DOI: 10.31891/2079-1372

THE INTERNATIONAL SCIENTIFIC JOURNAL

PROBLEMS OF TRIBOLOGY

Volume 26 ***No 1/99-2021***

МІЖНАРОДНИЙ НАУКОВИЙ ЖУРНАЛ

ПРОБЛЕМИ ТРИБОЛОГІЇ

PROBLEMS OF TRIBOLOGY

INTERNATIONAL SCIENTIFIC JOURNAL

Published since 1996, four time a year

Volume 26 No 1/99-2021

Establishers:
Khmelnitskiy National University (Ukraine)
Lublin University of Technology (Poland)

Associated establisher:
Vytautas Magnus University (Lithuania)

Editorial board address:
International scientific journal “Problems of Tribology”,
Khmelnitsky National University,
Institutskaia str. 11, Khmelnitsky, 29016, Ukraine
phone +380975546925

Indexed: CrossRef, Ulrichsweb, Google Scholar, Index Copernicus

E-mail: tribosenator@gmail.com

Internet: http://tribology.khnu.km.ua

ПРОБЛЕМИ ТРИБОЛОГІЇ

МІЖНАРОДНИЙ НАУКОВИЙ ЖУРНАЛ

Видається з 1996 р. ***Виходить 4 рази на рік***

Том 26 **№ 1/99-2021**

Адреса редакції:
Україна, 29016, м. Хмельницький, вул. Інститутська 11, к. 4-401
Хмельницький національний університет, редакція журналу “Проблеми трибології”
тел. +380975546925, **E-mail**: tribosenator@gmail.com

Internet: http://tribology.khnu.km.ua

Зареєстровано Міністерством юстиції України
Свідоцтво про держреєстрацію друкованого ЗМІ: Серія КВ № 1917 від 14.03. 1996 р.
(перереєстрація № 24271-14111ПР від 22.10.2019 року)

Входить до переліку наукових фахових видань України
(Наказ Міністерства освіти і науки України № 612/07.05.19. Категорія Б.)

Індексується в МНБ: CrossRef, Ulrichsweb, Google Scholar, Index Copernicus

Рекомендовано до друку рішенням вченої ради ХНУ, протокол № 10 від 25.03.2021 р.

***Problems of Tribology**, V. 26, No1/99-2021*

Problems of Tribology

Website: http://tribology.khnu.km.ua/index.php/ProbTrib

E-mail: tribosenator@gmail.com

CONTENTS

***Problems of Tribology**, V. 26, No 1/99-2021*

Problems of Tribology

Website: http://tribology.khnu.km.ua/index.php/ProbTrib

E-mail: tribosenator@gmail.com

ЗМІСТ

Problems of Tribology, V. 26, No 1/99-2021, 6-12

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-6-12

Substantiation of informative amplitudes during registration of acoustic emission signals from the friction zone of tribosystems

V.A. Vojtov, K.A. Fenenko, A.V Voitov

Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine
E-mail: vavoitovva@gmail.com

Abstract

In this work, the dependence of the change in the probability density of the distribution of the number of pulses and amplitudes of acoustic emission (AE) signals from the friction zone at the steady-state operation of the tribosystem is obtained. Acoustic vibrations that the tribosystem generates during operation are due to the impact interaction of the roughness of the friction surfaces of their elastoplastic deformation, processes of formation and destruction of frictional links, structural and phase rearrangement of materials, the formation and development of microcracks in the surface layers of contacting bodies, separation of wear particles. The dependence allows you to determine a sufficient number of pulses in the signal frame and their amplitude values for diagnosing tribosystems during their operation. The values of the informative amplitudes of the clusters are experimentally substantiated *K2, K3, K4* in relation to the base cluster *K1*. It is shown that an increase in the informative frequency $f_{AE(fix)}$ from 250 to 500 kHz, increases the value of the informative amplitude to 17,6…43,75%. Based on the results obtained, it was concluded that this fact must be taken into account when developing methods, which will increase the accuracy of diagnosing tribosystems.

The autocorrelation coefficient characterizes the closeness of the linear relationship of the current and previous frames of the series for each of the analyzed clusters. By the value of the autocorrelation coefficient, one can judge the presence of a linear relationship between the values of the recorded amplitudes, their reproducibility in terms of recording time in the steady-state operation of the tribosystem.

To confirm the sufficiency of the selected number of pulses in the clusters of the AE signal frame, as well as the reproducibility of the results of the analysis of frames when they shift in time of registration, an expression is obtained for calculating the autocorrelation function, which reflects the relationship between successive levels of the time series. Based on the results of the experimental data, the values of the autocorrelation coefficients were calculated, equal to 0,82…0,92, which indicates the robustness of the chosen diagnostic technique.

Key words: tribosystem; probability density; acoustic emission; cluster analysis; informative frequency; informative amplitude; autocorrelation function.

Introduction

The first publications on the application of acoustic emission (AE) as a method for diagnosing friction units, emerged in the late 1970s as a way to monitor friction and wear processes online. With the modern development of means for recording signals, the use of this method makes it possible to obtain information on the state of friction surfaces in the online mode.

Acoustic vibrations that the tribosystem generates during operation are due to the impact interaction of the roughness of the friction surfaces of their elastoplastic deformation, processes of formation and destruction of frictional links (mode stick-sleep [1]), structural and phase rearrangement of materials, the formation and development of microcracks in the surface layers of contacting bodies, separation of wear particles.

Currently, acoustic emission is actually understood as a secondary process, which is a superposition of signals from a huge number of elementary AE sources, i.e. acoustic radiation is a consequence of the collective processes of structural units (material structural defects). Moreover, it is believed that this secondary process is the result of the interference of primary acoustic waves that satisfy the coherence condition.

Literature review

In works [2, 3] analysis of publications on the use of AE for diagnosing various tribosystems, where it is concluded that studies on acoustic emission diagnostics of mechanisms are based on the use of discrete emission features. As for continuous emission, it is characterized by the parameters – root-mean-square deviation, crest factor, vibration spectrum [4]. In addition, time parameters are used (duration of the rise and fall of the pulses) [4], parameters of pulse amplitude distribution and wavelet transform [5].

Based on the analysis of works [6-11], in work [12] it is concluded that a promising direction is the substantiation of acoustic emission signs of defects invariant to signal amplitude scaling. This is due to the fact that signal fluctuations, differences in the amplitude-frequency characteristics of the sensors, affect the measurement result of energy parameters of emission, such as energy, average value of amplitudes, spectrum and result of wavelet transform.

The work is devoted to the selection of informative AE parameters for diagnostics of tribosystems [13], where it was theoretically and experimentally established that informative frequencies depend on the following groups of factors: constructive; technological and operational. The degree of influence of the listed factors on the change in the frequency range is determined. Operating factors (sliding speed and load) change the frequency range from 106 to 584 kHz, technological factors (roughness of friction surfaces) change the frequency range from 118 to 618 kHz, design factors (the value of the friction area of a fixed triboelement) change the frequency range from 140 to 530 kHz. It is concluded that for effective diagnostics of tribosystems, it is necessary to first determine the informative frequency range, taking into account the above factors.

To justify the choice of informative AE parameters in the work [14] a cluster analysis of AE signal frames from the friction zone of the tribosystem was performed with the division of the signal into groups of sources of its generation. A correlation has been established between the wear rate, the coefficient of friction and the values of the peak factor of various clusters. It has been experimentally confirmed that the cluster analysis of acoustic emission signals from the friction zone of the tribosystem allows identifying surface processes during wear, thereby increasing the robustness and information content of the AE method. The authors conclude that this analysis can serve as the basis for the development of a technique for diagnosing tribosystems during their operation, which will allow you to measure the wear rate at any time and calculate the tribosystem resource.

Based on the performed analysis of the work, it can be concluded that to determine the wear rate and the coefficient of friction during the operation of tribosystems (in the online mode), it is necessary to preliminarily determine the informative frequency range and within the boundaries of this range perform separation of the AE signal into components - clusters. Analysis of each cluster will provide information on a separate group of processes occurring in the surface layers of tribosystem materials, which will increase the robustness of this method and the information content of diagnostics.

Purpose

The purpose of this study is to substantiate informative amplitudes when registering AE signals from the friction zone of tribosystems taking into account the values of informative frequencies.

Methods

Based on the formulas given in the work [13, 14], let us simulate the distribution of the number of pulses in the general packet of AE signals from the friction zone over clusters *K2 – K4*. Experimental studies with the registration of frames for the tribosystem: steel 40H (movable triboelement) + Br.AZh 9-4 (fixed triboelement) at various loads, allows plotting the dependence of the probability density of the distribution of the number of AE pulses from the friction zone over the amplitudes. During the experiment, frames of length $t = 1*10^{-3}$ s. For the above tribosystem on loads N = 500…1500 N band of informative frequencies for a fixed triboelement Br.AZh 9-4 is in the range $f_{AE(fix)}$ =250…500 kHz, this follows from the expression given in the work [14]:

$$f_{AE(fix)} = n \cdot \dot{\varepsilon}_{fix} \cdot (1+\mu_{fix}) \cdot (1-2\mu_{fix}). \tag{1}$$

where $f_{AE(fix)}$ – information frequency of AE signals from the friction zone, dimension 1/s;

n is the the total number of contact spots on the friction surface of a fixed triboelement is determined by the formulas given in the work [14];

$\dot{\varepsilon}_{fix}$ is the value of the deformation rate of the material of a fixed triboelement at a single spot of actual contact, dimension 1/s, is determined by the formulas that are given in the work [14];

μ_{fix} is the Poisson's ratio of the material of the fixed triboelement.

Results

The dependences of the probability density of the distribution of pulses and amplitudes in the AE signal frame are plotted for the steady-state operating modes of the tribosystem in the boundary lubrication mode, fig. 1. Curves that characterize clusters *K1*, *K2*, *K3*, *K4*, obtained experimentally. The probability density of the registered impulses of individual clusters N_{Ki} we define in relation to the total number of pulses of the base cluster.

The envelope curve of the probability density of the distribution of pulses and amplitudes in the AE signal frame, curve 1, is approximated by the expression:

$$\frac{N_{Ki}}{N_{\Sigma}} = \frac{N_{K1}}{N_{\Sigma}} \cdot \exp(-\frac{A_{Ki}}{A_{K1}}), \quad (2)$$

where N_{Ki} is the the number of pulses that the i-th cluster contains;
N_{Σ} is the total number of pulses in the cluster;
N_{K1} is the the number of pulses that the 1st cluster contains *K1*;
A_{Ki} is the the magnitude of the amplitudes belonging to the i-th cluster;
A_{K1} is the the magnitude of the amplitudes belonging to the cluster *K1*.

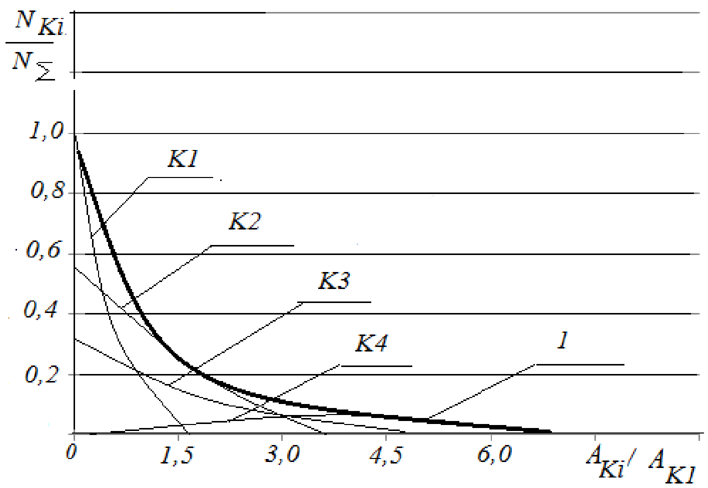


Fig.1. Dependences of the change in the probability density of the distribution of pulses and amplitudes in the steady-state operation of the tribosystem under load *N* = 1500 N: 1 – envelope curve

By progression of expression (2) we obtain:

$$\ln\frac{N_{Ki}}{N_{\Sigma}} = \ln\frac{N_{K1}}{N_{\Sigma}} + (-\frac{A_{Ki}}{A_{K1}}). \quad (3)$$

Assuming that the number of pulses in the frame N_{Σ} is equal to the number of pulses in the base cluster *K1*, expression (3) takes the form:

$$\frac{A_{Ki}}{A_{K1}} = -\ln\frac{N_{Ki}}{N_{\Sigma}}. \quad (4)$$

The simulation results according to expression (4) make it possible to establish the value of the ratio of amplitudes A_{Ki} / A_{KI} to perform diagnostics tribosystems. The resulting value of the amplitude A_{Ki} is called the informative amplitude that characterizes the i-th cluster.

For example, for tribosystem designs, where the informative frequency band corresponds $f_{AE(fix)}$ =250 kHz, the total number of informative pulses during the signal registration time equal to t = $1*10^{-3}$ s, will be N_{Σ} = 250 impulses. In the course of the experiment, at this informative frequency, the magnitudes of the amplitudes were recorded, which, based on the work [13] characterize clusters *K2, K3, K4.* The results of calculation by formula (4) make it possible to determine the excess of informative amplitudes relative to the base cluster *K1*.

The magnitudes of the ratio of the amplitudes are:

- for cluster *K2*:

$$\frac{A_{K2}}{A_{K1}} = -\ln\frac{50}{250} = 1{,}6 \quad (5)$$

- for cluster *K3*:

$$\frac{A_{K3}}{A_{K1}} = -\ln\frac{20}{250} = 2{,}52 \qquad (6)$$

- for cluster *K4*:

$$\frac{A_{K4}}{A_{K1}} = -\ln\frac{5}{250} = 3{,}91 \qquad (7)$$

Pulse count values for a cluster *K2*, equal to 50 pulses; cluster *K3*, equal to 20 pulses; cluster *K4*, equal to 5 pulses, obtained experimentally.

For tribosystem designs, where the informative frequency band corresponds $f_{AE(fix)}$ =500 kHz, the total number of informative pulses during the signal registration time equal to $t = 1*10^{-3}$ s, will be N_{Σ} = 500 impulses.

The values of the excess of informative amplitudes relative to the base cluster *K1* make up:

- for cluster *K2*:

$$\frac{A_{K2}}{A_{K1}} = -\ln\frac{50}{500} = 2{,}3 \qquad (8)$$

- for cluster *K3*:

$$\frac{A_{K3}}{A_{K1}} = -\ln\frac{20}{500} = 3{,}21 \qquad (9)$$

- for cluster *K4*:

$$\frac{A_{K4}}{A_{K1}} = -\ln\frac{5}{500} = 4{,}6 \qquad (10)$$

The obtained values of the excess of the informative amplitudes of the clusters *K2, K3, K4* relative to the base cluster *K1*, allow you to clarify the data given in the work [13] and draw a conclusion about the dependence of the informative amplitudes A_{Ki} from informative frequency $f_{AE(fix)}$. As follows from the formulas (5) – (10) increase of informative frequency $f_{AE(fix)}$ from 250 to 500 kHz, increases the value of the informative amplitude by 17,6…43,75%. This fact must be taken into account when developing methods, which will increase the accuracy of diagnosing tribosystems.

To confirm the sufficiency of the selected number of pulses N_{Ki} a certain amplitude A_{Ki} in the clusters of the AE signal frame, as well as the reproducibility of the results of the analysis of the frames when they are shifted in registration time, we will use the autocorrelation function, which reflects the connection between successive levels of the time series.

The autocorrelation function can be quantitatively determined using the linear correlation coefficient between the levels of the original frame of the AE signal amplitudes A_t and the levels of this series, shifted by several steps in time $A_{t-\tau}$.

Autocorrelation coefficient of time series levels r_A, measuring the relationship between adjacent levels of a series A_t and $A_{t-\tau}$, calculated by the formula:

$$r_A = \frac{\sum_{i=1}^{N}\left(A_t - \overline{A}_t\right)\cdot\left(A_{t-\tau} - \overline{A}_{t-\tau}\right)}{\sqrt{\sum_{i=1}^{N}\left(A_t - \overline{A}_t\right)^2 \cdot \sum_{i=1}^{N}\left(A_{t-\tau} - \overline{A}_{t-\tau}\right)^2}}, \qquad (11)$$

where $\overline{A}_t = \frac{\sum_{i=1}^{N} A_t}{N-1}$; $\quad \overline{A}_{t-\tau} = \frac{\sum_{i=1}^{N} A_{t-\tau}}{N-1}$.

Similarly, the autocorrelation coefficients of the second, third and fourth clusters of AE signal frames shifted in time are determined by the formula:

$$r_{A,Ki} = \frac{\sum_{i=1}^{N}\left(A_{t,Ki} - \overline{A}_{t,Ki}\right)\cdot\left(A_{t-\tau,Ki} - \overline{A}_{t-\tau,Ki}\right)}{\sqrt{\sum_{i=1}^{N}\left(A_{t,Ki} - \overline{A}_{t,Ki}\right)^2 \cdot \sum_{i=1}^{N}\left(A_{t-\tau,Ki} - \overline{A}_{t-\tau,Ki}\right)^2}}, \quad (12)$$

where $\overline{A}_{t,Ki} = \frac{\sum_{i=1}^{N} A_{t,Ki}}{N-1}$; $\overline{A}_{t-\tau,Ki} = \frac{\sum_{i=1}^{N} A_{t-\tau,Ki}}{N-1}$.

Based on experimental data, according to the formula (12), autocorrelation coefficients were calculated $r_{A,Ki}$. For the amplitudes that characterize the cluster *K2,* the autocorrelation coefficient is 0,92; for cluster amplitudes *K3,* the autocorrelation coefficient is 0,88; for cluster *K4,* the autocorrelation coefficient is 0,82.

The autocorrelation coefficient characterizes the closeness of the linear relationship of the current and previous frames of the series for each of the analyzed clusters. By the value of the autocorrelation coefficient, one can judge the presence of a linear relationship between the values of the recorded amplitudes, their reproducibility in terms of recording time in the steady-state operation of the tribosystem. High values of autocorrelation coefficients, equal to 0,82…0,92, indicate the robustness of the selected tribosystem diagnostics technique in the process of operation.

Based on the findings of previous work [13] let us formulate the physical meaning of the processes on the friction surface of tribosystems, which are characteristic of the following clusters.

Signal source generating a cluster *K2* are: jumps in deformation on the spots of actual contact, as a result of which slip bands are formed; abrupt movement of the roughness ridges due to changes in the adhesion forces, which in operation [1] named as mode stick-sleep.

Signal source generating a cluster *K3* are: formation of fatigue cracks parallel and perpendicular to the friction surface; separation of wear particles from the friction surface in the form of flakes or petals by the mechanism of fatigue wear; separation of wear particles from the friction surface by the mechanism of "rolling" of oxide films or secondary structures.

Signal source generating a cluster *K4* are: microcutting and plastic creasing of the protrusions of the friction surface roughness, which is characteristic of the first stages of running in.

Conclusions

The dependence of the change in the probability density of the distribution of the number of pulses and amplitudes of acoustic emission signals from the friction zone at the steady-state operating mode of the tribosystem has been established. The dependence allows you to determine a sufficient number of pulses in the signal frame and their amplitude values for diagnosing tribosystems during their operation. The values of the informative amplitudes of the clusters are experimentally substantiated *K2, K3, K4* relative to the base cluster *K1*. It is shown that an increase in the informative frequency $f_{AE(fix)}$ from 250 to 500 kHz, increases the value of the informative amplitude by 17,6…43,75%. This fact must be taken into account when developing methods, which will increase the accuracy of diagnosing tribosystems.

To confirm the sufficiency of the selected number of pulses in the clusters of the AE signal frame, as well as the reproducibility of the results of the analysis of frames when they shift in time of registration, an expression for calculating the autocorrelation function is obtained, which reflects the relationship between successive levels of the time series with autocorrelation coefficients equal to 0,82…0,92, which indicates the robustness of the chosen diagnostic technique.

References

1. Ferrer C., Salas F., Pascal M., Orozco J. Descrete acoustic emission waves during stick-slip friction between steel samples, Tribology International, 2010, No.43, pp.1–6. [English]

2. Shevchenka S.A. Klasyfikatsiya ta obgruntuvannya vymoh do akustyko-emisiynykh oznak defektiv par tertya mekhanizmiv, Visnyk Kharkivs′koho natsional′noho tekhnichnoho universytetu sil′s′koho hospodar-stva im.P.Vasylenka, 2012, vyp.121, s.159-163. [Ukraine]

3. Abdullah M., D. Al-Ghamd, Zhechkov, D. Mba. A comparative experimental study on the use of Acoustic Emission and vibration analysis for bearing defect identification and estimation of defect size, Mechanical System and Signal Processing, 2006, No.7, pp.1537–1571. [English]

4. Mazal P., V.Koula, F.Hort, F.Vlasic. Applications of continuous sampling of AE signal for detection of fatigue damage, NDT in Progress, 2009, No.4. –8 p. [English]

5. Yanhui Feng. Discrete wavelet-based thresholding study on acoustic emission signals to detect bearing defect on a rotating machine, The Thirteen International Congress of Sound and Vibration. Vienna, Austria, 2-6

July, 2006. –8 p. [English]

6. Faris Elasha., Matthew Greaves, David Mba, Abdulmajid Addali. Application of Acoustic Emission in Diagnostic of Bearing Faults within a Helicopter gearbox, The Fourth International Conference on Through-life Engineering Services. Procedia CIRP, 2015, Vol.38, pp. 30-36. [English]

7. Seyed A. Niknam, Tomcy Thomas, J. Wesley Hines, Rapinder Sawhney. Analysis of Acoustic Emission Data for Bearings subject to Unbalance, International Journal of Prognostics and Health Management, 2013, Vol. 15, pp. 1–10. [English]

8. Badgujar M.P., Patil A.V. Fault Diagnosis of Roller Bearing Using Acoustic Emission Technique and Fuzzy Logic, International Journal of Latest Trends in Engineering and Technology, 2014,Vol. 3, Issue 4, pp.170–175. [English]

9. Rao V.V., Ratnam Ch. A Comparative Experimental Study on Identification of Defect Severity in Rolling Element Bearings using Acoustic Emission and Vibration Analysis, Tribology in Industry, 2015, Vol. 37, No. 2, pp.176-185. [English]

10. Zahari Taha., Indro Pranoto. Acoustic Emission - Research and Applications. Chapter 4 – Acoustic Emission Application for Monitoring Bearing Defects, InTech. 2013, pp.71–90. http://dx.doi.org/10.5772/55434 [English]

11. Nienhaus K., Boos F.D., Garate K., Baltes R. Development of Acoustic Emission (AE) based defect parameters for slow rotating roller bearings, Journal of Physics: Conference Series. 364. 2012. 012034. 1-10. doi:10.1088/1742-6596/364/1/012034 [English]

12. Yongyong He., Xinming Zhang, Michael I. Friswell. Defect Diagnosis for Rolling Element Bearings Using Acoustic Emission, Journal of Vibration and Acoustics, 2009, Vol. 131 / 061012. [English]

13. Fenenko K.A. Cluster analysis of acoustic emission signals from the friction zone of tribosystems / Problems of Tribology, V. 25, No 2/96-2020, 25-33 DOI: https://doi.org/10.31891/2079-1372-2020-96-2-25-33 [English]

14. Fenenko K.A. The determination of the information frequencies in the frame of the acoustic emission signals from the friction zone of tribosystems / Problems of Tribology, V. 25, No 3/97-2020, 6-13 DOI: https://doi.org/10.31891/2079-1372-2020-97-3-6-13 [English]

Войтов В.А., Фененко К.А., Войтов А.В. Обгрунтування інформативних амплітуд при реєстрації сигналів акустичної емісії із зони тертя трибосистем

В роботі представлені результати дослідження щодо обґрунтування інформативних амплітуд при реєстрації сигналів акустичної емісії (АЕ) із зони тертя трибосистем з урахуванням значень інформативних частот.

Отримано залежність зміни щільності ймовірності розподілу кількості імпульсів і амплітуд сигналів акустичної емісії з зони тертя на сталому режимі роботи трибосистеми. Залежність дозволяє визначити достатню кількість імпульсів в фреймі сигналів, а також величини амплітуд для діагностування трибосистем в процесі їх експлуатації. Експериментально обгрунтовані значення величин інформативних амплітуд кластерів *К2, К3, К4* щодо базового кластера *К1*. Показано, що збільшення інформативної частоти $f_{AE(и)}$ з 250 до 500 кГц, збільшує значення інформативної амплітуди на 17,6 ... 43,75%. На підставі отриманих результатів зроблено висновок, що даний факт необхідно враховувати при розробці методик, що підвищує точність діагностування трибосистем.

Для підтвердження достатньості вибраної кількості імпульсів в кластерах фрейма сигналів АЕ, а також відтворюваності результатів аналізу фреймів при зсуві їх за часом регістрації, отримано вираз для розрахунку автокореляційної функції, яка відображає зв'язок між послідовними рівнями тимчасового ряду. За результатами експериментальних даних розраховані значення коефіцієнтів автокореляції, які дорівнюють 0,82 ... 0,92, що свідчить про робастність обраної методики діагностування.

Ключові слова: трибосистеми; щільність ймовірності; акустична емісія; кластерний аналіз; інформативна частота; інформативна амплітуда; автокореляційна функція.

***Problems of Tribology**, V. 26, No 1/99-2021, 13-19*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-96-1-13-19

Investigation of the structural viscosity of oil films on the friction surface with fullerene compositions

A.G. Kravtsov

Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, Ukraine
E-mail: kravcov@gmail.com

Abstract

The paper presents theoretical studies of changes in the structural viscosity of oil films on the friction surface with fullerene compositions in the field of action of electrostatic forces of the friction surface and the base lubricant.

A feature of the use of fullerene additives in lubricants is that fullerenes are readily soluble in a wide class of organic and inorganic solvents. At the same time, poor solubility of fullerenes in technical oils (mineral, semi-synthetic and synthetic).

The purpose of this work is to carry out theoretical studies of changes in the structural viscosity of oil films on the friction surface with fullerene compositions in the field of action of electrostatic forces of the friction surface and the base lubricant.

On the basis of the working hypothesis, it was theoretically established that for a thin oil film, located in the field of action of electrostatic forces of the friction surface, it is necessary to consider the structural dynamic viscosity of the lubricant, which at the friction surface has a gel structure, and as the electrostatic forces from the friction surface decrease, the gel structure transforms into the sol structure.

It is shown that the value of the structural viscosity of the considered aggregates is comparable with the viscosity of polymers or bitumen. Moreover, the viscosity of the gel structure is four orders of magnitude higher than the viscosity of the sol structure. An increase in the concentration of fullerenes leads to an increase in the dynamic viscosity of aggregates.

It is theoretically shown that the structure of the oil film, which corresponds to the structure of the gel, belongs to the class of non-Newtonian fluids. With an increase in the sliding speed, the dynamic viscosity of such structures decreases by a factor of 4, which explains the destruction of micelle clusters and the appearance of rotational motions of elastic flocks. It is assumed that this will lead to a decrease in the value of the coefficient of friction. It is shown that for the gel structure, the concentration of fullerenes in the bulk of the base lubricant does not have a large effect on the structural viscosity. Conversely, for the structure of a sol, the concentration of fullerenes has a significant effect on the value of the structural dynamic viscosity.

Key words: fullerenes; oil film; fullerene compositions; structural viscosity; sol structure; gel structure; friction surface electrostatic field; dynamic viscosity

Introduction

A feature of the use of fullerene additives in lubricants is that fullerenes are readily soluble in a wide class of organic and inorganic solvents. At the same time, poor solubility of fullerenes in technical oils (mineral, semi-synthetic and synthetic). To date, the solubility has been determined and analyzed C_{60} in a lot of liquids. It is shown that the solubility of fullerenes decreases with increasing polarity of the solvent. A number of unusual properties of fullerene solutions have been revealed, so for some solvents the effect of anomalous dependence of the solubility of fullerene on temperature was found. In the technical literature, there are publications that use the preliminary dispersion of fullerenes in solvents, for example, vegetable high oleic oils, and then the introduction of such compositions into technical oils. According to the authors of the work [1], this use of fullerenes gives a better positive effect than the addition of fullerenes in the form of nanopowders to lubricants.

The general structural feature of liquid lubricants in the presence of fullerenes in them is that in the volume of liquid clusters and micelles are formed. Thus, based on the findings [2] it can be argued that a viscous liquid can be considered as a continuous dispersion medium, clusters and micelles as a dispersion phase. Fullerene molecules that interact with each other and oleic acid molecules of vegetable oil form aggregates, and the viscous liquid medium becomes structured. If the dimensions of the units change over time at a constant flow velocity (sliding), then such a dispersed system is considered thixotropic [2].

Literature review

Author of the work [3] claims that structured fluids form aggregates in the form of doublets or chains, chains can form a continuous grid. The interaction of aggregates in the volume of fluid is expressed in the formation of sufficiently strong compounds, primarily of coagulation origin. Anisometric units (cylinders, disks, ellipsoids) are able to rotate when the layers of liquid are shifted. According to the author of the work [3] the rheological properties of suspensions are determined by the volume concentration of the dispersed phase, the magnitude of the forces of interaction between aggregates and particles and the structure of the formed aggregates. The author considers Brownian motion of particles to be the main factors influencing the process of aggregate formation, gravitational and repulsive forces arising between particles, hydrodynamic interaction between particles.

In our opinion, when considering the processes of friction and wear, when the friction surfaces accumulate electrostatic charge, it is necessary to consider the forces of electrostatic interaction between the units of the dispersed phase and the friction surface. It should be borne in mind that the concentration of units in the field of electrostatic forces of the friction surface will be greater than at a distance from the surface where the field does not act.

According to the conclusions of the work [2] dispersed phase units combined by external forces (in our case electrostatic), in a continuous grid (framework) on the friction surface, acquire the properties of a "solid body".

Minor external forces form an elastic deformation of the frame. At high enough voltages, the frame collapses and the individual units disconnect. In this case, according to the authors [2], individual units (in our case, fullerene molecules) can form a rotational motion between the friction surfaces. When such an interaction mechanism occurs, the viscosity of the fluid gradually decreases [2].

The above conclusion is accepted by us as a working hypothesis of reduction of friction forces in tribosystems in the presence of a dispersed phase in the lubricant, which will be further confirmed by theoretical models and experimentally.

The presence in the volume of the lubricant of the dispersed phase in the form of clusters and micelles requires, along with the total dynamic viscosity of the liquid, to consider the "structural viscosity". This concept was introduced by W. Oswald in 1925 and was further developed in the work of M. Rayner [4]. The use of this concept allows to take into account not only the dynamic viscosity of the liquid, but also the dynamic viscosity of the units that are in the volume of the liquid, taking into account the shear rate.

The authors of the work [5] provides an overview of the literature on lubricants with added nanoparticles. The effect of nanoparticles on the tribotechnical characteristics of oils is analyzed. It is noted in the work that the use of nanoadditives to lubricants leads to an increase in the viscosity of the base medium, high bearing capacity of the interface, reducing the coefficient of friction, increasing wear resistance.

It has been theoretically established that the use of fullerene "solvents", which can be high oleic vegetable oils, can "start" the micelle formation process, where the nucleus of the micelle is a fullerene molecule surrounded by molecules, for example, oleic acid. In works [6, 7] theoretical studies are presented, which showed that the number of micelles is 50 times higher than the number of clusters in the base lubricating medium at the same concentration of fullerenes, and the dipole moment of micelles is an order of magnitude higher than the dipole moment of clusters. At the same time, micelles are more effective, where a single fullerene molecule acts as a nucleus, rather than a cluster of fullerene molecules, which affects the size of the formed micelles. The role of the friction surface on the formation of clusters and micelles in the lubricant film near the friction surface is established. It is shown that under the action of the stress-strain state of the surface layers, the friction surface acts as a "generator of an electrostatic force field", which affects the formation of an electric field in the volume of the oil film. Expressions are obtained for calculating the value of the total electrostatic field strength of the system "friction surface + lubricant".

Purpose

The purpose of this work is to carry out theoretical studies of changes in the structural viscosity of oil films on the friction surface with fullerene compositions in the field of action of electrostatic forces of the friction surface and the base lubricant.

Methods

In developing a microreological model for the formation of a thin film of lubricant on the friction surface under the action of electrostatic forces, the following assumptions were made.

1. The base lubricant is a viscous liquid with a known value of dynamic viscosity at 100°C μ_l, dimension Pa·s.

2. Aggregates of micelles are considered as small rigid spheres. For example, the modulus of elasticity of the fullerene molecule $E_f = (18-20)\cdot 10^{11}$ Pa, that is 10 times the modulus of elasticity of steel.

3. The modulus of elasticity of a liquid lubricant is $E_l = 2\cdot 10^9$ Pa. When a certain amount of fullerenes is introduced into a viscous liquid, which have the value of the elastic modulus $E_f = 18\cdot 10^{11}$ Pa it is necessary to determine the value of the reduced modulus of elasticity of the lubricant – E_{red}. The value of the reduced modulus of elasticity of such a dispersed medium will be influenced by the concentration of fullerenes in the volume of the lubricant and the value of the intensity of the total electrostatic field of the system "friction surface + lubricant".

4. The dispersion of clusters and micelles in the volume of liquid lubricant outside the electrostatic field of the friction surface is taken as the structure of the sol [4]. In this structure, stresses are perceived by a viscous liquid medium and transmitted to elastic units. This structure has viscoelastic properties.

5. The dispersion of clusters and micelles near the friction surface (in the field of electrostatic forces), take the structure of the gel [6], where between the micelles and the friction surface there are forces of electrostatic interaction, which contribute to the formation of a framework of units, the cavities between which are filled with a viscous fluid. This structure has elastic and viscous properties. Intermicellar forces can relax, respectively, the structure behaves like Maxwell's body [4]. In such a structure, stresses are perceived by the elastic elements of the units and transmitted to a viscous liquid medium.

Results

The value of the reduced modulus of elasticity of such a dispersed medium will be influenced by the concentration of fullerenes in the volume of the lubricant, which can be determined by the following expressions.

Mass concentration of fullerenes per unit mass of lubricant (1 kg) outside the action of the electrostatic field of the friction surface, we express through the dimensionless coefficient:

$$k_f = \frac{M_f}{1000}, \tag{1}$$

where M_f is the fullerene weight, gram;

1000 is the mass of the base lubricant into which fullerenes are introduced, gram.

Therefore, the concentration of the remaining part of the lubricant is expressed through the dimensionless coefficient:

$$k_l = 1 - k_f . \tag{2}$$

The mass concentration of fullerenes per unit of lubricant on the friction surface, i.e. in the field of action of electrostatic forces, we express through the Langevin function, which takes into account that the dipole moment of the dispersed phase aggregates is directed with respect to the field of the friction surface at an angle, which is expressed by the dependence:

$$k_{f,el} = cth(E) - \frac{1}{E}, \tag{3}$$

where E – total intensity of the electrostatic field of the system "friction surface + lubricant", V/m.

We express the concentration of the remaining part of the liquid through the dimensionless coefficient:

$$k_{l,el} = 1 - k_{f,el} . \tag{4}$$

Having obtained dimensionless coefficients that take into account the mass concentration of fullerenes in the lubricant we can write expressions for determining the reduced elastic modulus of the lubricant for the structure of the sol $E_{red,\,s}$ and gel structure $E_{red,\,g}$:

$$E_{red,s} = \frac{2\cdot k_f \cdot E_f \cdot k_l \cdot E_l}{k_f \cdot E_f + k_l \cdot E_l}, Pa, \tag{5}$$

$$E_{red,g} = \frac{2 \cdot k_{f,el} \cdot E_f \cdot k_{l,el} \cdot E_l}{k_{f,el} \cdot E_f + k_{l,el} \cdot E_l}, Pa, \quad (6)$$

Based on the expressions obtained (5) and (6) it is possible to determine the shear modulus of a lubricant if it contains a dispersed phase of a certain concentration outside the action of the field of electric forces of the friction surface – $G_{red, s}$ and near the friction surface, where the field of electrostatic forces acts – $G_{red, g}$:

$$G_{red,s} = \frac{E_{red,s}}{(2 + 2 \cdot \nu_p)}, Pa, \quad (7)$$

$$G_{red,g} = \frac{E_{red,g}}{(2 + 2 \cdot \nu_p)}, Pa, \quad (8)$$

where ν_p is the Poisson's ratio of the dispersed phase is 0,3.

To improve the simulation accuracy, it is necessary to take into account the orientation of the dispersed phase particles outside the action of the forces of the electrostatic field and near the friction surface, where these forces act.

According to the authors of the works [2, 3] dispersed phase aggregates are ellipsoidal. Such aggregates, outside the action of the electrostatic field, can perform rotational movements in the course of the flow of a viscous fluid, and in the field of action of electrostatic forces of the friction surface, they can orient themselves towards the friction surface. This orientation can be taken into account by the angle φ, which is determined between the normal to the friction surface and the main axis of the unit, in the form of an ellipsoid. Taking this angle (in radians) as an average value, you can write an expression to determine the value $tg\varphi$ for sol and gel structures:

$$tg\varphi_s = th(h \cdot 1 \cdot 10^6), \quad (9)$$

$$tg\varphi_g = th(0{,}12 \cdot h \cdot 1 \cdot 10^6), \quad (10)$$

where h is the thickness of the oil film on the friction surface, which is formed under the action of the field of electrostatic forces of the friction surface, dimension m;

coefficient equal $1 \cdot 10^6$ is a conversion factor, dimension 1/m;

coefficient 0,12 takes into account the presence of a gradient of the electrostatic field strength with distance from the friction surface, we obtained experimentally, the dimensionless quantity.

Based on the above expressions (9) and (10), as well as the formulas given in the works [8, 9], we have obtained expressions for determining the dynamic viscosity of aggregates whose structure consists of Kelvin bodies μ_K and Maxwell bodies μ_M:

$$\mu_K = \frac{G_{red,s}(1 + tg^2\varphi_s)}{\omega \cdot tg\varphi_s}, \text{ Pa·s}, \quad (11)$$

$$\mu_M = \frac{G_{red,g}(1 + tg^2\varphi_g)}{\omega \cdot tg\varphi_g}, \text{ Pa·s}, \quad (12)$$

where ω is the frequency of vibrations that are excited by protruding roughnesses on the actual contact spots during sliding is determined by the expression:

$$\omega = \frac{v_{sl}}{d_{acs}}, \text{ 1/c}, \quad (13)$$

where v_{sl} is the sliding speed, m/s;

d_{acs} is the diameter of the actual contact spot, dimension m.

Based on expressions (11) and (12), which determine the viscosity of aggregates in the form of a Kelvin body and a Maxwell body, we can write an expression for the structural viscosity of the sol μ_s and gel μ_g:

$$\mu_s = k_l \mu_l + k_f \mu_K \text{, Pa·s,} \quad (14)$$

$$\mu_g = k_l \mu_l + k_f \mu_M \text{, Pa·s,} \quad (15)$$

Dependences of the change in the dynamic viscosity of a thin oil film on the friction surface, which has a sol structure μ_s and gel structure μ_g are shown in fig. 1 and fig. 2.

The nature of the change in the presented dependencies allows us to draw the following conclusions.

1. The value of the structural viscosity of the aggregates under consideration is comparable to the viscosity of polymers or bitumen. In this case, the viscosity of the gel structure is four orders of magnitude higher than the viscosity of the sol structure.

2. The structures under consideration belong to the class of non-Newtonian fluids, since their dynamic viscosity decreases with increasing sliding speed.

