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STUDY OF PROCESSED BY COMPRESSION PLASMA OF MULTILAYER PLASMA COATINGS BASED ON CERAMICS

The article considers the technique of compression plasma treatment of multilayer plasma coatings based on cermet powders. The optimization of the modes of action on the near-surface layers of the formed wear-resistant coatings was carried out, both the distance of the compression-plasma treatment and the total number of input energy pulses were varied. Both the level of energy supplied to the formed coating and necessary for the processes of their melting and compaction, and the thickness of the resulting layers formed during their processing, depend on these technological parameters. In all experiments, the optimal criterion for the experiment was to obtain a total porosity in the near-surface layers in the range of 1.5–2.5%, these parameters provide an improvement in the oil-retaining capacity and lead to an increase in the wear resistance of the formed wear-resistant plasma coatings. The optimal distances according to the criteria we have chosen when processing near-surface layers of formed wear-resistant coatings are 0.09-0.10 m (for ПР-Х18Н15) and 0.10-0.11 m (for ПР-Х18Н15 - Mo - MoS2). When controlling the parameters of the total porosity in accordance with the applied processing distances, almost complete coincidence with the required values of 1.0–2.0% is seen. Under a single impact with a pulse, the grains in the layers treated with a plasma flow are angular, non-isometric, and oriented almost in the direction perpendicular to the plane of the treated sample. This preferred orientation of grains is probably associated with the crystallization process during further cooling of the sample in the directions of heat removal.

Keywords: *ceramic-metal plasma coatings, compression plasma flows, treatment distance, molded structures, near-surface layers, wear-resistant coatings, mechanical properties.*

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ИССЛЕДОВАНИЕ ОБРАБОТАННЫХ КОМПРЕССИОННОЙ ПЛАЗМОЙ МНОГОСЛОЙНЫХ ПЛАЗМЕННЫХ ПОКРЫТИЙ НА ОСНОВЕ МЕТАЛЛОКЕРАМИКИ

В статье рассмотрена методика обработки компрессионной плазмой многослойных плазменных покрытий на основе металлокерамических порошков. Проведена оптимизация режимов воздействия на приповерхностные слои сформированных износостойких покрытий. Варьировались как дистанция компрессионно - плазменной обработки, так и суммарное количество подводимых импульсов энергии. От этих технологических параметров зависят как уровень энергии, подводимый к сформированному покрытию и необходимый для процессов их оплавления и уплотнения, так и формирующаяся при их обработке толщина полученных слоев. Во всех опытах оптимальным критерием проведения эксперимента служило получение общей пористости в приповерхностных слоях в пределах 1,5–2,5 %, эти параметры обеспечивают улучшение маслоудерживающей способности и приводят к повышению износостойкости у сформированных износостойких плазменных покрытий. Оптимальными дистанциями по выбранных нами критериям при обработке приповерхностных слоев у сформированных износостойких покрытий являются 0,09-0,10 м (для ПР–Х18Н15) и 0,10-0,11 м (для ПР–Х18Н15 – Mo - MoS_2). При управлении параметрами общей пористости в соответствии с применяемыми дистанциями обработки видно практически полное совпадение с требуемыми значениями 1,0–2,0 %. При однократном воздействии импульсом зерна в обработанных плазменным потоком слоях угловатые, неизометричны и сориентированы практически в направлении, перпендикулярном к плоскости обработанного образца. Такая преимущественная ориентация зерен, вероятно связана с процессом

кристаллизации при дальнейшем охлаждении образца в направлениях теплоотвода. При многократных воздействиях компрессионной плазмы приобретенная форма у зерен приповерхностных слоев носит изометричный характер.
Ключевые слова: *металлокерамические плазменные покрытия, компрессионные плазменные потоки, дистанция обработки, сформованные структуры, приповерхностные слои, износостойкие покрытия, физико-механические свойства*.

