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A comprehensive method of researching the tribological efficiency of couplings of parts of nodes, systems and aggregates of cars

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Abstract

In this work, a universal tribometer is proposed to study the tribological efficiency of the couplings of samples and parts. The design of the tribometer made it possible to carry out experimental studies in a wide range of force parameters of the load with their smooth change. A set of characteristics and parameters determined on tribometers during the study of couplings of samples according to the "disk-finger" scheme is given: wear intensity, coefficient of friction, temperature in the contact zone, specific work of destruction, specific energy capacity according to the heat index, electrical criterion for evaluating the structural adaptability of tribo couplings. Modes of friction and wear were determined by the characteristics of changes in the contact electrical resistance parameters: run-in, normal friction and wear, volume destruction. The results of the research of tribological efficiency according to the specified characteristics and parameters are given. For a comparative effect, the samples were strengthened by a complex chemical-thermal method, serial technology and boronization . The results made it possible to identify the characteristic zones of run-in regimes, normal friction and wear, and volumetric destruction. They are confirmed by the received electron microfractographies.

Keywords: tribological efficiency**,** tribo-bonding of samples and parts, tribotechnical parameters, contact electrical resistance, surface strength, operational reliability

Formulation of the problem

The flexibility and mobility of road transport at a relatively low cost of transportation contributes to the development of industrial production, which plays a significant role in the development of the economy of Ukraine. One of the important tasks facing the automotive industry is to improve the operational properties of vehicles by increasing reliability, efficiency and economy. The reliability and efficiency of road transport is largely determined by the phenomena of friction and wear that occur in the tribo couplings of parts of nodes, systems and units of cars. When worn, the tightness of the tribocouplers of parts is broken, the accuracy of their relative placement and relative movements is lost. The processes of jamming, impacts, and vibrations occur, which lead to the breakdown of individual parts, components, systems, and units of cars. The friction process leads to energy losses, overheating of mechanisms, reduced work effort, increased consumption of fuel, lubricants and other operating materials. The positive role of friction is necessary to ensure the operation of braking mechanisms, the clutch mechanism, and wheel movement. The phenomena of friction and wear are mutually conditioned: friction leads to wear, and wear of the surfaces of tribo-coupling parts during operation leads to a change in friction modes. Applied tasks of increasing wear resistance and friction management are the design and implementation in practice of new designs of tribocoupling parts, highly efficient fuel-lubricant and structural materials, optimal measures during car operation. The main directions of significantly increasing the operational reliability and efficiency of cars based on the use of tribology methods are: improving the efficiency of resource-determining structures tribocoupling of parts, reduction of material capacity; increasing the wear resistance and bearing capacity of tribocouplers of parts; increasing the tribological efficiency of conjugations of parts of nodes, systems and aggregates; use of environmentally friendly operating methods; use of new materials with increased anti-friction and friction characteristics; improvement of seal designs that ensure low friction; ensuring tightness and excluding the ingress of abrasive into the zone of frictional contact and others.

Among the main heavy-duty ones the tribocoupling of car parts is primarily the coupling of parts of fuel and gas distribution equipment of internal combustion engines. The coupling of parts of the cylinder-piston and connecting rod group, crankshaft with main and connecting rod bearings, gearboxes, reducers, belt and chain gears, braking mechanisms and others work in difficult conditions . Technological methods are one of the effective ways of increasing the surface strength, and therefore the wear resistance of the parts' joints. The effectiveness of the application of one or another method depends on the design features of the tribocoupling of parts as a whole and its individual parts and materials, lubrication conditions, power parameters of the load, the nature of the load, and the operating modes of the car.

Analysis of recent research and publications

Solving the problem of increasing operational reliability of heavy-duty vehicles tribocoupling of car parts requires a systematic approach to their tribological efficiency with the development of complex methods of researching tribotechnical characteristics and parameters and kinetic criteria for evaluating processes in the frictional contact zone. The structural-energetic approach [1] allows to systematize ways of searching for optimal solutions in order to increase the surface strength of tribocouplers of parts of nodes, systems and units of cars [2, 3, 4]. The development of the automotive industry shows a constant increase in the specific power of engines [5, 6, 7], an increase in the thermal and mechanical load on the parts of tribo couplings . This leads to a number of negative consequences [8, 9]. Effective ways of researching new methods and technologies, influencing tribotechnical characteristics and parameters of processes in the zone of frictional contact [10, 11, 12] . Along with design and operational tools, this will allow to create a complete set of technical solutions [13, 14], to expand the tribotechnical data bank of nodes, systems and units of cars, to develop practical recommendations for solving issues of applied tribotechnics [15]. This concerns the tribological efficiency of car parts couplings, its connection with technical operation and reliability.

