CHEMICAL TECHNOLOGIES, MATERIALS SCIENCES, METALLURGY

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Original article
UDC 621. 762. 1
https://doi.org/10.23947/2541-9129-2022-3-75-80

Thermal Spraying of Coatings on Aluminum Alloys of Combine Parts

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Introduction. At the present stage of technology development, special importance is given to improving the efficiency and durability of machine parts and especially parts of assemblies operating under increased loads. The problem of increasing reliability in the conditions of intensification of production, energy and resource conservation poses the task of introducing new technological processes and the use of modern materials into production. Often, the weakest element in the "material — working environment" system, which determines the operating conditions and the resource of mechanisms, is the surface of the material. Therefore, an important role in increasing its wear resistance is played by coatings that protect parts from the destructive influence of working environments.

Problem Statement. The main objective of the research is the development of technological modes for applying thermal coatings to the belt pulleys of the TORUM 750 combine harvester by Rostselmash, as well as the selection of optimal coatings to increase the durability and wear resistance of the pulley surface.

Theoretical Part. As a theoretical description, the application of various coating options is analyzed, as well as the mathematical processing of experimental data on the adhesion strength between the aluminum surface and the coating material is considered.

Conclusions. The studies carried out by the authors have shown that it is advisable to conduct thermal spraying on aluminum alloys of belt coatings on a heated substrate (preheating temperature from 210°C). In the case of spraying coatings on the rubbing surfaces of pulleys, the surfaces should be regularly cooled.

Keywords**:** belt pulleys, wear resistance, spraying, aluminum, nickel, titanium.

For citation**:** Egorov M. S., Fominov E. V. Thermal Spraying of Coatings on Aluminum Alloys of Combine Parts. Safety of Technogenic and Natural Systems, 2022, no.3, pp. 75–80. https://doi.org/10.23947/2541-9129-2022-3-75-80

Introduction. The industry is increasingly using processes based on the connection of materials in a solid state, various types of welding, as well as new coating technologies. The process of applying coatings by gas-thermal method to aluminum material studied by the authors has much in common with those listed above.

In order to select the optimal technological parameters that provide the necessary adhesion strength, it is extremely important to know the essence of the connection mechanism of the studied metal pairs and to have a clear understanding of the relationship between the conditions of connection of dissimilar materials with the physical processes occurring in the contact zone of the surfaces of these metals. Aluminum alloys have a number of properties that distinguish them from steels and cast irons. They have a lower density and relatively high strength (2.6–2.9103 kg/m^3). The most durable alloys are used for the manufacture of products operating under loads, with changes in bending and torques. Aluminum alloys are also used in structures operating under conditions of increased wear resistance and at temperatures up to 120 C [1–3].

These characteristics of aluminum alloys contribute to their widespread use as basic structural materials, for example in the automotive, aviation, and shipbuilding industries [4]. It is known that during operation, the surfaces of the parts are subject to wear and corrosion and erosion, which is why the problem of increasing their wear resistance is so urgent at the present time. For this purpose, gas-thermal wear-resistant coatings should be used. Gas-thermal spraying of coatings on aluminum alloys, in comparison with coatings on traditional structural materials (steel, cast iron), has its own characteristics caused by a large difference in the coefficients of thermal expansion of alloys and coatings.

The **Aim** of the work is to study the technological modes of gas-thermal spraying on the belt pulleys of the TORUM 750 harvester of Rostselmash company, which is designed for harvesting all traditional grain crops: grain, legumes, oilseeds, cereals and tilled crops. It is necessary to pay great attention to the adhesion strength of coatings to the surface of the parts on which they are applied, since the adhesion strength of materials with aluminum alloys is several times lower than with the rest.

Problem Statement. To create wear-resistant parts with high technological and mechanical properties, it is necessary to apply wear-resistant coatings on the working surfaces of products. In this regard, the aim of the authors is to select such technological modes of gas-thermal spraying and recommend such a coating material that would provide better adhesion to the aluminum base.

Theoretical Part. The ability of metal coatings to increase the durability and reliability of machine parts and whole units is determined by their adhesion, sponge surface, through porosity and coating thickness. Obtaining a reliable adhesion of the coating to the base is one of the main requirements for metal coatings. Paper [5] provides information that copper and bronze alloys are among those materials that can serve as a reliable protective coating for aluminum and its alloys due to the close coefficients of linear expansion. At the same time, to ensure a strong adhesion, the temperature of the particles when interacting with the base should be about 1200 °C. This temperature was achieved using spraying with oxidation of up to 10% Cu_2O, which interacts with the aluminum base by an exothermic reaction:

$$2/3\ Al_{ж}+Cu_2O_{тв}=1/3\ Al_2O_3+2Cu_{тв.} \quad (1)$$

The proposed reaction gives seven times more heat than the process of exothermic Ni–Al reaction, which is widely used when creating a sublayer on Al.

