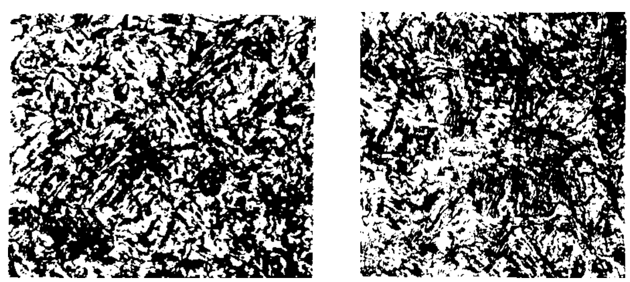


Fig. 1*. The effect of heating temperature and holding time on the dislocation density of normalized steel: a - steel 45; b - steel 40X.*

Steel holding time: 1 - 20 minutes; 2 - 2 hours; 3 - 5 hours

Hardened steel samples are the most convenient objects for studying the parameters of their structure, since their main structure is martensitic and some residual austenite (Fig. 2). Of particular importance is the level of dislocation density in steels quenched with an extreme heating temperature compared to quenching in a medium from commonly accepted temperatures (above heating temperatures Ac3 (or Ac1) + 30 ÷ 50 °C).



a b

Fig. 2*. Microstructure of steel 40X after quenching from various heating temperatures (× 500). Quenching temperature: a - 870 °C; b - 1100 °C*

This difference is large with a low carbon content, for example, armco-iron of 288%. On samples of steels 35, 45, 40X, 65G, U8 and U12A it is: 37, 37, 69, 28, 28 and 21%, respectively. In this case, during quenching cooling and at low tempering in extreme positions, redistribution of carbon atoms between phases is observed. Carbon atoms pass to dislocations and to residual austenite. Of particular interest are the results of changes in the dislocation density with increasing tempering temperature. When tempering above 200 °C, a general sharp decrease in the density of dislocations is observed, but during quenching with an extreme temperature of 1100 °C this decrease is much less (Fig. 3).

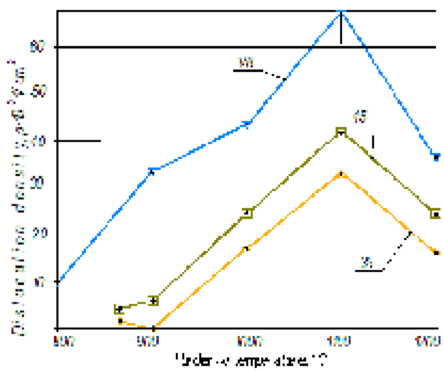


***Fig. 3**. The effect of quenching and tempering temperature on the dislocation density of various steels. Tempering temperature: a - 350 °C; b - 600 °C*

The higher the tempering temperature after steel hardening (from 200 to 600 °C), the greater the difference in the level of dislocation density between samples hardened with extreme temperatures that are usually accepted for a given steel. The effect on the level of dislocation density of the exposure time at various heating temperatures after quenching can be judged by the results of experiments presented in figure 4. The nature of the change in the density of dislocations with increasing exposure time is similar to what occurred during normalization. Similar results were obtained in the study of steel 40X. The dislocation density in the structure of crystalline steel increases when the heat treatment is preheated to extreme temperatures. During such normalization, the increase in the dislocation density in structural steels reaches 1.5 ÷ 2.5 times (from 40X steel from 150 to 258%). However, the absolute value is ρ · 109 1 / cm2, it eats two orders of magnitude less than after quenching. In the hardened state (ρ · 1014 1/cm2) this difference reaches from 28 to 50-60 %. However, the growth of asthenic grain reduces the ductility and toughness of steel. However, after normalization, hardening with tempering always follows. During repeated phase recrystallization during heating under quenching, the temperature was Ac3 (or Ac1) + 30 ÷ 50 °C.

