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ПІДВИЩЕННЯ ДОВГОВІЧНОСТІ ГВИНТІВ НАТИСКНОГО ПРИСТРОЮ РОБОЧОЇ КЛІТІ СТАНУ 650

У даній дослідницькій роботі розглядається використання хромованого покриття із застосуванням процесу саморозповсюджуваного високотемпературного синтезу (СВС) на гвинтах натяжного пристрою прокатного стану моделі 650. Основною метою роботи є підвищення зносостійкості та довговічності механізмів прокатного стану для поліпшення його продуктивності. Експериментальні дослідження включають проведення випробувань на машині тертя МТ-5 з метою оцінки мікротвердості та зносостійкості хромованого покриття. Також здійснено термодинамічний аналіз процесу отримання покриття та вивчення складу газової та конденсованої фази в реакторі. Результати роботи можуть бути використані для оптимізації технологічних процесів на прокатних станах, поліпшення якості продукції та зниження витрат на технічне обслуговування обладнання. Дослідження виявило, що леговане титаном і кремнієм хромоване покриття, отримане із застосуванням технології СВС, сприяє формуванню захисного шару, що поліпшує адгезію і стійкість до механічних впливів. Отримані результати підтверджують ефективність застосування технології СВС для підвищення зносостійкості та довговічності гвинтів натяжного пристрою прокатного стану 650, що є актуальним завданням у галузі промислового машинобудування та виробництва жерсті.

Ключові слова: *прокатний стан, хромування, саморозповсюджувальний високотемпературний синтез, зносостійкість, тертя.*

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INCREASING THE DURABILITY OF THE SCREWS OF THE PRESSING DEVICE OF THE MILL STAND 650

This research work deals with the use of chrome plating using the self-propagating high temperature synthesis (SHS) process on the idler screws of a Model 650 rolling mill. The main objective of the work is to improve the wear resistance and durability of the rolling mill mechanisms to improve its performance. Experimental studies include conducting tests on an MT-5 friction machine to evaluate the microhardness and wear resistance of the chrome plating. Also thermodynamic analysis of the process of obtaining the coating and study of the composition of the gas and condensed phase in the reactor were carried out. The results of the work can be used to optimize technological processes at rolling mills, improve product quality and reduce equipment maintenance costs. The study revealed that titanium and silicon doped chrome coating obtained using SHS technology promotes the formation of a protective layer that improves adhesion and resistance to mechanical effects. The obtained results confirm the efficiency of SHS technology application for increasing wear resistance and durability of screws of tensioning device of rolling mill 650, which is an actual task in the field of industrial machine building and tinplate production.

Key words: *rolling mill, chrome plating, self-propagating high-temperature synthesis, wear resistance, friction.*

Problem statement. Statement of the problem in this study is associated with the need to improve the wear resistance and service life of tensioning devices of rolling mill 650. The main problem is that standard materials do not provide the required level of wear resistance under high loads and intensive friction conditions. This requires the development and use of new technologies to improve mechanical properties and extend the service life of tensioning devices. The main direction to address this problem is to investigate the use of chrome plating produced using the self-propagating high-temperature synthesis (SHS) process and its effect on tensioner performance. However, successful implementation of this approach requires a more detailed analysis of the thermodynamic processes in the SHS reactor, as well as an evaluation of the structural and mechanical properties of the resulting coating to determine the optimal application parameters [1]. Thus, the problem statement includes the need for a comprehensive approach to the study of wear mechanisms and service life of tensioning devices, as well as the search for innovative technological solutions to improve them and increase the efficiency of the rolling process.

Analysis of recent research. An analysis of recent research in the field of functional coatings and alloying technologies to improve the durability of mechanical equipment in metallurgical production highlights several key areas and results. In recent years, numerous studies have been conducted to optimize the composition and structure of functional coatings to improve their adhesion, hardness, and wear resistance. One of the most promising approaches is the use of alloy coatings made of chromium, silicon and titanium, as these materials have high hardness and resistance to abrasive and adhesive wear, making them ideal for use in metallurgical production. Much attention is also paid to the study of wear mechanisms and surface interaction in contact, which allows us to more accurately determine the factors that affect the durability of coatings. The molecular mechanical theory of friction is widely used to explain the processes that occur during friction and to develop effective methods to reduce surface wear.

