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INVESTIGATION OF THE INFLUENCE OF FULLERENE-CONTAINING OILS ON TRIBOTECHNICAL CHARACTERISTICS OF METAL CONJUNCTION

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ABSTRACT

The influence of fullerene soot additive to M10g2k oil on some tribotechnical characteristics of "steel-steel" tribosystem had been studied. It had been discovered that optimal content of fullerene soot in oil is 0.1% wt. At this concentration, the lowest values of the friction coefficient of - 0.045 and linear wear intensity - 2.7×10^{-9} are observed. Optical studies have confirmed the involvement of fullerene soot in the formation of friction surface saturated with carbon, which resulted in an increase of tribotechnical characteristic of studied samples.

Keywords: fullerene soot, oil, concentration, tribotechnical characteristics.

INTRODUCTION

One of the directions for future development of technical leave of machines and mechanisms lies in the significant improvement of their productivity without sacrificing quality of produced or maintained products. Obviously, this cannot be achieved by changing their construction or material improvement [1], increasing operation intensity of triboconjuctions [2]. Changing construction is rather an effective way of improving the productivity of machines and mechanisms, but it requires significant amounts of human, intellectual and material resources, which is not always an optimal solution. Increasing operation intensity of main machine and mechanical junction leads to a decrease in the reliability and longevity. This problem is mainly related to friction junctions, which are the most sensitive to high loads, speeds and temperatures, increase of which is inevitable upon increasing workloads of equipment [3, 4]. Thus it is important to improve reliability and longevity of friction junctions which under high loads, speeds and temperatures. This objective can be accomplished by improving the lubricity of lubricants used in friction junctions. This would significantly decrease temperature load, friction and wear of parts sliding against each other. It is now that there are at least three requirements for oils: removal wear products from friction zone, a decrease of temperature load and friction coefficient. A range of other tribotechnical requirements is accomplished by various additives to the oils. However, nowadays it is possible to create lubricants with high lubricating characteristics which solve the problem of indifferent restoration of working surfaces of tribosystems. One way to improve lubricating properties of oils is the use of modifying additives, namely fullerenes in any form [7].

LITERATURE REVIEW

Use of fullerenes as a modifier of plastic lubricants and oils are proven to be effective [8]. The use of carbon microsphere as oil filler has also been studied [9]. In both cases, the addition of fullerene materials lead does decrease friction coefficient and wear. Obviously, use of fullerenes in oils lead to change in friction character upon friction interaction pf steel pieces as a result of tribochemical reaction in contract zone [10]. This allows to significantly reducing friction and wear of part in machine and mechanism junction, which leads to improved reliability and longevity. The dependencies of lubricating properties of oils filled with C_{60} fullerenes on the viscosity of mineral base have been obtained [11]. It has been discovered that use of fullerenes allows not only reducing friction and wear of sliding part but also restoring worn friction surfaces. It was revealed that low friction coefficient wears result from rolling of spherical nanoparticles [12]. This means that lower friction coefficient is a result of not sliding, but rather rolling of molecules and their groups on friction surfaces of working bodies. As such, it can be stated that owing to their physicochemical properties, fullerenes can be used as additives to oils in order to improve their lubricity, which would result in lower friction coefficient and wear of moving parts.

However, fullerenes are still a rather scarce and deficit materials and are mainly used for special equipment. Industrial-scale production of relatively cheap fullerenes at the current stage of technology development does not exist currently. This is a significant obstacle for their wide application in general mechanical engineering. This lead to studies on the effectiveness of using fullerenes and cheaper components, for instance thermally exfoliated graphite, as oil modifier [13]. The oil modified with these components had been tested on standard four layered friction machine, which revealed positive tribological effect. There are also other fullerene-containing materials which are by products of synthesis process of pure fullerenes. They are significantly cheaper and available. These materials include fullerene soot (FS) and fullerene black, which contain 1-10% of fullerenes [14]. Data on oils modified with these materials is insufficient. However, it was discovered that addition of 5% fullerene soot containing 15-20% fullerenes C_{60} reduces the tribological load on "steel-copper" conjunction [15]. The effect of soot containing C_{60} fullerenes was similar to those from extracted pure C_{60}. Application of fullerenes in metallurgy when for porous matrices also change friction regime and improved the tribotechnical characteristic of porous tribosystems [16]. The described results create the basis for studying the influence of FS and its influence on "steel-steel" tribosystem. Thus these materials can also be effective oil modifiers. This is of most importance for modifying cheap and widely used oils, such as M10g2k. As such, the present objective is to study the influence of FS on lubricating properties of oils used in friction junctions of machines and junctions on an industrial scale.

