

УДК 629.693

IMPERATIVES OF DEVELOPMENT OF ENVIRONMENTALLY CLEAN TECHNOLOGY IN MECHANICAL ENGINEERING¹¹

Orlova E., st. of gr. MC-51-21, KhNAHU

Abstract. The work is devoted to the actual problem: Increasing the durability of piston rings using a modern method of surface treatment. Solving this problem with the help of traditional methods of chemical and thermal treatment does not give stable industrial results, therefore, the development of the technology of using modern methods and the methodology of their testing is an important urgent task. For the first time in production conditions, a device was created that allows determining the influence of surface treatment methods on wear resistance, crack resistance and structural changes of bearing liners. To perform the work, methods of metallographic X-ray structural, electron microscopic analysis, and modern methods of hardness determination were used. The work describes the development and analysis of the applied coating by the method of two-wire metallization with a steel-molybdenum coating. The coating components - molybdenum and stainless steel (as well as the original materials themselves) have high corrosion resistance, which is not inferior to the corrosion resistance of chrome and cast iron, from which the rings are made.

Key words: piston, steel, durability, structure, molybdenum, corrosion.

ІМПЕРАТИВИ РОЗВИТКУ ЕКОЛОГІЧНО ЧИСТИХ ТЕХНОЛОГІЙ У МАШИНОБУДУВАННІ

Орлова Є., ст. гр. МС-51-21, ХНАДУ

Анотація. Робота присвячена актуальній проблемі - підвищенню довговічності поршневих кілець сучасним методом обробки поверхні. Вирішення цієї проблеми за допомогою традиційних методів хіміко-термічної обробки не дає стабільних промислових результатів, тому розробка технології використання сучасних методів та методик їх апробації є важливим актуальним завданням. Вперше у виробничих умовах створено прилад, який дозволяє визначити вплив методів обробки поверхні на зносостійкість, тріщиностійкість і структурні зміни вкладнів підшипників. Для виконання роботи використано методи металографічного рентгеноструктурного, електронно-мікроскопічного аналізу та сучасні методи визначення твердості. У роботі описано розробку та аналіз нанесеного покриття методом дводротової металізації зі сталемолібденовим покриттям. Компоненти покриття - молибден і нержавіюча сталь (як і самі оригінальні матеріали) мають високу корозійну стійкість, яка не поступається корозійній стійкості хрому і чавуну, з яких виготовлені кільця.

Ключові слова: поршень, сталь, довговічність, структура, молибден, корозія.

Introduction

The development of modern technology presents ever-increasing requirements for the performance characteristics of construction materials, the reduction of the metal content of parts, the increase of their economy, quality, and the development of scientific and technological foundations of surface strengthening of loaded parts of construction equipment based on the management of structural parameters and functional properties of coatings to ensure their reliability and longevity. In the complex of problems of increasing the reliability and durability of machines, a special place is occupied by the development of environmentally friendly technologies. Insufficient wear resistance of ma-

¹¹ Робота виконана під керівництвом професора Глушкової Д.Б.

materials limits the increase in the productivity of machines and their service life, increases the costs of repairs and spare parts. Far from always, the required set of product properties can be formed by traditional methods of heat and chemical treatments.

Currently, one of the problems of mechanical engineering is increasing the wear resistance of piston rings made of high-strength cast iron.

Electrolytic chromium coatings are widely used in the practice of domestic and foreign engineering, but they do not meet the environmental and safety requirements. Electrolytic chromium performs poorly on friction and wear at high temperatures, which leads to weakening; under certain conditions, it is prone to wet corrosion [1].

In this regard, the development of highly efficient, environmentally friendly technologies for increasing the durability of piston rings is quite important and relevant.

