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DETERMINATION OF THE INFLUENCE OF METASTABLE AUSTENITE IN THE SURFACE LAYER ON THE ABRASIVE WEAR RESISTANCE OF IRON-BASED ALLOYS

Purpose. *To consider and summarize the research results that show the influence of metastable austenite on the surface layer of steels in order to increase abrasive wear resistance. To demonstrate that in a number of cases, to enhance the specified characteristics in the structure of the surface layer of alloys, it is necessary to obtain metastable residual austenite alongside other components through various treatments. To present data showing that a self-hardening effect can be achieved under load, resulting in the formation of a renewable martensitic high-strength layer that provides protection against destruction. To present new data on the advantages of a differentiated approach to selecting the structure considering specific testing conditions or operational properties. Regarding these, it is necessary to optimize the quantity and stability of austenite in relation to the deformation martensitic transformation (DMT).*

Research methods. *Cemented steels 20Х, 18ХГ, 12Х13, 12ХН3А, and 12Х2Н4А, У8, ШХ15 were tested for abrasive wear resistance on the Х4Б installation. Abrasive wear tests were conducted on a setup designed according to the Brinell-Haworth scheme. The microstructure was studied on microsections prepared according to the generally accepted polishing and etching methodology. Metallographic and durometric studies were conducted. Cementation was carried out in a solid carburizer with additives that prevented surface oxidation.*

Results. *It has been established that to enhance the operational properties of cemented steels, it is necessary to utilize the self-hardening effect under load. It has been determined that the ambiguous assessments of the influence of residual austenite on the properties of cemented steels are due to the fact that the loading conditions, the amount, and the stability of austenite, which must be optimal for each specific case, are often not taken into account. It has been shown that in some cases it is advisable to ensure the formation of a large amount of metastable austenite after high-temperature treatment, and then, through deformation or (and) heat treatments, as well as other influences, to induce its partial transformation into martensite.*

Scientific novelty. *The work presents an alternative viewpoint, according to which, under dynamic loads, diffusion-alloyed steels should create a metastable austenite sublayer by means of the diffusion layer's absorption. To obtain wear-resistant thermodiffusion layers of significant thickness, it is advisable to create a structure of white chromium-manganese cast irons with metastable austenite. The effective use of concentrated energy sources for strengthening cemented steels ensures high surface hardness and the necessary amount of metastable austenite in the structure. Furthermore, this allows the creation of a discrete structure that alternates in a specified sequence between hard and soft components, significantly enhancing wear resistance.*

Practical value. *Increasing the mechanical properties of steels allows for greater operational stability of machine parts, which is an important task in materials science. One of the directions for solving this issue is to obtain a multiphase structure in steels, one component of which is metastable austenite, where dynamic deformation martensitic transformation (DDMT) occurs under load, resulting in the self-hardening effect under load (SHE). Methods for obtaining a surface layer structure of iron-based alloys, along with other components of metastable residual austenite, to enhance wear resistance under abrasive impact are easily implementable in production conditions. A differentiated approach to selecting the structure, taking into account specific testing or operational conditions, is necessary.*

Key words: *metastable austenite, self-hardening effect under load, dynamic deformation martensitic transformation (DDMT), cementation, strengthening.*

Introduction

Cementation and subsequent heat treatment are widely used in industry to increase the hardness, wear resistance, contact endurance, and other properties of steels. It is generally accepted that the surface layer of cemented steels should have a structure of tempered high-carbon martensite and carbides. The amount of residual austenite should not exceed 10–15 %. At some plants, a higher amount of austenite is considered a sign of defect. To reduce or completely eliminate the residual austenite in the structure, various methods are used: subcooling during quenching from cementation heating, cold treatment, intermediate high tempering followed by quenching from the

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intercritical temperature range, and others [1]. Meanwhile, there are known works [2–14] that demonstrate the positive influence of residual austenite obtained in the surface layer and the effect of self-hardening under load (SHUL) on wear resistance and fatigue strength. However, these works are few, and until now, in educational literature and practice, residual austenite is considered an undesirable structure. This is a consequence of the insufficient study of the conditions under which residual austenite is beneficial. In this regard, there is an interest in summarizing the research results on this issue, which is the focus of this work.

