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Structural and energetic self-organization of antifriction composite materials of car parts during friction and wear

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Abstract

The development and research of composite materials for heavily loaded tribo-couplings of car parts was based on the main provisions of the concept of structural and energetic adaptability of their materials during friction and wear. The presented data of experimental studies of the effect of ultrasonic treatment of materials on the nature of the change in the coefficient of friction depending on the value of the specific load at a constant sliding speed. Data were obtained that characterize the features of structural adaptation and self-organization during friction and wear of copper and lead alloys. The research was carried out using a universal tribometer according to the "finger-disc" end surface contact scheme in the medium of inactive petroleum jelly. The use of composite wear-resistant materials is proposed to increase the tribological efficiency of car parts, units and assemblies. Experimental studies and analysis of the obtained data were carried out on the basis of the developed parametric scheme for the study of tribocouples of samples and parts using the main provisions of system analysis.

Key words: tribo coupling, tribometer, vehicles, alloyed composite materials, friction and wear.

Formulation of the problem

Increasing the serv DSS life of tribo couplings of car parts is one of the most important technical problems in the automotive industry. In this regard, the development of comprehensive measures to manage tribological efficiency is relevant. This is done in order to increase the operational reliability of the main working nodes, systems and aggregates. At the same time, they significantly reduce the cost of repairing the car and the production of spare parts, increase their operational reliability while achieving satisfactory technical, economic and environmental results. The durability of cars mainly depends on the nature of the friction and wear processes that occur in the contact zones between tribo coupling parts. Intensive wear of the working surfaces of the parts leads to a violation of the tightness of the nodes, a loss of accuracy in the placement and movement of the parts, which leads to jamming, shocks and vibrations, which in turn lead to mechanical breakdowns. The complex of energy, strength and kinetic conditions, mechanical and thermal parameters of self-organization is a single tribosystem with direct and feedback connections. The final result of the self-organization process is the formation of protective dissipative secondary structures (DSS) and the normalization of friction and wear indicators, which are characterized by the appropriate range and level. One of the promising directions for solving the problem of increasing the tribotechnical reliability of tribo-couplings of machines and mechanisms is the development of anti-friction composite materials and their comprehensive research based on the provisions of the structural and energetic adaptability of materials during friction and wear, self-organization of tribosystems, the theory of surface strength and destruction, taking into account the properties of these materials and conditions their operation in real nodes and mechanisms.

Analysis of recent research and publications

Solving the problem of increasing the tribological reliability and durability [1,2] of tribocoupled elements of car parts requires a comprehensive approach [3]. This includes: the following measures: development of modern research methods and kinetic criteria for evaluating processes in the zone of frictional contact; creation of new antifriction composite alloys; methods of controlling the surface strength of materials during friction and wear [4,5]. Intensification of processes in the zone of frictional contact leads to an increase in thermal and mechanical load on the tribocoupler [6], with corresponding negative consequences [7,8]. A systematic approach to solving this problem includes a complex of design, technological and operational measures for the development and research of alloyed composite antifriction materials [9,10] to increase the tribological reliability of heavily loaded car tribo couplings [11,12]. As pract DSS shows, it is difficult to achieve the necessary accuracy in quantitative indicators of initial parameters in laboratory, bench research of tribo-coupling, despite its significant economic, scientific, interdisciplinary importance for automotive engineering and technology in general. To date, the phenomenon of friction and wear has not been sufficiently studied. There is no unified theory of this process, there is no centralized bank of tribological data. As a result, there are no comprehensive recommendations for designers, technologists, and operators on increasing the tribological reliability and durability of friction units of machines and mechanisms. The application of the basics of system analysis allows you to get an answer to the question of the functional (technical) purpose of the considered tribological system, which is considered as a "black box" with the corresponding inputs, transformations and outputs.

