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RESEARCH OF MODERN TECHNOLOGIES FOR APPLICATION OF WEAR-RESISTANT COATINGS ON MACHINE PARTS

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Abstract. The article briefly describes the importance of wear-resistant coatings in modern industry, and provides various types of such coatings used in various industries. The main methods and methods of applying wear-resistant powders are also highlighted. The research includes an analysis of the adhesive properties of metallic and wear-resistant materials. Based on the conducted research, promising areas for the development and standardization of innovative technologies aimed at increasing the wear resistance of equipment and parts are identified.

In modern industry, wear-resistant coatings play a key role, ensuring the durability and efficient operation of equipment. The article examines the variety of such coatings suitable for use in various industries. The main methods of applying wear-resistant powders are highlighted, including their advantages and limitations. Special attention is paid to the research of the adhesive properties and ensure the quality of coatings. The analysis reveals promising areas for the creation and standardization of innovative technologies aimed at improving the wear resistance of equipment and parts, which contributes to increasing their service life and operational efficiency.

Keywords: wear-resistant coating, coating application, adhesion properties, increased wear resistance.

Introduction. Today, in most material-intensive industries, much attention is paid to increasing the service life and restoring the working surfaces of various parts and mechanisms. In some cases, in order to increase the service life of parts, it is advisable to use various methods of applying protective and strengthening coatings on their working surfaces. At the same time, it is possible to achieve significant savings in expensive materials, since from simple materials, and all the necessary performance characteristics are provided by a protective coating applied to the working surface of the part.

It is known that the main equipment and its various parts, which are used in industrial enterprises, are operated under conditions of increased abrasive wear. The working environment of such equipment and parts combines pressure, vibration, shock loads, chemical aggression, which can result not only in reduced productivity, loss of profits of the enterprise, as well as accidents. For example, intensive wear by hard abrasive particles of buckets of excavators and loaders, cutting edges of bulldozers, roller bits, drill heads, parts of crushing and screening complexes, etc. And this is only in the mining industry. Such problem areas can be calculated in many industrial facilities [2].

Materials and methods. The energy state of the powder particles in the deposited or sprayed jet is in complex dependence on a large number of parameters. On the one hand, these are the thermophysical properties of the powder material: density, heat capacity, thermal conductivity, heat of melting, particle size and shape and other properties (fraction), on the other hand, these are the characteristics of the deposited or sprayed jet: velocity and temperature, viscosity, thermal conductivity and thermal content, degree of dissociation and ionization of gas molecules/atoms.

Optimizing these parameters in a specific technological process of surfacing or spraying during hardening and restoration of the working surface of equipment parts is a very difficult task. In order to meet various requirements (wear resistance to shock loads, friction or corrosion resistance in various corrosive environments) and depending on the operating modes of the parts, there are several types of alloy coating on equipment parts.

Electric arc metallization is used for coating wire of metals and alloys.

Advantages of the electric arc metallization method:

- ➢ low energy consumption for obtaining coverage;
- ➢ high process productivity (up to 100 kg/h and more for zinc) with sufficiently efficient use of the sprayed material (0.65-0.8);
- ➢ significant thicknesses of the sprayed coating (up to 10-15 mm);
- ➢ relatively low thermal effect on the substrate (heating within 80-200 °C);
- ➢ the possibility of coating products with virtually no size limitation;
- ➢ ease and ease of maintenance of the equipment, its high reliability;
- ➢ the possibility of automating the process with the creation of automatic lines.

The main disadvantages of electric arc metallization are:

- ➢ a limited range of materials for spraying due to the requirements of electrical conductivity and supply in the form of wire;
- ➢ the presence of a significant amount of oxides in the coating, which reduces its impact strength;
- ➢ in all cases, the adhesion strength of the coatings to the substrate is not sufficient (15-45 MPa);
- ➢ the presence of porosity prevents the use of coatings in corrosive environments without additional processing.

Flame spraying is used for spraying coatings made of metal powders, their alloys, compositions, oxides, organic compounds, etc., wires, ceramic rods.