3. An increase in the concentration of fullerenes leads to an increase in the dynamic viscosity of aggregates.

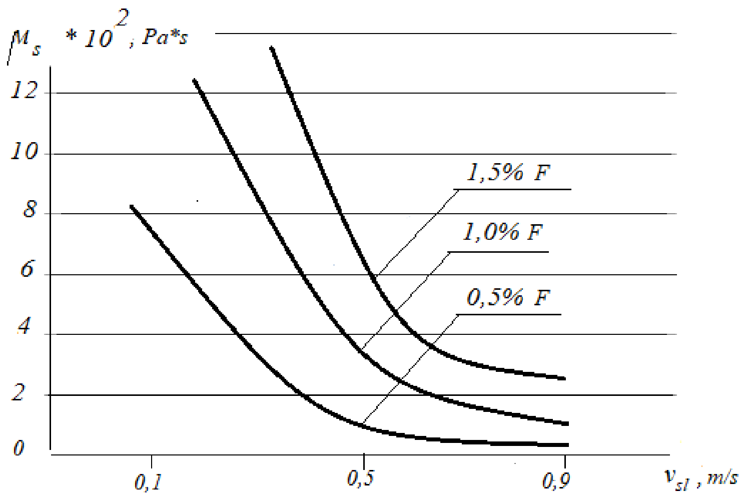


Fig.1. Dependences of the change in the dynamic viscosity of the sol structure on the slip rate and the concentration of fullerenes

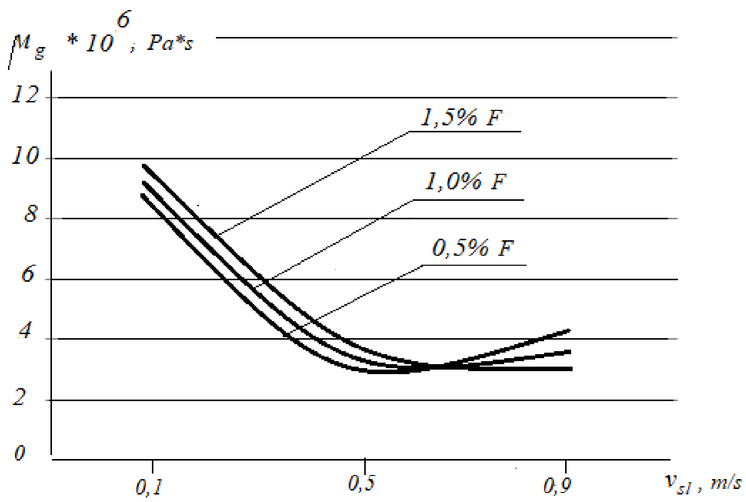


Fig.2. Dependences of the change in the dynamic viscosity of the gel structure on the slip rate and the concentration of fullerenes

As follows from the simulation results for the structures of sol and gel, the properties of a non-Newtonian liquid are inherent. For an oil film on the friction surface, which has a gel structure, fig. 2, dynamic viscosity decreases 4 times with increasing sliding speed. This phenomenon can be explained by the destruction of aggregates in the form of micelles and the appearance of rotational motion of flocks between friction surfaces [2, 3].

It should be noted that for the gel structure, i.e. for an oil film in the field of action of electrostatic forces of the friction surface, the concentration of fullerenes in the bulk of the base lubricant does not have a large effect. Conversely, for the structure of the sol, fig. 1, the concentration of fullerenes has a significant effect on the value of the dynamic viscosity.

Conclusions

Based on the working hypothesis, it was theoretically established that for a thin oil film located in the field of action of electrostatic forces of the friction surface, it is necessary to consider the structural dynamic viscosity of the lubricant, which has gel structures at the friction surface, and as the electrostatic forces from the friction surface decrease, the gel structure transforms into the sol structure.

The structure of such a film, which corresponds to the structure of the gel, belongs to the class of non-Newtonian liquids. With an increase in the sliding velocity, the dynamic viscosity of such structures decreases by a factor of 4, which is explained by the destruction of clusters and micelles and the appearance of rotational motions of elastic flocks. This will lead to a decrease in the value of the coefficient of friction. These theoretical conclusions will be confirmed by experimental studies and published in our further works.

References

1. Vojtov V. A., Kravcov A. G., and Tsymbal B. M. Evaluation of Tribotechnical Characteristics of Tribosystems in the Presence of Fullerenes in the Lubricant / FRICTION AND WEAR, 2020, Vol. 41, No. 6, 704- 710. DOI: 10.3103/S1068366620060197 [English]

2. Matviyenko V.N., Kirsanov Ye.A. Vyazkost' i struktura dispersnykh sistem // Vestnik Moskovskogo universiteta. Seriya 2. Khimiya. – 2011. – T.52. – № 4.– S. 243 – 276. [Russian]

3. Bibik Ye.Ye. Reologiya dispersnykh sistem. – L.: Izd-vo Leningradskogo un-ta, 1981. -172 c. [Russian]

4. Reyner M. Reologiya / M. Reyner. // perev. s angl. pod red. E.I. Grigolyuka. – M.: Nauka, 1965. – 223 s. [Russian]

5. Anurag Singh, Prashant Chauhan, Mamatha T. G. A review on tribological performance of lubricants with nanoparticles additives // Materials today: proceedings Volume 25, Part 4, 2020, Pages 586-591 https://doi.org/10.1016/j.matpr.2019.07.245 [English]

6. Kravtsov A. G. Razrabotka matematicheskoy modeli vzaimodeystviya elektricheski aktivnykh gete-rogennykh melkodispersnykh sistem na granitse razdela poverkhnost' treniya — smazochnaya sreda // Problemi tribologiї. — 2017, № 1, 89—99 [Russian]

7. Kravtsov A. G. Modelirovaniye formirovaniya maslyanoy plenki na poverkhnosti treniya pri nali-chii fullerenovykh dobavok v smazochnom materiale i yeye vliyaniye na skorost' iznashivaniya tribosistem // Problemi tribologiї. — 2018, № 1, 69—77 [Russian]

8. Badmayev B.B., Damdinov B.B. Issledovaniye vyazkouprugikh svoystv organicheskikh zhidkostey akus-ticheskim metodom // Akusticheskiy zhurnal. – 2001. – T. 47. – №4. – S. 561 – 563. [Russian]

9. Badmayev B.B., Bazaron U.B., O.R. Budayev, B.V. Deryagin. Issledovaniye nizkochastotnogo kompleks-nogo modulya sdviga zhidkostey // Kolloidnyy zhurnal. – 1982. – T. 44. – №5. – S. 160 – 163. [Russian]

Кравцов А.Г. Дослідження структурної в'язкості мастильних плівок на поверхні тертя з фулереновими композиціями

У роботі представлені теоретичні дослідження зміни структурної в'язкості мастильних плівок на поверхні тертя з фулереновими композиціями в поле дії електростатичних сил поверхні тертя і базового мастильного матеріалу.

На підставі робочої гіпотези теоретичним шляхом встановлено, що для тонкої масляної плівки, що знаходиться в полі дії електростатичних сил поверхні тертя, необхідно розглядати структурну динамічну в'язкість мастильного матеріалу, який у поверхні тертя має структур гелю, а в міру зменшення електростатичних сил від поверхні тертя - структура гелю переходить в структуру золю.

Показано, що величина структурної в'язкості розглянутих агрегатів порівнянна з в'язкістю полімерів або бітумів. При цьому, в'язкість структури гелю на чотири порядки вище в'язкості структури золю. Збільшення концентрації фулеренів призводить до збільшення динамічної в'язкості агрегатів.

Теоретичним шляхом показано, що структура мастильної плівки, яка відповідає структурі гелю, відноситься до класу неньютонівських рідин. При збільшенні швидкості ковзання динамічна в'язкість таких структур зменшується в 4 рази, що пояснюється руйнування кластерів і мицелл і появою обертальних рухів пружних флоків. Зроблено припущення, що це призведе до зниження величини коефіцієнта тертя. Показано, що для структури гелю, концентрація фулеренів в об’ємі базового мастильного матеріалу великого впливу на структурну в'язкість не робить. І навпаки, для структури золю, концентрація фулеренів робить істотний вплив на величину структурної динамічної в'язкості.

Ключові слова: фулерени; мастильна плівка; фулеренові композиції; структурна в'язкість; структура золю; структура гелю; електростатичне поле поверхні тертя; динамічна в'язкість

***Problems of Tribology**, V. 26, No 1/99-2021,20-27*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-20-27

Regularities of the influence of submicron ceramic powders TiO_2, AlN, Cr_2O_3 on the tribological properties of a friction material

A.V. Leshok[1*], A.V. Dykha[2]

[1]O.V.Roman Powder Metallurgy Institute, Minsk, Belarus
[2]Khmelnitskyi National University, Ukraine
E-mail: sdilav@tut.by

Abstract

Friction units for automotive and special vehicles are designed to operate under boundary friction conditions. Modern vehicles contain friction assemblies that use friction materials. Currently, friction materials are actively used: based on thermosetting resins; pulp and paper-based materials; sintered powder materials; materials of carbon or carbon composition; materials with a ceramic matrix. The development of a unified understanding of the effect of the size and chemical nature of ceramic additives on the processes occurring in a friction material during friction is very important and can be obtained both on the basis of experimental and theoretical studies. The paper presents the results of a study of the effect of submicron TiO2, Cr2O3, AlN powders with a size of 0.2-0.5 microns on the tribotechnical properties of a frictional material based on copper intended for operation under boundary friction conditions. It was found that when using the addition of Cr2O3 powder, the greatest increase in the value of the friction coefficient is noted - from 0.042 to 0.082, a slightly smaller increase in the friction coefficient is shown by the use of AlN and TiO2 defects - 0.042-0.074 and 0.042-0.060, respectively. The least wear of the friction material was obtained when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. Increasing the addition of any of the submicron powders by more than 7 vol. % leads to a significant decrease in wear resistance. This is due to the formation on the surface of the friction material of a modified layer containing ceramic particles and the metallic phase of the friction material. For the friction material, an unstable value of the friction coefficient and increased wear were recorded.

Key words: friction material, coefficient of friction, wear, ceramic particles, bronze.

Introduction

Friction units for automotive and special vehicles are designed to operate under boundary friction conditions. Boundary friction is realized when the thickness of the lubricating layer on the contact surfaces of friction is at least 0.1 μm, capable of physical adsorption or chemical reaction. At present, sintered friction materials based on copper are most widely used for operation under boundary friction conditions. This group of materials is characterized by a high value of the coefficient of friction, wear resistance, coefficient of thermal conductivity and service life. However, at present, higher values of tribotechnical and physical-mechanical properties are required. This is achieved through the use of additives of metal and ceramic powders. The most commonly used ceramic powders are 10-200 microns. However, the use of submicron ceramic powders with a size of less than 1.0 μm as an additive in a sintered friction material based on copper is of scientific and practical interest.

Literature review

Modern vehicles contain friction assemblies that use friction materials. Currently, friction materials are actively used: based on thermosetting resins; pulp and paper-based materials; sintered powder materials; materials of carbon or carbon composition; materials with a ceramic matrix [1-7].

Sintered powder friction materials are designed to work in severe operating conditions - temperatures up to 950 C, sliding speed up to 80 m / s, pressure up to 5 MPa. Sintered materials on copper and iron bases are most widely used in hydromechanical transmissions of automotive vehicles, parking brakes, on-board clutches of civil and special-purpose vehicles. Materials of this group are characterized by high wear resistance and heat resistance, mechanical strength. They consist of a metal matrix, and additives for various functional purposes, designed to increase the wear resistance, resistance of the friction material to the formation of a scuff, as well as imparting the required value of the coefficient of friction [8-10].

Providing the required value of the coefficient of friction of the friction material is possible in several ways: by changing the structure and composition of the metal matrix, using additives of metallic and non-metallic powders of various chemical nature. Considering the compositions of sintered friction materials, it can be noted that ceramic powders in the form of oxides, nitrides, borides are used as an additive that increases the value of the friction coefficient [11-17].

The presence of solid particles in the structure of the material allows localizing seizure in small areas of the surface, avoiding seizing and reducing the intensity of wear [18]. The process of friction and wear of a material containing solid inclusions can be considered as a process of continuous formation, change and destruction of frictional bonds at the points of actual contact.

Titanium dioxide is widely used in industry as an additive of low cost, characterized by stable properties and non-toxicity. In [19] it is noted that titanium dioxide is characterized by a very high specific surface area, up to 600 m2 / g, and a low thermal conductivity.

Chromium (III) oxide Cr2O3 is a typical amphoteric oxide with a corundum-type structure (α-form), thermal and moisture resistance, high microhardness - up to 2940 kgf / mm2, the highest strength of all chromium oxides [20, 21].

The choice of aluminum nitride as an additive in the composition of the composite friction material is based on the fact that it has good thermal conductivity, low temperature coefficient of linear expansion (4.6 10-6 K-1 at 20 - 500 ° C), high hardness (9 on the Mohs scale) and resistance to thermal shock [22].

In [10, 23, 24] it is indicated that the size of ceramic additives used in the compositions of friction materials can vary from 1 to 600 microns. It is noted that the optimal size of SiO2 particles is 20-60 microns, since at a particle size of 1 micron, their abrasive properties are lost, and at more than 60 microns, particles in the process of friction crumble from the surface, causing its wear, and quartz sand particles - 63- 160 microns. However, in [25] it is noted that the particle size of the SiO2 powder should be 20 μm to ensure an effective abrasive action.

The development of a unified understanding of the effect of the size and chemical nature of ceramic additives on the processes occurring in a friction material during friction is very important and can be obtained both on the basis of experimental and theoretical studies.

Purpose

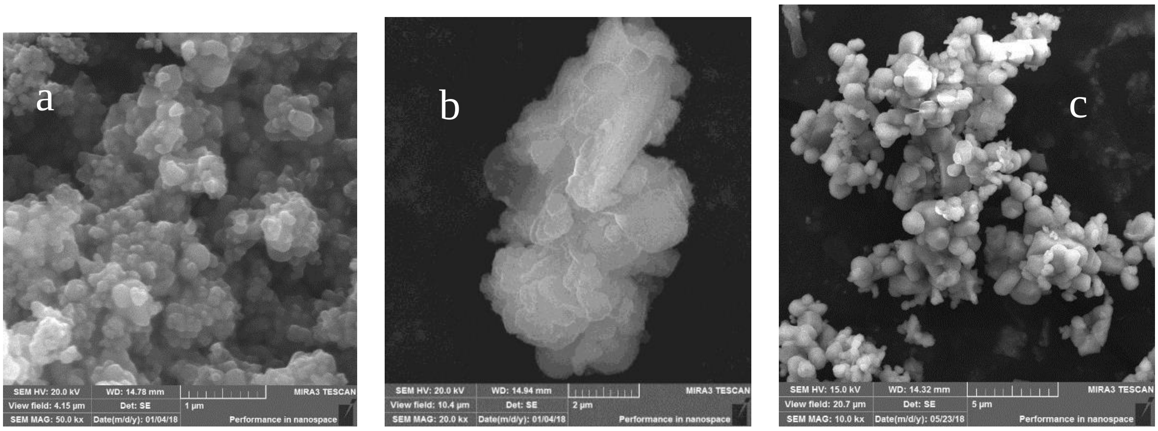
Investigation of the effect of submicron ceramic powders TiO_2, AlN, Cr_2O_3 on the tribological properties of a friction material.

Methods

A mixture of copper powders with 12% tin and 30 vol.% Elemental graphite GE-1 was used as the basis for the friction material. The initial charge was obtained by mixing powders of copper grade PMS-1 with an average particle size of 100 μm, tin grade PO 1 with an average particle size of 20 μm, elemental graphite grade GE-1 (GOST 7478-75), which has a flake shape, with an average size of flakes 100 μm in a "drunken barrel" mixer for 45 minutes. For the formation of friction materials, 7 types of charge were used based on copper with additions of TiO_2, AlN, Cr_2O_3 powders in the amount of 1.0-7.0 wt. % with a step of 1.0 wt.%. Figure 1 shows the appearance of TiO_2, AlN, Cr_2O_3 powders used for research. Powders with high activity are presented in the form of agglomerates, while themselves having a size of less than 1.0 μm.

Titanium dioxide is agglomerates with a size of 100-150 microns, consisting of submicron powders, predominantly spherical, up to 0.2 microns in size (Fig. 1a). Aluminum nitride also represents agglomerates with an average size of 20 μm, with a particle size of 0.5 μm (Fig. 1b). Chromium oxide powder consists of agglomerates 20-30 microns in size, including spherical particles 0.2-0.4 microns in size (Fig. 1c).

Samples of friction discs for testing were prepared as follows: the resulting mixture from the initial powders was applied by free pouring onto the surface of a steel base using special technological equipment, then preliminary sintering was carried out in dissociated ammonia at a temperature of 840 ° C for 50 min. The sintered blank of the friction disk was subjected to plastic deformation (embossing) with a punch having a profile in the form of a "mesh" on the surface, for molding a system of oil channels and grooves on the surface of the sintered material, as well as obtaining a porosity of 12-18%. Then the final sintering was carried out under a pressure of 0.1 MPa in a dissociated ammonia medium, which contains,%: H2 - 75, N2 - 25 at a temperature of 840 ° C for 3 hours.



а) б) в)

Fig. 1. Ceramic additives used for research in the composition of a composite friction material based on copper^ a) TiO2; b) AlN; c) Cr2O3

The principle of the tribological testing method was to simulate the braking process on the IM-58 inertial stand in the “A” oil medium during registration of the change in the moment of friction forces depending on the speed and time of braking [10]. The coefficient of friction and wear of the material was fixed after 500 test cycles. Measurement of material wear was carried out using MK 25-1 micrometer GOST 6507-90.

The tests were carried out under the following conditions:

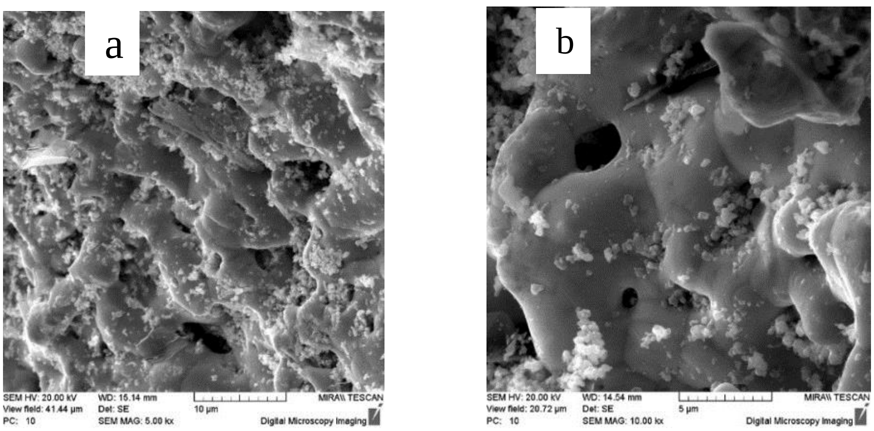
- initial braking speed – 19 m/s;
- specific load – 0.85 MPa;
- moment of inertia of flywheel masses – 0.56 N•m•s^2;
- friction work – 27.5 kJ;
- the coefficient of mutual overlap – 0.29.

A disc made of 65G steel with a hardness of 260-320 HB and a roughness of the working surface of Ra 0.7-0.8 was used as a counterbody.

The structure was studied using an optical microscope MEF-3 (Austria). The morphology of the friction disk friction surface and its microstructure were investigated on a high-resolution scanning electron microscope MIRA (Czech Republic) with an INCA 350 X-ray microscope attachment from Oxford Instruments (Great Britain). Non-etched areas were examined in a cross section perpendicular to the deposited layer. The strength of the powder material was determined by compressive testing of specimens 20 mm high, 15 mm wide and 15 mm long on a Tinius Olsen H150K-U testing machine at a loading rate of 2 mm / min.

Results

A very important condition for the use of ultrafine powders is their uniform mixing. Having a high activity, such powders are capable of forming agglomerates, which affects the properties of the finished product [26]. After mixing the initial charge of the friction material, a fairly uniform distribution of the addition of submicron particles of TiO_2, AlN, Cr_2O_3 powder on the side surface of the copper powder is observed (Fig. 2).



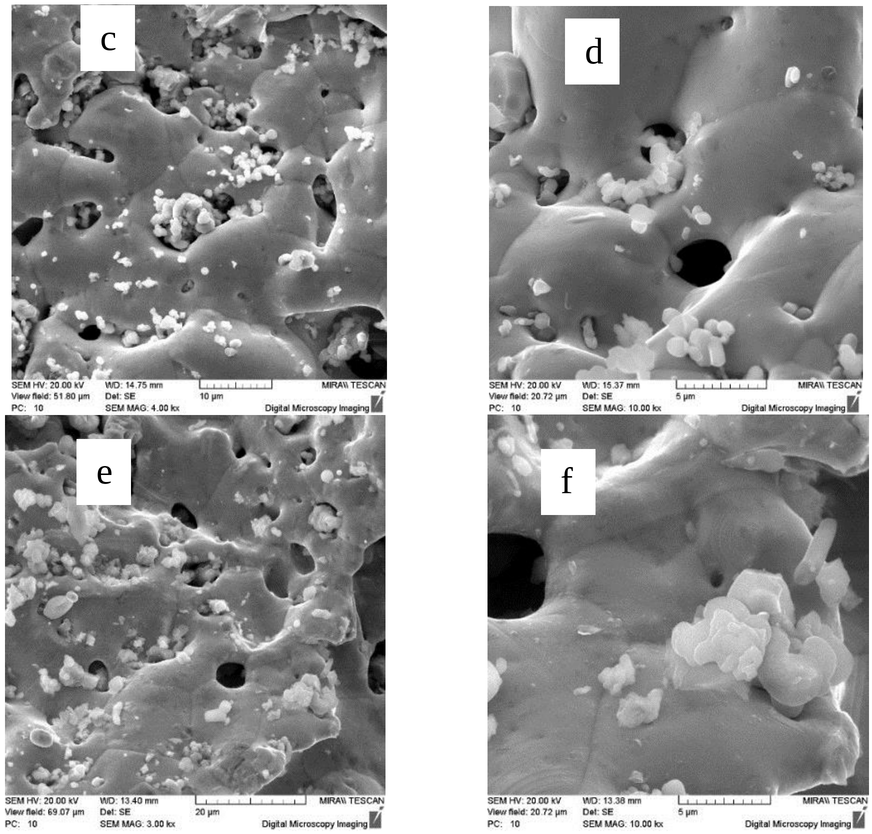


Fig. 2. Distribution of the addition of submicron powder particles in the friction material^ a, b) TiO2; c, d) Cr2O3; e, f) AlN

In fig. 3a shows the dependences of the change in the friction coefficient of the friction material on the content of the used additives of submicron powders. The addition of Cr_2O_3 powder provides the greatest increase in the value of the friction coefficient - from 0.042 to 0.082, slightly less - the addition of AlN and TiO_2 powders - 0.042-0.074 and 0.042-0.060, respectively.

The least wear of the friction material was observed when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. The wear of the material with the addition of 1.0 vol.% Chromium oxide is 2.6 μm / km. Titanium oxide in the amount of 0.5-7.0 vol. % has a lesser effect on reducing material wear. When the additive is increased by more than 7 vol. %, material wear is noted above the established value of 9.0 μm / km (Figure 3b).

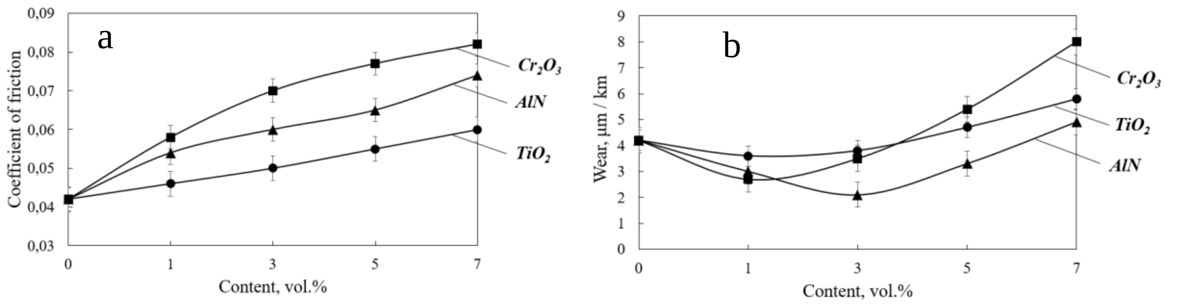


Fig. 3. Change in the coefficient of friction and wear of a friction material based on 12% tin bronze with 30 vol.% GE-1 versus the amount of addition of submicron ceramic powders TiO_2, AlN, Cr_2O_3

In the process of friction, a modified surface layer is formed, which can be present both on one of the friction surfaces, and on both. The formation of such layers during friction was noted in his works by the famous scientist L.I. Bershadsky, pointing out that such layers have a structure different from the structure of the initial materials, and determine the value of the coefficient of friction and wear [27]. These processes are discussed in great detail in the works of B.I. Kostetsky and representatives of his school [28].

Investigations in characteristic X-ray radiation over the surface area of the friction material showed the presence of such a layer. The layer is a mechanical mixture of the metallic phase of the friction material (tin bronze) with submicron ceramic particles (Fig. 4).

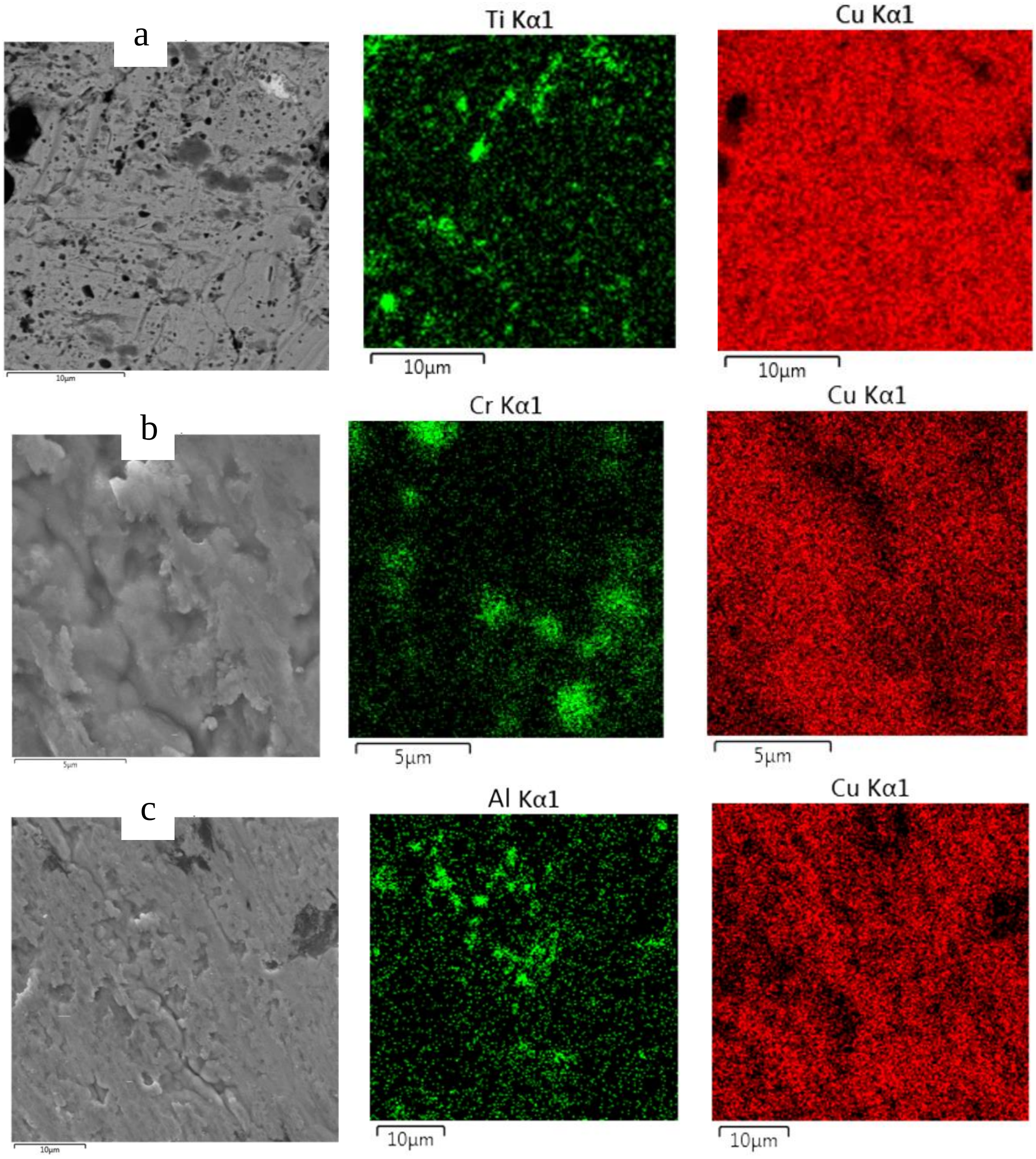


Fig. 4. Micro X-ray spectral analysis of the friction surface of a friction material containing submicron ceramic powders (300 test cycles): a) TiO_2; b) Cr_2O_3; c) AlN

It is noted in [29] that when ceramic particles of Al_2O_3 with a size of 100 μm are used in the composition of a sintered friction material, the friction surface is modified. It manifests itself in plastic deformation of the softer friction material, with an increase in wear. In addition, it is marked by the closure of the surface pores of the friction material. The effect of closing the pores is highly undesirable, since they, being additional sources of lubrication, preserve the conditions of boundary friction. To a greater extent, the effect of lubrication from the pores is manifested in the case of prolonged sliding, for friction materials called the slipping process.

It has been found that the use of additives of ultrafine powders TiO_2, Cr_2O_3, AlN in the range of 0.5-7.0 vol.% Preserves the structure of the surface layer of the friction material (Fig. 5). The presence of pores on the friction surface can be noted. In the case of an increase in the particle size of the TiO_2 defect to 100 μm, already at 3.0 vol.% On the friction surface of the friction material, plastic deformation is recorded, the formation of directed friction tracks from the abrasive action of ceramic particles, as well as the closure of surface pores (Fig. 5d). For the friction material, an unstable value of the friction coefficient and increased wear were recorded.

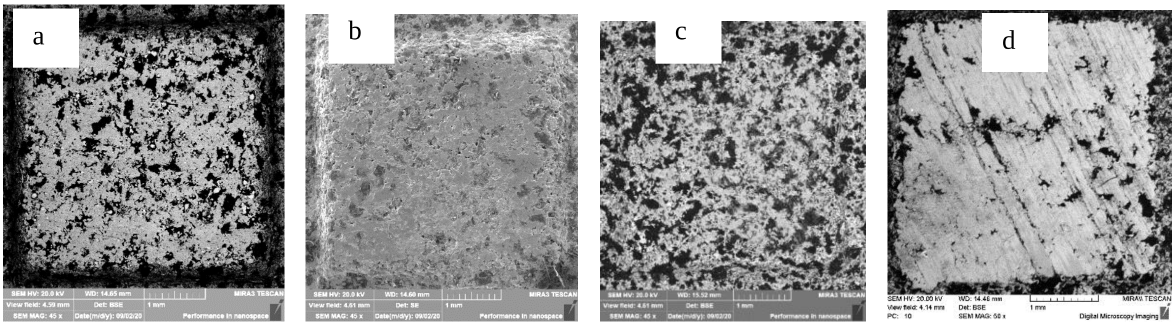


Fig. 5. Morphology of the friction surface of a friction material based on copper containing additives of ceramic powders (a - 7.0 vol.% TiO_2 (0.2 μm); b - 7.0 vol.% AlN (0.5 μm); c - 7.0 vol.% Cr_2O_3 (0.3 μm); d - 3.0 vol.% TiO_2 (100.0 μm)) after 500 test cycles

Conclusions

The addition of submicron powders of TiO2, Cr2O3, AlN (0.2-0.5 μm) into the sintered friction material based on copper leads to an increase in the value of the friction coefficient. So, when using the addition of Cr2O3 powder, the greatest increase in the value of the friction coefficient is noted - from 0.042 to 0.082. A slightly smaller increase in the friction coefficient is shown by the use of AlN and TiO2 defects - 0.042-0.074 and 0.042-0.060, respectively. It was found that the least wear of a friction material based on copper operating under boundary friction conditions was observed when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. The wear of the material with the addition of 1.0 vol.% Chromium oxide is 2.6 μm / km. Titanium oxide in the amount of 0.5-7.0 vol. % affects wear resistance to a lesser extent. Increasing the addition of any of the submicron powders by more than 7 vol. % leads to a significant decrease in wear resistance.

References

1 Sharipov V.M. (2002) Proyektirovaniye mekhanicheskikh, gidromekhanicheskikh i gidroob"yomnykh peredach traktorov. - M.: MGTU MAMI. - 2002. – S.300.

2 Tarasik V. P. (1973) Friktsionnyye mufty avtomobil'nykh gidromekhanicheskikh peredach. – Minsk: Nauka i tekhnika. – S.320.

3 Gordeyev R.V., Pyzhev A.I. (2014) Rossiyskoye avtomobilestroyeniye: rezul'taty, tendentsii i perspektivy [Ekonomicheskiy analiz: teoriya i praktika]. (48). – S.26-35.

4 Al'gin V. B., Poddubko S.N (2019) Resursnaya mekhanika transmissiy mobil'nykh mashin. - Minsk: Belaruskaya navuka. – S.549.

5 Miroshnichenko A.N. (2014) Osnovy teorii avtomobilya i traktora [Tomsk: Izd-vo Tom. gos. arkhit.-stroit. un-ta]. – S.489.

6 Rumyantsev L.A. (2008) Ustroystva upravleniya planetarnoy korobkoy peremeny peredach [Stroitel'nyye i dorozhnyye mashiny]. - (11). – S.31-35.

7 Krasnevskiy, L.G., Poddubko S.N., Nikolayev YU.I. (2014) Razvitiye konstruktsiy gidromekhanicheskikh peredach bol'shoy moshchnosti [Aktual'nyye voprosy mashinovedeniya: sb. nauch. tr. OIM NAN Belarusi], - (3). - S.83–87.

8 Ilyushchanka A.Ph., Leshok A.V., Dyachkova L.N., Alekseenko N.A. (2019) Formation of the friction surface of a friction material based on copper depending on the amount of tin under lubrication condition [10-th International conference Balttrib, 14-16 November 2019, Vytautas Magnus University Lithuanian Scientific Society Department “Tribologija” Akademija, Kaunas, Lithuania]. - Pp.100-106.

9 Ilyuschenko A.Ph., Leaghok A.V., Rogovoy A.N., Rudakovsky V.O. (2017) Application of sintered powder material FM-15 in the clutch coupling "Belarus-3522" tractors [Agricultural engineering]. – (49). - P.56-62.

10 Fedorchenko I. M., Pugina L.I. (1980) Kompozitsionnyye spechennyye antifriktsionnyye materialy [Nauk. Dumka]. - S.404.

11 Copper alloy powder, sintered copper alloy body, and brake lining for use in high-speed railways: pat.: US20160047016A1 / Futoshi Katsuki, Fumio Ishimoto, Osamu Kanda. – 18.02.2016.

12 Friction material containing brass powders: pat.: US5324592A / Fred Blankenhagen, Hermann Putz. – 28.06.1994.

13 Sintered friction material for high-speed railway: pat.: US20140109723A1 / Fumio Ishimoto, Futoshi Katsuki, Kazutaka Asabe. – 24.04.2014.

14 Sintered friction material: pat.: US20200038959A1 / Manabu Kubota, Naomitsu Mizui, Fumio Ishimoto. – 06.02.2020.

15 Sintered friction material for a friction lining: pat.: US20170363167A1 / Zoltan Csanadi, Bruno Tourneret, Peter Echtler. – 02.04.2019.

16 Sintered friction material for railway vehicles and method for producing the same: pat.: US20190292634A1 / Manabu Kubota, Kazutaka Asabe, Yuki Ichikawa, Takeshi Nakano. – 26.09.2019.

17 Sintered material for a magnetic track brake.: pat. US6648108B2 / Eckart Saumweber, Wolfgang Schröer, Wolfgang Valentin. –

18.11.2003. 18 Mashkov, YU. K. (2013) Tribofizika metallov i polimerov [Omsk : Izd-vo OmGTU]. - 2013. – 240 s.

19 Tarasov A.B. (2016) Sintez, struktura i funktsional'nyye svoystva nanostrukturirovannogo dioksida titana, poluchennogo geterogennym gidrolizom tetrakhlorida titana v aerozol'nykh sistemakh [dis. … kand. khim. nauk: 02.00.04]. – Chernogolovka. – 123 l.

20 Kozhina, L.F. (2017) Khrom i yego soyedineniya [Saratov]. - 48 s.

21 Arkhipov D.I. (2017) Regulirovaniye dispersnosti nanoporoshkov dioksida khroma putom modifitsirovaniya komponentami Mo-Sb, W-Sb, Mo-Sb-Fe, Sn-Te, Sn-Te-Fe [dis. … kand. tekhn. nauk : 05.16.08]. – 132 l.

22 Kudyakova V.S. (2019) Razrabotka tekhnologii stabilizatsii kubicheskikh modifikatsiy nitrida alyuminiya [dis. … kagd. tekhn. nauk : 05.17.11]. – Yekaterinburg. - 154 l.

23 Fedorchenko I.M. (1976) Issledovaniye materialov dlya tormoznykh i peredatochnykh ustroystv [Kiyev.: Naukova dumka]. – 240 s.

24 Fedorchenko I. M., Kryachek V. M., Panaioti I. I. (1975) Sovremennyye friktsionnyye materialy [Naukova dumka, Kiyev]. – s.336.

25 Bowden F.P. Tabor D. (1950) The friction and lubrication of solids [Clarendon press, Oxford]. – 424 p.

26 Girshov V.L., Kotov S.A., Tsemenko V.N. (2010) Sovremennyye tekhnologii v poroshkovoy metallurgii [SPb.: Izd-vo Politekhn. Un-ta]. - 385 s.

27 Bershadskiy L.I. (1990) Strukturnaya termodinamika tribosistem [Kiyev: Znaniye]. – 245s.

28 Kostetskiy B.I., Natanson M.E., Bershadskiy L.I. (1972) Mekhano-khimicheskiye protsessy pri granichnom trenii. [M.: Nauka]. - 1972. – 170s.

Лешок А.В., Дыха А.В. Закономерности влияния субмикронных керамических порошков TiO_2, AlN, Cr_2O_3 на трибологические свойства фрикционного материала

Узлы трения для автомобильной и специальной техники предназначены для работы в условиях граничного трения. Современные автомобили содержат фрикционные узлы, в которых используются фрикционные материалы. В настоящее время активно используются фрикционные материалы: на основе термореактивных смол; целлюлозно-бумажные материалы; спеченные порошковые материалы; материалы углеродного или углеродного состава; материалы с керамической матрицей. Развитие единого понимания влияния размера и химической природы керамических добавок на процессы, происходящие в фрикционном материале при трении, очень важно и может быть получено как на основе экспериментальных, так и теоретических исследований. В работе представлены результаты исследования влияния субмикронных порошков TiO2, Cr2O3, AlN размером 0,2-0,5 мкм на триботехнические свойства фрикционного материала на основе меди, предназначенного для работы в условиях граничного трения. Установлено, что при использовании добавки порошка Cr2O3 отмечается наибольшее увеличение значения коэффициента трения - с 0,042 до 0,082, несколько меньшее увеличение коэффициента трения показывает использование дефектов AlN и TiO2 - 0,042 -0,074 и 0,042-0,060 соответственно. Наименьший износ фрикционного материала был получен при использовании 3,0 об. % добавки нитрида алюминия - 2,1 мкм / км. Увеличение добавления любого из субмикронных порошков более чем на 7 об. % приводит к значительному снижению износостойкости. Это связано с образованием на поверхности фрикционного материала модифицированного слоя, содержащего керамические частицы и металлическую фазу фрикционного материала. Для фрикционного материала зафиксировано нестабильное значение коэффициента трения и повышенный износ.

Ключевые слова: фрикционный материал, коэффициент трения, износ, керамические частицы, бронза.