MATERIALS AND METHODS

The aim of the work was to determine optimal composition of fullerene oil by studying tribological properties of "steel-steel" friction pair when FS is used.
To reach the set aim, the next objectives were set:

- prepared samples of fullerene-containing oils with different FS content;
- study tribological properties of "steel-steel" friction pair lubricated with modified oil and determine the optimal content of fullerene-containing modifier in oil;
- by studying surface morphology of friction surfaces, determine the cause of altered properties of "steel-steel" friction pair.

Objects and investigation method for studying fullerene-containing oils on tribological characteristics of steel conjunctions

M10g2k was chosen for the study as one of the most widespread and cheapest oils that are used for wide range machinery: large vehicles, other types of transport and special vehicle and stationary equipment, such as stationary generators. This oil is widely used for diesel vehicles such as KamaAZ-740 and its variants. Key properties of the oil are summarized in Table-1.

Table-1. Key properties of M10g2k oil.

Property	Unit of measure	Value
Density at 20 °C	g/cm³	0.9
Kinematic viscosity at 100 °C	mm^2/s	11±0.5
Flash-point	°C	220
Freezing point	°C	-18
Sulfate sol	%	1.15
Active elements (admixtures) per wt: - calcium - zinc and phosphorous	%	 0.19 0.05
Solid admixtures, no more than	%	0.015

Fullerene soot, which is a by-product of pure C_{60} fullerene synthesis, was chosen as a fullerene-containing modifier. The fullerene soot used in studied was provided by Saint Petersburg State Institute of Technology.

The influence of fullerene soot on lubricating properties of oil was evaluated by studying changes in tribological properties of friction junction lubricated with modified oil. The studies were conducted using SMC-2 pin on a disc tribometer with the disc being submerged in oil. The load and sliding speed were 10 MPa and 1.3 m/s respectively. Duration of the experiment was 2 hours and it was repeated there times. The temperature of modified oils was measured using D-301 thermocouple. The roughness of working surfaces (parameter *Ra*) was measured using 296 profilometer according to standard methodology. The material of friction pair pieces was steel 45. Discs were thermally treated to a hardness of 42…45 HRC. Friction surfaces were treated to achieve a roughness of Ra = 0.63 µm.

Surface morphology was studied using scanning electron microscope (SEM) Hitachi S4800.

Experimental

Based on previous results [15], it was expected to achieve a decrease of tribological parameters at the optical content of FS in oil. Oils modified with 0.1; 0.3 and 0.5% FS wt. were used in experiments. Such range of concentration was chosen according to the previously published literature [17, 18].

Results of studying the change of friction coefficient for "steel-steel" pair during friction interaction in the medium of the base and modified oil are presented on Figure-1.

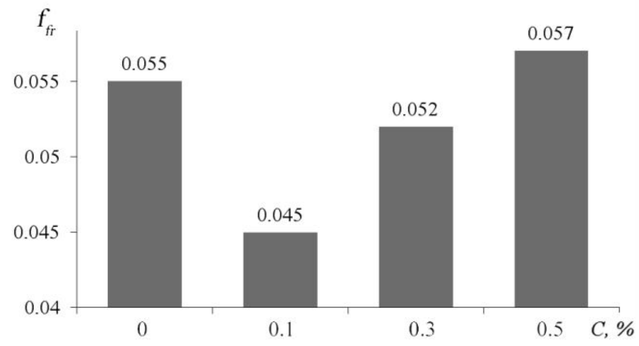


Figure-1. The dependency of friction coefficient f_{fr} on the concentration of FS in oil.