Relevance of development

Operating conditions of piston rings of parts of the cylinder-piston group

The piston rings of the parts of the cylinder-piston group work in stressful conditions, which are characterized by high temperatures (up to 1900 °C of the combustible mixture, up to 600 °C on the surface of the sleeve and up to 450 C on the piston skirt), pressures (up to 15 MPa) and an extremely unfavorable nature friction from liquid to dry during reciprocating motion.



Fig. 1. General view of rings

Methods strengthening piston rings

At the same time, the main method of strengthening is chrome plating with a thickness of 0.15-0.50 mm [2]. Chromium coating has a number of advantages: high hardness (HV 950-1100), low tendency to sticking, low coefficient of friction of chromium on cast iron and steel, high corrosion resistance.

However, along with the advantages, this coating has inherent disadvantages: it is difficult to process, has low heat resistance, due to which it cracks during operation, does not hold oil well on its surface. In addition, electrolytic chromium plating is not stable due to the depletion of the solution and is environmentally hazardous.

The difference in the operating conditions of modern piston rings requires a differentiated approach to the selection of materials and their compositions for spraying wear-resistant coatings, taking into account economic feasibility. For the wide distribution of piston ring coatings in the domestic engineering industry, optimization of their composition and materials for specific types of machines and testing are necessary first of all [3].

Research methodology. Research material

Strengthening piston rings from high-strength cast iron, the composition of which is given in (table 1).

Table 1 - Chemical composition of gray and high-strength cast iron

Cast iron	C	Si	Mn	Cr	No	Mo	Cu	Mg	P
SC 25	3.2-3.4	1.4-1.7	0.6-0.9	–	–	–	–	–	≤0.3
HF 42	3.4-3.7	2.1-2.5	0.85-1.3	0.15	1.2-1.5	0.6-0.9	0.3-0.4	0.03-0.1	≤0.1

Application of gas thermal coating.

The coating process includes the following operations: preliminary preparation of the surface of the product for coating, the coating process itself, further processing if necessary (melting, heat treatment, etc.). The operational properties of coatings depend on each of these operations.

Shot blasting was used to clean the sprayed surface and bring it out of thermodynamic equilibrium with the environment. A fraction with a grain size of 0.5-1.5 mm was used as an abrasive material. Blowing was carried out at a compressed air pressure of at least 0.4 MPa. The shotblasting zone was at least 3 mm larger than the spraying zone.

Modes of electric arc spraying of steel - molybdenum coatings on piston rings are indicated in the table. 2.

The positive pole is molybdenum. The speed of movement of the mandrel with piston rings should be within 60-95 rpm. The longitudinal movement of the apparatus along the frame with piston rings was made at a speed of 200-250 mm/min. The spraying distance is the distance from the point of intersection of the wires of the surface to be sprayed, and 100-110 mm. The coating is sprayed to a thickness of 0.8 (+ 0,1 mm).

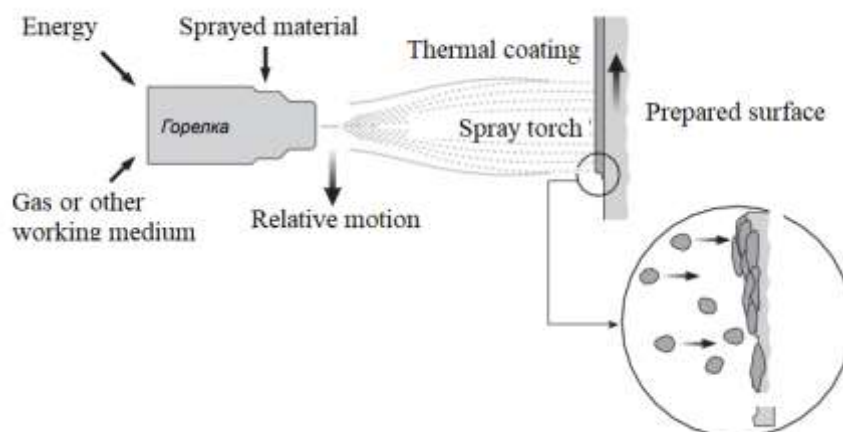


Fig. 1. Scheme of application of gas thermal spraying

Determination of hardness and microhardness of coatings.

