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THE MECHANISM OF FORMATION OF ANTI-FRICTION COATINGS BY EMPLOYING FRICTION-MECHANICAL METHOD

УДК 621.891.539.375.6

DOI:10.31891/2079-1372-2019-91-1-35-39

Different interpretations of the mechanism of formation of antifriction coatings by a friction-mechanical method hinders the widespread use of finishing antifriction non-abrasive treatment in the manufacture and repair of parts. It has been established that at the initial stage, the application of an antifriction coating by a friction-mechanical method will be accompanied by a process of micro-cutting of an antifriction material with its subsequent filling of the micro relief cavities in the form of chips. The fulfillment of the condition of micro-cutting of antifriction material is obligatory for the preparation of anti-friction coatings. A theoretical scheme of the process of micro cutting during the formation of an antifriction coating has been developed. The peculiarities of filling the micro relief cavity with antifriction material have been investigated. Taking into account the studied consistency, a new scheme for the application of anti-friction coatings with high tribological parameters has been proposed.

Key words: antifriction coating, finishing antifriction non-abrasive treatment, friction-mechanical method, formation of coatings, the process of micro-cutting, micro relief.

Introduction

Current trends in the production and operation of machines, and continuously increasing demands on the quality of the machines produced, are aimed at increasing their reliability, which largely depends on the performance properties of individual parts. Improving the performance properties of parts is achieved by improving the quality of working surfaces of parts. The quality indicators include the physicomachanical properties and the geometric characteristics of the surface layer, which are purposefully formed on the finishing operations of the technological process. An important role in the formation of physicomachanical properties is provided by an intermediate ambient through which the interaction of microasperity occurs. Consequently, one of the ways to improve the quality of parts in their manufacture and repair is the modification of the working surface by applying coatings on final operations.

Among the most simple, effective and environmentally friendly methods for obtaining coatings, a group of technologies for finishing treatment antifriction without abrasive (FTAA) should be distinguished, which is realized due to the frictional interaction of the processing tool with the surface of the workpiece. The result of the using of such technologies is the coating of copper and its alloys on steel and cast iron surfaces in order to improve burn-in and increase wear resistance due to the subsequent self-modification of surfaces under friction conditions during operation [1].

The existing various hypotheses explaining the mechanism of coating formation in FTAA are described in the literature, however, due to the lack of consensus on this issue, as well as due to the improvement by the authors of the presented work of the technology of applying coatings by the friction-mechanical method [2], the process of forming the coating by friction requires further more detailed study.

Materials and methods

According to studies [3], the formation of antifriction coatings by the friction-mechanical method has characteristic features similar to those processes that occur during spin welding: surface activation, presence of pressing forces, relative displacement of surfaces relative to each other. As a result, heating of the contacting areas occurs, the formation of juvenile surfaces, setting, etc., which conduce to the transfer of material from the rubbing tool, made of plastic material, to the workpiece. The author notes that the quality of the application of the friction copper-bearing coating depends on the operation of the four activation channels of the contact surfaces: mechanical, chemical, thermal, and the channel associated with plastic deformation, and the most complete operation of the channels, therefore, and the intensification of friction rubbing, is ensured by applying a tribo-coating with optimal load-speed processing modes and an effective compound of the technological environment.

In this work [4], the process of formation of the FTAA coating is presented in three successively passing technological transitions:

- surface pretreatment with the aim of activating the surface of the base metal and obtaining a juvenile surface;

- chemical interaction of the coating components and the formation of a diffusion layer;
- build-up of the coating layer.

According to [5], the following prerequisites are required for coating FTAA:

- microcutting conditions;
- plastic contact conditions;
- galling criterion;
- optimal coating parameters.

On the basis of experimental data and theoretical consideration, the formation of coatings at FTAA is considered by the authors [6] in three stages. At the first stage, a surface-active ambient (SAA) is applied to the surface of the part, which, possessing good surface wettability, contributes to the softening and dissolution of oxide films on the surface of the part and tool. In the second stage, the solid (the workpiece) is in contact with the soft counterbody (tool). Herewith tool wear occurs due to micro-cutting with surface roughness of the workpiece. This phase is characterized by high pressure and the associated introduction of protrusions of the surface roughness of the part into the surface of a softer material, forming a coating. As a result of tribo loadings and compressive pressures, part of the wear particles formed during microcutting are pressed in the hollows between the protrusions of the surface roughness of the part. This contributes to smoothing the surface, increasing the actual contact area, reducing the contact pressure. As a result of high local pressures, cohesive bonds arise. At the third stage, when the cavities of the treated surface are filled, an increase in the thickness of the coating layer occurs under the influence of adhesive interaction. The applied layer is strongly bonded to the base metal substrate, and the surface roughness enhances this bond. A further increase in the coating thickness will be determined by how much the shear strength of the coating layers will be greater than the strength of the tool material.