The purpose of the work

The purpose of this work is to develop a comprehensive methodology for researching the tribological efficiency of the couplings of samples and parts according to kinetic criteria for evaluating changes in the main tribotechnical characteristics and indicators: wear intensity, friction coefficient, temperature in the contact zone, specific work of destruction. the energy capacity of the friction system according to the thermal index, the processes of formation, transformation and destruction of dissipative secondary structures in the modes of running-in, normal friction and wear, volumetric destruction by the nature of changes in the contact electrical resistance of tribo-conjugation samples with various methods of strengthening technologies of their working surfaces in wide ranges of smooth changes in the power parameters of the load.

Research results

In order to obtain objective information about the processes in the zone of frictional contact, it is necessary to use modern tribotechnical equipment (tribometers) and a measuring complex to register the main tribotechnical and structural-energy parameters both directly in the process of friction and wear, i.e. in a dynamic and static state . The issue arose of developing a comprehensive methodology for researching the tribological efficiency of part couplings and kinetic criteria for evaluating friction and wear processes in the frictional contact zone. The disadvantages of existing tribometers include: a rather narrow range of force parameters of the load on the sample under study with the gradual nature of their change; lack of reversible nature of movement; imperfect lubrication system of tribocoupler samples; inconvenient shape of the working surface of the sample (friction surfaces) for further metallographic studies; the absence of the possibility of self-installation in the sample attachment mechanism for better practice. The vast majority of tribometers are characterized by varying degrees of accuracy, which leads to the impossibility of comparing the obtained results, creating a single bank of tribotechnical data on the wear resistance of parts, assemblies, systems and units of cars.

In the laboratory of tribological research of the automobile department of the Ternopil National Technical University named after Ivan Pulyuy created a complex of laboratory equipment - a tribometer, which includes: an automatic system for supplying lubricant to the friction zone, a measuring complex for recording the main tribotechnical indicators. Fig. 1 shows the design of the friction assembly and loading mechanism, and Fig. 2 shows the general view of the proposed tribometer.

The study was carried out according to the scheme "end surface of the disc (counterbody) - end surface of the cylinder (sample)". The shape of the contact surface is a plane. The contact scheme of the tribocouples of the samples was chosen to realize the limit mode of lubrication and the impossibility of its exit to the hydrodynamic mode. The flat working surface of the sample is convenient for the process of working in the contacting samples, as well as for their further metallographic studies.

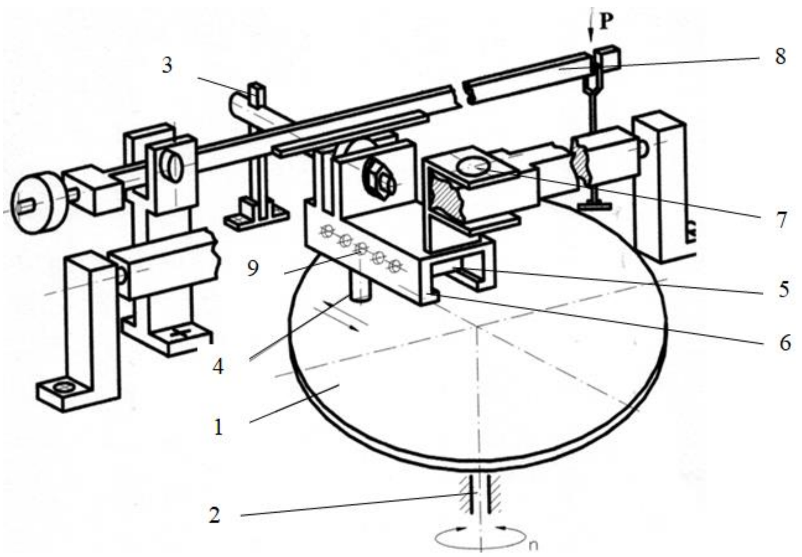


Fig. 1. Schematic representation of the structure of the friction assembly and the tribometer loading mechanism

