Investigation of the influence of fulleren-containing oils on tribotechnical characteristics

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Abstract: *The influence of fullerenes' soot concentration, which added to oil M10г2к on few tribotechnical characteristics «steel-steel» was investigated. It was found, that optimal volume of fullerene soot in the oil was 0,1% of the weight. At this level of concentration can be seen the lowest values of coefficient of friction – 0,045, and intense of linear wearing - $2,7\times10^{-9}$. Through optical investigation the participation of fullerene soot in surface forming mechanism and saturated with carbon was confirmed, it provided an increase in tribotechnical characteristics of the samples.*

KEYWORDS*: FULLERENE SOOT, OIL, CONCENTRATION, TRIBOTECHNICAL CHARACTERISTICS*

1. Introduction

One of directions of further progress in the engineering level of machines and mechanism lies in remarkable growth in their productivity without looses in products' quality, which are being launched or serviced. Obviously, it cannot be done without changing of their construction and improvement of materials [1], it's lead up to an increasing of intensity of the work rate in triboconjunctions [2]. Changing the design is a very effective means of improving the machines and mechanisms' productivity, but for its implementation it's necessary to spend a large number of human, intellectual and material resources, which are not always served as the optimal solutions. The growth of intensity of the operating mode of the main machines' joints and mechanisms lead to reducing in their reliability and longevity. Moreover, this issue connects mainly with friction assemblies, which are more sensitive to the effect of high levels of loads, velocities and temperatures, the growth of which is inevitable when the equipment is intensified [3, 4]. That's why an actual task is to rise up reliability and longevity of the tribology applications of machines and mechanisms, which are working under condition of the high loads, velocities and temperatures. Such task can be solved with aid to upgrading lubricants' facilities, which are being used in friction units. It will allow to decreasing in temperature load, friction and wear of working surfaces. It's well known, that there are at least three requirements to the oils, such as: removing from friction area wear debris, deduction of temperature load and coefficient of friction. There are another requirements to triboengineering, which are provided them with plenty number of additives, that were added to the oils. As follows, nowadays the starting conditions had been created in order to develop lubricants with high value of the lubricating properties; they could solve the problems with absolute restoration of working surface in triboengineering systems. One the way to increase oiliness is using modified additives, and also, fullerenes in any state [7].

2. Literature Review

Application of the fullerenes in the capacity of modifier of plastic lubricants and oils [8]. Although, with using carbonic microspheres as the fillers to oils [9]. In both cases, it would lead to decreasing in coefficient of friction and wear. Obviously, that application of the fullerenes in oils as the repening modifiers provides changing of friction character at the frictional engagement of steel parts with hope of triboengineering reactions in contact area [10]. It is allow to reduce significantly the friction and wear of details in machines' joints and mechanism, what assists the reliability and longevity to be risen. Received dependence of lubricating properties of oils, filled with fullerenes C_{60} from density of mineral base [11]. It was found, that application of fullerenes forward not only to reduce friction and wear-out of parts, which are in the frictional interaction, but to restore defective friction surfaces. It was found, that lower coefficient of friction and wear had provided due to rolling of specific nanoparticles [12]. It's mean, that decreasing in value of coefficient of friction was provided not even by sliding effect, but with aid of rolling of molecules and theirs groups on the operating points of surfaces. Consequently, it can be assumed, that due to fullerene's physical and chemical, they can influence on reducing in friction and tearing of details at the frictional interaction and in the condition of modified oils.

However, today the fullerenes are rather scare, expensive and used, as a rule in special machines. Industrial production of them is cheaper, cause to absence of development in this field at present stage. This is fundamental obstacle to their commonly use in machinery. That's why was found the necessity of investigation effective usage in fullerenes' mixtures and others, rather cheap components, such as thermically split graphite, in the function of modifier [13]. Modified oil was tested on the standard four ball machine, where positive tribological effect was defined. It is known, that other fullerene-containing materials, they are intermediates or borderline products, which were got with aid of synthesis of fair fullerenes. They are more available then others in the market. To such material as fullerene soot and fullerene crowd can be applied, they can be included in volume from 1 to 10% of fullerene's weight part [14]. Investigation of oils' properties, which were modified in so much that these materials it's still not enough. By the way, it was shown, that addition to the oils of fullerene crowds in volume of 5%, in which are 15…20 % of fullerenes C_{60}, it'd reduce tribological load in conjunction «steel-cooper» type [15]. As follows, positive effect at the application of fullerene soot, which was contained fullerenes що C_{60}, it was equal, as with applying extradite pure material C_{60}. The fullerenes can be implied in metallurgy at the exploitation of open-texture matrixes, also was found that friction mode had changed and characteristics of poromeric triboengineering systems had improved [16]. Described above results are created the starting condictions for investigation of influence of fullerene soot and on the tribosystems «steel-steel» type. Naturally, these materials can be in function of effective modifiers of oils. It's applied to commonly used oils, such as, for example, M10г2к. An actual task is defining the impact of FS on oils' lubricating properties, which are used in machines' and mechanisms' friction conjunctions commercially.