Measuring the hardness of various materials is one type of mechanical testing. In the method of measuring microhardness, small loads (from 2 to 200 g) are used, which is favorable for studying the microscopic structure of the material.

The price of the scale division on the drum of micrometric screws is 0.01 mm.

Table 2 - Spraying mode steel - molybdenum coating

Parameters		Parameter values
Coating composition, % by mass	Mo	50
	11X18M	50
Wire diameter, mm	Mo	2
	11X18M	2,3
Wire feed speed, m/min	Mo	3.8
	11X18M	3.8
Coating composition, % by volume	Mo	44
	11X18M	56
Voltage on the arc, V		40
Current strength, A		400
Compressed air pressure, MPa		0.50-0.55
Air nozzle diameter, mm		8

As a pressed the indenter in the PMT-3 device uses a diamond pyramid with a square base and an angle at the base of 136°. During the test, the length of the diagonal of the impression is measured and the hardness number is calculated according to the following formula:

$$H = \frac{P}{S} = \frac{2P \sin \alpha / 2}{d^2} = 1,854 \frac{P}{d^2} \quad (1)$$

After finishing the taring of the device, the position of the loading mechanism is fixed with the handle of the stopper and periodically checked.

. Standard samples of GOST 9454-78 with a size of 10 × 10 55 mm were used to determine the impact viscosity (type I sample – Menage). To determine the impact strength, it is necessary to divide the work spent by the plane of the cross-section of the sample at the point of the incision.

$$KS = \frac{K}{S} \quad (2)$$

Metallographic, electron microscopic and X-ray studies.

The assessment of the properties of materials was carried out using the methods of mechanical, metallographic, X-ray structural, micro-X-ray genostructural analysis, and methods of electron microscopy. Bench , laboratory and industrial trial performed with using appropriate methods State standards of Ukraine and ISO standards.

Preparation of microsands for metallographic research consists of sharpening, grinding, polishing and etching.

the position of the sample changes by 90°. Polishing of the sample is carried out on a polishing machine, first with the help of an aqueous suspension - chromium oxide, and then on a tool cloth. Polishing is considered complete when a mirror surface is reached.

The study of the microstructure and local composition of the samples was carried out on a JSM 7001F scanning electron microscope (fig. 2), equipped with an INCA Energy 350 system for energy dispersive microanalysis. Observations of the fine surface structure of the sample were performed with high resolution (2 nm), local analysis of the elemental composition (1 μm²) by the method of energy dispersive spectrometry (EDX). The analysis of the surface of the studied materials took place at an accelerated voltage of 20 kV and a beam current of 4.5 nA , which made it possible to fully display all lines on the energy dispersion spectrum and obtain high counting speeds.



Fig. 2. Electron microscope JSM 7001F

Methods of friction and wear tests.

Testing of new materials and technologies in the conditions of real production is associated with significant costs of material resources and time. In addition, it is difficult to fully assess the influence of certain factors on the processes of friction and wear in real conditions. Therefore, in order to evaluate the effectiveness of the use of materials, methods of their processing, structural changes of parts and other measures, laboratory and bench tests simulating the maximum approximation to real operating conditions were carried out. Tribotechnical characteristics are the main criteria for assessing the workability of materials for volumetric hydraulic drive parts and the effectiveness of their surface treatment.

In this regard, test methods were chosen for the work, which allow simulating the main processes of friction and wear of real parts.

The tests were carried out on the SMC-2 friction machine, which allows you to compare the tested materials in terms of wear resistance, anti-friction properties and properties in the process side jobs according to the "roller-pad" scheme (fig. 3).