To apply coatings to belt pulleys made of aluminum alloy AK4, powder mixtures based on nickel and titanium were used, which have high enthalpy due to exothermic reactions during plasma spraying, which significantly increases the adhesive strength (Fig. 1). Spraying was carried out using equipment from Rostselmash and on its premises (Fig. 2).

Fig. 1. Belt pulleys of the TORUM 750 combine harvester of the Rostselmash company

To ensure the adhesion of the sprayed layer with the base metal, it is recommended to carry out preliminary mechanical cleaning of surfaces with metal brushes and heating [7]. Heating of samples and parts to 210–230 °C before spraying was carried out in a two-chamber electric furnace with automatic temperature control. Heating above 230°C can change the mechanical properties of the alloy and leads to an increase in the transient contact resistance.

Fig. 2. Installation for gas-thermal surfacing of the Rostselmash company

There are recommendations to carry out thermal activation of the base to achieve chemical interaction with the coating [8]. However, preheating of the base made of aluminum alloy is associated with increased oxidation of its surface and the possibility of melting. At the same time, there are significant compressive stresses in the coating — base system caused by a sharp increase in the difference in the coefficients of linear thermal expansion of the aluminum alloy and the coating, which sometimes leads to negative results. In order to reduce residual stresses that may exceed the strength of the coating material, spraying should be performed on a cooled base.

In this paper, the authors investigated the structure and composition of oxide films on the surface of the AK4 alloy that occur when heated in air during plasma spraying, as well as the possibility of using a glow discharge at the stage of preparing the surfaces of parts for finishing coatings in order to increase the adhesion strength of the latter. It is established that the factor limiting the adhesion strength of coatings with the AK4 material is the formation of a magnesium oxide film on the surface of the latter. When processing the alloy with a glow discharge, the surface is modified due to the appearance of silicon oxides, which increases the adhesion strength of coatings by 1.3–2 times compared to traditional abrasive-jet treatment. It is noted that the "modified state" of the treated surface persists for a long time after the parts are removed from the vacuum chamber, since in all cases the coatings were sprayed 3-4 days after the surface of the pulleys was treated with a glow discharge. The technological possibilities of processing belt pulleys made of AK4 alloy with a glow discharge suggest the presence of complex vacuum equipment, and therefore the introduction of this technology into the workflow of Rostselmash had to be abandoned.

To prepare the surface of the belt pulley, it was necessary to carry out abrasive-jet treatment, requiring an optimal mode, which, creating the necessary surface roughness, would not cause deformation of the surface of the product [9–10]. The presence of metal shot residues on the surface negatively affects the adhesion strength, as well as the operational properties of the pulleys, which can cause abrasion of the V-belt. The following shot blasting mode was experimentally established (Table 1).

Table 1

Optimal shot blasting mode

Parameter	Value
Compressed air pressure, Pa	$4 \cdot 10^5$
Distance from the nozzle to the surface, m	0.1–0.18
Treatment time, s.	20–30
The incidence of the shot blast to the surface, deg.	90

The surface roughness was 15–20 microns. The deformation of the samples under this treatment mode is minimal and corresponds to an average of 40 microns.

To remove the smallest particles of shot and other impurities, the pulleys were washed in an alcohol-water mixture (in a ratio of 2:3). In order to reduce the effect of the difference in the coefficients of linear thermal expansion of the substrate and coating, as well as relaxation of residual stresses arising in them during spraying, the method of controlled cooling of pulleys was used [10–11]. To do this, during the spraying process, the heating temperature of the part was measured using a thermocouple. The sprayed part was placed in a heated (in this case up to 100-120 °C) muffel furnace. The furnace was cooled in various modes (fast cooling with a fan, cooling with an open door), the temperature regime of heating and cooling was maintained by an adjustment potentiometer RU5-01M. After each experiment, the adhesion strength of the coatings to the base was determined by the pin method. The measurement results were subjected to mathematical statistical processing. The average values (Xa), standard deviations (S) and confidence intervals of adhesion strength were calculated. Table 2 provides the results. The optimal rate of cooling temperature reduction is 5° C/min.