Problems of Tribology, *V. 26, No 1/99-2021,28-32*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-28-32

Closed ventilation and filtering system for cleaning of welding aerosols at deposition

V. Chigarev[1], Yu. Logvinov[2*]

[1]Mariupol State higher educational institution 'Priazovsky state technical university, Mariupol, Ukraine
[2]Mariupol institute Interregional Academy of Personnel Management city of Mariupol. Ukraine*
[*]E-mail: 07log07@gmail.com

Abstract

In the article the questions of development of construction of the closed ventilation and filtering system (CVFS) are considered on cleaning of air-gas mixture at deposition. The offered system consists of gas in-take, filters, containers for assembling of hard parts, hard constituent of welding aerosol (TSSA), by the gaseous constituent of welding aerosol (GSSA) and corps, special vent system with adjusting of speed and volume of extraction. Conducted research for cleaning of welding aerosols (SA) at deposition of high wear proof alloys of type of sormite with the use of the CVFS. Special CVFS is used, filters in particular mechanical, electric, chemical (sorption). Extraction of air-gas mixture from the area of melting of electrode and welding bath of is carried out by the pipe of small diameter, with adjusting of speed and volume of extraction passes the system of filtration the special vent system where clears up from TSSA. Thus cleared gas mixture is used as gas defense at depositing.

It is necessary it is not simple to catch SA, but to filter in the closed system, clean and give filtered clean y air in the area of deposition, technology and metallurgical properties of process of depositing must not be broken here. Features of the mechanical cleaning are in technologies of deposition, characterized that air-gas mixture has a temperature which influences on a sorbent. The mechanical cleaning by the centrifugal chamber of cleaning (CCC) is the modernized cyclone filter where centrifugal forces and gravities were used. Differs from existent cyclic filters a presence by a conical spiral insertion and rearranged surface of cone which engulfs it. In the entrance tangential union coupling appears, divided aero mixture into a few streams of entered in a spiral insertion. In the electric filter (electrostatic) electric forces operate on particles and gas molecules (based on the phenomena ionization of gas molecules, by an electric charge in the electric field). An electric charge is revealed to the particles, and they under the action of the electric field are besieged from a gas stream. If such gas, containing the several of transmitters of charges, to place between electrodes, connected with the source of high voltage, ions and electrons will begin to move to on power the field lines . This is important during neutralization of GSSA.

Keywords: harmful matters, welding aerosols, closed ventilation and filtering system, gaseous constituent of welding aerosol, mechanical filter, electric filter.

Introduction

Receipt of deposited metal with necessary wearproofness provided application, as a rule, depositing material of containing the alloying elements of the required amount. At depositing of high-alloyed of wear proof alloys the far of TSSA is selected, GSSA, polluting environment [1-4].

For the decline of selection of harmful constituents in air-gas medium during the lead through of deposition works need development of additional devices for their catching. By the area of tribology researches are the processes, of frictions, wears [1].

In it turn of process this to work-hardening of iron and steel machines, it is the real decision of task of wear of machines and mechanisms.

The filtration and ventilation systems are in-process [2-3] presented which partly decides cleaning of GSSA and TSSA at welding and depositing of wear proof alloys. Offered CVFS allows to clean SA here saving chemical composition for forming of deposition guy-sutures without extract in an atmosphere.

At welding or deposition in-process of a vent system the optimum mode of speed of sucking of volumes of the deleted air-gas mixture is set for providing of necessary chemical composition of deposited metal or welding guy-sutures.

Different foreign analogues are in-process [4] considered on filters and vent systems applied in a welding and surfacing production with extract in the atmosphere of TSSA and GSSA, that worsens the sanitary-hygienic indexes of environment

The objective of the article

Development of construction of CVFS, to find optimum technical decisions and decrease TSSA and GSSA, improve the working conditions at deposition of taking into account international standards.

Main materials

Development of construction of CVFS with the use of the special filters allows to neutralize harmful matters, and air-gas mixture. Air-gas mixture is taken away from the area of melting of electrode material and welding bath the special gas sampler passes filtration through the system of the special filters TSSA and GSSA delete in which. In same a gas sampler consists of pipes of different diameter, which are disposed in a demi hull and set in the area of melting of electrode metal.

Extraction of air-gas mixture from the area of melting of the electrode and welding bath is carried out by the pipe of small diameter of fig. 1.b (1) the special vent system with adjusting of speed and volume of hood and passes the system of filtration, where clears up from TSSA presented on fig. 1.

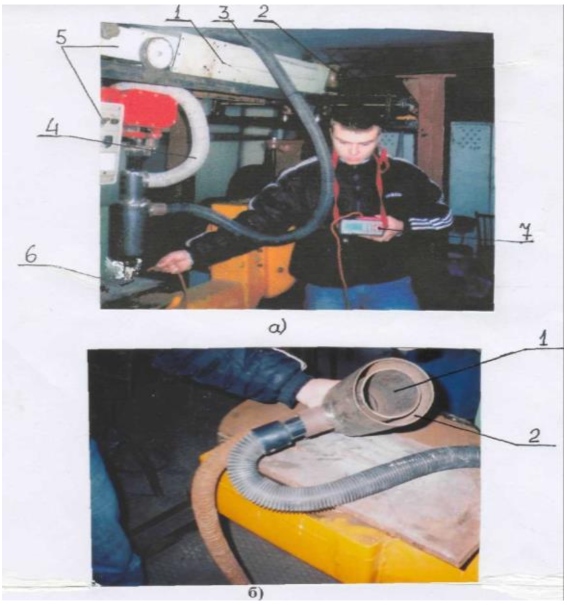


Fig. 1. Presented in CVFS at localization and SA neutralizes at deposition: a) there is an of principle chart of delete of harmful matters and SA on-condition: 1 – filter three-stage; 2 – pump; 3 –supply of air after filtration; 4 – -suction of harmful matters and SA; 5 – deposition automat; 6 – deposition deposited metal; 7 –measuring from the help of gas analyzer. b) specially developed adaptation for suction of harmful matters and SA, and serve of the filtered air in a working area: 1 – -chamber for suction of SA (on walls particles of dust and soot are visible); 2 – chamber of supply of the cleared air after filtration.

Where upon, the cleared gas mixture is used as gas protection at deposition [5]. It is necessary not simply to catch SA and to filter in the closed system, clean and give the filtered clean air in the area of deposition, here must not be broken technologically and metallurgical processes of deposition. Offered CVFS simple and reliable in exploitation. The closed ventilation and filtration system consists of 3^{kh} filters: mechanical; electric; chemical (sorption).

Features of the mechanical cleaning are in technologies of deposition, that air-gas mixture is characterized the temperature of T= 800…900°c away from the area of melting of electrode material. It is necessary to chill due to corrugated aluminum hose which reduce a temperature. A temperature influences on to the robot of sorbent. Mechanical cleaning by the centrifugal chamber of cleaning (CCC).

The modernized cyclone filter (centrifugal forces and gravities were used) [6] of which differs from existing a presence by a conical spiral insertion and rearranged surface of cone which engulfs it. In exit tangential union coupling appears, divided aero mixture into a few for-currents of entering in a spiral insertion. There is more intensive transformation of energy of pressure to kinetic. Thus force of static pressure is already comparable with weight of particles and excels it. On fig.2. the mechanical cleaning is presented by CCC.

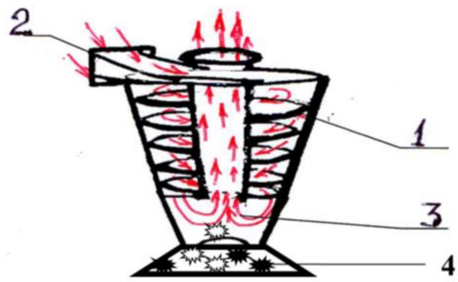


Fig. 2. Mechanical cleaning CVFS by CCC: 1– spiral insertion; 2 – cleaning of SA; 3 – exit from the insertion of SA; 4 – container with particulate dispersible compounds

A determinative is independent motion of certain amount of spiral streams and cleared stream to the exhaust. In the process of such motion the increase of circuitous speed of aero mixture can attain on an output 70 m/s, that results in the large concentration of sputtering particles. In the entrance tangential union coupling appears, divided aero mixture into a few streams of entered in a spiral insertion. On an exit from an insertion here speed of current of air is made by 50…70 m/ss.

Electric filters their principle of action explained action of electro--static forces. Electric forces operate on particles and gas molecules, based on the phenomena of ionization of gas molecules the electric field. An electric charge is revealed to the particles and they under the action of the electric field are precipitated from a gas stream.

If such gas, containing several of transmitters of charges, to place between electrodes, connected with the source of high tension, ions and electrons will begin to move to on power the field lines . That provides at neutralization of GSSA. TSSA in electrostatic precipitators clear up:

- sputtering d particles move to the electrodes with an opposite sign;
- precipitated on these electrodes; a dust, settling on electrodes by the shaken device, precipitated.

Practically charging of particles is performed at the key-in of particles through the crown of direct-current between the electrodes of electrostatic precipitator. The general view of electrostatic precipitator is resulted on fig.3.

On crowning electrodes the direct current of high tension is given 30...60 kV. Crowning an electrode has subzero polarity usually, an precipitating electrode is earthed. It is explained that a crown at such polarity is more steady, mobility of subzero ions is higher, than positive. The last circumstance is related to the acceleration of charging of sputtering. On a fig.3. the structural chart of electric filter is offered in CVFS.

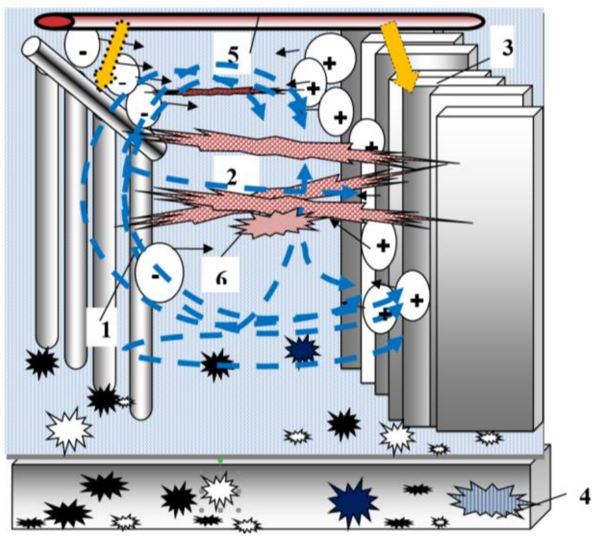


Fig. 3. Structural chart of electric filter in CVFS: 1 – thin wire rods; 2 – is created the electric field between electrodes, connected with the source of high tension; 3 – plates drank for besieging; 4 –container for collection was drunk including; 5 – shaking device; 6 – corona electrode.

Conclusions

1. The construction of CVFS is offered for the decline of selection of harmful constituents, formed in an air-gas environment at deposition of wear proof alloys.

2. The improvement of alloying in deposited metal will allow to improve the process of work-hardening of machines, it is the real solution of task of wear and is the area of tribology researches.

References

1. http://tribology.khnu.km.ua/index.php/ProbTrib

2. Safronov I.I. Fundamentals of rational alloying of alloys. / I.I. Safronov - Chisinau: Shtiintsa, 1991 .- 278 p.

3. Livshits L.S. Fundamentals of alloying of deposited metal / L.S., Livshits, N.A. Greenberg, E.G. Curcumelli. - M .: Mechanical engineering, 1969 . - 188 p.

4. Chigarev V.V. Sanitary-hygienic assessment of surfacing flux-cored tapes / V.V. Chigarev, O. G. Levchenko // Welding production. - 2004 - No. 12. - S. 35-37.

5. Logvinov Yu.V. Closed filtering system for neutralization and localization of welding aerosol during surfacing / Yu.V. Logvinov // Science and technology: mizhvuz. Topics. Zb. Sciences. Pr. - Mariupol: DVNZ 'PDTU'. - 2018.- VIP. 19. - P.32-35.

6. Breca D. Zeolite molecular sieve / D. Breca. - M: Mir, 1980.- T.1-504s.

Чігарьов В.В., Логвінов Ю.В. Замкнута фільтровентіляційна система для очищення зварювальних аерозолів при наплавленні

У статті розглянуті питання розробки конструкції замкнутої фільтровентиляційної системи (CFVS) по очищенню газоповітряної суміші при наплавленні. Пропонована система складається з газового забірника, фільтрів, контейнерів для збірки твердих частин, тверда складова зварювального аерозоля (ТСЗА), газоподібною складовою зварювального аерозоля (ГСЗА). і корпуси, спеціальної вентиляційної системи з регулюванням швидкості і об'єму витяжки. Проведені дослідження для очищення зварювальних аерозолів (ЗА) при наплавленні високолегованих зносостійких сплавів типу сормайт з використанням системи CFVS. Застосовуються спеціальні CFVS, фільтри зокрема механічний, електричний, хімічний (сорбційний). Необхідно не просто уловити ЗА, а відфільтрувати в замкнутій системі, очистити і подати відфільтрований чисті й повітря в зону наплавлення, при цьому не мають порушені технологія і металургійні властивості процесу наплавлення.

Особливості механічного очищення в технологіях наплавлення, характеризується тим що газоповітряна суміш має температуру, яка впливає на сорбент. Механічне очищення в технологіях наплавлення, характеризується тим що газоповітряна суміш має температуру, яка впливає на сорбент. Механічне очищення за допомогою відцентрової камери очищення (ВКО) – це модернізований циклонний фільтр де використовувалися відцентрові сили і сили тяжіння. Відрізняється від існуючих циклічних фільтрів наявністю конічною гвинтовою вставкою і перфорованою поверхнею конуса, який її охоплює. . У вхідному тангенціальному патрубку утворюється, аеросуміші розділяється на декілька потоків тих, що вводяться в гвинтову вставку.

У електричному фільтрі (електростатичні) на частки і газові молекули діють електричні сили (заснований на явищ іонізації газових молекул, електричним зарядом в електричному полі). Часткам повідомляється електричний заряд, і вони під дією електричного поля осідають з газового потоку. Якщо такий газ, що містить деяку кількість носіїв зарядів, помістити між електродами, сполученими з джерелом високої напруги, то іони і електрони почнуть рухатися по силовими лініям поля. Це поважно при нейтралізації ГССА.

Ключові слова: шкідливі речовини, зварювальні аерозолі, замкнута фільтровентиляційна система, газоподібній складовій зварювального аерозоля, механічний фільтр, електричний фільтр.

Problems of Tribology, V. 26, No 1/99-2021, 33-42

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-33-42

Research of tribotechnical properties of antifriction polymer compositions

R. M. Ostapenko

National University of Life and Environmental Sciences, Kyiv, Ukraine

E-mail: romaostapenko1504@gmail.com

Abstract

The analysis of antifriction polymer compositions on the basis of polyamide, epoxy, phenol-formaldehyde, furan resins, and also on the basis of fluoroplastic with various fillers working in friction knots is made. The influence of fillers on the mechanisms of friction is little studied, so when creating antifriction compositions capable of working in conditions of lubrication in water, the following tasks were set: to justify the number and type of fillers; to investigate the influence of fillers on the process of wear of material and counterbody; determine the optimal composition of the antifriction composition that provides minimal wear of the coating and the counterbody. The object of study were: compositions based on phenol-formaldehyde resin and fluoroplastic, modified with antifriction fillers; details of submersible pumps. The basis of the study was the study of tribotechnical and technological properties of polymer compositions. Based on the analysis of literature data, the target fillers for the creation of antifriction compositions for radial plain bearings and thrust bearings of submersible pumps are selected, their number and composition are substantiated. The criterion for optimization was the mass wear of the polymer coating and the counterbody. The optimal composition of the antifriction composition for radial plain bearings, which contains: a mixture of colloidal graphite Cl and carbon fabric "TGN-2M"; molybdenum disulfide DM-1; powder polyamide 12 APN-B; crushed prepreg comprising a fiberglass filler impregnated with a modified phenol-formaldehyde resin P2M. For thrust bearings, the optimal composition of the fluoroplastic composition is determined, which includes: fluoroplastic F4; molybdenum disulfide; carbon fabric; powdered copper. The physical and mechanical properties of the optimal composition are presented. Technological equipment has been developed for the restoration and manufacture of plain bearings and submersible pump bearings. Molds are made for industrial implementation.

Key words: plain bearings, thrust bearings, submersible pump, antifriction fillers, fluoroplastic, phenol-formaldehyde resin, mold

Introduction and problem statement

The use of antifriction compositions used in the restoration of parts, allows in many cases to increase the service life of machines and reduce repair costs. This is due to the relatively low coefficient of friction of polymeric materials containing various antifriction fillers. When creating new composite materials, the selection of the most effective types of fillers is of paramount importance. However, it is known that, depending on the operating conditions, the same fillers, or a combination thereof, affect the intensity of wear of friction pairs. Currently, there is no scientifically based theory for the choice of composition and amount of fillers when creating compositions for specific operating conditions. The influence of fillers on the mechanisms of friction is little studied. Therefore, when creating antifriction compositions capable of working in conditions of lubrication in water, the following tasks were set:

a) justify the number and type of fillers;

b) to investigate the influence of fillers on the process of wear of material and counterbody;

c) determine the optimal composition of the antifriction composition that provides minimal wear of the coating and the counterbody.

Analysis of antifriction materials

Coatings based on polyamide resins, such as polycaproamide PKA, caprolon B, polyamides P-68, AK-7, P-12L, ATM-2, aromatic polyamide (phenylene), FM-50, etc. are used to restore parts of agricultural machinery. [1]. Where the requirements for mechanical couplings are higher in terms of mechanical strength, rigidity, wear resistance at high temperatures, glass-filled polyamide with a fiber content of up to 30 ... 45% is used. According to BD Voronkova [2] glass-filled polyamides P-6VS, P-6VSU with a fiber content of up to 30% are used in friction units at high loads. But along with the advantages of polyamide bearings and coatings have a number of disadvantages, which include: low thermal conductivity; high shrinkage, etc. Under normal atmospheric conditions, polyamide bearings contain up to 3.5% moisture, which leads to a change in their size. With each percentage of absorbed moisture, the linear dimensions change by 0.15 ... 0.27%. This is a significant disadvantage of polyamides, as during operation the dimensions of the bearings must be stable. Carbon-graphite and carbon-plastic are used in various friction joints antifriction materials: AMC-1; AMC-3; AF-3T; graphite plastic DEZ; AG-1500-C0.5; antiglimite (ATM); ATM-1G; DFG-2 and others, which are based on epoxy-silicon-organic, phenol-formaldehyde and furan resins [3,4]. These materials are used in friction units, where the specific loads do not exceed 2.5 MPa. The increase in loads leads to an increase in the coefficient of friction and a decrease in wear resistance. Antifriction materials based on epoxy resins have become widespread in repair production. On the basis of epoxy resin ED-5 antifriction Epoxy-based antifriction material was developed - "epoxylite" plasticized with debutyl phthalate and filled with graphite, bronze chips, etc. On the basis of epoxy resin ED-6, an antifriction material "maslyanite" was developed, which contains MK-8 lubricant as a modifier and aluminum powder as a filler [5,6]. Insufficiently high mechanical properties, low operating temperatures, high coefficient of friction constrain the widespread introduction of epoxy compositions. Under conditions of limited lubrication, high wear resistance was shown by textolites based on resol phenol-formaldehyde resin. From antifriction textolites working in friction units are known: PTK-C; PTG-1 [7], the main advantages of which are stable operation under conditions of high compressive loads. Such requirements are met by compositions based on thermosetting phenol-formaldehyde resins, which can be used in Supervisor Ruzhilo ZV, Ph.D., Associate Professor (NULES), Kyiv. The production of coatings for the restoration and manufacture of bearingsECV. This polymer antifriction composition contains: as a binder - crushed prepreg, which consists of bakelite varnish and fiberglass in a ratio of 1: 1.6; molybdenum disulfide; a mixture of colloidal graphite and carbon fabric in a ratio of 1: 1 and powdered polyamide [8]. Compositions based on fluoroplastic (PTFE) have higher wear resistance. In its pure form, fluoroplastics as antifriction materials should not be used due to insufficient wear resistance, cold flow, low thermal conductivity and high coefficient of linear expansion. Composites are widely used for plain bearings, piston pumps: Ф4К20; FN-202; FCN-7 (14); AFGM-5 (10); Ф40М30; Ф40С15М1,5; Ф40Б20; FKM-80VS; graphite plastic KV, 7V-2A; flubon-10 (15, 20) and others. [3,9,10]. PTFE compositions with glass fillers (filler content from 5 to 40%) are produced in a wide range of branded products from the United States, Western Europe and Japan. The composition of the filler (fiber, dispersed particles) is not always specified by firms. Most often, glass fiber (SV) with a fiber length of 10 ÷ 15 μm is used for compounding PTFE. The firm "Du Pont" uses ground JI (type E) with a diameter of 13 μm, a length of 800 μm, the firm "Hoechst" - with a diameter of 10 μm, a length of 50-100 μm [11]. Glass-filled PTFE is used for the manufacture of bearings, gaskets, non-lubricating compressor rings, valve seats, insulation for work in the chemical industry, electrical engineering and mechanical engineering. These parts can be operated at temperatures from -267 to + 260 ° C, in liquid oxygen and sulfuric acid. They have advantages over unfilled PTFE: increased thermal conductivity; durability; dimensional stability and reduced cold flow. Known compositions of PTFE with metals, oxides and salts of metals, alloys, synthetic ceramics. The most common are PTFE compositions with bronze, as well as with a mixture of bronze, graphite and molybdenum disulfide. Firms use spherical and irregular dendritic bronze (particle size less than 60 μm). The ratio of copper to tin in this bronze is 9: 1 [9]. PTFE filled with bronze is characterized by the highest wear resistance during dry friction. At high-speed friction for better heat dissipation, it is advisable to add to the composition of graphite or carbon fiber. Fluoroplastic compositions can be effectively used when applying coolant to the friction zone. For example, the coefficient of friction without lubrication on steel X18H9T at a sliding speed of 1 m / s for such compositions as Ф40М30, Ф40 is 0.6 ... 0.66, when lubricated with water it decreases to 0.036 ... 0.06 [6]. For thrust pump bearings, it is advisable to use compositions based on fluoroplastic with the following fillers: carbon fabric; molybdenum disulfide; powdered copper [12]. Porous compositions based on fluoroplastic increase elasticity, dampen vibrations, provide lubrication to the friction zone (due to "pockets") [13,14]. Submersible pumps operate in conditions of high vibration, especially at start-up. Therefore, in these pumps it is advisable to use double-layer damping bearings, which are covered with a layer of polyurethane in outer diameter [15].

Research methodology

The object of study were: compositions based on phenol-formaldehyde resin and fluoroplastic, modified with antifriction fillers [8,12]; details of submersible pumps, including deep groove ball bearings and thrust bearings. The basis of the study was the study of tribotechnical and technological properties of polymer compositions. The study was performed on an experimental setup (fig. 1), created on the basis of a hydraulic press PSU-250.The PSU-250 press belongs to type of hydraulic with a torsion silt gauge.

Fig. 1. Hydraulic press PSU-250: Technical characteristics of the press: the maximum admissible loading at compression - 250 ts .; number of measuring ranges 2; limits of measurement of ranges: the first 25… 100 ts .; 50… 250 ts .; the largest stroke of the piston is 50 mm; speed of movement of the working piston -0… 20 mm / min .; the greatest distance between basic plates is 800 mm; the size of the base plate is 440 x 440 mm.

Fig.2. Mill MPR-2 :Technical characteristics: Productivity, samples / hour - 10; Grinding time of one sample, min-3; Mass of samples, Mr -100; Voltage, at 380; Power, kW - 0.6; Speed, rpm -7000

For mixing and grinding of components used mill MPR-2 (fig. 2) is designed for grinding dry materials with a moisture content of not more than 14% with particles of 40 mm in the largest size. Sintering of blanks from fluoroplastic compositions was performed at a temperature of 380 °C ± 5°C in the furnace SSHO-3.2 (fig. 3). Temperature regulation from 20 °C to 380 °C was carried out by changing the power output through an autotransformer, and the voltage and power of the thermoelectric installation were measured by the device NK-50, which included an ammeter, voltmeter and wattmeter.

Fig.3 Electric furnace SSHO-3, Technical characteristics: Voltage, at 220; Power, kW- 6; Nominal temperature, °C - 380

Fig.4 Friction machine SMC-2

Laboratory studies to determine the intensity of wear and the coefficient of friction were performed on a friction machine SMC-2 (fig. 4), and to determine the moment of friction used a special strain gauge [16]. The design of the device (fig. 5) provides the ability to determine the moment of friction directly from the movement of the pad, which is fixed on a digital strain gauge IDC-1. The wear resistance of the test compositions was determined according to the "pad-shaft" scheme. The experiments were performed at a sliding speed of 4.0 m / s and a load of 1.5 MPa (lubrication with water). The coating was applied to the inner surface of the sleeve with a diameter of 40 mm, a length of 10 mm, a coating thickness of 1 mm. Sectors with a cross-sectional area of 2 cm2 were cut from the bushings (fig. 6). To determine the wear resistance as a counterbody used samples made of steel 40X13, brake-treated to a hardness of HRC 42 ... 45.

The magnitude of the operation of the samples was determined by weighing to the nearest 0.1 mg on a laboratory scale of the second class of the model VLR-200 for 10 hours of continuous operation.

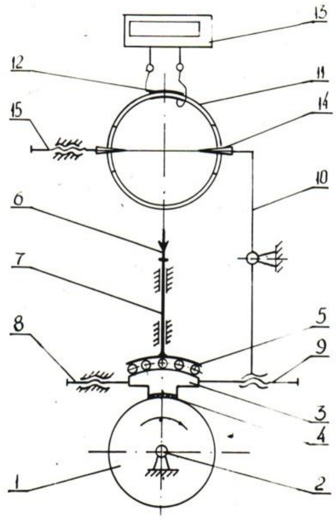


Fig. 5. General view of the strain gauge device for determining the moment of friction: 1- counter body; 2– shaft; 3 - pad; wear resistance; 4– polymer coating; 5 - rolling bearing; 6 - cargo; 7 - carriage; 6, 9 - adjustable screws; 10 - the lever; 11 – power meter;12 - strain gauges; 13– deformation meter; 14.15 –strings

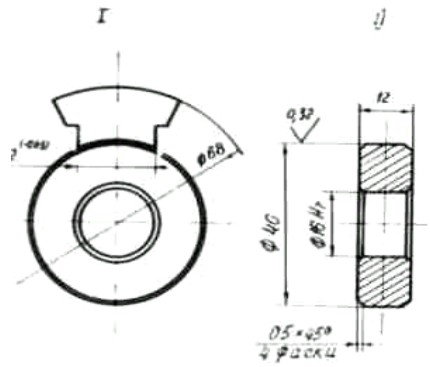


Fig.6 Sketches of samples for research

Presentation of research materials

At the first stage of research, the optimal composition of the composition for radial plain bearings of electric submersible pumps based on phenol-formaldehyde resin was determined.

The second determined the optimal composition of the polymer composition for the thrust bearings of the electric motor of submersible pumps based on fluoroplastic.

The parameters of optimization were mass wear.

Optimization of the composition of the polymer composition based on phenol-formaldehyde resin for radial plain bearings of the electric pump.

Preparation of antifriction compositions for plain bearings includes the following operations:

-grinding of high-strength fiberglass polymer AG-4V (GOST 20437-75) and sifting it through sieves with different hole sizes. After sieving, the composition of the polymer fraction was: up to 50 μm - not more than 10%; up to 150 microns - no more than 15%; up to 400 microns - no more than 55%; up to 500 microns - no more than 20%;

-mixing the prescription amount of crushed prepreg, a mixture of colloidal graphite and carbon fabric, molybdenum disulfide and polyamide powder for 10 minutes;

-coating of compositions by compression pressing in modes: pressing pressure 60 MPa; mold temperature 165 ° C; exposure time under pressure - 0.8 min / mm thick.

As antifriction fillers are taken: molybdenum disulfide DM-1; a mixture of colloidal graphite C-1 and carbon fabric TGN-2M and powdered polyamide 12 APN-B [8].

When creating an antifriction composition, we selected the levels of variation of fillers (table 1).

Table 1

Levels of variation of factors

The value of the factor	Code value of levels		
	-1	0	+1
X_1 – a mixture of graphite C-1 and carbon fabric TGN-2M (1: 1)	0	8	16
X_2 – molybdenum disulfide DM-1	0	2	4
X_3 – powder polyamide 12 APN-B	0	7	14

The criterion for optimization was the mass wear of the polymer coating (Y1) and the counterbody (Y2). When optimizing the composition of the composition varied the content of a mixture of colloidal graphite and carbon fabric (X1), molybdenum disulfide (X2), powdered polyamide (X3) with a constant content of crushed prepreg, including a mixture of fiberglass and modified phenol-formaldehyde resin P2M. To obtain a mathematical model of the optimum zone, a second-order plan (Box-Benkin) was used, consisting of 15 experiments (table 2) and including three points, which are fixed at zero.

Table 2

Planning matrix and results of experiments to determine the wear of the polymer coating and counterbody.

№ experience	X_1	X_2	X_3	$У_1$	$У_2$
1	16	4	7	3,0	1,9
2	16	0	7	3,3	3,2
3	0	4	7	4,6	2,4
4	0	0	7	5,3	3,8
5	16	2	14	2,9	2,6
6	16	2	0	3,2	3,3
7	0	2	14	4,2	2,8
8	0	2	0	5,1	4,2
9	8	4	14	1,9	1,8
10	8	4	0	2,4	3,0
11	8	0	14	3,0	2,2
12	8	0	0	3,8	4,0
13	8	2	7	2,3	2,0
14	8	2	7	1,8	2,2
15	8	2	7	2,1	1,7

As a result of calculation of coefficients of the equations received initial model of the following kind:

$$У_1 = 2{,}06 - 0{,}85X_1 - 0{,}44X_2 - 0{,}31X_3 + 1{,}53X_1^2 + \\ + 0{,}53X_2^2 + 0{,}23X_3^2 + 0{,}1X_{12} + 0{,}15X_{13} + 0{,}075X_{23} \quad (1)$$

$$У_2 = 2{,}03 - 0{,}275X_1 - 0{,}51X_2 - 0{,}73X_3 + 0{,}705X_1^2 + \\ + 0{,}08X_2^2 + 0{,}60X_3^2 + 0{,}025X_{12} + 0{,}175X_{13} + 0{,}15X_{23} \quad (2)$$

Regression analysis of the model allowed to select significant coefficients from the initial model and reject insignificant ones, as well as to check the adequacy of the model.

As a result of mathematical processing of experimental researches the mathematical models which adequately describe influence of structure of fillers on wear of a covering and a counterbody are received.

$$У_1 = 2{,}06 - 0{,}85X_1 - 0{,}44X_2 - 0{,}31X_3 + 1{,}53X_1^2 + 0{,}53X_2^2 \quad (3)$$

$$У_2 = 2{,}03 - 0{,}28X_1 - 0{,}51X_2 - 0{,}73X_3 + 0{,}7X_1^2 + 0{,}6X_3^2 \quad (4)$$

Analysis of regression coefficients proves that a mixture of colloidal graphite and carbon fabric, molybdenum disulfide and polyamide powder reduces the wear of both the polymer coating and the counterbody (coefficients at X1, X2, X3 are negative). Colloidal graphite has a stronger effect on reducing the wear of the polymer coating (-0.85X1) and has little effect on the wear of the counterbody. Powdered polyamide, on the contrary, has a stronger effect on reducing the wear of the counterbody (-0.73X3) and has little effect on the wear of the polymer coating. This is probably due to the fact that polyamide in comparison with graphite has a lower mechanical strength and hardness. The effect of the same molybdenum disulfide (X2) on the wear of the polymer coating and the counterbody is approximately equivalent (-0.44X2; -0.51X2).

The obtained dependences Y1 (X1, X2, X3) and Y2 (X1, X2, X3) were optimized for minimal wear of the friction surfaces. The dependences Y1 and Y2 are arranged in such a way that to study the extreme properties the problem is reduced to the study of the functions of two variables. This follows from the fact that for both Y1 and Y2 quadratic forms can be distinguished only for two variables, for the third variable both functions decrease linearly.

Define the line of extrema Y1:

$$\frac{\partial У_1}{\partial X_1} = 2 \cdot 1{,}53(X_1 - 0{,}278) = 0 \quad (5)$$

$$\frac{\partial У_1}{\partial X_2} = 2 \cdot 0{,}53(X_2 - 0{,}415) = 0 \tag{6}$$

$$\frac{\partial У_1}{\partial X_3} = -0{,}31 \tag{7}$$

X1 = 0.278, X2 = 0.415, X3 is arbitrary. Since the quadratic shape of X1 and X2 is positive, along the line Y1 (X3) = 1.85-0.31X3 is a sliding down minimum.

Similarly, we study Y2:

$$\frac{\partial У_2}{\partial X_1} = -0{,}28 + 1{,}4X_1 = 0 \tag{8}$$

$$\frac{\partial У_2}{\partial X_2} = -0{,}51 \tag{9}$$

$$\frac{\partial У_2}{\partial X_3} = -0{,}73 + 1{,}2X_3 = 0 \tag{10}$$

X1 = 0.2, X3 = 0.608, X2 is arbitrary. Y2 (X2) = 1,782-0,51X2.

The optimal value of X1 for the minimum wear of the coating (Y1) and counterbody (Y2) is 0.278 and 0.200, which corresponds to 10.25% and 9.65% of the mixture of graphite and fiber, ie the final conclusions on the results of research should be made at stabilization X1 = 0, 25 = 10% mixture of graphite and fiber.

Substituting the value of X1 = 0.25 in equations (3 and 4) we obtain:

$$У_1 = 1{,}94 - 0{,}44X_2 - 0{,}31X_3 - 0{,}53X_2^2 \tag{11}$$

$$У_2 = 2{,}0 - 0{,}51X_2 - 0{,}73X_3 + 0{,}6X_3^2 \tag{12}$$

According to equations (11 and 12), the surfaces of equal response of the wear process of the polymer coating and the counterbody are constructed (fig. 7).

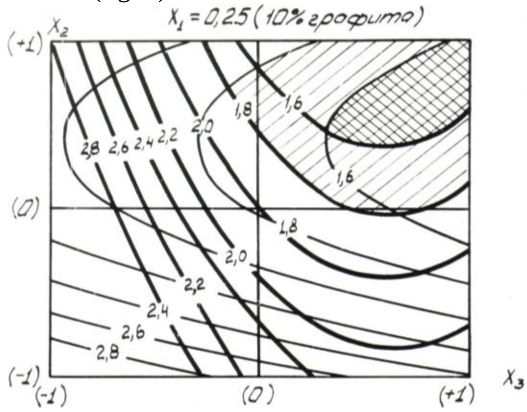


Fig. 7. Geometric image of the surface of the equal response of the wear process of the polymer coating and the counterbody

The shaded surface, limited by the isolines obtained in the calculation for the wear of the polymer coating and the counterweight equal to 1.6 mg, is optimal for determining the composition of antifriction fillers. However, previous studies have shown that when the increase in the composition of the content of powdered polyamide more than 10% leads to increased adhesion of the polymer coating to the mold surface.

To obtain a quality coating, it is necessary to cool the mold, which significantly affects the productivity of the molding process. Therefore, the optimum zone should be moved to the point of intersection of the isolines obtained for wear of 1.6 mg. At this point, the content of powdered polyamide 12 APN-B is 9%, and molybdenum disulfide DM-1 - 3%.

Since in the studied compositions the content of crushed prepreg, including fiberglass filler, was unchanged (83%), in terms of 100% by weight of the composition, the optimal content of antifriction fillers will be: a mixture of colloidal graphite and carbon fiber - 9.5%; molybdenum disulfide - 2.9%; powdered polyamide - 8.6%; crushed prepreg comprising a fiberglass filler impregnated with a modified phenol-formaldehyde resin P2M - the rest.

To restore the radial plain bearings thermosetting antifriction compositions used a universal mold (fig. 8)

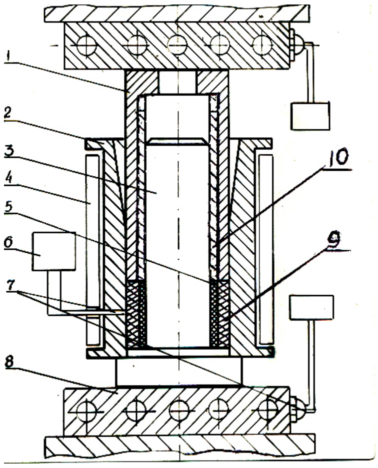


Fig.8 Scheme of a universal mold for restoring the inner diameter of plain bearings: a) thermosetting compositions; b) compositions based on fluoroplastic; c) coating the outer diameter with polyurethane (9). 1. sleeve, 2 - matrix, 3 - sign, 4 - matrix heater, 5 - primer composition, 6 - milliammeter, 7 - thermocouple, 8 - heater, 9 - outer sleeve made of stainless steel (polyurethane), 10 - punch.

Restored bearings are shown in figure 9.

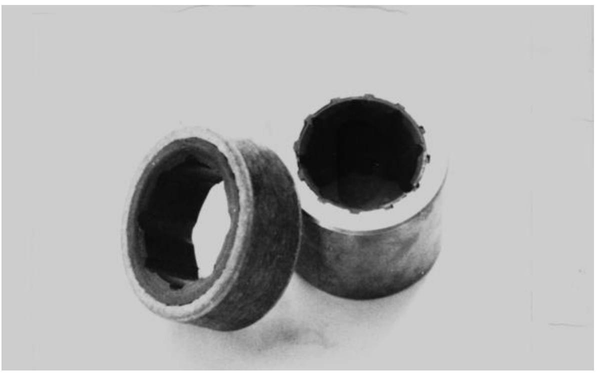


Fig.9 Restoration of the inner diameter of the radial bearing slip

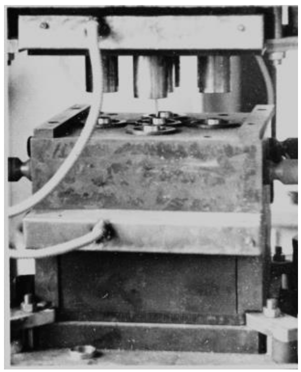


Fig.10. Five-seat mold for the restoration of plain bearings

For the industrial restoration of plain bearings made a five-seater mold (fig. 10). Development of compositions based on fluoroplastic F4 for thrust bearings. For antifriction polymer composition based on fluoroplastic F4 were taken the following components: polytetrafluoroethylene GOST 10007-78; carbon fabric TGN-2M (pre-shredded); powder copper PMS-1; molybdenum disulfide DM-1 [12]. A standard second-order rotatable plan was used for the study. The composition of the antifriction composition for thrust bearings was optimized by estimating the wear intensity and friction coefficient. After excluding insignificant coefficients, the following polynomial dependences of wear intensity I and friction coefficient f on three factors were obtained: the composition of molybdenum disulfide (X); carbon fabric (Y); powdered copper (Z). The dependence of wear intensity (J × 10-10) has the form:

$$I = 0{,}5234 - 0{,}0208X + 0{,}3315Z + 0{,}1984X^2 + \\ + 0{,}2053У^2 + 1{,}1128Z^2 - 0{,}0075XУ + 0{,}03УZ - 0{,}075\,X\,Z \quad (13)$$

The dependence of the coefficient of friction has the form

:

$$f = 0{,}0314 - 0{,}0005X + 0{,}0025У + 0{,}01322Z + 0{,}0072X^2 + \\ + 0{,}0089У^2 + 0{,}0465Z^2 - 0{,}002XУ - 0{,}001УZ - 0{,}0015ZX \quad (14)$$

Testing of the statistical hypothesis, made by Fisher's test, showed the adequacy of the regression model on the response function at a significance level of α = 0.05.Analysis of equations (13, 14) and the results of research revealed that the optimal composition, wt. h. Fluoroplastic F4 – 100. Molybdenum disulfide - 3.7… 3.9. Carbon fabric - 7.5… 9.4. Powder copper PMS-1 - 140… 160. With the optimal composition of the composition, the coefficient of friction is equal to 0.032, the wear intensity of 0.52 · 10-10 (fig. 11, 12).