The purpose of the work

The purpose of this work is the selection and comprehensive study of the tribological efficiency of the couplings of samples and parts made of composite alloys based on copper and lead, which were subjected to ultrasonic treatment, as well as alloyed composite alloys based on iron powder with the addition of copper powder and analysis of the nature of the change in the coefficient of friction from the specific load on triboconjugation of samples and parts, calculation of structural energy parameters: specific work of destruction A_r; energy capacity of the tribosystem according to the thermal index ECT_Q.

Research results

The work investigated the effect of ultrasonic treatment of alloys based on copper and lead (70,60,50% Cu + 30,40,50% Pb), as well as sintered compositions based on iron powders of the PZRV 2.200.28 brand with the addition of copper powder (respectively 2 ,4,6,8,10%) on the nature of the change in the coefficient of friction μ, the specific work of surface destruction A_r, the energy intensity of the friction system according to the thermal index ECT_Q depending on the value of the specific load p.

Tribological studies were carried out at the Department of Automobiles of the Ternopil National Technical University named after Ivan Pulyu on a complex of laboratory equipment, which includes: a tribometer, an automatic system for supplying lubricant to the friction zone, a measuring complex for recording the main tribotechnical indicators and parameters of the contact electrical resistance of tribocoupling [14] (Figure 1).

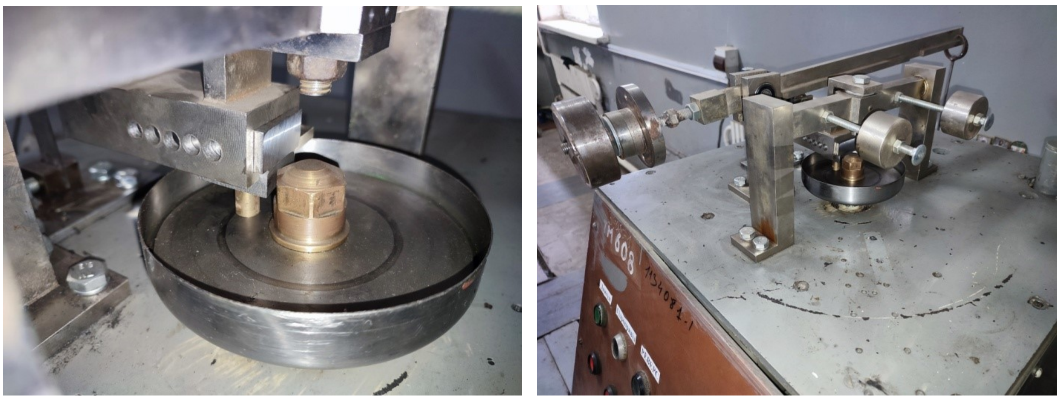


Fig. 1. General view of the tribometer friction assembly and loading mechanism

The research was conducted in an inactive petroleum jelly environment at a constant sliding speed of V = 0.35 m/s. The nature of the load on the test samples during the tests is smooth with fixation of the tested parameters at intervals of 1 MPa. The duration of the research process at each fixed load is 10 hours. A disk made of SHX15 steel (55...62 HRc, Ra = 0.63 μm) was used as a counterbody. The chosen planar scheme of tribo-coupling contact: the end surface of the disk (counterbody) - the end surface of the cylinder (sample). The structure and elemental composition of the friction surfaces were studied using a scanning electron microscope Cam Scan 4DV and the Link-860 system.

The results of the study of the influence of the specific load p on the coefficient of friction μ, the specific work of surface destruction A_r, the energy intensity of the friction system according to the thermal index ECT_Q of alloyed composite alloys based on copper and lead are presented in figures 2-4.

From the analysis of the obtained graphs, it follows that an increase in the content of Pb and its more uniform distribution in this alloy, under the influence of ultrasonic vibrations, contributes to the process of more intensive formation of internal combustion engines, which ultimately leads to an expansion of the range of normal friction and wear according to the load parameter p and a decrease in the value of μ.

