DOI: 10.25140/2411-5363-2023-2(32)-78-82
UDC 621.7

Borys Sereda[1], Iryna Kruglyak[2], Dmytro Sereda[3]

[1]Doctor of Technical Sciences, Professor, Head of the Department Of Automobiles and Automobile Industry
Dnipro State Technical University (Kamyanske, Ukraine)
E-mail: seredabp@ukr.net. **ORCID:** https://orcid.org/0000-0002-9518-381X

[2]Doctor of Technical Sciences, Associate Professor, Head of the Department of Mechanical Engineering
Dnipro State Technical University (Kamyanske, Ukraine)
E-mail: kruglyak1964@gmail.com. **ORCID:** https://orcid.org/0000-0001-8872-6778

[3]PhD in Technical Sciences, Associate Professor of the Department of Mechanical Engineering
Dnipro State Technical University (Kamyanske, Ukraine)
E-mail: etohardcore@gmail.com **ORCID:** https://orcid.org/0000-0003-4353-1365

INCREASING THE RELIABILITY OF MECHANISMS OF METALLURGICAL EQUIPMENT THAT USES SHS RESOURCE-SAVING TECHNOLOGY

In the course of the study, the use of advanced resource-saving technologies in the field of mechanical engineering, focused on the optimization of metallurgical production, was analyzed in detail. The main emphasis was placed on the study of complex saturating media, proposed as a means to improve the reliability of the operation of mechanical equipment. Representing an innovative approach, the study proposes the appropriate application of methods for surface hardening of machine parts using modern technologies under dynamically changing temperature conditions typical for metallurgical processes. Statistical data and experimental results confirm the effectiveness of the proposed technological solutions, and also make it possible to identify the optimal parameters and conditions for their application. Based on the conducted studies, it can be argued that the use of resource-saving technologies in the metallurgical industry contributes to a significant reduction in energy costs and a reduction in the time of production processes. This is of fundamental importance for improving the efficiency and competitiveness of industrial enterprises, contributing to the overall stability and sustainability of the industry, as well as to environmental protection. In addition to optimizing production processes, resource-saving technologies also make a significant contribution to improving the economic efficiency of enterprises. Reducing energy costs and improving equipment reliability can reduce operating costs and improve overall business profitability.

Keywords: *industry engineering; resource-saving technologies; strengthening; complex saturating media; energy costs; production process.*

Fig.: 4. References: 12.

Relevance of the topic of research. In connection to the accelerated development of mechanical engineering for metallurgy, the issues of increasing the reliability and durability of machine parts, and, consequently, the issues of saving metals, energy costs, combating corrosion and wear of machine parts, have become extremely relevant. To reduce energy costs, it is necessary to use resource-saving technologies, especially for the manufacture of parts for metallurgy. The solution of these problems is associated with the hardening of the surface layers of parts for mechanical engineering [1]. Among the methods of surface hardening, siliconized coatings obtained by various methods are widely used. The technologies based on the phenomenon of self-propagating high-temperature synthesis using composite saturating charges are the least energy-intensive and also short-term effects on the surface of parts.

Problem statement. To improve the reliability of metallurgical equipment, it is necessary to strengthen the surface of machine parts. This is especially important in the working mechanisms of rolling conditions, namely, the details of the pressure mechanism. The objective of the study is to determine energy-efficient methods of surface strengthening, which can significantly reduce energy costs.

Analysis of recent research and publications. An analysis of literature sources [2–5] indicates that at present there are many methods for diffusion saturation of a steel surface with silicon. Common to them is the implementation of the saturation process at high temperatures, when the free energy of the system is large enough for diffusion to occur in the solid phase.

To obtain coatings based on silicon, the following methods are used: in a medium of molten electrolytes, in the gas phase, using powder masses in a neutral or reducing atmosphere [6–10].

