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Preparation of powder coatings on the surface of steel balls by mechanochemical synthesis

This work presents the results of the study of tribological and corrosion properties of powder coatings based on VN, TiN, SiC and Cr_2N obtained by mechanochemical synthesis on the surface of steel balls ShKh15. The idea of this method is using the impact energy of moving balls to apply coatings on metal surfaces. Based on the conducted research, it was proved using the method of mechanochemical synthesis possible to obtain a coating of VN, TiN, SiC, and Cr_2N on the surface of steel balls. The optimal parameters for coating were chosen: amplitude of the oscillation 3.5 mm; frequency of the oscillation 50 Hz; volume of filling of the chamber 50 %, the diameter of the ball 6 mm; ratio mass of the powder to the mass of the balls m_p:m_b=1:30, processing time by mechanochemical synthesis is 1 hour. It is established that the change in the characteristics of coatings directly depends on the stiffness and physical and mechanical properties of the source material (substrate) and surface roughness. The results of the tribological study showed that a wear-resistant coating was formed on the surface of the steel balls.

Keywords: mechanochemical synthesis, steel ShKh15, coating, coefficient of friction, wear resistance, corrosion, vibration stand, bearing.

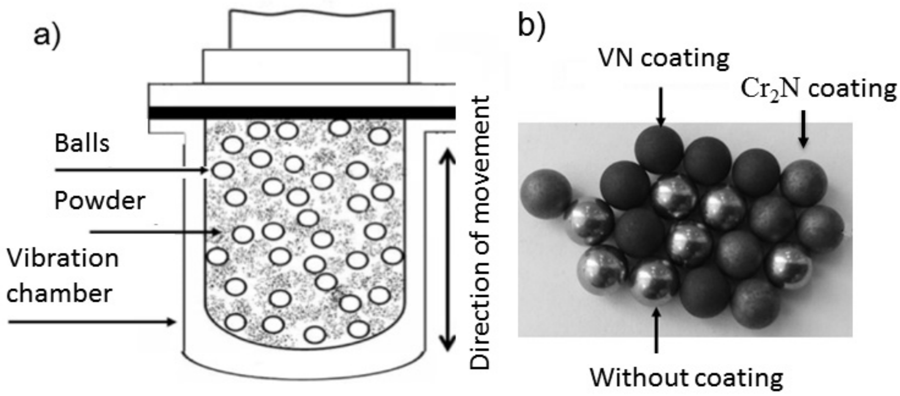
Introduction

The machines longevity and mechanisms are mostly determined by the wear resistance used in their construction of bearing units. Wear of bearing units is followed by changes in the size of all components of their construction the rubbing detail. Feature of the work friction bearing units is the impact of: working pressure, temperatures, changing speeds of relative sliding or rolling, environmental aggression which leads to a certain type of wear (fatigue, abrasive, water-abrasive, corrosion-abrasive, etc.) and as a result of decrease in performance and reduce the durability of the friction bearing unit. The wear resistance of friction bearing units is largely determined by the quality of the lubricant material, the parameters of the contact surfaces of the details (shape deviation, waviness, roughness), and the physical-mechanical properties of the surface layer, which are formed during production and change during exploitation.

The application of the mechanical alloying (MA) method to obtain coatings on the metal surface is a new direction of surface treatment. Special attention is paid to the surface treatment of steel balls using the MA method. Steel bearing balls used in mechanical engineering, construction, etc. are exposed to rapid wear under various loads and have a negative impact on production. A significant role is played by improving the physical and mechanical properties of the surface by applying various powders to the surface of steel balls [1–4]. Methods such as electrochemical, ion implants, chemical and physical coatings, and electron beams, which are widely used in practice, always do not give good results. Therefore, in this direction, it is more effective to increase the surface properties of the material by using MA. This process has been the object of intensive research confirming the importance of its application in various industries. Recently, processes activated by mechanical action (mechanochemical synthesis, mechanical activation, mechanical alloying) have become the subject of intensive research in connection with their prospective application in various industries, as they provide the creation of new non-traditional, ecologically pure and less expensive technologies compared to existing methods of coating metal surfaces such as chemical and physical vapor deposition, self-propagating high-temperature synthesis, thermal spraying, sol-gel method, etc. Exists needs to develop new methods of deposition coating the surface of metals and alloys [5–9]. In this regard, the aim of this work is to obtain coatings on the surface of the ShKh15 steel balls by method of mechanochemical synthesis.