The main advantages of flame spraying coatings include:

- • the possibility of obtaining coatings from most materials that melt at temperatures up to 2800°C without decomposition;
- • relatively low thermal effect on the substrate (within 50-150 ° C), which allows coating on the surface of a wide range of materials, including plastics, wood, cardboard, etc.;
- • coating thickness can be provided in the range from 50 microns to 10 mm or more;
- • the possibility of regulating the gas mode of operation of the burner allows you to control the chemical composition of the medium (reducing, neutral, oxidizing) and the energy characteristics of the jet and sprayed particles;
- • high process productivity (up to 10 kg/h), for example, 8-10 kg/h for powders of self-fluxing alloys of the PG-CP4 type at an acetylene consumption of 0.9 m^3/h and a high material utilization factor (0.60-0.95);
- • the possibility of coating products with virtually no limitation of their size, provided that the necessary means of mechanization and safety regulations are in place;
- • Relatively low noise level (see Noise protection) and radiation;
- • the possibility in many cases of coating at any spatial position of the device;
- • ease and simplicity of equipment maintenance;
- • flexibility of technology and mobility of equipment, which allows for flame spraying on site, without dismantling products;
- • the ability to automate the process and integrate into an automatic line at low cost, etc.

The main disadvantages of the flame spraying method of coatings are:

- • in some cases, the adhesion strength of the coatings to the substrate (5-45 MPa) is insufficient when tested for normal separation;
- • the presence of porosity (usually in the range of 5-25%), which prevents the use of coatings in corrosive environments without additional treatment;
- • low energy utilization of the flame jet for heating the powder (2-12%);

• the inability to apply coatings from refractory materials with a melting point of more than 2800°C.

Plasma coating spraying is one of the types of gas thermal coating spraying (GOST 28076-89) used in the technology of hardening and restoration of working surfaces of machine parts, mechanisms, apparatuses, devices, etc. Plasma spraying is widely used to harden and restore the working surfaces of product parts.

The significant technical and economic advantages of the technology include:

- high process performance;
- obtaining high-quality coating, especially in general protection conditions;
- the presence of a large number of technological factors, the variation of which provides flexible regulation of the spraying process;
- High utilization rate of powder material;
- wide availability of the method in both basic and repair production;
- cost-effectiveness;
- low cost of the simplest equipment;
- the possibility of complex mechanization and automation of the process;
- prolongation of the life of expensive parts (crankshafts, sliding bearings, piston tracks, etc.);
- versatility of application of powder materials, including those with a high melting point.

The method of plasma spraying of coatings also has a number of disadvantages, which are essentially a reserve in improving the technology, namely:

- low power consumption coefficient, powder 0.001-0.020;
- the presence of discontinuity (porosity) of the coating (2-15%), in some cases porosity contributes to the retention of lubricant in the coating, which effectively affects the operation of parts in conditions of conjugate friction;
- low adhesion strength of the coating to the substrate and in the coating itself – 80-100 MPa;
- high noise level – 60-120 dB;
- the need to use personal protective equipment against harmful and dangerous influences during the spraying process.

The widespread use of plasma spraying of coatings, especially for strengthening and restoring the working surfaces of parts of products of a wide range, necessitates an increase in the level of equipment and materials used, including:

- improving the reliability and service life of electric arc plasma torches, powder dispensers, spray chambers and abrasive treatment;
- improving the reliability and efficiency of water and gas supply systems for plasma installations;
- improvement of plasma coating technology while expanding the range of sprayed parts;
- increasing the range of powder materials used in order to expand the operational properties of the plasma coating;
- increasing the level of measures to protect service personnel from harmful and dangerous influences arising in the process of plasma spraying, etc.

The adhesion of coatings, that is, the phenomenon of adhesion of coatings to the substrate upon contact, characterizing the bond between them, is caused by the interaction between molecules (atoms) of contacting bodies and is estimated by the adhesive strength, which is determined experimentally by various methods of separation or destruction of the coating [2]. When the coating is torn off or destroyed, the integrity of the coating itself, i.e. its cohesion, may be violated. In this regard, there is an adhesive separation along the coating –substrate interface and a cohesive separation when destruction occurs along the coating. A mixed adhesive-cohesive separation of the coating is also possible.

The adhesion of coatings is primarily due to various types of interactions between molecules or atoms. These interactions lead to the formation of intermolecular and chemical bonds. The amount of adhesion depends not only on the presence, but also on the number of bonds between the contacting bodies. In turn, the number of bonds is determined by the area of actual contact between the coating and the substrate. The size of this area is determined by the coating formation process and depends on the properties of the substrate and coating surface. Such properties include the parameters and type of surface roughness of the substrate; the coating method; the process of filling the depressions of the substrate surface depending on temperature and time characteristics, and a number of others [3].