An important research result is the determination of optimal production parameters, such as temperature, pressure, and speed, which allow for maximum efficiency of coatings and alloyed materials. This helps to optimize application processes and improve the quality of the final product [2-4]. Thus, the analysis of recent studies shows significant progress in the field of functional coatings and alloying technologies to increase the durability of mechanical equipment in metallurgical production, which opens up new prospects for the development of this area and increase the efficiency of production processes. Until now, intensive research has been conducted using self-propagating high-temperature synthesis to apply alloy chrome coatings to important mill parts. The results of these studies have shown the high potential of SHS in forming wear-resistant and durable coatings that significantly improve the performance of equipment. In particular, the thermodynamic features of the processes in the SHS reactor were studied, the chemical and physical properties of the formed compounds were analyzed, and the optimal process parameters were determined to obtain the best results in ensuring the durability and efficiency of the mechanism.

Setting objectives. The purpose of this work is to study and analyze the production technology of a 650 tinplate rolling mill using an alloyed chromium coating obtained by self-propagating high-temperature synthesis. The main objective is to evaluate the effectiveness of the alloyed chromium coating on the bolts of the tensioning mechanism of the rolling mill and its effect on the wear resistance and mechanical properties of the bolts. In addition, the work plans to thermodynamic analysis of the gas and condensed phase composition in the SHS process to determine the optimum coating parameters. Tests on the MT-5 friction machine will be used to verify the durability and reliability of this coating under real operating conditions. Based on the results obtained, recommendations will be formulated to optimize the coating process in order to improve the durability and reliability of the tin mill 650.

Presentation of the main material. Hardening of machine parts and mechanisms in industrial engineering for metallurgical production is one of the key strategies to ensure the reliability and uptime of rolling mills. To achieve these goals, it is important to strengthen the surface layer of parts, in particular, the screws of the pressure device of the 650 cold rolling mills. The wear resistance of these parts can be significantly improved by applying functional active layers, which can reduce hardening costs and energy consumption.

The use of self-propagating high-temperature synthesis technology to form protective coatings is an effective approach. The SHS technology is based on exothermic reactions occurring in the combustion wave mode, which contributes to the formation of products with high physical and chemical characteristics. This approach differs from traditional powder metallurgy methods, as it allows not only surface hardening but also the formation of active chemical and thermal zones.

Such synthesis of materials differs significantly from standard methods of powder metallurgy based on sintering of chemically inert compounds and has a number of obvious advantages, among which the following can be noted: - formation of active chemical and thermal zones, which allows to intensify transformations of reagents and leads to the formation of desired products; - use of less expensive chemical energy (heat generation during exothermic reactions) instead of electrical energy to achieve high temperatures required for obtaining products; - use of relatively simple equipment (instead of furnaces and other heating devices); - use in the process of rapid layer-by-layer heating of large volumes of reagents instead of slow heating of blacks.

One of the advantages of using SHS technology is the efficient use of energy and reduced costs for strengthening parts. It is also worth noting that this technology makes it possible to produce materials with high technical characteristics that meet modern industrial requirements. From this point of view, the use of SHS technology has great potential in the production of industrial parts and machinery, where reliability, service life and efficiency are important factors.

The 650 cold rolling mill stand consists of two massive closed-type stands, usually cast from 35L steel, a set of rolls, a pressure and balance device, and a leash table. The top and bottom stands are connected to each other by bolts and crossbeams. The support and working rolls with cushions are installed between the beds. Side bars are attached to the outer parts of the bed posts to guide the cushions in the beds and to adjust the rolls in the axial direction[5].

Side strips are attached to the outer parts of the bed posts to guide the cushions in the beds and to adjust the rolls in the axial direction.