3. Materials and Methods

The main aim was to approve optimal volume of fullerene-containing oil with aid to studies of tribological properties of friction pair «steel-steel» at the application of fullerene.

To reach the goal, the next tasks were set:

- fullerene-containing oil through various volume of fullerene;
- to investigate tribilogical properties of friction pair «steel-steel» at the greasing by modified oil and determination of optimal fullerene-containing in it;

- to define the reason of changing of tribological properties of friction pair «steel-steel» at the greasing by fullerene-containing oil through investigation of friction surfaces'.

Objects and methods of investigation fullerene-containing oils on tribological characteristics of steel conjunctions.

In the function of basic material for investigation was chosen oil М10г2к, as the most widespread, and customer grade price, that was using numerous numbers of machines, like: large machines, lots of other means of transport and for special equipments, for instance, stationary generator. This oil is used in diesel, including, such as КамА3-740 and its' modifications. The main features of oils are presented in table 1.

Table 1: Some of the main features oil М10г2к

Parameter	Unit of measure	Value
Density at 20°C	g/sm³	0,9
Kinematic viscosity at 100°C	mm^2/s	11±0,5
Flash point	°C	220
Freezing point	°C	-18
Ash residue	%	1,15
Active elements (additives) per wt: - calcium - zink and phosphorous	%	 0,19 0,05
Additions from mechanical origin, less than or equal to	%	0,015

As modifier was chosen fullerene-containing material – a fullerene soot, as co-product of the synthesis of basic fullerenes C_{60}. To carry out the studies fullerene soot was used, that was given by Saint Petersburg State Institute of Technology.

The impact of fullerene soot on lubricating facilities by changing their tribological properties in friction area, which was working with these oils was defined. The investigation of properties was being conducted on the friction machine СМЦ-2 by scheme «disk-shoe» at the oil immersion. The load and rubbing speed at the experiment were 10 MPa and 1,3 m/s respectively. Each of experiments was being carried out among two hours and was repeated three times. The temperatures of modified oils were defining with aid of thermo couple D-301. Ruggedness of working surfaces (parameter *Ra*) was defined with aid of point contact follower 296 by standard methodology. In function of materials for friction pairs were used steel samples based on steel 45. The disks were heat treated to 42…45 HRC. Wearing surface roughness was bought up to Ra = 0,63 mkm.

The morphology of surfaces was studied with hope of scanning electron microscope (CEM) Hitachi S4800.

4. Experimental

According to our previous results [15], we expected to get decreasing in the main tribological parameters by optimal volume of fullerene soot in oil. To conduct teats the oils were prepared such as, modified in volume 0,1; 0,3 and 0,5% of the weight part in fullerene soot. Such levels of concentration were chosen in order to previous studies [17, 18].

The results of investigations of changing coefficient of friction in friction pair «steel-steel» type at the process of frictional engagement in the condition of basic and modified oils showed on the fig. 1.

In accordance to received results concentration dependences have growth character. It had been discovered, that in the area of modifiers' concentration FS 0,1 % could be seen dramatic reduce in coefficient of friction (fig.1), temperature (fig. 2) and remarkable – intensity of linear wear (fig. 3).

