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DEVELOPMENT OF WEAR-RESISTANT COMPOSITE MATERIAL BASED ON MULTIFUNCTIONAL CERAMICS FOR PLASMA SPRAYING IN AIR

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Abstract. This paper presents a technology for producing a composite ceramic material. Oxide ceramic powders were prepared by agglomeration of a fine-dispersed powder mixture followed by high-temperature sintering of the following compositions: Al_2O_3 - Cr_2O_3 - 15 % (MoS_2–Ni), Al_2O_3 - Cr_2O_3 - 15 % (CaF_2 - Ni), and Al_2O_3 - Cr_2O_3 - 15 % (graphite - Ni). The structure of the developed powders provides the basis for producing wear-resistant coatings with high performance under corrosive wear conditions. Granulation was carried out for 3–3.5 h, followed by spheroidization in an argon atmosphere using a 50-kW plasma torch. The resulting composite ceramic material exhibits high processability, maintains its chemical composition during plasma spraying, and enables the formation of coatings with high wear resistance and a low coefficient of friction. Coatings produced from Al_2O_3 - 25 % TiO_2 - 25 % Cr_2O_3 - 12.5 % MoS_2 and Al_2O_3 - 25 % TiO_2 - 25 % Cr_2O_3 -12.5 % CaF_2 powders exhibited wear resistance 1.8 times higher under lubricated friction conditions and 1.7 times higher under dry friction in a corrosive environment than coatings produced from the conventional Al_2O_3 - 30 % TiO_2 - 12.5 % MoS_2 powder.
Keywords: composite ceramic material, plasma spraying, oxide ceramics, wear resistance, corrosion resistance.

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РАЗРАБОТКА ИЗНОСОСТОЙКОГО КОМПОЗИЦИОННОГО МАТЕРИАЛА НА ОСНОВЕ МНОГОФУНКЦИОНАЛЬНОЙ КЕРАМИКИ ДЛЯ ПЛАЗМЕННОГО НАПЫЛЕНИЯ НА ВОЗДУХЕ

Аннотация. В статье представлена технология получения композиционного керамического материала. Порошки оксидной керамики получены методом агломерирования мелкодисперсной шихты с последующим высокотемпературным спеканием составов Al_2O_3 - Cr_2O_3 - 15 % (MoS_2 - Ni), Al_2O_3 - Cr_2O_3 – 15 % (CaF_2 - Ni) и Al_2O_3-Cr_2O_3 - 15 % (графит-Ni). Строение разработанных порошков создает предпосылки получения износостойких покрытий, эффективных в условиях коррозионного изнашивания. Ганулирование проводили в течение 3–3,5 ч с последующей сфероидизацией в потоке аргона плазменным распылителем мощностью 50 кВт. Полученный композиционный материал обладает высокой технологичностью, устойчив к поддержанию химического состава при плазменном напылении и обеспечивает формирование покрытий с высокой износостойкостью и низким коэффициентом трения. Покрытия, полученные из порошков Al_2O_3 - 25 % TiO_2 – 25 % Cr_2O_3 - 12,5 % MoS_2 и Al_2O_3 – 25 % TiO_2 – 25 % Cr_2O_3 - 12,5 % CaF_2 имеют износостойкость в 1,8 раза выше при трении со смазкой и в 1,7 раза выше при сухом трении в условиях коррозии по сравнению со стандартным порошком Al_2O_3 – 30 % TiO_2 - 12,5 % MoS_2.

Ключевые слова: композитный керамический материал, плазменное напыление, оксидная керамика, износостойкость и коррозионная стойкость.