Gas siliconizing is carried out in different ways: by continuously passing chlorine through the reaction space with parts and ferrosilicon; using hydrogen chloride instead of chlorine; in a mixture H_2+$SiCl_4$ or N_2+H_2+$SiCl_4$; in a mixture Ar+$SiCl_4$ or N_2+$SiCl_4$; in a mixture H_2+SiH_4 (monosilane), NH_3+SiH_4. Gas siliconizing of steels is carried out in hermetically sealed retorts, in which parts are placed, and they are covered with powder of ferrosilicon, carborundum, pure silicon or other substances containing silicon. Silicon containing gas $SiCl_4$, is formed as a result of the interaction of these substances with chlorine, which is fed into the retort in its pure form, mixed with hydrogen, or introduced in another way. When gaseous silicon chloride comes into contact with iron, free silicon is released, which diffuses into the workpiece [11]. The chemistry of the process lies in the fact that during the processing of samples $SiCl_4$ silicon enters the samples as a result of the exchange reaction, as well as the reduction of silicon tetrachloride with atomic hydrogen dissolved in iron.

Highlighting unexplored parts of a general problem. The preliminary studies of the technological processes of hardening of parts of metallurgical equipment indicate that they are characterized by a fairly long hardening time of 6–8 hours at temperatures of 900–1100 °C. This leads to significant energy costs, both electrical and thermal energy.

Formulation of the problem. The purpose of the work is a study of the use of resource-saving technology of surface hardening of equipment parts for industrial engineering in metallurgy.

Presentation of the main material. The formation of multicomponent siliconized coatings occurs under conditions of thermal self-ignition or combustion of powder media containing gas transport additives. The time-varying temperature, first due to external heating, and then due to ignition, leads to the fact that neither thermal nor chemical equilibrium is possible until the process is completed and the products cool. The rates of chemical processes are determined by kinetic laws that depend on both temperature and diffusion factors. However, assuming, at least at the heating stage, that the inhibition of the diffusion processes of the gas phase is small, and the rate of temperature change is small compared to the rate of gas-phase chemical reactions, we can assume that each temperature value corresponds to the equilibrium composition of the products.

Then, having calculated the equilibrium composition of the reaction products for a number of specific temperatures from the range of its change, one can follow the chemical picture of the development of the process.

The calculation of the equilibrium composition of the products was carried out for the initial mixture, consisting of M substances containing l - chemical elements. At fixed values of volume (V) and temperature (T), as a result of chemical reactions, m_k can be formed from these elements - substances present in $k = 0, 1…q$ different phases.

The existence of limiting temperatures, up to which the propagation of the combustion front is possible, introduces certain restrictions on the use of the combustion mode as a technological one. On the contrary, the regime of thermal self-ignition is free from these restrictions. By diluting the initial powder mixture with an inert substance, up to 85-90% wt., it is possible to reduce the maximum process temperature to the technologically required temperatures.

The main compounds in the gas phase in the temperature range 400–1600 K are: $SiCl$, $SiCl_2$, $SiCl_3$, $SiCl_4$, SiI_2, SiI_3, AlI, AlI_2, $AlCl$, $AlCl_2$, $CrCl_2$, CrF, CrF_2, CrF_4, BF_3, $TiCl_2$, $TiCl_3$, $TiCl_4$, WCl_2, WCl_3, WCl_4, and others, as well as iodine in atomic and molecular form (Fig. 1-2).

