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Uninterrupted control of coating thickness during the wear process of vehicle units

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Abstract

In the course of this research in the field of automotive technology, systematic patterns and features of wear of structural materials with wear-resistant coatings that were applied using various technologies, depending on the change in friction modes, were revealed. Our research led to the identification of physical parameters of tribological properties and their changes in the friction process.

An interesting property discovered in the course of our work is the fact that changing the contact area several times does not significantly affect the change in the friction coefficient. Instead, changes in the coefficient of friction are mainly related to the chemical composition of the secondary structures that are formed during friction.

An important aspect of our findings is that the change in the coefficient of friction is usually due to the chemical composition of the secondary structures, which in turn depend on the chemical composition of the base material, the characteristics of the coating, the characteristics of the environment and the temperature conditions in the friction zone. An analysis of the chemical composition of secondary structures formed during friction was carried out, which allows for a deeper understanding of wear mechanisms and creates opportunities for optimizing materials and coatings in the field of automotive technology.

Keywords: wear, coatings, automatic measurement, thickness, chemical composition.

Introduction

Over the past decades, wear-resistant coatings have been widely used in various fields of human activity, performing various functions under different conditions - from chemical composition to application methods. This direction is extremely important, because the development of multilayer or combined coatings is equivalent to the creation of a new material with unique properties.

During the development of new coatings, laboratory studies of wear resistance are an important stage, which make it possible to predict the duration of operation of the tribocouple with the coating. The formation of secondary structures under the influence of specific conditions and modes of friction solves one of the key tasks - determining the thickness of the coating.

Insufficient or too large coating thickness can significantly affect the result: the difference in adhesion indicators and insufficient tribological effect from the first case, or the risk of rupture due to internal stresses from the second case. That is, the thickness of the coating plays a decisive role in achieving the desired indicators of wear resistance.

One of the important aspects is establishing the nature and dynamics of the process of wear of the coating over time. Knowing the necessary and sufficient thickness of the coating allows you to effectively influence the results of operation, and the detection of optimal values guarantees maximum indicators of wear resistance. Methods of determining the wear resistance of coatings, aimed at establishing tribological characteristics, play a key role in this process.

To determine the tribological characteristics of coatings in the field of automotive technology, it is necessary to focus on measuring and controlling the thickness of these coatings during their operation. The coating thickness usually ranges from a few micrometers to hundreds of millimeters, which is important to consider when analyzing its tribological properties in the automotive industry.

According to the recommendations of the GOST 30431-96 (DSTU 3366-96) standard for automotive tribological studies (autotribology), it is important to pay attention to point 4.4, where it is stated that the lapping of the coated sample should take place at a speed of 0.7 m/s and a pressure of 1 MPa to values of the roughness parameter from 0.2 to 0.3 μm. If the transition from the technological microrelief to the operational one takes less than 15-35 minutes, using the specified parameters, then a gradual increase in pressure up to 3 MPa, testing of various options for increasing the sliding speed should be considered. The maximum possible sliding speed is 3 m/s in the context of automotive research.

Before running in the sample with the coating, it is necessary to carry out a similar process with the base sample without coating. In thin-layer coatings, in particular thin films, their partial or complete wear is observed. It is important to consider that there are coatings that are used in the automotive industry to improve the wear resistance of assemblies, and whose tribological characteristics can be difficult to determine using standard techniques, especially if they are relatively soft and have a small thickness.

As a result of exposure to uncontrolled high specific pressures and temperatures during processing, a change in the internal structure may occur on the surface of the sample or a certain part of it. Accordingly, research results may be limited and used only for comparative analyses. In the automotive field, all these factors introduce significant errors into the final conclusions and results regarding materials and coatings. Using standard methods allows you to establish the tribological properties of both the coating itself and the base material, but this leads to obtaining average values, since it can be difficult to distinguish between the wear of the base and the coating.

Usually, determination of the thickness of car coatings is carried out by a chemical method. The sample, usually a plate, is covered with a layer of material, and then the base is chemically dissolved, leaving only the coating (foil), which is weighed. This approach is relatively accurate and simple. However, to establish wear resistance, friction coefficient and other tribological parameters, it is necessary to use experimental methods using mechanical action.

