defects. At the same time, the material is strengthened and there is a reduction in internal friction. The parallel occurence of the competing processes of pinning and unpinning of dislocations with an increase in total dislocation density leads to the appearance of several stages in the change in internal friction and resonant frequency which show which of the processes of strengthening or loss of strength predominates in a given interval of cycling.

Further cycling leads to the origin of submicroscopic failure of continuity in the metal which occurs in those volumes where the critical dislocation density has already been reached. The accumulation in local volumes of the metal of failures in continuity causes a sharp increase in internal friction and a reduction in the modulus of elasticity. The period of accumulation of damage of the metal is replaced by the stage of failure, the formation and development of microcracks, internal friction continues to increase, and the modulus of elasticity decreases with increasing heat.

There is practical interest in establishment of the boundaries of the change in internal friction and modulus of elasticity starting with which the last stage of failure starts, i.e., when the life of materials is exhausted. In this case there are no general criteria for determination. For each of the materials depending upon its previous treatment, it is necessary to make individual investigations, to establish the critical values of the changes in these values, and then to use them for evaluating the life of a material.

The most useful for these purposes are units making it possible to measure internal friction and the modulus of elasticity during cycling without removal of the sample, which eliminates uncertainties related to repeated fastening and placement of the sample.

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STRUCTURE AND SURFACE STRENGTH OF MATERIALS IN FRICTION

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The total problem of reliability and life of machines, mechanisms, and instruments includes two problems, through and surface strength. The processes of through failure occur as a result of the accumulation in the volume of the material of defects in its structure leading to macroscopic failure of the part or structure. The processes of surface failure consist of a large quantity of microscopic acts of failure revealed in a gradual decrease in the volume of material, or wear.

In the problem of surface strength of materials significant successes have been attained both in the theory and in the solution of practical problems. Failures as a result of through failure of machine parts occur comparatively rarely and predicting and eliminating them is possible in the design stage. The overwhelming majority of breakdowns (up to 80%) occur as a result of surface failure, wear, and damage in friction.

The basic differences in the mechanisms of through and surface failure and their great applied value make it possible to separate surface strength into an independent problem. The mechanisms of surface strength and failure are determined by the processes of friction, lubricating action, and wear.

The creation of a general, sufficiently complete, and uncontradictory theory of friction, lubrication, and wear (tribology) relating the parameters of load (P, V) with the whole combination of mechanical and physicochemical properties of rubbing materials and working media has become one of the central problems of mechanical engineering.

The development and solution of this problem are very necessary for all stages of design, manufacture, and service of machines.

Despite this, it must be acknowledged that the efforts which have been undertaken for the solution of problems of tribology are far from appropriate to the significance of this problem.

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At present there are no simple and correct methods of calculating and controlling friction and wear and no sufficiently well based and standardized methods of testing and test machines.

Practically all applied problems of controlling friction and wear are solved empirically with a great expenditure of time and means and are not always the optimum.

Development of Theoretical Concepts and Practical Problems. The study of friction and wear originated as a result of the needs of mechanics and first developed as a division of mechanics, which has made its impression on the whole subsequent development of this problem. The mechanical approach was acceptable in the early stages of development of technology (low-speed machines, simple materials, dry friction). Subsequently, the general progress in technology, the sharply broadening increased complexity of the conditions of friction, and the development and use of new materials revealed the whole tremendous complexity and variety of the phenomena of friction and wear.

It was established that in friction together with mechanical processes there is great significance in physical, chemical, mechanicochemical, and thermal processes. It has also become necessary to observe the processes of friction in all of its stages, including in static contact, at the start of movement, during running in, under steady conditions, and in changes to damage. It became clear that modern problems of the theory of friction and wear may not be solved with the use of models where such simplified forms of interaction as "mechanical," "molecular," "adhesion," "deformation," etc. are postulated, particularly since in the final analysis, despite some differences in designations, these models remained essentially mechanical [1, 2].

The mechanical approach, in which the friction force is determined only as the resistance to deformation of irregularities and the overcoming of molecular attraction at points of contact, ignores modern concepts of the nature of friction. The formal expressions of the molecular-mechanical theory obtained are not equations of movement of the surface layer as a continuum; velocity is absent in them.