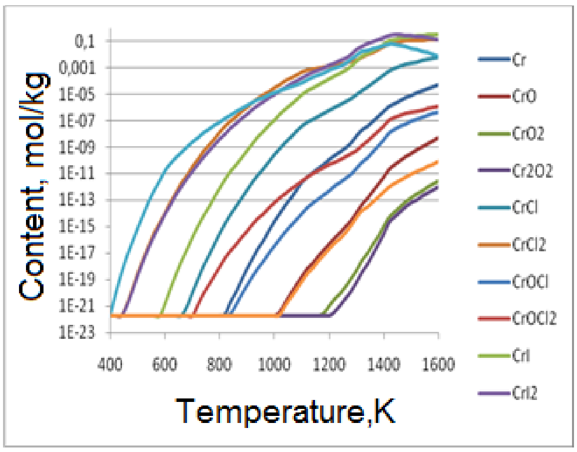

Fig. 1. Content of gaseous chromium compounds in SHS charge

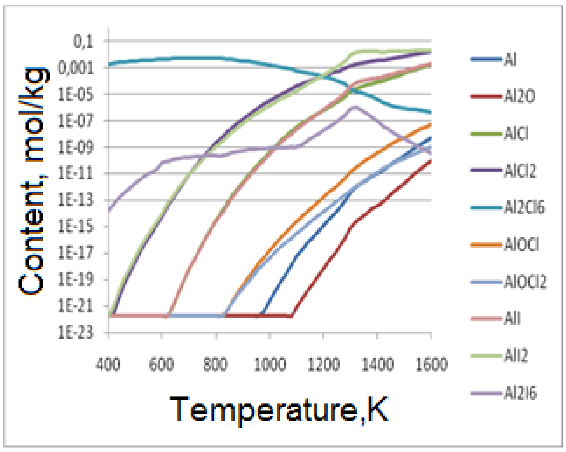

Fig. 2. Content of gaseous aluminum compounds in SVS charge

With increasing temperature, the amount of products in the gaseous phase increases and condensed products are released. Characteristically, in the temperature range of 400–1600 K, the proportion of the condensed phase decreases, which is associated with the evaporation of the carriers used. Simultaneously, starting from a temperature of 800 K, the reaction products decompose, which confirms the appearance of decomposition products and a sharp increase in the number of gas moles. Gaseous products interact with the elements of the powder system (Al, Si, B, Ti, W, Cr) and transfer them into the gas phase (appear SiCl, $SiCl_2$, $SiCl_3$, $SiCl_4$, SiI_2, SiI_3, AlCl, $AlCl_2$, $AlCl_3$, BF_3, CrF, CrF_2, CrF_4, $TiCl_2$, $TiCl_3$, $TiCl_4$, WCl_3, WCl_4, AlI and etc.). At temperatures above 800 K, the proportion of the condensed phase remains virtually unchanged. This fact suggests that in the temperature range of 800–1600 K, reactions occur with the release of a condensed phase, but without a change in the number of moles, which is typical for reactions of decomposition, disproportionation, or exchange with the substrate, i.e. in essence, chemical transport of elements takes place. As a result of the thermodynamic calculation of the equilibrium composition of the reaction products, we can assume the following kinetic scheme of chemical transformations in the systems under study.

The microhardness of siliconized coatings doped with Cr and Al on the sample surface is H_{50} = 6400–7100 MPa; alloyed Cr, Al, B: H_{50} = 13200–15400 MPa; alloyed Cr, Al, Ti: H_{50} = 9500–9800 MPa and alloyed Cr, Al, W: H_{50} = 11600–12800 МПа. After carrying out the combustion process and obtaining protective coatings, a standard heat treatment was carried out, consisting in hardening and low tempering, to prevent the layers from “punching”. With an increase in the carbon content in the sublayer, the microhardness increased.

On the siliconized layer doped with chromium and aluminum, a uniform layer is formed, under which there is a pearlite layer and the next carbon-depleted zone. As a result of X-ray diffraction analysis, it was found that on the surface of technical iron and steel 20, a layer of an ordered solid solution is formed $(Fe, Cr, Al)_3Si$. Below is an α-solid solution of chromium, aluminum and silicon in iron. On steel 45 and U8A, a layer is formed consisting of a solid solution of chromium, aluminum, and silicon in α-iron with inclusions of carbides (Fig. 3, 4).