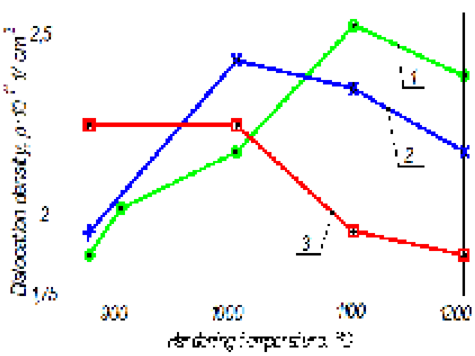


***Fig. 4**. The effect of temperature and heating time on the density of dislocations in hardened steel 45. Tempering during heating 200 °C. Holding time during heating: 1 - 20 minutes; 2 - 2 hours; 3 - 5 hours*

In the above case [10], the austenitic grain will be small, but the following factors remain unclear:

- how significant is the influence of the parameters of the initial structure on the grain size and the state of the fine structure after repeated phase recrystallization;
- whether the heating time during repeated phase recrystallization affects the fine structure of steel.

In this case, there is a slight effect of the initial coarse grain on the grain size during repeated phase recrystallization with heating to Ac3 (or Ac1) + 30 ÷ 50 °C. However, the grain size is always smaller if the initial normalization was carried out with a heating temperature of 1100 °C and higher. The effect of the temperature of the initial normalization on the level of dislocation density after the final quenching and tempering is shown in figure 5. 1 - steel 35; 2 - steel 65G; 3 - steel U8; 4 - steel U12AThe maximum dislocation density falls on the temperature of preliminary normalization 1150-1200 °C. The longer the reheat time, the less the effect of an increase in the density of dislocations. A shift of the peak of the maximum dislocation density to higher temperatures of preliminary normalization is observed. A similar picture is observed if the preliminary heat treatment is quenching from various heating temperatures with an intermediate tempering of 450 °C. This is the temperature of the polygonization, when the dislocation structure is stabilized.

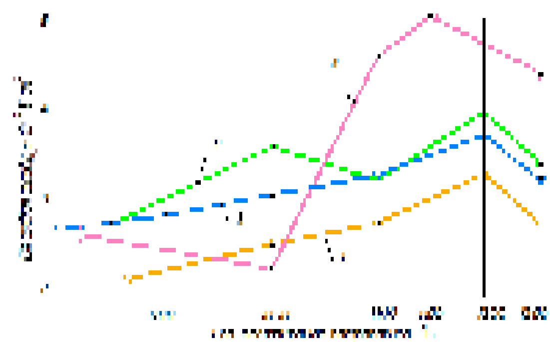


***Fig. 5**. The density of steel dislocations after preliminary normalization from various heating temperatures.*

Re-heating Ac3 (or Ac1) + 30 ÷ 50 ° C after quenching and low tempering:

Presented in the diagram (Fig. 6) can explain the mechanism of change in the fine structure during phase recrystallization of steels that were previously normalized or hardened from different temperatures. In this case, the final hardening is always carried out from the heating temperature Ac3 (or Ac1) + 30 ÷ 50 °C. The scheme (Fig. 6) has sufficient grounds for existence, since created using data obtained during metallographic and x-ray diffraction studies.

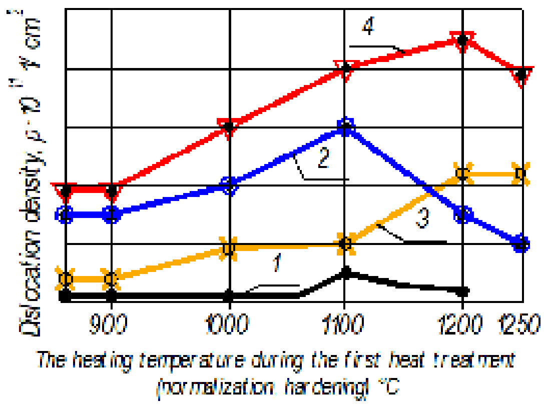


Fig. 6. *The scheme of formation of the fine structure of steel after double phase recrystallization: 1 - initial normalization; 2 - during hardening with Ac3 (or Ac1) + 30 ÷ 50 °C; 3 - growth of lattice micro distortions due to secondary intragranular texture; 4 - the total effect of increasing dislocation density*