In addition, it is important to establish the optimal, as thin as possible thickness of the coating, which would prevent intensive wear, considering that thick coating layers do not always guarantee a high-quality and durable coating.

In the automotive industry, there are tribological pairs, such as coating-substrate or coating-coating (in the case of multi-layer coatings), which exhibit high wear resistance despite their small thickness (a few micrometers). Studies show that with an increase in the thickness of the coatings, even a small amount of wear can become more intense [1-3]. This confirms that tribological methods should be used to evaluate the tribological characteristics of coatings, and not any other approaches.

In general, the interaction of friction in the field of automotive engineering is an extremely complex process, which at the moment is almost impossible to completely describe mathematically for any conditions. Thus, the friction properties of materials are studied with the help of experiments. The obtained results can be used to develop mathematical models and engineering calculations.

Increasing the wear resistance of automotive parts can be achieved at the design stage, using technological methods, as well as during operation. Among the most common methods of increasing wear resistance in the automotive industry is the use of technological methods.

One of the ways to protect the friction unit from wear in the automotive sector is to use wear-resistant coatings using various technological methods. Application of composite and multi-layer coatings is carried out in various ways, such as powder sintering, surfacing, galvanic methods and others.

Understanding the characteristics of each material used in complex multilayer or composite coatings, predicting the behavior of such a composite becomes a challenge, as it depends on many factors: chemical composition, proportions of components, application technology and thickness of the coating itself. The interaction of heterogeneous elements leads to an effect equivalent to the creation of a new material [1], the properties of which differ from the properties of each individual component in terms of qualitative and quantitative indicators. The difference in the characteristics of materials is directly related to their composition and structure. In the field of automotive technology, this is especially relevant, since the properties of complex coatings can determine the quality and durability of automotive elements.

According to A. V. Chichinadze [2], the main difficulty in the development of wear-resistant coatings is that in the modern process of designing mechanisms there is no agreed methodology for the optimal use of various methods of strengthening friction nodes.

A. S. Vereshchak [3], considering a cutting tool that works under conditions of high load, tries to use multilayer composite coatings to create tool materials with "ideal properties". However, this task is not an easy one, since the improvement of some parameters usually leads to the deterioration of others. This limits the technological possibilities of using known tooling materials in the automotive industry, as their effectiveness is usually within a limited range of applications.

Purpose and setting of the task

The purpose of this study is to track the process of coating thickness reduction under the influence of wear and analyze the change of tribological parameters during operation, focusing on the context of automotive technology.

Presentation of research materials

Research was carried out on HVG steel (the chemical composition is presented in Table 1) using a modernized tribomachine UMT 2168 [4, 5], specially adapted for the automotive field. This allowed tribological parameters such as linear wear, friction moment and average temperature in the friction zone to be automatically captured and recorded at a frequency of 0.5 seconds, without the need to remove the sample from the rig. The obtained data were processed on a computer for further analysis of the results.

Table 1

Chemical composition of the investigated steels

Steel	Chemical composition, % (weight)									
	C	Si	Su	Mn	No	P	Cr	S	W	Mo
KhVG	0.90-1.05	0.10-0.40	<0.30	0.80-1.10	<0.35	<0.03	0.90-1.20	<0.030	1.20-1.60	<0.30

The steel was heat treated to a Rockwell hardness of HRC 55. After that, the samples were ground to remove the decarburized layer, achieving a roughness Ra of 0.8 to 1.6.

The research was carried out according to the scheme of dry disc-finger friction with a spherical surface (see Fig. 1), which has advantages for automotive subjects: no need for running-in, no distortions and base errors, the possibility of achieving high specific pressures in the contact zone.

The main goal is achieved thanks to the selected spherical working surface of the sample, which does not require additional work-in. Fixation of wear is carried out with the help of a linear displacement sensor, which allows you to determine the wear limit of the coating and the base without interrupting the friction process.

Requirements for the working surface of the specimen include 100% contact with the counterbody and immediate run-in, which is achieved through the use of a spherical friction surface (see Fig. 1).

A series of experiments made it possible to identify several key areas of wear on samples with coatings, which can be conventionally marked in fig. 1: a) the point of contact of the sample with the counterbody at the stage of initial friction, marked as the I-I section and point A (at this moment the maximum specific pressures occur), which ensures immediate work-in and 100% further adhesion of the contacting surfaces; b) the wear area directly of the coating, marked as section II-II and plane B; c) transitional zone of general wear of the matrix and coating, marked as section III-III, wear of the coating (plane C) and base (plane D).