The processes of grinding and uniform distribution of Pb in the alloy create favorable conditions for the formation of protective films of internal combustion engines on the friction surfaces of the samples, due to which their surface strength increases. The structural state of friction surfaces and the results of their microspectral analysis testify to the evolution of surface phenomena in the zone of frictional contact in the entire tribo-coupling load range. In this case, the presence of clear areas of structural adaptation of materials to operating conditions is typical.

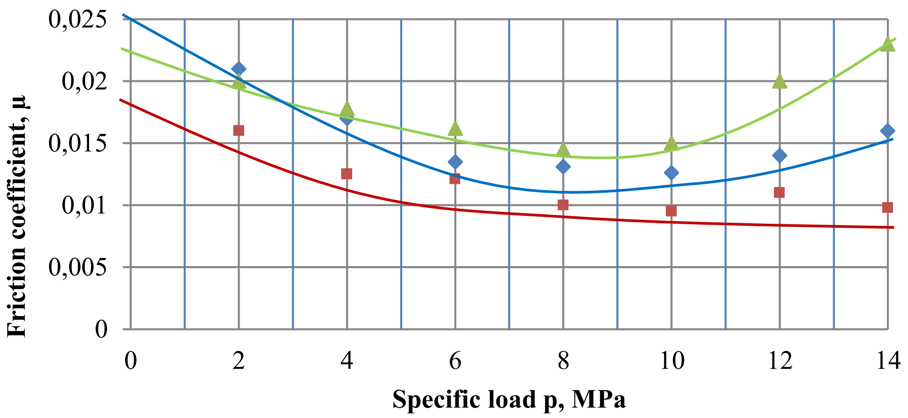


Fig. 2. The nature of the change in the friction coefficient μ from the specific load p:
♦ – alloy: (70% Cu + 30% Pb) ; ■ – alloy: (60% Cu + 40% Pb), ▲ – alloy: (50% Cu + 50% Pb)

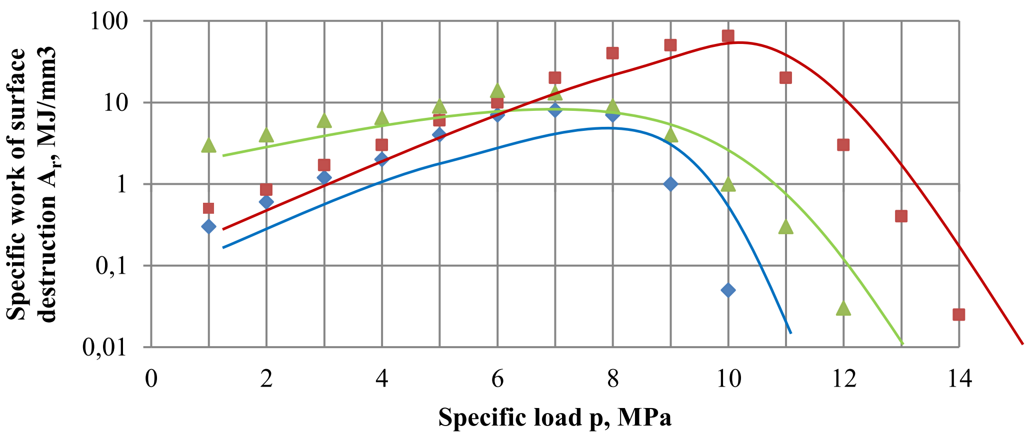


Fig. 3. The nature of the change in the specific work of surface destruction (A_r) from the specific load p:
♦ – alloy: (70% Cu + 30% Pb) ; ■ – alloy: (60% Cu + 40% Pb), ▲ – alloy: (50% Cu + 50% Pb)