According to the researchers [7], the process of friction-mechanical coating is accompanied by two competing phenomena: the formation of a coating and its destruction. Thus, the shear stresses acting in the contact zone at the initial moment are destructive only for the material of a more ductile metal — copper alloy. It is dispersed in the form of small particles which are transferred to the treated surface. With an increase in the thickness of the coating, its strength decreases and a moment comes when the surface layer of the part cannot pull particles from the tool, the growth of the coating thickness stops.

Such an approach to the description of the mechanism of formation of a tribo-covering, in the opinion of the author of the work [8], seems somewhat one-sided, because it does not take into account the chemical processes that occur during rubbing, although in most of the known developments the composition of technological liquids includes glycerin, which is a reducing agent for copper. Researchers [3, 8] emphasize the fact that it is necessary to consider the temperature factor, to a greater extent determining the physicomaterial properties of interacting metals.

The model of applying antifriction coating of FTAA is considered in details in the works of German researchers [7, 9], where it is indicated that at the initial moment of tribo-interaction the process of microcutting of a copper alloy prevails. The presence of SAA resulting from the triodegradation of glycerol allows loosening the oxide layers on the friction surfaces and plastically deforming the particles of the transferred metal in the friction zone. Some particles are compressed in the cavities between the protrusions of the roughness, which causes a general decrease in the roughness parameter of the treated surface. Under the influence of high local compressive forces, the particles are pressed, and their adhesive bond is formed between themselves and the substrate.

Most accurately, in our opinion, the mechanism for the formation of a coating is described in [8], where the FYAA process is presented as a three-stage process. At the first stage, surface grinding occurs in the mode of external friction, where only low-strength surface layers participate, providing a positive gradient of mechanical properties over the depth of each of the friction bodies. The second stage is characterized by friction of pure metals free from oxide films. Normal and tangential stresses appear on the contact surfaces of the microprotrusions, exceeding the yield strength and shear stress of the ductile metal. Due to the plastic deformation of the near-surface volumes, the collapsing and cutting of microprotrusions occurs, and an increase in temperature in the contact zone leads to a decrease in the yield strength of the material. As a result, there is a transfer of plastic metal particles to a solid substrate, their deformation and the formation of new adhesive bonds. At the third stage, a low-strength coating layer is formed on the surface, which creates a positive gradient of mechanical properties over the depth. The transition of internal friction to external leads to the termination of the build-up of the coating and the achievement of an equilibrium state in terms of the shear characteristics. The author notes that the FTAA process ends at the phase when there is no bulk plastic flow of the material and the maximum temperature is reached, which eliminates the deformation of the parts.

Summarizing the analysis of works explaining the mechanism of coating formation under FTAA, it should be noted that there are different approaches to the description of the presented process. The formation of

friction coatings has its own characteristics and requires further more detailed research, which will determine the ways and means of intensifying the process of producing coatings with high tribological indicators, and thus improve the quality of processing and the overall performance properties of parts.

Purpose of research

The research of the initial stage of formation of antifriction coating by a friction-mechanical method, including the process of micro-cutting.

Results

Adhering to the hypothesis that at the initial moment of the tribo-interaction, the process of micro-cutting of the copper alloy prevails, we make next assumptions:

- since the residual scallops of the base microrelief always have a wedge-shaped shape with a sharp edge, each of them can be considered as a separate cutting wedge;
- the space between the residual combs (hollows) of the microrelief should be considered as grooves for the location of chips, which is formed in the process of interaction of the tool from the antifriction material with the surface of the substrate.

To ensure the condition of micro-cutting, the working part of the tool, having the shape of a wedge, should go deep into the cutting layer. Otherwise, there is only a mutual crushing and the process of micro-cutting will not be. Since the cutting wedge is under heavy loads, its material must satisfy a number of requirements, the main ones being hardness and mechanical strength. Moreover, for the application of an antifriction coating by a frictional-mechanical method, the hardness and strength of the base materials must exceed in certain extent the mentioned indicators of antifriction materials.