Analysis of research and publications

Let's first consider the influence of residual austenite on abrasive wear resistance. The study [2] shows that during tests of cemented steels 20Х, 18ХГ, 12Х13, 12ХН3А, and 12Х2Н4А on the Х4Б installation, abrasive wear resistance increases with the increase in the content of residual austenite to levels that reduce hardness by almost 2 times. A pattern is observed, explained by the fact that during the impact of abrasive particles, austenite transforms into thermodynamically more stable martensite. At this point, the carbon remains in solid solution, determining its increased resistance to destruction. It has been established [3] that in cemented steel 20Х, hardened from an elevated temperature (1080 °C), when approximately 3 7% of austenite transforms into martensite under abrasive impact, wear resistance is at a high level. It differs little from the level in high-alloy steel Х12Ф1, which has a martensitic-carbide structure after heat treatment. The influence of residual austenite on the abrasive wear resistance of steels 18ХГ and 12ХН3А was studied in [4]. It was shown that the highest wear resistance is achieved when the surface layer structure is predominantly austenitic (80 %). This is achieved by hardening from the carburizing heating without cooling, as well as from reheating at 1000 °C (tempering at 180 °C for 1 hour). In this case, the increase in deformation martensite on the worn surface is the largest (40 %). Based on the obtained data, it was concluded that to increase the resistance to abrasive wear of cemented steels, heat treatment should not be aimed at achieving high hardness, which is provided by a martensitic-carbide structure, but at realizing the self-hardening effect under load due to the formation of metastable austenite and abrasive particles in the surface layer. Depending on the loading conditions, austenite can be obtained alongside martensite and carbides [5]. The necessary amount of metastable austenite alongside martensite and carbides, ensuring high wear resistance can be achieved in low-carbon high-chromium stainless steels through surface carburizing and subsequent heat treatment. This is demonstrated on steel 12Х13 [6].

The purpose of the work

Consider and summarize the results of studies that show the influence of metastable austenite on the surface layer of steels in order to enhance abrasive wear resistance. It should be demonstrated that in a number of cases, to improve the specified characteristics in the structure of the surface layer of alloys, metastable residual austenite should be obtained alongside with other components through various treatments. Provide data showing that a self-hardening effect can be achieved under load, resulting in the formation of a renewable martensitic high-strength layer that provides protection against destruction. Present new data on the advantages of a differentiated approach to selecting the structure, taking into account specific testing conditions or operational properties. In relation to them, the quantity and stability of austenite should be optimized concerning the deformation martensitic transformation (DMT).

Materials and research methodology

Cemented steels 20Х, 18ХГ, 12Х13, 12ХН3А, and 12Х2Н4А, У8, ШХ15 were tested for abrasive wear resistance on the Х4Б installation. Tests for abrasive wear were conducted on a setup designed according to the Brinell-Hauworth scheme. The scheme of the testing installation is shown in Fig. 1.

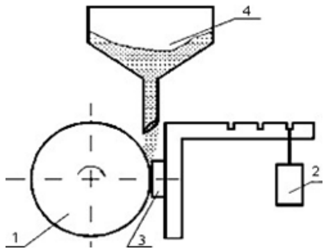

Figure 1. Scheme of abrasive wear testing:

1 – roller; 2 – weight; 3 – sample; 4 – hopper with abrasive

The rubber disk (1), which rotates, presses the sample (3) sized 25×10×10 mm with the weight (2). Through a funnel with a calibrated opening from the hopper (4), the abrasive (sea sand) is fed, which is captured by the rubber disk and drawn across the surface of the sample, causing its wear. A sample made of steel 45 (hardness HV220) was used as a reference. The tests were conducted for 30 minutes (with weighing the samples every 5 minutes of wear).

Tests for impact-abrasive wear were conducted according to the scheme presented in Fig. 2.

The samples were fixed on a disk that rotated at a speed of 1350 rpm. Impact-abrasive wear of the surface of the samples occurred due to collisions with particles of cast iron shot (0.8 mm) that fall freely. The samples were weighed with an accuracy of up to 0.01 g. Wear (I) was evaluated by the weight loss relative to the area of the samples using the equation: $I = P/S$, where P is the weight loss, kg; S is the area of the sample, m². The relative wear resistance (ε) was determined as the ratio of the indicators of the sample (I_sample) to the reference (I_reference) using the equation: $\varepsilon = I\_sample / I\_reference$.

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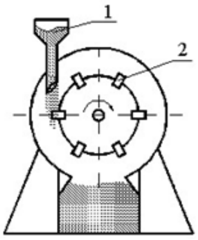

Figure 2. Scheme of impact-abrasive wear tests:
1 – hopper with shot; 2 – samples

Hardness was determined by the Rockwell method according to DST 9013-59 (indentation with a diamond pyramid under a load of 1500 N). Hardness was defined as the average of three measurements.

The microstructure was studied on microsections, which were made according to the generally accepted polishing and etching methodology.

Metallographic studies were conducted using an optical microscope "Neophot-21" and an electron microscope "JEM-100CX-11" (by the method of transmission of thin foil).