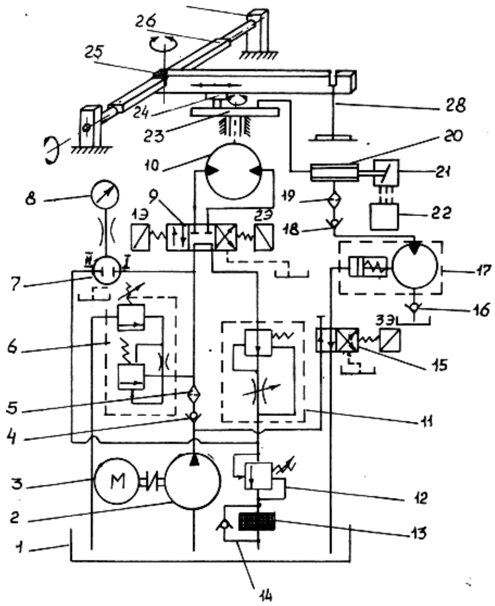
Fig. 2. General appearance of the tribometer

The hydraulic drive of the tribometer, the design of the friction unit and the loading mechanism allow you to smoothly change the power parameters of the load in wide ranges: sliding speed 0.1...12 m/s; specific load on the tested sample 0.2...40 MPa . In addition, the hydraulic drive of the tribometer also ensures the reversible nature of the rotation of the counterbody .

The main units of the tribometer are: a welded frame of increased rigidity, a hydraulic drive, a hydrokinematic scheme shown in Fig. 3, a friction unit and a loading mechanism, a lubricant supply system to the frictional contact zone of tribo-coupling samples.

The designs of the friction unit and the load mechanism are designed to increase the efficiency and reliability of the obtained results by reducing the dynamic loads on the test sample during transient processes and modes of friction and wear, expanding the range of force parameters of the load, the possibility of using the entire working surface of the counterbody . The characteristic features of the tribometer are: simplicity of design, versatility of the drive mechanism, small dimensions, increased rigidity of the friction unit and the load mechanism, openness of the friction unit for visual inspection.

Structurally, the tribometer consists of a welded body (frame), counterbody 1, which, together with its fastening mechanism, is installed on the shaft of the hydraulic motor 2, with the possibility of rotational movement around its own axis. The friction node is equipped with a tension beam 3 to register the moment of friction of the test sample 4, which is placed in the sample receiver 5, with the possibility of its radial movement along the surface of the counterbody. The sample holder is placed in the guide 6, which is hinged at one end to the rotation shaft 7 , and the other end is in contact with the load lever 8 through the bearing. The working position of the sample is relative to the guide, and therefore to the friction surface of the counterbody fixed with the help of screw 9. The longitudinal axis of the guide and the axis of the examined sample are placed in the same plane, which is perpendicular to the working surface of the disc and protects the sample from possible distortions. A significant increase in the value of the specific load on the test sample is achieved due to shoulders , both on the load lever and on the guide.



1 – reservoir; 2 – pump BG12-23; 3 – electric motor; 4 - check valve G51-23; 5 – FMS filter; 6 - pressure valve BPG 52-24; 7 - manometer spool ZM2.2- C32O; 8 – manometer MT-160; 9 - hydraulic distributor 64P173-12; 1O - hydraulic motor G15-22; 11 - flow regulator PG55-22; 12 - support valve PG54-24; 13 - oil cooler ; 14 - non-return valve G 51-23; 15 - hydraulic distributor 54BPG73-11; 16 - suction valve; 17 - lubrication station with hydraulic drive ЭС12OO1; 18 - discharge valve; 19 - filter FLG 18-100; 20 - feeder MI-5 (5E); 200 21 - microswitch MP 2302; 22 - PVE-21-3 control device; 23 – disc; 24 - sample; 25 - lever; 26 - shaft; 27 - rack; 28 – a set of sinkers