1. Introduction. An increase in the efficiency of plasma-applied self-fluxing coatings based on powder materials based on diffusion-alloyed austenitic steels with the addition of molybdenum and molybdenum disulfide can be carried out by controlling the properties of their individual sections. This contributes to the optimal combination of the properties of various sections of the obtained coatings, which must correspond to the functional purposes of the materials deposited by the plasma. Nevertheless, the technologies for their creation have prospects for further improving the properties of the formed materials as a result of the use of methods for processing them using highly concentrated energy flows. Using layer-by-layer processing of wear-resistant coatings deposited using a plasma installation with short-term pulses of compressive plasma flows using different levels of input energy, it is possible to create the possibility of forming certain structures with adjustable and decreasing from the upper outer layers of the obtained coatings to the base (substrate) total porosity. This type of treatment contributes to an increase in their oil-retaining capacity and wear resistance of the formed friction surfaces to an additional combination with an increased cohesive and adhesive strength near the boundary layers. On the basis of statistics on the values of limiting wear variations for operated parts, for which the technologies created by us are intended, the thickness of the layers applied by the plasma installation was taken to be about 0.5 - 0.6 mm. Plasma wear-resistant coatings from composite powder materials obtained by diffusion alloying from powder materials based on austenitic grade steels (ПР–Х18Н15) and the same materials with the addition of molybdenum and molybdenum disulfide (ПР–Х18Н15-Mo- MoS_2) was treated layer by layer with pulses of compression plasma flows generated using a magnetic plasma compressor (МПК) [1–8].

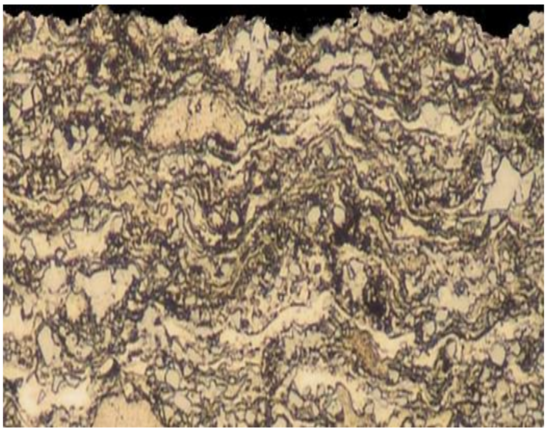
2. Experimental technique.

A previously evacuated MPC vacuum chamber was used; it was filled with nitrogen to the required pressure (100-1300 Pa). The amplitude values of the parameters of the discharge current of the МПК varied in the ranges from 70 to 100 kA, with a corresponding increase in the parameters of the initial voltage at the energy storage device (from 3 to 5 kV). The duration of the pulse discharge values was about 150 μs. Under the accepted conditions, a compression plasma flow with a diameter of 1 cm and a length of 10 cm is formed at the output of this discharge device (МПК) [4–8]. During our optimization, the modes of action on the near-surface layers of the formed wear-resistant coatings varied both the distance of compression-plasma treatment and the total number of input energy pulses. Both the level of energy supplied to the formed coating and necessary for the processes of their melting and compaction, and the thickness of the resulting layers formed during their processing, depend on these technological parameters. In all experiments, the optimal criterion for the experiment was to obtain a total porosity in the near-surface layers in the range of 1.5–2.5%, these parameters provide an improvement in the oil-retaining capacity and lead to an increase in the wear resistance of the formed wear-resistant plasma coatings [4]. The results obtained by optimizing the process modes are presented in Table 1. The optimal distances according to the criteria we have chosen when processing the near-surface layers of the formed wear-resistant coatings are 0.09-0.10 m (for ПР–Х18Н15) and 0.10 -0.11 m (for ПР–Х18Н15 - Mo - MoS_2). When controlling the parameters of the total porosity in accordance with the applied processing distances, almost complete agreement with the required values of 1.0–2.0% is seen. It is difficult to completely reduce the experimentally obtained and the specified intervals for the parameters of the total porosity, which is dictated by the multifactorial nature of the process of formation in coatings during compression-plasma treatment of layer structures. Regarding the required number of required pulses for high-quality processing of near-surface layers of wear-resistant plasma coatings with a total thickness of 0.5-0.6 mm, for ПР–Х18Н15 and ПР–Х18Н15 - Mo - MoS_2 they were 15 and 14 impacts, respectively. Based on the performed metallographic analysis of the structures of the samples treated with compression plasma during our optimization of the required number of pulses, we can draw the following conclusions: under a single pulse xposure, the grains in the layers treated with a plasma flow are angular, non-isometric and oriented almost in the direction perpendicular to plane of the processed sample. Such a predominant orientation of grains is probably associated with the crystallization process during further cooling of the sample in the directions of heat removal. Under repeated exposure to a flow of compression plasma, the acquired shape of the grains of the near-surface layers is isometric. In Figure 1, using the example of ПР–Х18Н15 and ПР–Х18Н15 – Mo - MoS_2 coatings, typical structures of the treated near-surface layers are shown. These structures are fused plasma coatings with a fine-grained structure evenly distributed in the coating. In the ПР–Х18Н15 coating, this is a γ-solid solution, as well as the Fe_2B, FeB, Fe_3 (BC) phases, and in the ПР–Х18Н15 – Mo - MoS_2 coating, the M_{23}(C, B)$_6$, Mo_2(B, C), and Fe_3Mo_3 phases (C, B), where (M = Fe, Cr, Mo), which contributes to an increase in the wear resistance of the treated wear-resistant coatings under the conditions of the friction process with boundary and imperfect lubrication. The total porosity evenly distributed in the coating stabilizes the formed lubricating film at the tribo-couplings. An ordered distribution of phases significantly increases the hardness characteristics of the obtained wear-resistant coatings, reduces the deformation parameters of the working surfaces in friction pairs, thereby reducing the actual interaction area of the rubbing surfaces. Consequently, the probability of direct metal contact at the formed friction surfaces also significantly decreases, and this reduces the intensity during wear by microcontact setting. These properties of the formed near-surface layers lead to an increase in the wear resistance of the resulting coatings, their microhardness, as well as the formation of predominantly residual compressive stresses.