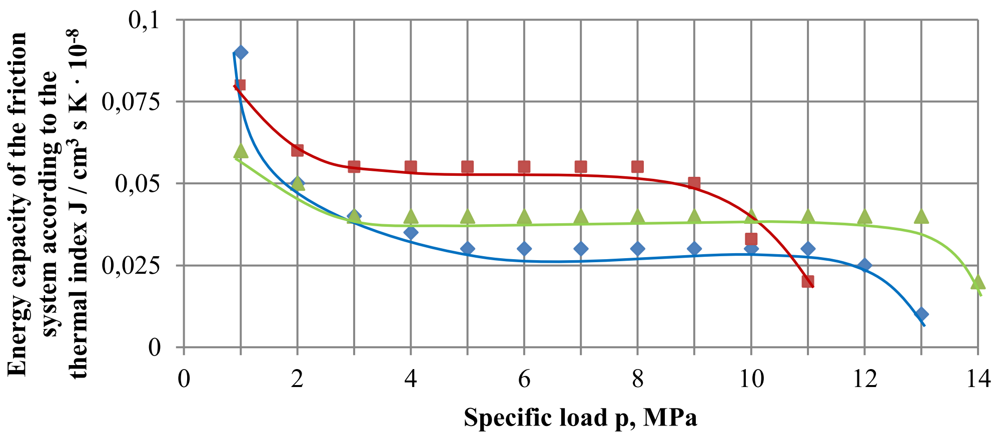
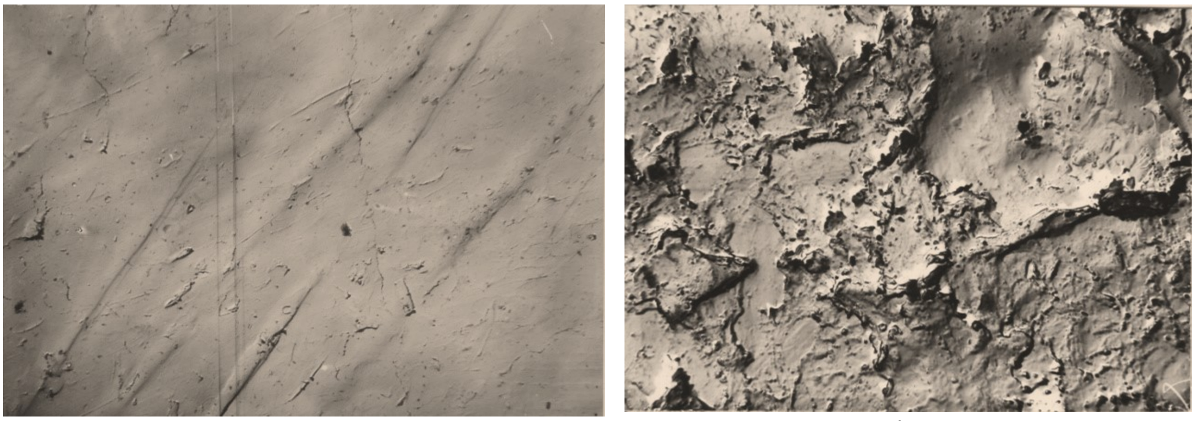


Fig. 4. The nature of changes in the energy capacity of the friction system according to the thermal index ECT_Q from the specific load p: ♦ – alloy: (70% Cu + 30% Pb) ; ■ – alloy: (60% Cu + 40% Pb), ▲ – alloy: (50% Cu + 50% Pb)

From the analysis of the data presented in the graphs (fig. 2-4) for all the studied materials, ranges are clearly distinguished, according to the power parameters of the load, in which the optimal (minimum and stable) value of the main tribotechnical indicators is fixed, with minimal dispersion - the range and level of normal friction and wear. Optimization of tribotechnical parameters is determined by the processes of formation, transformation and destruction of DSS types I and II [15].

The presence of friction on the surfaces of one or another type of internal combustion engine depends on the physical and mechanical properties of the starting materials, the lubricating medium, the lubrication regime, the nature of the change and the magnitude of the force parameters of the load, the scale factor, and others.