Fig. 3. Hydrokinematic diagram of the tribometer

The tribometer is characterized by a simple design, small dimensions, and the convenience of conducting tribological studies. Together with the metallographic analysis of the structural state of tribo-conjugation samples, the tribometer is a complex that possesses a certain degree of perfection. The technical capabilities and reliability of the tribometer are confirmed by the experience of its operation, especially when the tribological efficiency of the couplings of samples and parts is determined. The design of the friction unit and the loading mechanism were designed to increase the efficiency and reliability of the results of tribotechnical studies of the characteristics and parameters of tribo-coupling samples by reducing the dynamic loads on the sample during transient friction and wear processes, as well as to expand the range of force parameters of the load. According to the developed comprehensive methodology for researching the tribological efficiency of heavily loaded couplings of car parts, the following parameters were measured: intensity of mass wear I (weight method), coefficient of friction μ (tensometry), temperature in the contact zone T (thermocouples), the value of contact electrical resistance of the tribocoupling KEO (R), according to electrical measurement circuit (Fig. 4).

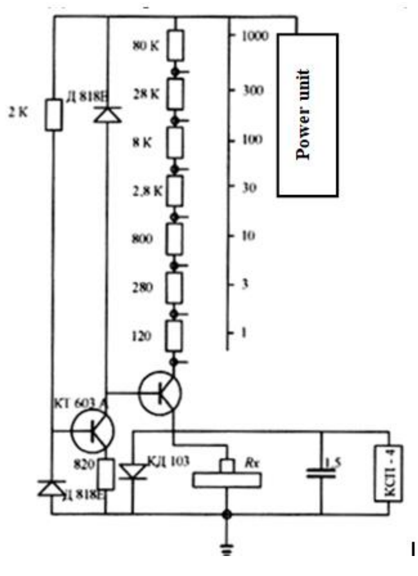


Fig. 4. Electrical circuit for measuring KEO (R) parameters of tribocoupling parts

In addition, the following parameters were calculated: the specific work of destruction of secondary dissipative structures - A_p and the energy intensity of triboconjugation according to the thermal index - ECT $_Q$.

The value of the specific work of destruction A_p characterizes the level of structural adaptability and is determined by the cost of friction work A_{tr} to remove a unit volume of material Δ V from the friction surface:

$$A_p = \frac{A_{тр}}{\Delta V}, \frac{Дж}{мм^3}. \quad (1)$$

The parameter A_p characterizes the processes that take place in the zone of frictional contact of tribocouples and is general for evaluating the processes of surface destruction. The value of this parameter depends on the wear mechanism and can take different values for the same tribocoupler.

The specific energy capacity of the friction system according to the thermal index characterizes the friction work costs for a temperature increase in the contact zone by 1 K. It is an energy criterion for evaluating the range of structural adaptability of tribo-conjugate materials:

$$E_q = \frac{A_{тр}}{\Delta T}, \frac{Дж}{см^2 \cdot с \cdot К}. \quad (2)$$

The criteria A_p and ECT_Q are significant in solving applied problems of tribology: the selection of structural and lubricating materials, determination of optimal force load parameters that ensure structural adaptability, its level and limits.

The control values of the listed parameters were taken as their stable values after each stage of force load (change in sliding speed, normal load. Research was carried out in wide ranges of changes in load parameters with their smooth change, different lubricating media, using different test samples (different processing methods). This made it possible to comprehensively investigate the processes of running-in, normal friction and wear, transitional processes, to fix the critical values of load parameters during the transition to volumetric destruction, and to draw a conclusion about the effectiveness of tribo couplings of samples and parts. The most important for the theory and practice of friction and wear is the range of normal mechano-chemical wear, which is characterized by the dynamic balance of the processes of formation, transformation and destruction of dissipative secondary structures - the range of structural adaptability. Identification by tribotechnical parameters (I, μ, T), KEO (R) and structural parameters (type of dissipative secondary structures) was carried out within the range of structural adaptability. The structure of friction surfaces was studied using a scanning electron microscope of the Cam system Scan 4DV with Link 860 energy dispersive X-ray analysis system.