To determine the phase composition, an X-ray diffractometer DRON-4 was used.

Cementation was carried out in a solid carburizer with additives that prevented surface oxidation. The cementation temperature was 930 °C, and the depth of the carbon layer was 0.7 mm.

Diffusion chromizing was carried out by a gas contact method in a powder mixture of ferrochrome, aluminum oxide, and ammonium chloride at a temperature of 1050° C for 10 hours. The chromized samples were heated in the range of 850–1000 °C and held for 20 to 240 minutes. Metallographic and durometric studies showed that there is a certain heating regime for diffusion-chromized steels before hardening, which allows obtaining a white sublayer that is not etched and has a microhardness of H100 > 9000 MPa.

Research results

A promising direction is the development of methods for strengthening cemented (nitrocemented) steels, in which, unlike those traditionally used in industry, it is proposed to obtain a certain amount of metastable austenite in the structure of the surface layer and its subsequent transformation into martensite under load during the wear process [14–19]. According to the method [18], alloyed steels are subjected to nitrocementation to obtain an austenitic structure in the surface layer, after which strengthening is carried out using means of strain hardening or dispersion hardening. As a result, high hardness of 60–62 HRC is achieved without the use of quenching, which eliminates warping of the parts. At the same time, favorable compressive stresses are created. However, this work does not consider the possibility of using the deformation martensitic transformation of austenite under subsequent loading during the wear process. This is implemented in a method that includes conducting thermochemical treatment, plastic deformation (δ) with a degree of 40 % at elevated temperatures to obtain metastable austenite in the structure. It is proposed [20] that after obtaining a large amount of metastable austenite, a deformation or thermal effect should be applied in such a way that, along with strengthening the austenite and transitioning part of it into martensite, it would be preserved in the structure to a certain amount. This ensures the occurrence of DDMT during the loading in the operation of parts and tools, and, accordingly, increases their durability. The amount and degree of stability of the austenite remaining after processing must be regulated concerning specific operating conditions. It is proposed [16] to obtain a differentiated (discrete) structure in the surface layer of cemented steels with alternating martensitic and austenitic areas. This can be implemented by quenching with laser, electron beams, or plasma jets in specified local areas. This ensures a regular alternation of areas of high and low hardness.

Usually, the microstructure of the surface after cementation consists of pearlite and carbides, while the core consists of martensite and ferrite. After quenching from 900 °C and low tempering (200 °C), the surface structure contains tempered martensite, carbides, and a small amount of residual austenite. As the heating temperature during quenching increases to 1000–1100 °C, the hardness of the cemented surface decreases due to the complete dissolution of carbides in austenite and an increase of the amount of residual austenite (table 1).

Table 1 – The influence of heating temperature during hardening on the hardness and amount of residual austenite in the surface layer structure of carburized steel 12X13

Temperature, °C	Hardness, HRC	$\gamma_{residual}$, %
900	59,3	12
1000	49,0	17
1100	45,0	25

A similar effect is achieved by conducting local chemical-thermal treatment and hardening. The macro-heterogeneous structure significantly increases resistance to destruction during operation, as softer areas with increased toughness prevent chipping due to the propagation of cracks that originate in regions of high hardness. Furthermore, the Sharpy principle can be realized, as the premature wear of local areas of low hardness-forming "pockets"-allows for better retention of lubrication and, consequently, greater durability of the components. The effect of such treatment is also due to a significant increase in microhardness from 6000–6500 MPa (after conventional heat treatment) to 8000–12300 MPa (after the application of laser and electron beam treatments), as well as the formation of metastable austenite, which undergoes DMT under load during operation. The authors of the work [20] showed that in the case of obtaining a predominantly austenitic

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structure, laser and electron beam treatments under certain conditions cause the formation of martensite in the affected zone, which is due to the high levels of stress that arise. This allows for the management of the ratio of martensite to austenite in the structure of steels subjected to preliminary chemical-thermal treatment. Maximum wear resistance and contact fatigue occur when a concentrated heat source achieves 50–60 % residual austenite in the surface layer of steels and cast iron.

The increase in heating temperature during the hardening of cemented steel 12X13 from 900 to 1100 °C, despite a decrease in hardness, results in an increase in abrasive wear resistance by 1.5 times compared to the level achieved after hardening at 900 °C. This is due to DMT and dynamic aging. When determining the resistance to destruction under impact-abrasive wear, a different pattern is observed. Wear resistance changes according to a curve with a maximum at 1000 °C. The lowest level is observed in steel after hardening from 900 °C, when the structure of the surface layer is predominantly martensitic-carbide. This is due to the formation of microcracks in high-carbon martensite, which has increased brittleness. After hardening from 1000 °C, the wear resistance of cemented steel 12X13 increases by 1.35 times compared to the level achieved after hardening from 900 °C. Hardening from 1100°C already reduces wear resistance due to excessive stability and, accordingly, less development of DMT. The presented data confirm the position that it is possible to significantly enhance the properties of alloys by achieving optimal amounts and stability of austenite in the structure for specific loading conditions.

