Scientific-technical journal

Volume 4 | Issue 1 Article 2

3-25-2021

INFLUENCE OF PARAMETERS OF NON-STANDARD MODES OF HEAT TREATMENT ON INCREASING THE WEAR RESISTANCE OF STEEL PRODUCTS

Dorob Murotovich Berdiyev DSn
ashkent state technical University, the department “Metal Forming”

Abdulaziz Abdullajanovich Yusupov head teacher
Tashkent state technical University, the department “Metal Forming”, abdulazizyusupovabd@gmail.com

Ravshan Kobilovich Tashmatov doctoral student
ashkent state technical university named Islam Karimov, ravshan_iqtisod@mail.ru

Tuychi Nemat ogli Ibodullayev assistant
Tashkent state technical university named Islam Karimov

Kabira Erkinovna Qurbonova head teacher
Tashkent state technical university named Islam Karimov

MECHANICS

UDC. 621.78

INFLUENCE OF PARAMETERS OF NON-STANDARD MODES OF HEAT TREATMENT ON INCREASING THE WEAR RESISTANCE OF STEEL PRODUCTS

Berdiyev D.M., Yusupov A.A., Tashmatov R.K., Ibodullayev T.N. Qurbonova K.E.

Tashkent state technical university named Islam Karimov

ВЛИЯНИЕ ПАРАМЕТРОВ НЕСТАНДАРТНЫХ РЕЖИМОВ ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА ПОВЫШЕНИЕ ИЗНОСОСТОЙКОСТИ СТАЛЬНЫХ ИЗДЕЛИЙ

Бердиев Д.М., Юсупов А.А., Ташматов Р.К., Ибодуллаев Т.Н., Курбонова К.Э.

Ислом Каримов номидаги Тошкент давлат техника университети

ПЎЛАТЛИ МАҲСУЛОТЛАРНИ ЕЙИЛИШГА БАРДОШЛИЛИГИГА НОАНЪАНАВИЙ ТЕРМИК ИШЛОВ БЕРИШ КЎРСАТКИЧЛАРИНИНГ ТАЪСИРИ

Бердиев Д.М., Юсупов А.А., Ташматов Р.К., Ибодуллаев Т.Н., Курбонова К.Э.

Ташкентский государственный технический университет имени Ислама Каримова

Abstract: *The use of non-standard modes of heat treatment increases the density of dislocations in the crystal structure of the α-phase and increases the wear resistance of carbon, low-alloy steels under various friction conditions, which is comparable to the results when heated to a standard temperature (Ac_3+30÷50 °C). The preliminary extreme heating temperature is determined. After re-quenching at standard temperature and low tempering, the wear resistance of steels under various types of friction increases by up to 40 % compared to standard quenching.*

Key words: wear resistance, heat treatment, hardness, carbon and low-alloy steels, and dislocation density.

Аннотация: *Использование нестандартных режимов термической обработки увеличивает плотность дислокаций в кристаллическом строении α-фазы и повышает износостойкость углеродистых, малолегированных сталей в различных условиях трения, что сопоставимо с результатами при нагреве до стандартной температуры (Ac_3+30÷50 °C). Определена предварительная экстремальная температура нагрева. После повторной закалки при стандартной температуре и низком отпуске износостойкость сталей при различных видах трения повышается до 40 % по сравнению со стандартной закалкой.*

Ключевые слова: износостойкость, термическая обработка, твёрдость, углеродистые и малолегированные стали, плотность дислокаций.

Аннотация: *Ноанъанавий термик ишлов бериш режимини қўллаш, стандарт ҳароратда (Ac_3+30÷50 °C) қиздиришдаги натижаларга нисбатан α-фазани кристалл тузилишдаги дислокация зичлигини ўсишига олиб келади ва углеродли, камлегирланган пўлатларни турли шароитларда ишқаланишдаги ейилишга бардошлилигини оширади. Дастлабки экстремал қиздириш ҳарорати аниқланган. Стандарт ҳароратда қайта тоблаш ва паст ҳароратда бўшатилган пўлатларни турли шароитда ишқаланиши, стандарт тоблашга нисбатан 40 % гача ошиши кузатилган.*

Таянч сўзлар: ейилишга бардошлилик, термик ишлов бериш, қаттиқлик, углеродли ва кам легирланган пўлатлар, дислокация зичлиги.