The proposed electrical criteria for assessing the structural adaptability of tribocoupler materials (KEO (R), ΔT, ΔR, ΔR/ R_{out}, R_{out}, R_{st}) made it possible to significantly shorten the research cycle, objectively identify the main tribotechnical parameters with the corresponding structural state of the friction surfaces, and also, to clearly fix the critical points of transition of processes: running-in - normal friction and wear - damage (volumetric destruction). These criteria can be determined with the required accuracy by observing the standardized research conditions: ensuring the conditions of limit friction, equilibrium of the processes of heat generation and heat removal, equilibrium of the processes of formation and destruction of dissipative secondary structures with a wide range of changes in the power parameters of the load with their smooth nature of change, reproduction on an appropriate scale (real operating conditions of the tested tribocouplers of the samples). The specified circumstances led to the development of a fundamentally new tribometer design.

The influence of load modes (p, v) of tribocouplers of samples and parts on the nature of the change in KEO parameters (R) over time is shown in Fig. 5.

p – specific load; ν – sliding speed; R_{ini} is the initial (preliminary) value of the KEO (R) tribocoupling ; R_{st} – stable (optimal) value of KEO (R) given p, ν data; δR is the magnitude of the drop in R values (strength margin of dissipative secondary structures); ΔR = R_{st} - R_{ins} - when transitioning to the mode of normal friction and wear; Δ t is the time for the tribocoupler to reach a stable KEO value (R); - KEO scattering ranges (R).

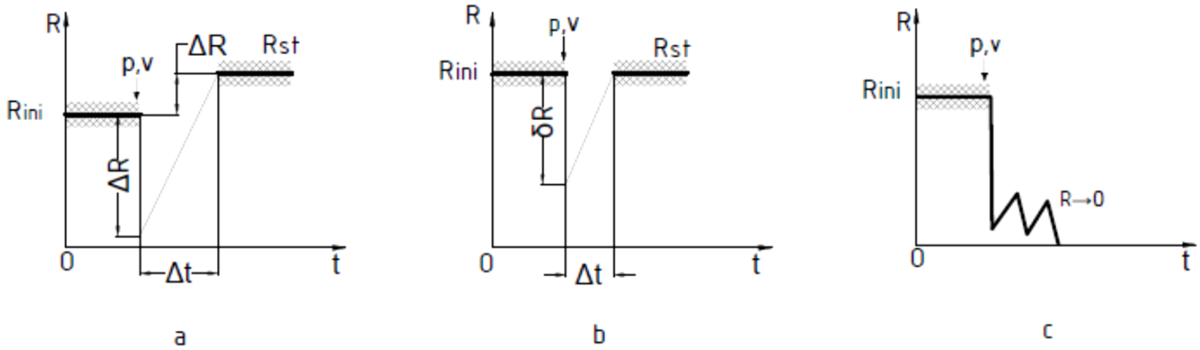


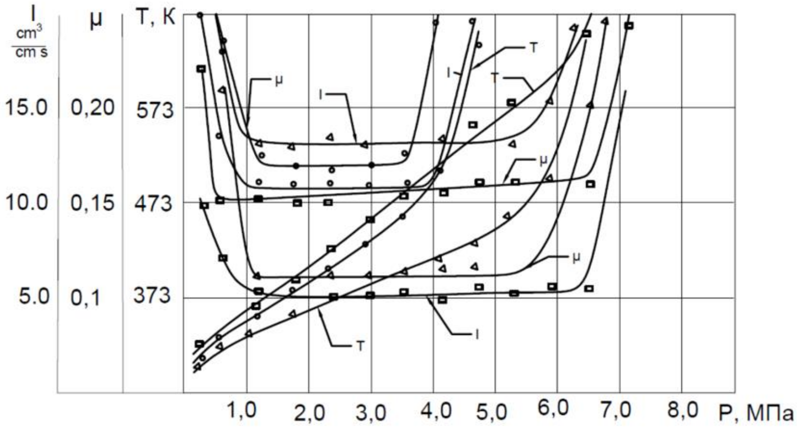
Fig. 5. Schematic representation of the nature of the change in the KEO parameters (R) at the moment of time t from the power load parameters p, v of the tribocoupler of the samples: a - run-in modes (transient processes); b – modes of normal friction and wear; c - volumetric destruction.