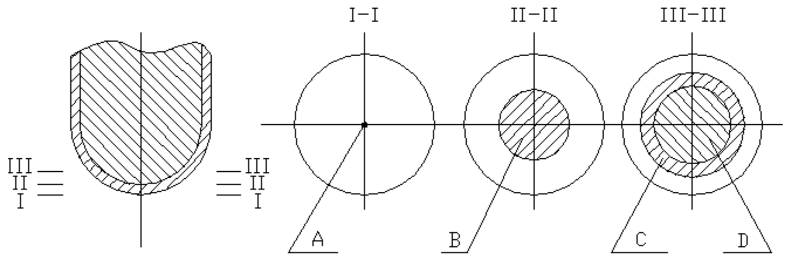

Fig. 1. Stages of wear of the coated sample

To evaluate the resistance to wear, samples made of thermally hardened steel ХВГ (HRC 55) were used. The counterbody is made of high-carbon heat-strengthened steel U10A HRC 62. The tests were carried out according to the "disk - finger" friction scheme with a spherical contact shape (see Fig. 1). The AlN-ZrB2 coating was applied to the sample by electrospark alloying with a thickness of approximately 0.1 mm. The test regime included an initial specific pressure of 1300 MPa and a sliding speed of 0.67 m/s. These experiments are important for the automotive industry, as they allow to determine the effectiveness of materials in friction nodes and provide optimal performance for automotive parts.

As illustrated in Figures 2–4, data obtained during friction are presented. Figure 2 shows the linear wear of the coating and the base, which can be divided into three stages: 1) 0 ... 30 m, 2) 30 ... 400 m, 3) 400 ... ∞. From the information on material consumption during coating, it is known that the thickness of the coating is approximately 0.1 mm.