The stand stands are fixed to the plates with anchor bolts using special tides. The distance between the cold rolling mill stands is 4.3 to 5 meters. According to A.I. Tselikov, the cross-sectional area of the bed stand is approximately equal to (1,0 – 1,2) d^2, where d is the diameter of the neck of the support roll[6].

A pressing device is provided in the upper part of the stand to install the rolls and adjust the gap between them. In modern cold rolling mills, each pressure screw is driven by an electric motor through two globular gearboxes. The drives of the two screws are coupled via an electromagnetic clutch, which allows for joint or separate operation of the screws.

The power supply for each motor of the pressure screws is carried out according to the D-D system. The power and control systems ensure minimal acceleration and deceleration times. The accuracy of stopping the screws is ± 0.01 mm. Figure 1 shows a diagram of the pressing device[7-8].

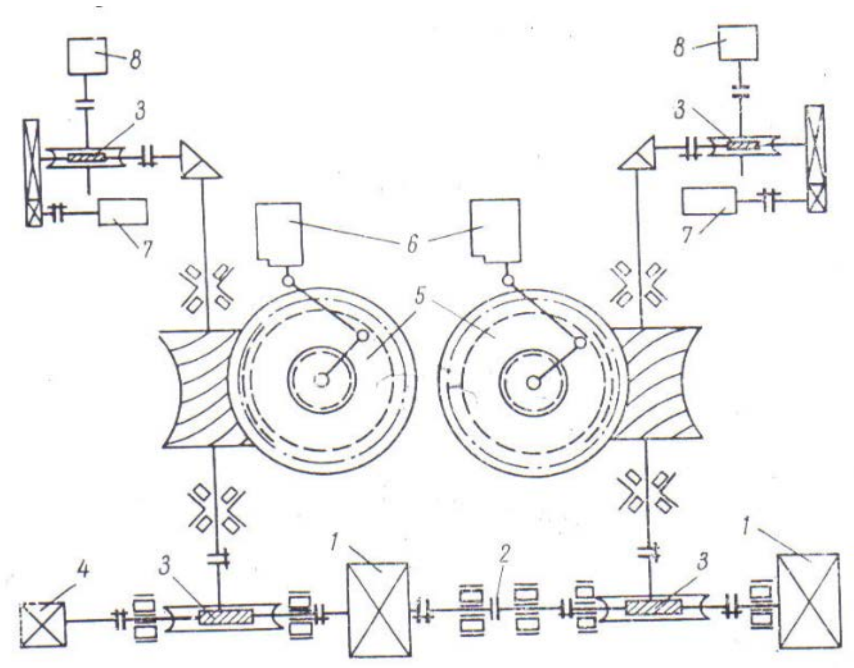

Fig 1. **Schematic of the pressing device of the mill stand 650 [5].**
1 - electric motor; 2 - electromagnetic clutch; 3 - worm gearbox; 4 - tachogenerator; 5 - globular gearbox; 6 - rotation angle sensors; 7 - selsin sensor; 8 - command unit.

The operating speed of the pressure screws is significantly lower than the maximum speed possible. This is done in order to accelerate the movement of the screws during swath handling. The balancing device consists of a single hydraulic cylinder, two crossheads, a lever system and rods. The hydraulic drive system for the pressure device is shown. The torque is transmitted from the stand to the work rolls via a spindle connection. connection of the quarto stand of a cold tinplate mill. The spindles are supported in the middle section by plain bearings. The plain bearings are mounted on traverses that move vertically along guide rails under the action of coil springs and rest on a spindle chair. The spindle connection allows the torque to be transmitted at a certain angle. The weak link in the spindle device is the bronze bushings, which wear out quickly under heavy loads.

For the thermodynamic analysis of the SHS process of forming alloyed protective coatings, we used the universal program for calculating multicomponent heterogeneous systems TERRA, created on the basis of the ASTRA-4 program for the WINDOWS environment and developed for high-temperature processes. In contrast to the traditional methods of calculating equilibrium parameters in chemical thermodynamics using the Gibbs energy, equilibrium constants, and the Goldberg and Waget law of masses, the universal thermodynamic calculation program TERRA is based on the principle of maximum entropy for isolated thermodynamic systems in equilibrium. It is characterized by the maximum entropy with respect to thermodynamic degrees of freedom, which include the concentrations of system components, temperature, pressure, etc.