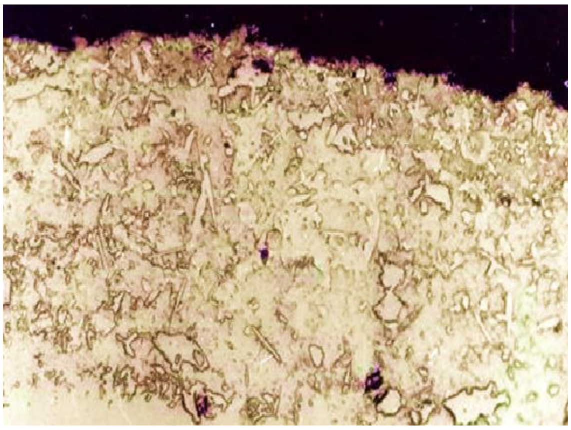
Table 1. – Data for optimizing the processing distance

Formed coating	Characteristic distances of compression-plasma treatment, m	Values of the total coating porosity, %
ПР–Х18Н15	0,14	2,6-2,9
	0,13	2,3-2,7
	0,12	2,1-2,5
	0,11	2,0-2,3
	0,10	1,7-1,9
	0,09	1,5-1,6
	0,08	1,8-2,2
	0,07	destruction fixation
ПР–Х18Н15 – Mo - MoS_2	0,14	3,0-3,3
	0,13	2,6-3,1
	0,12	2,4-2,8
	0,11	2,2-2,5
	0,10	1,6-2,0
	0,09	2,3-2,6
	0,08	destruction fixation

The increase in microhardness indicators is also confirmed by experimental data (table 2). An increase in the values of the microhardness parameters in comparison with the untreated material indicates the strengthening of the near-surface layers, which creates the preconditions for an increase in their resistance to mechanical wear.



a



b

Figure 1. Microstructure of layers of plasma wear-resistant coatings ПР–Х18Н15 и ПР–Х18Н15 - Mo – MoS_2after exposure to pulses of compression plasma flows at optimal modes (×200)

The obtained maximum values of microhardness are mainly observed at depths of 100-120 microns, this is due to processes associated with the nature of the shock-wave effects of compression plasma jet pulses, which cause hardening hardening. The characteristics of the rigidity of the shock wave action, the degree of hardening and microhardness are significantly reduced with distance from the surface of the wear-resistant coating formed by plasma spraying. At parameters that form a hard shock wave action directly on the resulting sample surface, overhardening phenomena take place, they weaken the formed coating and reduce its microhardness. The compressive stresses obtained in the coating as a result of compressive plasma treatment lead to a significant increase in resistance during mechanical destruction occurring during friction processes. Residual compressive stresses in the coating are formed due to shock-wave effects and significant plastic deformation, as well as cold hardening that occurs in this case.

Table 2. – Microhardness of the surface layers of the formed coatings.