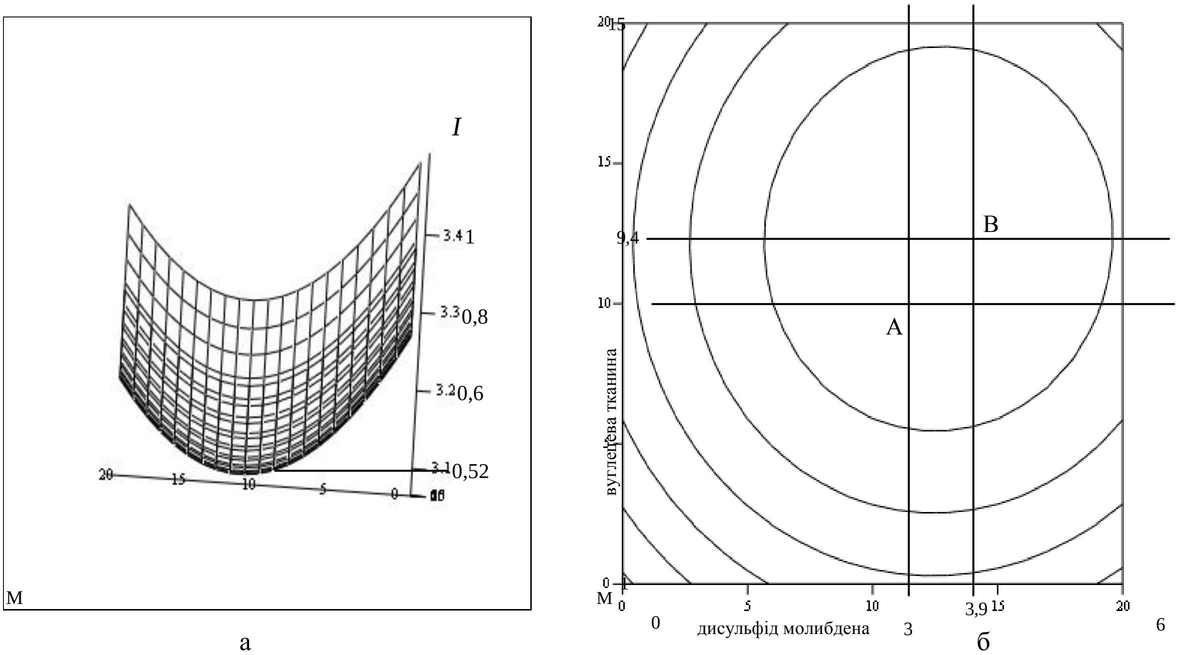


Fig. 11 - Graphical interpretation of the mathematical model of wear intensity (a) and two-dimensional section of the function f (Xi, Yi, Zi) at Zk = 0.

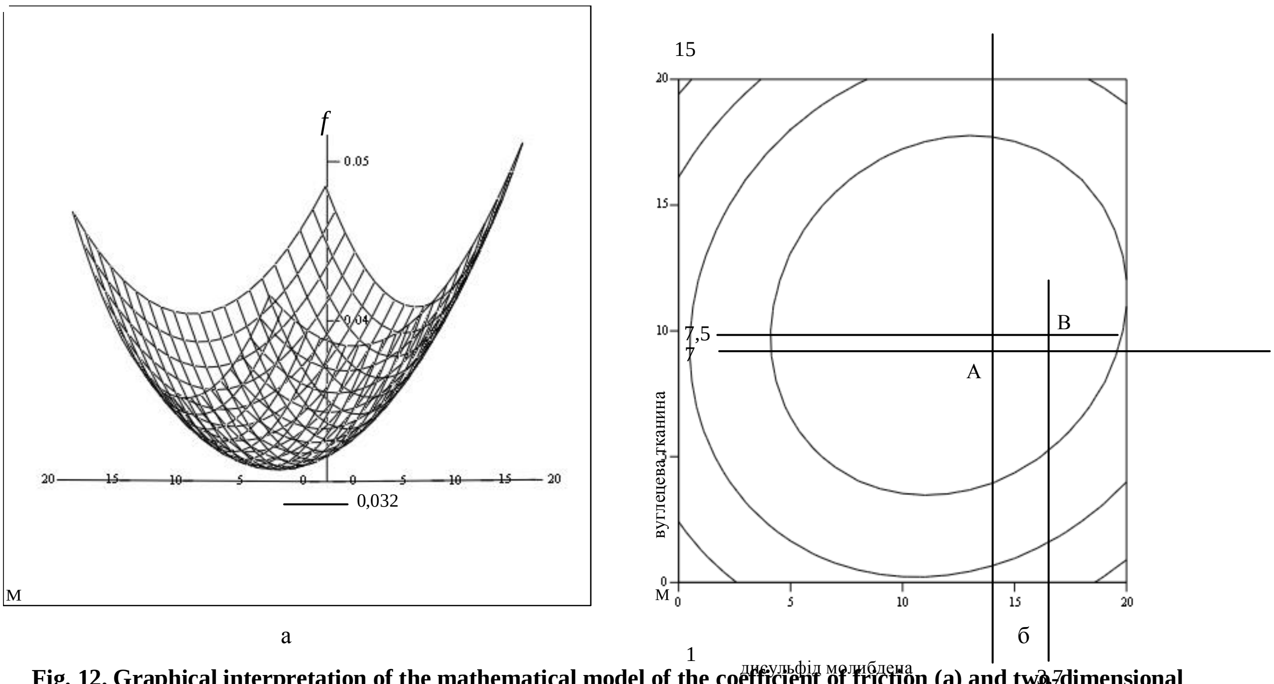


Fig. 12. Graphical interpretation of the mathematical model of the coefficient of friction (a) and two-dimensional section (b) of the function f (X1, Y1, Z1) at Zк = 0

Figure 13 shows the thrust bearings of electric submersible pumps.

Fig.13. Billets for the thrust of the electric motor of the pump.

Technical characteristics of the optimal composition for thrust bearings are presented in table 3.

Table 3

Characteristics of antifriction material

Properties of the composition	Parameters
Density, kg / m3	3600-3700
Thermal conductivity, W / mK	0,80-1,02
Coefficient of friction	0,02-0,09
Operating temperature, 0C	від -60 до +250
Maximum specific load, MPa	від 1 до 8

Conclusions

1. Based on the analysis of the literature data, the target fillers are selected to create antifriction compositions for radial plain bearings and thrust bearings for submersible pumps.

2. The obtained regression equations that adequately describe the process of wear of the polymer coating and the counterbody. It was found that a mixture of colloidal graphite CI and carbon fabric helps to reduce wear

polymer coating, and powder polyamide 12 APN-B has a stronger effect on reducing the wear of the counterbody. The effect of molybdenum disulfide on the wear of the coating and the counterbody is equivalent.

3. The obtained equations, which allowed to graphically represent the surface of the equal response of the wear process of the polymer composition for plain bearings of electric submersible pumps, which determined the optimum zone of antifriction fillers:

a) a mixture of colloidal graphite Cl and carbon fabric THN-2M 9.5%

b) molybdenum disulfide DM-1 2.9%

c) powder polyamide 12 APN-B 8.6%

d) crushed prepreg comprising a fiberglass filler,

impregnated with modified phenol-formaldehyde resin P2M the rest.

References

1. Trenie i iznos materialov na osnove polimerov. V.A.Belyj, .A.I.Sviridenok.,M.I.Petroeovec,V.G.Savkin – Minsk.:Nauka i tekhnika, 1976, 432 s.

2. Voronkov V.D.Podshipniki suhogo treniya. –L.: Mashinostroenie, 1979. – 224 s.

3. Tribotekhnicheskie svojstva antifrikcionnyh samosmazyvayushchihsya plastmass / Pod red. Salagaeva G.V., SHembel' N.L. – M.: Izdatel'stvo standartov, 1992.-64s.

4.Fel'dman D.I, Gejman YU.P., Volodarskij I.A. Antifrikcionnyj material «grafitoplast DEZ» i opyt ego primeneniya. – L., 1967.-21 s.

5. Evdokimov YU.A., Barsukov R.H. Novye antifrikcionnye polimernye kompozicii, izgotovlennye na baze epoksidnyh smol.- Rostovskoe knizhnoe izdanie, 1976. – 80 s.

6. Fel'dman D.I. Antifrikcionnyj material «Epoksilit». –L., 1966.- 16 s.

7.Gorohovskij G.A.. Primenenie polimerov dlya povysheniya protivozadirochnyh svojstv stal'nyh povekhnostej.- V kn. Trenie, smazka i iznos detalej mashin. K.,1961 s.99-107 (Trudi KIGVF, vyp. 2).

8. Dudchak V.P. Sposib vidnovlennya porshniv i antifrikcijna kompoziciya dlya jogo zdijsnennya. Pat. na vinahid Ukraïni №61442A, SO8F114/26. Zayavl. 06.02.2003. Opubl. 17.11.2003. Byul. №11.

9. Polimery v uzlah treniya mashin i priborov / Spravochnik pod red. d.t.n. A.V. CHichinadze.-M.: Mashinostroenie, 1980.-208s.

10. Sirenko G.A. Antifrikcionnye karboplastiki. .-K.: Tekhnika 1985.-195s.

11.O’Rourke J.T. Design properties of filled –TFE plastics – Machine Design, Sept. 1962.

12.Ostapenko R.M.,Ruzhilo Z.V. Dudchak T.V. ta in..« Polimerna antifrikcijna kompoziciya» Patent na korisnu model' № 136085. Byul. № 15 vid 12.08.2019.

13.Dudchak V.P., Ostapenko R.M., Dudchak T.V. Sposib oderzhannya poristoï antifrikcijnoï kompoziciï na osnovi ftoroplastu Patent na korisnu model' № 82868. Byul №16 vid 27.08.2013.

14.Dudchak V.P., Duganec V.I., Ostapenko R.M., Dudchak T.V. Sposib oderzhannya poristoï antifrikcijnoï kompoziciï. Patent na korisnu model' № 81028 Byul № 12 vid 25.06.2013.

15. Ostapenko R.M., Sandik A.M., Ruzhilo Z.V. ta in.. «Sposib vigotovlennya dvosharovogo dempfiruyuchogo pidshipnika kovzannya dlya elektrozagliblyuval'nih nasosiv» Patent na korisnu model' № 136454 27.08.2019.

16. Petrov YU.N., Dudchak V.P., Kolyasko I.V. Pribor dlya izmereniya momenta treniya podshipnikov skol'zheniya. A.s. №1223730 SSSR Opubl. 8.12.1985. Byul. №47.

Остапенко Р.М. Дослідження триботехнічних властивостей антифрикційних полімерних композицій

Зроблений аналіз антифрикційних полімерних композицій на основі поліамідних, епоксидних, фелолформальдегідних, фуранових смол, а також на основі фторопласту з різними наповнювачами, які працюють в вузлах тертя. Вплив наповнювачів на механізми тертя мало вивчені, тому при створенні антифрикційних композицій, здатних працювати в умовах змащення у воді, були поставлені наступні задачі: обґрунтувати кількість і тип наповнювачів; дослідити вплив наповнювачів на процес зносу матеріалу і контртіла; визначити оптимальний склад антифрикційної композиції, що забезпечує мінімальний знос покриття і контртіла.

Об'єктом дослідження були: композиції на основі фенолформальдегідної смоли і фторопласта, модифіковані антифрикційними наповнювачами; деталі заглиблювальних насосів.

Основою дослідження було вивчення триботехнічних і технологічних властивостей полімерних композицій.

На підставі аналізу літературних даних обрані цільові наповнювачі для створення антифрикційних композицій для радіальних підшипників ковзання та підп'ятників електрозаглиблювальних насосів, обґрунтовано їхню кількість і склад. Критерієм оптимізації служили масовий знос полімерного покриття і контртіла. Визначено оптимальний склад антифрикційної композиції для радіальних підшипників ковзання, який містить: суміш колоїдного графіту Cl та вуглецевої тканини «ТГН-2М»; дисульфід молібдену ДМ-1; порошковий поліамід 12 АПН-Б; подрібнений препрег, що включає скловолокнистий наповнювач, просочений модифікованою фенолформальдегідною смолою Р2М.

Для підпятників визначено оптимальний склад фторопластової композиції, який включає: фторопласт Ф4; дисульфід молібдену; вуглецеву тканину ; порошкову мідь. Представлені фізико-механічні властивості оптимальної композиції.

Розроблено технологічну оснастку для відновлення і виготовлення підшипників ковзання і підп'ятників електрозаглиблювальних насосів. Виготовлені пресформи , для промислового впровадження .

Ключові слова: підшипники ковзання, підп'ятники, заглиблювальний насос, антифрикційні наповнювачі, фторопласт, фенолформальдегідна смола, пресформа.

Problems of Tribology, V. 26, No 1/99-2021,43-50

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-43-50

Evaluation of operational properties of aviation oils by tribological parameters

O.O. Mikosianchyk, O.Ye. Yakobchuk, R. H. Mnatsakanov, A.M. Khimko

National Aviation University, Ukraine
E-mail: oksana.mikos@ukr.net

Abstract

The quality of aviation oils was evaluated online on the basis of their lubricating, antifriction, rheological and antiwear properties in the friction contact. The use of the software and hardware complex for evaluation of operational characteristics of triboelements is offered. Approbation of the proposed methodology was performed on aviation oils SM-9. The increase in antifriction properties of the "Bora B" SM-9 oil was established to be due to the formation of limiting adsorption layers of lubricant on friction-activated contact surfaces, which are characterized by low shear stresses of the lubricant, and their structuring provides high effective viscosity in the contact at a level of 5142 Pa.s. It was revealed that at start-up the lubricant temperature is 20 ^{0}C and the mixed lubrication mode prevails, but with increasing the lubricant temperature to 100 ^{0}C the elastic-hydrodynamic (contact-hydrodynamic) lubrication mode dominates, then at maximum rotation speed of friction pairs the hydrodynamic lubrication mode dominates, regardless of oil temperature, which indicates the effective separation of the contact surfaces due to the formation of a lubricating layer between them. Analysis of the specific work of friction in the friction contact showed that the instability of this parameter evidences to intensification of destructive processes in the near-surface layers of metal and reduction in its wear resistance. The decrease in wear resistance of the lagging surface in the conditions of rolling with sliding for all types of investigated oils is due to the different directions of the friction force vector in the contact. In the course of operation of friction pairs in nonstationary conditions, the softening of the surface metal layers occurs, which has a positive effect on the tribological processes in the contact.

The practical significance of the work consists in developing a methodology of analysis of lubricants, which makes it possible to more accurately evaluate their performance and provide recommendations for the choice of lubricant for specific friction units.

Key words: aviation oils, lubricating layer, antifriction properties, lubrication mode, wear, microhardness.

Introduction

The reliability of mechanical systems is laid at the design stage, provided during the manufacture and confirmed during the operation of machines and mechanisms. Lubricants significantly affect the reliability. The current requirements for the reliability of tribological systems are associated with the qualitative improvement of lubricants and their components, as a rule, on the basis of in-depth analysis of the lubricating medium and the contact metal surface under friction. Nowadays the technology for production of lubricants and their components is intensively developing and improving. New lubricants on mineral and synthetic base are created, serious developments on optimization of component composition of oils and lubricants are conducted and their physical, chemical and operational properties are improved.

First of all, yet at the design stage, the designer should be provided with a methodological base for not only selecting materials of machine parts according to strength criteria, but also for selecting lubricants, including assessment of temperature range of their operation, compatibility with friction pair materials, wear properties, bearing capacity of lubricating layer, tendency to form protective layers on the friction surfaces, etc.

Lubricants, when optimally selected for a specific technical problem, can exert a marked effect at the expense of saving energy, reducing wear and expenses for maintaining, increasing the service life of machinery and equipment, and finally, they can be a rational means of solving urgent ecological problems and environment protection [1].

Thus, the development of tools and methods for monitoring the behavior of lubricants and processes occurring in the friction contact, as well as substantiation of the criteria for their evaluation is an urgent task.

Literature review

The improvement of controlling and measuring devices and the rapid development of computer technology provide a real opportunity to study for the first time the tribological processes of formation of dissipative structures during friction at the atomic and molecular levels. For example, the SFA complex made it possible to measure film thickness to 0.1 nm and to record extremely small surface forces, which gives it significant advantages over other devices and thus allows one to use it as the main tool in the study of rheological, lubricating and antifriction properties of tribocontact at the nanolevel [2].

Modes and conditions of accelerated tests of motor oils in the engine have been proposed [3], which allow decreasing the time for evaluation of operational properties of oils by 8 times, in line with providing high reliability of the results of determination of washing-dispersing and anticarbon properties through selection and qualification tests of motor oils to be used in forced transport diesels.

Laboratory evaluation of physicochemical parameters, antiwear and antifriction properties of oils can confirm or refute the level of operational parameters declared by the manufacturer. In [4], based on analysis of data of industrial tests of G-Profi MSI Plus engine oil, it is shown that the oil has a sufficient resource of performance thanks to the balance of acid and alkali numbers along with effective viscosity, and this offers the possibility of prolongation of the service break time while replacing motor oils in line with the corresponding control of operational indicators.

Thus, one of the current topical trends in the area of introducig new lubricants in production is the development of an algorithm for qualification tests concerning determination of the level of oil operational properties. The scope of methods for evaluating the qualitative characteristics of oils should include both laboratory studies and model stands or installations.

In Ukraine, new technical specifications are being developed for a number of aviation lubricants. One of the most promising ones for production and introduction in practice is the mixture SM-9 [5] designed for use in gearboxes of helicopters in winter. It is composed of aviation oils AMG-10 and TSGip with a ratio of 1/3 to 2/3. The AMG-10 oil is produced on the basis of deeply dearomatized waxy fraction obtained from products of the hydrocracking of mixture of paraffinic oils and consisting of naphthenic and isoparaffinic hydrocarbons. It contains thickening and antioxidant additives, as well as a special organic dye. Oil for hypoid transfers TSGip belongs to the group of universal oils with antiscoring additives of high efficiency and multipurpose action. It ensures the normal operation of hypoid gears under shock loads at contact stresses above 3000 MPa and oil temperatures in the volume up to 150 °C.

As for aviation lubricants of domestic manufacturers, it is necessary to develop measures for the introduction of them in practice (stand, flight tests, operation under supervision, etc.), aimed at evaluating the operability of aircrafts using a new oil, establishing resource and application restrictions. Upon receiving positive test results at all stages, a new brand of oil can be included in the related operation instructions.

Purpose

The aim of the work is to evaluate online the quality of aviation oils taking into account their lubricating, antifriction, rheological and antiwear properties in the friction contact.

Methodology for evaluating the operational properties of oils

The study of lubricants was carried out with using a software and hardware complex (PAC) designed to evaluate the tribotechnical characteristics of triboelements [6]. PAC is a complex, which includes a friction unit, electronic unit and software "Friction", installed on a personal computer of the IBM PC type. The software unit of mathematical data processing performs calculations according to a given calculation algorithm. The created program has a separate channel for visual assessment of the kinetics of changes in the main tribological indicators of the tribocontact in the online mode.

Methods for determining the tribological characteristics of the friction unit with using PAC are as follows:

– Lubricating properties (of hydrodynamic and non-hydrodynamic components of the lubricating film thickness) are determined by the method of voltage drop in the mode of normal glow discharge. According to this technique, the voltage drop across the lubricating layer is measured at a current of 2 and 4 A, then the thickness of the lubricating layer is determined from the calibration tables.

– Antifriction properties of the contact are determined on the basis of data on the kinetics of changes in friction torque and subsequent calculation of the friction coefficient in the contact.

– Rheological characteristics of lubricants (shear rate gradient, shear stress of lubricating layers, effective viscosity in the contact) are determined from the kinetics of changes in the thickness of the lubricating layer, the rolling speed of the leading and lagging surfaces and the lubricating layer temperature [7].

– Determination of the specific work of friction in the contact (through integrating the area outlined by the friction moment curve and choosing an arbitrary range of integration along on the x-axis at a certain selected time of operation, taking into account the kinetic energy of rotating parts).

– Strength characteristics of the contact metal surfaces are determined according to GOST 22162-76 (Method for determining the microhardness).

Antiwear properties of lubricants are determined by measuring the indentation made by pressing the indenter of the device PMT-3 (GOST 27860-88. Parts of friction unit. Methods for measuring wear).

Objects of research and experimental conditions

Objects. Lubricants: sample 1 - oil "Bora B" SM-9 (TU U 19.2-38474081-017: 2018 with change 1 "Transmission oils" Bora B ") and sample 2 – Kvalitet-Avia aviation oil mixture SM-9 (TU 0253-001-49878493-2005 with changes 1-13).

Material of friction pairs: rollers from steel 40ChN (analog of steel 3130H (USA), 1.5710 (Germany), 40CrNi (China)), HRC 38, Ra 0.34 μm. Lubrication of the contact surfaces was provided through immersing the lower roller in the lubricant bath.

Experimental conditions. Friction mode: nonstationary conditions – cyclic operation in the start-up mode – stationary operation – braking – stop (Fig. 1).

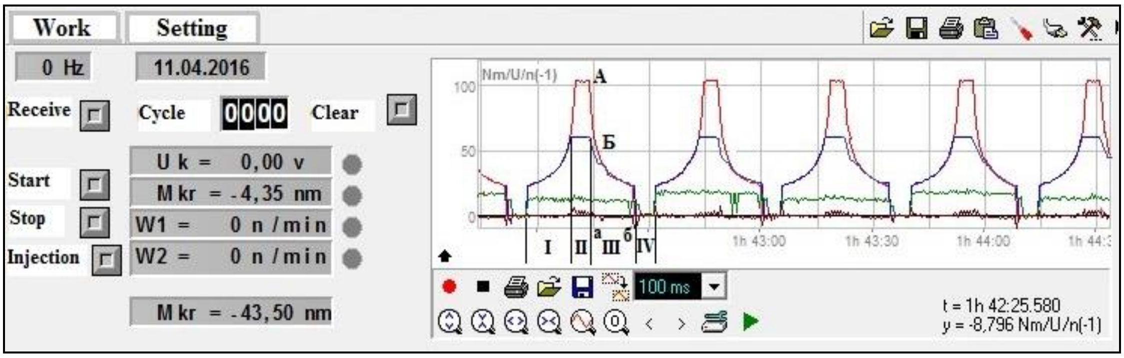


Fig. 1. Schematic representation of tribosystem operation in nonstationary conditions of friction. Areas: I - start; II - stationary work; III - braking; IV - stop.

Maximum rotation speed: 700 rpm for the leading surface and 500 rpm for the lagging surface. Sliding 30%. Friction path for one cycle: 91.845 m for the leading surface and 62.8 m for the lagging surface. Total friction path: 9184.5 m for the leading surface and 6280 m for the lagging surface. The maximum contact load by Hertz: 200 MPa.s . Number of cycles: 100 cycles. Oil temperature: 20 ^{0}C from the 1st to the 45th cycle; heating in the 20-100 ^{0}C range from the 46th to the 50th cycle; 100 ^{0}C from the 51st to the 100th cycle. The duration of the cycle: 80 s.

Results

Let us analyze the kinetics of changes in the tribotechnical parameters of aviation oils in the course of operation in nonstationary friction conditions.

Samples 1 and 2 are characterized by high antifriction properties in the investigated temperature range (Fig. 2). For sample 1, the average friction coefficient is 0.0183, regardless of the lubricant temperature, the friction coefficient is stable, the range of its oscillations is within 0.015…0.026. The increase in the friction coefficient through 58 - 60 cycles is due to the change in the nature of boundary layers with increasing lubricant temperature. For sample 2, the average friction coefficient is 0.0147, regardless of the lubricant temperature; the friction coefficient is unstable, the range of its oscillations is within 0.009…0.034. The established periodic increase/decrease in the friction coefficient during operation indicates the instability of tribotechnical processes in the friction contact.

Let us compare the kinetics of changes in the lubricating properties of aviation oils in the tribological contact.

The investigated oil "Bora B" SM-9 (sample 1) is characterized by effective lubricating properties both at start-up and at the maximum revolutions studied (Fig. 3). With increasing temperature in the tribological contact, the adsorption layer thickness decreases due to changes in their nature: the boundary layers of mostly physical nature are replaced by boundary layers of chemical nature, which are characterized by more effective antiwear properties. No failure of the lubricating layer during start-up and direct metal contact of the friction surfaces was fixed. At start-up, the lubricant temperature was 20 ^{0}C and the mixed lubrication mode prevailed. With increasing the lubricant temperature to 100 ^{0}C the elastohydrodynamic (contact-hydrodynamic) lubrication mode dominated, which testifies to the effective starting properties of “Bora B” SM-9 oil. At maximum speeds of the samples, the hydrodynamic mode of lubrication dominated, regardless of the oil temperature, which indicates the evident separation of the contact surfaces due to the formation of a lubricating layer.

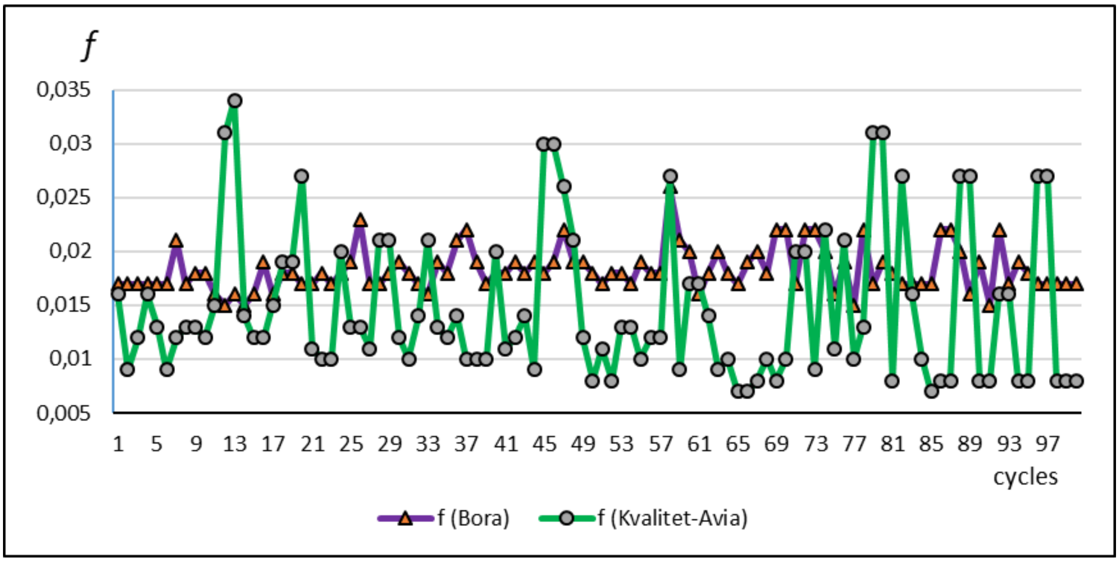


Fig. 2. The kinetics of change in the friction coefficient

Kvalitet-Avia oil mixture SM-9 (sample 2) is characterized by effective lubricating properties at the maximum studied speeds, providing a hydrodynamic mode of lubrication. The total thickness of the lubricating layer for sample 2, on average, is 1.32 times less than that of sample 1 (Fig. 3). At start-up, instability of lubrication is revealed, 20% of cycles demonstrate a dry-semidry mode of lubrication, related to the long period of formation and adaptation of the lubricant boundary layers to nonstationary friction conditions.

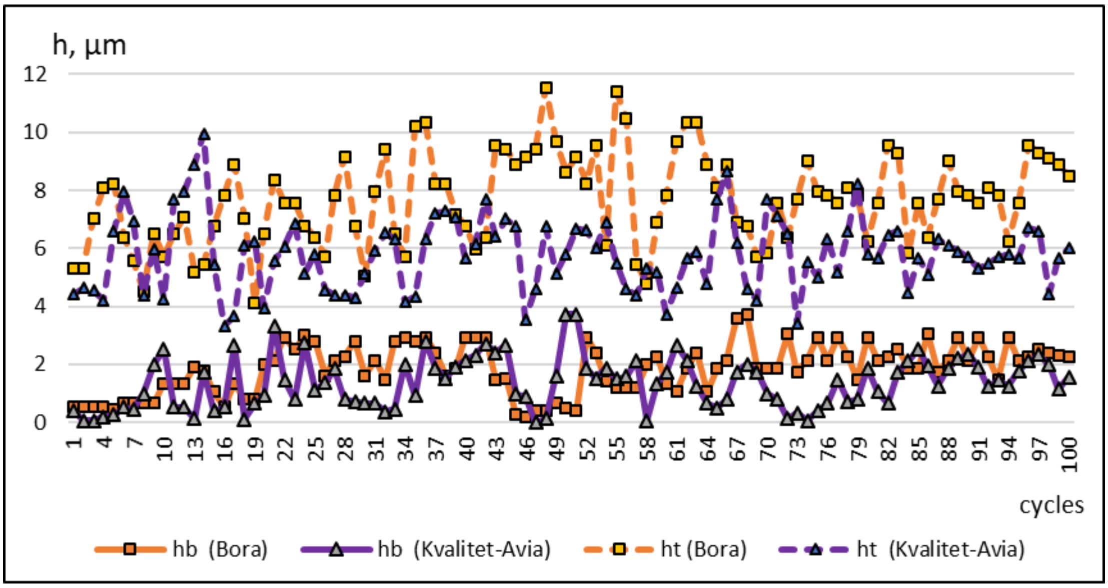


Fig. 3. Kinetics of change in the thickness of the boundary adsorption layers (h_b) and the total thickness of the lubricating layer (h_t) in the course of operation.

Since oils are used in helicopter transmission reducers, characterized by large contact loads and shear rate gradients, it is reasonable to analyze the rheological parameters of lubricants.

The oil “Bora B” SM-9 (sample 1) is characterized by efficient rheological properties. With it, the hydrodynamic mode of lubrication at maximum speeds of the cycle in the conditions of rolling with 30% sliding is provided owing to the high bearing capacity of the lubricant and the formation of hydro- and non-hydrodynamic components of the lubricating layer thickness, which are characterized by low shear stresses equal to 13.89 MPa with a range of divergences within 10.91…18.85 MPa.

Despite high rotation speed gradients in the contact, from $1.99.10^3$ to $2.26.10^5$ s^{-1}, which arise at a maximum sliding velocity of 0.71 m/s in the conditions of rolling with sliding, the lubricant is characterized by high effective viscosity, on average 5142 Pa·s (Fig. 4). This indicates a high resistance of the oil components to destruction due to increasing shear rate gradient. The greatest decrease in the effective viscosity in the contact down to 378...914 Pa·s occurs at the beginning of increasing oil temperature, i.e., during 45 - 50 test cycles. This is caused by change in the nature of the boundary adsorption levels, characterized by effective adaptation in a wide range of temperatures.

Different changes in the rheological parameters in nonstationary lubrication conditions were established for the Kvalitet-Avia oil mixture of SM-9 (sample 2). First, the average shear stress of the lubricating layer is 1.27 times less than in sample 1 and equals 10.98 MPa. However, a wide range of discrepancies were revealed in the range of 5.19… .29.38 MPa for this lubricant, which is due to the long-term adaptation of the lubricant boundary layers to high shear rate gradients in the conditions of rolling with 30% sliding, which reach $1.17 \cdot 10^3$ to $7.2 \cdot 10^5$ s^{-1}. There is observed periodic destruction of the boundary layers in the friction contact during operation, which indicates a decrease in their antiwear properties.

Second, the low tendency to structurization of the lubricant components on the friction-activated metal surface leads to a less pronounced dependence of the effective viscosity of the oil on the shear rate gradient: the average is at the level of 500 Pa·s. When the oil temperature increases to 100 ^{0}C, the effective viscosity first decreases to 80 Pa·s, but with further operation of friction pairs increases to 600 - 800 Pa·s (Fig. 4).

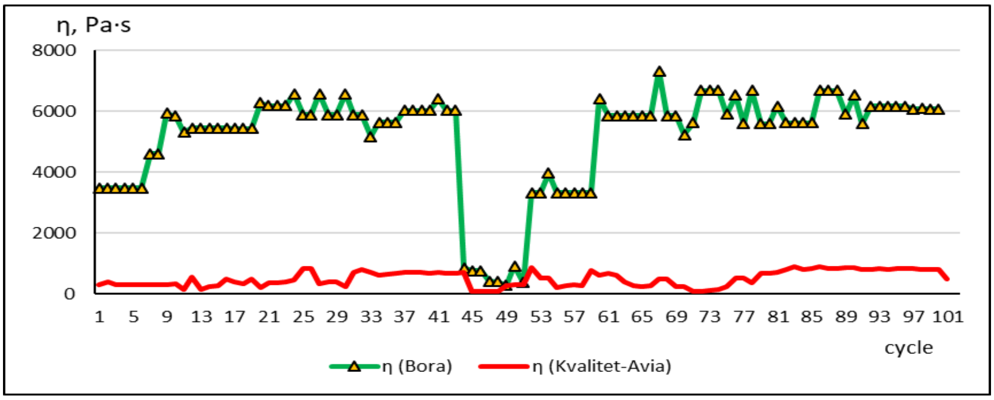


Fig. 4. The kinetics of change in the effective viscosity of oil (η) n the contact

An important operational parameter of the tribosystem is the energy load on the friction contact, which can be evaluated from the kinetics of changes in the specific work of friction, A_{fr}. It depends on the type of lubricant, contact surface material and operation conditions of the tribosystem.

The obtained experimental values of A_{fr} for sample 1 in the range 1186…6328 J/mm^2 indicate the normal operation conditions of the tribosystem (Fig. 5). With increasing oil temperature from 20 to 100 ^{0}C, the specific work of friction increases, on average, by 1.6 times, which indicates transition of the tribosystem to more complex conditions of friction. However, the investigated lubricant in such conditions provides realization of the hydrodynamic mode of lubrication in the contact and high wear resistance for the metal.

For sample 2, more intense energetic processes in the friction contact were established. The specific work of friction is unstable and characterized by a wide range of oscillations in the range of 1300…33430 J/mm^2, regardless of the lubricant temperature. The failure to achieve a metastable state of the tribosystem in terms of energy can lead to intensification of destructive processes in the surface layers of the metal and reduction in its wear resistance.

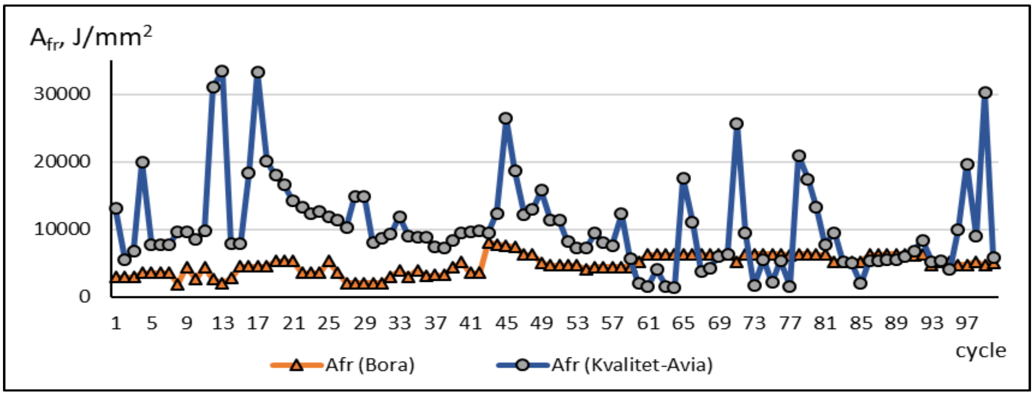


Fig. 5. Kinetics of changes in the specific work of friction in the course of operation

One of the most important characteristics of oils during operation is their antiwear properties, so the establishment of regularities of friction pair wear will make it possible to predict its durability and reliability.

The total linear wear of the 40ChN steel rollers upon lubricating the friction pairs with oil is 4.9 µm and 5.74 µm for samples 1 and 2, respectively (Fig. 6). The wear of the lagging surface is 2.38 (sample 1) and 1.9 (sample 2) times greater than that of the leading surface, which is due, by the K.T. Trubina theory [8], to reducing the endurance limit of the lagging surface because of the increase in the rate of fatigue destruction in conditions of different directions of friction forces in the contact on the leading and lagging surfaces.

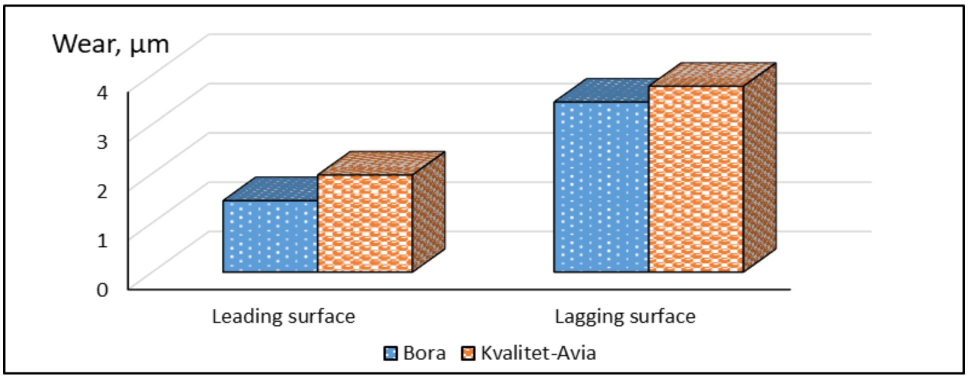


Fig. 6. Wear of contact surfaces in the course of operation

The wear intensity of both the leading and lagging surfaces is characterized by low values, which indicates high wear resistance of the contact surfaces and effective antiwear characteristics of the oils studied (Table 1). In the case of lubrication of friction pairs with sample 2, the wear intensity of the leading and lagging surfaces increases by 1.36 and 1.09 times, respectively, compared with sample 1.

Table 1

Antiwear characteristics of aviation oils

Indicator	Lubricant material			
	Sample 1 Oil «Bora B» SM-9		Sample 2 Kvalitet-Avia oil mixture SM-9	
	Wear of contact surfaces (steel 40ChN) after 100 cycles			
Total linear wear of the samples studied, µm	4.9		5.74	
	Leading surface	Lagging surface	Leading surface	Lagging surface
Wear, µm	1.45	3.45	1.97	3.77
Wear intensity	$1.57875 \cdot 10^{-10}$	$5.49363 \cdot 10^{-10}$	$2.14492 \cdot 10^{-10}$	$6.00318 \cdot 10^{-10}$
Wear resistance	$6.33 \cdot 10^{9}$	$1.82 \cdot 10^{9}$	$4.66 \cdot 10^{9}$	$1.67 \cdot 10^{9}$
	Microhardness of the samples (steel 40ChN)			
Microhardness of surface before experiment , MPa	4377	4590	4310	4658
Microhardness of surface after 100 cycles, MPa	2764	2758	3118	2914

Since the lubricant components affect the near-surface layers of the metal by modifying them during friction, the strength characteristics of contact surfaces were evaluated. The reduction of microhardness of steel 40ChN after 100 cycles was determined to be by 1.58 and 1.66 times for the leading and lagging surfaces, respectively, in the case of lubricating with sample 1; and by 1.38 and 1.6 times for the leading and lagging surfaces, respectively, in the case of lubricating with sample 2. The hardening of metal surface layers is due to the manifestation of the Rebinder effect, i.e., adsorption plasticization of solids under the action of oil surfactants. The thickness of the plasticized layer can be up to 0.1 µm. This phenomenon exerts a positive effect on tribological processes in the contact as it reduces the surface energy due to adsorption of the active components of the oil additive and formation of boundary adsorption layers of both physical and chemical nature. This leads to increased wear resistance of the contact surfaces at the expense of reducing the resistance of the surface layer of the solid body to plastic deformation, facilitating plastic shear in the grains and the emergence of dislocations as well as forming finer granular structure.