According to study results, the obtained concentration dependencies have systematic growth characters. It was discovered, that at FS modifier concentration of 0.1 % a significant decrease of friction coefficient (Figure-1), temperature (Figure-2) and linear wear intensity (Figure-3) is observed. It worth noting, that for modified oils these parameters are lower by 10-20% in comparison to base oil. With the increase of FS contentment in oil, values of all parameters grow steadily. At FS content of 0.5 % the friction coefficient value f_{mp} exceed those of base oil

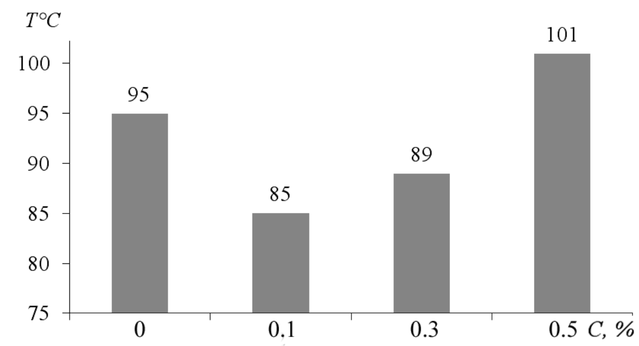


Figure-2. The dependency of temperature on the content of FS modifier in oil.

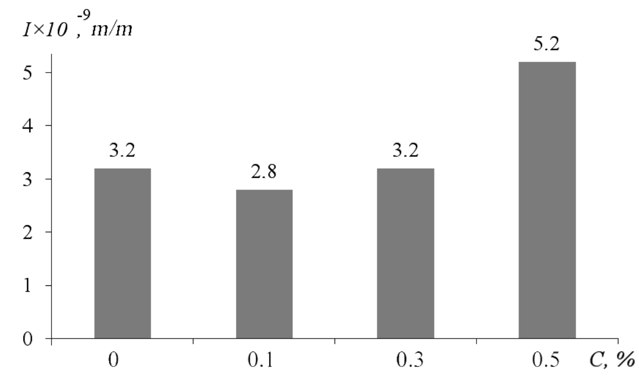


Figure-3. The dependency of linear wear intensity L on the content of FS modifier in oil.

It is known, that even in small amounts, fullerene can actively form a structure on friction surface [19, 20]. This results in the formation of hard and springy antifriction film, which improves tribological properties of the friction pair.

In order to evaluate the presence of such film on friction surface, after friction interaction in FS-modified oil, the roughness of the samples had been measured. The measured roughness *Ra* of friction surfaces after friction interaction in oil samples are presented in Figure-4.

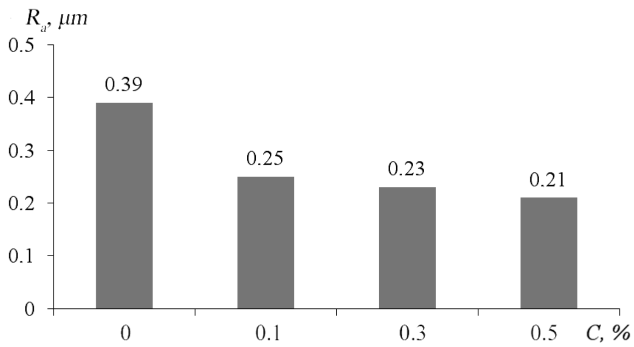


Figure-4. The surface roughness *Ra* after friction interaction in oil samples vs different FS content.

It was discovered that introduction of FS to the oil, results in the lower roughness of working friction surfaces. Additionally, the decrease in surface roughness *Ra* is proportional to FS content in oil. In general, the surface roughness is decreased by 36…46 % in comparison to surface measured after friction in base oil. Figure-5 shows proposed surface profiles after friction interaction in the base and modified oils.