Research results. So in the world there are many types of wear-resistant protective coatings in the form of rods, welding electrodes, powder alloys, etc. The main material used to harden and restore the working surface of product parts is powder. Powder materials are used both homogeneous (metals, alloys, oxides, oxygen-free refractory compounds) and complex structures (mechanical mixtures, composite powders, including those entering into exothermic reactions with the release of thermal energy when heated).

The parameters of the powder material are determined both by the physico-chemical properties of the powder material itself and by the influence of external factors, including the transporting gas, etc.

Powder materials have the following main parameters [3]:

- material density, kg/m^3;
- particle velocity in the conveying channel (close to the gas velocity) 2.0-4.5 m/s;
- the mass consumption of the powder material is 0.25-2.00 g/s, a large amount of powder fed into the jet cools it and reduces the efficiency of the process;
- physical properties of the gas transporting the powder (viscosity, etc.);
- the rate of evaporation, sublimation and dissociation of the powder material, %;
- the density of the flow of sprayed particles by volume;
- the total particle density (porosity) along the spray spot is 103-105 particles/(cm^2•s), Figure 1 shows the schematic dependences of the parameters on the diameter of the powder particles during application;
- particle shape and size;
- powder fluidity throughout the movement track (determined according to GOST 20899-75);
- the maximum allowable particle diameter of the powder material (fraction).

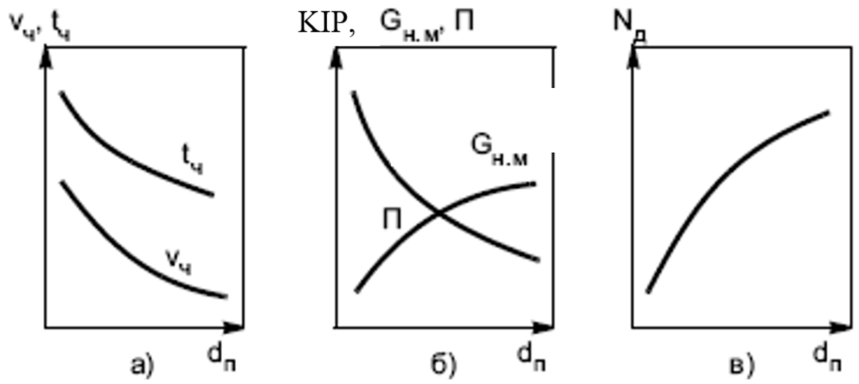

Figure 1. Dependence of plasma spraying parameters: velocity Vx and temperature tx of particles (a), KIP of performance and porosity of coating N (b), arc power T (c) on the diameter d_p of powder particles.

Due to demand and purpose, there are currently various modifications of corrosion-resistant powder alloys on the market:

Iron-based metal powders (high-alloy steel): FeCrSiMoWV, Fe Cr Ni Si Mo Mn, Fe Cr Ni Si Mn, FeCrNiSiMoMn;

Iron-based metal powders (high-alloy carbon steel);

Iron-based metal powders (stainless steel): Fe Cr Ni Si Mo Fe Cr Si Mn Fe Cr;

Metal powders based on iron (carbon steel): X13;

Metal powders based on iron (chrome-aluminum steel): X16H2;

Metal powders based on iron (chrome steel): X16H2;

Iron-based metal powders (chrome-nickel steel): 316L;

Metal powders based on iron (aluminum-molybdenum steel).

Currently, there are a number of theories justifying the adhesion of coatings [4]:

- the adsorption theory of adhesion, according to which the process of forming a bond between the coating and the substrate is determined by the adsorption of coating molecules to the surface of the substrate. Adsorption processes take place in the case of the formation of a coating from a liquid layer.

- diffusion theory, which determines the amount of adhesion depending on the nature and number of bonds per unit area of contact between the coating and the substrate. For the implementation of diffusion processes, two conditions must be met:

thermodynamic, which boils down to the mutual solubility of the coating and substrate and their compatibility; kinetic, which is achieved by the mobility of molecules.

- microrheological theory (rheology studies the flow processes of various bodies) [5], which consists in the fact that during the formation of the coating, the cavities of the surface roughness, as well as cracks and pores of the substrate are filled, the area of actual contact increases, and, consequently, the number of bonds between the coating and the substrate, which leads to an increase in adhesion and adhesive strength.