To develop specific methods for obtaining protective coatings on structural materials under high-temperature synthesis conditions, it is necessary to clarify the thermodynamic features of the process.

Among the various factors that affect the mechanism of coating formation under SHS conditions are the initial conditions preceding the process of diffusion of elements into the material, which directly or indirectly depend on the physicochemical factors of saturation (thermodynamic characteristics of phases in the system of interacting elements; thermodynamic characteristics of the saturated medium). Let's consider the most important ones.

The main condition for the spontaneous occurrence of this reaction is the higher thermodynamic strength of aluminum oxides compared to oxides of renewable metals. The strength of oxides of various metals is characterized by the value of the isobaric potential ΔZ^0 when these metals interact with oxygen. The greater the difference in the isobaric potentials of aluminum oxide formation and the element (metal) being reduced, the more complete and energetic the reduction reactions are.

The heating temperature of the mixture as a result of the SHS reaction depends on the temperature of its preliminary heating, as well as the amount of heat released as a result of the reduction reaction. It should be borne in mind that the final heating temperature depends not only on the amount of heat from the reduction reaction, but also on the temperature range in which the reaction itself takes place.

In most cases, the temperatures that develop during reduction reactions are significantly higher than the melting points of metals and alloys.

In SHS processes, which can take place during reactive mechanical alloying, an important characteristic is the adiabatic interaction temperature T_{ad}. In the course of a single SHS reaction, the thermodynamic calculation of the adiabatic interaction temperature is based on the following assumption: the reaction proceeds completely (with a conversion rate of 100%) under adiabatic conditions. The heat of reaction at the initial temperature T_o (T_0>298 K) is consumed for heating to T_{ad} and possible melting of the products. The calculation is reduced to determining the value of $_{Tad}$ from the nonlinear enthalpy balance equation.

Powdered saturating charges for alitization under SHS conditions contain a chromium component, aluminum, transport activators, and chromium. The equilibrium composition of SHS charges in the mode of thermal self-ignition was calculated for the system: XC + Al + Cr + Al_2O_3 + NH_4 I + NH_4F, for a large range of changes in the output components depending on temperature (Fig. 2, 3).

At temperatures above 700 K, the proportion of the condensed phase practically does not change. This fact suggests that in the temperature range of 700-1500 K, reactions occur with the release of the condensed phase, but without changing the number of moles, which is typical for decomposition reactions, exchange with the material, i.e., in fact, chemical transport of elements occurs The content of gaseous aluminum compounds in the reactor, the mode of thermal self-ignition of the SHS charge for the system: XC + Al + Cr + Al_2O_3 + NH_4 I + NH_4F in temperature range 400–15000 K є: AlH, AlH_2, AlF, AlF_2, AlF3, AlHF, AlH_2F, AlI, AlI_2, AlI_3, Al_2I_6 etc. Content of gaseous chromium compounds: Cr, Cr_2, CrO, CrH, CrOH, CrF, CrF_2, CrF_3, Crl, Crl_2, Crl_3 etc., as well as the content of condensed products: Al(c), Al_2O_3(c), AlF_3(c), AlI_3(c), AlN(c), Cr© etc.

Deformation interaction occurs in areas of contact with rough surfaces and causes repeated deformation of the surface layer by irregularities. Mechanical impact can be in the form of elastic or plastic interaction, as well as micro-cutting. Adhesive interaction occurs when micro-welds are formed in the contact zone. Reducing the intensity and even suppressing wear, according to molecular mechanical theory, helps to: prevent the formation of strong adhesive bonds in friction pores; increase the hardness of friction surfaces. Applying a durable coating to rubbing surfaces can, on the one hand, form a barrier that prevents adhesion of the mating surfaces, and, on the other hand, increase the surface hardness. Increasing the hardness of the coated surface, making it difficult to deform and eliminating microcutting, contributes to the elastic interaction of rubbing surfaces, which is most favorable for increasing wear resistance.