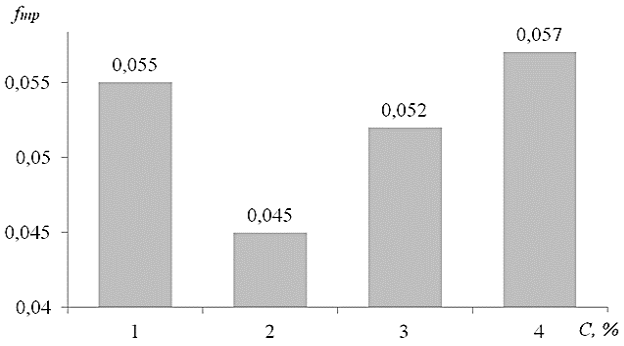

Fig. 1 *– The concentration dependence of coefficient of friction f_{mp} at the process of frictional engagement in the condition of basic and modified oils.*

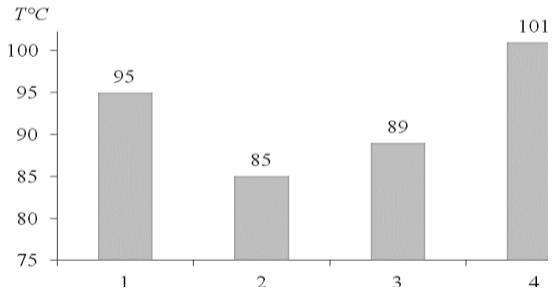

Fig. 2 *– Concentration dependence of the sample's temperature in friction area f_{mp} at the process of frictional engagement in the condition of basic and modified oils: 2 – 0,1 %; 3 – 0,3 %; 4 – 0,5 %.*

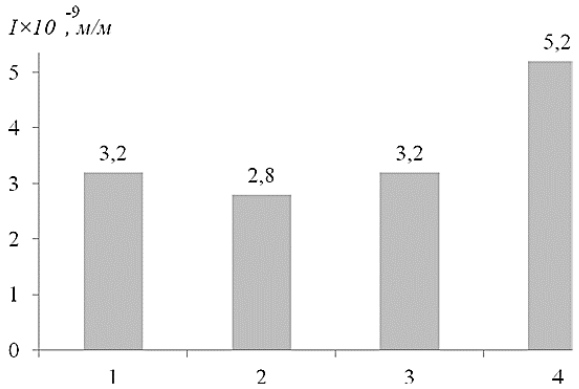

Fig. 3 *– Concentration dependence of the sample's linear wear L at the frictional engagement at the process of frictional engagement in the condition of basic and modified oils: 2 – 0,1 %; 3 – 0,3 %; 4 – 0,5 %*

Hear with reducing of these parameters is within 10-20% or less, than at the friction in non-modified oil. With increasing in weight part of fullerene soot in oil, all mentioned parameters are having steady growth. At the weight part of fullerene soot in oil even 0,5 % the value of the coefficient of friction f_{mp} has been exceed in basic variant.

It's known [19, 20], that fullerenes, even in small quantity are able to form the structure on the rubbing surface. It leads to creation of solid and flexible coat, which rise the tribological properties of friction pair, that we defined.

To finding out such coat on the friction surface after frictional engagement in oil, modified with FS, there was conducted an investigation on the subject surface roughness. It was determined by one the main parameters of roughness *Ra*. The results of tests are devoted on the fig. 4.

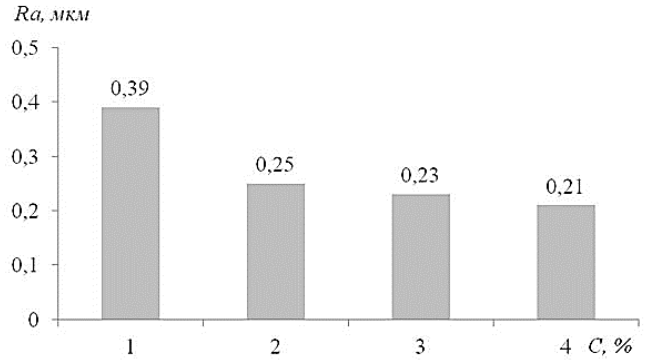

Fig. 4 *– Concentration dependence of roughness according to Ra of friction surface after frictional interaction in condition of basic and modified fullerene-containing oils: 2 – 0,1 %; 3 – 0,3 %; 4 – 0,5 %.*

It was set, that immerse of fullerene soot in oil provides decreasing in wearing roughness of surfaces. By the way, in this particular case they are accurate propulsions of these parameters: with increasing in weight part of fullerene soot in oil, roughness *Ra* is going back. In general ii was found reducing in roughness within volumes of 36…46 % in comparison with surface's roughness, which was got from clear oil. On the fig. 5 is showed proposed scheme of rubbing surfaces' profiles after frictional engagement in base and modified oils.