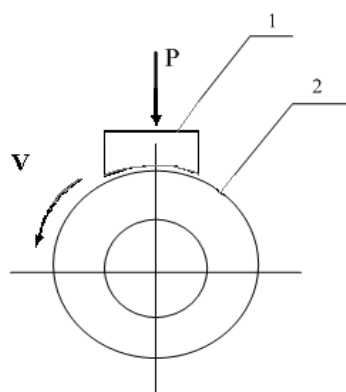


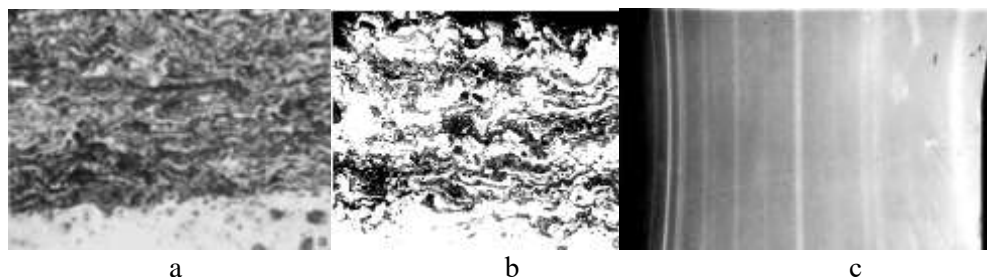
Fig. 3. "Roller-pad" scheme

Research results and their discussion

Research of the structure and properties of gas-thermal steel-molybdenum coating

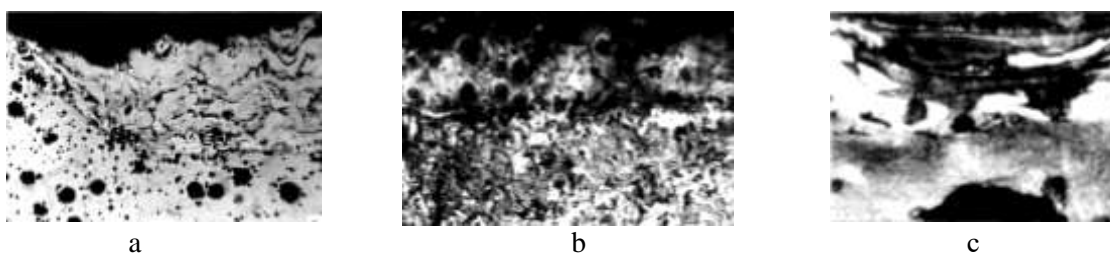
The coating on the cast iron ring was applied by the method of two-wire metallization with independent supply of molybdenum and steel wires. Sputtering from two wires of different materials leads to the formation of a pseudoalloy in the layer, built with particles of steel 11X18M and molybdenum (fig. 4). This is evidenced by the data of X-ray structural analysis: two series of lines -

molybdenum and iron - are found on X-ray images. It turned out to be impossible to choose an etchant that simultaneously reveals the structure of both molybdenum and stainless steel. In this regard, sequential etching of layers was used), and then another component. The selective action of the reagents made it possible to clearly differentiate steel and molybdenum particles in the layer.



a – complete digestion, $\times 115$; b – etching on molybdenum, $\times 115$;
c – X-ray pattern of the deposited layer, λ -Fe
Fig. 4. General view of the sprayed layer

For the successful operation of the coating, its connection with the surface of the base metal is important. Metallographic analysis showed that the steel-molybdenum coating tightly adheres to the substrate along the entire profile (fig. 5). It has been proven that preliminary shot blasting of the groove provides favorable conditions for adhesion. An important role in creating good adhesion is played by the composition of the coating, in particular, the presence of molybdenum in it.



a - unetched grind; b - complete digestion; c - etching on steel; $\times 315$
Fig. 5. Border of coating – cast iron

There is noticeable porosity in the layer, which is inevitable during isothermal application of coatings. Our assessment of the porosity of the steel-molybdenum coating on many rings using quantitative metallography shows that it is 11–12 %. Porosity within such limits is considered useful for coatings operating under conditions of extreme friction, as it creates the effect of "self-lubrication" in conditions of lack of lubricant and certain damping properties of the coating.