Methods and materials

A thin coating of Cr_2N was obtained on the surface of the bearing balls made of ShKh15 steel by the method of mechanochemical synthesis on the vibration stand IV-50. The optimal parameters for coating were selected: amplitude of the oscillation 3.5 mm; frequency of the oscillation 50 Hz; volume of filling of the chamber 50 %, the diameter of the ball 6 mm; ratio mass of the powder to the mass of the balls m_p:m_b=1:30, processing time by mechanochemical synthesis is 1 hour. Figure 1 shows a scheme of the MA method. The essence of this method is that steel balls and powder of a specific chemical composition are placed in a chamber, and in a particular range of frequency form a coating on the surface of the material processed under the influence of the shock energy of the balls, exposing the mechanical vibration accelerator to vibration in a specific frequency range. The frequency of mechanical vibration is determined by the composition of the applied mixture and in accordance with the mechanical properties of the treated material.



a — scheme the method of mechanical synthesis; *b* — steel balls with coating

Figure 1. Vibration stand IV-50 for the obtained coatings

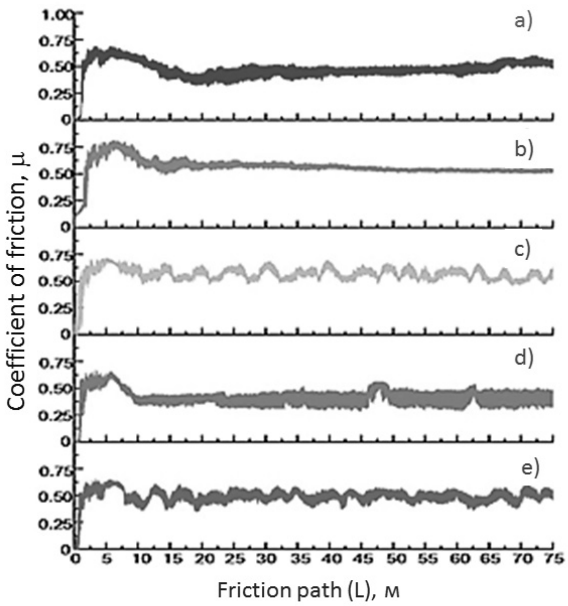
VN, TiN, SiC, Cr_2N coatings obtained by MA method on the surface of steel ShKh15 was selected as the object of research. The diameter of the ball is 6 mm, the fraction of selected powders is 20–40 mμ. The mass of the balls (m_b=36 g) and the powder (m_p=12 g) which placed in the chambers were stable. The volume filling of the chamber with balls was about 80–85 %, depending on the size of balls It was selected that the distance between the surface of the ball layer and the treated material was close to the value of the oscillation span (two amplitudes) to obtain the maximum impact force of the balls. It should be noted that by varying the filling volume of the vibration chamber with balls, possible changes character of the impact on the treated material. At low filling coefficients, the movement of the balls occurs at the maximum speed, but the interaction of the balls with each other and the treated surface is minimal, which leads to low values of the intensity of the bringing energy. With an increase in the filling volume the chamber with balls, the frequency of collisions increases significantly, but due to the reduction in the length of the free path, the balls do not have time to accelerate to high speeds.

Turning medium unbalanced vibration stand relative to the two extremes unbalanced was adjusted working amplitude oscillation 3.5 mm. Considering the technical characteristics of the installation, the set value of the amplitude provides a sufficient intensity of the bringing mechanical energy of the impact of the balls for coating. A significant increase in the amplitude (about 5 mm) with a high degree of loading leads to a sharp rise in the consumption of energy. On this basis, an excessive increase in the amplitude is not always effective, in addition, it influenced the construction of the used installation.