Fig. 5 presents electronic photos of the structure of the friction surfaces of the studied sample covered with DSS I (a) and DSS II (b) types (mode of normal friction and wear), and table 1 shows their main characteristics.



a b

Fig. 5. Electronic photographs of the friction surface of the studied alloy sample (50% Cu + 40% Pb) covered with DSS I (a) and DSS II (b)

For each metal and alloy, there are certain critical conditions of external mechanical influence and environment, under which DSS of one or another type is formed on the friction surfaces. This factor has a significant applied value for achieving fractional and anti-frictional states.

Table 1

Main characteristics of DSS I and DSS II types

Type of dissipative secondary structures	Roughness parameters Ra, μm	Depth of destruction, nm	The temperature of the surface layer °C, no more	Composition of the surface layer	Relative change in hardness of the surface layer	Type of destruction	The coefficient of increase in the volume of the surface layer	The speed of the destruction process, μm/g, no more
I	01-0,006	10-30	100	Solid solution and eutectics	2-3	Viscous	1 – 1,05	0,1
II	0,2-0,012	10-100	200	Oxides and eutectics	4-5	Viscous - fragile	1,05-1,08	0,05

Dissipative secondary structures have extreme anti-frictional (frictional) and strength characteristics, which normalize the processes of friction and wear of tribo-coupling samples, protect the original material of the parts' surfaces from mechanical and physico-chemical destruction.

Experimental samples for laboratory studies of iron-copper sintered compositions were made by the method of powder metallurgy. The mixtures were prepared on the basis of PZRV 2.200.28 iron powder. Depending on the copper content in the studied sintered compositions, their physical and mechanical properties are shown in fig. 6.