Tests on the MT-5 friction machine (friction under shock-dynamic loading) show that the best wear resistance is provided by alloyed coatings alloyed with Si and Ti with a wear value of $\Delta I = (33 - 55) \cdot 10^{-4}$ g/m^2. This can be explained by the higher values of the total brittle fracture score of isothermal coatings, where it is 20-25% higher.

Conclusions. This work discussed various aspects of the production technology of a 650 tinplate rolling mill, with a particular focus on improving the wear resistance and mechanical properties of the tensioner bolts. The use of alloyed chrome plating using the self-propagating high-temperature synthesis (SHS) process was shown to significantly improve the durability and wear resistance of important parts of the mill. Thermodynamic analysis of gas and condensed phase composition in the SHS process allowed to determine the optimal parameters of the coating process providing high quality and desired chemical properties: XC + Al + Cr + Al_2O_3 + NH_4 I + NH_4F in temperature range 400–15000 K: AlH, AlH_2, AlF, AlF_2, AlF3, AlHF, AlH_2F, AlI, AlI_2, AlI_3, Al_2I_6 etc. Content of gaseous chromium compounds: Cr, Cr_2, CrO, CrH, CrOH, CrF, CrF_2, CrF_3, Crl, Crl_2, Crl_3 etc., as well as the content of condensed products: Al(c), Al_2O_3(c), AlF_3(c), AlI_3(c), AlN(c), Cr(c) i in. i in. The results of tests on the MT-5 friction machine confirmed the effectiveness of alloyed chrome coating, which is an important step in ensuring the reliability and durability of the rolling mill. The best wear resistance is provided by aluminized coatings alloyed with Si and Ti with a wear rate of $\Delta I = (33 - 55) \cdot 10^{-4}$ g/m^2. This can be explained by the higher values of the total brittle fracture score of isothermal coatings, where it is 20-25% higher. Thus, this research has shown that the use of SHS process for coating the screws of the tensioning mechanism of the rolling mill is a promising and effective method to improve its performance characteristics.