Sliding friction on a fixed abrasive material is the most stringent test method. Steel samples were tested with very little residual austenite. Pre-normalized samples from various heating temperatures were reheated to a single temperature Ac3 (or Ac1) + 30 ÷ 50 °C, hardening and low tempering were carried out, a comparative increase in the dislocation density during preliminary normalization from 1150 ° C from 20 to 39 %, reduction in wear 10 -15 %.Sliding friction on loose abrasive material is the kind of friction that exists with all tillage agricultural machines. Steel samples were previously normalized above the heating temperature Ac3 (or Ac1) + 30 ÷ 50 °C, and then all the steels were heated to 900 to 1200 °C. Heating time 20 minutes. Reheating of samples of each steel grade was taken Ac3 (or Ac1) + 30 ÷ 50 °C, regardless of the temperature of preliminary normalization, quenching and tempering were carried out. The effect of reducing the amount of wear, upon preliminary normalization from the extreme heating temperature (1150 and 1100 °C), compared with the first heating temperature, turned out to be significant, the decrease in wear is higher by the tempering temperature, for steel 35 14-23%, for steel 45 19-32 %, for steel 65G 20-40%, for steel U8 20-50%.During metal-to-metal sliding friction, direct quenching was studied after heating steel from various heating temperatures. In cases where the magnitude of the austenitic grain is not very important or when fast heating is used, direct quenching with extreme temperature can be used. Tests for sliding friction with lubrication of 40X steel rollers on a box made of gray cast iron are shown in Figure 7.

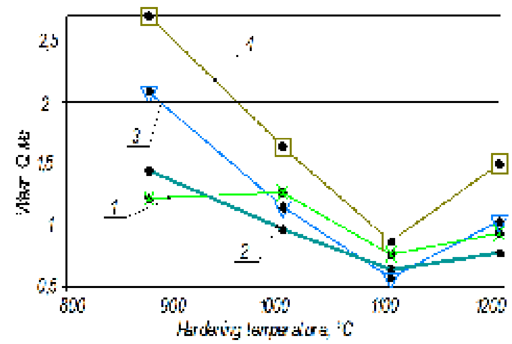


Fig. 7. *Change in the amount of wear of steel 40X during friction with lubricant from hardening and tempering temperatures. Tempering temperature: 1 - 200 °C; 2 - 350° C; 3 - 450 °C; 4 - 600 °C*