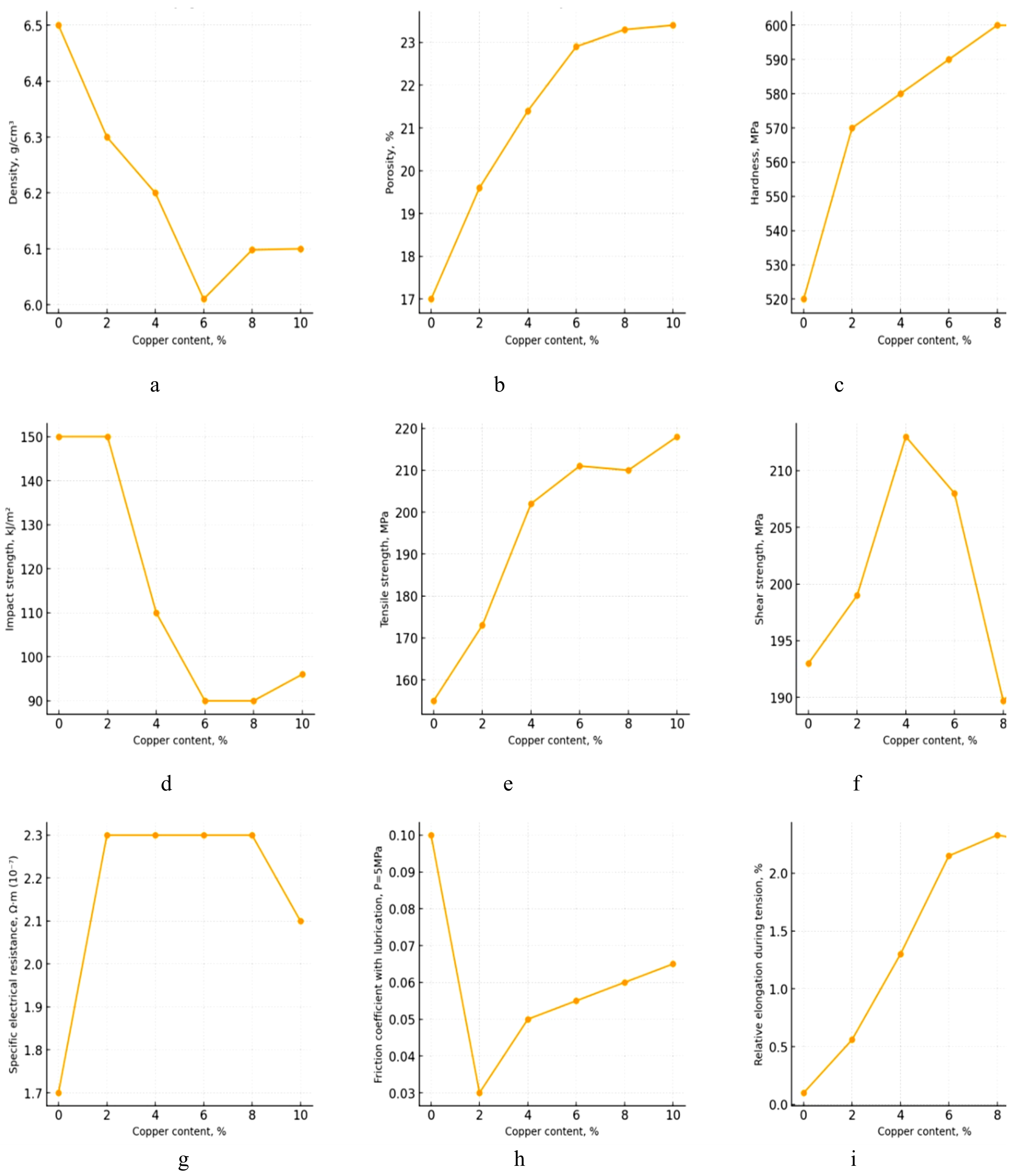


Fig. 6. Physical and mechanical properties of iron-copper compositions depending on the copper content: a - density, g/cm³, b - porosity, %, c - hardness, MPa, d - impact strength, kJ/m², e - tensile strength, MPa, f - shear strength, MPa, g - specific electrical resistance, Ω·m (10^{-7}), h - friction coefficient with lubrication, P=5MPa, i - relative elongation during tension, %

Laboratory (tribotechnical) studies of these compositions were carried out according to a similar tribo-coupling contact scheme. We investigated the mode of normal friction with the smooth nature of the change in the value of the specific load p (at a constant sliding speed v = 0.35 m/s) for a sample in the medium of inactive petroleum jelly. The results of tribotechnical studies are presented in fig. 7.

The graphs (Fig. 7) show areas characterized by stable values of the friction coefficient μ. At the same time, the indicated stability is typical both for pure iron samples (curve 1) and for compositions containing copper powder of different concentrations (curves 2-6). For sintered compositions that contain copper powders, there is a not DSS able decrease in the level of normal friction according to the μ parameter.