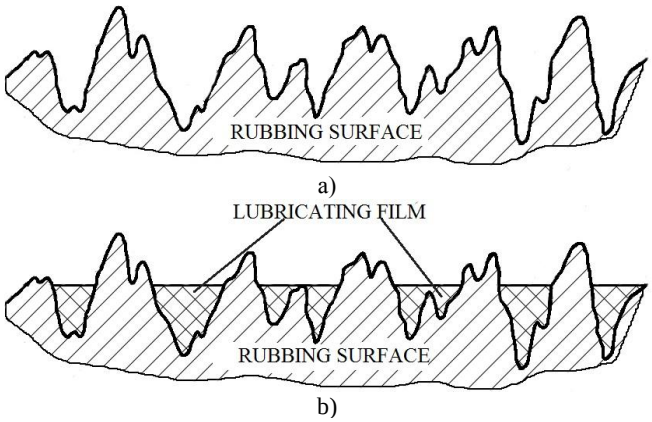

Fig. 5 *– Proposed scheme of rubbing surfaces profiles after frictional engagement in condition of base (a) and modified (b) oils.*

Existence of lubricating film on the surfaces also can be confirmed by micrometric shots of them after frictional engagement in condition of base and modified oils (Fig. 6).

While zooming to × 2500 times, there were found an intensive filling of micro depressions (Fig. 7, *а*) and forming superficial formations by the components of fullerene soot.

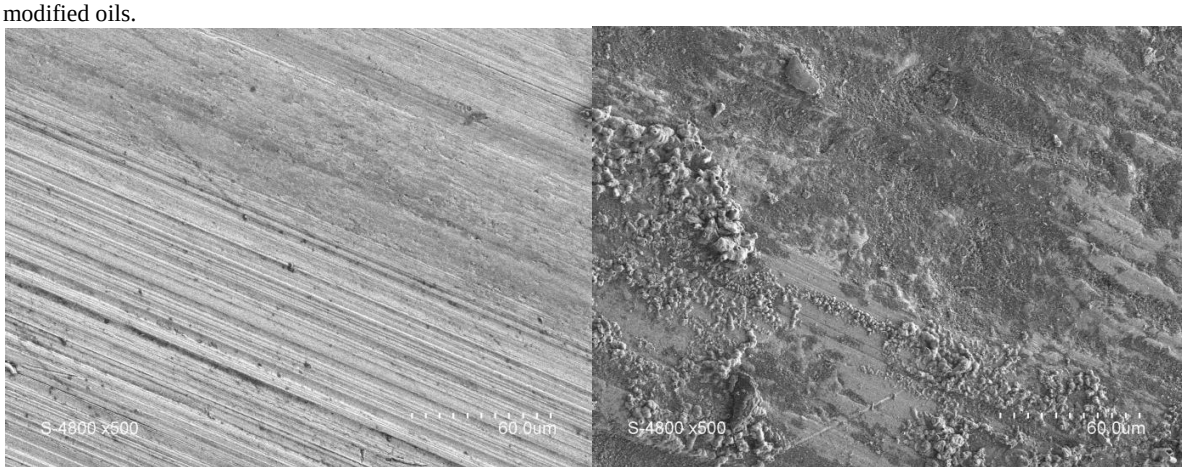

Fig. 6 *– Micrometrical shots of rubbing surfaces after frictional engagement in condition of (a) base and (б) modified oils. Picture CEM, × 500 times.*