The choice of materials for tribo-coupling parts , methods of their strengthening, lubricating medium, magnitudes and nature of changes in the power parameters of the load was carried out in accordance with the research goal and the possibility of their practical use.

The material of the counterbody - steel SHX15 (HPc=60...63, Ra=0.32μm) was chosen from the point of view of its high wear resistance in comparison with the studied materials of the samples. The material of the studied sample is steel 40X (HPc=48...52, Ra=0.32μm). The working surface of the sample, in order to increase its wear resistance, was subjected to special processing methods. The research was carried out at a constant sliding speed (ν= 1.2 m/s) with a smooth change in the value of the specific load R.

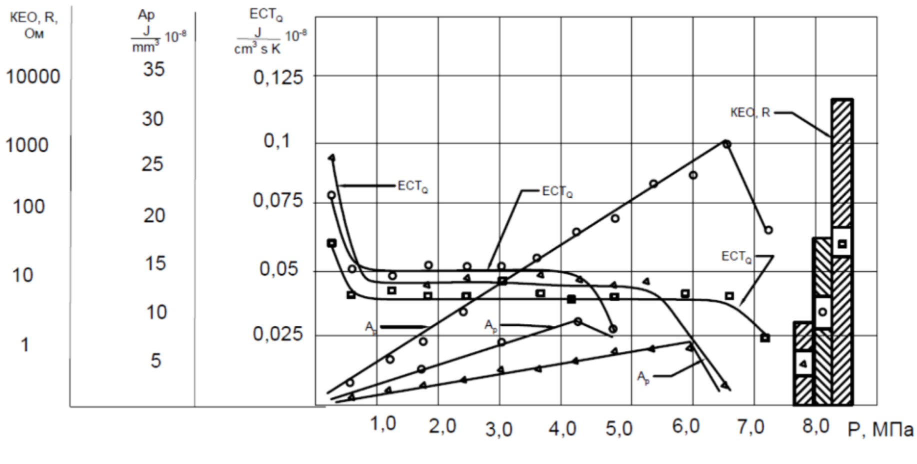
An inactive , non-polar, low-viscosity petroleum jelly lubricant was chosen as a lubricating medium with the need to exclude the influence of hydrodynamic and adsorption effects, since technical lubricants have a complex carbon and fractional composition, contain in special additives of active substances, resin-forming products and mechanical impurities.

As an example of studies of the tribological efficiency of sample couplings, Fig. 6.7 shows the results of the main tribotechnical characteristics and parameters for various strengthening technologies: Δ – complex chemical and thermal treatment, o – serial technology, □ – boronizing .



Δ – complex chemical and thermal treatment, o – serial technology, □ – boron treatment .

Fig. 6. Graphical dependence of the intensity of wear J, the coefficient of friction μ, the temperature T in the contact zone on the value of the specific load P.



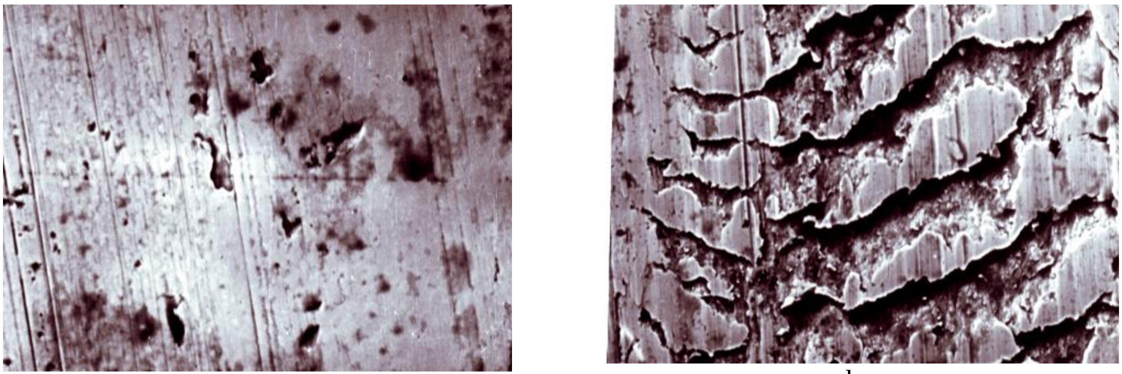
Δ – complex chemical and thermal treatment, o – serial technology, □ – boron treatment