Introduction.

The most important problem of modern engineering and repair enterprises should be considered a reduction in metal consumption and energy. However, mainly their wear resistance determines the service life of metal products. 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].

The aforementioned even concerned a uranium alloy [5, 6], 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, 8] 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 [7].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 [8].

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].

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 (Ac_3 (or Ac_1) + 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 αphase 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 [7-9], 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.

MECHANICS

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.

MATERIAL AND METHODS. The objects of research were samples of steel for industrial smelting of grades 35, 45, 40Kh, 65G, U8, U12A. Armco iron samples were used as reference material. Steel grades are regulated by GOST 8559-75. The samples were heat treated by heating to various temperatures, the first of which was selected for each steel from the calculation of Ac_3 (or Ac_1) + 30÷50 °C, and then 900, 1000, 1100, 1150 and 1200 °C. The exposure time at these temperatures was different: 5 min, 20 min, 2 h and 5 h. 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 Ac_3 (or Ac_1) + 30÷50 °C for each steel.

Metallographic analysis was performed on Neofot-21 and MIM-8M microscopes [10]. X-ray diffraction analysis was performed on a DRON-2.0 apparatus [11]. The state of the fine structure of steel was determined (dislocation density, mosaic block sizes and micro distortion 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 [12], on an unsecured abrasive material on a PV-7 machine [13], when sliding metal-by-metal on an SMTS-2 friction machine and during rolling friction with slipping on the friction machines MI-1 [14-15].

RESULTS OF THE STUDY. 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 min, when after cooling it is possible to fix the maximum level of dislocation density (table).

Table.

Density of steel dislocations after normalization at various heating temperatures (austenization 20 min)

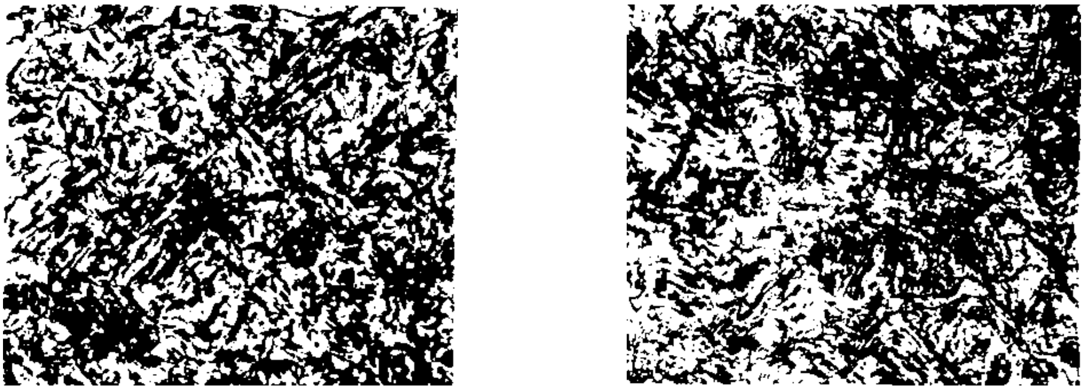
	Steel grade							
	Armco iron		Steel 35		Steel 45		Steel 40X	
	$\rho \cdot 10^9$ cm^{-2}	ρ/ρ_{900}	$\rho \cdot 10^9$cm^{-2}	ρ/ρ_{850}	$\rho \cdot 10^9$cm^{-2}	ρ/ρ_{850}	$\rho \cdot 10^{10}$cm^{-2}	ρ/ρ_{870}
Ac_3 +30÷50	-	-	-	-	1,0	-	1,13	-
900	0,37	-	0,51	-	-	-	1,13	1,0
1000	0,88	2,38	1,76	3,45	1,73	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 [16].

