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Lubricants and specific materials for achieving/ triggering the selective transfer – a short presentation with applications

Abstract

The paper aims to present lubricants and materials that allow and can be used under selective transfer conditions as an application with a useful effect on the friction and wear process. In order to achieve selective transfer, it is necessary to have appropriate lubricants and materials. The molecular phenomena at the separation interface of two adequately lubricated solid materials are complex. Experimental studies proved that physicochemical processes take place as long as there is relative movement on the real contact area, but also afterwards. Under optimal operating conditions in the friction process, a thin, superficial protective layer (usually based on copper) is formed in the contact areas by the selective transfer, with the possibility of self-regulation. The self-regulation process of the protective layer owes its special properties to one or more of the chemical elements of the lubricants and materials, and in the presence of a local energy that favors the process. These properties take into account, in particular, the reduced sliding resistance after a certain direction and the possibility of transfer in a very short time, specific to contact on roughness, with a positive effect on friction and wear.

Keywords: selective transfer; lubricants and specific materials; friction and wear, applications

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Introduction

Selective transfer is used to reduce friction and wear in friction pairs of various machine subassemblies, as a result of the formation of a very thin copper layer (1 – 5 µm) on the friction surfaces. Concrete applications are found in sliding bearings, mechanical transmissions with gears, screw-nut pairs, seals of drilling and pump installations, low-current contacts, in the construction of aircraft, motor vehicles, engines, machine tools, in chemical installations, oil installations, etc. It has been established that this copper layer leads to an increase in friction and wear resistance, and sometimes even to the complete elimination of wear.

The increase in friction and wear resistance can be explained by selective transfer in the contact areas, although the same principles are not practiced in all countries that use selective transfer. Thus, in refs[1–4] analyzed the factors influencing wear and also described the factors of the selective transfer process. Among other things, the influence of metal transfer from one surface to another was analyzed, as a result of which it was concluded that zero wear can be achieved if copper is transferred unhindered from one surface to another, similar to the landing gears of airplanes.[1,2,5–9]

Rabinowicz and Tabor[9] extended the research into the field of layer formation reactions. As a result of these studies, it was concluded that a layer can appear in the process of heterogeneous catalysis and, in the case of mechanochemical reactions, as in the case of selective transfer, can eliminate wear.[1,9–11]

The clarification of the advantages of selective transfer in sliding bearings, compared with other friction conditions, was carried out by Challen and Oxley.[12] For this, comparative tests were made with glycerin, engine oil, and polyethylene glycol. These experiments showed that sliding bearings working with selective transfer have better sliding properties than those working with engine oil or polyethylene glycol. At the same time, establishing the friction and wear criteria for the effect of selective transfer under variable working conditions.[1,2] Also, the influence of selective transfer on the reliability of friction pairs in machines was established, showing that by using selective transfer, reliability increases compared with oil lubrication, and the possibility of parts being taken out of service due to wear decreases.[2,12]

A new, self-lubricating material for bearings, called "permoglide".[13–16] Bearings made of this material are used in installations operating in water, for example, in nuclear reactors or turbines.[17] A mixture of metal powder called "kollodium" has also appeared on the market, which, when added to the bearing lubricant, visibly reduces the coefficient of friction and also regenerates worn surfaces. An addition of "kollodium" to the emulsions used in machining makes it possible to increase the cutting speed and reduce the wear of cutting tools. The mixture consists of 70% copper, 30% lead, as well as additions of tellurium, silver, and tin.[18,19]

Additionally, it has been proposed to reduce wear in the cylinders of internal combustion and diesel engines by copper-plating cast iron segments. Experimental tests have established that the use of copper-plated segments reduces cylinder wear by about 500 times.[20,21]

In the following, a presentation will be made of lubricants and materials that reliably achieve selective transfer in various friction pairs of machines, installations, and industrial equipment.

Lubricants that contribute to achieving selective transfer

Experimental research has shown that when copper, bronze, or brass powders are introduced into glycerin or in a consistent grease, the friction surfaces of steel parts are covered with a thin layer formed by the powdered material.[1,2]

Thus, we distinguish two principles of action when introducing powders:

- the particles are anchored on the friction surfaces, thus achieving the premises of a selective transfer. At the same time, the alloying elements in the bronze or brass particles dissolve during the friction process, as they react by exchange with the lubricant, and, as a consequence, the friction surfaces will be covered with a layer of copper;[22]

- the particles anchor themselves on the friction surfaces, to eliminate irregularities to a minimum.[22]

If the first principle of action is known as adhesion, then the second is a mechanical mechanism in the microscopic domain.

The use of powders according to the principle of mechanical action involves the addition of copper and lead powders to ordinary mineral oil. The mixture thus obtained reduces the friction force and possesses, to a certain extent, the property of regenerating the friction surfaces.[22] This is the case of machine tool guides, polished surfaces of valves, cylinders, and other parts, where wear occurs due to the frictional stresses of hydraulic system seals.