Conclusions

A methodology for evaluating the operational properties of aviation oils taking into account their lubricating, antifriction, rheological and antiwear properties in the friction contact in the online mode has been developed. Based on studies of tribological characteristics of aviation oils, it was found that the oil "Bora B" SM-9 is characterized by more effective lubricating, antifriction, antiwear and rheological characteristics in nonstationary conditions of friction in the mode of rolling with 30% sliding compared with the aviation oil mixture SM -9. In particular, a comprehensive evaluation of tribological parameters of oil "Bora B" SM-9 showed the stability of the friction coefficient in the start-stop mode, formation of boundary adsorption layers of lubricant on friction-activated contact surfaces, dominance of hydrodynamic lubrication at maximum speed, high effective viscosity in the contact at low shear stresses of the oil layer and low wear intensity of friction pairs, which allows one to more accurately evaluate its operational characteristics. This, in turn, makes it possible to more accurately evaluate the quality of the oil and provide recommendations for the choice of lubricant for specific friction units.

References

1 Singh Y., Singh P., Sharma A., Choudhary P., Singla A., Singh N. (2018) Optimization of wear and friction characteristics of Phyllanthus Emblica seed oil based lubricant using response surface methodology. Egyptian Journal of Petroleum, 27 (4), 1145-1155.

2. Israelachvili J. N. (2011) Intermolecular and surface forces, 3-rd ed., USA: Academic Press, 674.

3. Bychkov V.Z., Hrytsiuk A.V., Zaitsev A.V., Klimenko N.V., Shcherbanenko G.V. (2005) Metod uskorennoy otsenki moyushchikh i antinagarnykh svoystv motornykh masel v dvukhtaktnom forsirovannom dizelnom dvigatele [Method for accelerated evaluation of the detergent and antinagar properties of engine oils in a two-stroke forced diesel engine]. Dvigateli vnutrennego sgoraniya, 1, 118-121.

4. Korneev S.V., Pashukevich S.V., Savoskin A.S., Shirlin I.I. (2017) Izmeneniye kharakteristik motornogo masla pri ekspluatatsii dvigateley cummins avtobusnogo parka g. Omska [Change in the characteriistics of the engine oil during operation of the cummins engines of bus fleet in the city of Omsk]. Vestnik SibADI, 2 (54), 66-69.

5. https://bora.in.ua/ukraine_import/aviamasla/tsgip.html

6. Mikosianchyk O.O. (2013) Patent 88748, Ukraine, IPC G01N 3/56. Prystrii dlia otsinky trybotekhnichnykh kharakterystyk triboelementiv [Device for estimating tribological characteristics of triboelements], 6, 4.

7. Mikosianchyk O.O., Mnatsakanov R.G., Kindrachuk M.V. (2013) Patent 89261, Ukraine, IPC G01N 11/00. Sposib otsinky dynamichnoi efektyvnosti vyazkosti mastylnykh materialiv v trybotekhnichnomu kontakti [Method for estimating dynamic efficiency of viscosity of lubricants in tribotechnical contact], 7, 4.

8. Kurapov P.A., Novikov V.S., Efros D.G., Fedosh D.A. (2016) O mehanizme iznashivanija zubchatyh koles reduktornyh sistem gazoturbinnyh dvigatelej [On the wear mechanism of gear wheels of reduction systems of gas turbine engines]. Tribologiya – mashinostroyeniyu: Trudy XI mezhdunarodnoy nauchno-tekhnicheskoy konferentsii — Moscow: Institute for Computer Research, 137-138.

Мікосянчик О.О., Якобчук О.Є., Мнацаканов Р.Г., Хімко А.М. Оцінка експлуатаційних властивостей авіаційних олив за триботехнічними параметрами

Проведена оцінка якості авіаційних олив з урахуванням їх змащувальних, антифрикційних, реологічних та протизношувальних властивостей в фрикційному контакті в режимі on-line. Запропоновано застосування програмно-апаратного комплексу для оцінки експлуатаційних характеристик трибоелементів. Апробація методики проведена на авіаційних оливах СМ-9. Встановлено підвищення антифрикційних властивостей оливи «Бора Б» СМ-9 за рахунок формування граничних адсорбційних шарів мастильного матеріалу на активованих тертям контактних поверхнях, які характеризуються низькими напруженнями зсуву мастильного шару, а їх структуризація забезпечує високу ефективну в'язкість в контакті на рівні 5142 Па·с. Проаналізовано, що при пуску, температура мастильного матеріалу 20 0С, переважає змішаний режим мащення, при зростанні температури мастильного матеріалу до 100 0С домінує еластогідродинамічний (контактно-гідродинамічний) режим мащення, при максимальних обертах пар тертя домінує гідродинамічний режим мащення, незалежно від температури оливи, що свідчить про ефективне розділення контактних поверхонь внаслідок утворення мастильного шару між контактуючими поверхнями. Аналіз питомої роботи тертя в фрикційному контакті показав, що нестабільність даного параметру свідчить про інтенсифікацію деструкційних процесів в приповерхневих шарах металу та зниження його зносостійкості. Встановлено зниження зносостійкості відстаючої поверхні в умовах кочення з проковзуванням для всіх типів досліджуваних олив, що обумовлено різновекторною направленістю сил тертя в контакті. При напрацюванні пар тертя в нестаціонарних умовах встановлено знеміцнення поверхневих шарів металу, що позитивно впливає на триботехнічні процеси в контакті.

Практичне значення роботи полягає в розробленні методики аналізу мастильних матеріалів, що дозволяє більш точно оцінити їх експлуатаційні характеристики та надати рекомендації щодо вибору мастильного матеріалу для конкретних вузлів тертя.

Ключові слова: авіаційні оливи, змащувальний шар, антифрикційні властивості, режим мащення, знос, мікротвердість

Problems of Tribology, V. 26, No 1/99-2021,51-58

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-51-58

Creation of theoretical bases of tribotechnologies of running-in and restoration as means of effective increase of operational wear resistance of motor transport and mobile agricultural machinery

V.V. Aulin, S.V. Lysenko, A.V. Hrinkiv, V.V. Slon, A.E. Chernai

Central Ukrainian National Technical University, Ukraine
E-mail: AulinVV@gmail.com

Abstract

The bases for creation of theoretical bases of tribotechnologies of running-in and restoration of conjugations of details of systems and units of motor transport and mobile agricultural machinery are defined.

The specifics of selective transfer on the surface of contacting parts of machines and creation of servito films, formation of coatings during running-in and restoration from antifriction materials, which are a part of additives in motor and transmission oil, are considered.

A number of tribophysicochemical processes that occur in the conjugations of parts materials and how they affect the creation of tribotechnologies of running-in and restoration are clarified. The creation of tribotechnologies using geomodifiers is considered. It is proposed to build a single theory of tribotechnologies of running-in and recovery on the basis of the mechanism of triboplasm formation in the conjugations of parts of systems and units of machines. It is also proposed to add to this the thermofluctuation theory of S.M. Zhurkova taking into account the change of dilaton and compression bonds of atoms of materials of tribocouples of details with creation of local areas of deformations of compression and tension and zones of thermoplastic deformation.

Key words: tribotechnologies of running-in and restoration, conjugation of details, triboplasm, oil, additive, motor vehicles, mobile agricultural machinery

Introduction

Recently, most consumers of motor transport (MTM) and mobile agricultural machinery (MACM) are insufficiently informed about the achievements of tribology in issues: modern quality and tribological properties of motor and transmission oils, special means of improving them and the possibilities of tribotechnologies of running and recovery. To some extent, this is due to the lack of training of engineering and technical staff and consumers for the perception of new advances in the science of friction, wear and lubrication in machines.

One of the most interesting drugs of modern car chemistry used in practice are complexes of triple compounds (additives) designed to reduce the effects of friction, wear intensity and renovation of couplings of engine parts and transmissions of motor and mobile agricultural machinery.

The vast majority of manufacturers of motor and transmission oils in relation to these triplets, are usually negative. Due to the fact that, in their opinion, modern lubricants already contain all the necessary package of functional additives, and the introduction of additional components in them is not only undesirable, but possibly harmful, due to the imbalance of properties.

However, experience and research [1,2] show that functional additives and additives determine the operation of the conjugations of parts in normal conditions, mainly hydrodynamic friction and in no way take into account the real state of their working surfaces. Note also that they work the same for both new and worn couplings of engine parts and transmissions. At the same time, the lubrication conditions for different stages of operation of motor vehicles and mobile agricultural machinery differ significantly. Wear of friction surfaces during operation makes individual differences in the operation of each triad of parts of systems and units of machines, and therefore when developing tribotechnologies of running-in and restoration it is necessary to take into account the dynamics of changes in characteristics and properties of oils with additives and additives. Note that their condition, operating conditions at different stages of the life cycle and the condition of the working surfaces of the parts changes significantly. The solution to this problem and the problems that arise from it are certainly relevant.

Literature review

Any triad coupling of parts of MTM and MACM systems and units in the simplest embodiment is three components, two of which are conjugate friction surfaces of parts, the third is a film of lubricant or lubricating medium that separates these surfaces [3,4]. Packages of additives in oils determine the properties of only the third component - the oil film, with virtually no effect on the properties of work surfaces and materials of the other two [1,5]. In recent years, tribologists are actively searching for additives or catalysts that synthesize in the oil and form films on the friction surface of the conjugation of parts of systems and units of machines.

The results of research show that the acquired average characteristics and properties of oils are not enough to fully protect the reliable and efficient operation of triad couplings of parts of systems and units and MTM and MACM in general. Accordingly, in some cases, it is still recommended to add additives to the engine and transmission oil [5,6]. This is not the only way to increase the operational reliability of machines, because from an economic point of view it is justified that first of all it is necessary to change not the characteristics and properties of oil, but the characteristics and properties of working surfaces MTM and MACM.

Processing of tribocouples of parts by tribocomposition of composite additives changes the characteristics and properties of working surfaces of parts: roughness, friction coefficient, wear intensity, burr force, hardness, microgeometry, gaps between the couplings and others.

Properly designed and competently developed technology for processing the couplings of engine parts and transmission triboskladom and created composite oil can significantly improve the tribotechnical characteristics of the couplings of parts of systems and units in any mode of their operation. However, as studies have shown [7,8], the greatest effect is achieved in those modes where the most likely to violate the standard modes of lubrication of the tribocouple parts. This is observed at rated loads, high load modes and low speeds. Due to the fact that in these modes the hydrodynamics of tribocouples of parts of systems and units of machines is disturbed, the work of standard packages of lubricants and additives is inefficient, and the condition of working surfaces becomes decisive for power losses and wear of engine and transmission parts [9,10] .

However, the situation is far from clear, as currently on the market of autochemicals there are many different functional additives and additives to oils, different mechanisms of action. Incompetent use of these drugs can not only dramatically reduce the positive effect, but also lead to significant negative consequences.

At the same time, it is important to ask at what stage of operation the engine and transmission oil should be treated with one or another triad of substances. The vast majority of car owners in the process of operation bring the coupling of engine parts and transmission to a working condition, and then try to resuscitate it by using tribotechnologies running and recovery [11,12]. In some cases, it is possible to partially restore the size of the parts, but their shape, initial surface hardness, elasticity of the piston rings, the shape of the profile of the side surface of the piston can not be reproduced [1,14-16].

According to the results of studies [15,17-20] related to the introduction of tribotechnologies of running-in and recovery, the best effect can be achieved with an average degree (up to 50%) of wear and tear of engines and transmissions of motor vehicles and mobile agricultural machinery. In practice, engines whose oils are treated with a tribocomposition of additives before running-in, or in the process of running-in have 3 times more service life and no breakdowns, in contrast to untreated motor oil [1,21-23].

Thus, the use of a triad of additives and additives in engine and transmission oils can be an effective way to influence the operational reliability of MTM and MACM, and, in particular, their power units and transmissions.

Purpose

The aim of this work is from the tribophysicochemical and tribofluctuation points of view to theoretically substantiate the impact of processes occurring in the friction zone of parts, on increasing operational durability and reliability of motor and mobile agricultural machinery by changing the characteristics and properties of their working surfaces. in tribotechnologies of running-in and restoration.

Results

In the development of tribotechnologies of running-in and restoration of resource-determining conjugations of machines, a single class of antifriction additives has been sufficiently studied. This class of additives is based on the discovery of № 41 of September 13, 1966. The effect of selective friction transfer ("Effect of wear". The authors of the discovery are Ph.D., Professor D.N. Garkunov and Ph.D., Professor V.I. Kragelsky. When rubbing copper alloys on steel in limit lubrication, which eliminates the oxidation of copper, there is a phenomenon of selective transfer of copper from a solid solution of copper alloy to steel and its reverse transfer from steel to copper alloy, accompanied by a decrease in friction to the characteristic value when working in a liquid medium and leads to significant wear triad couplings of details.

As a result of the sampling process, tribological, physical and chemical processes take place on the surface of the contacting parts, which lead to the formation of a protective servo film, which cannot be destroyed by friction, because it creates it. The discovery of selective friction transfer in triad couplings of machine parts allowed to develop a number of fundamentally new materials of functional additives and additives to motor and transmission oils and tribotechnologies, which are widely used to significantly reduce running time and increase the service life of triad couplings of parts, systems and units.

The results of the study indicate that the formation of protective servito films can occur in the conjugations of parts whose materials do not contain copper or other plastic alloys. To do this, the necessary components of additives and additives are introduced into the lubricant. This principle underlies the development of metal-plating additives and tribotechnologies of running-in and restoration [24]. In the development of tribotechnologies of reduction, the composition of metal-plating additives mostly includes *Cu* - copper, *Zn* - zinc, *Ni* - nickel, *Sn* - tin, *Ag* - silver, *CuSn* - bronze, *CuZn* - brass. These metals and alloys with a dispersion of about 100 nm should be placed in a special liquid composition - an organic complexing agent.

Theoretical bases of creation and functioning of tribotechnologies of running-in and restoration in the final version are not created. In the implementation of such technologies, the formation of antifriction film occurs in the conditions of shear and plastic deformations, high specific loads and temperatures. The film formed under the conditions has special properties: a large degree of porosity of the working surface of the parts, the parameter of the crystal lattice of the film material is different from the parameter of the lattice of the base metal of the part.

Since during normal friction the parts are in contact on a very small area, which is 0.01...0.0001 of the area of the conjugate surfaces, the contact areas have high concentrations of mechanical stresses, which causes intense wear. When metal-clad additives are introduced into the lubricant, a servolite film is formed from nanometric metal clusters. Based on the metal-plating additive with a particle size less than 100 nm, charged particles or micelles are formed in the lubricant. The direction of movement of micelles in the lubricant is due to the potential difference that occurs in the triad couplings of parts during their operation. At the initial moment of contact, when the metal particles are positively charged, the destruction of micelles occurs on one surface of the part. Then there is a recharge, and a similar process takes place on another surface of the conjugate part or sample. Charged particles are transferred to the contact micro-irregularities of the roughness of the working surface of the part, and then there is a filling and depressions of micro-irregularities. The described process continues until the formation of friction on both surfaces of the servo film with a thickness of 1… 3 μm, after which the transfer process is stopped and the passivation mode occurs. The thickness of the formed servo film corresponds to the sizes of microroughnesses (or overlaps them) of the majority of details of motor transport and mobile agricultural machinery.

This is the theoretical tribophysical and experimental basis for the creation and application of tribotechnologies of running-in and restoration of conjugated parts of systems and units of machines. During selective transfer, the friction process is carried out through a plastically deformed soft and thin layer of metal. In this case, the area of actual contact increases by 10-100 times, and the material of the parts experiences only elastic deformations. In addition to increasing the actual contact area, thin films of antifriction material themselves reduce the friction between the solid tangential surfaces and the coefficient of friction becomes close to the coefficient of liquid friction. The metal-plating servo film formed in the contact zone is a nanoobject and behaves like a newtonian fluid under tensile and compressive conditions and, as a result, becomes unbearable and superficial [1,2,24].

It was found that when using a tribocomposite material - geomodifier [25] (additives KGMF-1) in the developed tribotechnology we obtain the following:

– increases the compression of the engine by 0.2-0.5 MPa;
– reduced consumption of engine oil for burnout in 1.0-1.5 times;
– reduced fuel consumption per 100 km;
– the content of CO and CH in the exhaust gases decreases by 1.5-2.0 times;
– increases the resource and operational reliability of engines and transmissions of machines;
– noise and vibrations in MTM and MACM systems and units are reduced;
– operating temperatures in the friction zone of resource-determining couplings of engine parts and transmissions are reduced.

When creating tribotechnologies use tribophysicochemical processes occurring in the composite oil and its interaction with the working surface of the conjugation of parts. However, it should be noted the lack of a strict unified theory, which would theoretically from a tribophysical point of view would justify complex and diverse tribophysicochemical phenomena and processes caused by the interaction between additive particles or components of geomodifiers, with oil and working surfaces. The most appropriate is a model approach using the percussion mechanism of interaction. Based on this approach, it is possible to identify a complex combination of deformation-structural, thermal, electromagnetic, optical and chemical processes. These include the occurrence and migration of defects in the structure of the materials of the parts, their amorphization and rapid local heating at the point of contact. At the same time, chemical bonds are broken during the formation of a fresh surface, and short-lived active centers are formed on it. To the full picture of the phenomena should be added the emission of electrons, photons, ions and the emergence of electrostatic charge.

The only theory that can explain the formation of films on the friction surfaces of tribocouples of parts is a model representation of the mechanism of triboplasm formation. The power of analogies and model representation of phenomena and processes observed at nano-, micro-, meso- and macro-levels are also used. The interaction of the conjugations of the parts during operation and grinding of the particles of the components of the geomodifier of the additive material, leads to the concentration of energy in the microlocal surface area of the contacting parts. As a result, the formation of a thin layer of melt is possible for short periods of time, and even the transition of the substance to a high-energy state similar to the plasma state is observed [26].

In addition, the thermofluctuation theory of S.M. Zhurkova [24]. The state of the working surface of the conjugations of parts is also formed under the influence of changes in the dilaton and compression bonds of atoms of materials in their local regions. The transition of materials in the contact zone from nonequilibrium to equilibrium, the formation of nano-, micro-, meso- and macro-destruction depends on the acquisition of electromagnetic dipoles of local areas of dilaton or compression connections between them and their mutual transition. In solid state physics, this is due to the parallelism and antiparallelism of the spins and the creation of local areas of tensile or compressive strain.

These issues in tribotechnologies of running-in and recovery require careful study.

Since the process of friction is a set of a large number of acts of mechanical interaction of micro-irregularities of conjugate surfaces of parts, the protrusions of micro-contacts that slide towards each other are in a state of impact – elastic or plastic. This interaction occurs during 10^{-7}-10^{-8}s, during which a lot of energy is supplied to the tribocontact. The area of local heating is on average 10^{-2}-10^{-4} cm^2, and the duration of formation and existence of triboplasma is of the order of 10^{-5}-10^{3} s.

This makes it possible to explain most of the phenomena that accompany the tribochemical activation of materials in the contact zone. The model of the plasma state of the tribocontact of parts, the energy released during loading on the materials of the tribocouples of parts, shows that it can significantly exceed the heat of fusion and due to low thermal conductivity leads not only to melting but also to sublimation. The substance is in the contact zone in the form of ions and electrons, ie there is a plasma state.

It is established that for the conditions of realization of tribo technologies of running-in and restoration the laws of classical thermodynamics are not fulfilled, and characteristics and properties of material of a thin surface layer of details essentially change, because of formation in a zone of friction of triboplasm. The process of its creation is accompanied by the emission of electrons, which from the friction surface is directed into the lubricant, in which there is a certain catalyst for antifriction films in the form of certain components of the geomodifier.

Electrons, colliding with atoms of lubricant and atoms of matter components of the geomodifier introduced as a catalyst for the formation of films convert them. The ionic decay of the catalyst structure of the components is observed. This process triggers a mechanism, the end result of which is the formation on the friction surfaces of the conjugations of the parts of the protective films, consisting of wear products of the starting materials of tribochemical reactions and a modified form of carbon. The consequence of the above processes is the selective adsorption of carbon ions, which build a crystal lattice of the solid phase on the metal surface of the parts under the action of cohesive forces. Note that due to the peculiarities of the triggered mechanisms, the catalyst for protective films and coatings is equally effective for surfaces of ferrous and nonferrous metals.

The observed plasma state of the surface layers of the conjugations of the parts emits triboplasm in their sliding contact. This is caused by frictional heating or high energy formed in the deformed layer by the sliding contact. In addition, the intensity of radiation around the sliding contact increases with increasing resistivity of materials. This indicates that the triboplasm is generated by electrification by friction.

For a better understanding of such triboplasm by friction, further research is needed, as it is a completely new direction in the field of tribotechnology of running-in and restoration of conjugated parts. From a practical point of view, this allows using a synthesized catalyst to process and restore worn surfaces of parts in the normal operation of systems and units of motor vehicles and mobile agricultural machinery.

The proposed additives in tribotechnologies must be compatible with all lubricants used in systems and units of motor vehicles and mobile agricultural machinery.

The high effect from the use of the catalyst of antifriction films is observed in the processing of oils in the couplings of engine and transmission parts, plain and rolling bearings, gearboxes, pumps, drives. The main direction of further promotion of the catalyst as a component of the geomodifier of antifriction films can be the creation of lubricants with high characteristics both in terms of friction coefficient and resource on the developed theoretical foundations of tribotechnologies of running-in and recovery.

Conclusions

1. It is shown that to increase operational wear resistance and reliability of motor transport and mobile agricultural machinery it is possible by addition of additives and additives to motor and transmission oils, ie changing characteristics and properties of oils. It is substantiated that more effective increase of operational

reliability can be realized purposefully, changing characteristics and properties of working surfaces of conjugations of details of systems and units by tribotechnologies of their running-in and restoration.

2. The use of metal-clad antifriction additives with nanocomponents in the formation of servomotable films, the implementation of selective transfer processes and changes in the contact area of the conjugations of parts and the formation of micelles in the lubricating medium.

3. From the theoretical point of view the possibilities of tribotechnology of running-in and restoration at use of the KGMF-1 geomodifier are shown and the characteristic processes proceeding thus in triboconjugations of details are considered.

4. It was found that when creating tribotechnologies it is necessary to create a tribophysical and chemical theory that would explain and generalize complex and diverse phenomena and processes caused by the action of different natures of forces in tribocouples of parts with composite oil.

5. It is determined that it is expedient to create a thermofluctuation theory of destruction of materials of conjugations of machine parts under the influence of changing dilaton and compression bonds of their atoms and formation of corresponding local regions of tensile and compressive deformations when creating a tribophysicochemical theory.

6. It is shown that based on the model of triboplasm arising in triboconjugation of parts due to electrification of friction materials, it is possible to explain the mechanism of synthesis of servo-antifriction film on friction surfaces of parts due to mechanochemical activation of their materials in the contact zone.

References

1. Aulin V.V., Lysenko S.V., Kuzyk O.V., Hrynkiv A.V., Holub D.V. (2016). *Trybofizychni osnovy pidvyshchennia nadiinosti mobilnoi silskohospodarskoi ta avtotransportnoi tekhniky tekhnolohiiamy trybotekhnichnoho vidnovlennia: monohrafiia [Tribophysical bases of increase of reliability of mobile agricultural and motor transport technics by technologies of tribotechnical restoration: monograph]*. Kropyvnytskyi: Lysenko V. F., 303 c [in Ukrainian].

2. Aulin V.V. (2014). *Fizychni osnovy protsesiv i staniv samoorhanizatsii v trybotekhnichnykh systemakh [Physical bases of processes and states of self-organization in tribotechnical systems]*. Kirovohrad: Lysenko V.F., 369 c [in Ukrainian].

3. Gorskiy V.V. (1993). Masshtabnyiy skachok i formirovanie amorfno-kristallicheskih splavov v yavlenii strukturnoy prisposablivaemosti metallov pri trenii v aktivnyih sredah [Large-scale jump and formation of amorphous-crystalline alloys in the phenomenon of structural adaptability of metals by friction in active media]. *Trenie i iznos - Friction and wear*. №1. S.34-41 [in Russian].

4. Aulin V.V., Kuzyk O.V., Lysenko S.V., Verbytskyi O.V. (2017). Osoblyvosti strukturno-fazovykh peretvoren v materialakh detalei mashyn ta mekhanizmiv pry terti [Features of structural-phase transformations in materials of details of machines and mechanisms at friction]. Problemy konstruiuvannia, vyrobnytstva ta ekspluatatsii silskohospodarskoi tekhniky: *materialy XI Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of the XI International scientific-practical conference*. Kropyvnytskyi: TsNTU, S. 225-227 [in Ukrainian].

5. Aulin V.V., Lysenko S.V., Zhylova I.V., Lysenko V.M. (2017). Fizychna mezomekhanika znoshuvannia robochykh poverkhon detalei trybospriazhen mobilnoi silskohospodarskoi i avtotransportnoi tekhniky [Physical mesomechanics of wear of working surfaces of details of tribocouples of mobile agricultural and motor transport equipment]. Problems of design, production and operation of agricultural machinery: *materialy XI Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of the XI International scientific-practical conference*. Kropyvnytskyi: TsNTU, S. 223-225 [in Ukrainian].

6. Aulin V.V., Lysenko S.V., Hrynkiv A.V., Chernai A.Ie., Lukashuk A.P. (2018). Mozhlyvosti tekhnolohii trybotekhnichnoho vidnovlennia dlia pidvyshchennia znosostiikosti i dovhovichnosti spriazhen detalei transportnykh zasobiv [Possibilities of tribotechnical restoration technologies for increase of wear resistance and durability of conjugations of details of vehicles]. *Suchasni tekhnolohii v mashynobuduvanni ta transporti. Naukovyi zhurnal - Modern technologies in mechanical engineering and transport. Scientific journal*, №1(10). S.5-11 [in Ukrainian].

7. Aulin V.V., Dykha O.V., Lysenko S.V., Hrynkiv A.V. (2018). Vplyv rezhymu mashchennia na trybotekhnichni kharakterystyky poverkhni spriazhen detalei dyzeliv avtomobiliv [Influence of lubrication mode on tribotechnical characteristics of the interface surface of diesel car parts]. Innovative technologies for the development and efficiency of road transport: *zbirnyk naukovykh materialiv mizhnarodnoi naukovo-praktychnoi internet-konferentsii - a collection of scientific materials of the international scientific-practical Internet conference*. TsNTU, m.Kropyvnytskyi, Ukraina, 14-15 lystopada 2018 r.. Kropyvnytskyi. S.218-240 [in Ukrainian].

8. Aulin V.V., Tarnavskyi D.V. (2018). Systemne zastosuvannia trybotekhnolohii prypratsiuvannia i vidnovlennia na etapakh zhyttievoho tsyklu zasobiv transportu [Systematic application of tribotechnologies of running-in and restoration at the stages of the life cycle of vehicles]. Improving the reliability of machinery and equipment: *zb. tez dopovidei KhII Vseukrainskoi naukovo-praktychnoi konferentsii studentiv, aspirantiv ta*

molodykh naukovtsiv - Coll. abstracts of the XII All-Ukrainian scientific-practical conference of students, graduate students and young scientists. Kropyvnytskyi: TsNTU, S. 86-87 [in Ukrainian].

9. Aulin V., Zamota T., Hrynkiv A., Lysenko S. at all. (2019). Increase of formation efficiency of gears contact spot at electrochemical-mechanical running-in. *Problems of tribology*. Khmelnytskyi. KhNU, 24 (4/94). S.33-39 [in English].

10. Aulin V., Zamota T., Hrynkiv A., Lysenko S. at all. (2019). Increase of formation efficiency of gears contact spot at electrochemical-mechanical running-in. *Problems of tribology*. Khmelnytskyi. KhNU, 24 (4/94). S.33-39 [in English].

11. Aulin V.V., Lysenko S.V., Hrynkiv A.V., Chernai A.E., Lukashuk A.P. (2019). Systemno-spriamovanyi pidkhid do rozrobky tekhnolohii bezrozbirnoho vidnovlennia spriazhen detalei [System-oriented approach to the development of technologies for disassembly of conjugation of parts]. Kramarov readings: *zb. tez dopovidei VI Mizhnarodnoi naukovo-tekhnichnoi konferentsii - collection. abstracts of the VI International Scientific and Technical Conference*, 21-22 liut. 2019 r., m. Kyiv, NUBiP. – K.: Vydavnychyi tsentr NUBiP Ukrainy, S. 94-96 [in Ukrainian].

12. Aulin V.V., Lysenko S.V., Zhylova I.V., Verbytskyi O.V. (2019). Synerhetychne pidvyshchennia nadiinosti trybospriazhen detalei system i ahrehativ transportnykh mashyn [Synergetic increase of reliability of tribocouples of details of systems and units of transport cars]. Increase of Machine and Equipment Reliability: *materialy 1oi Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of the 1st International scientific-practical conference*,17-19 kvitnia 2019 r., Kropyvnytskyi: TsNTU, S.7-8 [in Ukrainian].

13. Aulin V.V., Lysenko S.V., Zhylova I.V., Verbytskyi O.V. (2019). Synerhetyka pidvyshchennia znosostiikosti i nadiinosti trybospriazhen detalei system i ahrehativ mashyn [Synergetics of increase of wear resistance and reliability of tribocouples of details of systems and units of cars]. Kramarov readings: *zb. tez dopovidei VI Mizhnarodnoi naukovo-tekhnichnoi konferentsii - collection. abstracts of the VI International Scientific and Technical Conference*, 21-22 liut. 2019 r., m. Kyiv, NUBiP. – K.: Vydavnychyi tsentr NUBiP Ukrainy, S. 127-129 [in Ukrainian].

14. Aulin V.V., Lysenko S.V., Hrynkiv A.V., Zhylova I.V. (2019). Problemy stvorennia smart-pokryttiv v zelenii trybolohii (2019). Increase of Machine and Equipment Reliability: *materialy 1oi Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of the 1st International scientific-practical conference*, 17-19 kvitnia 2019 r., Kropyvnytskyi: TsNTU, S.53-56 [in Ukrainian].

15. Aulin V., Lysenko S., Lyashuk O., Hrinkiv A., Velykodnyi D., Vovk Y., Holub D., Chernai A. (2019). Wear resistance increase of samples tribomating in oil composite with geo modifier KGMF-1. *Tribology in Industry*. Vol. 41, No. 2. P. 156-165 [in English].

16. Aulin V., Hrynkiv A., Lysenko S., Dykha A., Zamota T., Dzyura V. (2019). Exploring a possibility to control the stressed-strained state of cylinder liners in diesel engines by the tribotechnology of alignment. *Eastern-European Journal of Enterprise Technologies*. Vol. 3 (12 - 99). P. 6-16 [in English].

17. Aulin V., Lysenko S., Hrynkiv A., Chernai A., Zhylova I., Lukashuk A. (2019). Wear resistance increase of samples tribomating "Steel 45-cast iron SCH20" with geo modifier KGMF-1. *Problemy trybolohii*. Khmelnytskyi. KhNU, №2 S.55-60 [in English].

18. Aulin V., Hrynkiv A., Lysenko S., Lyashuk O., Zamota T., Holub D. (2019). Studying the tribological properties of mated materials C61900-A48-25BC1.25BNo.25 in composite oils containing geomodifiers. *Eastern-European Journal of Enterprise Technologies*. Vol. 5 (12-101). P. 38-47 [in English].

19. Aulin V., Lyashuk O., Hrynkiv A., Lysenko S. at all. (2019). Determination of the rational composition of the additive to oil with the use of the Katerynivka friction geo modifier. *Tribology in Industry*. Vol. 41. No. 4. P.548-562 [in English].

20. Aulin V., Hrynkiv A., Lysenko S., Zamota T., Pankov A., Tykhyi A. (2019). Determining the rational composition of tribologically active additive to oil to improve characteristics of tribosystems. *Eastern-European Journal of Enterprise Technologies*. Vol. 6 (12-102). P. 52-64 [in English]

21. Aulin V.V., Lysenko S.V., Hrynkiv A.V. (2019). Model nadiinosti detalei transportnykh mashyn za protsesamy realizatsii trybotekhnolohii yikh prypratsiuvannia i vidnovlennia [The model of reliability of details of transport cars on processes of realization of tribotechnologies of their running in and restoration]. *Tsentralnoukrainskyi naukovyi visnyk. Tekhnichni nauky - Central Ukrainian Scientific Bulletin. Technical sciences*, Vyp. 2(33). S.50-64 [in Ukrainian].

22. Aulin V.V., Hrynkiv A.V., Lysenko S.V., Chernai A.Ie., Lukashuk A.P. (2020) Protses zminy stanu olyvy pry prypratsiuvanni spriazhen detalei ta obkattsi dvyhuniv transportnykh mashyn [The process of changing the state of the oil during the running-in of the couplings of parts and running-in of engines of transport machines]. Increase of Machine and Equipment Reliability: *materialy Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of the International scientific-practical conference*, 15-17 kvitnia 2020 r., Kropyvnytskyi: TsNTU, S.162-165 [in Ukrainian].

23. Aulin V.V., Lysenko S.V., Hrynkiv A.V., Chernai A.Ie., Lukashuk A.P. (2020). Optymalne keruvannia rezhymamy funktsionuvannia trybospriazhenniamy detalei system i ahrehativ transportnykh mashyn [Optimal control of modes of operation of tribocouples of details of systems and units of transport cars]. Increase of Machine and Equipment Reliability: *materialy Mizhnarodnoi naukovo-praktychnoi konferentsii - materials of*

the International scientific-practical conference, 15-17 kvitnia 2020 r., Kropyvnytskyi: TsNTU, S.178-179 [in Ukrainian].

24. Aulin V.V. (2015). Trybofizychni osnovy pidvyshchennia znosostiikosti detalei ta robochykh orhaniv silskohospodarskoi tekhniky [Tribophysical bases of increase of wear resistance of details and working bodies of agricultural machinery].- *Doctor's thesis*, Khmelnyts. nats. un-t. Khmelnytskyi, [in Ukrainian].

25. Pat. 81598 Ukraïna, MPK (2013) C10M 125/04. Prypratsiuvalna mastylna kompozytsiia [Running lubricating composition]. V.V. Aulin, V.V. Slon, S.V. Lysenko, D.V. Holub; zajavnik i vlasnik Kirovohradskyi nats. tekhn. universytet no. u201213907 ; zajavl. 06.12.2012; opubl. 10.07.13, Bjul. no. 13, [in Ukrainian].

26. Aulin V., Lysenko S., Hrynkiv A., Chernai A. at all. (2020). New approach to elucidating the physical nature of the processes that occur in the friction zone of mates of machine parts. *Problems of tribology*. Khmelnytskyi. KhNU, 25 (4/98). S.13-19 [in English].

Аулін В.В., Лисенко С.В., Гриньків А.В., Слонь В.В., Чернай А.Е. Створення теоретичних основ триботехнологій припрацювання і відновлення як засобу ефективного підвищення експлуатаційної зносостійкості автотранспортної та мобільної сільськогосподарської техніки

Визначено підстави для створення теоретичних основ триботехнологій припрацювання і відновлення спряжень деталей систем і агрегатів автотранспортної та мобільної сільськогосподарської техніки.

Розглянуто специфіку вибіркового переносу на поверхні контактуючих деталей машин та створення сервовитних плівок, формування покриттів при припрацюванні і відновленні з антифрикційних матеріалів, що входять до складу присадок в моторну та трансмісійну оливу.

З'ясовано ряд трибофізикохімічних процесів, які відбуваються в спряженнях матеріалів деталей, та як вони впливають на створення триботехнологій припрацювання та відновлення. Розглянуто створення триботехнологій при використанні геомодифікаторів. Запропоновано єдину теорію триботехнологій припрацювання і відновлення будувати на основі механізму утворення трибоплазми в спряженнях деталей систем і агрегатів машин. Також запропоновано до цього додати термофлуктуаційну теорію С.М. Журкова з урахуванням зміни дилатонних і компресонних зв'язків атомів матеріалів трибоспряжень деталей з створенням локальних областей деформацій стиску і розтягу та зон термопластичної деформації.

Ключові слова: триботехнології припрацювання і відновлення, спряження деталей, трибоплазма, олива, присадка, автотранспортна техніка, мобільна сільськогосподарська техніка.

***Problems of Tribology**, V. 26, No 1/99-2021,59-65*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-59-65

High-carbon steel: microstructure and abrasive wear resistance of heat affected zone after welding with fast cooling

M.N.Brykov[1*], V.G.Efremenko[2], M.Yu.Osipov[1], A.E.Kapustyan[1], T.A.Akrytova[1], Yu.A.Kalinin[3]

[1]"Zaporizhzhya Polytechnic" National University, Ukraine,
[2]Priazovskyi State Technical University, Ukraine
[3]PrJSC "Zaporozhtransformator", Ukraine

**E-mail: brykov@zntu.edu.ua*

Abstract

The goal of this work is to estimate the abrasive wear resistance of heat affected zone (HAZ) after welding high-carbon low-alloy steel 120Mn3Si2 with fast cooling. The following benchmark data were used: microstructures of HAZ of 120Mn3Si2 steel after welding with cooling in water; abrasive wear resistance of different microstructure constituents of 120Mn3Si2 steel in two-body abrasive wear conditions. It is shown that high abrasive wear resistance of material in HAZ is provided in the vicinity of fusion line. The reason is unstable retained austenite which appears in HAZ as a result of quenching at fast cooling right after welding. The wear resistance of material in HAZ is altered by microstructural changes from austenite to austenite+martensite and finally martensite. The martensitic zone is about 0.5 mm wide and it is followed by zone of tempering of initial structure of steel. Zone of tempering is 1.5-2.0 mm wide and is the only zone of low abrasive wear resistance in HAZ of 120Mn3Si2 steel welded with fast cooling. Welding of 120Mn3Si2 steel with fast cooling in water results in welding joints which have as high wear resistant as the base material or even higher. This enables manufacturing flat welded elements with high wear-resistance and large surface area.

Key words: high-carbon steel, welding, fast cooling, austenite, martensite, bainite, abrasive wear resistance, microstructure.

Introduction

Protection against abrasive and other kinds of wear requires materials with specific properties. For example, high abrasive wear resistance of steels is attributed to high carbon content (1.0 wt. % of carbon or even more) and specific thermal treatment to obtain certain microstructure. The problem may arise if such thermally treated machine parts are to be welded. Heat input during thermal welding cycle changes the initial wear resistant microstructure inside heat affected zone (HAZ). Special efforts are needed to minimize HAZ and provide quality welding joints while welding heat treated high-carbon wear resistant steels. Anyway, the width of HAZ in any case would not be less than approximately 5 mm from the fusion line. Therefore, if two plates of high-carbon steel are welded, a zone of changed wear resistance appears to be 10 mm wide. It is necessary to know the wear resistance of this zone because local low wear resistance may negatively affect the overall lifetime of machine part. In this study the attempt is made to estimate the abrasive wear resistance in HAZ of high-carbon low-alloy steel 120Mn3Si2 after welding with fast cooling.