1. Introduction

Due to the use of high-temperature gas jets, thermal spraying is most effective for applying coatings from refractory materials, particularly metal oxides, which have high bond strength in the crystal lattice and simultaneously exhibit high cohesive strength, hardness, and wear resistance. Plasma spraying is the most widely used method for applying ceramic coatings. The plasma spray hardening process offers several advantages: ease of control over the coating process, the plasma energy characteristics can be changed depending on the technological requirements during the spraying process; the possibility of applying a coating to large and small surfaces, as well as products with complex shapes; during the spraying process, the coated surface is heated to relatively low temperatures, which helps preserve the structural features and properties of the base material; a plasma jet has a significantly higher temperature and a harder torch than a gas flame jet formed during the combustion of acetylene, and plasma coatings have a higher density and adhesion to the base than gas flame coatings. Due to a number of the above-mentioned reasons, the plasma spraying method is unrivaled and often has no alternative. Many design and technological challenges of modern technology can be successfully solved only with the help of plasma protective coatings, and the majority of materials that ensure high performance indicators can be applied only by plasma spraying methods and not by any other. At the same time, most plasma spraying methods meet the requirements of modern technology in terms of their main technical and economic indicators, and the properties of the coatings satisfy the most stringent requirements for operation in extreme conditions. The performance of the applied materials is determined by their structure. The latter largely depends on the optimization of the spraying process parameters and subsequent coating processing. Coatings based on multifunctional oxide ceramics with the addition of solid lubricants differ from coatings made of pure oxides by better ductility and increased resistance to impact loads, and also have lower porosity values, a uniform structure and isotropic properties [1-4]. Solid lubricants are finding increasingly widespread use in friction units of modern machines and mechanisms. Under conditions of sliding friction with high specific loads, aggressive environments, deep vacuum, and radiation conditions over a wide temperature range (from 180 to 400°C), the use of solid lubricants is the only way to ensure reliable operation of friction units. The conducted analysis allows us to conclude [5-12] that the most effective method for increasing the service life of components is plasma spraying of a wear-resistant ceramic coating based on multifunctional oxide ceramics with solid lubricant inclusions. The performance properties of the coatings will largely depend on the properties of the resulting powder. To improve the antifriction properties of wear-resistant ceramic plasma coatings under corrosive conditions, it is necessary to introduce chromium oxide into the composition of the original powders. Aluminum oxide-chromium oxide coatings are characterized by increased ductility, corrosion resistance, and impact resistance, as well as lower porosity, a uniform structure, and isotropic properties compared to aluminum oxide-titanium oxide composites. The heating rate of oxide particles in a plasma jet is limited by their low thermal conductivity [13-14]. Agglomeration methods and the binders used make it possible to produce agglomerates with high porosity and specific surface area from finely dispersed charge components (1-3 µm in size). This leads to intensified heat exchange between the jet and the particles, as well as increased particle velocity. The aim of the work is to create a composite ceramic material based on titanium dioxide - aluminum oxide - solid lubricant - chromium oxide, which has good technological characteristics, is resistant to maintaining the chemical composition during the process of thermal spraying and is capable of forming plasma coatings with high wear resistance under corrosion conditions [15].

2. Research Results and Discussion

A technology comprising the following stages was developed for the production of agglomerated composite ceramic powders of alumina, chromium oxide, and a nickel-clad solid lubricant (graphite, molybdenum disulfide, and calcium fluoride). The first stage involves weighing (dosing) the batch components and binder. The second stage involves preparing the batch and binder. The binder is then added to the batch and granulated. After granulation, the volatile component of the binder is removed and sintered to increase the strength of the agglomerates. The sintered material is then milled and screened. Powder with a particle size of 40–63 µm is the finished product; the remaining powder is reprocessed. This fraction is most frequently used for spraying wear-resistant coatings; its narrow fractional composition allows for easy transport of the powder in a stream to the substrate. In addition, the 40-63 µm fraction allows for producing dense and non-oxidized coatings. The powders obtained after agglomeration are characterized by a complex geometric shape and developed surface relief of the particles. The particle sizes during loose pouring and ultrasonic dispersion are, respectively, within the following ranges: Al_2O_3 - Cr_2O_3 – 15 % (MoS_2 - Ni) composition - 10-220 µm, 0-63 µm; Al_2O_3 - Cr_2O – 15 % (CaF_2 - Ni) composition – 10-280 µm, 0-63 µm; Al_2O_3 - Cr_2O -15 % (graphite-Ni) composition - 10-250 µm, 0-63 µm. A noticeable difference in the sizes of composite particles during loose pouring and ultrasonic dispersion indicates a tendency of the powders to form lumps. This is due to the hygroscopicity of the powders, their complex shape and relief. The tendency to form lumps reduces the "flow" of powder materials and their processability during thermal spraying of coatings. Therefore, in order to improve the technological parameters of the powders, they were spheroidized by introducing powder particles into a plasma spray jet and spraying in an argon environment. Oxide ceramic powders with the introduction of a nickel-plated solid lubricant of the following compositions were obtained: Al_2O_3 - Cr_2O_3 - 15% (MoS_2 - Ni) composition; Al_2O_3 - Cr_2O – 15 % (CaF_2 - Ni) composition; Al_2O_3 - Cr_2O - 15% (graphite-Ni) composition. Mixing of finely dispersed components of the batch was carried out in a jar mixer model 022. Then the batch portions were placed in the drums of a rotary granulator model 03-03-01. A binder was introduced and the granulation operation was carried out. Granulation of the batch was carried out at optimal operating modes of the rotary granulator, ensuring the highest yield of finely dispersed fractions: - amount of batch in the drum - 125 g; - drum rotation speed - 36 rpm; - drum inclination angle - 40o. To study the effect of granulation time on the kinetics of agglomerate formation, material samples were taken 1.5; 2.0; 2.5; 3.0; 3.5; 4.0 hours after the start of the granulation operation, which were subjected to analysis after removing the binder, sintering, crushing and sieving. The binder removal, sintering, crushing, and sieving modes were maintained constant throughout all experiments. The effect of granulation time on the content of various fractions in the powder was determined. The effect of granulation time on the content of various fractions in the powder is shown in Figure 1.