Thus, it should be expected that the application of an anti-friction coating by a friction-mechanical method will be accompanied by a process of micro-cutting of an anti-friction material. At the same time, antifriction material will fill microscopic irregularities in the form of chips and influence the formation of a coating film.

The process of microcutting with the friction-mechanical method of coating will be considered as a low-temperature process of deep plastic deformations with a predominance of a simple shear of the material being processed in the chip formation zone according to the free orthogonal cutting pattern characteristic of the broaching process. The theoretical scheme of the process of microcutting during the formation of an anti-friction coating by the friction-mechanical method is shown in Fig. 1. In this case, we used standard terms and notation that refer to the treatment with cutting [10].

Suppose that a separate micro-comb on the surface of the base plays the role of a cutting wedge, and the anti-friction bar is the object from which the metal layer is cut. According to the presented scheme (Fig. 1), the process of micro-cutting is ensured by pressing the antifriction bar to the base surface being processed with a force P and moving it across the asperities V . In this case, the thickness of the cutting layer a will be determined

by the depth of penetration of the cutting wedge into the antifriction material, which depends, besides the force P , on the plastic properties of the latter and the angle of tapering β of the cutting wedge.

Under certain conditions of micro-cutting, a growth is formed on the front surface of the cutting wedge, which is a piece of plastically deformed material being processed, the hardness of which is in 2 - 5 times greater than the initial one. The fit is wedge-shaped and influences significantly the process of micro-cutting by changing the initial geometry of the tool. The phenomenon of growth is also characteristic of the process of cutting broaching, which is characterized by low speed and temperature of cutting, which occurs when applying antifriction coatings according to the method proposed in [11].

A build-up A (Fig. 1), performing the function of a cutting wedge, first of all, changes the rake angle γ from negative to positive γ_ϕ to a certain value and provides a stable value of the cutting angle δ_ϕ , increases the thickness of

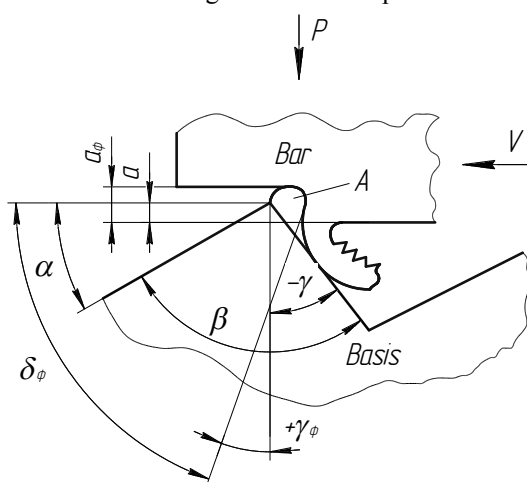


Fig. 1 – The theoretical scheme of the process of microcutting during the formation of an anti-friction coating by the friction-mechanical method

the layer being cut to a_ϕ , which positively affects the process chip formation.

It is difficult to obtain a high-quality coating on a surface that has a coarse regular microrelief. This is due to the peculiarities of filling the interbrain depressions with antifriction material. So, when the coating film is applied by a friction-mechanical method, voids appear between the individual particles of the antifriction product (Fig. 2). This phenomenon affects the quality of the coating, namely the continuity and density of the anti-friction film.

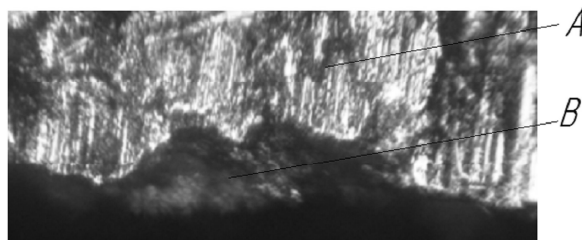


Fig. 2 – Fragment (× 140) coated bases:
A – the basis (cast iron GCI20);
B – coating in the inter-ridge cavity (bronze TZS 5-5-5)

Therefore, it is possible to improve the quality of the coating by creating favorable shapes and sizes of asperities in the previous FTAA operations. To strengthen the antifriction film, it seems reasonable to use one of the methods of cold plastic deformation - deforming broaching, which will allow:

- to ensure the packaging of individual elements of the antifriction product (chips) into a continuous mass, the strengthening of the coating materials and the substrate by means of surface plastic deformation;
- to improve the quality of adhesion of antifriction material with the base;
- to create a microrelief with a greater bearing capacity of the surface.