The effect of reducing wear after quenching with an extreme temperature of 1100 °C compared with quenching at ordinary temperature (Ac3 + 30 ÷ 50 °C) turned out to be quite large 40-68%.Tests without lubrication were carried out on samples (rollers) of steels 45, 40X, U8 during their friction on a hardened axle box. The effect of reducing wear after quenching from an extreme temperature of heating turned out to be significant (with the same hardness), for steel 45 41-52%, for steel 40X 50-53%, for steel U8 32-50%.In a state of preliminary normalization, samples of steel 40X were previously normalized from different heating temperatures (austenization for 20 minutes). Reheating of all samples was carried out at 870 °C (austenization was also 20 minutes), quenching of all samples in oil, tempering at a temperature of 200 °C to 600 °C. The test results for sliding friction in the presence of lubricant, as well as without lubricant, fully corresponded to the laws of change in the fine structure, which were described earlier [10]. The effect of reducing the wear of samples thermally processed under extreme conditions was significant, with sliding friction with lubricant 57-67%, with sliding friction without lubricant 49-51%.During rolling friction with slipping of the direct quenching, the samples for wear were heated to various temperatures with a holding time of 20-30 minutes and 2 hours. After mechanical treatment, part of the samples was released at 200 °C, and part at 600 °C. Tests have shown that after quenching from extreme temperatures (1100 ° C at a holding time of 20 minutes and 1000 ° C at a holding time of 2 hours) after tempering at 200 °C, a decrease in wear of 32-39 and 13-16%, respectively, was observed. After tempering at 600 °C, wear increases with the growth of austenitic grain. The state of preliminary hardening and preliminary normalization in the development of heat treatment regimens with double phase recrystallization, depending on the size of the part, has to take into account the heating time. If the preliminary heat treatment includes quenching from various temperatures, intermediate tempering is 450 °C, then after repeated quenching at the generally accepted heating temperature (for steel 40X - 870 °C), then a minimum of wear is detected at the first quenching temperature of 1200 °C. The effect of reducing wear is 53%.If the preliminary heat treatment involves normalization from different heating temperatures, then after re-heating to the generally accepted temperatures (for steel 45 - 850 °C, for steel 40X - 870 °C) and subsequent quenching with tempering, the effect of reducing wear is also found when preliminary normalization of 1200 °C. This effect for steel 45 - 37%, for steel 40X - 55%. An increase in the heating time during repeated heating reduces this effect to

15%.

3 RESULTS

To increase the wear resistance of machine parts and tools use alloy steels and alloys. Their effectiveness is verified by special wear tests. As a reference, any steel is selected whose specimen wear is taken as unit. In our studies, another goal was set - to determine the effectiveness of the use of unconventional heat treatment technologies. In this case, the reference is a sample of the same steel that has been thermally treated according to generally accepted conditions. As a rule, the hardness of the samples in both cases is the same. Even under such conditions, the effectiveness of unconventional heat treatment modes was significant. When sliding friction on a fixed abrasive material (abrasive skin) a very rigid test method is implemented. Steel samples 45, 65G and U8 underwent preliminary normalization at an extreme heating temperature. After repeated phase recrystallization from the temperature Ac3 (or Ac1) + 30 ÷ 50 °C, quenching and low tempering, the decrease in wear was 16, 15 and 15%, respectively. When sliding friction on loose abrasive material (silica dust), wear reduction was for steels 45, 65G, U8, respectively 32, 40, 50%.When friction sliding metal on metal after using non-traditional heat treatment modes, the decrease in wear reaches from 40 to 60%.With rolling friction with slippage, this effect is in the range of 40-50%.The data obtained above indicate the advisability of using non-traditional heat treatment modes for hardening machine parts and tools, therefore, to increase their wear resistance, which will eliminate the use of high alloy steels, reduce material costs and will contribute to localization of production. An alternative to the above is the creation and production of new steel grades. In particular, to increase the wear resistance of the working bodies of tillage agricultural machines, new steel grades with yield strengths of 1200, 1500 and 1700 MPa have been developed. Such high mechanical properties were achieved by complex alloying of medium-carbon steel with 0.3 ÷ 0.45% carbon. The main alloying elements are Mn, Cr, Ni, Cu, Mo, V, as well as small additives Nb, Al, Ti, Cu. Only 12 regulated by the composition of the elements. The proposed heat treatment is hardening of 900 ° C and low tempering. Assessment of wear resistance during bench tests on a PV-7 type installation (sliding friction on loose abrasive material) was carried out in comparison with the standard - steel 45 HRC 37-42. Tests have shown that the relative wear resistance of the new B1200 steel is 1.2-1.25; B1500 - 1.36-1.54; B1700 - 1.52-1.59. In the studies conducted by the authors, after a double phase recrystallization of quenching and low tempering, the following results were obtained: the relative wear resistance of steel 45 at a hardness of 47 HRC - 1.47; 65G steel with a hardness of 60 HRC -1.66, U8 steel with a hardness of 59 HRC - 2.0. When metal glides over metal and rolling friction with slippage, the effectiveness of reducing wear and increasing relative wear resistance increases.