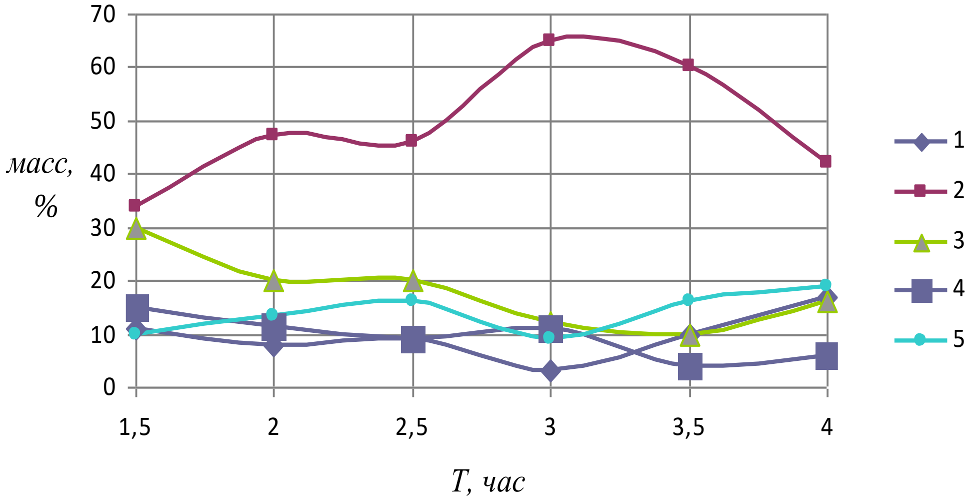

Figure 1. Effect of granulation process time on the content of various fractions in the processed products: 1 – fraction 0-40 µm; 2 – fraction 40-63 µm; 3 – fraction 63-80 µm; 4 – fraction 80-100 µm; 5 – fraction more than 100 µm

Table 1. Results of measuring the fractional composition of $Al_2O_3 – Cr_2O_3 –$ 15 % ($MoS_2 – Ni$) powder

Powder granulation method	Percentage ratio of fractional composition of powder – $Al_2O_3 – Cr_2O_3 –$ 15 % ($MoS_2 – Ni$); after granulation, µm				
	0–40	40–63	63–80	80–100	More than 100
Granulation at a rotary granulator drum speed of 24-36 rpm and an inclination angle of 40-50° for 2-2.5 hours	8	48	20	10	14
Granulation at a rotary granulator drum speed of 24-36 rpm and an inclination angle of 40-50° for 3-3.5 hours	3	65	12	11	9

The fraction of 40-63 µm was selected for spraying. The obtained results show that the highest yield of the powder fraction in the size of 40-63 µm is achieved with a granulation time of 3-3.5 hours. Table 1 shows the results of measuring the fractional composition of the Al_2O_3 - Cr_2O_3 + 15 % (MoS_2 - Ni) powder after granulation according to the technology [14] and the developed technology [13]. The morphology of the particles is shown in Fig. 2. Then the obtained conglomerates were placed in PD-KVPT alundum boats, which were installed in a SNOL 3.5/300 drying oven. Removal of the easily evaporating component of the binder was carried out at a temperature of 150 °C for 1.25 hours. Sintering of the material was carried out at a temperature of 1100 °C for 4 hours in a SNOL 1.6.2.5.1/II-I2 chamber furnace.