The microhardness of the sprayed layer was measured on the surface of the samples, since measuring the hardness of individual particles on cross sections is very difficult due to the small thickness of flattened particles (table 3).

The evaluation of the thickness of the particles in the layer and the depth of the impressions obtained when measuring the microhardness with a load of 0.49 HV showed that in most cases the pressing of the particles is excluded. The method of making the sandpapers, which is the same for all samples, involved the introduction of as little slander as possible into the surface layer. To separate the structural components in the layer, weak etching of the sections was performed to detect molybdenum particles.

The macrohardness of steel and molybdenum wires, as well as the sprayed layers, was measured by Vickers at a load of 49 HV, which did not allow the layer to be pushed through.

Table 3 - Hardness of the studied materials

Material	Hardness according to Vickers, HV	Microhardness, HV
Molybdenum wire	120	1800–2000
Steel wire	240	2900–3200
electrolytic chromium	–	7400–7900
Steel-molybdenum coating after spraying:	230-240	
molybdenum particles		4000–8000
steel particles		3000–6000
Steel-molybdenum coating after grinding:	230-240	
molybdenum particles		5000–8000
particles of steel		3000–6000
high-strength cast iron	220	

The obtained data on the hardness of the components of the steel-molybdenum gas-thermal coating and the coating with electrolytic chromium show that the gas-thermal coating is on average softer than the chrome one, which should provide it with better adaptation to the cylinder. The presence of particles with significant differences in hardness in the sprayed layer should have a positive effect on the antifriction properties of the steel-molybdenum coating.

Thus, it can be concluded that the high hardness of molybdenum particles in the sputtered layer is due to a number of factors: small grains, defatation of particles and a change in their chemical composition create conditions for hardening by aging; and the hardness of steel particles is determined by finely dispersed carbides and austenite slander.

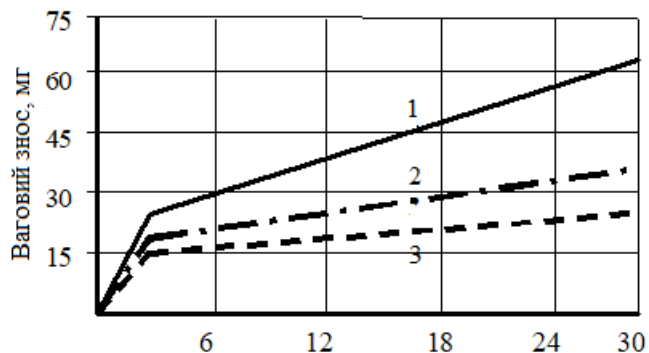
Determination of tribotechnical characteristics of piston rings strengthened by various methods

Tests on the SMC-2 friction machine were carried out for 2 hours at a load of 1.0 kN and a sliding speed of 1.3 m/s, cast iron discs were processed using serial technology for 30 minutes, M14B2 oil was used. The test results are shown in table 4.

Table 4 - Results of wear resistance tests

Piston ring	Wear intensity by mass, g/m		Coefficient of friction
	blocks (rings) ×10	discs (sleeves) ×10	
chrome	5.3	1.5	0.12
with steel-molybdenum coating	3.2	0.4	0.09

The analysis of the results shows that the steel-molybdenum coating is more wear-resistant in the studied conditions than the electrolytic chromium coating (fig. 6). The steel-molybdenum coating wears the mating material to a lesser extent and has a lower coefficient of friction.



1 – a ring with a bronze insert; 2 - chrome a ring;
3 – a ring with steel molybdenum coating
Fig. 6. Dependence of piston ring wear on test time

The analysis of the obtained data can indicate that the rings with steel-molybdenum coating wear less and the sleeve (both processed according to serial technology and strengthened by laser hardening) wears out less than serial rings with solid and porous chromium coating. Porous chrome plating reduces sleeve wear to a lesser extent than steel-molybdenum coating.