4 CONCLUSION

1. When steel is heated to high temperatures, extreme temperatures are observed when, after cooling, structures are formed with an increased level (after normalization) of the dislocation density or with its high level (after quenching). Extremes of the dislocation density occur at heating temperatures of 1100, 1000, 900 °C with a holding time of 20-30 minutes, 2 hours and 5 hours, respectively, when heated. The magnitude of the increase in the density of dislocations depends on the content of carbon and alloying elements in it.
2. When hardening steel with an extreme heating temperature, during the γ - α transformation, an increase in the density of dislocations occurs due to the fragmentation of mosaic blocks and the growth of microdistortions of the crystalline structure. In this case, a significant redistribution of carbon atoms between the phases is observed: the transition of a part of the atoms from the tetragonal positions of the crystalline structure of martensite to dislocations and residual austenite.
3. The dislocation structures obtained upon quenching or normalization after heating to extreme temperatures are thermally very stable, and upon reheating, they have reached subcritical temperatures, and their density is tens of times greater than that of steels after heating to ordinary temperatures.
4. Repeated phase recrystallization of steels preheated to extreme temperatures leads to a sharp increase in dislocation density from 32 to 100 and even 150% after quenching cooling and low tempering. In this case, the maximum dislocation density is shifted by 50-100 °C to the region of higher temperatures of preliminary heat treatment (1150-1200 °C).
5. Heat treatment with double phase recrystallization also leads to the redistribution of carbon atoms between the phases of hardened steel - the migration of some carbon atoms from the martensite lattice to dislocations and residual austenite.
6. The value of austenitic grain after the final hardening depends on both the temperature of preliminary hardening or normalization and the intermediate tempering of hardened steel.
7. As a result of the research, the problem of developing the theoretical foundations for maximizing the implementation of the hardening steel structure structural parameters in increasing their overall level of wear resistance using non-traditional heat treatment modes was solved.

5 REFERENCES

[1] Stepanova Elina Vyacheslavovna, Sotnikova Yana Aleksandrovna World experience in the production of steel structures // Age of Science. 2015. No4.

[2] Ginne Svetlana Viktorovna On methods of protecting building steel structures against corrosion that reduce the aggressiveness of a corrosive environment // The Age of Science. 2019. №18.

[3] Fist V.V. To the question of the protection of steel from corrosion / Science and Youth: Problems, Searches, Solutions: Proceedings of the All-Russian Scientific Conference of Students, Graduate Students and Young Scientists. -Novokuznetsk: Publishing. Center SibGIU, 2016. - Vol. 20. - Part IV. Technical science. – 1922 pp.

[4] Kosachev VB Corrosion of steels / News of heat supply. - 2002. - No. 1. 34-39 pp.

[5] Tsivadze A.Y. Science and technology/Corrosion: materials, protection. - 2003. - No. 10. 13-16 pp.

[6] Shluger M.A. Corrosion and protection of steels / M.A. Schluger, F.F. Azhogin, M.A. Efimov. M., 1981. - 216 pp.

[7] Tapaeva A.P. Methods of corrosion protection/Young scientist. 2014. No. 12. 5-7 pp.
[8] Chen W. Environmental aspects of Near-neutral stress corrosion cracking of pipeline steel/ Metallurgical and materials transitions. Pittsburgh, 2002.1429-1436 pp.
[9] Parkins R.N., Fessler R.P. Line pipe stress corrosion cracking - mechanisms and remedies / Corrosion86. - Houston, 1986. - Pap. 320. 1-19 pp.
[10] Backman V. Cathodic protection against corrosion / M.: Metallurgy, 1984. 496 pp.
[11] Rosenfeld I.L. Corrosion Inhibitors: Monograph/M.: Chemistry, 1977.352 p.