The model of frictional fatigue does not contain the most important experimental results on tribochemical and thermal phenomena, phase and structural transformations, and others determining the actual mechanisms of failure. Such a model may not be the basis for the selection of materials for wear-resistant rubbing pairs [1].

The materials science and physical aspects of friction have been investigated very insufficiently. Methods and concepts of experimental and theoretical physics developing at the present time have opened great possibilities for the development of the problem of friction, lubricating action, and wear from the position of material science and the thermodynamics of irreversible processes.

Friction is a process of the conversion of external mechanical energy into the energy of internal processes and the rules of this conversion are determined by the structural condition of the frictional system and the thermodynamic activity of the medium.

The frictional system refers to the tremendous class of thermodynamically open systems, i.e., of those systems which may be exchanged with the medium both by energy and by a substance [3-5].

As the result of a large number of systematic investigations with the use of modern methods of experimental physics, the prerequisites have been created for development of the fundamentals of the structure-energy theory of friction, lubrication, and wear [5, 6].

Classification of the Forms of Surface Failure. Investigation of a large number of parts and operating elements of actual machines, instruments, and mechanisms used in various branches of the national economy and reproduction of the forms of surface failure observed in service on laboratory units have made it possible to classify the forms of wear and damage of rubbing interfaces by the processes dependent upon the mechanics, physics, and chemistry of the contact phenomena [7-9].

The whole range of phenomena of friction and wear are divided into two clearly expressed areas: 1) the steady process of normal friction and wear; 2) damage in friction. The external geometric and structural signs, mechanisms, and intensity of surface failure in normal wear and in appearances of damage have sharp differences.

Together with this it has been established that all forms of surface failure have a single basis dependent upon energy triboactivation and passivation of the materials of the frictional system. The structure, properties, and phase and chemical composition of the materials determine the specific values of tribotechnical indices appearing under certain conditions of activation and passivation.

The classification of the processes of surface failure by material science signs is shown in Table 1 and by energy relationships in Table 2.

In accordance with the first law of thermodynamics, the work of the forces of friction A, which is the source of activation G_{act}, is primarily expended on the formation of heat Q (thermal activation) and partially stored by the material of the surface layers ΔE (structural activation):

$$A = Q + \Delta E. \tag{1}$$

The primary components of passivation are the energy dissipated by the friction unit G_{dis} and the energy absorbed in friction G_{abs}:

$$A = G_{dis} + G_{abs}. \tag{2}$$

The level of effective activation is determined by the amount of energy absorbed by the frictional system G_{abs}. In passivation, the decisive value upon which depends the range of loads in normal friction will be the energy necessary for the formation of secondary structures G_{SS}. At the same time, there is significant importance in the capacity of the frictional system to dissipate energy in the form of heat (G_{dis}).

All of the qualitative and quantitative parameters of the process of friction and wear are determined by the values of A, G_{abs}, G_{dis}, and G_{SS} [1, 5]. A necessary condition of normal mechanicochemical forms of wear is the dynamic equilibrium of the processes of activation and passivation at which the effective activation energy G_{act} is within the limits of values necessary for the formation of secondary protective structures:

$$G_{act} = G_{SS}. \tag{3}$$

With failure of this equilibrium as a result of excess activation, different processes of damage arise. The reasons for excess activation may be deformation, heating, the dynamic character of application of the load, the plasticizing action of the medium, or technological heredity (Tables 1 and 2). An equilibrium metastable state with excess activation is attained as a result of strengthened dynamic oxidation, the formation of metallic bonds in the contact of fresh surfaces, and direct failure of surface layers.

The interrelationship between the forms of wear and different phenomena of damage is confirmed by the presence of critical points of transition from normal processes to processes of damage and by the existence of threshold values of load P, rate of movement V, temperature T, concentration of active elements of the medium C, critical values of the mechanical and thermophysical properties of the materials M, and the scale factor SF.

The generality and interrelationship of all of the processes occurring in the contact zone in external friction make it possible to consider the classification of the forms of surface failure as a single system described by a functional relationship between the processes of activation and passivation of the materials of the frictional system.