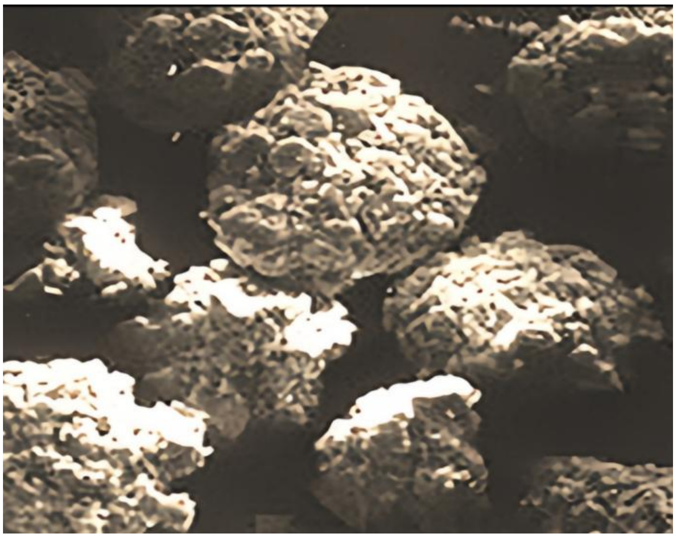

Figure 2. Morphology of powder particles - Al_2O_3 - Cr_2O – 15 % (MoS_2 - Ni)
after granulation (×200)

The material was ground in an MBL-1 ball mill using 15 mm diameter steel balls as grinding media, with a drum rotation speed of 40 rpm and a powder-to-ball weight ratio of 1:3. Sieving was performed using an air classifier to separate the 40 to 63 µm fraction. After sieving, the powder (40 to 63 µm fraction) was injected into a plasma spray jet (Plasma-Technik F4 plasma torch, Switzerland) and sprayed into a 1 m long steel cylinder filled with argon. The plasma jet power varied from 10 to 60 kW (Figure 3).

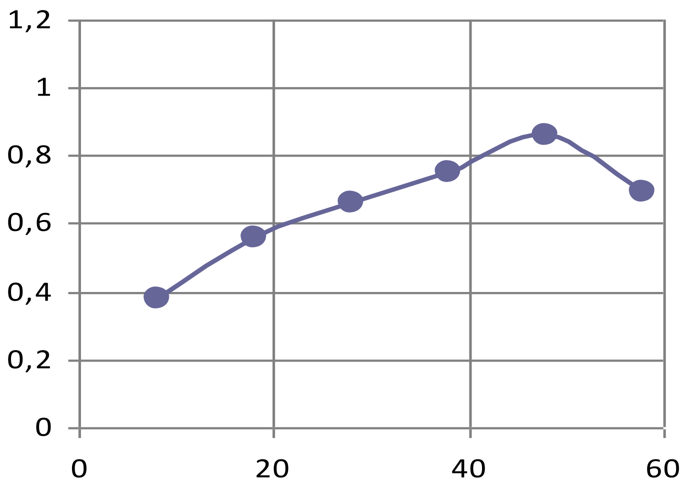

Figure 3. Dependence of agglomerate form factor change on plasma torch power

The degree of spheroidization was determined based on the particle form factor (the degree of no sphericity; a value of 1 corresponds to a sphere) using optical metallography. The maximum degree of spheroidization corresponds to a plasma jet power of 50 kW (Figure 3). The maximum degree of spheroidization (form factor - 0.9) of particles is achieved with a plasma jet power of 50 kW. At plasma jet power below 50 kW, the particles have a form factor of 0.4 - 0.8. As plasma jet power increases above 50 kW, the particle form factor decreases. Figure 4 shows the morphology of Al_2O_3 - Cr_2O_3 – 15 % (MoS_2 - Ni) particles after spheroidization. The agglomerates are spherical, structurally composed of particles 0.5 - 3 μm in size, and exhibit porosity and a developed specific surface area.

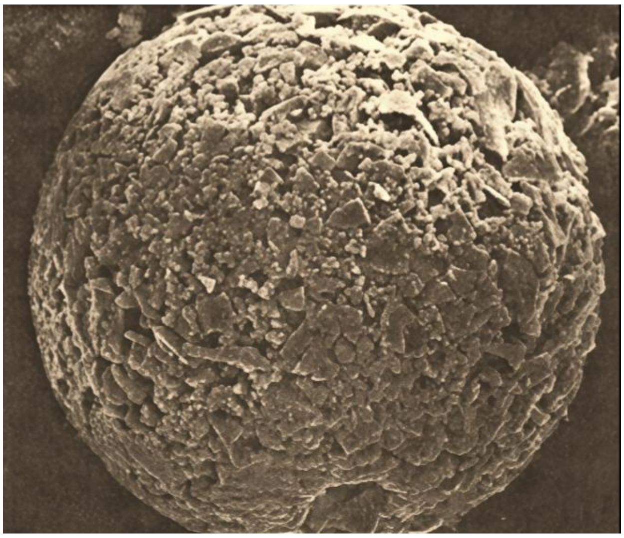

Figure 4. Morphology of Al_2O_3 - Cr_2O – 15 % (MoS_2-Ni) particles after spheroidization (×500)