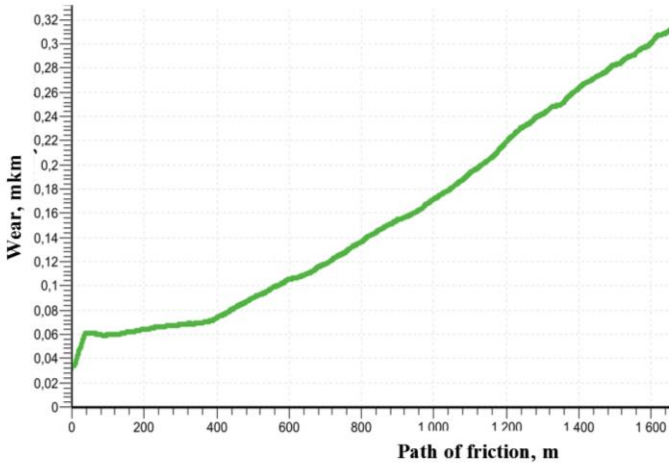

Fig. 2 Change in the value of linear wear from the path of friction

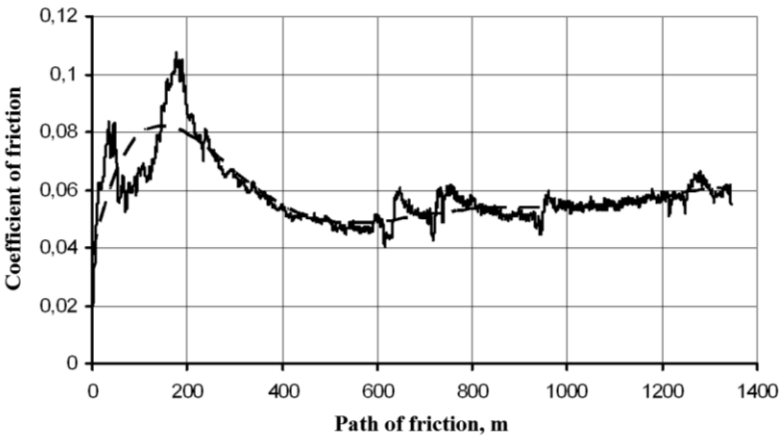

Fig. 3. Variation of the coefficient of friction from the path of friction

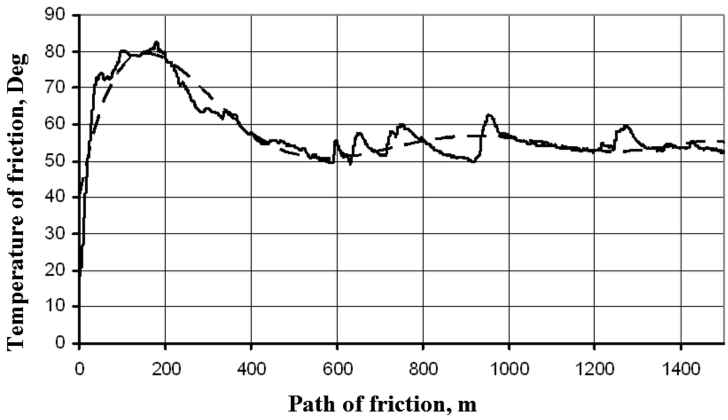

Fig. 4. Change of the average temperature in the friction zone from the friction path

The inflection of the curve when reaching a friction path of 400 m corresponds to wear with a value of h = 0.08 mm (Figure 2), after which the intensity of wear increased. That is, the actual thickness of the coating is 0.08 mm. The tribological properties of this coating and the characteristics of its tribological behavior during friction and wear were also determined.

In addition to the specified tribological characteristics, the technical capabilities of the equipment make it possible to establish the process of changing the friction coefficient, the average temperature in the friction zone, and the intensity of wear. It is well known that the friction coefficient for a certain tribopair under constant friction conditions is constant. Figure 3 shows that the friction coefficient undergoes changes. This change is associated with wear of the coating at a distance of 250 m of the friction path, from 250 to 400 m - wear, partial contact of the microprotrusions of the base (roughness). The number of microprotrusions from 250 to 400 m gradually increased, and therefore the proportion of the surface contact area decreased, which led to changes in the friction coefficient and temperature (Figures 3, 4).

There are cases where accurately defining the boundary between the substrate and the coating becomes a challenge, and therefore a complex of tribological characteristics such as the coefficient of friction, the temperature in the friction region and the intensity of wear must be considered. To obtain more accurate data on the thickness of the coating, especially in the case of diffusion coatings, there is a difficulty due to the smooth transition from a more saturated layer to a less saturated one.

Determining the thickness of such a layer turns out to be a difficult task, since there is a smooth transition from a solid surface to a less solid base. The change in hardness is determined using a hardness tester on a cut and specially prepared sample. This technique is quite time-consuming, it is especially difficult to cut the sample and prepare it, requiring special equipment and high qualification of the laboratory technician.

Figures 3 and 4 show that the relative stability of the tribological parameters occurs after about 500 meters (averaged dashed curve), which is explained by the inertness of temperature indicators and residual friction products. This is important for the automotive industry, as it allows to determine the effectiveness of the materials in the friction nodes and to ensure optimal performance for the automotive parts.

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Маковкін О.М., Вичавка А.А., Вальчук І.К. Безперервний контроль товщини покриття під час процесу зношування вузлів автомобіля

У ході даного дослідження в галузі автомобільної техніки виявлено систематичні закономірності та особливості зношування конструкційних матеріалів із зносостійкими покриттями, нанесеними за різними технологіями в залежності від зміни режимів тертя. Наші дослідження привели до визначення фізичних параметрів трибологічних властивостей та їх зміни в процесі тертя.

Цікавою властивістю, виявленою в ході нашої роботи, є те, що зміна площі контакту кілька разів не впливає істотно на зміну коефіцієнта тертя. Натомість зміни коефіцієнта тертя в основному пов'язані з хімічним складом вторинних структур, які утворюються під час тертя.

Важливим аспектом наших висновків є те, що зміна коефіцієнта тертя зазвичай пов'язана з хімічним складом вторинних структур, які, у свою чергу, залежать від хімічного складу основного матеріалу, характеристик покриття, характеристик навколишнього середовища і температурного режиму в зоні тертя. Проведено аналіз хімічного складу вторинних структур, що утворюються під час тертя, що дозволяє глибше зрозуміти механізми зношування та створює можливості для оптимізації матеріалів і покриттів у сфері автомобільної техніки.

Ключові слова: зношування, покриття, автоматичний вимір, товщина, хімічний склад.