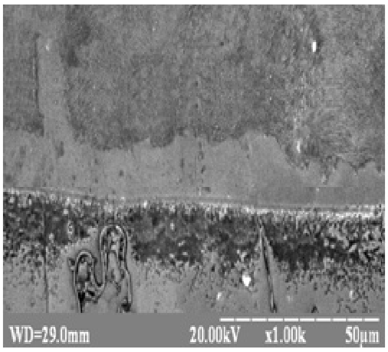

Fig. 3. Steel 45 with a protective coating

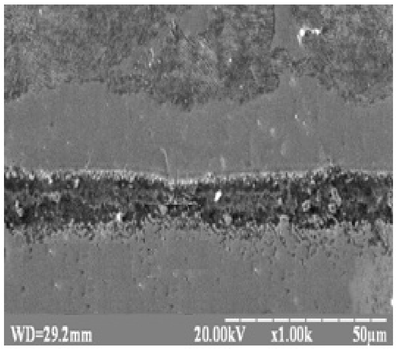

Fig. 4. Steel U8A with a protective coating

Corrosion tests (gravimetric method) were carried out in 3% aqueous NaCl solution, 10 % aqueous solution H_2SO_4, HNO_3 and 30% aqueous solution of HCl. The most effective protection, when tested in the media under consideration, was shown by siliconized coatings doped with Cr-Al-Ti, Cr-Al-W. Thus, in comparison with the base coating obtained by cold treatment under isothermal conditions, the corrosion resistance increases by 2.1–3 times.

As a result of X-ray microanalysis, it was found that the concentration of aluminum, chromium, and silicon on the surface of steel 20 is 9.8% Al, 8.2% Cr, and 4.6% Si. Accordingly, on U8A steel: 10.2% Al, 8.9% Cr and 5.1% Si. With an increase in the silicon content in the SHS powder mixture, the thickness and columnarity of the layer change; the highest columnarity is observed at 15% Si content.

The outer zone is enriched with chromium, aluminum and silicon. Based on the data on the distribution of elements, one can make an assumption about the features of the kinetics of the formation of siliconized layers doped with chromium and aluminum. It is known that silicon increases the thermodynamic activity of carbon [12]. Therefore, when saturated with silicon, carbon is displaced from the surface layers to deeper ones.

Wear resistance of protective coatings increased by 2.1 - 4.2 times. The best indicators of wear resistance (test on the SMT-1 friction machine) were shown by siliconized coatings alloyed with chromium, aluminum and boron. When tested on an MT-5 friction machine, siliconized layers alloyed with chromium, aluminum and tungsten have the best wear resistance.

Conclusions. Multicomponent siliconized layers were obtained in the combustion mode for hardening the pressure mechanism of a rolling mill. This mode allows you to quickly form a coating, without a significant change in the microstructure of metals. The combustion process lasts for 5-10 minutes and allows to achieve an increase in operational properties by 2-2.7 times on the gears of the blooming pressure mechanisms 1300. The consumption of electrical and thermal energy is reduced by 8-10 times due to the fact that the mixture is heated by a combustion wave during chemical treatment using composite saturating charges under SHS conditions.

References

1. Bialik, O.M., Chernenko, V.S., Pysarenko, V.M., & Moskalenko, Y.N. (2002). Metallurgy: Textbook. 2nd ed. processing and additional. VC "Polittekhnika Publishing House".

2. Sereda, B.P., Kruglyak, I.V., Baskevich, O.S., Belokon, Y.O., Kruglyak, D.O., & Sereda, D.B. (2022). *Surface strengthening of structural materials using composite saturating sharges: monograph Kamianske*. DDTU.

3. Sereda, B.P., Kruglyak, I.V., Belokon, Yu.A., & Zherebtsov, A.A. (2009). *Processing of metals by pressure under non-stationary temperature conditions*. ZGIA.

4. Firstov, S.O. (2020). *Uspikhy materialoznavstva [Successes in materials science].* IPM im. I.M. Frantsevycha NAN Ukrainy, 1, 3–7.

5. Siaociu, D., Hrechaniuk, M.I., Kucherenko, P.P., Melnyk, A.H., Hrechaniuk, I.M., & Bahliuk, H.A. (2019). *Promyslove elektronno-promeneve obladnannia dlia nanesennia zakhysnykh pokryttiv (ohliad). Poroshkova metalurhiia [Industrial electron beam equipment for applying protective coatings (review). Powder metallurgy]*. IPM im. I.M. Frantsevycha NAN Ukrainy, 01/02, 140–154.