Fundamental Rules of Friction and Wear. An analysis of the general classification of forms of surface failure, concepts of the thermodynamics of irreversible processes, the results of thorough experimental investigations, and the use of positive production experience made it possible to experimentally establish and theoretically base the existence of a general rule of friction and wear and to draw a number of fundamental conclusions [5].

The general rule of friction and wear, which is confirmed by all accumulated experimental data of investigations in various laboratories of the world and in production, consists of the following. For all materials known in nature and in technology and also for bodies which will be detected and created there is a range of loads and rates of movement where friction and wear are several orders of magnitude less than outside this range [5]. The range of normal processes (limited by the values of the activation G_{act} and passivation G_{pas} energies) necessary for the formation of protective secondary structures depends upon the properties of the materials and the medium (area II in Fig. 1).

The excess energy of triboactivation sharply increases the heterogeneity of deformation and failure and depending upon the specific conditions of overloading causes increased wear or a certain form of damage (area III of Fig. 1).

For example, a concentration of stresses in contact in the presence of an abrasive and at a ratio of material hardness to abrasive hardness of $H_{mat}/H_{abr} > 0.6$-0.7 causes excess deformation (structural) activation and intensification of mechanicochemical processes (range 2 in Fig. 1). The intensity of wear increases (mechanicochemical form of abrasive wear). A sharp increase in concentration of stresses leads to failure of the base material – cutting, i.e., to the mechanical form of abrasive wear ($H_{mat}/H_{abr} < 0.6$-0.7) (range 6 in Fig. 1).

Excess activation with a dynamic character of application of the load increases the intensity of mechanicochemical wear and with small amplitudes of movement causes dynamic oxidation and microseizing, the fretting process (range 3 in Fig. 1). Strengthened thermal activation at rates of movement and temperatures above the allowable V_{cr} and T_{cr} leads to the occurrence of type II seizing (hot scoring) (range 4 in Fig. 1). Excess structural activation with loads above the allowable causes type I seizing (cold scoring) (range 5 in Fig. 1).

With low values of the loading parameters and activation energy (area I in Fig. 1), the processes of friction and wear are unsteady.

TABLE 1. Results of a Composite Material Science Investigation

Acceptable phenomena — wear (formation and failure of types I and II secondary structures	Unacceptable phenomena — damage (failure of the base material)
1. Normal mechanical (oxidation)	1. Type I seizing
2. Normal mechanical films of nonoxygen origin	2. Type II seizing
3. Mechanicochemical form of abrasive wear	3. Fretting process
	4. Mechanical form of abrasive wear
	5. Contact fatigue (pitting)
	6. Erosion, corrosion, cavitation*

*Not directly related to friction.

TABLE 2. Results of an Analysis of Energy Relationships (processes of conversion and dissipation of energy)

Activation (thermal, structural)	Passivation (absorption, dissipation)
$\boxed{A = Q + \Delta E}$	$\boxed{A = G_{pas} + G_f}$
$G_A = \varphi(P, V, T, C, M)$	$G_p = \varphi(C, M, SF)$

Energy conditions and critical values of load parameters

Necessary conditions and results of normal processes (equilibrium of processes of formation and failure of secondary structures)	Conditions and results of processes of damage (failure of equilibrium of formation and failure of secondary structures)
$\left.\begin{array}{l}1.\\2.\\3.\end{array}\right\} - G_{pas} = G_{SS}$	1. P_{cr} 2. V_{cr}, T_{cr} 3. $G_{pas} \gg G_{SS} - D_{cr}$ 4. $H_{mat}/H_{abr} < 0{,}7$ 5. σ_{cr}^{-1}
$V_{ef} \to \min \frac{V_{\bar{E}}}{V_{ef}} \to 1$	$V_{ef} \to \max \frac{V_{\bar{E}}}{V_{ef}} \to \min$
$A_f = \frac{A}{\Delta W} \to \max$	$A_f = \frac{A}{\Delta W} \to \min$

The fundamental physical basis of the general rule (range of normal friction) is the universal phenomenon of adaptation, structural adaptibility of materials, the essence of which consists of the following. In normal friction in the zone of contact there is formed a dissipative structure possessing the property of minimum production of entropy. The possibility of formation of such structures in living and nonliving nature is based on fundamental physics [3-5].