Particle size, shape, and surface topography of the composite powders were analyzed using scanning electron microscopy (SEM). Powders were prepared for SEM studies using two methods: loose pouring onto a glass slide and ultrasonic dispersion followed by powder deposition onto the slide. The particle structure of the composite powders was studied by metallophysical analysis of cross-sectional sections. Unimet (Japan) and MeF-3 (Austria) microscopes were used for this study. The structure of the developed powders creates the prerequisites for producing wear-resistant coatings that are effective against wear and corrosion. The following equipment was used for the coating deposition process: a Plasma-Technic plasma spraying system (Switzerland), equipped with an F4 plasma torch; Powder feeder TWIN-10; shot blasting unit. The coating was applied in the following equipment operating modes: spraying of the sublayer coating (PN85U15 powder) with a thickness of 0.05-0.1 mm: hydrogen consumption 7 l/min; argon consumption - 30 l/min; electric arc current I = 300-350 A; electric arc power N = 30 kW; powder consumption Rpor. = 4 kg/h, spraying distance - 100 mm; spraying of a wear-resistant layer from Al_2O_3 - TiO_2 + 12 % (MoS_2 + Ni) powder (manufactured using standard technology) and Al_2O_3 - Cr_2O_3 + 15 % (MoS_2 + Ni) (manufactured using the developed technology) with a thickness of 0.3-0.35 mm: hydrogen consumption 8 l/min; argon consumption - 40 l/min; electric arc current I = 450 - 500 A; electric arc power N = 40 kW; powder consumption Rpor. = 2.5 kg/h, spraying distance - 110 mm. Friction and wear tests were carried out on a special stand according to the following scheme: coated pads - nitride steel (St45). Tribotechnical tests were carried out under friction conditions with lubrication and in the absence of lubricant under a load in the friction pair of 5 MPa for 10 hours, simulating the operating conditions of wearing parts of internal combustion engines. Test conditions (gas 1 % SO_2 – 76 % O_2 - N_2; salt Na_2SO_4 - 3.6 % $PbSo_4$ - 5 mg·cm^{-2}, T = 650 ºC) corresponded to the composition of combustion products of engines of automotive and tractor equipment. The data on the friction and wear parameters of coatings from powders obtained using the technology given in the source [14,15] and developed by the authors are presented in Table. 2. As can be seen from Table 2, the coatings obtained from Al_2O_3 - Cr_2O_3 -15 % (MoS_2 - Ni) powders, manufactured using the technology developed by the authors, have 1.7 times greater wear resistance under lubricated friction and 1.6 times greater wear resistance under dry friction on steel than the coating obtained from Al_2O_3 - TiO_2 – 12 % (MoS_2 - Ni) powder, manufactured according to source [14]. Thus, the proposed method makes it possible to increase the wear resistance of coatings under corrosive conditions.

Table 2. Friction and Wear Parameters of Powder Coatings

Method of obtaining material	Friction according to St 45 (test conditions: 1% SO_2 gas, 76% O_2, N_2; Na_2SO_4 salt, 3.6% $PbSo_4$, 5 mg·cm^{-2}, T = 650 °C))			
	Lubricated Friction		Dry Friction	
	Coating wear, μm	Friction coefficient, kg	Coating wear, μm	Load scuffing, kg
Al_2O_3 – 30 % TiO_2 -12,5 % MoS_2	6,6	0,09	14,0	5,9
Al_2O_3 – 25 % TiO_2 -25 % Cr_2O_3 - 12,5 % MoS_2	3,9	0,05	7,9	8,6

To test the feasibility of producing SHS powders with solid lubricant components, compositions containing MoS_2 and CaF_2 were synthesized. Powders of the following compositions were studied:

1) Al_2O_3 - 25 % TiO_2 - 25 % Cr_2O_3 - 12.5 % MoS_2;
2) Al_2O_3 - 25 % TiO_2 - 25 % Cr_2O_3 - 12.5 % CaF_2.