Obtaining austenite alongside with martensite in the surface layer and increasing resistance to dynamic loads is facilitated by the heat treatment of diffusion-chromated high-carbon steels, as a result of which there is a “dissolution” of the external carbide layer [10]. This has been demonstrated on steels У8 and ШХ15. For each heating temperature during hardening in the studied range, there is an optimal holding time that ensures the greatest strengthening of the sublayer and its magnitude. Figure 1 shows the microstructure of steel У8, in which the sublayer has been obtained.

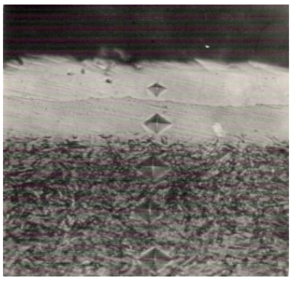

Figure 3. Microstructure of diffusion-chromized steel У8 after “dissolution” at 900 °C, 2 hours; ×500

The lowest of the studied tempering temperatures that allow for the necessary microhardness of the sublayer with acceptable holding time (1.5–2 hours) is 900 °C. At lower temperatures, it is not possible to obtain a solid sublayer in which no etching occurs within the specified time (1.5–2 hours), and at higher temperatures, the microhardness is not achieved. After hardening at 1000°C and low tempering, the microhardness of the sublayer is H = 6200–6500 MPa. At the same time, the grain of the base metal increases significantly. The highest level of resistance of the studied steels to impact and high contact loads is provided by diffusion chromizing at 900–920 °C with a holding time of 1.5–2 hours, followed by cooling to 800-820°C, hardening, and low tempering. The amount of residual austenite in the sublayer is 17–20 %. In this case, the wear resistance of diffusion-chromized steels increases by 1.5–2.0 times compared to the wear resistance obtained after conventional hardening and low tempering. The effectiveness of the proposed method was confirmed by operational tests of diffusion-chromized wedges in the binding systems of machines.

The method of strengthening discussed above can be applied when the permissible wear is relatively small (hundredths or tenths of a millimeter), which corresponds to the total thickness of the layer and sublayer obtained through diffusion chromizing and heat treatment. Moreover, the process of saturating the surface with chromium is lengthy, as it occurs in the solid phase – austenite. In this regard, [10] proposed and implemented a technology for obtaining thick diffusion layers, the structure of which corresponds to that of alloyed white cast irons. The basis of the technology is the principle that a shell of liquid phase is created on the surface of the treated part, in which the diffusion of alloying elements occurs, coming from a saturated medium. The liquid phase itself, enriched with the necessary elements, becomes a coating after crystallization. Since the diffusion process in the liquid phase occurs at a high speed, it is possible to alloy a layer several times thicker in a relatively short time than with the conventional saturation technology. To create a shell of liquid phase on the surface of the treated part, a metal or alloy containing the necessary components for the coating and having a lower melting point than the part and the saturating mixture is used. The temperature of diffusion alloying should be higher than the melting point of the low-melting alloy while keeping the part in a solid state. Numerous variants of the proposed technology can be implemented, as various heating methods, application of low-melting alloys, and different compositions of their saturating media are applicable. One of the simple methods for creating multi-component thermodiffusion layers of large thickness is the gas contact method using a saturating mixture containing ferroalloys, an inert additive, and a halide. Authors [21] studied the production of coatings from the a Fe-Cr-Mn-C system. The liquid phase during the process temperature was created by melting the filler elements placed on the surface of the steel sample. The filler elements were made from cast iron with a composition close to eutectic in the form of plates with a

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diameter of 25 mm and a thickness of 4 mm. They were placed on the surface of the samples being strengthened, which were made of steel 45, and placed in a container with the saturating mixture. This container was sealed and placed in a furnace heated to 950–1000 °C. Then the temperature was raised to 1250–1280 °C and held for 0.5–1.5 hours. As a result of this treatment, wear-resistant chromium-manganese cast irons of various chemical compositions were obtained in the surface layer. The most successful were the diffusion coatings of the following composition: 2.5 %C, 12–15 % Cr, 4–7 % Mn. They had an austenitic-martensitic-carbide structure after heat treatment, which provided the highest abrasive wear resistance. These data became the basis for further development of chromium-manganese cast irons and filler materials with a similar structure [21]. The presented data demonstrate the great potential for obtaining surface layers through chemical-thermal and subsequent thermal treatment of multi-phase structures with metastable austenite.