Fig. 7. Graphical dependence of the change in the specific work of destruction Ap , the temperature energy capacity of the friction system on the thermal index ECT $_Q$ and the contact electrical resistance of the KEO tribocoupler (R)

The exit of the tribocoupling to the mode of normal friction and wear after each stage of loading (optimal values of the parameters I, μ, T in the range of structural adaptability), directly during the research process, can be judged by the stabilization of the KEO parameter (R). In addition, according to the kinetics of the change of KEO (R), the processes of completion of tribo conjugation run-in, the ranges of normal friction and wear, the moment of transition to the process of volumetric destruction are recorded

As can be seen from the given graphs, the nature of the change in wear intensity, friction coefficient, and temperature for the studied methods of chemical-thermal strengthening is in accordance with the general pattern of friction and wear. Three characteristic zones are distinguished: 1 – run-in mode (unstable values of these parameters), 2 – range of normal friction and wear (minimum and stable values of these parameters), 3 – transition of tribocoupling to damage mode (volumetric destruction).

The results of studies of the structure of the friction surfaces of the studied samples made of 40X steel strengthened by serial technology are presented in Fig. 8, complex chemical and thermal treatment in Fig. 9 and boronization in Fig. 10.



a b

Fig. 8. Electronic microfractograms surface friction sample from steel 40 X strengthened on serial technologies : and - the normal mode friction and wear , b – mode of damage

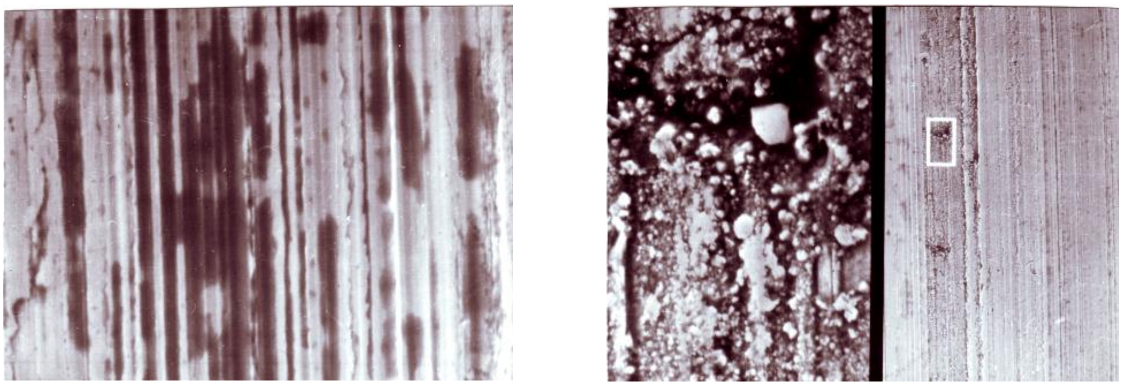


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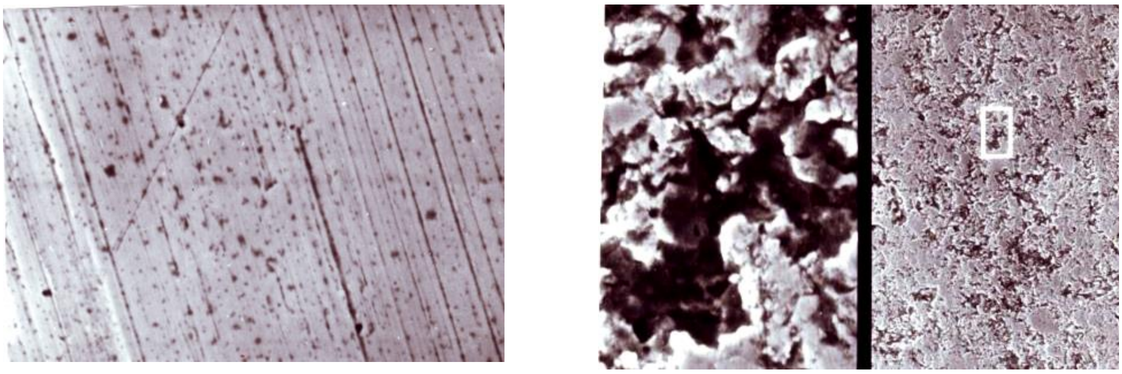
Fig. 9. Electron microfractograms of the friction surface of a sample made of 40 X steel strengthened by complex chemical and thermal treatment: and - the normal mode friction and wear , b – mode of damage