The oscillation frequency of the three-phase asynchronous motor (5A80MA2UZ) was regulated by the frequency Converter MG.02.C2.50-VLT (Danfoss). Using the tachometer TCh10-P, the oscillation frequency was measured by direct connection to the asynchronous engine. At a nourishing frequency of 50 Hz, the oscillation frequency of the asynchronous engine was equal to 2688 ± 69 rpm.

Results and discussion

The tribological properties of the balls are determined on the TRB^3 tribometer. The rotation radius is 5 mm, the speed is 5 cm/s, the installed load is 15 N, the path length is 75 m. Figure 2 shows the coefficient of friction of coatings VN, TiN, SiC, Cr_2N applied to steel balls ShKh15. The friction coefficient of steel ShKh15 is $\mu_{ShKh15} = 0.488$, for $\mu_{VN} = 0.416$, $\mu_{TiN} = 0.562$, $\mu_{SiC} = 0.563$, $\mu_{Cr2N} = 0.476$ (Table 1). A thin and strong coating is formed on the surface of the balls by using MA. According to the tribological research, the greatest friction coefficient was observed with TiN and SiC balls. Based on the results of the study of the wear intensity by weight loss, we can say that balls with TiN and Cr_2N coatings have a high wear resistance.



a — Steel ShKh15; *b* — VN coating; *c* — TiN coating; *d* — SiC coating; *e* — Cr_2N coating

Figure 2. The friction coefficient of the samples

Table 1

The results of tribological research of steel ShKh15 and coatings

Samples	Steel ShKh15	VN coating	TiN coating	SiC coating	Cr_2N coating
the middle of the friction coefficient, $\mu_{mid.}$	0,488	0,416	0,562	0,563	0,476
Standard deviation	0,064	0,071	0,070	0,083	0,081

With a view to improve the durability and reliability of gas turbine engine bearings by increasing their corrosion resistance, various methods are being developed to extend the service life of bearings in situations when may occur lubricating oil pollution with the salt water. If water or aggressive environments penetrates in the bearing to such an extent that lubricants cannot protect the steel surfaces and corrosion occurs. In work [10], the influence of heating on the corrosion properties of TiN and CrN coated steels was investigated. The results of the research showed that samples coated with Cr_2N showed better anti-corrosion properties than TiN-coated steels. The corrosion of steel ShKh15 before and after the application of a thin film coating Cr_2N

by mechanochemical alloying was determined by the method of potentiometric. The method of potentiometry is based on the dependence of the concentration/activity of ions in a solution with an electrode on the equilibrium electrode potential, i.e. the EDS of a reversible galvanic cell consisting of electrodes immersed in the test solution was measured, where the potential depended on the concentration of the determining ions. Corrosion tests were performed on a potentiostat-galvanostat P150, in a 4 % solution of nitric acid (HNO_3). The corrosion test results of samples are shown in Table 2.

Table 2

Corrosion test results of samples

Sample	S, cm^2	E_{corr}, mV	lg(I)	M, g/mol	n, g/mol	t, s	p, g/cm^3	i_{corr}, A	j_{corr}, A/cm^2	m, g	l, cm	R_{corr}, cm/year
Shh15 initial	0.45	–926	–2.32	56	56	3.15E+07	7.8	0.0047	1.06E-02	1.563	0.445	0.445
ShKh15 with Cr_2N coating	0.45	–1098	–3.11	118	60	3.15E+07	5.8	0.0008	1.72E-03	0.498	0.191	0.191

The corrosion behavior of samples was estimated by the size of their electrode potentials, by measuring and regulating the currents and voltages at the working electrode during electrochemical research. The test results showed that after applying the Cr_2N coating, the corrosion rate was 0.191 cm / year, which is twice as less as that of uncoated steel ShKh15.