Conclusions

It has been established that to enhance the operational properties of cemented steels, it is necessary to utilize the self-hardening effect under load. For this purpose, austenite capable of transforming into martensite under load should be obtained in the structure of the surface layer. The amount of austenite, the degree of its strengthening, and stability should be regulated by processing concerning specific loading conditions, taking into account the initial chemical and phase compositions of the steels obtained after heat treatment.

It has been determined that the ambiguous assessments of the influence of residual austenite on the properties of cemented steels are due to the fact that the loading conditions, the amount, and the stability of austenite, which must be optimal for each specific case, are often not taken into account.

It has been shown that in a number of cases, it is advisable to ensure the formation of a large amount of metastable austenite after heat treatment, and then, through deformation or (and) heat treatments, as well as other influences, to induce its partial transformation into martensite. At the same time, it is necessary to implement dynamic deformation martensitic transformation, which significantly enhances the service properties of the surface layer.

Under dynamic loads, diffusion-alloyed steels should create a substrate with metastable austenite due to the absorption of the diffusion layer.

To obtain wear-resistant thermodiffusion layers of significant thickness, it is advisable to create a structure of white chromium-manganese cast iron with metastable austenite.

The effective use of concentrated energy sources for strengthening cemented steels ensures high surface hardness and the necessary amount of metastable austenite in the structure. Moreover, this allows the creation of a discrete structure that alternates hard and soft components in a specified sequence, significantly enhancing wear resistance.

References

1. Dyachenko, S. S.,Doshchechkina, G. V., Movlyan, A. A., & Pleshakov,E. I. (2007). Material science (440). Khnadu Publishing House.

2. Malinov, L. S., Malinova, E. L., & Kharlanova, E. Ya. (1993). Increasing the abrasive wear resistance of cemented steels 18KHGT and 12KHN3A due to the production of metastable austenite. Metals, (2), 108–111.

3. Malinov, L.S., Malinov, V.L., Malysheva, I., & Burova, D.V. (2022). Principle Universality of Obtaining Metastable Austenite in the Alloy and Cast Iron Structure to Increase the Abrasive Wear Resistance. Journal of Friction and Wear, 43, 185–190. DOI: https://doi.org/10.3103/s1068366622030102

4. Malysheva, I. E. (2004). Increasing the abrasive and impact-abrasive wear resistance of steels and cast iron due to metastable austenite. Abstract of Candidate of Technical Sciences dissertation, Specialty 05.16.01 (19). Priazovskyi State Technical University.

5. Wang, W., Song, R., Peng, S., & Pei, Z. (2016). Multiphase steel with improved impact-abrasive wear resistance in comparison with conventional Hadfield steel. Materials & Design, 105, 96–105. DOI: https://doi.org/10.1016/J.MATDES.2016.05.056

6. Siepak, J. (1982). The influence of contact stress on the wear of a carburized steel case with a high content of retained austenite. Wear, 80, 301-305. DOI: https://doi.org/10.1016/0043-1648(82)90258-7

7. Efremenko, V.G., Zurnadzhi, V.I., Chabak, Y.G., Tsvetkova, O.V., & Dzherenova, A.V. (2017). Application of the Q-n-P-Treatment for Increasing the Wear Resistance of Low-Alloy Steel with 0.75% C. Materials Science, 53, 67-75. DOI: https://doi.org/10.1007/s11003-017-0045-3

8. Efremenko, V.G., Shimizu, K., Noguchi, T., Efremenko, A.V., & Chabak, Y.G. (2013). Impact–abrasive-corrosion wear of Fe-based alloys: Influence of microstructure and chemical composition upon wear resistance. Wear, 305, 155–165. DOI: https://doi.org/10.1016/J.WEAR.2013.06.006

9. Efremenko, V.G., Hesse, O., Friedrich, T., Kunert, M., Brykov, M.N., Shimizu, K., Zurnadzhy, V., & Suchmann, P. (2019). Two-body abrasion resistance of high-carbon high-silicon steel: Metastable austenite vs nanostructured bainite. Wear. 418–419, 24–35. DOI: https://doi.org/10.1016/J.WEAR.2018.11.003

10. Malinov, L. S.,& Malinov,V. L. (2009). Resource-saving economically alloyed alloys and hardening technologies that ensure the effect of self-hardening (568). Renata Publishing House.