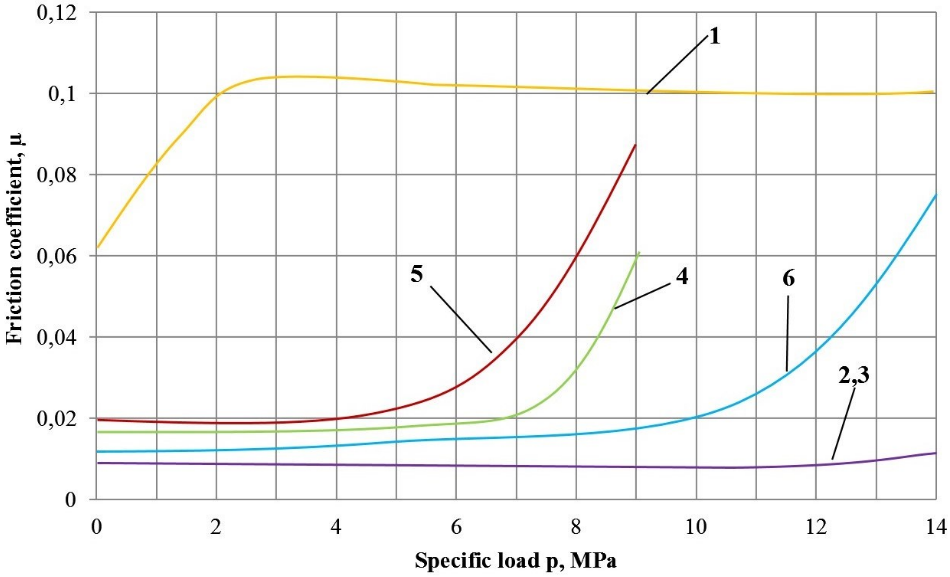


Fig. 7. The nature of the change in the coefficient of friction μ from the specific load p, for compositions with different Cu content, %: 1 – 0%; 2 - 2%; 3 - 4%; 4 - 6%; 5 - 8%; 6 - 10%.

When the critical values of the specific load p are reached, the output of the tribocoupler is fixed in the volumetric destruction mode (damage of the main material of the parts).

Conclusions

1. According to the research results, it was established that when the lead content in the Cu - Pb alloy changes (respectively 30, 40 and 50%) and its uniform distribution under the influence of ultrasonic treatment, the main tribotechnical indicators of the friction and wear process improve. In the mode of normal mechano-chemical friction and wear, this leads to an expansion of the range and a decrease in the level of structural adaptability of this alloy with the formation of the corresponding DSS I or DSS II types on the friction surfaces.

2. When adding copper powders of various concentrations to the composition of sintered compositions based on PZRV 2.200.28 iron powder, the tribotechnical indicators of heavily loaded tribo couplings are improved, which is due to the structural rearrangement of the friction surfaces and the appearance of anti-friction copper films on them, which realize the process of normal friction and wear in a wide range of force load with a decrease in the level of self-organization according to the μ parameter.

3. Informative, from the point of view of tribological research and analysis of the obtained results, are the structural and energy parameters A_r - the specific work of surface destruction and the energy intensity of the friction system according to the thermal index ECT_Q, which characterize the relationship between the values of the main tribotechnical parameters, the kinetics of friction processes and wear, structural state of friction surfaces (internal combustion engine type), mechanisms of their formation, transformation and destruction.

4. The practical operation of the universal tribometer during laboratory studies confirmed its reliability and efficiency, the satisfactory comparability of the obtained results, the high rigidity of the friction unit and the load mechanism, the absence of vibration, a wide range of force parameters of the load with their smooth change, the reversible nature of the movement, the openness of the friction unit for visual control, a convenient shape of the friction working surface of the sample for further studies of the structural state.

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Гупка А.Б., Аулін В.В., Міронов Д.В., Лещук Р.Я., Ярема І.Т., Буховець В.М., Тесля В.О.
Структурно-енергетична самоорганізація антифрикційних композиційних матеріалів деталей автомобілів при терті та зношуванні

Розробка та дослідження композиційних матеріалів для важконавантажених трибоспряжень деталей автомобілів базувались на основних положеннях концепції структурно-енергетичної пристосовуваності їх матеріалів при терті та зношуванні. Наведенні дані експериментальних досліджень впливу ультразвукової обробки матеріалів на характер зміни коефіцієнта тертя в залежності від величини питомого навантаження при постійній швидкості ковзання. Отримано дані, які характеризують особливості структурної адаптації та самоорганізації при терті та зношуванні сплавів міді та свинцю. Дослідження проводили з використанням універсального трибометра за схемою контакту торцевих поверхонь «палець-диск» у середовищі інактивного вазелінового мастила. Запропоновано використання композиційних зносостійких матеріалів для підвищення трибологічної ефективності деталей, вузлів та агрегатів автомобілів. Експериментальні дослідження та аналіз одержаних даних проводили на базі розробленої параметричної схеми дослідження трибоспряжень зразків і деталей з використанням основних положень системного аналізу.

Ключові слова: трибоспряження, трибометр, транспортні засоби, леговані композиційні матеріали, тертя та зношування.