6. Sereda, B., Baskevich, O., Sobolev, V., & Sereda, D. (2021). Modeling of conditions of phase transformations in micro-areas of metal materials with extreme. *Mathematical modeling*, 1(45), 91–102.

7. Bilous, O.I., Tantsura, G.I, & Belmas, O.L. (2015). *Hnuchki tiahovi orhany v mashynobuduvanni. Diahnostuvannia ushkodzhen [Flexible traction bodies in mechanical engineering. Diagnosis of injuries]*. DDTU.

8. Fedirko, V.M., Pogrelyuk, I.M., Lukyanenko, O.G., & Trush, V.S. (2020). *Chemical and thermal treatment of titanium alloys. Surface solid solution modification*. Scientific idea.

9. Sereda, B., Kryglyak, I., Sereda, D., & Kryglyak, D. (2023). Modification of the surface of copper alloys with aluminum in the conditions of self-propagating high-temperature synthesis. *Problems of Atomic Science and Technology, 2*(144), 130–133.

10.Tikhontsov, O.M., Solod, V.Iu., & Chernyshov, O.V. (2017). *Ekspluatatsiia ta remont tekhnolohichnoho obladnannia mekhanichnykh tsekhiv Kamianske: DDTU MON Ukrainy [Operation and repair of technological equipment of mechanical shops Kamianske: DDTU MES of Ukraine]*.

11.Harnets, V.M., Kovalenko, V.M. (2007). *Construction materials science*. Lybid.

12. Chumak, M.H. (2000). *Materialy ta tekhnolohiia mashynobuduvannia [Materials and technology of mechanical engineering].* Lybid.

Список використаних джерел

1. Metallurgy: Textbook / O. M. Bialik, V. S. Chernenko, V. M. Pysarenko, Y. N. Moskalenko. – 2nd ed. processing and additional. – VC "Polittekhnika Publishing House", 2002. – P. 384.

2. Surface strengthening of structural materials using composite saturating sharges / monograph B.P. Sereda, I.V. Kruglyak, O.S. Baskevich, Y.O. Belokon, D.O. Kruglyak, D.B. Sereda. – Kamianske: DDTU, 2022. – 245 p.

3. Processing of metals by pressure under non-stationary temperature conditions: monograph / B.P. Sereda, I.V. Kruglyak, Yu.A. Belokon, A.A. Zherebtsov. – Zaporozhye: ZGIA, 2009. – 252 s.

4. Фірстов С. О. Успіхи матеріалознавства / С. О. Фірстов. – Київ : ІПМ ім. І.М. Францевича НАН України, 2020. – № 1. – С. 3–7.

5. Промислове електронно-променеве обладнання для нанесення захисних покриттів (огляд) / Д. Сяосю, М. І. Гречанюк, П. П. Кучеренко, А. Г. Мельник, І. М. Гречанюк, Г. А. Баглюк // Порошкова металургія. Київ: ІПМ ім. І. М. Францевича НАН України. – 2019. – № 01/02. – С.140–154.

6. Modeling of conditions of phase transformations in micro-areas of metal materials with extreme / B. Sereda, O. Baskevich, V. Sobolev, D. Sereda // Mathematical modeling. – Kamianske: DDTU. – 2021. – Issue 1(45). – Pp. 91–102.

7. Білоус О. І. Гнучкі тягові органи в машинобудуванні. Діагностування ушкоджень / О. І. Білоус, Г. І. Танцура, О. Л. Бельмас. – Дніпродзержинськ : ДДТУ, 2015. – 120 с.

8. Chemical and thermal treatment of titanium alloys. Surface solid solution modification / V. M. Fedirko, I. M. Pogrelyuk, O. G. Lukyanenko, V. S. Trush ; NAS of Ukraine, Institute of Physics and Mechanics named after H.V. Karpenko. – Kyiv : Scientific idea, 2020. – 183 p.

9. Modification of the surface of copper alloys with aluminum in the conditions of self-propagating high-temperature synthesis / B. Sereda, I. Kryglyak, D. Sereda, D. Kryglyak // Problems of Atomic Science and Technology. – 2023. – Vol. 2(144). – Pp. 130–133.

