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Satbayev University

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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
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MODIFICATION OF COATINGS BASED ON Al2O3 WITH CONCENTRATED ENERGY FLOWS

Abstract. This paper presents the study results of structural-phase composition and mechano-tribological properties of Al_2O_3 coatings after exposure of concentrated energy flows. Revealed that the treated coatings are generally characterized by high microhardness compared to the initial coating. Determined that after treatment with detonation and air-plasma action is observed an increase in the intensity of α-Al_2O_3 reflexes. Established that the increasing hardness of detonation coatings is associated with an increasing density of the material and the recovery of the α-phase Al_2O_3 in the composition of the protective layer under the influence of thermal activation of the surface. Determined that after treatment with detonation and plasma exposure is observed an increase in the intensity of reflexes α-Al_2O_3. Established that the treatment with detonation and air-plasma action leads to a decrease in the friction coefficient. The obtained data indicate that the tribological characteristics of coating based on aluminium oxide can be improved by exposure to concentrated energy flows. Established that coatings treated with plasma action showed high tribological properties.

Key words: Detonation spraying, plasma spraying, hardness, wear resistance, coating.

1. Introduction. Obtaining coatings with high-performance characteristics that provide increased products reliability and durability in extreme conditions characterized by improved mechanical loads, wear, corrosion, aggressive media, and cyclic exposure is a fundamental task of the industry.

To increase the adhesive strength, reduce porosity, eliminate non - molten powder particles in the coating structure and provide an even distribution of micro-hardness on the depth of the hardened layer is used re-melting of the coating with concentrated energy sources [1-3].

The technological capabilities analysis of processing main methods with concentrated energy sources (electric arc, electron beam, laser, plasma and induction) [4], which can be used for repeated high-energy effects on the structure of plasma coatings, showed that when re-processing current conductive plasma coatings have a clear advantage high-energy heating with high-frequency currents [5-7]. A characteristic feature of this process is that the heating source is volumetric, and energy is released in the surface layer, the thickness of which is determined by the current frequency, electrical resistivity and thermal physical characteristics of the coating material. Selecting the relevant frequency of the generator allows concurrent heating throughout the entire thickness of the applied coating.

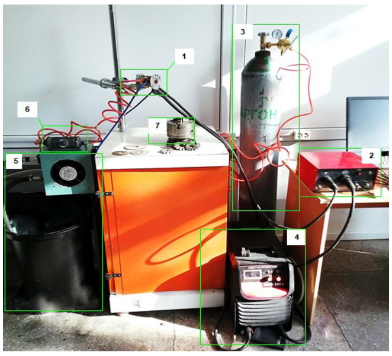
In this connection, we conducted experiments on the treatment of aluminium oxide coating with concentrated energy flows

2. Research Method. 12H18N10T stainless steel was chosen as a substrate. The samples were sandblasted before coating. Corundum powders (α-Al2O3) were used to obtain coatings from aluminum oxide. The particle size of the powder is up to 22-45 μm.

Detonation coatings were obtained on a computerized complex of new generation detonation spraying CCDS2000 (Computer Controlled Detonation Spraying) [8-10]. CCDS2000 allows applying coatings from a wide range of materials to various substrates. The main elements of the complex are shown in figures 1.

a) working body (gun), consisting of a barrel, a gas distribution block and powder dispensers; b) block control based on an industrial computer; c) gun complete with three coordinates manipulator
Figure 1 – Detonation complex CCDS2000

Surface modification of coatings was carried out using detonation and plasma action. The detonation effect was carried out on the CCDS2000 detonation complex by detonating a gas explosion without using powder. The expense of working gases is at an average frequency of shots in 4 Hz no more: acetylene 4-7; propane butane mixture 2...3,5; oxygen 10...12; nitrogen 10...15 m3/h. Nitrogen was used as a carrier gas. Plasma action was carried out on the set up (Figure 2) of plasma spraying at atmospheric pressure [11]. The figure shows a general view of the plasma installation. Experiments on plasma treatment were carried out without using powder in the following mode: the movement speed is 2-30 mm / s, the distance between the plasmatron and the product is 45-55 mm, the diameter of the spray spot is 10-25 mm. The heating temperature of the parts during spraying does not exceed 150-200°C. The working pressure of the gas (air) is 0.2-0.3 MPa.



1 - plasmatron, 2 - process control unit, 3 - gas supply cylinder, 4 - power supply system, 5 - cooling system, 6 - bifurcated powder supply channel with expansion barrel, 7 - sample holder. 8 - compressor.