Literature review

Friction and wear are estimated to cause approximately 20% of the world energy consumption [1]. Wear is responsible for short lifetime of many critical machine parts and even for their sudden catastrophic failures. Abrasive wear is the most aggressive form of wear. Generally it appears during operation in mining sector [2, 3] and other industries where hard particles of natural or artificial abrasives are in direct contact with metallic surfaces. Losses connected to abrasive wear are estimated as 4% of the GNP of industrially developed countries

[4]. Extensive investigations have been made on abrasive wear resistance of steels and cast irons during last century. Important results were obtained by I.N.Bogachev and R.I.Mints, B.A.Voinov, V.I.Dvoruk, V.G.Kaplun and P.V.Kaplun, V. N. Kashcheev, M.V. Kindrachuk, L.G.Korshunov, A.V.Makarov, L. S. Malinov, V.S.Popov and N.N.Brykov, M.M.Tenenbaum, V.M.Tkachev, M. M. Khrushchev and M. A. Babichev, A.P.Cheiliakh, V.V.Shevelya, A.Fisher, I.I.Garbar, A.Misra и I.Finnie, R.C.D.Richardson, G.W.Stachoviak, A.A.Torrance, J.H.Tylczak, K.-H. Zum Gahr. Main attention of researchers has been concentrated on wear resistance of martensite and austenite. Abrasive wear resistance of austenite depends on its degree of hardening during friction and the ability of the wear medium to provide such hardening. I.M.Bogachev and R.I.Mints have discovered the phenomenon of deformation transformation of austenite to martensite during mechanical load [5]. Since then this effect was widely used to increase wear resistance of machine parts under conditions of abrasive wear. Researches of L. S. Malinov [6], A.P.Cheiliakh [7], M. A. Filippov [8] should be mentioned among the works devoted to the study of the properties of steels with the structure of unstable residual austenite. V.S.Popov and N.N.Brykov [9, 10] have made extensive research on abrasive wear resistance of retained austenite in numerous applications in refractory industry. In [10] the range of optimal chemical composition for wear resistant austenitic alloys was proposed. It was shown that high carbon content, i.e. 1.0 mass.% or higher, is responsible for high abrasive wear resistance. According to [11] maximal wear resistance in Fe-C alloys is achieved at 2 mass.% of carbon. As a result of studying the effect of alloying on the wear resistance of steels with the structure of unstable austenite during abrasive wear, it was found that the level of alloying of wear-resistant alloys should be maintained at the lowest possible level [12]. Thus, the requirements for the chemical composition of abrasive wear resistant steels are specified as follows: approximately 3% of alloying elements (e.g. Mn, Cr) in total, the carbon content should provide the martensite start temperature at 20 ^{o}C. The simplest example is the steel containing 1.2% C and 3% Mn. After quenching from 1000 ^{o}C (single-phase γ-region) austenite retains almost completely and is capable to deformation martensitic transformation in the course of abrasive wear. This provides high wear resistance for steel after above mentioned thermal treatment, much higher than the one of high-carbon untempered martensite. High ability of austenite to deformation martensitic transformation is useful in the case of impactless-abrasive wear. But if the machine part is subjected not only to wear but also to impacts, the instability of austenite is also a disadvantage. In the initial stages of the impacts, when the crack is not yet formed, the initial plastic deformation takes place. But after the formation of the first crack, a stress concentration occurs at its tip. Under the large local stresses near the crack tip, a deformation martensitic transformation occurs, and the crack actually propagates in brittle high-carbon martensite during repeated shocks. Thus, low resistance to shock loads is the price for high abrasive wear resistance. This significantly narrows the potential range of possible successful usage of high-carbon low-alloy steels as a wear-resistant material in conditions of mechanical wear. In [13, 14] it is proposed to use isothermal treatment of residual austenite of high-carbon low-alloy steels in order to reduce the susceptibility to brittle fracture while maintaining abrasive wear resistance at a sufficiently high level. High-carbon low-alloy steels, for example, 120Mn3 steel, allow to obtain up to 100% of residual austenite after quenching from a single-phase region. Therefore, such steels do not require baths with liquid media for the isothermal treatment of austenite. It is enough to quench them in water, to heat further in a conventional air furnace and to hold at a constant temperature for the required time. During isothermal holding of quenched 120Mn3 steel, bainite transformation of austenite takes place. If silicon content is high enough (1.5-2.0%), cementite is not formed during bainite transformation. After isothermal transformation the structure contains bainitic ferrite and austenite, which is carbon supersaturated [15, 16]. Due to increasing the carbon content the austenite stabilizes and its susceptibility to deformation martensitic transformation is reduced. Thus, it is possible to eliminate the catastrophic fragility of unstable residual austenite due to a small loss of abrasive wear resistance [13, 14]. In order to accelerate the bainite transformation, it is necessary to quench 120Mn3Si2 steel from such a temperature that after cooling, martensite was present in the structure in small amount. Martensite acts as a catalyst for bainite transformation [17], which begins less than in 1 hour if the steel 120Mn3Si2 is hardened from 900 ^{o}C [18]. Welding of previously quenched 120Mn3Si2 steel may be needed for large-part manufacturing. In order to minimize influence of welding heat on initial microstructure of steel it is proposed to use fast cooling of just-welded joints in water [19]. It was shown that due to rapid cooling it is possible to minimize dimensions of heat affected zone (HAZ) and obtain welding joints of acceptable quality. The width of HAZ was about 5 mm from fusion line from each side of a welding joint. This results in a 10 mm wide zone of altered microstructure and hence altered wear resistance at the location of welding joint on a produced large-scale part.

The goal of this work is assessing the abrasive wear resistance of a material inside HAZ of 120Mn3Si2 welding joint after welding with fast cooling in water.

Methods

The assessment of the abrasive wear resistance of the material in HAZ of 120Mn3Si2 steel was carried out according to the known experimental data. The authors have performed numerous experiments on abrasive wear of steels with different microstructures in two-body abrasive wear conditions and reported the results in [11-14, 20- 22]. The microstructure of HAZ in welding joints of 120Mn3Si2 after welding with fast cooling in water has been investigated and reported in [19, 23]. Hence, it is possible to accurately predict the abrasive wear resistance of each point in HAZ depending on the microstructure. For the sake of this research, wear mode was assumed to be two-body abrasive wear of cylindrical specimen 2 mm in diameter sliding against fresh surface of abrasive cloth under load of 300 g. The assumed abrasive is 0.6…0.8 mm grits of Al_2O_3. The ability of material to resist abrasive wear is expressed as relative wear resistance ε. The assumed reference sample is pure iron having ε = 1,0.

Results and discussion

According to [19] optimal heat treatment of 120Mn3Si2 steel includes quenching from 900 ^oC and subsequent isothermal treatment at 250 ^oC. After quenching from 900 ^oC microstructure is preliminary austenitic with nearly 30% of martensite. Certain amount of undissolved carbides is present as well. Subsequent isothermal treatment leads to appearance of fine lamellas of bainitic ferrite. The amount of bainitic ferrite depends on isothermal holding time. The very first lamellas are observed even after 1 hour of isothermal holding [18]. Decarburized layer inevitably appears when 120Mn3Si2 steel is exposed to quenching heat. The depth of decarburized layer depends on holding time at quenching temperature and may reach 1 mm. Because of decrease in carbon content, martensite start temperature (Ms) significantly increases. Therefore the martensitic layer appears after quenching in the near surface regions where significant decarburization had happened [22]. 5 mm thick plates of 120Mn3Si2 steel where quenched from 900 ^oC, held isothermally at 250 ^oC and then were welded with fast cooling in water. The microstructure of welding joint from 120Mn3Si2 side is shown on Fig.1, a. Because of fast cooling after welding the material in HAZ is quenched. Therefore HAZ consists of several zones of microstructures depending on peak temperatures during heating cycle in each particular point.

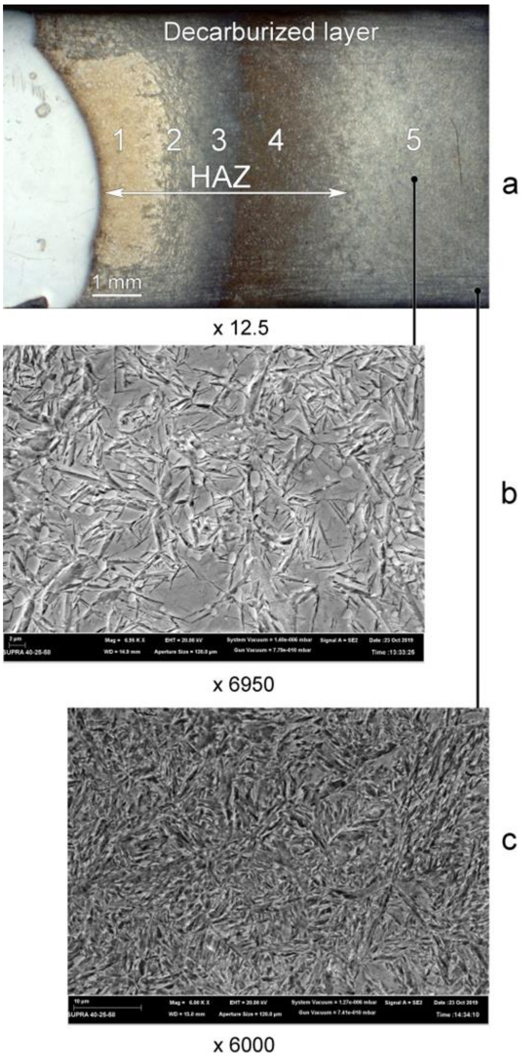


Fig. 1. Macro- and microstructure of welding joint of thermally treated 120Mn3Si2 steel: a – macrostructure of welding joint with different zones of HAZ, 1 – austenite, 2 – austenite + martensite, 3 – martensite, 4 – zone of high tempering of initial microstructure, 5 – thermally unaffected core; b – microstructure of thermally unaffected core: austenite + tempered martensite + bainitic ferrite + carbides; c – microstructure of decarburized layer: tempered martensite + austenite

Four different zones may be distinguished in HAZ. Zone 1 appears as a result of heating the material to the temperatures between Acm critical point and solidus temperature (single-phase γ-region). The structure in zone 1 is almost fully austenitic because the Ms temperature is near 30 ^oC [13]. The more the distance from fusion line is, the less is the peak temperature. Zone 3 is preliminary martensitic and is equivalent to classic quenching for maximal hardness of hyper-euthectoid steels. It corresponds to quenching from temperatures slightly above Ac_1 critical point. Zone 2 corresponds to quenching from a range of temperatures between Ac_1 and Acm. The structure is austenite + martensite. The closer to fusion line in the zone 2, the more amount of austenite is present in the structure.

If heating temperature doesn't exceed Ac_1, then no phase transformation takes place during welding cycle (zone 4). The structure in this zone right at the border with zone 3 contains products of diffusional decomposition of initial microstructural constituents. The more the distance to zone 3 is, the less is the peak temperature in the welding cycle in zone 4. Thus, microstructure gradually changes from products of high tempering to products of low tempering and further to zone 5 where initial microstructure is not changed at all.

Having the information on microstructures of different zones in HAZ it is possible to determine changes in relative wear resistance of material on different distance to fusion line (Fig. 2). Relative wear resistance of preliminary austenitic structure in zone 1 of HAZ is at the level of 4.0. This value corresponds to wear resistance of 120Mn3Si2 steel quenched from 1000 ^oC as reported in [14]. If quenching temperature decreases to 900 ^oC then some amount of martensite appears after quenching. This is due to less carbon content in austenite before quenching and rising the Ms. Retained austenite becomes even more unstable, therefore relative wear resistance of 120Mn3Si2 steel after quenching from 900 ^oC is slightly higher than that after quenching from 1000 ^oC [20]. This microstructure corresponds to zone 2. Relative wear resistance gradually increases to some maximum due to gradual alteration in content of retained austenite. This maximum corresponds to microstructure which is equivalent to those obtained after quenching from 900 ^oC. The expected value of relative wear resistance at the point of maximum is 4.2-4.3.

Further increasing of distance from fusion line leads to decreasing of peak temperatures in welding cycle. Consequently, the amount of martensite gradually increases until zone 3 is reached. Relative wear resistance of untempered martensite (eutectoid composition) is 2.9 [21]. Therefore the same relative wear resistance is provided in zone 3.

Sharp drop in relative wear resistance takes place upon transition from zone 3 to zone 4. The structure of zone 4 in the vicinity of zone 3 is equivalent to that after recrystallization annealing, i.e. pearlite. Relative wear resistance of pearlite is 1.4 [21], so that is the value to which ε is decreased on the border of zones 3 and 4. The more is the distance from zone 3, the finer is the pearlite. The microstructure gradually changes to sorbite, troostite, and finally the thermally unaffected zone 5 is reached. Relative wear resistance increases respectively from 1.4 to the level that is specific for the base preliminary treated material. In the case of quenching 120Mn3Si2 steel from 900 ^oC and subsequent isothermal treatment at 250 ^oC the structure is austenite+tempered martensite+bainitic ferrite+carbides. Relative wear resistance of such microstructure is slightly higher than that of untempered high-carbon martensite [14].

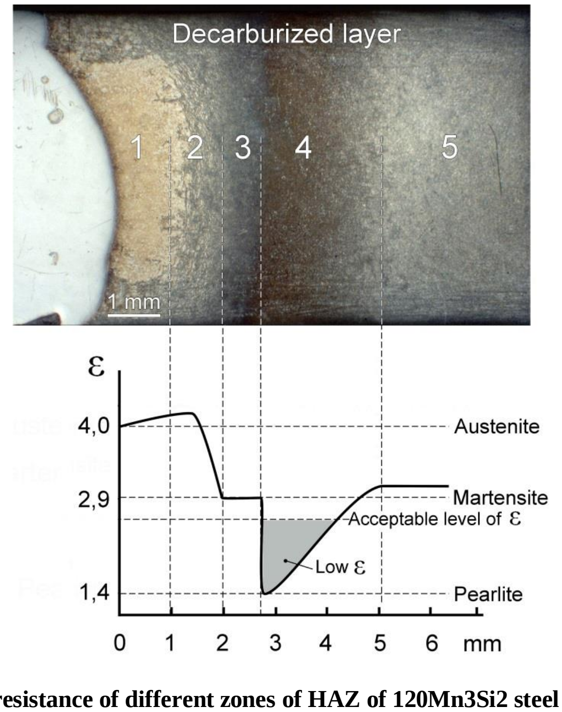


Fig. 3. Relative wear resistance of different zones of HAZ of 120Mn3Si2 steel after quenching from 900 ^oC, isothermal treatment at 250 ^oC and welding with fast cooling in water

Steels with martensitic microstructure are widely used as abrasive wear resistant material. Because of high brittleness of untempered martensite this microstructure is not acceptable for majority of machine parts. At least low temper is needed to get lower brittleness of material after quenching. Low tempering decreases hardness and hence abrasive wear resistance. Thus, relative wear resistance of tempered martensite is the lowest level that is practically acceptable. This level of ε is designated as "Acceptable level of ε" on Fig. 2. All points in HAZ with higher values of ε should be considered as zone with high relative wear resistance to abrasive wear.

It is evident, that the only zone of low wear resistance is that designated in gray on Fig. 2 ("Low ε"). The width of this zone is 1.5-2.0 mm. The rest of HAZ possesses wear resistance that is above acceptable level. Relative wear resistance in zones 1 and 2 is even higher than the one of the base material.

All considerations expressed above allow to claim that welding of 120Mn3Si2 steel with fast cooling in water enables HAZ with wear resistance that is the same or even higher than the one for base thermally treated material. The only zone with low wear resistance is 1.5-2.0 mm wide and corresponds to heating the material to high but subcritical temperatures. This zone cannot be eliminated since it is not possible to avoid places in HAZ that are heated to subcritical temperatures. This zone also cannot be made less wide since cooling is as fast as possible.

Conclusions

Abrasive relative wear resistance of heat affected zone of 120Mn3Si2 steel after welding with fast cooling in water is assessed in this research. The only zone with low wear resistance is 1.5-2.0 mm wide. This zone cannot be neither avoided nor narrowed. It corresponds to heating material to subcritical temperatures during welding cycle. The relative wear resistance of material in this zone corresponds to that for pearlite.

The relative wear resistance of the rest of HAZ appears to be higher or at the same level as for previously heat treated steel. Thus, welding 120Mn3Si2 steel with fast cooling in water enables obtaining welding joint with high abrasive wear resistance of heat affected zones.

The research shows that welding of 120Mn3Si2 steel with fast cooling in water results in welding joints which have as high wear resistance as the base material or even higher. This enables manufacturing flat welded elements of high wear-resistance and large surface area.

References

1. Holmberg, K., Erdemir, A. Influence of tribology on global energy consumption, costs and emissions. Friction 2017, 5, 263–284.

2. Holmberg, K., Kivikytö-Reponen, P., Härkisaari, P., Valtonen, K., Erdemir, A. Global energy consumption due to friction and wear in the mining industry. Tribology International 2017, 115, 116–139. https://doi.org/10.1016/j.triboint.2017.05.010

3. Terva, J., Kuokkala, V.-T., Valtonen, K., Siitonen, P. Effects of compression and sliding on the wear and energy consumption in mineral crushing. Wear 2018, 398–399, 116–126.

4. Totten, G.E. (Ed.). Friction, Lubrication, and Wear Technology. ASM International 2017.

5. Bogachev I.N., Mincz R.I. Kavitaczionnoe razrushenie zhelezouglerodistykh splavov. M., Sverdlovsk : Mashgiz, 1959. 111 s.

6. Malinov L. S., Malinov V. L. Ekonomnolegirovannye splavy s martensitnymi prevrashheniyami i uprochnyayushhie tekhnologii : monografiya. Khar`kov : NNCz KhFTI, 2007. 346 s.

7. Chejlyakh, A. P. Ekonomnolegirovannye metastabil`nye splavy i uprochnyayushhie tekhnologii : monografiya. Mariupol` : PGTU, 2009. 483 s.

8. Filippov M. A., Litvinov V. S., Nemirovskij Yu. R. Stali s metastabil`nym austenitom. M. : Metallurgiya,1988. 257 s.

9. Popov V. S., Brykov N. N., Dmitrichenko N. S. Iznosostojkost` pressform ogneupornogo proizvodstva. M. : Metallurgiya, 1971. 160 s.

10. Schastlivczev V. M., Filippov M. A. Rol` princzipa metastabil`nosti austenita Bogacheva-Mincza pri vybore iznosostojkikh materialov. Metallovedenie i termicheskaya obrabotka metallov. 2005. # 1, S.6-9.

11. Brykov M. N. Abrazivnoe iznashivanie zhelezouglerodistykh splavov. Trenie i iznos. 2006. # 1, S. 105-109.

12. Brykov M. N., Andrushhenko M. I., Kulikovskij R. A. Vliyanie legirovaniya na iznosostojkost` zhelezouglerodistykh splavov pri abrazivnom iznashivanii. Novi materiali i tekhnologiyi v metalurgiyi ta mashinobuduvanni. 2006. # 2, S. 59-62.

13. Hesse O., Liefeith J., Kunert M., Kapustyan A., Brykov M., Efremenko V. Bainit in Stählen mit hohem Widerstand gegen Abrasivverschleiß. Tribologie + Schmierungstechnik. 2015. V 63. № 2, S. 5-13.

14. Brykov M. N. Iznosostojkost` bejnita pri abrazivnom iznashivanii. Problems of Tribology. 2015. # 1, S.113-118.

15. Bhadeshia H. K. D. H. Nanostructured bainite. Proc. R. Soc. A. 2010. V 466, P. 3-18.

16. Gabarello F. G., Miller M. K., Garcia-Mateo C. Opening previously impossible avenues for phase transformation in innovative steels by atom probe tomography. Materials Science and Technology. 2014. V 30, P. 1034-1039.

17. Jellinghaus W., Anregung der Zwischenstufen-Umwandlung des Stahles durch kleine Mengen von a-Eisen. Arch. Eisenhütt. 1952. V 23, P. 459-470.

18. Kalinin Yu. A., Petrishinecz I., Efremenko V. G., Kapustyan A. E., Brykov M. N. Vliyanie izotermicheskoj obrabotki na mikrostrukturu zakalyonnoj na austenit vysokouglerodistoj nizkolegirovannoj stali. Visnik KhNADU. 2020. T 1. vip. 88, S. 58-66.

19. Microstructure and properties of heat affected zone in high-carbon steel after welding with fast cooling in water / M.N. Brykov, I. Petryshynets, M. Džupon, Yu. A. Kalinin, V. G. Efremenko, N.A. Makarenko, D. Yu. Pimenov, F. Kováč // Materials. 2020. 13(22). 5059.

20. Efremenko V.G. Two-body abrasion resistance of high-carbon high-silicon steel: Metastable austenite vs nanostructured bainite / V.G. Efremenko, O. Hesse, T. Friedrich, M. Kunert, M.N. Brykov, K. Shimizu, V.I. Zurnadzhy, P. Šuchmann // Wear. 2019. V. 418-419, P. 24-35.

21. Brykov M.N., Efremenko V.G., Efremenko A.V. Iznosostojkost` stalej i chugunov pri abrazivnom iznashivanii : Nauchnoe izdanie / M.N.Brykov, V.G.Efremenko, A.V.Efremenko. Kherson : Grin` D.S., 2014. 364 s.

22. Khesse O. Iznosostojkost` obezuglerozhennogo sloya vysokouglerodistoj nizkolegirovannoj stali v ekstremal`nykh usloviyakh treniya / O. Khesse, M. Kunert, V.G. Efremenko, K. Shimiczu, M.N. Brykov, A.E. Kapustyan // Naukovi notatki. 2017. Vip. 58, S. 301-307.

23. Struktura okoloshovnoj zony zakalyonnoj vysokouglerodistoj stali posle svarki s uskorennym okhlazhdeniem / Yu. A. Kalinin, A. A. Shumilov, I. Petrishinets, V. G. Efremenko, M. N. Brykov // Novi materiali i tekhnologiyi v metalurgiyi ta mashinobuduvanni. 2019. # 1, S. 31-36.

Бриков М.М., Єфременко В.Г., Осіпов М.Ю., Капустян О.Є., Акритова Т.О., Калінін Ю.А. Високовуглецева сталь: мікроструктура і абразивна зносостійкість зони термічного впливу після зварювання із швидким охолодженням у воді.

Метою роботи є оцінювання абразивної зносостійкості зони термічного впливу (ЗТВ) після зварювання високовуглецевої низьколегованої сталі 120Г3С2 із швидким охолодженням. Було використано такі вихідні дані: мікроструктура ЗТВ сталі 120Г3С2 після зварювання з охолодженням у воді; абразивна зносостійкість різних мікроструктурних складових сталі 120Г3С2 в умовах абразивного зношування закріпленими частинками. Показано, що в ЗТВ у безпосередньої близькості до границі сплавлення забезпечується висока абразивна зносостійкість матеріалу. Причиною є структура нестабільного залишкового аустеніту, який утворюється в ЗТВ в результаті гартування під час швидкого охолодження одразу ж після зварювання. Зносостійкість матеріалу в ЗТВ змінюється із зміною мікроструктури від аустеніту до аустеніт+мартенсит і, нарешті, мартенситу. Ширина мартенситної зоні становить приблизно 0,5 мм. За мартенситною зоною утворюється зона відпуску вихідної мікроструктури сталі завтовшки 1,5-2,0 мм. Ця зона є єдиною зоною зі зниженою зносостійкістю. Зварювання сталі 120Г3С2 із швидким охолодженням у воді дозволяє отримати зварні з’єднання із зносостійкістю, що дорівнює зносостійкості вихідного матеріалу, або навіть перевищує її. Це дає можливість виготовляти пласкі зварні елементи з високою зносостійкістю і великою площею поверхні.

Ключові слова: високовуглецева сталь, зварювання, швидке охолодження, аустеніт, мартенсит, бейніт, абразивна зносостійкість, мікроструктура.

Problems of Tribology, *V. 26, No 1/99-2021,66-73*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-66-73

Tribological researches of electroerosive processing of steel details of cars

D.D. Marchenko*, K.S. Matvyeyeva

Mykolayiv National Agrarian University, Mykolayiv, Ukraine
**E-mail: marchenkodd@mnau.edu.ua*

Abstract

The article considers the technology of electroerosive treatment of steel friction pairs and presents the results of experimental studies. Analysis of experimental studies has shown that an increase in the anode-cathode voltage leads to a sharp decrease in the microhardness of the surface layer. The study also allowed to determine the characteristic size of the structural elements, the height parameters of the surface roughness. The elemental composition of the initial surface of the sample made of steel 15HGN2TA differs from the composition of the coatings and surface layers of the samples modified by electroerosive treatment with different electrodes. In the mode of operation of the "anode - cathode" system on the cathode surface due to dissipative processes, a thin layer of coating of a stable modified structure is formed. It is shown that the height of surface irregularities in the areas after friction is higher than in the areas of the surface outside the friction track, which is associated with the formation on the surface of the samples of the friction transfer film. It was found that the frictional interaction of steel samples treated by electroerosion method forms a thin film on the friction surface of steel samples, which leads to a change in the topography of surfaces with increasing height of microroughnesses and structuring of the transfer film in the sliding direction. The influence of electroerosive treatment of steel surfaces on the wear resistance of the metal-polymer tribosystem was established and the optimal treatment modes were obtained: voltage U = 145-150 V, capacitor capacity C = 225-230 μF, treatment duration t = 3-4 min / cm^2, providing the greatest reduction in speed wear of the polymer counterbody and recommended in the development of technological processes of electroerosive treatment.

Key words: wear, electrode, roughness, wear resistance, friction steam, coating, electroerosive treatment.

Introduction

Reliability and efficiency of machines and technological equipment are determined mainly by wear resistance and durability of parts of tribosystems. Depending on the operating conditions of the products, various methods of surface hardening of steels and alloys are used in the industry, such as surface plastic deformation, chemical-thermal treatment, formation of hardening wear-resistant coatings (microarc oxidation, spraying, etc.), high-energy methods etc.) and their various combinations. All known methods of surface hardening have their advantages and scope, but do not fully meet modern requirements for efficiency, versatility and cost-effectiveness of technological processes. Therefore, the development of an effective, fairly simple to master in industrial production and economic method of increasing wear resistance remains an urgent scientific and practical task. The most promising are the methods of surface modification of parts of tribosystems with the use of highly concentrated energy flows, which include electroerosive treatment (EET), which allows to obtain coatings with high physical, mechanical and tribotechnical properties.

Combined surface hardening methods allow to create coatings with high predetermined performance properties [1]. Thus, surface alloying with subsequent nitriding of low-alloy steels allows to increase the characteristics of mechanical strength above the level of properties of high-alloy steels. In [2] the problems of increasing the wear resistance of a long tool by the method of combined hardening, which includes nitriding and coating (Ti, Nb, Al, N) are considered. Production tests have shown that the combined strengthening of broaches on the offered modes allows to increase in 2-4 times their stability in comparison with not strengthened.

The combination of methods of physical cathodic-arc and chemical deposition from the gas phase in the treatment of plunger pairs of high pressure fuel pumps made of steel 25X5MA, allows to obtain a coating with high hardness, wear resistance and corrosion resistance [3]. The essence of the method is the destruction of carbon gas molecules as a result of their collisions with high-energy ions generated by high-current pulsed cathode-arc discharge on the surface of the graphite target. The products of this interaction settle on the substrate and form a wear-resistant coating. It is established that the coefficient of friction of surfaces with such a coating in the conditions of extreme lubrication is 0.10 - 0.12 and practically does not change in the presence of impurities of water and fine abrasive particles, while for surfaces without coatings the coefficient of friction increases by 1, 4 times in the presence of impurities.

In [4-6] it was shown that the preliminary application on the surface of the alloying sublayer with concentrate by the method of electroerosive doping with its subsequent remelting by an electric arc in a carbon dioxide environment allows to significantly change the performance of steel St3 in the desired direction.

Electroerosive treatment of steel 45 with a hard alloy VK6M, chromium and molybdenum with subsequent laser hardening reduces the wear intensity of coatings formed by hard alloy by 70%, and coatings formed by Cr and Mo - respectively 3.5 and 3 times, compared with untreated steel [7, 8].

An experimental study of the process of microarc cementation of steel products in powder media was carried out in [9, 10]. The use of coal powder intensifies the process of diffusion saturation with carbon and the formation of a diffusion layer up to 0.3 mm deep occurs in the course of 2...3 minutes, which reduces the cementation process by hundreds of times.

Therefore, the purpose of work consists in establishment of laws of formation of wear-resistant coverings on a steel substrate by a method of electroerosive processing providing increase of wear resistance of steel details of knots of friction of cars.

To achieve this goal it is necessary to solve the following tasks:

1. To conduct an experimental study of the influence of the chemical composition of the electrode material (anode) on the structure and phase composition of coatings formed on steel samples.

2. Investigate the dependences of microhardness and tribotechnical properties of coatings on the composition of the alloying electrode material and energy modes of electroerosive treatment.

3. By the method of contact atomic force microscopy to investigate the influence of the composition of the material of the alloying electrodes and the modes of electroerosive treatment on the dimensions of the structural elements of the formed coatings and the roughness parameters of the treated surface.

4. Carry out an optimization study of EET modes and develop practical recommendations for the appointment of optimal technological modes of electroerosive treatment of steel 15HGN2TA, providing the highest wear resistance of metal-polymer friction pairs.

Research methodology

As an object of experimental research used structural alloy steel 15HGN2TA, which is widely used for the manufacture of gears, axles, bushings, shafts of gearboxes, multi-purpose tracked and wheeled vehicles and other equipment. To increase the mechanical properties of steel 15HGN2TA use chemical-thermal treatment followed by heat treatment, which significantly complicates and increases the duration of the technological process of manufacturing parts.

Processing of samples was carried out on installations for electroerosive processing of models IMEI-02-2-1ME8 and IMEI-1001-1ME8, providing technological modes: anode-cathode voltage i = 40-160 V; bit capacitance of capacitors C = 34-240 uF.

The surfaces of steel samples were treated with various alloying electrodes (AE): standard electrode brand T15K6 (TiC-15%, Co-6%, WC - 79%); electrode IMX21 (WC-Co-50%, Ni-Cr-B-Si-50%); electrode Sh21 with mineral raw materials of the Far East region based on scheelite concentrate (TiC-60%, Ni-Cr-Al-30%, SC (scheelite concentrate CaWO4) - 10%). The choice of alloying electrodes was made on the basis of previous studies.

The research method included the study of the influence of the material of the alloying electrode and technological modes of processing on the microhardness and thickness of the coatings formed during electroerosive processing. The microhardness of the molded surface layers was determined using a microhardness tester PMT-3M under load on an indenter of 0.49 N. The thickness of the applied coatings was determined on a horizontal optimeter IKG-3 relative measurement method.

The study of the structure and phase composition of the modified surface layer of steel 15HGN2TA after electroerosive treatment was performed by X-ray phase analysis of the initial and modified samples on a diffractometer D8 ADVANCE (Bruker) in Cu-K_{α} radiation at angles $5^0 \ldots 120^0$.

Using a scanning probe microscope NTEGRA Prima (NT-MDT) in the mode of contact atomic force microscopy (k-AFM) studied the microrelief and determined the characteristic dimensions of the structural surface elements of the initial samples and samples modified by EET different electrodes, as well as IMX2 electrode in different modes after friction and wear tests. Mathematical post-processing of the obtained results was carried out using the modular program Gwyddion.

To study the elemental composition of the initial surface of steel 15HGN2TA and surface layers modified by EET with different electrodes, as well as coatings formed by the electrode IMX2 in different modes after tribotechnical tests used a scanning electron microscope Jeol JCM - 5700 and X-ray energy dispersion spectrometer.

Studies of the characteristics of tribotechnical properties were performed on a special installation created on the basis of a desktop drilling machine according to the friction scheme "finger-disk" at a contact pressure P = 2.66 MPa and a sliding speed V = 1.20 m/s. Cylindrical fingers made of PTFE-based composite material were used as counter-samples.

Research results

From the diagrams (Fig. 1) it is seen that with increasing energy regimes EET: voltage from 80 V to 160 V and capacity from 34 μF to 240 μF, the thickness of the coatings increases with any material LE. In this case, when processing the electrode T15K6, the coating thickness increases by 48.6%, when processing the electrode IMX2 - by 75%, when processing the electrode W2 - by 83.3%.

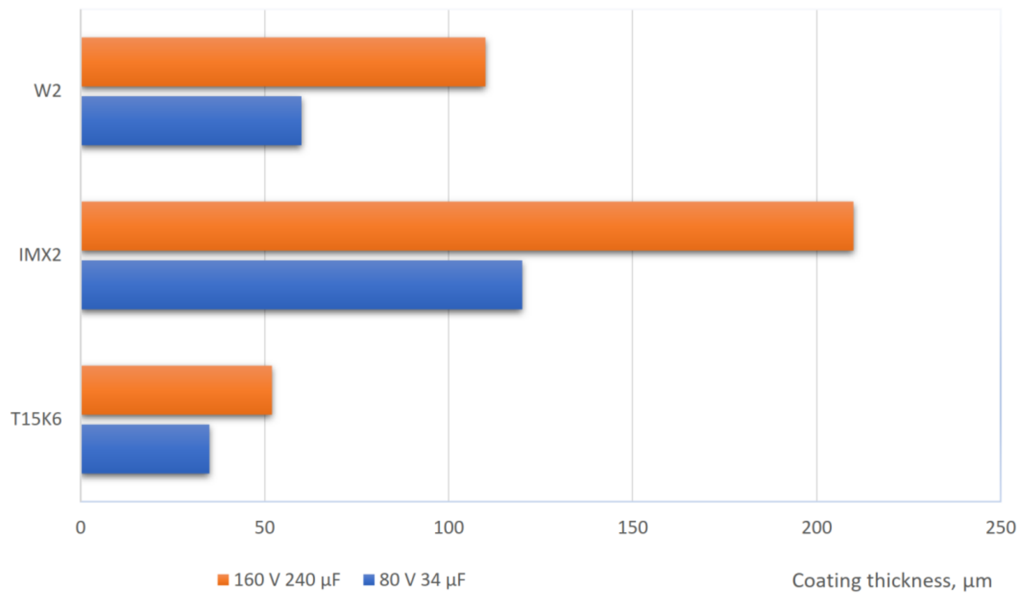


Fig. 1. The thickness of the coatings of the samples of steel 15HGN2TA with different electrode materials

The diagrams also show that when the EET electrode IMX2 based on tungsten carbide with the addition of components that form with the base material unlimited solid solutions, the largest coating thickness (210 μm). This can be explained by the fact that the introduction of boron and silicon in the composition of LE slows down the formation of oxide films in the molded structure, which has a positive effect on the continuity and increase the thickness of the coating. In addition, the introduction of boron reduces the erosion resistance of LE, as a result, increases the mass transfer of electrode material to the treated surface. The use of the electrode W2 also leads to the formation of coatings that exceed the thickness of the coatings formed by the electrode brand T15K6, 1.7-2 times. This is due to the fact that the mineral raw material (scheelite concentrate) in the electrode material creates a protective atmosphere in the EET zone, preventing the burning of erosion particles and contributing to the intensification of mass transfer of the electrode material. The obtained results allow to use EET to restore worn surfaces of precision friction pairs within 100 μm.

Analysis of experimental dependences of microhardness of coatings on 15HGN2TA steel samples, anode-cathode voltage and capacitor discharge capacity, showed that increasing energy treatment regimes differently affects the nature of changes in microhardness of coatings when changing the material of the alloying electrode (Fig. 2, 3).

The highest values of microhardness of coatings (HB 900...1080) were obtained using electrodes IMX2 and T15K6. The greatest effect of increasing the microhardness is provided by the EET electrode IMX2 with a voltage of U = 140 V and a capacity of C = 120 μF. When treated with the electrode T15K6, the maximum microhardness is obtained at a voltage U = 120 V and a capacity of C = 150 μF. A further increase in the anode-cathode voltage leads to a sharp decrease in the microhardness of the surface layer.

These results show that the elemental composition of the initial surface of the sample made of steel 15HGN2TA differs from the composition of the coatings and surface layers of the samples modified by EET by different electrodes. In the modified samples the presence of a number of elements of steel 15HGN2TA is not established: chromium, manganese and nickel at processing by the T15K6 electrode, chromium and manganese at processing by the Sh2 electrode, manganese and titanium at processing by the IMH2 electrode. The presence of tungsten (LE T15K6), oxygen (LE SH2) and silicon (LE IMH2) was established, which can be explained by the erosion of alloying elements and their low concentration in steel, as well as the interaction of electrode elements with steel.

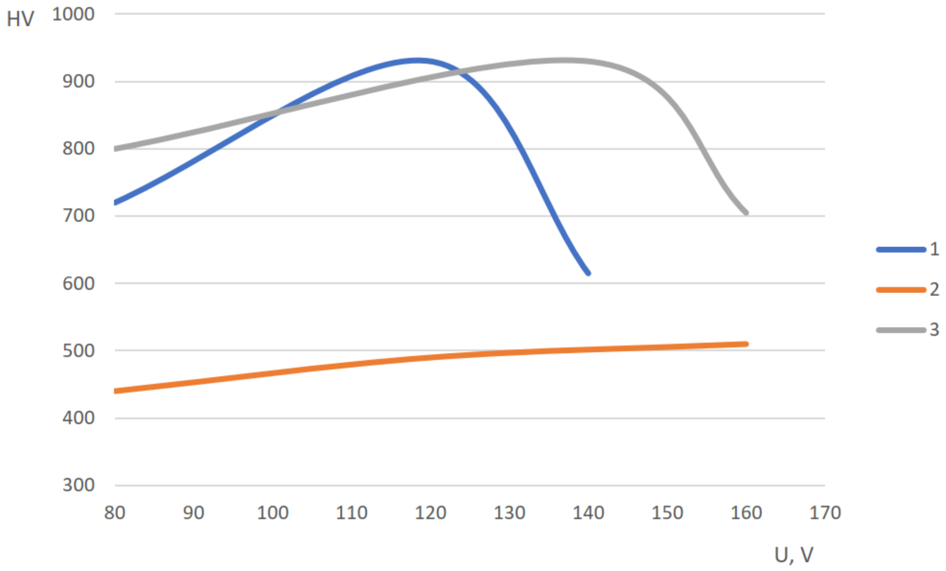


Fig. 2. The dependence of the microhardness of the surface layers of the samples modified by EET by different electrodes, from anode-cathode voltage at C = 34 µF:
1 - T15K6; 2 - W2; 3 - IMX2

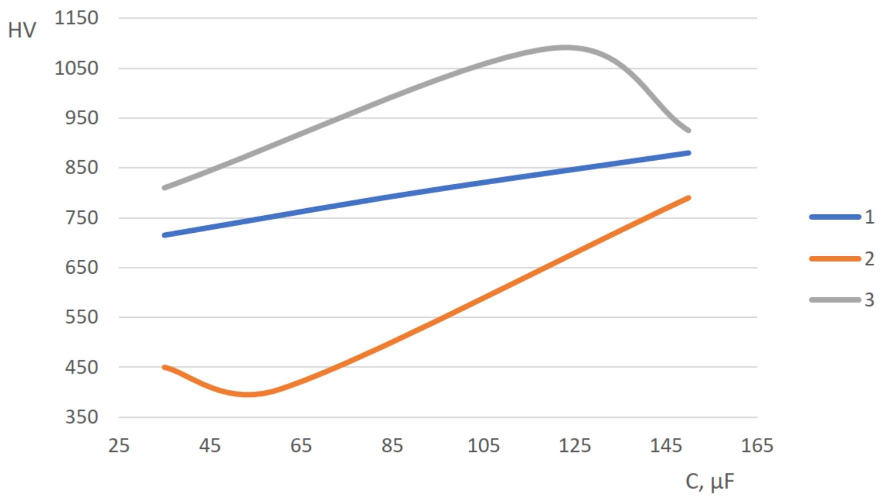


Fig. 3. The dependence of the microhardness of the surface layers of the samples modified by EET by different electrodes on the discharge capacity at U = 80 V: 1 - T15K6; 2 - W2; 3 - IMX2

Quantitative chemical composition of the initial (unmodified) sample and coatings on steel samples treated with electrodes T15K6, Sh2 and IMH2, are given in Table 1.