11. Malinov, L.S., Malysheva, I., Klimov, E., Kukhar, V.V., & Balalayeva, E.Y. (2019). Effect of Particular

DOI 10.15588/1607-3274-2026-1-5

Combinations of Quenching, Tempering and Carburization on Abrasive Wear of Low-Carbon Manganese Steels with Metastable Austenite. Materials Science Forum, 945, 574–578. DOI: https://doi.org/10.4028/www.scientific.net/msf.945.574

12. Cheiliakh, Ya. A., Cheiliakh, A. P.,Shimmitsu, K.,& Noguchi, T. (2013). The use of chemical and thermal treatment to create metastable modifications that realize the effect of self-hardening during steel wear. Bulletin of the Azov State Technical University. Series: Technical Sciences, (27), 98–110.

13. Cheiliakh, A. P., Cheylyakh, Y. A., & Samotugina, Y. S. (2016). Strengthening technologies of materials treatment (337). KU Leuven.

14. Cheiliakh, O. P., Cheiliakh, Y. A., Karavaieva, N. E. et al. (2014). Development of innovative ways of surface hardening by means of creation of wear-resistant layers with metastable structure, strengthening at wear (part 1). Tratamientos Térmicos (Heat Treatment of Metals), (143), 35–36.

15. Cheiliakh, O. P., Cheiliakh, Y. A., Karavaieva, N. E., et al. (2014). Development of innovative ways of surface hardening by means of creation of wear-resistant layers with metastable structure, strengthening at wear (part 2). Tratamientos Térmicos (Heat Treatment of Metals), (144), 25–66.

16. Malinov, L.S. (1997). Obtaining a macroscopically nonuniform regular structure in steel by methods of differential treatment. Metal Science and Heat Treatment, 39, 139-143. DOI: https://doi.org/10.1007/BF02469067

17. Cheylyakh, Y., Cheiliakh, O.P., Mak-Mak, N.E., & Kazumichi, S. (2016). Effect of rising wear-resistance by plasma treatment of carburized structural steel. Vestnik of Nosov Magnitogorsk State Technical University, 14(2), 76–82. DOI: https://doi.org/10.18503/1995-2732-2016-14-2-76-82

18. Malinov, L.S., Malinov, V.L., & Burova, D.V. (2018). Impact of Metastable Austenite on the Wear Resistance of Tool Steel. Journal of Friction and Wear, 39, 349-353. DOI: https://doi.org/10.3103/S1068366618040098

19. Mak-Mak, N. E. (2019). Creation of metastable states and strengthening of structural steels by thermal and chemical-thermal treatment (24). Abstract of Candidate of Technical Sciences dissertation, Specialty 05.16.01. Priazovskyi State Technical University.

20. Malinov, L. S., & Malysheva, I. E. (2019). Abrasive wear resistance of alloys with metastable austenite (217). Priazovskyi State Technical University.

21. Malinov, L.S., Malinov, V.L., Burova, D.V., & Anichenkov, V.V. (2015). Increasing the abrasive wear resistance of low-alloy steel by obtaining residual metastable austenite in the structure. Journal of Friction and Wear, 36, 237–240. DOI: https://doi.org/10.3103/S1068366615030083

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ВИЗНАЧЕННЯ ВПЛИВУ МЕТАСТАБІЛЬНОГО АУСТЕНІТУ В ПОВЕРХНЕВОМУ ШАРІ НА АБРАЗИВНУ ЗНОСОСТІЙКІСТЬ СПЛАВІВ НА ОСНОВІ ЗАЛІЗА

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Мета роботи. *Розглянути і узагальнити результати досліджень, які показують вплив метастабільного аустеніту на поверхневий шар сталей для того, щоб підвищіти абразивну зносостійкость. Показати, що в ряді випадків для підвищення зазначених характеристик у структурі поверхневого шару сплавів слід за рахунок різних обробок отримувати поряд з іншими складовими метастабільний залишковий аустеніт. Привести дані, які показують, що можна отримати ефект самозагартування при навантаженні, в результаті зовнішнього впливу відбувається утворення поновлюваного мартенситного високоміцного шару, що забезпечує захист від руйнування. Представити нові данні о перевагах диференційованого підходу до вибору структури з урахуванням конкретних умов випробувань властивостей чи експлуатації. Стосовно них слід оптимізувати кількість та стабільність аустеніту по відношенню до деформаційного мартенситного перетворення (ДМП).*

Методи дослідження. *Цементовані сталі 20Х, 18ХГ, 12Х13, 12ХН3А, та 12Х2Н4А, У8, ШХ15 випробовували на абразивну зносостійкість на установці Х4Б. Випробування на абразивне зношування проводили на установці, яку сконструювали за схемою Брінеля-Хауорта. Мікроструктуру вивчали на мікрошліфах, які виготовляли по загальноприйнятій методиці полірування і травлення. Були проведені металографічні та дюрометрічні дослідження. Цементацію проводили у твердому карбюризаторі з добавками, що запобігали окисленню поверхні.*