The adhesive interaction itself is realized due to molecular forces and the chemical bond between the contacting surfaces. Based on this theory, there is some optimal coating deposition time, which corresponds to the time of coating formation in the microdefects of the substrate. An increase in the deposition time of the coating above this value does not significantly affect the adhesive strength.

There are also certain standards, techniques and instructions for the manufacture of such wear-resistant materials.

The minimum thickness of the coating, provided that its cohesive strength is less than the adhesive strength (when external forces are applied, destruction occurs along the coating) is units of micrometers. At the same time, the maximum calculated thickness of the coating, provided that the equilibrium adhesion and the magnitude of internal stresses, which determine the possibility of spontaneous peeling, are equal, is 0.6 microns [6]. Thus, based on these conditions, the optimal coating thickness should not exceed a fraction of micrometers, and in some cases, units of micrometers.

In most cases, an oxide film is present on metal surfaces, which affects the adhesive strength of the applied coating. In this case, the formation of a loose oxide film causes a lack of adhesion. Studies of the adhesive strength of various metal films to glass have revealed the following patterns. The adhesive strength of films made of precious metals (silver, gold, platinum), which do not have an oxide film, as well as films made of zinc and aluminum, on the surface of which there are oxides of ZnO and Al_2O_3, is relatively small. At the same time, films made of magnesium with an MgO oxide film and iron with an Fe_3O_4 oxide film have an adhesive strength increased hundreds of times, which is explained by the peculiarities of the interaction of these oxides with the glass surface. In this case, the thickness of the oxide film on the iron should not exceed 25-30 nm, which is achieved at a surface heating temperature of 250°C. The higher temperature contributes to the formation of a thicker and looser oxide film, which reduces the adhesive properties.

The adhesive strength of coatings is also influenced by the relative humidity of the air [7]. This effect is due to the penetration of moisture into the gap between the forming coating and the substrate as a result of adsorption and capillary condensation. The main reason for the decrease in adhesion of coatings in the presence of moisture on the substrate surface is the wedging pressure of a thin layer of liquid in the gap between the coating and the substrate. Therefore, the dewatering of the surface or its preheating is a fundamentally important technological operation when applying coatings. The use of vacuum during coating is known to help remove moisture from the surface of products, which in turn causes the applied coating to approach the substrate and increase adhesion [8].

The adhesive strength of coatings also depends on the properties of the environment in which the coating is formed, due to the adsorption of gases. In comparison with air, the adhesive strength in oxygen increases sharply, and decreases in the argon medium [9]. Oxygen promotes adhesion growth due to the chemical interaction of the contacting bodies, which occurs as a result of thermal oxidation, which promotes the appearance of polar groups on the surface of the substrate and increases adhesion due to the interaction of these groups with the coating. Thus, the presence of oxides on the surface of the substrate or coating and their thickness determine the adhesive strength of the coatings. In this case, the preheating temperature of the substrate surface is of great importance. For a steel surface, for example, when applying aluminum films in vacuum, maximum adhesion is achieved at a temperature of 300-350°C, for titanium and chromium films this temperature is 400-450°C, and for cadmium films - no higher than 80°C.

Discussion. In most cases, coatings during their condensation application are formed as a result of solidification of the liquid layer on the substrate surface [2]. In this case, a liquid layer is obtained by spreading and merging droplets, followed by the formation of a continuous liquid film. Spreading is preceded by wetting with liquid droplets of the coating material of the substrate surface. Thus, the formation of the coating goes through three stages: wetting and spreading of the liquid; formation of a contact area between the two phases; the appearance of an adhesive bond.

The spreading of the liquid coating material only contributes to an increase in the area of actual contact. Only in this sense should we consider the direct relationship between the spreading coefficient and the adhesive strength. Spreading depends on the time elapsed after contact of the droplet with the surface, the size of the droplet, the viscosity of the liquid and its surface tension. Thus, the condition for sufficient adhesive strength is the wetting of the substrate surface. With a decrease in the edge angle, i.e. with an increase in wetting, the adhesive strength increases. This is due to an increase in the actual contact area on well-wetted surfaces. Spreading and wetting create the necessary conditions for adhesion: filling cracks, increasing the contact area, etc., which leads to an increase in the number of bonds and adhesion in general. Wetting is a necessary but insufficient condition for the formation of adhesive interaction of coatings.