Figure 2 – Installation for plasma coating

Table 1 shows the modes of obtaining coating Al2O3 and its modification by detonation and plasma action.

Table 1-Technological parameters for obtaining and modifying Al_2O_3 coatings

Processing type	Barrel filling volume, %	Distance, mm	Shots number	Delay time between shots, s	Working gas	Arc current, A	
Detonation spraying of Al_2O_3 coatings	63	250	20	1	-	-	-
Treatment of Al_2O_3 coatings by the detonation action	80	250	20	0,25	-	-	-
Treatment of Al_2O_3 coatings by plasma action	-	200	-	-	Ar	135	40

The microhardness of the samples was measured by methods indentation of a diamond indenter on a PMT-3M (LOMO, Russia) device in accordance with GOST 9450-76 [12], at a load of 200 g and an exposure time of 10 s. The study of the surface microstructure was carried out on a scanning electron microscope Vega3 (Tescan, Brno, Czech Republic). The research phase composition of the samples was studied by X-ray diffractometer X'PertPro (Philips Corporation, Nederland) using CuKα radiation. The shooting was carried out in the following modes: tube voltage U = 45 kV; tube current I = 35 mA; exposure time 1s; shooting step $\Delta 2\theta \sim 0.02°$ and $2\theta = 10–90°$. Tribological tests for sliding friction were performed on a high-temperature tribometer TRB3 (Anton Paar Srl, Peseux, Switzerland) using the standard "ball-disc" technique (international standards ASTM G 133-95 and ASTM G 99). Sample tests for abrasive wear were carried out on an experimental stand (Figure 2 a) for testing for abrasive wear when frictional against not hard fixed abrasive particles according to the scheme "rotating roller-flat surface" by GOST 23.208-79, which coincides with the American standard ASTM C 6568. The wear resistance of the test material was estimated by the weight loss of the samples during the test. The measurement of hardness and elastic modulus was determined by the indentation method on the NanoScan - 4D compact (FSBI TISNCM, Russia) nanotoughness tester in accordance with GOST R 8.748-2011 and ISO 14577 indentation with a load of 0.1 N.

3. Research results and discussion. Figure 3 shows a comparative graph of the microhardness distribution over the depth of samples with Al_2O_3 coated which treated by detonation and plasma action. The treated coatings are generally characterized by high microhardness compared to the original coating. High hardness is observed on the surface of the coating, and as it approaches the surface of the substrate, the hardness decreases.

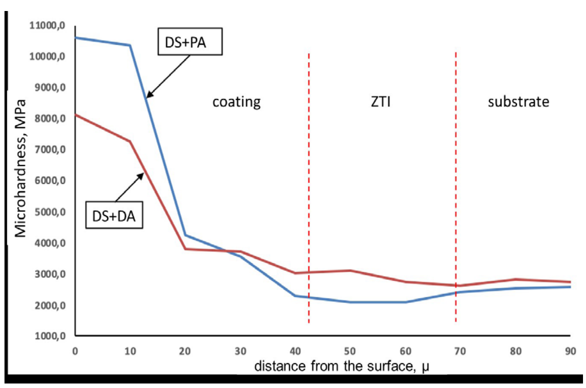


Figure 3 – Graph of the hardness distribution over the depth of Al_2O_3 coatings

Morphology analysis of the cross-section of coatings showed that detonation coatings based on Al_2O_3 after treatment with detonation action (Figure 4) only slightly smoothes the roughness of the powder layer. After treatment with plasma action (Figure 5), it leads to a noticeable decrease in roughness, which makes it possible to deposit Al_2O_3 coatings that are uniform in thickness and form a coating with a size of inhomogeneities of 1.0 microns. Plasma heating of Al_2O_3 coatings causes intensive melting, partial sputtering and degassing of the treated sections of the protective layer. Distribution maps of elements along the line obtained by the SEM method with energy dispersion analysis clearly confirm the mutual penetration of the coating and substrate elements (Figure 6 and Figure 7). Since the depth of this penetration is significant, in this case, it can be argued that we are observing the development of radiation-stimulated diffusion.