Table 1

Elemental composition of coatings on samples of steel 15HGN2TA

Sample	Chemical element %							
	Fe	Cr	Mn	Ni	Si	Ti	W	O
Steel 15HGN2TA (initial)	95,3	1,09	1,95	1,66	-	-	-	-
Coating of LE T15K6	54,87	-	-	-	-	12,34	32,8	-
Coating of LE IMH2	23,73	14,39	-	58,02	3,86	-	-	-
Coating LE Ш2	47,05	-	-	7,32	-	29,56	-	16,07

The study also allowed to determine the characteristic size of the structural elements (D), the height parameters of the surface roughness: the arithmetic mean deviation of the profile (Ra), the depth of the largest depression (Rv) and the height of the largest protrusion (Rp) of the sample surfaces (Table 2).

Analysis of the obtained values of the roughness parameters of the studied surfaces shows that the parameters: Ra, Rp and Rv vary depending on the electrode material. The parameters are increased in the following order: the initial state of the surface → treatment with the electrode T15K6 → treatment with the electrode W2 → treatment with the electrode IMX2 (Table 2). In this case, the parameter Ra increases by 1.5-3.9 times. The largest increase in the roughness parameter Ra to 6.3 and the RR parameter to 538.3 nm is observed when treated with the electrode IMX2. This may be due to the higher level of energy action at the EET by this electrode.

The obtained values (Table 2) of the characteristic dimensions of the structural elements of the surface show that in the modified samples in comparison with the initial state, they decrease by 8-13 times. The minimum dimensions of the parameter D are obtained by processing the electrode W2.

In order to study the effect of frictional interaction of polymer counter-samples with metal samples after their EIO on the topography of friction surfaces, a study of friction surfaces on atomic force (k-AFM) and scanning electron microscopes was performed (Fig. 4, 5).

Table 2

Surface parameters of the initial and modified samples

Sample / Parameter	Typical structure size D, nm	Ra, µm	Height of the largest protrusion of the profile Rp, nm	Depth of the largest depression of the profile Rv, nm
Steel 15ХГН2ТА (initial)	2000-2500	≈1,6	379,0	344,8
Coating LE T15K6	200-250	≈2,5	477,3	378,5
Coating LE Ш2	150-200	≈3,2	504,1	485,7
Coating of LE IMH2	250-300	≈6,3	538,3	484,4

The images of the surfaces of the samples obtained by contact atomic force microscopy show that the topography of the surfaces on the friction track and outside the track differ (Fig. 4). The figure shows that the height of surface irregularities in areas after friction is higher than in areas outside the friction track. This may be due to the formation on the surface of the samples of the friction transfer film.

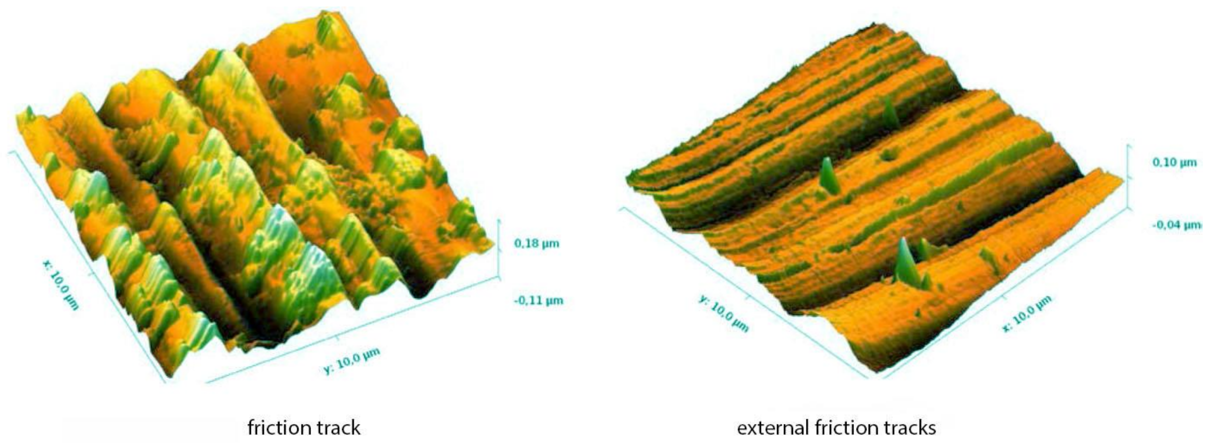
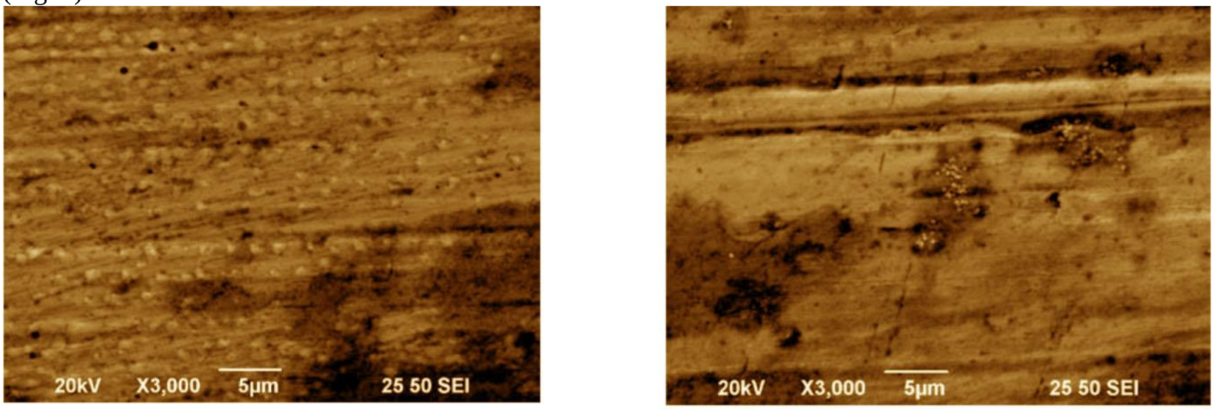


Fig. 4. Topography of the surface of the sample of steel 15HGN2TA, treated with the electrode IMX2 (U = 120 B; C = 150 µF; t = 4 min / cm^2), after friction and wear tests

In Fig. 5 shows images of surfaces after tribotechnical tests obtained by scanning electron microscopy. The surface areas of the samples on the friction track are markedly different from the surface areas outside the track. The friction transfer polymer film (FP), structured in the sliding direction, is clearly visible on the friction track section. In the area near the friction track there is an island coating without a film of AF. Thus, it was found that the frictional interaction of steel samples treated by the EET method with polymeric countersamples on the friction surface of steel samples forms a thin film of FP, which leads to a change in surface topography with increasing microroughness and structuring of the transfer film in the sliding direction.

Tribotechnical properties of steel-based structures at EET were evaluated by the wear rate of polymeric counter-samples during sliding friction on the modified surface of steel samples. Steel samples were treated with an electrode IMX2. In order to get a clear idea of the influence of the level of energy action on the wear resistance (wear rate) of the friction pair, the dependences J = f (E) were constructed according to the test results (Fig. 6).



friction track external friction tracks

Fig. 5. The surface of the sample made of steel 15HGN2TA, treated with an electrode IMX2 (U = 120 V; C = 150 μF; t = 4 min / cm^2), after tests for friction and wear

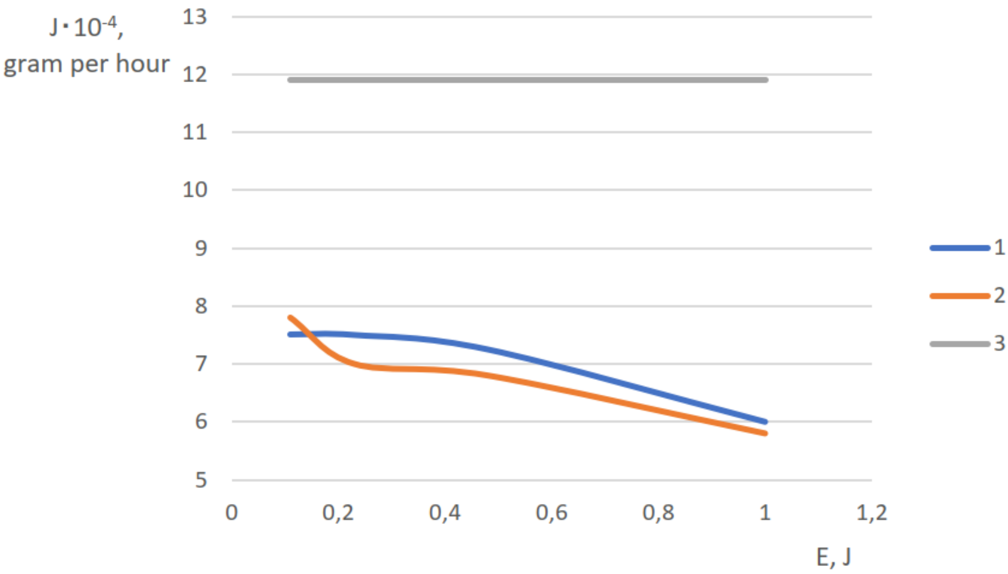


Fig. 6. Dependence of wear rate of polymeric countersamples on pulse energy at EET of samples from steel 15HGN2TA:
1 - samples with EET duration of 4 min/cm^2; 2 - samples with EET duration of 5 min/cm^2; 3 - hardened sample without EET

The obtained dependences allow us to conclude that with increasing pulse energy in the EET of steel samples, the wear rate of the polymer countersample decreases by 1.2-1.3 times. At the same time, the increase in the duration of EET has a negligible effect on the wear rate of polymeric counter samples (by ~ 3%). It was also shown that the wear rate of metal-polymer friction pair with samples modified by EET is less than this parameter in friction pairs with hardened sample, approximately 1.6-2 times.

Conclusions

By the method of X-ray phase analysis of the surfaces of the modified samples, the regularities of the formation of coatings of different phase composition depending on the chemical composition of LE are established, which consist in the fact that the phase composition of coatings is determined by the chemical composition of LE.

It is established that the thickness of the molded coating depends on the chemical composition of the material of the alloying electrode and energy regimes EET: the largest coating thickness is formed when processing the electrode IMX2, which is 4 times more than when processing serial electrode T15K6; increasing the energy modes of EET leads to an increase in the thickness of the coating regardless of the material of LE, which allows us to recommend EET electrodes T15K6, IMH2, Sh2 to increase wear resistance and restore worn surfaces of parts of the friction units of machines.

It is established that the microhardness of coatings depends on the modes of EET and the material of the alloying electrode; experimental dependences of microhardness of coatings on voltage and discharge capacitance of capacitors have extreme character with maxima at voltage U = 120-140 V and discharge capacity C = 120 uF.

The method of contact atomic force microscopy revealed a significant (8-13 times) reduction in the characteristic size of the structural elements (D) in the coatings formed by the EET by different electrodes, compared with the original (unmodified) surface. It is also established that at EET surfaces with height parameters of roughness (Ra, Rv, Rp), characteristic and commensurate with similar parameters of the surface received at finishing machining are formed. In this case, as a result of the EET electrode IMH2 there is the largest increase in the roughness parameter Ra 3.9 times, which is due to the higher level of energy action during treatment with this alloying electrode.

References

1. Dolbilin E.V. Himiko-termicheskaja obrabotka metallov v jelektricheskom razrjade / E.V. Dolbilin. – M.: MJeI, 2001. – 298 s.

2. Eighteenth International Conference on Numerical Simulation of Plasmas (ICNSP'03) and US-Japan simulation workshop "Scope of Simulation Science", 7–10 September 2003, Cape Cod, Massachusetts USA.

3. Celebration of High Temperature Plasma Physics, 5–7 June 2002, Princeton Plasma Physics Laboratory, Princeton, New Jersey USA. Contact Dolores Lawson, MS37, Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, New Jersey 08543 USA.

4. Gitlevich A.E. Jelektroiskrovoe legirovanie metallicheskih poverhnostej / A.E. Gitlevich, V.V. Mihajlov, N.Ja. Carkanskij. – Kishinev: Izd-vo AN MSSRJu, 1985. – 387 s.

5. Marchenko D.D. Improving the contact strength of V-belt pulleys using plastic deformation / D.D. Marchenko, K.S. Matvyeyeva // Problems of Tribology. – Khmelnitsky, 2019. – Vol 24. – No 4/94 (2019) – S. 49–53. DOI: https://doi.org/10.31891/2079-1372-2019-94-4-49-53.

6. Butakov B.I. Usovershenstvovanie processa chistovogo obkatyvanija detalej rolikami / B.I. Butakov // Vestnik mashinostroenija. – 1984. – № 7. – S. 50 – 53.

7. Marchenko D.D. Investigation of tool wear resistance when smoothing parts / D.D. Marchenko, K.S.Matvyeyeva // Problems of Tribology. – Khmelnitsky, 2020. – Vol 25. – No 4/98 (2020) – S. 40–44. DOI: https://doi.org/10.31891/2079-1372-2020-98-4-40-44

8. Dykha A.V. Study and development of the technology for hardening rope blocks by reeling. ISSN 1729–3774 / A.V. Dykha, D.D. Marchenko, V.A. Artyukh, O.V. Zubiekhina–Khaiiat, V.N. Kurepin // Eastern–European Journal of Enterprise Technologies. Ukraine: PC «TECHNOLOGY CENTER». – 2018. – №2/1 (92) 2018. – pp. 22–32. DOI: https://doi.org/10.15587/1729-4061.2018.126196.

9. Dykha A.V. Prediction the wear of sliding bearings. ISSN 2227–524X / A.V. Dykha, D.D. Marchenko // International Journal of Engineering and Technology (UAE). India: "Sciencepubco–logo" Science Publishing Corporation. Publisher of International Academic Journals. – 2018. – Vol. 7, No 2.23 (2018). – pp. 4–8. DOI: https://doi.org/10.14419/ijet.v7i2.23.11872.

10. Marchenko D.D. Analysis of the influence of surface plastic deformation on increasing the wear resistance of machine parts / D.D. Marchenko, V.A. Artyukh, K.S. Matvyeyeva // Problems of Tribology. – Khmelnitsky, 2020. – Vol 25. – No 2/96 (2020) – S. 6–11. DOI: https://doi.org/10.31891/2079-1372-2020-96-2-6-11.

Марченко Д.Д., Матвєєва К.С. Трибологічні дослідження електроерозійної обробки стальних деталей машин.

В статті розглянута технологія електроерозійної обробки сталевих пар тертя і приведені результати експериментальних досліджень. Аналіз експериментальних досліджень показав, що збільшення анодно-катодної напруги призводить до різкого зниження мікротвердості поверхневого шару. Виконане дослідження дозволило також визначити характерний розмір структурних елементів, висотні параметри шорсткості поверхні. Елементний склад початкової поверхні зразка із сталі 15ХГН2ТА відрізняється від складу покриттів і поверхневих шарів зразків, модифікованих електроерозійної обробки різними електродами. У режимі роботи системи «анод - катод» на поверхні катода внаслідок дисипативних процесів формується тонкий шар покриття стійкої модифікованої структури. Показано, що висота нерівностей поверхні на ділянках після тертя вище, ніж на ділянках поверхні поза доріжкою тертя, що пов'язано з формуванням на поверхні зразків плівки фрикційного перенесення. Виявлено, що при фрикційній взаємодії сталевих зразків, оброблених електроерозійним методом на поверхні тертя сталевих зразків формується тонка плівка, що призводить до зміни топографії поверхонь зі збільшенням висоти мікронерівностей і структуризацією плівки перенесення у напрямі ковзання. Встановлено вплив режимів електроерозійної обробки сталевих поверхонь на зносостійкість металополімерної трібосистеми та отримані оптимальні режими обробки: напруга U=145-150 В, місткість конденсаторів С=225-230 мкФ, тривалість обробки t=3-4 хв/см^2, що забезпечують найбільше зниження швидкості зношування полімерного контртіла і рекомендовані при розробці технологічних процесів електроерозійної обробки.

Ключові слова: знос, електрод, шорсткість, зносостійкість, пара тертя, покриття, електроерозійна обробка..

Problems of Tribology, V. 26, No 1/99-2021,74-83

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-74-83

Study influence factors of the spraying process on the properties of electric arc spraying coatings

M. Ageev[1]*, E. Solovuch[2], V. Lopata [3], O. Burlachenko[3], N. Vihilianska[3]

[1]*Kherson State Maritime Academy, Ship Power Plant Operation, c. Kherson, Ukraine*
[2]*Central Ukrainian National Technical University National technical, Kropyvnytskyi, Ukrain*
[2]*E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine*

**E-mail: beryuza@ukr.net*

Abstract

The paper considers possibilities to increase the wear resistance, corrosion resistance, and service life for parts machines and mechanisms via their hardening and renovating using electric arc coatings characterized by high density, adhesion strength, and micro hardness thanks to activation of the spraying process. Also, the possibility of controlling the properties of restored surfaces owing to choice of the related equipment with required structure and characteristics in order to prolong the service life of machinery parts is shown. The right choice of equipment for spraying makes it possible to increase the speed and temperature of the spraying gas and particles, reduce the droplet diameter, increase the density and reduce the oxidation of coatings.

The influence of spray factors such as the flow rate and pressure of working gases, composition of combustion mixture, spraying distance, dispersion of the spray, properties of wire material, etc. on the properties of the coatings obtained has been investigated. The possibility of controlling the properties of surfaces owing to choice with required characteristics electric arc coatings is shown. The influence of spray factors such as the flow rate and pressure of working gases, composition of combustion mixture, spraying distance, dispersion of the spray, properties of wire material, etc. on the properties of the coatings obtained has been investigated.

The use of coatings makes it possible to increase the wear and corrosion resistance of working surfaces of machine parts and mechanisms, in particular ship parts, and so to reduce the costs of alloyed steels and alloys. The coatings application is associated with implementation of a fundamentally new approach, according to which the strength and carrying capacity of a part is provided by its basic material, whereas the resistance to corrosion, wear, and other factors may be increased via using hardening protective coatings. There are many alternative methods for producing coatings, from which it is advisable to choose an optimal, easy to implement, and inexpensive one.

Of the variety of methods for hardening coating deposition, the most common technologies used to restore and improve the performance properties of parts are gas-thermal spraying techniques, among which the cheapest and simplest method is electric arc spraying (EAS), whose current improvement is aimed at modifying and activating the spraying process. Such combined technologies do not require additional expensive equipment and operations, which predetermines a reduction in the cost of hardening processes.

Key words: electric arc coating, wear resistance, corrosion resistance, adhesion strength, spraying process

Introduction. The state of the problem and the purpose of the research.

In the practice of restoring and hardening parts through the use of hardening protective coatings, extensive experience has been accumulated in the application of coatings by methods of gas-thermal spraying (GTS) [1-3]. The reasonability of using GTS is evidenced by the appearance of a number of special firms for manufacture of equipment and materials for spraying, for example, Metko, Wall Cobmonoy Corp. Linde Div., Union Carbide Corp. et al. [4-7]. The produced domestic and foreign GTS units [8], spray materials [6-10], and published recommendations have made it possible to solve a series of items related to the repair, restoration, and prolongation of the service life of parts [1-3].

In the development of techniques for restoration of parts, it is necessary, of all the possible GTS methods (Table 1) [4-6], to choose such one that provides the longest service life of a part and the lowest cost of its recovery as well as can be fairly versatile, simple, and easy to implement [8].

When choosing a method for GTS, it is necessary to consider the basic conditions for high-quality coating formation [4]: i) thermal effects on the part must prevent the phase or structural transformations in the base metal; ii) participation of the base metal in the coating must be negligible, and iii) in the contact zone, no relaxation process capable to change its phase composition and structure should arise.

Table 1

Characteristics of spraying modes

Parameter	Spraying mode			
	Electric arc	Gas-flame	Plasma	Detonation
Efficiency, kg/h	3 - 31	1 -10	0.5 - 8.0	0.1- 6.0
Coefficient of material	0.8 -0.9	0.8 -0.95	0.4 -0.9	0.3 - 0.6
Adhesion strength, MPa	to 40	to 50	to 60	to 200
Temperature of part heating , °C	100-150	100-150	150 -200	100-150

From the standpoint of these conditions, the use of electric arc spraying (EAS) is promising [9, 10]. EAS is widely used in the European countries and displaces the traditional gas-flame method [7]. This is due to the simplicity of the equipment, the availability of energy source for metal melting, higher thermal efficiency, which reaches 57% compared to 13 and 17% for gas and flame spraying [9, 10].

Despite the large number of innovations concerning electric arc spraying (EAS), researches on the improvement of this method and required equipment are actively being carried out and has become aimed at activating the spray process using various techniques, methods, and devices [11-13]. The spray process activation is the basis for improving the technology and equipment for deposition of high-density wear-resistant layers. In practice, the following procedures for spray process activation have been implemented [11-13]:

- intensification of mixing working gases;
- provision of sprayed particles and the substrate with additional energy *via* heating them;
- diminution of the sprayed particles size;
- activation of the particle and the substrate surfaces by mechanical methods (increase in roughness) or by reduction of oxides;
- increase in the enthalpy of the spray flux by introducing thermo-reactive components;
- coating with the use of external effects (ultrasonic waves, electromagnetic fields, etc. [14];
- heat treatment [15, 16] or chemical heat treatment of coatings [17, 18], etc.

On the basis of studying the problem of hardening and restoring parts of the using electric arc spraying (EAS) coatings, the aim of the work was set up to increase the wear resistance and service life of parts via combining electric arc spraying (EAS) coatings characterized by high density, adhesion strength, and microhardness due to the activation of the spray process and nitriding of the coatings sprayed.

The influence of choice of design parameters for of electric arc spraying equipment on the factors of spray process and properties of coatings

The quality of electric arc spraying (EAS) coatings used for renovation and hardening of the working surfaces of parts markedly depend on the technical characteristics of the equipment used.

Currently, there is in operation a wide range of power sources and devices for spraying produced by various companies [19-22]. However, a comparative analysis of the influence of the main technical characteristics of spray units and power sources on the physicomechanical properties of the coatings obtained has not been carried out; and no science-based recommendations on the use of electric arc spraying (EAS) equipment have been made. The above reasons make it difficult to choose the right equipment for electric arc spraying (EAS) that could provide high performance and quality of the recovered parts. This paper presents the characteristics of the most used units and analysis of them in order to ensure their correct choice. The characteristics of the power source and the design of an apparatus for an electric arc determine such electric arc spraying (EAS) factors as the welding current; the type, pressure, and flow rate of the spraying gas; the diameter and shape of the nozzle, and the scheme of a blowing system. To create electric arc spraying (EAS) coatings, units with various blowing systems and nozzle geometry are used [23, 24]. Currently, there are several schemes for the formation of the metal-air flow for electric arc spraying (EAS), namely diaphragm, central-nozzle, differential, and closed ones. In particular, the most widespread diaphragm scheme is used in the manufacture of electric arc spraying (EAS) units at the Barnaul plant (Russia) and firms "Metco" and "Mogul" (the United States). For this scheme, formation of a fairly wide metal-air flow is characteristic. The use of it is effective for obtaining anti-corrosion coatings. The central nozzle scheme is used in the electric arc apparatus EM-17 (Barnaul), where a narrow metal-air flow is created, which is particularly efficient for coating of bodies of revolution, for example shafts, including crankshafts [23, 24].

At the Physical-Mechanical Institute (PMI) of NAS of Ukraine (Lviv), through improving the design of electric arc spraying (EAS) equipment and increasing the protective-energy level of the spray arc flame, the problem of increasing the physicomechanical properties of coatings was solved by weakening the dispersed metal oxidation in the spray flame and increasing the velocity of particles [23, 24]. In order to improve the quality of coatings, an electric arc apparatus with a spray head was used [23,24], which was based on a closed scheme for the formation of metal-air flow. Such a scheme is used in the units manufactured by the GMP "Gasothermic" at PMI of NAS of Ukraine. The advantages of EM-14 units with a closed scheme and a differential nozzle over an open scheme and a central nozzle are considered in [24]. The closed scheme of metal-air flow formation allows the manufacture of extremely fine fractions of sprayed particles (below 50 μm) thanks to their high flight velocity (50-130 m/s) from the burning arc zone to the surface being restored (Fig. 1, a, b). Such a spray scheme should be used when the need arises in fine-particle (50 - 200 μm) coatings *via* spraying wires that include refractory components. If the metal-air flow scheme is closed, the arc burns in a channel bounded with the spray head of the electric arc spraying (EAS) apparatus. This scheme realizes its advantages when the arc cross section size becomes commensurate with the cross section of the cylindrical channel where it burns. The closed metal-air flow scheme allows two deposition modes: continuous and pulsed. Upon reducing the diameter of the nozzle cylindrical part, the pressure in the nozzle may become equal to that in the arc gap. With this, cold air may actively penetrate into the arc burning zone and so help decrease its length. When the arc length decreases so much that the melt can close the arc gap, a pulsed mode is realized. The pressure in the arc markedly depends on the nozzle diameter and arc power.

It was established experimentally that the larger the nozzle diameter, the greater the arc power should be in order to realize the pulsed mode of the electric arc apparatus operation. When the pulverization apparatus is in the pulsed mode, the wire tips become parallel. The liquid phase closes the tips, and the reycotron effect is realized, which is manifested in the fact that an electrodynamic force acts parallel to the surfaces of wires, which melt in the gaps between the two parallel wires-electrodes. The melt is ejected from the gap by electrodynamic forces, and after a pause the cycle repeats. The frequency of emissions depends on the wire feed speed. Portions of the liquid metal receive an additional impulse owing to the reycotron effect, which increases the velocity of particles and contributes to the melt dispersion.

The use of the closed scheme for the formation of metal-air flow during EAS [23, 24] allows production of coatings with a density of over 90% and adhesion strength to 180 MPa. The maximum size of sprayed particles does not exceed 50 μm. Thus, the EM-14 spraying system (Fig. 1, c), which provides arc burning in a channel bounded with the nozzle walls or in the formed flow of pressing air, makes it possible to produce droplets with a high flight velocity, which improves the properties of the surfaces being restored.

a, b) c) d)

Fig. 1. Dependence of the velocity of metal particles on their size for different modes of metal-air flow formation (a, b): central nozzle scheme (a) and closed scheme (b); apparatus EM-14 for electric arc spraying (c); d) unit for electric arc spraying (EAS) with a propane-air combustion chamber

In the apparatus EDM-6GD designed by the Mariupil State University and the company TOPAZ, spraying is performed with gas-dynamic dispersion of metal and using an external chamberless combustion scheme. Here the energy source (electric arc and compressed air) is replaced by an electric arc and a fast jet of the products of liquid hydrocarbon fuel combustion [25]. This design allows reduction in the oxidation potential of the medium compared to air by twice and improvement in the properties of surfaces restored. The adhesion strength of coatings increases by 56% and hardness by 18%, while the porosity of coatings decreases by 2.6 times. At the same time, the cost of the electric arc spraying (EAS) process decreases thanks to the replacement of cored wires with 2-3 times cheaper standard solid-drawn ones.

The units for electric arc spraying (EAS) produced by NPOOO "MAD" (Minsk) combine the advantages of electric arc and fast spraying [19-22] (Fig. 1, d). The main distinguishing feature of the electric arc spraying (EAS) unit is the presence of an efficient small-sized chamber for propane/air mixture combustion. A fast jet of the combustion products leaves it with a speed of 1500 m/s at the outlet. The unit operates on the basis of melting wires by an electric arc and spraying molten wire droplets with the fast jet of combustion products. It requires supply of compressed air with pressure from 0.6 to 0.8 MPa and propane with pressure from 0.3 to 0.45 MPa as well as a source of welding current with a “hard” voltage-current characteristic (of the “VDU-506” type). By varying the consumption of propane and air, it is possible to create a neutral or reducing atmosphere in the melting zone of the electrode wire and thereby to weaken metal oxidation and burnout of alloying elements [19–22]. Moreover, the design features of such units make it possible to increase the velocity of sprayed material particles and the coefficient of material utilization to 0.85; herein the jet angle does not exceed 10°. The EAS-10 unit has an electric drive which provides the required speed of wire electrode feed. It is powered from a three-phase network of 220 V, frequency 50 Hz [22]. In the case of using an alternating current, the electric arc burning proceeds with periodic interruptions that occur as a result of the voltage drop. The power supply for the electric arc apparatus with a direct current forms the necessary conditions for obtaining coatings with a uniform thickness. Analysis of the research results made it possible to recommend the EM-14 apparatus (Fig. 1, c) and the EAS-10 unit (Fig. 1, d) for deposition of EAS coatings. The proper management of the design parameters of equipment for electric arc spraying (EAS) provides the creation of coatings with high performance characteristics, which is very important for increasing the service life of parts. Thus, the work shows the possibility, through the selection of design parameters and characteristics of equipment for electric arc spraying (EAS), to control the properties of coated surfaces in order to increase the service life of restored parts. The right choice of equipment for electric arc spraying (EAS) allows one to increase the speed and temperature of the jet of spraying gas and particles, decrease the size of droplets, increase the density and reduce the oxidation of coatings. Additionally, it has made it possible to use standard solid-drawn wires from martensitic steels 40Kh13 and 95Kh18 and austenitic steels Kh18N10T and 12Kh18N10T instead of more expensive cored wire FMI.

Study influence factors of the spraying process on the properties of electric arc spraying coatings. Control of structure formation processes in sprayed coatings

A distinct feature of the martensitic and austenitic steels is the ability for phase transformations and structural changes during deposition and processing of coatings, which results in improving the physicomechanical and operational properties of hardened surfaces. The process of restoration of surfaces *via* electric arc spraying (EAS) coating is divided into three main stages: surface preparation, coating, and subsequent treatment of the surface coated. Studies of the effect of the average particle size of spray wires from 20Kh13, 12Kh18N10T, and nichrome on the physicomechanical properties of coatings revealed that coatings made from steel wires show a decrease in adhesion with increasing porosity, whereas nichrome does not obey this rule. Comparative tribological tests were conducted for coatings from steel 40Kh13. For comparison, samples from rolled steel 40Kh13, which was pre-quenched and tempered at 970 K for 5 h (H_v = 27 GPa), were tested as well. Under friction without lubrication, an adhesion interaction of the coating material with the counterbody occurs, accompanied by a tear and intense weight wear of the coupling materials (Fig. 2).

As seen in the figure, the curve of accumulated weight wear of tempered steel has a characteristic stage of running-in and a steady wear stage with almost linear dependence of the weight wear on the friction path. For electric arc spraying (EAS) coatings, the stages of steady wear periodically alternate with the relatively short-term stages of accelerated wear, i.e., wear of electric arc spraying (EAS) coatings is pronouncedly cyclical (Fig. 2). The highest averaged weight wear rate was 0.41 mg/m (Table 2).

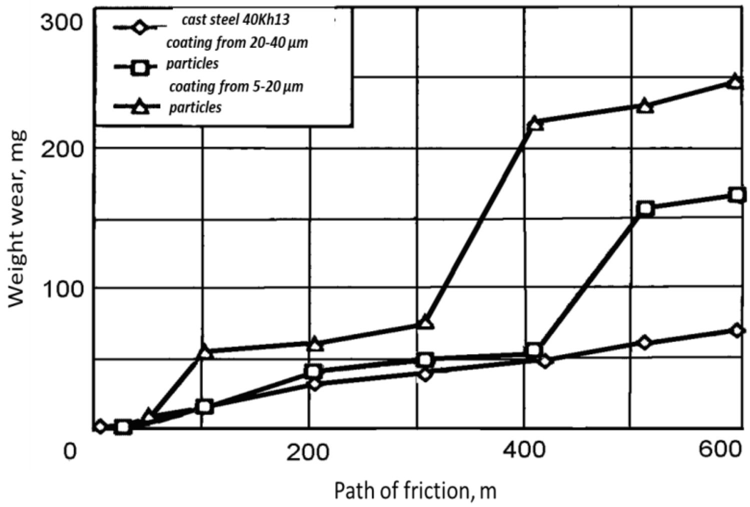


Fig. 2. Dependence of the weight wear on the friction path for electric arc spraying coatings from steel 40Kh13 (friction without lubrication, pressure 1.5 MPa, counterbody from hardened steel 60)

Table 2.

Wear rate and coefficient of dry friction for electric arc spraying coatings and tempered cast steel 40Kh13

Material	Wear rate, mg/m	Coefficient of friction
Cast steel 40Kh13	0.11	0.80 – 0.92
EAS coating	0.28	0.85 – 0.95
EAS coating	0.41	0.95 – 1.05

A number of researchers have noted that the structure of coatings obtained by spraying the same wire material by different modes can differ not only in the number of pores, but also in the phase composition [19-21, 26-29]. This paper presents the results of studies of the structural features of electric arc spraying (EAS) coatings. As spray materials, 40Kh13 wires with a diameter of 2 mm were used. Spraying was performed using an apparatus for electric arc spraying (EAS) in the following modes:

- mode 1: spaying of metal melted in an electric arc with a reactive jet of combustion products of propane/air mixture with an excess of propane (reducing atmosphere);
- mode 2: spraying of metal melted in an electric arc with a reactive jet of combustion products of the propane/air mixture with an excess of air (oxidizing atmosphere);
- mode 3: spraying of metal melted in an electric arc with a fast air jet.

To improve the adhesion of coatings to a steel 3 substrate, an intermediate layer from alloy Kh20N80 was created. The velocity of molten particles was 120–130 m/s (modes 1and 3) and 400–500 m/s (modes 1 and 2). The sizes of the particles from which the coatings were formed fell in the range of 5–40 μm. The dominant amount of oxides was formed as a result of the molten particles/air contact. In the work, the effect of the spraying air flow rate on the amount of oxygen in the coatings obtained by electric arc spraying (mode 3) was studied (Fig. 3). Here the oxygen content in electric arc spraying (EAS) coatings was 2.5–3 times that in gas-flame ones (Fig. 4), with achieving the maximum concentration 3.8% at flow rates of about 0.5 m^3/min.

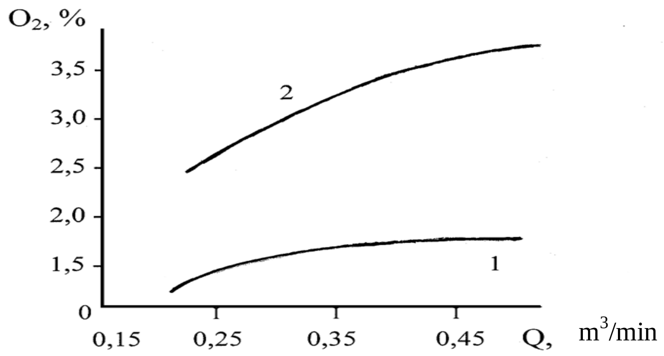


Fig. 3. Influence of the flow rate of spraying air on the oxygen content in coatings obtained by (1) mode 2 and (2) mode 3.

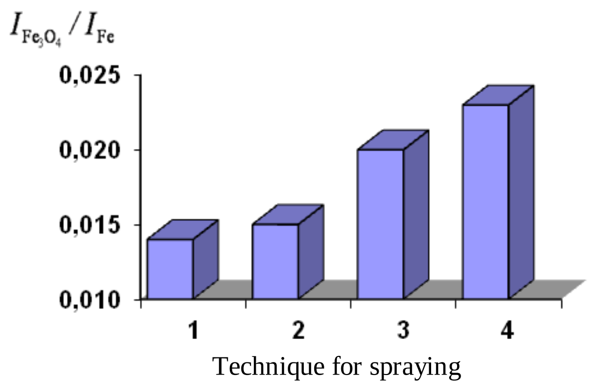


Fig. 4. The relative content of Fe_3O_4 in coatings obtained using: (1) gas flame; (2) activated EAS in a reducing atmosphere; (3) activated EAS in an oxidizing atmosphere; (4) spraying with air.

An XRD analysis (diffract meter DRON-3.0, monochromatic CoKα radiation, V = 30 kV, I = 10 mA) revealed that the phase composition of the coatings includes: α-phase (martensite), γ-phase (austenite), oxides Fe3O4, γ-Fe2O3 (traces), and Cr2O3 (traces) (Fig. 5). The hardness of the coatings obtained using various spray schemes was within the HV range of 2800 - 3500 MPa.

Activation of electric arc spraying (AEAS) in a reducing atmosphere leads to the formation of dense coatings with a porosity of 2 - 5% and hardness HV = 3000 MPa, characterized by low content of residual austenite (Vγ ≈ 20 vol%) and oxides. The lattice parameters of martensite and austenite are aα= 0.2875 nm and aγ= 0.3592 nm, respectively.

Activation of electric arc spraying by a reactive jet with an excess of air provides the formation of a layer with a porosity of 2 - 5% and hardness HV = 3500 MPa, characterized by substantial content of oxidation products. The content of residual austenite in the coating is Vγ ≈ 20 vol%. The lattice parameters of martensite and austenite are aα= 0.2875 nm and aγ= 0.3592 nm, respectively.

Coatings obtained by spraying with air had a hardness of HV=3200 MPa and a residual austenite content of Vγ≈18 vol% at the porosity 6–8%. The XRD data fixed the highest concentration of oxidation products in the coating after electric arc spraying (EAS) with air. Lattice parameters were aα = 0.2875 nm and aγ= 0.3596 nm for martensite and austenite, respectively.

The results of the study of the phase composition and hardness of coatings from steel 40Kh13 indicate the influence of the deposition technique on the structure and properties of the layer obtained. A distinctive feature of deposited layers is the presence of an anomalously large amount of residual austenite (up to 30 vol%) and oxides. Generally, the content of residual austenite in hardened steel 40Kh13 does not exceed 3 - 5 vol% [26-29].

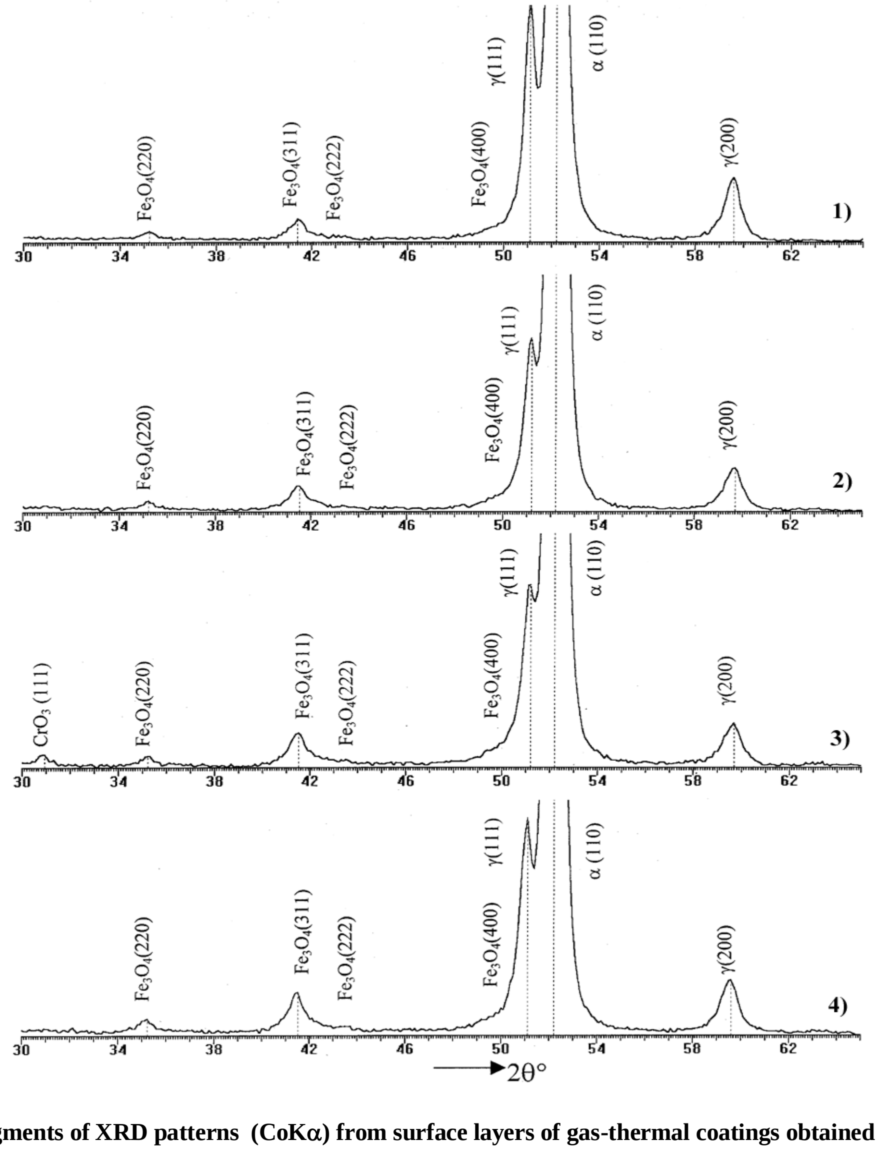


Fig. 5. Fragments of XRD patterns (CoKα) from surface layers of gas-thermal coatings obtained under modes 1-4.