Table 2

Mathematical statistical processing of experimental data on adhesion strength

Coating material	Base material	Xa	S	Confidence interval
Nickel alloy PG-Yu10-N	V95	12.36	1.81	11.50<X<13.20
Titanium Alloy (PTS2)	D16	24.40	3.70	22.68<X<26.16
Stainless steel PKh18N9T	D16	11.62	1.44	10.95<X<12.29
Titanium Alloy (PTC2) and stainless steel PKh18N9T	D16	22.39	2.12	21.39<X<23.38

This technique was used during the development of gas-thermal coatings for the pulleys in question. The coatings were formed from titanium, nickel and stainless steel powders manufactured in Russia by Polema (Tula). Of the powders studied, PTS2 is the most technologically advanced by a number of indicators. The coating of this powder has a coefficient of friction with a rubber V-shaped belt of 0.16-0.18 with satisfactory wear resistance. The coating of stainless steel powders PKh18N9T has a coefficient of friction of 0.12–0.137. Their wear resistance is satisfactory. The nickel alloy showed an increased coefficient of friction of 0.21–0.23, but a more granular coating structure (Fig. 3).

Fig. 3. Belt pulleys after nickel alloy spraying

Heating the samples to 210°C reduces the temperature difference between the base material and the coating itself, which leads to an increase in the crystallization time of the sprayed particles, improves the filling and repeatability of the surface geometry of the sprayed layer, reduces the number of pores and defects on the surfaces (Fig. 4).

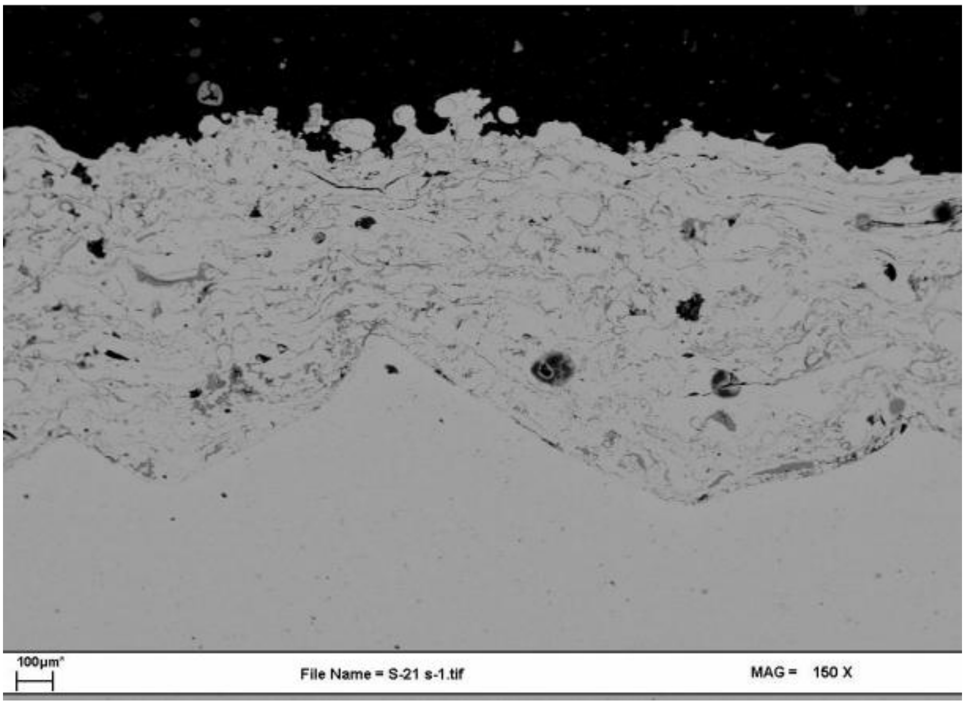

Fig. 4. The structure of the titanium coating on the aluminum surface of the pulley

Conclusions. The studies carried out by the authors have shown that it is advisable to carry out gas-thermal spraying on aluminum alloys on a heated base (preheating temperature from 210 °C). In the case of spraying coatings on the rubbing surfaces of pulleys, a regular surface cooling regime should be introduced. After the surface hardening operations, the pulleys were installed on TORUM 750 combines, which are currently undergoing field tests.

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Received 10.06.2022
Revised 19.07.2022
Accepted 19.07.2022

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Claimed contributorship

M. S. Egorov — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions; E. V. Fominov — calculations, analysis of the research results, revision of the text, correction of the conclusions.