Conclusion. In conclusion, the study of wear-resistant coatings on machine parts has revealed their importance for modern industry. The analysis of various types of coatings and methods of their application allowed us to determine the optimal approaches to protecting equipment from wear. Studies of the adhesive properties of materials have helped to improve the quality of coatings and their durability. The results obtained indicate the need to develop and standardize innovative technologies aimed at increasing the service life of equipment and parts, which in turn contributes to increased productivity and economic efficiency of production.

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МАШИНА БӨЛШЕКТЕРІНЕ ТОЗУҒА ТӨЗІМДІ ЖАБЫНДАРДЫ ЖАҒУҒА АРНАЛҒАН ЗАМАНАУИ ТЕХНОЛОГИЯЛАРДЫ ЗЕРТТЕУ

Аңдатпа. Мақалада қазіргі заманғы өнеркәсіптегі тозуға төзімді жабындардың маңыздылығы қысқаша сипатталған, өндірістің әртүрлі салаларында қолданылатын осындай жабындардың әртүрлі түрлері келтірілген. Тозуға төзімді ұнтақтарды қолданудың негізгі әдістері мен әдістері де қамтылған. Зерттеулерге металл және тозуға төзімді материалдардың жабысқақ қасиеттерін талдау кіреді. Жүргізілген зерттеулер негізінде жабдықтар мен бөлшектердің тозуға төзімділігін арттыруға бағытталған инновациялық технологияларды әзірлеу және стандарттау үшін перспективалық бағыттар айқындалады.

Қазіргі заманғы өнеркәсіпте тозуға төзімді жабындар жабдықтың беріктігі мен тиімді жұмысын қамтамасыз етуде шешуші рөл атқарады. Мақалада өнеркәсіптің әртүрлі салаларында қолдануға жарамды осындай жабындардың әртүрлілігі қарастырылады. Тозуға төзімді ұнтақтарды қолданудың негізгі әдістері, олардың артықшылықтары мен шектеулері қамтылған. Металл және тозуға төзімді материалдардың адгезиялық қасиеттерін зерттеуге ерекше назар аударылады, бұл оңтайлы қолдану жағдайларын анықтауға және жабындардың сапасын қамтамасыз етуге көмектеседі. Талдау нәтижесінде жабдықтар мен бөлшектердің тозуға төзімділігін арттыруға бағытталған инновациялық технологияларды құру және стандарттау үшін перспективалық бағыттар анықталады, бұл олардың қызмет ету мерзімі мен жұмыс тиімділігін арттыруға ықпал етеді.

Кілт сөздер: тозуға төзімді жабын, жабындарды қондыру, адгезиялық қасиет, тозуға төзімділікті арттыру.

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ИССЛЕДОВАНИЕ СОВРЕМЕННЫХ ТЕХНОЛОГИЙ ДЛЯ НАНЕСЕНИЯ ИЗНОСОСТОЙКИХ ПОКРЫТИЙ НА ДЕТАЛЕЙ МАШИН

Аннотация. В статье кратко описывается значимость износостойких покрытий в современной промышленности, приводятся различные типы таких покрытий, применяемых в различных отраслях производства. Также освещаются основные методы и способы нанесения износостойких порошков. Исследования включают анализ адгезионных свойств металлических и износостойких материалов. На основе проведенных исследований выявляются перспективные направления для разработки и стандартизации инновационных технологий, направленных на увеличение износостойкости оборудования и деталей.

В современной промышленности износостойкие покрытия играют ключевую роль, обеспечивая долговечность и эффективную работу оборудования. Статья рассматривает разнообразие таких покрытий, подходящих для применения в различных сферах промышленности. Освещаются основные методы нанесения износостойких порошков, включая их преимущества и ограничения. Отдельное внимание уделяется исследованиям адгезионных свойств металлических и износостойких материалов, что помогает определить оптимальные условия нанесения и обеспечить качество покрытий. В результате анализа выявляются перспективные направления для создания и стандартизации инновационных технологий, направленных на повышение износостойкости оборудования и деталей, что способствует увеличению их срока службы и эффективности работы.

Ключевые слова: износостойкое покрытие, нансение покрытий, адгезионные свойства, повышение износостойкости.