In the realization of structural adaptibility all of the interactions of rubbing solids and the medium are localized in a thin-film object, the secondary structures. Rearrangement of the original structure into a new phase occurs in the direction of maximum strengthening, refinement, and orientation relative to movement in friction and of impregnation by the active components of the medium. The new phase occurring screens the original material from mechanical and physicochemical destruction. External mechanical actions unavoidably lead to failure of the screening phase but these same actions and the associated processes of transfer of a substance from the medium provide regeneration of it.

Three basic stages of this phenomenon may be differentiated:

1) activation of the surface layers of the rubbing metals, structural and thermal;

2) passivation, the formation of protective secondary structures;

3) failure of the secondary structures.

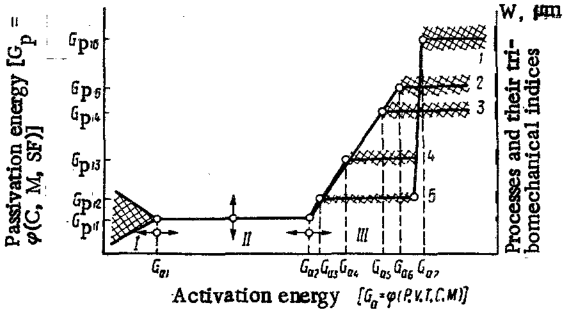

Fig. 1. General rule of friction M and wear W: activation: I) area of unsteady processes, $G_{act} < G_{SS}$; II) area of normal mechanicochemical processes, G_{a_1}, G_{a_2}, $G_{a_3} = G_{SS}$; III) area of damage, G_{a_4}, G_{a_5}, G_{a_6}, $G_{a_7} \gg G_{SS}$; passivation: 1) range G_{p_1}, normal oxidation; 2) range G_{p_2}, strengthened oxidation; 3) range G_{p_3}, dynamic oxidation; 4) range G_{p_4}, type II seizing; 5) range G_{p_5}, type I seizing; 6) range G_{p_6}, mechanical failure.

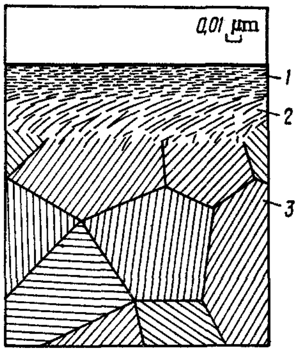

Fig. 2. Plan of the structure of surface layers in normal mechanicochemical wear: 1) secondary structures; 2) subsurface deformed layer; 3) base (unchanged) metal.

In contrast to the equilibrium condition in the cross section of the surface layers of materials operating under conditions of structural adaptability, it is possible to distinguish three zones differing in their structural condition (Fig. 2):

a) the contact zone or zone of secondary structures with a thickness on the order of tens of nanometers [1];

b) the subsurface zone with a thickness up to several microns [10];

c) the zone of original structure [2].

Composite investigations of the process of formation of protective secondary structures have made it possible to establish that in the occurrence of the phenomenon of secondary structures in the zone of contact the kinetic phase transformation occurs spasmodically.

1. There is a scale jump. All forms of interaction are localized in a thin-film object, the secondary structures. The depth of the layers actively participating in the process of friction and wear (h) in normal wear is four or five orders of magnitude less in comparison with the damage [5, 11].

2. There is a kinetic jump. The rates of diffusion and chemical reactions increase by several orders of magnitude and the diffusion coefficient increases by 5-11 orders of magnitude in comparison with diffusion in heating [5, 7].

3. The characteristics of the structure and phase conditions with a change to structural adaptability sharply differ from the characteristics known for equilibrium conditions. The secondary structures have a dislocation-free structure, the solubility in the surface layers increases by 3-5 orders of magnitude, and there is a sharply expressed lack of stoichiometry of chemical compounds [5, 11, 12]. The transition occurs under the cooperative synergistic action of the processes of deformation, diffusion, and heating.