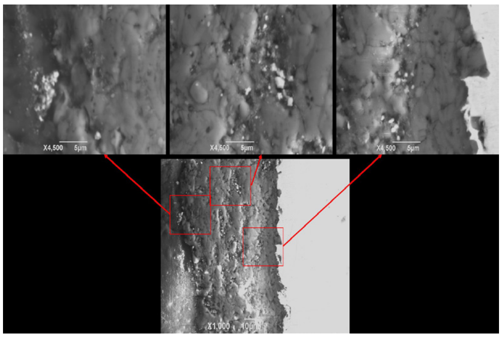


Figure 4 – Detonation coatings based on Al_2O_3 after treatment with detonation action

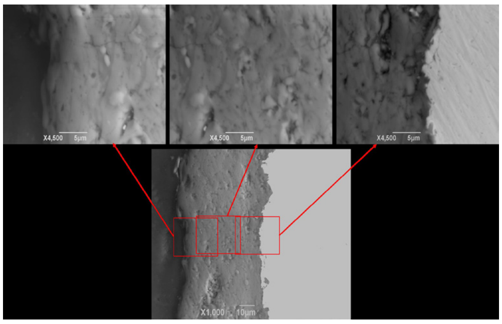


Figure 5 – Detonation coating based on Al_2O_3 after plasma treatment

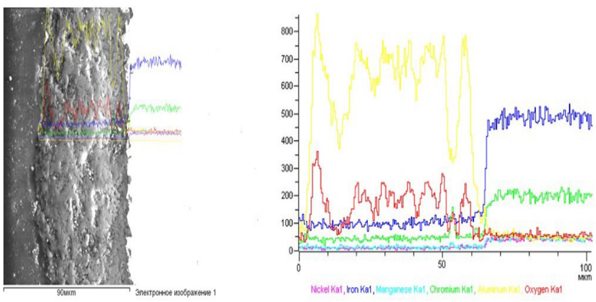


Figure 6 – Distribution of elements along the Al_2O_3-based coating line after treatment by the detonation action

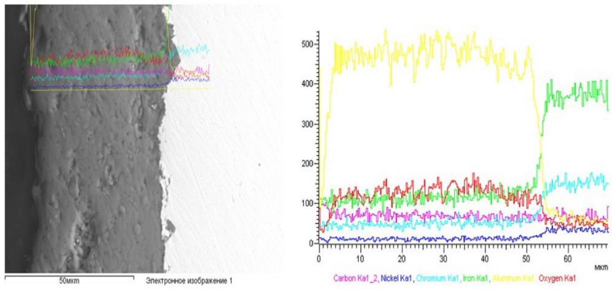


Figure 7 – Distribution of elements along the Al_2O_3-based coating line after treatment by plasma action

Figure 8 shows the results of tribological tests of aluminium oxide coatings obtained by the combined method. The figure shows that after detonation and plasma action, the wear intensity decreases, as well as the mass loss after the abrasive wear test. This indicates an increase in the wear resistance of coatings. At the same time, coatings treated with plasma action showed high indicators of tribological properties.

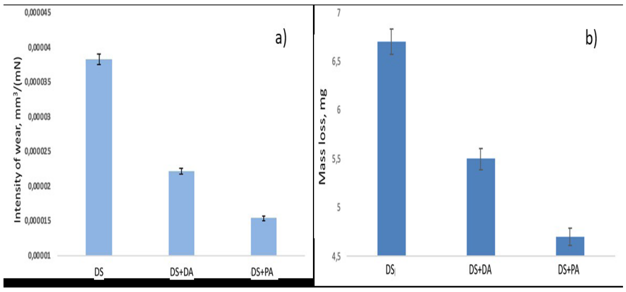


Figure 8 – Results of tribological tests by methods of testing according to the scheme ball-disk (a) and abrasive wear test (b)

Figure 9a shows the diffractograms of the aluminium oxide coating obtained by the combined method. Visible that after treatment with detonation and plasma action is observed an increase in the intensity of α-Al_2O_3 reflexes. The increased hardness of coatings is associated with increased density of the material and the recovery of α-phase Al_2O_3 in the composition of the protective layer under the influence of thermal activation of the surface.

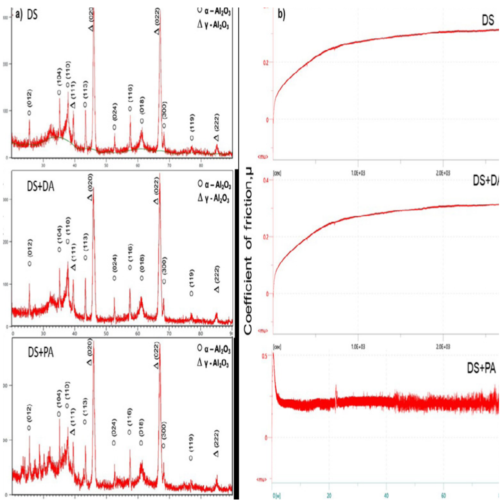


Figure 9 – Diffractogram and curves of the friction coefficient of Al_2O_3 coatings obtained under different deposition modes.