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. 1). 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 Ac_3 (or Ac_1) + 30÷50 °C). This difference is large with a low carbon content, for example, armco-iron of 288 %. On samples of steels 35, 45, 40Kh, 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 [17].



a *b*

Fig. 1. Microstructure of steel 40Kh after quenching from various heating temperatures (× 500). Quenching temperature 870 (*a*) and 1100 °C (*b*).

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 2.

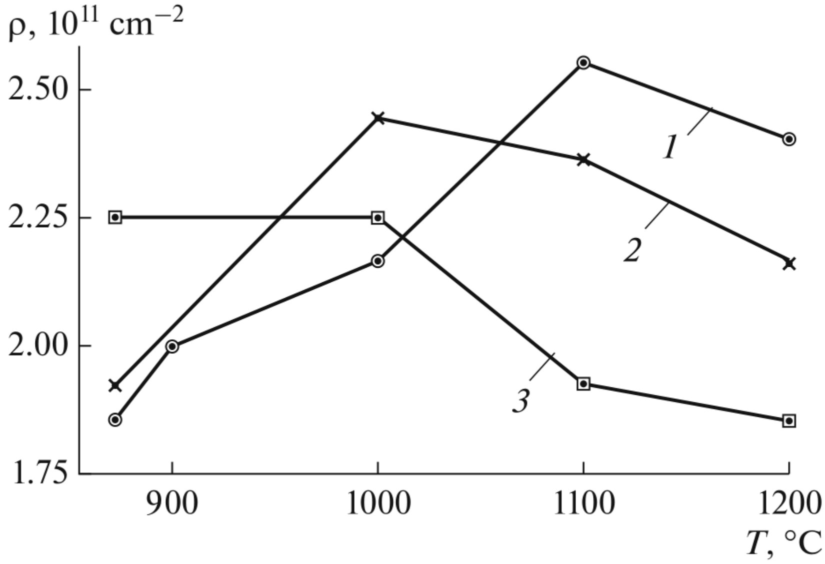


Fig. 2. Influence of the temperature *T* on the dislocation density *ρ* of quenched steel 45 tempered at 200 °C, when the holding time is 20 min (*1*), 2 h (*2*), and 5 h (*3*).

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 40Kh.

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 40Kh steel from 150 to 258 %). However, the absolute value is $\rho \cdot 10^9$ cm^{-2}, it eats two orders of magnitude less than after quenching. In the hardened state ($\rho \cdot 10^{14}$ cm^{-2}) 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 Ac_3 (or Ac_1) + 30÷50 °C.

In the above case [18], 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 Ac_3 (or Ac_1) + 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 4. The 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.

Presented in the diagram (Fig. 3) 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 Ac_3 (or Ac_1) + 30÷50 °C. The scheme has sufficient grounds for existence, since created using data obtained during metallographic and x-ray diffraction studies.

Sliding friction on a fixed abrasive material is the most stringent test method [19]. Steel samples were tested with very little residual austenite. Pre-normalized samples from various heating temperatures were reheated to a single temperature Ac_3 (or Ac_1) + 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 [16]. Steel samples were previously normalized above the heating temperature Ac_3 (or Ac_1) + 30÷50 °C, and then all the steels were heated to 1200 °C. Heating time 20 min. Reheating of samples of each steel grade was taken Ac_3 (or Ac_1) + 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 %.