Conclusion

Tribological and corrosion characteristics of chromium-based thin-film coatings applied by mechanochemical method on the surface of steel balls were researched. It is established that the mechanical alloying of nitride coatings depends on the process parameters that determine the flow of energy bringing. The growth rate of the coating is determined by the processing time and the intensity of the energy brought, the latest depends on the size and mass of the balls. The thickness of the coatings, uniformity and structure can be adjusted widely by changing the process parameters. The thickness of the coatings, uniformity and structure can be adjusted widely by changing the process parameters. The developed method of mechanochemical alloying allows obtaining VN, TiN, SiC, Cr_2N coatings on bearing balls at room temperature, in a short processing time and with minimal energy expenditure. The improvement of tribological and corrosion characteristics of ShKh15 steel was identified after applying thin-film coatings based on TiN and Cr_2N applied by mechanochemical method..

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Механохимиялық синтез әдісімен болат шарлардың бетіне ұнтақ жабындарын алу

Мақалада ШХ15 болат шарларының бетінде механохимиялық синтез әдісімен алынған VN, TiN, SiC және Cr_2N негізіндегі ұнтақ жабындарының трибологиялық және коррозиялық қасиеттерін зерттеу нәтижелері келтірілген. Бұл әдістің негізі — соқтығысқан шарлар энергиясын пайдалана отырып, металл беттеріне жабындар жағу. Жүргізілген зерттеулер негізінде механохимиялық синтез әдісін қолдана отырып, болат шарлардың бетіне VN, TiN, SiC, Cr_2N жабындысын алуға болатындығы дәлелденді. Жабын алу үшін оңтайлы параметрлер таңдалды: тербеліс амплитудасы 3,5 мм; тербеліс жиілігі 50 Гц; камераны толтыру дәрежесі 50 %, шардың диаметрі 6 мм; ұнтақ массасының шарлардың массасына қатынасы $m_{Ұ}:m_{ш} = 1:30$, механохимиялық синтез әдісімен өңдеу уақыты 1 сағ. Жабындардың сипаттамаларының өзгеруі бастапқы материалдың (субстраттың) қаттылығы мен физикалық-механикалық қасиеттеріне және бетінің кедір-бұдырына тікелей байланысты екендігі анықталды. Трибологиялық зерттеудің нәтижелері болат шарлардың бетінде тозуғатөзімді жабын пайда болғанын көрсетті.

Кілт сөздер: механохимиялық синтез, ШХ15 болаты, жабын, үйкеліс коэффициенті, тозуғатөзімділік, коррозия, дірілді стендтер, подшипник.

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Получение порошковых покрытий на поверхности стальных шаров методом механохимического синтеза

В статье приведены результаты исследования трибологических и коррозионных свойств порошковых покрытий на основе VN, TiN, SiC и Cr_2N, полученных методом механохимического синтеза на поверхности стальных шаров ШХ15. Идея данного метода состоит в использовании энергии ударов движущих шаров для нанесения покрытий на металлические поверхности. На основании проведенных исследований было доказано, что, с использованием метода механохимического синтеза, можно получить покрытия VN, TiN, SiC, Cr_2N на поверхности стальных шаров. Оптимальными параметрами для нанесения покрытий были выбраны амплитуда колебания 3,5 мм; частота колебания 50 Гц; степень заполнения камеры 50 %, диаметр шара 6 мм; отношение массы порошка к массе шаров $m_{п}:m_{ш} = 1:30$; время обработки методом механохимического синтеза составляло 1 ч. Установлено, что изменение характеристик покрытий напрямую зависит от жесткости и физико-механических свойств исходного материала (подложки) и шероховатости поверхности. Результаты трибологического исследования показали, что на поверхности стальных шаров образовалось износостойкое покрытие.

Ключевые слова: механохимический синтез, сталь ШХ15, покрытие, коэффициент трения, износостойкость, коррозия, вибрационный стенд, подшипник.

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