The influence of surface preparation methods on the adhesion of film antifriction coatings

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Abstract. The article presents the equipment, methods and results of studies of the adhesion strength of a film anti-friction coating with a steel base. A multivariate experiment was performed. The factors and the significance level of each of them, affecting the strength of the antifriction film coating, are revealed. The dependence of the adhesion strength on the modes of applying the film coating is established and described. Recommendations have been developed on the choice and method of applying film anti-friction coatings for maintenance and repair of motor vehicles.

1. Introduction
In recent time, modified friction surfaces of two interacting parts are often used using various coatings. This is done to increase the reliability and resource of the product or mechanism [1]. Moreover, these coatings very often represent a multilayer coating, the thickness of which depends on the material and the method of its application. In this case, the coating property must fully comply with the operating conditions of this product [2]. According to their purpose, the coatings used in the service and repair of machines can be divided into the following groups: paint and varnish, corrosion-resistant, wear-resistant, anti-friction, heat-resistant. When coating is applied, as a rule, the overall and mounting dimensions change, while the dimensions of the parts increase by the thickness of the applied coating layer. In many cases, this is unacceptable, as it leads to a change in the technical parameters of units and parts [3]. However, the use of new materials, in particular film coatings (the thickness of the film layer is from 5 μm to 30 μm) and the technological processes of their deposition can significantly increase the efficiency of machine parts.

2. Problem formulation
Today, huge quantities of different film coatings, different in composition and their properties, are sold around the world. They differ in packaging, method of application, and their purpose. An important factor is the pricing policy for this type of coating. Often, the consumer finds himself in a difficult situation when choosing what he needs. The main problem is that it is necessary to choose a coating that will perform its functions, can be easily applied to the surface of the product, does not require complex devices and equipment, and at the same time have high adhesive strength to the base metal [4]. In many cases, the manufacturer does not indicate one of the main and important parameters, such is the adhesion strength. This parameter is fundamental in the further operation of the product. Tribological properties of the formed film coatings largely depend on it [5]. The study of the
adhesion strength of the film coating to the base and the preparation of the surface for its application deserve special attention to provide further recommendations for their widespread use.

3. Theoretical part
One of the main parameters of the operation of the node (tribological unit) is wear resistance. It determines the resource of the tribological unit and depends on the technological and operational parameters. First of all, it is possible to increase the wear resistance technologically - by forming a film of antifriction coating on the friction surface. The process of forming a film antifriction coating can be represented in the form of the following operations:
- preliminary processing (preparation) of the surface;
- applying the first layer of film coating;
- building up subsequent layers of anti-friction coating.

The process of forming a film anti-friction coating has much in common with the application of paintwork. Thus, the adhesion strength of the film coating (adhesion) is determined by the dependence

$$Y = f(L, \alpha, C, Ra, t, \rho, v, d, D), \quad (1)$$

where:
- $L$ - coating application distance, mm;
- $\alpha$ - coating application angle, degrees;
- $C$ - surface preparation method;
- $Ra$ - surface roughness, microns;
- $t$ - ambient temperature, °C;
- $\rho$ - coating density, g/l;
- $v$ - ambient humidity, %;
- $d$ - spray diffuser diameter, mm;
- $D$ - pressure in the air line, atm.

When carrying out maintenance and repair of automotive equipment, the issue of surface preparation before applying film coatings and finding the optimal parameters (surface roughness of the product, angle of coating and spraying distance) are especially acute. Consider how these parameters are related to the adhesion strength of film coatings to the base.

After studying literary sources, we opted for the method of determining the adhesion strength by normal separation [6]. This method applies to decontaminated protective coatings up to 400 microns thick (single and multi-layer) applied to metal bases, and establishes a method for determining the adhesion strength of coatings by normal separation, based on measuring the force required to tear off the coatings in a direction perpendicular to its surface (Figure 1). The test sample consists of two cylindrical surfaces 1 and 4, on one of which an anti-friction coating 3 is applied, after it dries, both surfaces are glued with special glue 2. The design parameters of the samples are shown in Figure 2.

The tensile strength of the anti-friction coating at separation of the sample ($\sigma$) is calculated by the formula.

$$\sigma = \frac{P}{F}, \text{Pa} \quad (2)$$

where:
- $P$ - sample separation force, H;
- $F$ - base area, m².
4. Experimental studies

According to the studies [7, 8], we chose one type of coating for further in-depth study of its adhesive properties. This is an antifriction coating based on molybdenum disulfide (12%) with an organic binder, hardening at normal temperature. The coatings were applied to the samples in two layers (Figure 3), while the total coating thickness was 15 μm.

Samples were tested on a universal tensile testing machine with an electronic force meter IR5047-50 at a temperature of 20 °C and a relative humidity of 70% (Figure 4, 5).
Figure 4. Experimental setup.

Figure 5. Destruction of the coating.

Constant parameters for all samples:
C - surface preparation method – sandblasting;
t - ambient temperature – 20°C;
ρ - coating density - 1200 g / l;
v - ambient humidity – 75 %;
d - spray diffuser diameter – 1,1 mm;
D - pressure in the air line - 3 atm.

As a mathematical model describing the dependence of changes in adhesion strength, a statistical regression model was chosen. To obtain an adequate model, a level 2^3 factor experiment was set up and carried out, which was set in the local time domain. The output parameter Y was taken as the value of the adhesion strength σ_{ctn}, MPa. Based on preliminary studies and analysis of literature data, the following were selected as the main factors affecting adhesion strength:
X1 – coating application distance L, mm;
X2 – surface roughness Ra, microns;
X3 – coating application angle α, degrees.

The choice of levels and ranges of variation of factors (Table 1) was carried out on the basis of preliminary experiments.

| Factors                              | Designation | Levels of variation | Variation Intervals |
|--------------------------------------|-------------|---------------------|---------------------|
| coating application distance L, mm   | X1          | -2 150 170 190 210 230 | 20                  |
| surface roughness Ra, microns       | X2          | 0,2 0,4 0,8 1,6 3,2  - | -                   |
| coating application angle α, degrees | X3          | 30 45 60 75 90 15     | -                   |
A full-factor experiment was conducted on $5 \times 5 \times 5 = 125$ readings. As a result of the calculations, the equation of the dependence of the adhesion strength on the studied factors was obtained regression equation, which has the following form:

$$Y = -8.12 + 0.126x_1 + 0.575x_2 - 0.00033x_1^2 - 0.197x_2^2 \quad (3)$$

Substituting factors for the notation, we obtain an equation of the following form:

$$Y = -8.12 + 0.126L + 0.575Ra - 0.00033L^2 - 0.197Ra^2 \quad (4)$$

The test results for determining the adhesion strength of the base metal of the sample and the applied film antifriction coating are shown in Figures 6 - 8.

**Figure 6.** The effect of roughness parameters Ra on the adhesion strength $\sigma_{coh}$.

**Figure 7.** Influence of the coating application distance L on the adhesion strength $\sigma_{coh}$. 
5. Conclusions

It follows from the regression equation that the change in the adhesion strength is dominated by the change in the quantitative values of the coating distance and then the surface roughness. The coating application angle has virtually no effect on adhesion.

From a practical point of view, not only an independent change in the quantitative values of the studied factors, but their joint interaction is important in changing the adhesion strength. The greatest adhesion strength can be achieved with the following values: coating application distance $L = 180 \div 200 \text{ mm}$, surface roughness $Ra = 0.8 \text{ } \mu \text{m}$ and coating application angle $\alpha = 90 \pm 5$ degrees.

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