Отримані результати. *Встановлено, що для підвищення експлуатаційних властивостей цементованих сталей необхідно використовувати ефект самозагартування при навантаженні. Визначено, що неоднозначні*

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оцінки впливу залишкового аустеніту на властивості цементованих сталей обумовлені тим, що часто не враховуються умови навантаження, кількість та стабільність аустеніту, які мають бути оптимальними для кожного конкретного випадку. Було показано, що доцільно в ряді випадків забезпечити отримання після ХТО великої кількості метастабільного аустеніту, а потім за допомогою деформації або (і) термообробок, а також інших впливів викликати його часткове перетворення на мартенсит.

Наукова новизна. *У роботі розглядається альтернативна точка зору, згідно з якою при динамічних навантаженнях дифузійнолегованих сталей слід створювати за рахунок розсмоктування дифузійного шару підшар із метастабільним аустеніт. Для отримання зносостійких термодифузійних шарів великої товщини доцільно створювати структуру білих хромомарганцевих чавунів із метастабільним аустенітом. Ефективне для зміцнення цементованих сталей використання джерел концентрованої енергії, що забезпечує високу твердість поверхні та отримання необхідної кількості метастабільного аустеніту у структурі. Крім того, це дозволяє створювати дискретну структуру, що є чергуванням в заданій послідовності твердих і м'яких складових і істотно підвищити зносостійкість.*

Практична цінність. *Підвищення механічних властивостей сталей дозволяє збільшити експлуатаційну стійкість деталей машин, що є важливою задачею матеріалознавства. Одним із напрямків її вирішення є отримання в сталях багатофазної структури, однією зі складових якої є метастабільний аустеніт, в якому відбувається при навантаженні динамічне деформаційне мартенситне перетворення (ДДМП) ефект само гартування при навантаженні (СГН). Способи отримання в структурі поверхневого шару сплавів на залізній основі поряд з іншими складовими метастабільного залишкового аустеніту для підвищення зносостійкості при абразивному впливі легко реалізуються в умовах виробництва. Необхідно використати диференційований підхід до вибору структури з урахуванням конкретних умов випробувань властивостей чи експлуатації.*

Ключові слова: *метастабільний аустеніт, ефект самозагартування при навантаженні, динамічне деформаційне мартенситне перетворення (ДДМП), цементація, зміцнення.*

Список літератури

1. Матеріалознавство / С.С. Дьяченко, Г.В. Дощечкіна, А.О. Мовлян, Е.І. Плешаков. – Харьків : Видавництво ХНАДУ, 2007. – 440 с.

2. Малінов Л. С. Підвищення абразивної зносостікості цементованих сталей 18ХГТ і 12ХН3А за рахунок отримання метастабільного аустеніта / Л. С. Малінов, Е.Л. Малінова, Е.Я. Харланова // Метали. – 1993. – № 2. – С. 108–111.

3. Principle Universality of Obtaining Metastable Austenite in the Alloy and Cast Iron Structure to Increase the Abrasive Wear Resistance / L. S. Malinov, V. L. Malinov, I. E. Malysheva, D. V. Burova // Journal of Friction and Wear. – 2022. – Vol. 43, No. 3. – P. 185-190. – DOI: https://doi.org/10.3103/s1068366622030102

4. Малишева І. Є. Підвищення абразивної і ударно-абразивної зносостійкості сталей і чавунів за рахунок метастабільного : автореф. дис. на здобуття наук. ступеня канд. техн. наук : спец. 05.16.01 / Малишева Інна Юхимівна; Приазов. держ. техн. ун-т Маріуполь, 2004. – 19 с.

5. Multiphase steel with improved impact-abrasive wear resistance in comparison with conventional Hadfield steel / W. Wang, R. Song, S. Peng, Z. Pei // Materials & Design. – 2016. – Vol. 105. – P. 96–105. – DOI: https://doi.org/10.1016/j.matdes.2016.05.056

6. Siepak, J. The influence of contact stress on the wear of a carburized steel case with a high content of retained austenite / J. Siepak // Wear. – 1982. – Vol. 80, No. 3. – P. 301–305. – DOI: https://doi.org/10.1016/0043-1648(82)90258-7

7. Application of the Q-n-P-Treatment for Increasing the Wear Resistance of Low-Alloy Steel with 0.75% C / V. G. Efremenko, V. I. Zurnadzhi, Y. G. Chabak et al. // Materials Science. –2017. –Vol. 53. – № 1. – P.1-9. – DOI: https://doi.org/10.1007/s11003-017-0053-3