The introduction of copper and lead powders into cooling emulsions considerably reduces the wear of cutting tools and makes it possible to increase the cutting speed. This mixture consists of 70% copper powder, about 30% lead powder, and very small additions of tellurium, silver, zinc, and antimony powders.

The authors believe that the wear-protective properties of some metals and alloys are due to the fact that at the first contact of the friction surfaces, very fine particles are released, which then form a more or less stable suspension in the lubricating oil.[2] This significantly reduces the wear and friction coefficient of the metal surfaces.

Based on these findings, it is recommended to apply oils containing colloidal metal additives to the friction surfaces, since without colloidal metal additives, the lubricating oil forms salts that are adsorbed only on the surface of the metals in contact.[2,22] In this case, the intermediate layer of lubricating oil consists of two free salts and a thin layer of oil between them. When superfine metal powders are added as a dispersed phase of the corresponding colloidal organic solution, the intermediate layer of lubricant in the space between the two parts in relative motion has a different structure. As a result of the existence of a large amount of colloidal metal particles and the formation of a lubricant layer on the surface of each particle, almost all of the lubricating oil in such an intermediate layer is in a free state. A lot of free salts appear in the friction space, which act favorably to reduce the friction coefficient and wear of metals and alloys.

In addition to the action presented, of raising the load capacity of the interacting layers, organic colloidal solutions smooth the microscopic asperities of the surfaces in contact and thereby reduce the real contact pressure, thus having a mechanical effect.[23] Also, such organic colloidal solutions are widely used to reduce the wear of parts stressed by friction when starting engines after assembly.

The action of the metal powder found in the lubricant, to ensure a selective transfer, is also based on adhesion processes. This principle differs from the others in that copper, bronze, or brass powders are added to the lubricant, which are used in the industry to manufacture electric brushes and other metal-ceramic products. Also, very fine bronze powder from the manufacture of paints can be used. The powder used must have a grain size such that (65-90)% of the particles pass through a 0.045 mm sieve, and 15% are retained by a 0.08 mm sieve. This very fine powder is produced by appropriate treatment and grinding of brass or bronze and can be used by mixing (5-10)% with the lubricant in order to obtain the lubricant that creates metal coatings. The anti-corrosion protection properties of the lubricant are not modified thereby.

Lubricants that create metal (surface) coatings can be used, especially in steel/steel friction pairs, at relatively low temperatures and high pressure.

Such examples are the bolts in the joints and the threaded transmissions in the steering mechanisms of aircraft, in machine tools, in technological equipment, and in the joints of cardan shafts. In aircraft, for example, welding of steel/steel friction pairs has been frequently observed. In order to reduce wear, constructive modifications of the friction zones were often necessary in the past. This requires a lot of time and material.

The use of lubricants that provide metallic coatings (deposits) eliminates this tendency of the friction-wear zones.

Materials that can be used under selective transfer conditions

Recently, materials have been known that, under optimal operating conditions, form a thin layer of copper in the contact areas and, therefore, can operate under selective transfer conditions. These materials are used in various friction pairs of machines, installations, equipment, etc. These materials have in common the fact that special physicochemical processes take place in the area of the friction (contact) surfaces, which lead to the formation of a thin, almost pure layer of copper.[22,24] This copper layer differs in its structure from the copper deposited by common electrolytic (galvanic) processes. A special characteristic of these materials is that some can even be used in combination with themselves.

Selective transfer can be obtained with the following materials: metals, metallic polymers, metal-ceramic materials, glass with fillers, noble metal alloys, materials based on epoxy resins, and others. For the first time, the selective transfer was discovered in friction pairs using such materials lubricated with lubricants of the type presented above. It was confirmed by experimental tests, not only those presented in the paper and performed by the author, but also others, performed on other friction and wear testing facilities.

For example, a transport of copper on the contact surface of friction pairs was also found in the case of lubrication with a mixture of glycerin and alcohol with a consistent grease based on lithium and calcium. This was observed when one element is made of steel or cast iron, and the other element is made of a copper alloy (bronze or brass), as well as in the presence of other lubricants containing special surfactant substances for regeneration.[1,2]

The isolated transport of some alloy elements has been known for a long time. For example, the good sliding properties of gray cast iron are known, which can be explained by the fact that the graphite particles present in the cast iron are released and form a very thin layer on the surface of the rubbing parts (elements). An almost identical mechanism occurs in lead bronzes. Lead, due to its low hardness and high adhesion properties, is easy to apply to the surface of a steel and serves as a solid lubricant. Similar mechanisms occur in other self-lubricating materials.

In the case of the transfer of copper from a bronze alloy to a friction surface, there is no tearing of alloying elements from the alloy, but a breaking of the crystals in the bronze mixture. Only after the breaking of the mixture crystals does the separation of copper occur.

Practically no wear occurs on the friction surfaces of the bronze/steel pair, due to deposition of a copper layer on both friction surfaces. But, it can be assumed that by selective transfer, real wear is determined without blocking (sticking) of the copper particles on surfaces, and without their oxidation.