The following dispersed materials were used to produce these compositions: PTM grade titanium, EBM-40 grade aluminum oxide, grade chromium, molybdenum disulfide MoS_2, or calcium fluoride CaF_2, taken in a ratio of 37.5:25:25:12.5. The initial components were mixed in a ball mill at a ball-to-blend ratio of 25:1 and a mechanical activation time of 2-4 hours. Synthesis of the composites was carried out in a self-propagation reactor without external energy supply, in a nitrogen-oxygen atmosphere with an oxygen content of 8 to 30 wt.% and a pressure of 0.05-1 MPa. The reactor was equipped with current leads with a tungsten coil for process initiation. The use of a nitrogen-oxygen atmosphere with an oxygen content of 8 to 30 wt.% during synthesizing is necessary for the oxidation reaction of titanium and chromium powders. At an oxygen content of less than 8 wt.% and a pressure of less than 0.05 MPa, complete oxidation of the powders and insufficient penetration of the reactant gas into the batch layer do not occur. At an oxygen content of more than 30 wt.% and a pressure of more than 1 MPa, the combustion temperature rises so much that the particles melt, forming a barrier layer that prevents the penetration of the reactant gas into the batch layer. The synthesis products were ground in a jaw crusher to a fraction of 0.050-0.063 mm, which ensures the deposition of oxide ceramic coatings with maximum material utilization. Thermochemical treatment in air at a temperature of 500-800 ºC for 4-5 hours is carried out to further oxidize the composite powder particles. At a thermochemical treatment temperature of less than 500 ºC and a treatment time of less than 4 hours, complete oxidation of the particles does not occur, while conducting the treatment at a temperature above 800 ºC and a treatment time of more than 5 hours leads to increased energy consumption and partial sintering of the particles. For spheroidization, particles of the resulting composite powder were introduced into a plasma jet and sprayed into a 1 m long steel cylinder filled with argon. The degree of spheroidization was determined by the particle form factor (the degree of nonsphericity; a value of 1 corresponds to a sphere) using optical metallography. The plasma jet power was varied from 30 to 40 kW. At a plasma jet power of less than 30 kW, more than 50 % of the particles had a form factor of less than 0.7, at a plasma jet power of 40 kW, more than 90 % of the particles had a form factor of 0.9 - 1. With an increase in the plasma jet power above 40 kW, an increase in the particle form factor value increases insignificantly. The application of a thin-film metal shell onto particles of Al_2O_3 -25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % MoS_2; Al_2O_3 – 25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % CaF_2 powders was carried out by chemical nickel plating. When performing the main operation, a solution of the following composition was used: nickel chloride - 28 g/l; sodium hypophosphite - 30 g/l; sodium citrate - 10 g/l; acetic acid - 10 ml/l. The solution temperature was maintained between 363 and 368 K, and the pH was 9.0 to 9.5. To ensure uniform particle coating, the solution containing the powder in the bath was subjected to forced stirring. The optimal nickel-plating time is 10-12 hours. During this time, a thin-film Ni coating 6-7 μm thick forms on the particles, which is necessary and sufficient according to the adopted optimization criterion for powder cladding for plasma spray coatings. Particle size, shape, and surface topography of the synthesized composite powders were analyzed using scanning electron microscopy (SEM). The coatings were applied using an APS air plasma spraying system on a UPU-3D system using the modes listed in Table 3.

Table 3. Plasma spraying modes

Sprayed material	Spraying Modes				
	Plasma torch arc current, A	Arc voltage, V	Spraying distance, mm	Plasma gas flow rate (Nitrogen), L/min	Powder flow rate, kg/hour
Al_2O_3 – 30 % TiO_2 - 12,5 % MoS_2	450	65	100	45	3,5
Al_2O_3 – 30 % TiO_2 - 12,5 % CaF_2	450	65	100	45	3,5
Al_2O_3 – 25 % TiO_2 - 25 % Cr_2O_3 - 12,5 % MoS_2	500	70	110	50	3,0
Al_2O_3 – 25 % TiO_2 - 25 % Cr_2O_3 -12,5 % CaF_2	500	70	110	50	3,0

Friction and wear tests were conducted on a special test bench using the following setup: coated pads - nitride steel (St45). Tribological tests were conducted under lubricated and unlubricated friction conditions under a friction pair load of 5 MPa for 10 hours, simulating the operating conditions of wearing parts in internal combustion engines. Test conditions (1% SO_2 gas - 76% O_2 - N_2; Na_2SO_4 salt - 3.6% $PbSo_4$ - 5 mg·cm^{-2}, T = 650 °C) corresponded to the composition of combustion products in automotive and tractor engines. The friction and wear parameters for the powder coatings cited in and developed by the authors are presented in Table 4.