8. Impact-abrasive-corrosion wear of Fe-based alloys: Influence of microstructure and chemical composition upon wear resistance / V. G. Efremenko, A. V. Efremenko, Y. G. Chabak et al. // Wear. – 2013. – Vol. 305, No. 1–2. – P. 155–165. – DOI: https://doi.org/10.1016/j.wear.2013.06.006

9. Two-body abrasion resistance of high-carbon high-silicon steel: Metastable austenite vs nanostructured bainite / V. G. Efremenko, V. I. Zurnadzhy, O. Hesse et al. // Wear. – 2019. – Vol. 418–419. – P. 24–35. – DOI: https://doi.org/10.1016/j.wear.2018.11.003

10. Малінов Л. С. Ресурсосберігаючі економнолеговані сплави та зміцнюючі технології, які забезпечують ефект самозагартування/ Л. С. Малінов, В. Л. Малінов. – Маріуполь : Вид-во «Рената», 2009. – 568 с.

11. Effect of particular combinations of quenching, tempering and carburization on abrasive wear of low-carbon manganese steels with Metastable austenite / L. S. Malinov, I. E. Malysheva, V. V. Kukhar et al. // Materials Science Forum. 2019. – Vol. 945. – P. 574–578. – DOI: https://doi.org/10.4028/www.scientific.net/MSF.945.574

12. Використання хіміко-термічної обробки для створення метастабільних модифікацій, які реалізують ефект самозміцнення при зношуванні сталі / Я. А. Чейлях, А. П. Чейлях, К. Шиміцу, Т. Ногучи // Вестник Приазовского державного технічного університета. Серія: Технічні науки. – 2013. – № 27. – С. 98–110.

DOI 10.15588/1607-3274-2026-1-5

13. Cheiliakh A.P. Strengthening technologies of materials treatment / A. P. Cheiliakh, Y. A. Cheylyakh, Yu. S. Samotugina. – Leuven: KU Leuven (Belgium), 2016. – 337 p.

14. Development of innovative ways of surface hardening by means of creation of wear-resistant layers with metastable structure, strengthening at wear (part 1) / O.P. Cheiliakh, Y.A. Cheiliakh, N.E.Karavaieva et al. // Treatamientos Termicos (Heat Treatment of Metals). – Spain. – 2014. – № 143. – P. 35–36.

15. Development of innovative ways of surface hardening by means of creation of wear-resistant layers with metastable structure, strengthening at wear (part 2) / O.P. Cheiliakh, Y.A. Cheiliakh, N.E. Karavaieva [et al.] // Treatamientos Termicos (Heat Treatment of Metals). – Spain. – 2014. – № 144. – P. 25–26.

16. Malinov, L. S. Obtaining a macroscopically nonuniform regular structure in steel by methods of differential treatment / L. S. Malinov // Metal Science and Heat Treatment. – 1997. – Vol. 39, No. 3–4. – P. 139–143. – DOI: https://doi.org/10.1007/bf02469067

17. Effect of increased wear-resistance by the plasma treatment of carbonized structural steel / Y.A. Cheylyakh, O.P. Cheiliakh, N.E. Mak-Mak, Sh. Kazumichi // Vestnik of Nosov Magnitogorsk State Technical University. – 2016. – Vol. 14. – № 2. – P. 76–82. DOI: https://doi.org/10.18503/1995-2732-2016-14-2-76-82

18. Malinov, L. S. Impact of Metastable Austenite on the Wear Resistance of Tool Steel / L. S. Malinov, V. L. Malinov, D. V. Burova // Journal of Friction and Wear. 2018. – Vol. 39 (4). – P. 349–353. DOI: https://doi.org/10.3103/S1068366618040098

19. Мак-Мак Н. Є. Створення метастабільних станів та зміцнення конструкційних сталей способами термічної та хіміко-термічної обробки : автореф. дис. на здобуття наук. ступеня канд. техн. наук : спец. 05.16.01 /Мак-Мак Н. Є. – Маріуполь, 2019. – 24 с.

20. Малінов Л. С. Абразивна зносостійкість сплавів з метастабільним аустенітом / Малінов Л. С., Малишева И. Е. – Маріуполь : ПДТУ, 2019. – 217 с.

21. Increasing the abrasive wear resistance of low-alloy steel by obtaining residual metastable austenite in the structure / L. S. Malinov, V. L. Malinov, D. V. Burova, V. V. Anichenkov // Journal of Friction and Wear. – 2015. – Vol. 36, No. 3. – P. 237–240. – DOI: https://doi.org/10.3103/S1068366615030083

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DOI 10.15588/1607-3274-2026-1-5