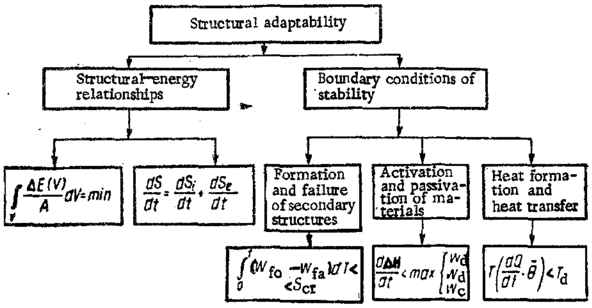

Fig. 3. Physical model of structural adaptability in friction: ΔE) absorbed energy; V) volume; A) work of friction; t) current time; dS_e) change in entropy as a result of exchange of heat and substance with the external medium; dS_i) change in entropy within the system; W_{fa}) rate of failure of secondary structures; W_{fo}) rate of formation of secondary structures; ΔH) change in heat content of the effective volume V_{ef}; S_{cr}) critical area of secondary structures; W_a, W_d, W_c) rate of adsorption, diffusion, and chemical reactions; Q) heat; T) temperature of V_{ef}; $\bar{\theta}$) combination of thermophysical constants of the material; T_d) temperature of the processes of failure (desorption of lubricant, decomposition of the structure, etc.).

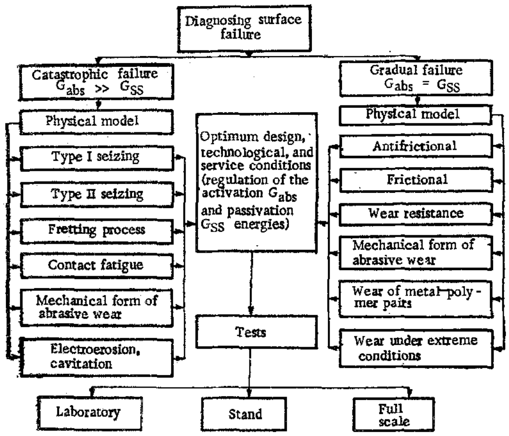

Fig. 4. Plan of controlling friction and wear.

As a result in normal mechanicochemical wear, a new and previously unknown form of the organization of the structure of rubbing surfaces occurs [5, 6, 11].

The phenomenon of structural adaptibility is universally observed in the friction of any materials under certain loading conditions for each pair of materials but the mechanisms of adaptibility in the rubbing of different metals and nonmetals are fundamentally specific. A minimum friction and wear is general for all cases of structural adaptability.

The Stability of Normal Friction and Wear. The dissipative structure of friction in the area of normal processes is stable and possesses the property of self-regulation [5, 13]. The stability of the phenomena of structural adaptability, established with the use of methods of measurement of electrode potential, quantitative microfractography, television technology, and precision tribometric equipment is due to the dynamic equilibrium of all destructive activating processes and processes of passivation and formation of a screening phase (the formation and failure of secondary structures, heat formation and transfer, formation of forces of friction, submicrorelief). As a result of investigations, the occurrences of steadiness of and minimum thermal flow, of the relative area of secondary structures and submicrorelief, and of the steadiness of the electrode potential were established [5, 14]. The rules given are an indication of the presence of the phenomenon of self-regulation in the friction and wear of materials [5, 13, 15].

A structural and energy analysis of the processes of friction and wear makes it possible to consider the important question of the relationship between the forces of friction and the intensity of surface failure.

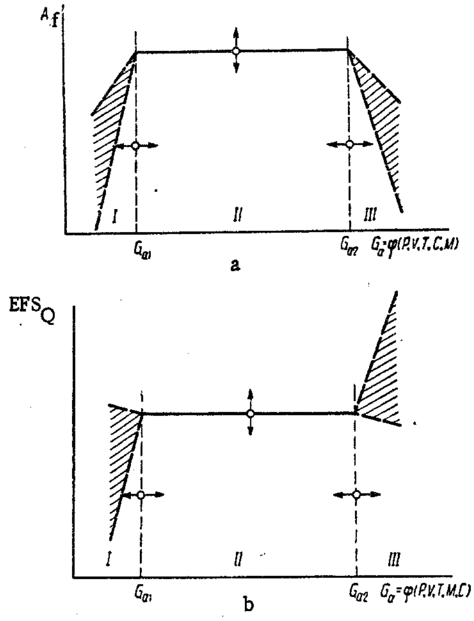

Fig. 5. Plan of the change in A_f and EFS_Q. Designations the same as in Fig. 1.