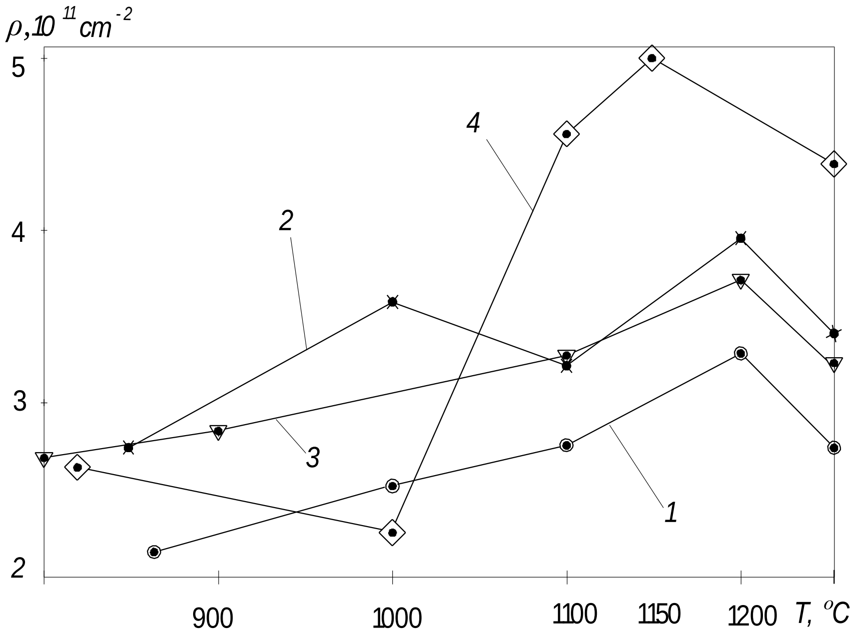


Fig. 3. The density of steel dislocations ρ after preliminary normalization from various heating T temperatures. Steel 35 (1); steel 65G (2); steel U8 (3); steel U12A (4).

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 40Kh steel rollers on a box made of gray cast iron are shown in figure 4.

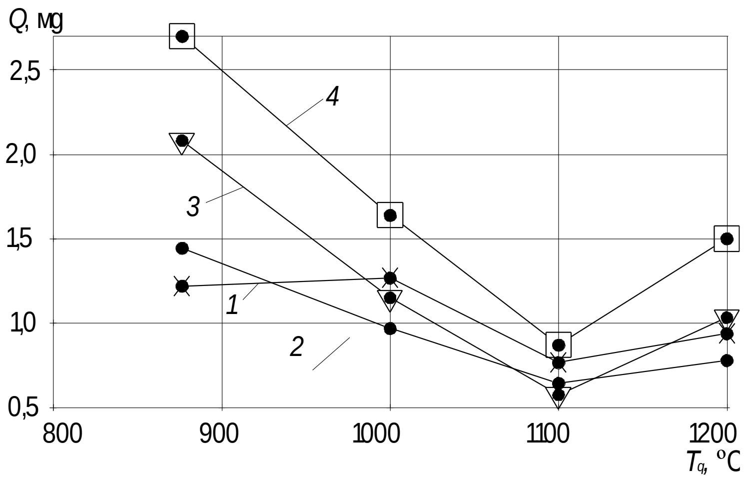


Fig. 4. Dependences of the wear Q of 40Kh steel under friction with lubrication on the quenching temperature T_q at the tempering temperature T_t = 200 (1), 350 (2), 450 (3) and 600 °C (4)

The effect of reducing wear after quenching with an extreme temperature of 1100 °C compared with quenching at ordinary temperature (Ac_3 + 30÷50 °C) turned out to be quite large 40-68 %.

Tests without lubrication were carried out on samples (rollers) of steels 45, 40Kh, 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 40Kh 50-53 %, for steel U8 32-50 %.

In a state of preliminary normalization, samples of steel 40Kh were previously normalized from different heating temperatures (austenization for 20 min). Reheating of all samples was carried out at 870 °C (austenization was also 20 min), 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 [18]. 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 min and 2 h. 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 min and 1000 ° C at a holding time of 2 h) 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 40Kh - 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 40Kh - 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 40Kh – 55 %. An increase in the heating time during repeated heating reduces this effect to 15 %.