10.Тіхонцов О. М. Експлуатація та ремонт технологічного обладнання механічних цехів / О. М. Тіхонцов, В. Ю. Солод, О. В. Чернишов. – Кам'янське : ДДТУ МОН Украины, 2017.

11.Harnets, V. M. Construction materials science / V. M. Harnets, V. M. Kovalenko. – K. : Lybid, 2007. – 384 c.

12.Чумак М. Г. Матеріали та технологія машинобудування / М. Г. Чумак. – Київ: Либідь, 2000. – 368 с.

Отримано 06.06.23

УДК 621.7

Борис Середа[1], Ірина Кругляк[2], Дмитро Середа[3]

[1]доктор технічних наук, професор, завідувач кафедри автомобілі та автомобільне господарство
Дніпровського державного технічного університету (Кам'янське, Україна)
E-mail: seredabp@ukr.net. **ORCID:** https://orcid.org/0000-0002-9518-381X

[2]доктор технічних наук, доцент, завідувач кафедри галузевого машинобудування
Дніпровського державного технічного університету (Кам'янське, Україна)
E-mail: kruglyak1964@gmail.com. **ORCID:** https://orcid.org/0000-0001-8872-6778

[3]кандидат технічних наук, доцент кафедри галузевого машинобудування
Дніпровського державного технічного університету (Кам'янське, Україна)
E-mail: etohardcore@gmail.com **ORCID:** https://orcid.org/0000-0003-4353-1365

ПІДВИЩЕННЯ НАДІЙНОСТІ РОБОТИ МЕХАНІЗМІВ МЕТАЛУРГІЧНОГО УСТАТКУВАННЯ З ВИКОРИСТАННЯ РЕСУРСЗБЕРІГАЮЧОЇ ТЕХНОЛОГІЇ СВС

Під час проведеного дослідження було детально проаналізовано застосування передових ресурсозберігаючих технологій у галузі машинобудування, сфокусованих на оптимізації металургійного виробництва. Основний акцент було зроблено на дослідження комплексних насичувальних середовищ, запропонованих як засіб для підвищення надійності функціонування механічного обладнання. Представляючи інноваційний підхід, дослідження пропонує доцільне застосування методів поверхневого зміцнення деталей машин з використанням сучасних технологій за температурних умов, що динамічно змінюються, характерних для металургійних процесів. Статистичні дані та результати експериментів підтверджують ефективність запропонованих технологічних рішень, а також дозволяють виявити оптимальні параметри та умови їх застосування. Ґрунтуючись на проведених дослідженнях, можна стверджувати, що використання ресурсозберігаючих технологій у металургійній галузі сприяє істотному зниженню енергетичних витрат і скороченню часу виробничих процесів. Крім оптимізації виробничих процесів, ресурсозберігаючі технології також роблять істотний внесок у поліпшення економічної ефективності підприємств. Скорочення витрат на енергію і підвищення надійності обладнання дає змогу знижувати експлуатаційні витрати і покращувати загальну рентабельність діяльності.. Багатокомпонентні силіційовані шари були отримані в режимі горіння для зміцнення натискного механізму прокатного стану. Цей режим дозволяє швидко сформувати покриття, без істотної зміни мікроструктури металів. Процес випалювання триває 5-10 хвилин і дозволяє досягти підвищення експлуатаційних властивостей в 2-2,7 рази на шестернях обтискних механізмів блюмінгів стану 1300. Витрата електричної і теплової енергії знижується в 8-10 рази за рахунок того, що суміш нагрівається хвилею горіння при хіміко-термічній обробці з використанням комплексних насичуючих середовищ в умовах СВС.

Ключові слова: *галузеве машинобудування; ресурсозберігаючі технології; зміцнення; комплексні насичувальні середовища; енергетичні витрати; виробничий процес.*

Рис.: 4. Бібл.: 12.

Sereda, B., Kruglyak, I., & Sereda D. (2023). Increasing the reliability of mechanisms of metallurgical equipment that uses SHS resource-saving technology. *Technical sciences and technologies,* (2(32)). С. 78-82.