The friction force F is a function, more accurately an operator N, of the whole combination of processes occurring with one combination or another of normal load P, rate of sliding V, and vector of the parameters of friction $\overline{M}$, $\overline{C}$ (materials, conditions of the medium, etc.) [9, 7]:

$$F(P) = \{P, V, \overline{M}, \overline{C}\}. \tag{4}$$

The intensity of surface failure is a quantitative characteristic of the final stage of the combination of contact phenomena [8].

In mechanical friction, physical, chemical, electrical, and other processes occur at the contact. The relationship of the intensities of these processes may be very different depending upon the loading condition (P, V), the properties of the rubbing materials, and the physicochemical action of the working media. Therefore, the interaction of bodies in friction and the formation of the forces of friction may not be described by a simple fundamental rule. Satisfactory relationships describing the processes of friction may be obtained for conditions of structural adaptibility with which the relationship of the various forms of interaction, the processes of transformation, and surface failure are stable and minimized and change proportionally.

In operation of pairs under conditions of damage, the direct relationship between friction and wear breaks down and the relationship becomes more complex [5, 8].

Quantitative Relationships. The general rule and its primary physical mechanism, the phenomenon of structural adaptability, may be expressed in the form of a minimum principle and the relationship of entropies (Fig. 3) [5, 15].

The integral of absorption of energy ΔE, referred to the work of friction A for the volume being transformed V, tends toward a minimum. The important results of this principle are that the specific work of failure A_f and the ratio of the volume V_E^- which has absorbed the limiting energy of failure to the effective voluem V_{ef} tend toward a maximum. The energy within the system is transformed from higher forms to lower (mechanical work changes to heat). The "internal" contribution of entropy is always positive (dS_i/dt). The entropy which is produced in the system in liberation of heat is compensated by the influx of negative entropy supplied from the source of mechanical movement (dS_e/dt). The influx of substance from without compensates the changes caused in the system by diffusion and chemical reactions. With structural adaptibility the friction unit is found in a condition of current equilibrium.

The boundary conditions of the existence of structural adaptability are the principle of screening, consisting of agreement of the rates of destructive and restorative processes in the zone of friction (Fig. 3) [5, 8].

Control. The generalized classification of the forms of wear and damage, the establishment of a general rule, and discovery of its physical mechanism, the phenomena of structural adaptability, make it possible to formulate the basic

TABLE 3. Control of Activation [$G_{act} = \varphi(P, V, T, M, C)$] and Passivation [$G_{pas} = \varphi(C, M, SF)$] (design, technological, and service means)

Activation (structural, thermal)	Passivation (absorption, formation of secondary structures — G_{SS}, and dissipation — G_{dis})
1. Loading conditions (P, V). Change in intensity and form of activation — structural (P) and thermal (V).	1. Lubricating medium (C). Regulation of the processes of passivation as a result of modification of the surface layers of creation of secondary structures of a specified type with specified properties, dissipation of thermal energy.
2. Thermal conditions (T). Regulation of thermal activation as a result of coaling, heating, dimensions and form of the part, materials, and media with different thermophysical characteristics.	2. Materials (M). Regulation of passivation as a result of alloying of the changing area of secondary structures of a specified type, changes in the properties of secondary structures.
3. Strengthening method (M). Restraint of structural activation as a result of an increase in hardness (H) or a reduction in ductility (σ_y).	3. Running in (M, C). Regulation of passivation as a result of loading conditions, temperature, composition of the medium, geometric and structural heredity.
4. Alloying of alloys (M). Restraint of structural and thermal activation as a result of a change in mechanical and physical properties	4. Scale factor (SF). Regulation of activation and passivation as a result of dimensions and form of the rubbing parts.
5. Lubricating medium (C). Restraint of structural and thermal activation as a result of homogenization of stresses, modification of surface layers, and reduction in the coefficients of friction.	
6. Surface quality (M). Change in the intensity of structural and thermal activation as a result of homogenization of stresses and deformations and structural and geometric heredity.	

principles and means of control of processes of friction and wear. The purpose of control becomes clear, to broaden the range of normal mechanicochemical processes and to change the level of structural adaptability.

