Perspective for the use of industrial waste in lubricating compositions to reduce wear in friction pairs

V Yu Konyukhov¹, D N Permyakova² and T A Oparina¹

¹ Irkutsk National Research Technical University, Lermontov Street, 83, Irkutsk, 664074, Russia
² Bauman Moscow State Technical University, 2-ya Baumanskaya Street, 5/1, Moscow, 105005, Russia

E-mail: konyuhovvy@ex.istu.edu, PermyakovaD@student.bmstu.ru

Abstract. The article presents an analysis of the mechanisms of lubricating action used to reduce the wear of rails and wheels. A review of lubricant compositions that increase the service life of the wheel-rail pair showed that graphite is the main filler used to create rail lubricants. Since the production of synthetic graphite requires high energy costs, this material is relatively expensive. Replacing graphite with cheaper analogs will help reduce the cost of operating rails without losing lubricating properties in friction pairs. Today, there are many lubricant compositions. Many of them require experimental research since they are based only on theoretical knowledge in the field of tribology. In addition, the adhesion properties of a wheel to a rail depend not only on the action of the lubricant but also on weather and climatic conditions. When choosing a rational lubricant, it is worth focusing on a set of factors, and not only on the properties of an individual filler. The data obtained in theoretical analysis cannot always be verified experimentally. The reasons may be economic inexpediency, the complexity of experimental research, or lack of time. The analysis carried out in the course of this work showed that the study of the effect of lubricant components could be optimized using mathematical and digital modeling. The application of these methods will help to select a rational area for research, simulate the behavior of lubricants containing production wastes, and make the mathematical forecast of the operation of friction pairs more accurate.

1. Introduction

One of the key parameters that determine the rail usability group and their characteristics is wearing [1]. The wear of the wheel-rail friction pair can lead to a change in the shape, size, and condition of the tool surface due to destruction and accidents. Wear resistance - The property of a material to resist wear. It depends on many input factors: speed, load, operating temperature, the nature of the rubbing bodies, and the intermediate medium (lubricant) [2]. In modern industry, graphite is used as a lubricant component. The antifriction properties of this material are explained by its crystal lattice. Its crystal lattice is shown in Figure 1 [3].

Graphite is a constituent of a large number of lubricants used in various fields of mechanical engineering [4-9]. Synthetic graphite, produced by repeated pressing, roasting, and graphitization of coke, possesses higher antifriction properties in comparison with natural ones. This process requires significant energy consumption, therefore it is rather complicated and expensive [10]. To simplify the process of obtaining lubricants and make it cheaper, it was proposed to replace graphite with
processed products, for example, polysulfide polymers and petroleum coke. Replacement will help not only reduce the cost of the material obtained but also make waste disposal more environmentally friendly and profitable. At this stage, the problem of finding and analyzing the properties of materials analogous to graphite arises. So it is not always possible to experimentally test the behavior of lubricants in a particular work environment.

In order to make the research more effective, it is possible to replace some of the experimental research with mathematical and digital modeling. The search for alternative ways of studying will allow minimizing errors in the choice of material, analyzing the antifriction properties of graphite in various climatic conditions, and will provide a theoretical basis for replacing graphite with a cheaper analogue.

![Figure 1. Crystal lattice of graphite: A - horizontal axis; C - vertical axis [3].](image)

2. Replacement of graphite with industrial waste

Existing studies prove that replacing graphite with industrial products is a promising task. Particular attention is paid to the problem of obtaining new lubricant components.

The work [11] describes the synthesis of polymers containing sulfur atoms in the chain. The synthesis of organosulfur polymers, which is based on a polymerization reaction, is not economically viable. Hard-to-reach monomers are used in the polymerization reaction. For example, dithiols and thietokones. Although it is possible to manufacture some of the monomers on an industrial scale, a more efficient synthesis process is used. With the help of aqueous hydrazine-alkalis, it is possible to obtain semi-sulfide polymers. The high content of sulfur atoms allows these polymers to be used in lubricating compositions.

The work [12] was devoted to the creation of a lubricant based on polymers. As a result of the research carried out, a lubricant based on low molecular weight polyethylene and diesel oil was created. The grease also included graphite, but its content did not exceed 10%. That is, most of the components that make up the lubricant are processed products. It is also interesting that an increase in the graphite content up to 15% did not give a significant effect. This is proof of the possibility of creating lubricants with a reduced graphite content without compromising antifriction properties. The viscosity of the resulting composition can be adjusted by changing the ratio of polyethylene and diesel oil.

In the northern countries, a very urgent task is to create technologies that ensure the operation of the railway in harsh climatic conditions [13-16]. Replacing graphite with petroleum coke during creation is one of the ways to solve the problem.
The article [13] describes a lubricant that includes petroleum coke, spent diesel fuel, and low molecular weight polyethylene. At the moment, the grease is successfully used on the East Siberian Railway, including on curved sections. Since the hydrocarbons used in its creation are biodegradable, the lubricant is environmentally friendly.