a b

Fig. 10. Electronic microfractograms surface friction sample from steel 40 X strengthened boring : and - the normal mode friction and wear , b – mode of damage

These assumptions are confirmed by electronic microfractograms of the friction surfaces of the studied samples. In the mode of structural adaptability (normal friction and wear), the working surfaces of the samples are covered with appropriate dissipative secondary structures (Fig.s 8a, 9a, 10a); when transitioning to the damage mode, the dynamic balance of the processes of formation and destruction of dissipative secondary structures is disturbed (Fig.s 8b, 9b, 10b) , which leads to volumetric destruction of friction surfaces.

Conclusions

1. A comprehensive methodology for researching the tribological efficiency of the couplings of samples and parts on the proposed design of the tribometer has been developed. The tribometer allows you to study samples according to the "disk - finger" scheme. The flat contact scheme makes it possible to realize different modes of friction, to smoothly change the force parameters of the load in a wide range, and in combination with tribotechnical characteristics and metallographic analysis to more comprehensively characterize the tribological efficiency of tribocouplers of samples and parts.

2. The application of the developed research methodology and kinetic criteria for evaluating operational wear resistance allows identifying the main factors that determine the development of the leading types of wear, studying the mechanisms of their development, and reasonably choosing constructive, technological and operational means of managing the surface strength of tribo-coupling parts , including heavily loaded ones car tribocoupling . In combination with the metallographic study of the structural state of friction surfaces (types of internal combustion engines), the possibility of a comprehensive study of processes in the frictional contact zone with the expansion of the existing bank of tribotechnical data in order to increase the tribological efficiency of couplings of parts of machines for controlling friction and wear processes appeared.

3. A correlational dependence was revealed between the characteristics of changes in tribotechnical parameters: wear intensity, friction coefficient, temperature in the contact zone, structural-energy parameters: specific energy of destruction of dissipative secondary structures according to the thermal index, contact electrical resistance and type of dissipative secondary structures in the range of normal friction and wear. This correlation dependence is universal in nature, as it was discovered during the study of other materials of experimental samples, methods of strengthening friction surfaces, various lubricants and additives, both when the specific load and the sliding speed change.

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Аулін В.В., Гупка А.Б., Ляшук О.Л., Стухляк П.Д., Гриньків А.В. Комплексна методика дослідження трибологічної ефективності спряжень деталей вузлів, систем та агрегатів автомобілів

В даній роботі для дослідження трибологічної ефективності спряжень зразків і деталей запропоновано універсальний трибометр. Конструкція трибометра дозволила проводити експериментальні дослідження в широкому діапазоні силових параметрів навантаження при їх плавній зміні. Наведено комплекс характеристик і параметрів, які визначаються на трибометрів при дослідженні спряжень зразків за схемою «диск-палець»: інтенсивність зносу, коефіцієнт тертя, температура в зоні контакту, питома робота руйнування, питома енергоємність по тепловому показнику, електричний критерій оцінки структурної пристосовуваності трибоспряжень. За характерами зміни параметрів контактного електроопору визначали режими тертя і зношування: припрацювання, нормальне тертя і зношування, об'ємна деструкція. Наведені результати дослідження трибологічної ефективності за зазначеними характеристиками та параметрами. Для порівняльного ефекту зразки зміцнювали комплексним хіміко-термічним способом, серійною технологією та боруванням. Результати дали можливість виділити характерні зони режимів припрацювання, нормального тертя та зношування, об'ємної деструкції. Вони підтверджені отриманими електронними мікрофрактографіями.

Ключові слова: трибологічна ефективність**,** трибоспряження зразків і деталей, триботехнічні параметри, контактний електроопір, поверхнева міцність, експлуатаційна надійність