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 min, 2 h and 5 h, 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 micro distortions 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. Pre-normalization at extreme temperatures (1150 ^oC) and after re-quenching from the temperature Ac_3 (or Ac_1)+30÷50 °C, low tempering increases the wear resistance of steels with different types of friction by 25-30 %.
7. Direct quenching from extreme heating temperatures (1100 ^oC) and after low temperature tempering increases the wear resistance of steels under different types of friction by 30-40 %.
8. The use of non-standard maintenance modes for strengthening machine parts and tools, and, consequently, to increase their wear resistance, eliminates the use of high-alloy steels, reduces material costs and will contribute to the localization of production.

References

[1]. Stepanova E.V., Sotnikova Y.A. World experience in the production of steelstructures // Age of Science. 2015. no. 4. pp. 35-38.
[2]. Dyuchenko S.S. Heredity in phase transformation: mechanism of the phenomenon and effect on the properties // Metall Science and heat treatment. 2000. V. 42. no. 3-4. pp. 122-126.
[3]. Fist V.V. To the question of the protection of steelfrom 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 p.
[4]. Kosachev V.B. Corrosion of steels // News of heat supply. - 2002. no.1. pp. 34-39.
[5]. Grebenkov S.K., Shatsev A.A., Ryaposov I.V. Deformation hardening of low-carbon martensitic steels with pronounced structural heredity // Metallology and heat treatment of metals. 2013. no. 11. pp. 34-36.
[6]. Tsivadze A.Y. Science and technology // Corrosion: materials, protection. - 2003. no. 10. pp. 13-16.
[7]. Shluger M.A. Corrosion and protection of steels // M.A. Schluger, F.F. Azhogin, M.A. Efimov. M., 1981. - 216 p. (in Russian)
[8]. Tapaeva A.P. Methods of corrosion protection // Young scientist. 2014. no. 12. pp. 5-7.
[9]. Chen W. Environmental aspects of Near-neutral stress corrosion cracking of pipeline steel // Metallurgical and materials transitions. Pittsburgh, 2002. pp. 1429-1436.
[10]. Bataev V.A., Bataev A.A., and Alkhimov A.P., The structural analysis of materials and quality control of the parts, Moscow: Nauka, 2007. - 224 p. (in Russian)
[11]. Gorelik S.S., Skakov Yu.A. and Rastorguev L.N. X-Ray and Electron-Optical Analysis, Moscow: Mosk. Inst. Stali Splavov, 1994. - 328 p. (in Russian)
[12]. The machine X4-B is a test unit for studying the wear of materials with a fixed abrasive. Dictionary-reference on friction, wear and lubrication of machine parts. Kiev: Naukova dumka, 1979. - 185 p. (in Ukraine)
[13]. Berdiev D.M. Basic parameters of non-tradition methods of thermal processing for increasing abrasive wear-resistance of steel products // Scientific-technical journal. 2020 Vol. 24 : Iss. 1, Article 3, pp. 35-41.
[14]. Tenenbaum M.M. Regularities of abrasive wear of parts of working bodies of agricultural machines // Friction and wear. 1980. T. 1. no 2. pp. 357-364.
[15]. Garkunov D.N. Tribotechnika. Moscow: Mosk. Inst. Stali Splavov, 2005. - 356 p. (in Russian)
[16]. Mukhamedov A.A., Berdiev D.M. Improving the wear resistance of steels by heat treatment with preliminary preparation of the structure // Vestnik mashinostroeniya. (Bulletin of Mechanical Engineering) Moscow, 2018. no. 9. pp. 57-59.
[17]. Berdiev D.M., Yusupov A.A. Improving the wear resistance of gear teeth by cyclic quenching with Inductive Heating // Russian Engineering Research. 2020. V. 40. no. 6. pp. 473-475.
[18]. Berdiev D.M., Umarova M.A., Toshmatov R.K. Phase and structural transformations of structural steels in nontraditional heat treatment // Russian Engineering Research. 2021. Vol. 41, no. 1, pp. 46-48