Полученные покрытия	Значения показателей микротвердости, $МПа_{100}$				
	Пояса замеров по длине поперечного сечения покрытия				
	1	2	3	4	5
ПР–Х18Н15 before processing	6895-8025	4885-6839	5432-7745	5168-7621	6170-7537
ПР–Х18Н15 after processing	9065-10041	8124-9614	8766-10295	7710-9223	7989-9621
ПР–Х18Н15-Mo-MoS_2 before processing	7012-8193	5067-7012	5619-7924	5276-7762	6311-7703

ПР–Х18Н15-Mo-MoS_2 after processing	9236-10194	8312-9781	8987-10402	7957-9455	8095-9877

3. Conclusion.

Optimization of layer-by-layer processing by pulses of compression plasma flows generated by a magnetoplasma compressor (МПК) has been carried out., plasma coatings from composite materials obtained by diffusion alloying from powders based on austenitic steels (ПР–Х18Н15) and the same materials with the addition of molybdenum and molybdenum disulfide (ПР–Х18Н15 -Mo-MoS_2). During the optimization by the modes of action on the surface layers of the formed coatings, the distances of compression-plasma treatment, as well as the total number of input pulses, varied. Both the level of energy supplied to the coating for the processes of reflow and compaction and the thickness of the layers obtained during processing depend on these technological parameters. The optimal criterion was to obtain a total porosity in the surface layers in the range of 1.5–2.5%, which provides an improvement in the oil-retaining capacity and an increase in the wear resistance of the formed plasma coatings. The optimal distances for processing the surface layers of the formed coatings are 0.09-0.10 m for ПР–Х18Н15 and 0.10-0.11 m for ПР–Х18Н15-Mo-MoS_2. As for the required number of pulses for the complete treatment of surface layers of wear-resistant plasma coatings with a total thickness of 0.5 - 0.6 mm, it was 15 and 14 impacts for ПР–Х18Н15 and ПР–Х18Н15-Mo-MoS_2 coatings, respectively. Structural elements are fairly evenly distributed in the coating. In the ПР–Х18Н15 coating, this is a γ-solid solution, Fe_2B, FeB, Fe_3 (BC) phases, and in the ПР–Х18Н15-Mo-MoS_2 coating, the M_{23} (C, B)$_6$, Mo_2(B, C) and Fe_3Mo_3(C) phases , B), where (M = Fe, Cr, Mo), which contributes to an increase in the wear resistance of the treated coatings under friction conditions with boundary and imperfect lubrication. Evenly distributed phases significantly increase the hardness of the resulting coatings, reduce their degree of deformation of the working surface in the friction pair, which reduces the actual contact area of the rubbing surfaces. Therefore, the probability of direct metal contact at the friction surfaces decreases and the intensity of wear by microcontact setting decreases. The properties of the surface layers obtained in this way contribute to an increase in the wear resistance of the coatings. Along with the factors discussed above, an increase in the wear resistance of the treated surface layers is also achieved by an increase in their microhardness, as well as the formation of residual compressive stresses.

LITERATURE:

1. Restoration of machine parts: Ref. / F. I. Panteleenko [and others]; ed. V. P. Ivanova. - M.: Mashinostroenie, 2003. - 672 p.

2. Wear-resistant gas-thermal coatings from diffusion-alloyed powders based on cast-iron shavings / V. M. Konstantinov [et al.]: ed. F. I. Pan-Teleenko. - M.: Technoprint, 2005. - 146 p.

3 Theory and practice of applying protective coatings / P. A. Vityaz [et al.]. - M.: Belorus. science, 1998. - 583 p.

4. Ilyushchenko, A. F. High-energy processing of plasma coatings / A. F. Ilyushchenko, V. A. Okovity, A. I. Shevtsov; under total ed. A. F. Ilyushchenko. – M.: Bestprint, 2007. – 246 p.

5.Grigoryants, A.G. Fundamentals of laser processing of materials / A.G. Grigoryants. - M.: Mashinostroenie, 1989. – 304 p.

6. Parallel Laser Melted Tracks: Effects on the Wear Behavior of Plasma-Sprayed Ni-Based Coatings / D. Felgueroso [et al.] // Wear. – 2008. Vol. 264, nos. 3–4. – R. 257–263.

7. Panteleenko, A. F. Composite coatings obtained by high-energy methods / A. F. Panteleenko, O. G. Devoino // Advanced materials and technologies / VSTU; editorial board: V. V. Klubovich [and others]. – Vitebsk, 2013. – S. 587–607.

8. Panteleenko, A.F. Study of the morphology and microstructure of coatings from diffusion-alloyed powder PR-Kh18N9 obtained by plasma spraying with subsequent laser modification / A. F. Panteleenko // Vestnik BrGTU. – 2012. – No. 4. – S. 37–39.

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