Conclusions

The widespread use of the FTAA friction-mechanical method is hampered by the absence of a single theoretically grounded approach to the formation of an anti-friction coating, and the existence of different opinions on the mechanism of the formation of coatings indicates the need for further research based on modern scientific ideas about the processes occurring on the contact surfaces during friction coating.

Taking into account the predominance of the micro-cutting process at the initial stage of the formation of the coating, a theoretical scheme of the micro-cutting process with the FTAA friction-mechanical method is proposed. The peculiarities of filling the microrelief of the depression with antifriction material allowed us to propose the following scheme for applying FTAA coatings: mechanical surface preparation with the creation of a regular microrelief, coating by friction-mechanical method, deforming broaching. The using of this technology will improve the quality of the surface layer and operational properties of parts.

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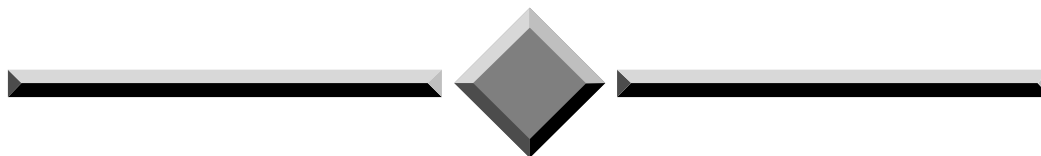
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Шепеленко І.В., Посвятенко Е.К., Черкун В.В. **Механізм утворення антифрикційних покриттів фрикційно-механічним методом.**

Відмінності в підходах і трактуванні механізму утворення антифрикційних покриттів фрикційно-механічним методом стримує широке застосування фінішної антифрикційної безабразивної обробки під час виготовлення та ремонту деталей. Встановлено, що початковий етап нанесення антифрикційного покриття фрикційно-механічним методом супроводжується процесом мікрорізання антифрикційного матеріалу з наступним заповненням западин його мікрорельєфу. Виконання умови мікрорізання антифрикційного матеріалу є передумовою для одержання якісного антифрикційного покриття. Процес мікрорізання при фрикційно-механічному методі нанесення покриттів розглянутий як низькотемпературний процес глибоких пластичних деформацій з перевагою простого зсуву оброблюваного матеріалу в зоні стружкоутворення за схемою вільного ортогонального різання. Розроблена теоретична схема процесу мікрорізання під час формування антифрикційного покриття фрикційно-механічним методом із використанням стандартних термінів і позначень з теорії різання. Доведено, що оскільки залишкові гребінці мікрорельєфу основи завжди мають клиноподібну форму з гострим краєм, то кожні з них можна розглядати як окремий ріжучий клин, а простір між гребінцями (западни) мікрорельєфу варто вважати канавками для розташування мікростружки, яка утворюється в процесі взаємодії інструмента з антифрикційного матеріалу з поверхнею основи. Показано, що в процесі мікрорізання антифрикційний матеріал буде заповнювати мікронерівності мікростружкою і впливати на утворення плівки покриття. Досліджені особливості заповнення западини мікрорельєфу антифрикційним матеріалом. Внаслідок нанесення покриття фрикційно-механічним методом між окремими частинами антифрикційного продукту виникають порожнини, що негативно позначається на якості покриття, його щільності та щільності. Встановлено, що підвищити якість покриття можливо шляхом створення сприятливих форм і розмірів мікронерівностей на операціях, що передують нанесенню покриття. З урахуванням вивчених закономірностей запропонована нова схема нанесення антифрикційних покриттів з високими триботехнічними показниками: механічна підготовка поверхні зі створенням регулярного мікрорельєфу, нанесення покриття фрикційно-механічним методом і деформуюче протягування. Застосування такої технології дає змогу підвищити якість поверхневого шару й експлуатаційні властивості деталей.

Ключові слова: антифрикційне покриття, фінішна антифрикційна безабразивна обробка, фрикційно-механічний метод, формування покриття, процес мікрорізання, мікрорельєф.



“Problems of Tribology”