Figure 9b shows the friction coefficient curves. Visible from the figure that the treatment with detonation and air-plasma action leads to a decrease in the friction coefficient. Reducing the friction coefficient will have a positive effect on the wear resistance of aluminium oxide coatings.

4. Conclusion

The effect of modification by concentrated energy flows of Al_2O_3 coatings was studied obtained by the detonation method. The study showed that after treatment with plasma exposure roughness of Al_2O_3 coatings decreased, and after treatment with detonation exposure, the roughness practically does not change. After detonation and plasma exposure is observed an increase in the volume fraction of α-Al2O3, and this is especially noticeable when treated with plasma exposure. The results of experimental studies have shown that the surface treatment of coatings with detonation and plasma exposure leads to an increase in micro-hardness and wear resistance. It is determined that after plasma exposure, the wear intensity 2 times decreases, and the friction coefficient decreases by 30%. An increase in the tribological properties of Al_2O_3 coatings is associated with an increase in the volume fraction of α - Al_2O_3.

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Al2O3 НЕГІЗІНДЕГІ ЖАБЫНДАРДЫ КОНЦЕНТРАЦИЯЛАНҒАН ЭНЕРГИЯ АҒЫНДАРЫМЕН МОДИФИКАЦИЯЛАУ

Аннотация. Бұл жұмыста концентрацияланған энергия ағындарының әсерінен кейін Al_2O_3 жабындарының құрылымдық-фазалық құрамын және механикалық-трибологиялық қасиеттерін зерттеу нәтижелері келтірілген. Өңделген жабындар, бастапқы жабынмен салыстырғанда жоғары микро қаттылықпен сипатталады. Градиент жабындарының қаттылығының жоғарылауы материалдың тығыздығының жоғарылауымен және бетінің термиялық активтенуінің әсерінен қорғаныс қабатының құрамындағы Al_2O_3 α-фазасының төмендеуімен байланысты екендігі анықталды. Al_2O_3 жабындыларын плазмалық қыздыру қорғаныш қабатының өңделген телімдерінің қарқынды еруін, жартылай тозаңдануын және газсыздандыруын тудыратыны анықталды. Детонациялық және ауа-плазмалық әсермен өңдеу үйкеліс коэффициентінің төмендеуіне әкелетіні анықталды. Алынған мәліметтер концентрацияланған энергия ағындарының әсерінен алюминий оксиді негізіндегі жабынның трибологиялық сипаттамаларын арттыруға болатындығын көрсетеді. Трибологиялық қасиеттердің жоғары көрсеткіштері ауа-плазмалық әсермен өңделген жабындарды көрсетті. Трибологиялық сипаттамалардың жоғарылау себептері негізінен α-Al_2O_3 көлемдік үлесінің артуымен байланысты екендігі анықталды.

Түйін сөздер: детонациялық тозаңдату, плазмалық тозаңдату, қаттылық, тозуға төзімділік, жабын.

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МОДИФИЦИРОВАНИЕ ПОКРЫТИЙ НА ОСНОВЕ Al2O3 КОНЦЕНТРИРОВАННЫМИ ПОТОКАМИ ЭНЕРГИИ

Аннотация. В данной работе представлены результаты исследования структурно-фазового состава и механико-трибологических свойств покрытий Al_2O_3 после воздействия концентрированными потоками энергии. Обработанные покрытия в целом характеризуются высокой микротвердостью по сравнению исходным покрытием. Установлено, что повышение твердости градиентных покрытий связано с увеличением плотности материала и восстановлением α-фазы Al_2O_3 в составе защитного слоя под влиянием термической активации поверхности. Установлено, что плазменное нагревание покрытий Al_2O_3 вызывает интенсивное плавление, частичное распыление и дегазацию обработанных участков защитного слоя. Определено, что после детонационного и воздушно-плазменного воздействия уменьшается интенсивность изнашивания, а также потеря массы после испытания на абразивное изнашивание. Установлено, что обработка детонационным и воздушно-плазменным воздейстием приводит к уменьшению коэффициента трения. Полученные данные свидетельствуют о том, что путем воздействия концентрированными потоками энергии можно повысить трибологические характеристики покрытия на основе оксида алюминия. Определено, что высокие показатели трибологических свойств показали покрытия, обработанные воздушно-плазменным воздействием. Установлено, что причины повышения трибологических характеристик в основном связано с увеличением объемной доли α-Al_2O_3.

Ключевые слова: детонационное напыление, плазменное напыление, твердость, износостойкость, покрытие.

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