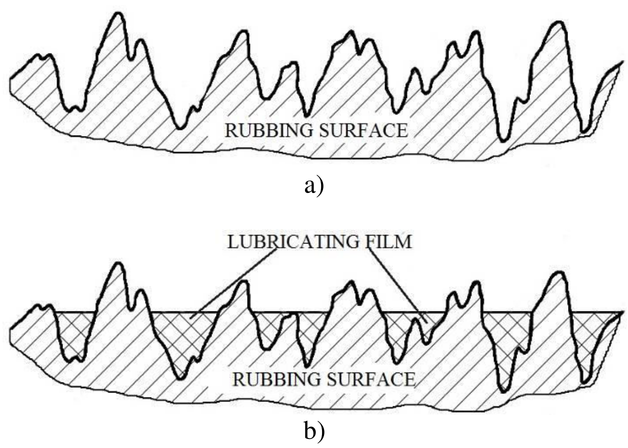
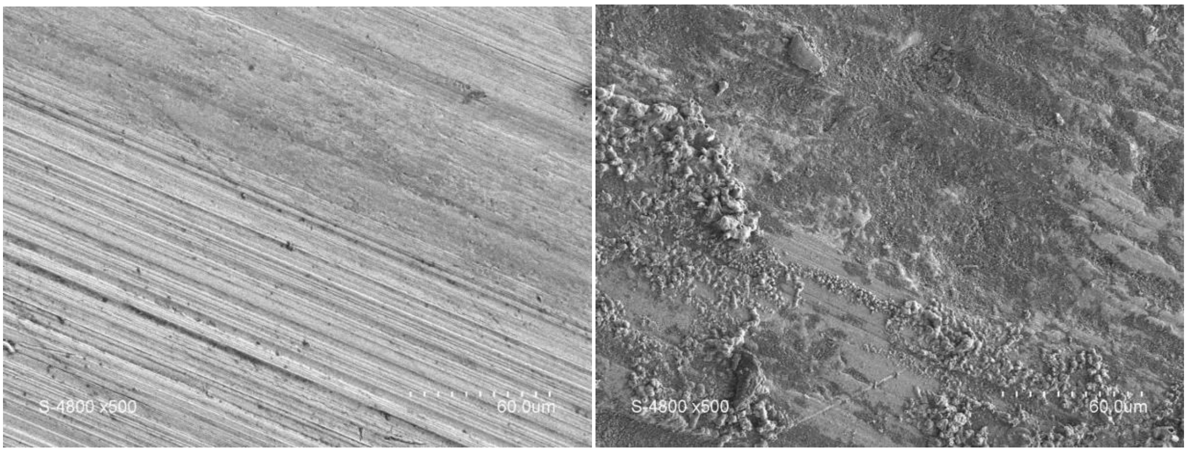


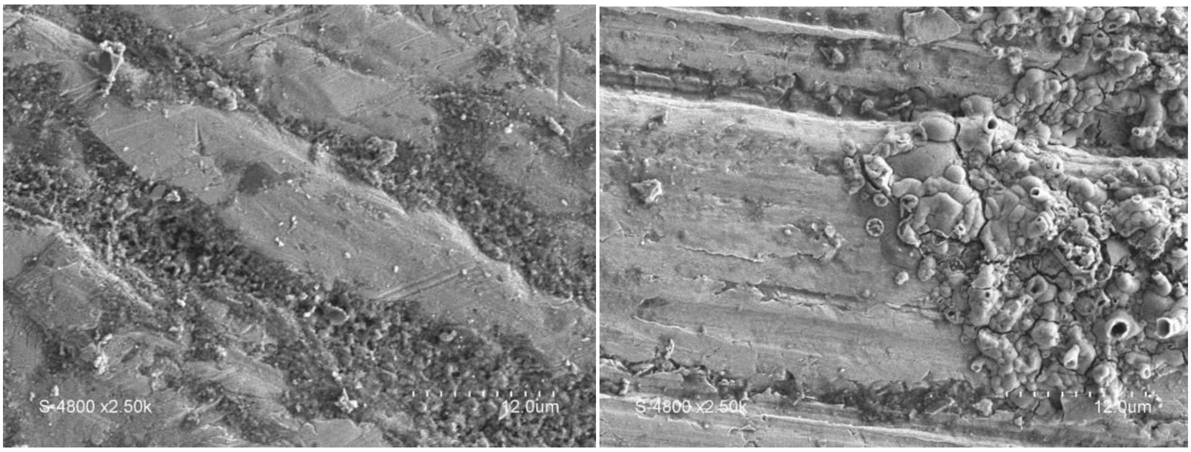
Figure-5. Proposed surface profiles after friction in the base (a) and modified (b) oils.