Industrial results

Piston rings with steel-molybdenum coatings were installed on paired CPG blocks of a 10-cylinder engine of a special purpose machine for operational testing (fig. 7). Serial rings with chrome coating work on odd blocks. After 100,000 km of mileage (which is equivalent to 4,000 hours of operation), sets of four rings from blocks 4,8 and 7 are removed for comprehensive research.

The structure and hardness of steel-molybdenum coatings from four rings of blocks 4 and 8, as well as the condition of chrome rings, were investigated in the work .

As a result of the structural features of the CPG unit, the upper compression rings (4H-1, 8H-1, 7H-JI) work in the most severe force and temperature conditions, and the lower ones (4H-4, 8H-4 and 7H-4) in less stressful ones.

As already mentioned, the assessment of the degree of wear by the depth of the filed layer is difficult due to the ambiguity of the coating depth from ring to ring and in one ring ($h_0 = 0.5 + 0,1$ mm). This also applies to coating with electrolytic chromium ($h_0 = 0.12-0.18$ mm). Data on the depths of the remaining layers are given in the (table. 5).

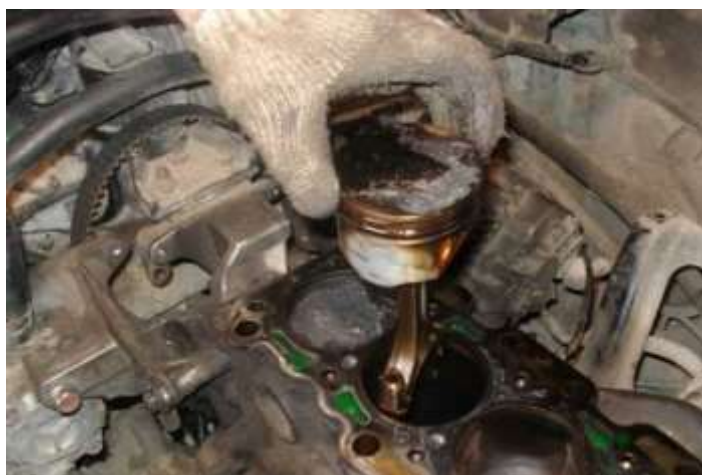


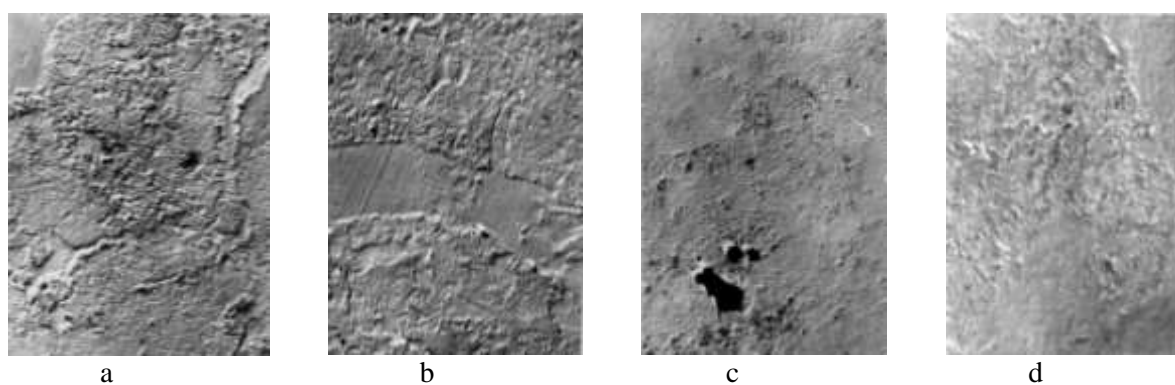
Fig. 7. Dismantling the piston

From the table 5 it can be seen that there is no certain regularity in the change of the depth of the layer from ring to ring, which may indicate a different depth of sputtering. Greater wear of the upper ring is observed for electrolytic chromium.