3. Selection and study of lubricant properties

Several factors affect wear resistance. These are the physicochemical characteristics, the coefficient of friction calculated through the magnitude of the acting stresses, external pressure, sliding speed, surface microgeometry, and the coefficient of contact fatigue. Features of the process of wear of the surface of rails are described in detail in [17-20].

In addition, the lubricant used must comply with current safety requirements. At this stage, the development of lubricants based on biodegradable polymers is underway. Article [21] provides an ecological rationale for the synthesis and use of polysulfide polymers, which can be obtained directly from processed products. The use of waste is of interest not only from the point of view of the economy in production but also as a way to reduce the number of utilized chemical compounds.

The creation of new materials is practically impossible without a theoretical basis. For example, the main features of the creation of lubricants used in high-speed rail transport are described in [23].

Before being put into practice, lubricants must be studied and tested. Friction measuring machines are often used to test rail lubricants. Figure 2 shows the device of the machine, which was used to analyze the work of a friction pair during the study [13].

This machine is required for wear testing. The ability to adjust the external parameters of friction, as well as its type (sliding or rolling), allows testing the material under conditions as close as possible to the operating conditions of a real friction system "wheel - lubricant layer - rail".

![Figure 2. Machine for measuring friction MI-1M: 1 - motor; 2 - pendulum, which measures the friction torque; 3 - sample No. 1; 4 - spring; 5 - sample No. 2; 6 - drum fixing the main torque.](image)

Now, such wastes as organosulfur polymers [11], petroleum coke [13], chlorinated lignin [22], and low molecular weight polyethylene [24] have a complete theoretical basis. However, during the implementation and operation of the lubricant, problems can arise. Theoretical data do not always fully reflect the behavior of the lubricant during operation. In order to analyze the available data and predict the behavior of the material under the conditions of the wheel-lubricant-rail friction system, mathematical and digital modeling methods can be used.
4. Application of mathematical and computer modeling to analyze the behavior of a lubricant during friction

Methods of mathematical modeling are successfully applied in various fields of science and technology [25-29].

In most cases, mathematical modeling is based on computer modeling of physical processes. Computer modeling can be implemented using an object-oriented approach to process modeling. For example, using the visual modeling environment MARS (SM MARS), Simulink, or using a graphical language similar to the G language in the Labview environment [30].

Thus, work [31] describes in detail the creation of a multilevel visual layer (V-layer) in the MARS program. Based on the experience of using various programs by scientists in other fields of science, it is possible to optimize the study of the friction process, and in particular to study the effect of lubrication on the wear of rubbing surfaces.

Simulink and Mathlab can be used to study lubricants to more efficiently store, transmit, and process research data.

Modeling friction processes is of particular interest to scientists. Friction is accompanied by a change in the thinnest surface layer, namely its structure, structure, and properties. Mathematical modeling of the friction process has been studied in [32-35].

The author of the article [32] raises an important question of studying the correlation between wear resistance and hardness for rail steel. Taking into account the modes of operation, the friction pair "wheel-rail" is considered as a system. To establish an optimum between the strength characteristics of a wheel and a rail, the researcher chooses mathematical modeling using a non-compositional rotatable second-order design. In addition, the results of the experiment were interpreted graphically by plotting lines of the equal response of wheel wear (Fig. 3a) and rail wear (Fig. 3b) [32]. With the help of these lines, you can select the optimal value of the travel speed and load, which will ensure the minimum wear of the wheel and rail. When analyzing points A, B, C, and D, it was established at what load and speed, the amount of wear are minimal.

Mathematical modeling is also used in the studies described in [36]. The author conducts physical and chemical modeling of systems. The simulation is based on a mechanical subsystem and a physical model. An equivalent circuit has replaced the mechanical subsystem, which is a rather complex network. This scheme has the same number of degrees of freedom as the number of masses of a real object, and the same number of equations describes its motion. Further, the problem of modeling the main dynamic characteristics is solved by analyzing the differential equations of motion. As a result of building the model, the researchers proved the rationality of using a 1520 mm track and also developed methods for tribospectral identification and optimization of friction processes.
5. Conclusion
At the moment, production waste is an ineffective raw material. Their disposal requires additional costs. At the same time, graphite, the main component of most anti-friction lubricants, is an expensive material, the synthesis of which also requires significant efforts. In the future, graphite can be partially replaced by raw materials synthesized from waste, or by the waste itself. Several works are presented, proving that the use of such lubricant components as low molecular weight compounds, petroleum coke, and others provides the same level of properties as graphite. However, their cost is much lower. That is why the use of production waste in the creation of lubricant compositions is a promising task.

However, a huge number of factors that affect the operation of a friction pair complicate the study of the properties of rail lubricating compositions. In order to optimize the choice of waste, to assess the prospects of working with a particular lubricant, as well as to process and transmit information more efficiently, it was proposed to use mathematical and computer modeling. These methods of modeling processes are actively used in other fields of science. Experience in using a mathematical approach to simulate the operation of systems and processes can significantly simplify the solution of problems associated with the creation of a new generation of lubricants.

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