Presence of antifriction film is also supported by SEM images after friction interaction in the base and modified oils (Figure-6).



a) b)

Figure-6. SEM images after friction interaction in the base (a) and modified (b) oils. 500x magnification.



a) b)

Figure-7. SEM images after friction interaction in base (a) and modified (b) oils, 2500x magnification.

At a magnification of × 2500, it can be observed that surface microcrevices (Figure-7a) are filled with FS formations.

RESULTS AND DISCUSSIONS

IT was estimated use of fullerene-contain oils would improve friction conditions and reduce wearer of metal triboconjuctions and, in general, the estimation was correct.

Influence of fullerene content on the coefficient of friction, temperature, and linear wear intensity. Addition of FS 0.1% wt. of FS to oil lead to significant improvement of tribological properties of friction pair, which is explained by the change of friction character owing to the presence of fullerenes in FS. However, higher FS content leads to a steady increase of friction coefficient (Figure.1), the temperature in contact zone (Figure.2) and linear wear intensity (Figure.3). It canes assumed, that at higher FS content, the main role is taken by the soot itself, which like matrix contains carbon and by-products of fullerene synthesis. These products prevent rolling fullerene molecule groups on working surface, resulting in sliding friction being the dominant factor. it can also be assumed, that low FS content is sufficient enough to saturate the surface with carbon, and when this process is stopped or there is an excess of carbon, the tribological properties worsen.

Influence FS content on surface roughness. Lower surface roughness *Ra* supports assumption regarding the formation of the film on friction surfaces, that levels surface relief, which significantly lowers roughness after friction interaction in modified oil. In addition, such conditions can lead to polishing effect with structural products of FS. it is expected, that film format is limited up to a certain thickness. It provides decreased vibration and noise in triboconjunctions.

As can be seen from SEM images of friction surfaces, recorded after friction interaction in the medium of the base and modified oils, show significant differences. Thus on, surface depicted in Figure.6 a, micro valleys without any inclusions can be observed. While surface (Figure-6, *b*) is covered with a described film which is the main causes of lower friction and wear of friction pair during friction in modified oil. The surface has a different structure, of to formation of FS structures. The different morphology of formed film (Figure-7) should also be noted. Obviously, these microparticles are fullerene-containing material, which has a positive effect. They are

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concentrated in micro valleys, forming hard material layers, which are strong, possible, chemically, bound to the friction surface. Figure-7, *b* shows structural formation, which forms and developed as a result of tribochemical reactions, that occur during friction. At a high content of FS in oil, this formation lead to negative processes - the shearing energy of FS particles increases, which results in higher friction coefficient f_{mp}, the temperature in contact zone T and wear I. Thus, profile levelled with FS particles can be observed on friction surface (Figure-7, *b*).

CONCLUSIONS

The influence of fullerene soot content in oil on tribological properties of "steel-steel" triboconjuctions had been studied and optimal modifier content had been established.

It has been established, that addition of fullerene soot to oil in optimal amounts of 0.1 % wt. provided a decrease of friction coefficient by 19 %; temperature in contact zone be 11 %; linear wear intensity by 13 %; roughness of working friction surface by 36 %.

By means of SEM analysis, it was revealed, that friction interaction in fullerene-modified oil leads to the formation of a film which alters friction characters, which results in improved tribotechnical characters of metal samples manufactured from Steel 45.

Tithe M10g2k oil, modified with fullerene soot 0.1 % wt. is recommended for application on an industrial scale.

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