Table 5 - The depth of the remaining layer

Ring	4N				8N			7H (Sc)	
	1	2	3	4	1	3	4	1	4
layer depth, mm	0.35	0.60	0.37	0.56	0.35	0.35	0.35	0.091	0.119

The study of the wear surface shows that mainly abrasive wear is realized, which leads to the appearance of scratches on the surface of the layer. The condition of the wear surface is almost the same on all rings with steel-molybdenum coating due to large pores. Estimation of the porosity of the rings after a run of 100,000 km using the methods of quantitative metallography shows that it, like after spraying, is 11-13 %, that is, the cracking of the layer with pores is not related (fig. 8).



a, b – 4H-2 ring, c, d – 8H-4 ring; $\times 5000$
Fig. 8. The structure of the molybdenum component of coatings, mileage 100 thousand to m

Despite the high hardness of the chrome coating, the nature of the abrasive effect on the surface is basically the same as on the sprayed coatings. The difference is that there are areas with uneven wear on chrome coatings (fig. 8), which is a consequence of some misalignment of the ring and negative wear of the chrome coating to the cylinder. X-ray structural analysis showed that the amount of residual austenite decreases to 68–58 %.

A comparison of the microhardness data and the structure of molybdenum particles allows us to conclude that the increase in hardness is not related to an increase in the temperature of the ring, but may be a consequence of additional defatation of the layer during operation.

Conclusions

The conducted studies showed:

1. Steel-molybdenum coatings have high anti-friction properties and wear resistance, and are superior to standard chrome coatings in these parameters. They are characterized by high durability and do not require prior application of any special coatings, as for electrolytic chromium.

2. Component coatings - molybdenum and stainless steel (as well as the original materials themselves) have high corrosion resistance, which is not inferior to the corrosion resistance of chrome and cast iron, from which the rings are made.

3. The steel-molybdenum coating, applied according to the selected modes, has good adhesive strength, which is very important for ensuring the reliability of its operation.

4. Gas-thermal steel-molybdenum coating has high resistance to temperature effects: in a wide temperature range, the hardness of gas-thermal the steel-molybdenum coating does not decrease, but increases, while the hardness of the chrome coating begins to decrease already when heated to 300°C. At temperatures above 300 ° C, hard chrome is unusable in conditions of unsatisfactory wettability with oil - burns and burrs occur . A local increase in temperature leads to intensive softening, microwelding , chipping of the coating.

5. The high operational properties of steel-molybdenum coatings are due to the structure of the coating: optimal porosity, which ensures sufficient involuntary lubrication of friction surfaces; the presence in the layer of structural components with different hardness (heterogeneity of the structure); high antifriction properties of the molybdenum component.

6. The developed technology was implemented at the State Enterprise " Malyshev Plant " with an economic effect of UAH 65,000.

References

1. Hlushkova D.B. Visualization of friction surfaces / D.B. Hlushkova, V.P. Tarabanova, E.A. Nesterenko // Science in Europe-2012: materials of the international scientific and practical. conf . – Warsaw, 2012. – Vol. 46. – Z. 60 –65.

2. Bilashchenko V.V. The effective temperature of the substrate during exposure high temperature jet in the process spraying / V.V. Bilashchenko, V.A. Vakhalin, V.V. Kudinov, Yu.B. Chernyak // Physics and chemistry processing materials. - 2006. - No. 4-5. – pp. 22–26.

3. Semenov A.P. Creation wear-resistant and anti-friction coverage in and layers on surfaces friction of new machine parts methods / O.P. Semenov // Friction and wear. - 2003. - T. 3. - P. 401-411.