Metallographic analysis results were also taken into account when studying the particle size and shape. According to metallographic analysis data, the main components of the composite particles are oxide phases and inclusions of solid lubricant in the form of molybdenum disulfide or calcium fluoride (Figure 5).

Table 4. Friction and wear of coatings on steel

Method of obtaining material	Friction according to St 45 (test conditions: 1% SO_2 gas, 76 % O_2, N_2; Na_2SO_4 salt, 3.6 % $PbSo_4$, 5 mg·cm^{-2}, T = 650 °C))			
	Lubricated Friction		Dry Friction	
	Coating wear, μm	Friction co-efficient, kg	Coating wear, μm	Load scuffing, kg
Al_2O_3 – 30 % TiO_2 - 12,5 % MoS_2	6,8	0,1	13,3	5,6
Al_2O_3 – 25 % TiO_2 -25 % Cr_2O_3 - 12,5 % MoS_2	3,8	0,06	7,8	8,9

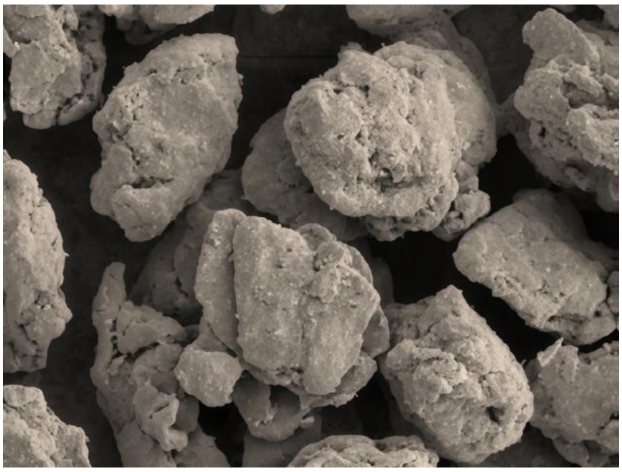

Figure 5. Morphology of the Al_2O_3 – 25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % MoS_2 composite powder obtained by SHS after crushing (× 200)

The presence of these constituent powder particles creates the prerequisites for producing wear-resistant coatings that are effective against molecular-mechanical and abrasive wear under unfavorable friction conditions (boundary lubrication or lack of lubricant, elevated temperatures). These powders are characterized by a complex geometric shape and a developed surface relief of the particles. Their tendency to form lumps reduces the flowability of the powder materials and their processability during plasma spraying of coatings. Therefore, to improve the process parameters of the powders, they were spheroidized by introducing the powder particles into a 30-40 kW plasma jet and spraying them in an argon environment (Figure 6), followed by cladding (Figure 7). According to Figure 7, a continuous coating is formed on the particle surfaces during powder cladding (individual micro-areas crumbled during section preparation). The mass content of Ni-P in the form of a cladding shell is 30-40 %. As can be seen from Table 4, the wear-resistant coating obtained from Al_2O_3 – 25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % MoS_2 powder, manufactured using the developed technology, exhibits 1.8 times greater wear resistance under lubricated friction and 1.7 times greater wear resistance under dry friction on steel under corrosive conditions than the coating manufactured using the technology from Al_2O_3 – 30 % TiO_2 - 12.5 % MoS_2 powder.

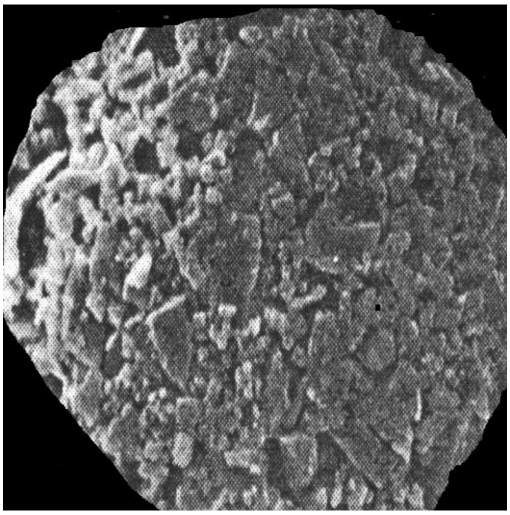

Figure 6. Morphology of the Al_2O_3 -25 % TiO_2 – 25 % Cr_2O_3 -12.5 % MoS_2 composite powder obtained by SHS after spheroidization (× 400)