One of the reasons for the appearance of the "austenitic effect" in coatings is a higher concentration of alloying elements (chromium and carbon) owing to the complete dissolution of chromium carbides during melting of the wire and saturation of the molten droplets with carbon from the propane flame. This is confirmed by the absence of Cr23C6 carbide particles in the coating. While analyzing the causes of austenite stabilization in the layer, one should keep in mind that under spraying surface layers are heated to 500–670 K. As a result, the sprayed coating undergoes isothermal aging at 520–670 K during its formation and cooling, which promotes thermal stabilization of austenite [26-29]. A factor that increases the stability of austenite in the sprayed layers is saturation of the molten droplets with carbon during melting and spraying with propane flame (Table 3).

The low velocity of molten steel particles and high concentration of carbon-containing propane in the combustion products contribute to a deeper saturation of molten droplets with carbon.

These circumstances are associated with a high content of residual austenite in coatings obtained by the gas flame procedure (technique 1).

The smaller amount of austenite in coatings obtained by activation of electric arc spraying (AEAS) in the reducing atmosphere of the spray torch (technique 2) is due to the higher flight velocity of the molten particles, which is characteristic for this technique.

In this case, the processes of diffusion saturation of the droplets with carbon from the reducing atmosphere of the products of propane/air mixture combustion do not have enough time to complete (flight time of molten droplets in the atmosphere of combustion products is not more than $5\ 10^{-4}$ s), and the content of residual austenite in the layer decreases to ~ 20 vol%. An increase in the oxygen concentration in the mixture is not accompanied by change in the amount of residual austenite in the coating obtained under conditions of supersonic velocities of molten particles (technique 3) and at relatively low particle velocities (technique 4). In both cases, the content of residual austenite in the layer does not exceed 20 vol%.

The carried-out studies made it possible to conclude that for electric arc spraying (EAS) there are such regimes and steels that can provide the formation of a large amount of metastable austenite in the coatings, which during the performance of the tribocoupling will turn into martensite.

Table 3

The influence of the composition of combustion mixture forming the spray on the carbon and oxygen contents in electric arc spraying (EAS) coatings from steel 40Kh13

Technique of spraying	Air/propane volume ratio in mixture	Oxygen content in coatings, %	Carbon content in coatings, %
1	(Gas flame) propane/oxygen ratio 1/4	1.3	0.6
2	Activation of electric arc spraying (AEAS) 18	1.4	0.5
3	Activation of electric arc spraying (AEAS) 30	2.2	0.4
4	Activation of electric arc spraying (AEAS) clean air	3.3 – 3.5	0.4

The experiments established a relation between the temperature of the beginning of martensitic transformation, T_M, for the wire material and the amount of metastable austenite formed in the resultant coating (Table 4) [26-29].

In steels of group 1, as well as in corrosion-resistant martensitic steels, the temperature T_M is within 550 - 700 K. When spraying wires from these steels, the volume content of metastable austenite reaches 45%.

Table 4

Metastable austenite content in electric arc spraying (EAS) coatings obtained by spraying various steel grades

Group of steels	Steel grade	Temperature, T_M, K	Temperature of heating under spraying, K	Content of austenite in coating, vol%
1	09G2S, 40KhN, 20Kh13, 40Kh13	550–700	1700-2000 2100-2500 > 2600	25-45 17-20 < 6
2	9KhS, Kh12MF, 9Kh12, Kh6VF, 35KhNM, 40KhFVA, 65G	420–540	1700-2100 2200-2500 > 2500	15- 25 8 -12 < 6
3	08Kh18N10, 12Kh18N10T, 110G13	70–110	1700-2000 2000-2500 > 2500	95 - 98 90 - 95 90 - 95

In the case of spraying wires from steels of the first two groups, the preservation of a large amount of metastable austenite can be prescribed to the high rate of crystallization of steel particles in the course of forming the sprayed layer and slowing down its cooling rate in the martensitic transformation region. The decrease in austenite stability in coatings from steels of the third group, sprayed over 2500 K, is explained by the effect of manganese and chromium contained in the steel on the temperature range of its martensitic transformation. Thus, a decrease in the manganese content from 5% to 1% leads to an increase in the temperature from 270 to 470 K [26–29]. In this regard, one of the possible ways to increase the T_M temperature is reduction in the chromium or manganese content in the austenitic phase of steels by oxidizing it during spraying.

Conclusions

The present work recommends to increase the wear resistance, corrosion resistance, and service life of SMM parts *via* hardening and renovating them using combined electric arc spraying EAS coatings characterized by high density, adhesion strength, and microhardness due to activation of the spraying process and subsequent nitriding of the coatings sprayed.

It has been shown that by properly choosing design parameters and characteristics of equipment for electric arc spraying EAS, it is possible to control the properties of restored surfaces in order to increase the service life of parts. The right choice of equipment for spraying will allow one to increase the speed and temperature of the jet of spraying gas and molten particles, decrease the droplet diameter, increase the density, and reduce the oxidation of coatings.

Moreover, the phase composition and microhardness of coatings obtained by spraying wires from austenitic and martensitic steel were investigated. The presence of an abnormally large amount of residual austenite (to 50 vol%) in coatings from martensitic steel was established.

Studies of the resistance to fatigue failure showed that coatings deposited by electric arc spraying (EAS) of wires provide a slight decrease in the fatigue strength limit to 10–13% (for comparison, coatings obtained by vibro-arc surfacing reduce the fatigue limit by 35–40%).

In the course of tribological tests, the wear of sprayed coatings was established to be cyclical. The cyclicity of weight wear of sprayed coatings is associated with the degradation of their surface layer under friction, described in terms of physical mesomechanics of solids.

References

1. Ageev M.S. Protective and hardening coatings in ship building and repair / Ageev M.S, Volkov Yu.V., Chigrai S.L. // Bulletin KhDMA - Kherson:. 2 (13). 2015. P.110-124.

2. Ageev M.S. Welding and related processes in ship building / Ageev M.S., Volkov Yu.V., Chigray S.L. // “Water Transport” Kyiv, №2 (24), , 2015. P. 15-26.

3. Kornev A. Development of strategy for repair of tribocouplings of large-sized parts using gas-thermal spraying in ship repair: Thesis. N. Novgorod, 2006. – 23 p.

4. Iliuschenko A.F. Formation of gas-thermal coatings: theory and practice / Iliuschenko A.F. Okovity V.A., Kundas S.P., Formanek B. - Minsk, 2002.

5. Theory and practice of gas-thermal spraying / Vitiaz P.A., Ivashko V.S., Manoilo E.D. and others. - Minsk: Science and Technology, 1993. - 295 p.

6. Gas-thermal spraying / L.Kh. Baldaev et al. - Market DS, 2007. 344 p.

7. Kharlamov Yu.A. Thermal spraying of coatings and ecological compatibility of production, operation and repair of machines / Yu.A. Kharlamov // Heavy engineering- №2. 2000 - P. 3-10.

8. Kondratiev V.A., Kondratiev M.V. Choosing a rational recovery method. Innovative technologies and equipment of the machine-building complex: Coll. scientific works. Issue 4. Voronezh: 2005, P. 35-38.

9. Boronenkov V.N., Korobov Yu.S. Fundamentals of arc metallization. Physicochemical regulairities. USU; Yekaterinburg: Univ. Publ. house 2012, 267 p.

10. Zagorsky Ya.V. The mechanism of electric arc hardening of low- and medium-carbon steels. Congress materials. Ufa: Mir pechati, 2003, 105 p.

11. Korobov Yu.S. Efficiency of using activated arc coating metallization / Yu.S. Korobov // Welding Production., No. 2. 2005. P. 47-50, 62, 64.

12. Priadko A.S., Korobov, Yu.S., Lukanin V.L. Activated arc metallization: the characteristics of the equipment and its application // Films and Coatings 98: Proc. 5th Inter. conf. Saint-Pb. 1998. P. 249-251.

13. Belotserkovsky M.A. Technological features and areas of using hypersonic metallization / M.A. Belotserkovsky, A.S. Pryadko, A.E. Cherepko // Innovations in mechanical engineering: Coll. of papers. Minsk, OIM NAS Belarus. 2008. -P. 479 - 484.

14. Vitiaz P.A., Azizov R.O., Belotserkovsky M.A. Hardening of gas-thermal coatings. - Minsk: Bestprint, 2004. - 192 p.

15. Glebova M.A., Kornev A. B., Glebov V.V. *et al*. Improving the quality of gas-thermal coatings by heat treatment with high-frequency currents and a laser beam // Welding Production № 6, 2004. P.43-46.

16. Sokolov Yu.V., Sadova M.A., Popok, D.A. Heat treatment of sprayed coatings / Vest. Belarus tech. inst. № 3, 2004. - P. 40-41

17. Improving the quality of gas-thermal coatings from wire materials by means of chemical heat treatment / P.A. Vitiaz, R.O. Azizov, M.A. Belotserkovsky, V.A. Kukareko // Friction and wear. - Vol. 24, No. 6. 2003. - P. 666–672.

18. Belotserkovsky M.A. Hardening by chemical heat treatment of coatings obtained by fast spraying steel wires / M.A. Belotserkovsky, V.M. Konstantinov, G.A. Tkachenko // Surface Engineering, Welding: Proc. Int. Symp., Minsk, 2009. P. 178–184.

19. 33. Priadko A.S., Dudan A.V., Brusilo Yu.V., *et al*. Choice of equipment for hardening and restoring automotive transport parts by arc spraying. Polotsk, Bull. of Polotsk State University. 3, 2014, P. 121-126.

20. 34. Brusilo Yu.V. Choice of equipment for hardening and restoring parts of piston engines by arc spraying. J. "Aerospace Engineering and Technology" Kharkiv. No. 4 (71), 2010. P. 38-42.

21. 35. Karp I.N., Petrov S.V., Rudoi A.P. Installation for arc metallization in a supersonic flow of natural gas combustion products // Welding Production, 2, 1991. P. 22-23.

22. 36. Device for fast spraying (versions) / Belotserkovsky M.A, Priadko A.S., Cherepko A.E. // Patent of Belarus No. 4365, Publ. 03/30/2002.

23. Pokhmursky V.I. Protective and restorative electric metallization of coatings from cored wires // V.I. Pokhmursky, M.M. Student, V.S. Pikh // New processes and equipment for gas-thermal and vacuum coating: Coll. of papers "Electric welding"- Kyiv, 1990. P. 66 - 69.

24. Student M.M. Development of old and new electrometallic coatings to cover powder darts: Thesis. Lviv, 1998 - 18 p.

25. Ageev M.S. Restoration of ship pump shafts using a combined method of applying protective coatings / Ageev M.S., Kozhevnikova E.E, Lopata V.N. // Science Bulletin KhDMA - Kherson: 2015, No. 2 (13). - P. 4-16.

26. Buriakin A.V., Kuzmin A.V. Electric arc metallization with metal spraying by combustion products of hydrocarbon fuels // Welding Production, 3, 1993. P. 7-9.

27.. Belotserkovsky M.A. Structural anomalies in steel gas-thermal coatings and the possibility of their use / M.A. Belotserkovsky // Strengthening Technologies and Coatings, 10, 2008. P. 39-44.

28.Vitiaz P.A, Belotserkovsky M.A., Kukareko V.A., *et al.* Structure and properties of coatings from steel 40Kh1 produced using various methods for gas-thermal spraying // Physical mezomechanika.-, V.5, No. 1. 2002 P. 15-22.

29. 40. Potekhin B.A., Lobanov M.N., Nasedkina E.M. Influence of unstable austenitic structure of steel 9Kh18 on cavitation and abrasive resistance // Phys.-chemical mechanics of materials, , 2. 1976. P. 116-118.

Агеев М. С., Солових Е.К., Лопата В. Н., Бурлаченко А.Н., Вигилянская Н.В. Дослідження факторів процесу напилення на властивості електродугових покриттів

В роботі запропоновано підвищувати зносостійкість, корозійну стійкість і термін служби деталей машин і механізмів при їх відновленні і зміцненні ЕДН-покриттями з високою щільністю, міцністю зчеплення і мікротвердістю за рахунок керування параметрами процесу напилення та його активацією.

В роботі розглянута можливість за рахунок вибору конструктивних параметрів і характеристик обладнання для ЕДН керувати властивостями відновлених поверхонь з метою підвищення ресурсу деталей машин. Правильний вибір конструкції обладнання для напилення дозволить збільшити швидкість і температуру струменя транспортуємих газу і частинок, зменшити діаметр крапель, підвищити щільність і знизити окислюваність покриттів. В роботі виконані дослідження впливу чинників процесу електродугового напилення: витрати і тиску робочих газів, складу горючої суміші, дистанції напилювання, дисперсності розпилення, властивостей матеріалу дроту і ін.

Ключові слова: покриття, отримані електродуговим напиленням, процес напилення, зносостійкість, корозійна стійкість, міцність зчеплення, щільність

Problems of Tribology, V. 26, No 1/99-2021,84-88

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-84-88

Evaluation of the suitability of introduction of multifunctional samples of aviation ground equipment in aircraft maintenance

O.N. Bilyakovych[1*], A.N. Savchuk[2], Y.A. Turitsa[2], L.V. Kurbet[1]

[1]*National Aviation University, Kyiv, Ukraine*
[2]*National Transport University, Kyiv, Ukraine*

**E-mail: oleg65@voliacable.com*

Abstract

Quite often there is an oversaturation of the platform with ground aircraft, which is designed for the operation of modern international airports, especially in the so-called "rush hour". The emergence of such a situation may affect the emergence of risks in the implementation of airport technologies, which are associated with a probable reduction in the level of safety of ground vehicles on the platform, the formation of clusters of aircraft maintenance at the parking lot and the possibility of damage to aircraft on the ground, psychological stress aviation personnel and other unforeseen situations.

To avoid melon situations that are directly related to the possible danger at airports, it is necessary to use multifunctional models of aviation ground equipment, which will provide several technological processes for ground handling of aircraft, passengers, mail and cargo by creating hybrid structures of special vehicles and equipment. and automation. For example, the use of multifunctional telescopic ladders allows not only to ensure a high level of comfort when boarding / disembarking passengers in aircraft, but also significantly increase the parking space in the buffer area of ground maintenance of aircraft for other types of ground aircraft by reducing the latter, which will increase the level of safety of aircraft maintenance and economic efficiency in the activities of airport services and handling companies.

Key words: aeronautical ground equipment, multifunctional ant samples, hybrid designs of special vehicles and means of mechanization and automation, multifunctional telescopic ladders.

Presentation of the main material

During the operation of modern international airports, especially during the so-called "rush hour", the platform is often oversaturated with aircraft ground equipment (AGE), designed for technical and commercial maintenance of aircraft (AIR). This situation can lead to additional risks in the implementation of airport technologies associated with the likely reduction in the level of safety of ground vehicles on the platform, the accumulation of aircraft maintenance at the parking lot, the possibility of damage to aircraft on the ground, psychological stress of aviation personnel, etc. [1].

One of the ways to overcome the above dangers at airports is the use of multifunctional AGE models that can provide several technological processes for ground handling of aircraft, air passengers, mail and cargo by creating hybrid designs of special vehicles and mechanization and automation.

The number of types and units of AGE involved in platform service is determined primarily by the volume of passenger and freight traffic in accordance with the seasonal schedule and daily flight plan of the aircraft, taking into account the requirements of airlines for the appropriate level of quality and efficiency of work, service air passengers, etc.

It is known that the number of types of AGE, which ensures the implementation of airport technology, is calculated by ten, not to mention the number of units for each type that can be simultaneously involved in platform work. The most common types of AGE include:

- refuelers;

• aerodrome power supplies;
• aerodrome air conditioners;
• airfield tractors;
• passenger ladders;
• platform buses;
• container loaders;
• road trains from freight or container carts, etc.

The process of ground maintenance of the aircraft, illustrated in fig. 1, involving different types of AGE, can be optimized by reducing the units of ground equipment, which can be replaced by stationary equipment mounted, for example, on a telescopic ladder (passenger landing gallery).

It is well known that passenger landing galleries (PLG) are designed for boarding (disembarking) of passengers directly from the terminal building to the cabin of the aircraft without access to the platform, bypassing intermediate vehicles. Typically, such structures are installed at airports with a volume of passenger traffic exceeding 2 million passengers per year.

Currently, the evolution of the use of PLG is associated with the expansion of their functionality, which is confirmed in the developments of leading manufacturers of this type of AGE. In this regard, it is worth mentioning such companies as FMC (USA), CIMC (China), FMT (Sweden), which produce PLG with built-in aerodrome power sources (AC and DC power supply systems) and cabin air conditioning systems AIR [2].

In addition to combining the functions of a telescopic ladder (TL), an aerodrome air conditioner and an aerodrome power supply, it is also worth noting the possibility of solving another problem, in modern airports - it is about transporting passengers with disabilities to the aircraft. It is the telescopic ladder that allows them to get on (with) the plane without delay, along with the general flow of passengers. The lack of stairs in the TL allows people with disabilities to move along the tunnels without undue effort, which speeds up the process of boarding and disembarking passengers and does not require additional involvement of such mechanization as ambulifts.

Therefore, when using multifunctional passenger galleries (air bridges) due to the technical means and technological capabilities they provide, there may be a reduced need for some types of special vehicles.

The time of service cycle of aircraft by special vehicle depends on the type and model of the aircraft, the required volumes and types of work that is performed when using this type of aviation ground equipment.

When using PLG with built-in air-conditioning and power supply system of the aircraft during the calculation of the number of mechanization means it is possible to remove them from the final result.

In order to plot the dependence of the amount of ground equipment on the result of the implementation of multifunctional ladders, the information on the intensity of air traffic at the Boryspil International airport and technical capabilities of terminal complexes was analyzed. The graph shows the number of GPUs and self-propelled ladders that have been in use by handling companies over the last 15 years and with the prospect of expanding the airport's terminal D to 2025.

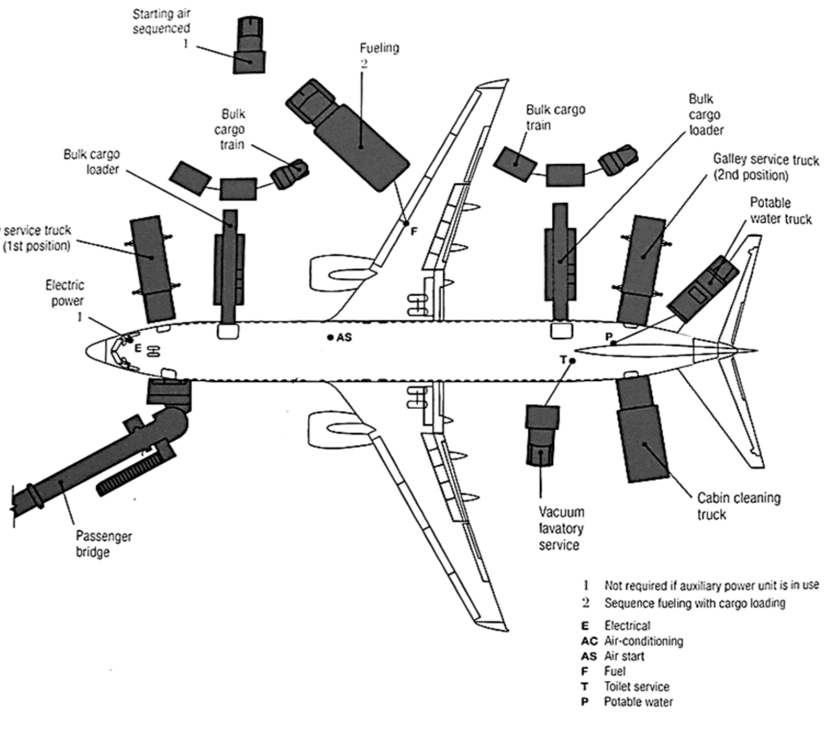


Fig. 1. Scheme of ground maintenance of the B737 aircraft

Based on the data obtained during the calculation and taking into account the statistical indicators of the airport, you can make a schedule of the actual and projected number of certain types of aviation special equipment at the airport, taking into account the introduction of multifunctional passenger galleries (fig. 2).

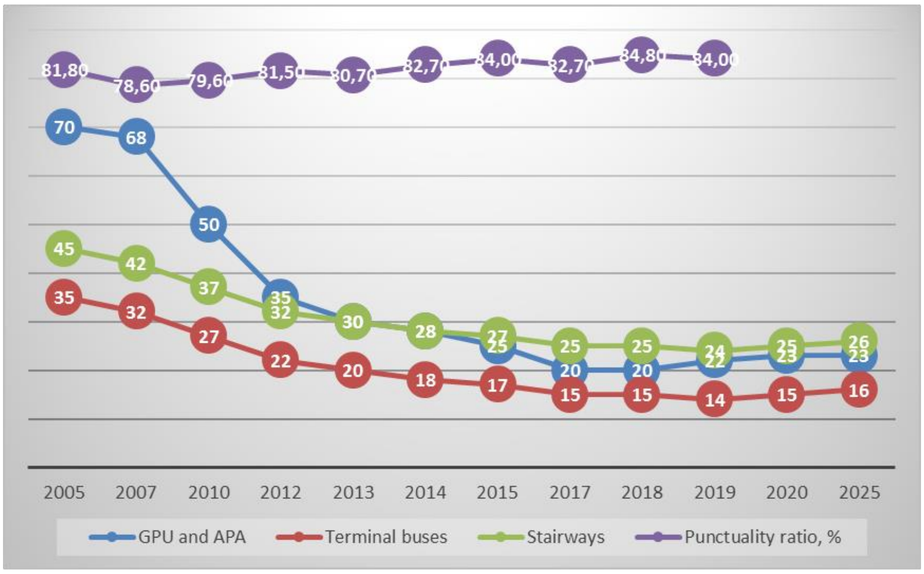


Fig.2. The actual and projected number of certain types of aviation special equipment at the airport, taking into account the introduction of multifunctional PLG

The turnaround time (TAT) of an aircraft is defined as the time that passes from when an aircraft lands until it takes off again for a new flight. During this period, the resources of the airline involved and the airport are mobilized to get the aircraft set up in the shortest possible time [3].

One of the most time-consuming processes for servicing an airplane is boarding and disembarking passengers.

When using passenger ramps, the required time on delivering passengers on the apron is reduced due to the lack of this need. The average time to complete one leg by the average terminal bus is 5-7 minutes, the average capacity of one bus is 100 passengers. As well as the capacity of one B 737 aircraft is 189 passengers, a minimum of 2 buses are required for handle 1 flight.

TAT has hence become a very important and key parameter in determining the profitability of an airline company. Such situations can lead to a lot of undesirable consequences, as it has a direct impact on the survival of the organization due to a series of payment crisis one after another.

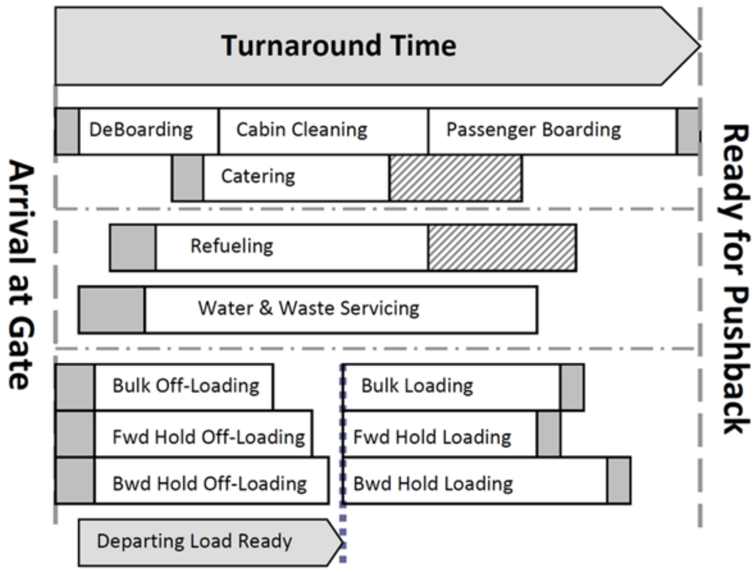


Fig.3. Turnaround time distribution [4]

It is also necessary to consider the design of the airport, cause with the hub model of the airport most passengers use such airports like transit point of their journey and the time for a transfer from one flight to another, for example from international to domestic, is very important.

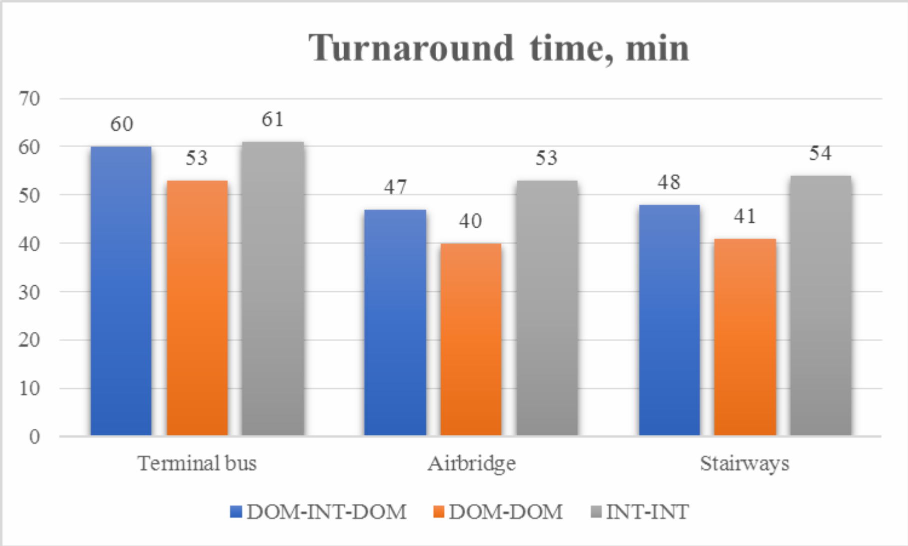


Fig. 4. Turnaround time for different means

Conclusions

Thus, the use of multifunctional passenger landing galleries allows not only to provide a high level of comfort when boarding / disembarking passengers in the aircraft, but also significantly increase the parking space in the buffer area of ground handling of aircraft for other types of AGE by reducing the latter, which will increase safety. and economic efficiency in the activities of airport services and handling companies. The above design solutions are, of course, promising provided that the requirements of the feasibility of combining several types of AGE and ensuring a high level of reliability of such developments.

Refrences

1. Білякович О.М. Аеродромно-технічне забезпечення польотів: конспект лекцій / О.М.Білякович. – К.: НАУ-друк, 2009. – 84 с.

2. Білякович О.М. До питання багатофункціональності авіаційної наземної техніки / О.М.Білякович // Матеріали IX міжнародного науково-практичного семінару «Авіаційна наземна техніка: наукові дослідженні, виробництво, експлуатація та підготовка персоналу», травень 2018 р.: тези доп. – К.: Асоціація «Аеропорти України» цивільної авіації, 2018. – С.10.

3. Passenger Boarding Bridge [Електронний ресурс]. – Режим доступу: https://www.skybrary.aero/index.php/Passenger_Boarding_Bridge

4. Airport passenger boarding bridges [Електронний ресурс]. – Режим доступу: https://www.adelte.com/airports/passenger-boarding-bridg

Білякович О.М., Савчук А.М., Туриця Ю.О., Курбет Л.В. Оцінка доцільності впровадження багатофункціональних зразків авіаційної наземної техніки при обслуговуванні повітряних суден

Досить часто спостерігається перенасиченість перону засобами авіаційної наземної техніки (АНТ), яка призначена при експлуатації сучасних міжнародних аеропортів, особливо, у так звані, «години пік».Поява такої ситуації може вплинути на появу ризиків в процесі реалізації аеропортових технологій, які пов'язані з ймовірним зменшенням рівня безпеки руху наземних транспортних засобів по перону, утворенням скупчення засобів обслуговування ПС на місці їх стоянки та імовірною можливістю пошкодження літаків на землі, психологічним напруженням авіаційного персоналу та іншими непередбачуваними ситуаціями.

Для уникнення диних ситуацій, які безпосередньо повязані з можливою небезпекою в аеропортах є необхідність використання багатофункціональних зразків АНТ, що дасть можливість забезпечити проведення декількох технологічних процесів з наземного обслуговування ПС, авіапасажирів, обробки пошти та вантажів шляхом створення гібридних конструкцій спецмашин та засобів механізації і автоматизації. Так, наприклад застосування багатофункціональних телескопічних трапів дозволяє не тільки забезпечити високий рівень комфорту при посадці/висадці пасажирів в ПС, а й суттєво збільшити паркувальний простір в буферній зоні наземного обслуговування літаків для інших типів АНТ за рахунок скорочення одиниць останніх, що сприятиме підвищенню рівня безпеки обслуговування ПС та економічної ефективності у діяльності аеропортових служб та хендлінгових компаній.

Ключові слова: авіаційна наземна техніка (ант), багатофункціональні зразки ант, гібридні конструкції спецмашин та засобів механізації і автоматизації, багатофункціональні телескопічні трапи

***Problems of Tribology**, V. 26, No 1/99-2021*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

INFORMATION ABOUT JOURNAL"PROBLEMS OF TRIBOLOGY"

POLICY (GOAL AND TASKS)

"Problems of Tribology (Problems of Tribology)" - an international scientific journal.

Along with the main task of collecting information from tribology, the journal also performs organizational and coordinating functions:

- coordination of scientific and technical work in the field of tribology;
- organization of conferences, sympsiums;
- organization of work on the creation of databases and expert systems in the field of tribology;
- the organization of communications and information exchange between specialists in the field of tribology internationally.

2. The journal contains articles directly or indirectly related to tribology, including:

- theoretical problems (physics, chemistry, mechanics, mathematics)
- experimental methods and research results;
- contact mechanics, friction, wear, lubrication, durability and reliability of friction units of machines and units;
- scientific, technical and production problems of manufacturing, repair, improving the quality, reliability and durability of friction;
- technological and structural methods of improving wear resistance, frictional and anti-friction properties of friction units;
- problems of tribo materials science;
- methodological and methodological issues of training specialists in tribology.

3. The main requirements of the article is the novelty and completeness of information.

Articles of theoretical content should include theoretical explanation (possibly in the form of an annex to the article) to assess the scientific novelty of the publication.

Experimental articles should contain complete information about the methodology, conditions and results of the experiment.

Technological profile articles should contain a description of the technology as much as possible. If it is impossible to disclose "know-how", the method of obtaining the necessary detailed information must be indicated.

4. All articles are reviewed by a closed double review for compliance with the topics and level requirements. At the same time, the authors are fully responsible for the content of the articles.

5. Due to the international nature of the journal it is preferably submit articles in English.

REQUIREMENTS TO THE ARTICLES

In order to publish an article in the journal authors should submit it by e-mail.

Text of an article should be laid out on A4 format (210 x 297 mm) page with the following margins set: left and right – 2.0 cm, top and bottom – 2.5 cm. Use the font Times New Roman throughout, single-spacing, 10-point type and 1.0 cm indention for body text. Use lower-case bold 14-point type for headings. Put subheadings in bold.

Article structure:

– Universal Decimal classification index (in the upper left corner).

– Initials and surnames of all authors (no more than 4 people) and the article title (up to 10 words) in Ukrainian, Russian and English (one-column format).

– Abstract (200–300 words, only commonly accepted terminology) in Englishshould be structured and contain the following elements: purpose, methodology, findings, originality, practical value, keywords (6–8 words), one-column format. The abstract should not repeat the heading of the article.

– Body text.

– Reference list.

– Abstracts and keywords (up to 6–8words) in the Ukrainian and Russian languages;

Each article should include the following sections:

– An introduction, indicating article’s scientific problem.

– An analysis of the recent research and publications.

– Unsolved aspects of the problem.

– Objectives of the article.

– Presentation of the main research and explanation of scientific results.

– Research conclusions and recommendations for further research in this area.

– The title and number of the project in terms of whichthe presented results were obtained and Acknowledgements to the organizations and/or people contributing to or sponsoring the project (at the discretion of the author)

The recommended length of articles (including text, tables, and figures) is 6–9 pages. Figures should not exceed 25 % of length of an article. The text should be laconic, and should not contain duplicated information. No running titles and section brakes should be applied in the file.

Figures must be provided both in color and grayscale. They must be included in the text after corresponding references and given as separate files TIFF, JPG. EPS (300 dpi). The preferable width for the figures is 8.15 cm; not more than 17 cm for maps, charts, etc. All figures should be placed within the text, not in tables. Lettering, lines and symbols must be readable. Captions under the figures should contain order number and description of the figure and should be put in Italics. Placing the figure numbers and captions inside figures is not allowed.

Equationsshould be entered using Microsoft Word for Windows Editor plug-in or Microsoft Equation, 10-point type. The equations sited in the text are to be numbered in order of their appearance in the text (number in brackets with right justify). Equations should be column width (<8 cm). Long formulas should be divided into parts of 8 cm width. Before and after each formula there should be one empty line. Physical quantities should be measured in SI units. An integer part should be separated from a decimal by a dot.

Tablesmust be in portrait orientation, have titles and be numbered. Preferably tables should not exceed 1 page in length; width should make 8.15 cm or 17 cm. It is recommended to use 8–9-point type (not smaller than 6-point type for big data).

References(no more than 15 items, published not earlier than 5 years before, no more than 20%of self-citations) should be listed in the order of appearance in the text of the article. The in-text references should be given in square brackets.

Also the author should submit the following data about all authors of the article: surname, name and patronymic, academic degree, academic rank, place of employment (complete name of organization), position, city, country, phone number, e-mail and authors' ORCID identifier, in a separate file in English, Ukrainian and Russian (one-column format, comma-separated).

REVIEW PROCEDURE

All manuscripts are initially treated by editors to assess their compliance with the requirements of the journal and the subject.

After the editor decision the manuscripts are sent to at least two external experts working in this area. **The manuscript goes double-blind peer review**, neither the authors nor the reviewers do not know each other.

Review comments transmitted to the author, together with a recommendation for a possible revision of the manuscript. Publishing editor reports to the authors about adopting manuscript without require revision or authors are given the opportunity to review the manuscript and submit it again, or manuscript rejected.

EDITORIAL ETHICS

Principles of professional ethics in the work of the editor and publisher

The editor of a peer-reviewed journal is responsible for deciding which of the articles submitted to the journal should be published. The validation of the work in question and its importance to researchers and readers must always drive such decisions.

- An editor should make decisions on which articles to publish based on representational faithfulness and scholarly importance of the proposed work.

- An editor should be alert to intellectual property issues and must not to publish information if there are reasons to think that it is plagiarism. ·

- An editor should evaluate manuscripts for their intellectual content without regard to race, gender, sexual orientation, religious belief, ethnic origin, citizenship, social set-up or political philosophy of the authors.

- Unpublished materials disclosed in a submitted manuscript must not be used in an editor's own research without the express written consent of the author. Privileged information or ideas obtained through peer review must be kept confidential and not used for personal advantage.

- An editor should take reasonably responsive measures when ethical complaints have been presented concerning a submitted manuscript or published paper, in conjunction with the publisher (or society). Every reported act of unethical publishing behavior must be looked into, even if it is discovered years after publication.

Publishers should provide reasonable practical support to editors and define the relationship between publishers, editor and other parties in a contract.

- Publishers should protect intellectual property and copyright.

- Publishers should foster editorial independence.

- Publishers should work with journal editors to set journal policies appropriately and aim to meet those policies, particularly with respect to editorial independence, research ethics, authorship, transparency and integrity (for example, conflicts of interest research funding, reporting standards), peer review and the role of the editorial team beyond that of the journal editor, appeals and complaints.

- Publishers should communicate and periodically review journal policies (for example, to authors, readers, peer reviewers).

- Publishers should assist the parties (for example, institutions, grant funders, governing bodies) responsible for the investigation of suspected research and publication misconduct and, where possible, facilitate in the resolution of these cases.

- Publishers are responsible for publishing corrections, clarifications and retractions.

Ethical principles in the reviewer work

Peer review assists the editor in making editorial decisions and through the editorial communications with the author may also assist the author in improving the paper. That is why actions of a reviewer should be unbiased.

- Any manuscripts received for review must be treated as confidential documents. They must not be shown to or discussed with others except as authorized by the editor.

- Reviews should be conducted objectively. Personal criticism of the author is inappropriate. Referees should express their views clearly with supporting arguments.

- Unpublished materials disclosed in a submitted manuscript must not be used in a reviewer's own research without the express written consent of the author. Privileged information or ideas obtained through peer review must be kept confidential and not used for personal advantage.

- Any selected referee who feels unqualified to review the research reported in a manuscript or knows that its prompt review will be impossible should notify the editor and excuse himself from the review process.

Principles that should guide the author of scientific publications

Authors realize that they are responsible for novelty and faithfulness of research results.

- Authors of reports of original research should present an accurate account of the work performed as well as an objective discussion of its significance. Underlying data should be represented accurately in the paper. A paper should contain sufficient detail and references to permit others to replicate the work. Fraudulent or knowingly inaccurate statements constitute unethical behavior and are unacceptable.

- An author should ensure that they have written entirely original works, and if the author has used the work and/or words of others, then this has been appropriately cited or quoted. Plagiarism in all its forms constitutes unethical publishing behavior and is unacceptable.

- Proper acknowledgment of the work of others must always be given. Author should cite publications that have been influential in determining the nature of the reported work. Information obtained privately, as in conversation, correspondence, or discussion with third parties, must not be used or reported without explicit, written permission from the source. Information obtained in the course of confidential services, such as refereeing manuscripts or grant applications, must not be used without the explicit written permission of the author of the work involved in these services.

- An author should not in general publish manuscripts describing essentially the same research in more than one journal or primary publication. Submitting the same manuscript to more than one journal concurrently constitutes unethical publishing behavior and is unacceptable. In general, an author should not submit for consideration in another journal a previously published paper.

- All those who have made significant contributions should be listed as co-authors. Where there are others who have participated in certain substantive aspects of the research project, they should be acknowledged or listed as contributors. The corresponding author should ensure that all co-authors have seen and approved the final version of the paper and have agreed to its submission for publication.

- When an author discovers a significant error or inaccuracy in their own published work, it is the author's obligation to promptly notify the journal editor or publisher and cooperate with the editor to retract or correct the paper. If the editor or the publisher learns from a third party that a published work contains a significant error, it is the obligation of the author to promptly retract or correct the paper or provide evidence to the editor of the correctness of the original paper.

CONTACTS

International scientific journal “Problems of Tribology”,
Khmelnitsky National University,
Institutskaia str. 11, Khmelnitsky, 29016, Ukraine
phone +380975546925
E-mail: tribosenator@gmail.com
Internet: http://tribology.khnu.km.ua