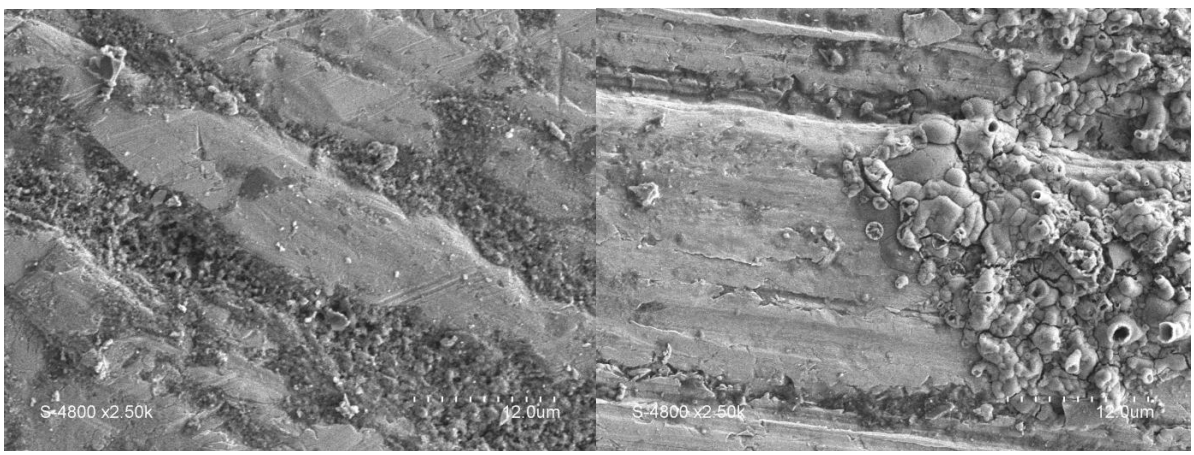

Fig. 7 *– Micrometric shots of the friction surfaces after frictional interaction in the condition of modified oil. Picture CEM, × 2500 times*

5. Results and discussion

It was known, that using fullerene-containing oils should improve friction mode and reduce wear of metal tribological distinction. Generally, such suppose was absolutely appropriate.

Influence of fullerenes' weight part on coefficient of friction, temperature and intensity of linear wear. Actually, at the addition fullerene soot into the oil in volume till 0,1 % of weight can be seen improvement of tribological properties of friction pair, that is explained by changing in character of friction due to contents of FS in the structure. By contrast, in case of increasing the weight part of fullerene soot in the oil, the coefficient of friction (picture1), temperature in contact area (picture 2) and intensity of linear wear (picture 3) are on the rise. As can be assumed, that at the increasing

in volume of FS, the soot shall be has preference, as a matrix, which contains physical carbon and rests of fullerenes' synthesis. These products are making impossible to roll-out of fullerene molecules groups on the working surface. In fact, friction shift plays a valuable role. Here can be made a hypothesis, that shows how at the small quantity of FS is taking place carbonation of working surface, and in case of its end or numerous volume of carbon, tribological properties will be disimpoved.

Influence of weight part of FS on surfaces' roughness. Process of growth down of working surface roughness *Ra* is justified supposes as for forming lubricating film on the rubbing surfaces, it is filling out microroughnesses, that declining the level of roughness after frictional interaction in condition of modified oil. Despite of this, in such conditions appears a smooth finish on the rubbing surface with aid of fullerene soot's products. As supposed, the layers of film would be within defined values. It allows to downturn the parameters of vibration and noise in tribological distinctions.

As can be seen micrometric shots, working surfaces, which are gotten after frictional interaction in condition of base and modified oils they have a significant differences. So, on the surface, is performed on the picture 6, *a*, are seeing in microroughnesses without any notable additives and inclusions. And surface (picture 6, *б*) is covered with lubricating film, and it is key reason, which influence on reducing friction and wear of friction pair at the friction in modified oil. The surfaces have different structures; there are superposition and concentration of fullerene soot. The difference between morphology of created coats should be noted (picture 7). Basically, these micro parcels are fullerene-containing materials, what has lead to positive effect. They are concentrated in dimples of microroughnesses, and it's creating solid lays of material, substantial, may be, fixed by chemical means on the rubbing surface. On the picture 7, *b* can be seen textual features; they are creating and developing with aid of tribochemical reactions, which are taking place at the friction. At the increasing of weight part of FS in oil such layers lead to negative consequence – force of moving FS molecules is growing, that is the reason of growth values of coefficient of friction f_{mp}, temperature in contact zone *T* and wear *I*. So, on the rubbing surface (picture 7, *a*) can be seen how unevenness of profile are filled with FS.

6. Conclusion

It was studied the impact of weight part of fullerenes in oil on the subject of tribological properties in tribological conjunctions «steel-steel» type and it was found optimal volume of modifier.

In conclusion, implementation of fullerene soot into the oil in optimal volume 0,1 % of its weight provided decreasing in: coefficient of friction to - 19%; temperature in contact area to - 11%; intense of linear wearing to - 13%; Wearing surface roughnesses to - 36%.

According to research, which was done on CEM it had found, that on the rubbing surfaces at the frictional engagement in condition of modified oil with added fullerene soot, it is taking place in process of forming the film, which is changing character of friction, and it's contribute to improvement of triboengineering characteristics of the metal samples, which are made from steel 45.

It was deeply recommended to apply oil М10г2к industrially, which has been modified with fullerene soot in volume 0,1 % of the weight.

7. References

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