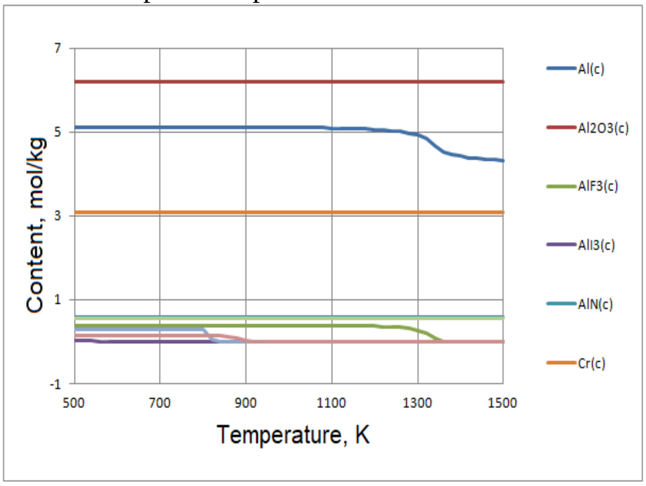

Fig. 2. **The content of condensed products in the reactor.**

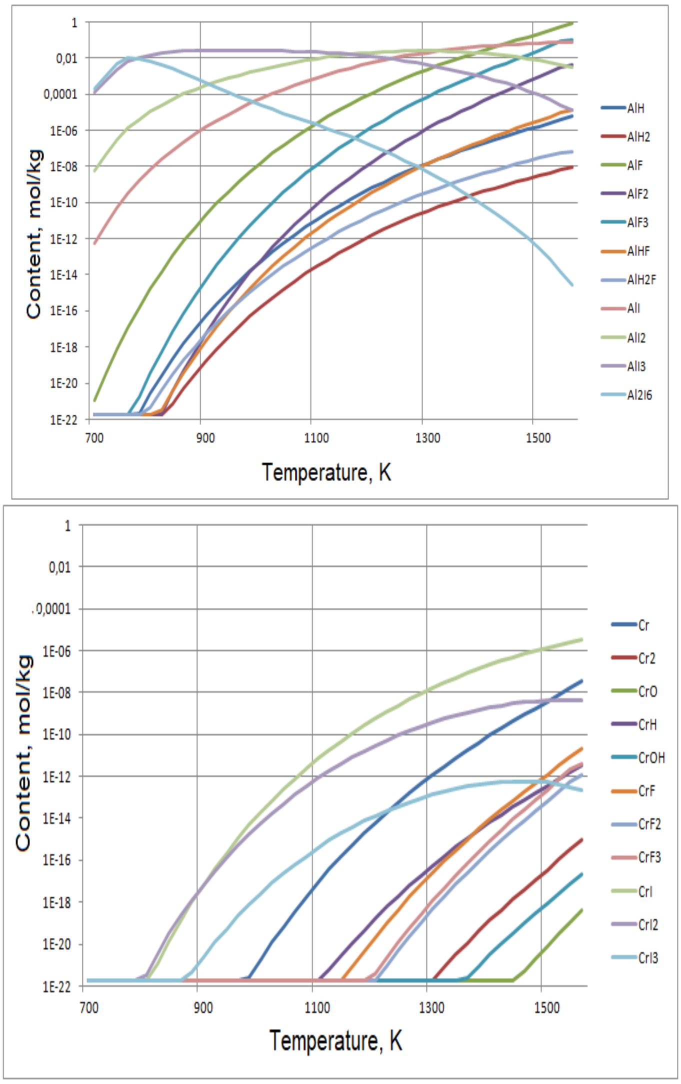

Fig. 3. **Content of gaseous aluminum and chromium compounds in the reactor, thermal self-ignition mode of SHS charge**

References

1. Савуляк В.І. Наплавлення високовуглецевих зносостійких покриттів/ Савуляк В. І., Шенфельд В.Й.// Моногшрафія. Вінниця: ВНТУ, - 2016. -124с.
2. Поверхневе зміцнення матеріалів працюючих в умовах комплексного впливу агресивних речовин: монографія. Б.П. Середа, Л.П. Банніков, С.В. Нестеренко, І.В. Кругляк, О.С. Гайдаєнко, Д.Б. Середа – Кам'янське: Дніпровський державний технічний університет, 2019. – 170с.
3. Sereda B. High-performance chrome coatings to protect against wear and corrosion Steel Properties and Applications in Conjunction with Materials Science and Technology 2021, P. 39–41.
4. Cheiliakh, O. P., Ryabikina, M. A., & Kutsomelia, Y. Y. (2015). Моделювання впливу параметрів дифузійного хромування на експлуатаційні та фізико-механічні властивості сталей для штампового інструменту. *Вісник Приазовського Державного Технічного Університету. Серія: Технічні науки*, (29), 56–64.
5. Обладнання прокатних цехів Навчальний посібник для студентів ЗДІА металургійних спеціальностей денної та заочної форми навчання / Укл.М.Г. Прищип, - Запоріжжя: ЗДІА, 2016. – 116с.
6. Прокатне виробництво [Текст]: навч. посіб. для студ. ВНЗ / Б. П. Середа; Запорізька держ. інженерна академія. - Запоріжжя: Вид-во Запоріэької держ. інж. акад., 2008. - 310 с. - Бібліогр.: с. 310 (12 назв). - ISBN 978-966-7101-96-1
7. Обробка металів тиском [Текст]: навч. посіб. для студ. ВНЗ / Б. П. Середа; Запорізька держ. інженерна академія. - Запоріжжя: [Видавництво Запорізької держ. інж. акад.], 2009. - 342 с. - Бібліогр.: с. 342. - ISBN 978-966-8462-11-5
8. Обробка металів тиском [Текст]: навч. посіб. для студ. вищ. навч. закл. за напрямком "Металургія" / В. М. Данченко. - Д.: Пороги, 2006. - 183 с.: рис. - ISBN 996-525-716-1