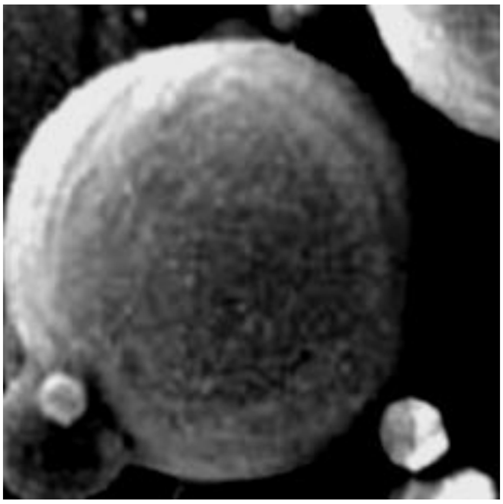

Figure 7. Morphology of the Al_2O_3 -25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % MoS_2 composite powder obtained by SHS after cladding (× 400)

Thus, the proposed method improves the wear resistance of coatings under corrosive conditions. Plasma coatings made from composite powders of Al_2O_3 – 30 % TiO_2 - 12.5 % MoS_2; Al_2O_3 – 30 % TiO_2 - 12.5 % CaF_2 are promising for restoring and strengthening components operating under unfavorable friction conditions, as confirmed by the results in Table 4.

3. Conclusions

A technology has been developed for producing a composite material based on multifunctional oxide ceramics with solid lubricant inclusions for thermal spraying by agglomerating a finely dispersed charge followed by high-temperature sintering. The resulting conglomerates were then placed in PD-KVPT alundum boats, which were installed in a SNOL 3.5/300 drying oven. The volatile component of the binder was removed at a temperature of 150 °C for 1.25 hours. Sintering of the material was carried out at a temperature of 1100 °C for 4 hours. The material was ground in an MBL-1 ball mill using 15 mm diameter steel balls as grinding media at a drum rotation speed of 40 rpm and a powder to ball weight ratio of 1:3. The sieving operation was carried out using an air classifier to separate the fraction from 40 to 63 µm. After sieving, the powder with a fraction of 40 to 63 µm was introduced into a plasma spray jet (F4 plasma torch by Plasma-Technik, Switzerland) and sprayed into a steel cylinder, 1 m long, filled with argon. The plasma jet power was varied from 10 to 60 kW. The degree of spheroidization was determined by the particle form factor (degree of nonsphericity, a value of 1 corresponds to a sphere) using optical metallography. The maximum degree of spheroidization corresponds to a plasma jet power of 50 kW. The maximum degree of spheroidization (form factor - 0.9) of particles is obtained with a plasma jet power of 50 kW. At a plasma jet power of less than 50 kW, the particles have a form factor of 0.4-0.8. With an increase in the plasma jet power above 50 kW, the value of the particle form factor decreases. Al_2O_3 - Cr_2O_3 – 15 % (MoS_2-Ni) agglomerates are spherical, structurally composed of particles 0.5-3 µm in size, and are porous with a developed specific surface area. The structure of the developed powders creates the prerequisites for producing wear-resistant coatings that are effective against wear and corrosion. Composite ceramic material based on multifunctional oxide ceramics with the addition of a solid lubricant, obtained by self-propagating high-temperature synthesis, exhibits good technological characteristics, is resistant to maintaining the chemical composition during plasma spraying, and is capable of forming coatings with high wear resistance and a low friction coefficient. Coatings obtained from Al_2O_3 – 25 % TiO_2 -25 % Cr_2O_3 - 12.5 % MoS_2 powders; Al_2O_3 – 25 % TiO_2 – 25 % Cr_2O_3 - 12.5 % CaF_2 coatings produced by self-propagating high-temperature synthesis exhibit 1.8 times greater wear resistance under lubricated friction and 1.7 times greater wear resistance under dry friction under corrosive conditions than a coating produced from a standard Al_2O_3 – 30 % TiO_2 - 12.5 % MoS_2 powder. Thus, the proposed method for producing a composite powder based on multifunctional oxide ceramics allows for increased wear resistance of coatings.

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