Research with different types of bronze has established that they have different friction and wear behavior under selective transfer conditions. Research carried out to date on the friction and wear resistance of the bronze/steel friction pair in a glycerin environment has shown that bronze wear depends on the test conditions and can be high or very low.[2] When the bronze surface is covered under stationary conditions with a thin layer of copper, the detachment of material no longer occurs, and passivation occurs, which leads to a large decrease in wear. However, when the bronze contains many easily dissolving alloying elements and the contact pressure is high, significant wear occurs. In this case, the separated copper binds to the steel and forms an amorphous, slightly friable layer that does not crystallize.

The wear resistance of the bronze under such conditions is relatively low. At lower loading pressures, the detachment rate decreases and a passive layer forms on the bronze surface, which also reduces the wear intensity.[1,2]

The research on the possibilities of using different additive materials in polymers, which can ensure selective transfer, was carried out using cuprous oxide (Cu_2O) as an additive material. The mechanism of friction of polytetrafluoroethylene and polypropylene with Cu_2O addition on steel surfaces, in different lubricating media, was investigated.[2,25–27] In order to improve the physico-thermal properties, especially the thermal conductivity, and to reduce wear, up to 40% Cu_2O was added to the polymers.

The tests were carried out on a plant that works on the principle of a sliding bearing, using air, glycerin, bearing oil, and transmission oil as lubricants. It was found that when Cu_2O particles were added to polypropylene, they activated as ordering nuclei, thus achieving a much more homogeneous appearance in the section, which was not observed in polytetrafluoroethylene.[27]

The research conducted led to the following conclusions:

- the lowest friction coefficient, without lubrication, is presented by polytetrafluoroethylene with Cu_2O;

- when lubricated with glycerin, the friction coefficient decreases continuously, due to the formation of a thin copper layer on the steel surface (Cu_2O being reduced by friction to pure copper);

- the addition of copper to polytetrafluoroethylene decreases friction without the addition of lubricant, approximately 3 times, compared to polytetrafluoroethylene + 40% aluminium oxide (Al_2O_3);

- when friction without lubrication of polypropamide + 40% Cu_2O under identical test conditions, wear is about 6 times lower than that of pure polypropylene, and when lubricated with glycerin, it decreases about 120 times.

Very good results were also obtained by using binders based on epoxy resins with the addition of copper powder with a grain size of 5 – 15 μm. Materials based on epoxyfuran oligomers and essentially soft mixtures, with the addition of copper-based materials in a glycerine and bearing oils environment, in which the formation of thin copper layers is possible by decomposition of the additive material,[27] have also been tested. Stable friction and wear behavior have been observed in materials with copper powder. The mentioned materials are used to seal hydraulic cylinders of motor vehicles, pumps, and compressors of oil installations.

There are situations when a pair of materials or lubricants does not allow operation under selective transfer conditions. In this situation, by using appropriate technological processes for processing friction surfaces, they can operate under such conditions in the friction process, such as friction coating with bronze, brass, or copper. The basic principle of these processes is that steel parts are protected before assembly with a thin layer of brass, bronze, or copper.

During operation, these thin, metallic, sliding layers improve running-in and prevent the appearance of wear zones.

Friction coating does not require special equipment or special qualifications of personnel and can be used instead of electrolytic copper plating in acidic electrolytes. This is of great economic importance, especially since copper-cyanidation baths are unprofitable and require special measures from the point of view of labor protection. This friction coating system with brass or bronze is used for bolts, joints, pins, bushings, axles, pistons, and cylinders.

Conclusion

Based on the above, it is found that there are other lubricants that certainly contribute to achieving the conditions for selective transfer (the introduction of copper, lead, bronze, or brass powders in glycerin, thick greases, mineral oils, cooling emulsions, etc.).

Also, in this field, special metallic mixtures (permoglide, collodion) have been created and developed, which, when added to lubricants, achieve selective transfer, minimizing friction and wear and contributing to the regeneration of worn surfaces of friction pairs.

Theoretical and experimental research has also allowed the production of materials that, under optimal operating conditions, can function under selective transfer conditions by forming a thin layer of copper on the friction surfaces. As an example, there are the metals, metallic polymers, metal-ceramic materials, glass with various fillers, noble metal alloys, materials based on epoxy resins, etc.

If a pair of materials or the lubricants used do not allow the operation of friction pairs under selective transfer conditions, through appropriate technologies for processing the friction surfaces, such as friction coating with bronze, brass, or copper, they can function under such conditions. All of these have concrete practical applications in various friction pairs in machine construction, with a direct effect on reducing friction and wear. In support of these statements comes the experience accumulated from the study of various works on the use of selective transfer in friction pairs.

It is recommended that research in the field continue by deepening and highlighting selective transfer in other pairs of materials and in the presence of other lubricants capable of achieving this process.

Highlighting selective transfer and testing on friction pairs with sliding and rolling motion, oscillatory sliding, and pivoting. Also, researching this transfer at very low sliding speeds and high contact pressures to know and explain the ways in which selective transfer does not occur.

It is important and of interest to research and know the rheological effects of lubricants under boundary and mixed friction conditions, for materials with selective transfer potential.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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