The principle of the basis of control is regulation of the effective energy of triboactivation and passivation of the materials of a frictional system with the use of design, technological, and service means.

Table 3 presents the basic means in principle and possibilities of regulating the processes of activation and passivation of the materials of the frictional system.

Broadening the range of normal processes (phenomenon of structural adaptability) may be accomplished by measures reducing the intensity of triboactivation G_{act} or increasing the energy of formation of secondary structures G_{SS}. The relationship $G_{act} \gg G_{SS}$ (Table 1) must be reduced to the equality $G_{act} = G_{SS}$. The most effective means of restraint of processes of activation is strengthening methods. Effective means of increasing the energy for formation of secondary structures are alloying the lubricating materials with chemically active additions and alloying of the alloys with elements broadening the area of existence of secondary structures.

A change in the level of tribotechnical indices of normal mechanicochemical processes is attained by obtaining secondary structures with specified strength properties and characteristics of the formation of frictional bonds. In practice this may be accomplished by all means of regulating passivation processes (lubricating media, their composition and concentration, materials used, methods and conditions of running in).

Specific problems of controlling friction and wear in machines are solved in the following manner (Fig. 4). In the first stage the form of wear or damage of the rubbing surface is diagnosed. Each form of surface failure causing gradual or catastrophic failure is described by a physical model revealing the energy reasons and structural kinetics of failure. The second stage includes adoption of the optimum solution with the use of design, technological, or service means. In the third stage the solution adopted is checked under laboratory conditions and in full-scale tests.

TABLE 4. Specific Work for Wear or Damage in Friction

Form of wear or damage	Specific work for wear or damage, kgf·m/mm^3 (10^{10} J/m^3)
Normal mechanicochemical wear	100000...1000000
Mechanicochemical form of abrasive wear	10000...100000
Fretting process	100...10000
Type II seizing	100...1000
Type I seizing	10...100
Mechanical form of abrasive wear	1...10

As a result of a large amount of experimental work, the structure and energy effects have been revealed and studied and physical models have been constructed which are widely used in control [5, 9, 8, 16].

Energy Criteria. Evaluating the effectiveness of the solutions adopted is done with the use of energy criteria describing the level of the structural adaptability, A_f [5], and the limiting values of activation energy in changing to damage, EFS_Q [17].

The level of structural adaptability is characterized by the value of the specific work for failure:

$$A_f = \frac{A}{\Delta W}, \ \text{J/mm}^3, \tag{5}$$

where the value A_f determines the expenditures of the work of friction A for the removal of a unit of volume of material ($\Delta W = 1$ mm^3) from the rubbing surface. For different processes it varies by several orders of magnitude (Table 4) [5, 18]. The stability of A_f within the limits of structural adaptibility creates the necessary grounds for methods of determining it (Fig. 5a) [5].

The energy capacity of the frictional system (EFS) serves as the energy criterion for evaluating the range of structural adaptability [17]. The most important for practical purposes is the energy capacity of the frictional system based on the thermal index, the EFS_Q, since heat is the primary component of the energy balance of friction under all conditions of use of machines:

$$EFS_Q = \frac{A}{\Delta T}, \ \text{J/cm}^2\cdot\text{sec}. \tag{6}$$

This value quantitatively describes the energy of thermal activation of the materials of a frictional system and characterizes expenditures of the work of friction A for an increase in temperature on the surfaces of contact of 1°C (Fig. 5b) [17]. In addition, it makes it possible to determine the range of structural adaptability based on the thermal parameter. Knowing the work of friction consumed for an increase in temperature on the surface of friction of 1°C and the temperature for destruction of the materials of the frictional system T_d, it is possible with sufficient accuracy to determine the critical values of the work of friction A_{cr} causing a change to type II seizing (hot scoring) [17]:

$$A_{cr} = EFS_Q \cdot T_d. \tag{7}$$

Tests and Calculations. The proposed energy criteria for evaluating the life of rubbing pairs (specific work for failure A_f and thermal heat content of the frictional system EFS_Q) possess the property of stability within the limits of normal mechanicochemical friction and wear. This was established experimentally and established on a theoretical basis [1, 5, 15, 17, 18].

The values of A_f and EFS_Q for any frictional system may be determined with sufficient accuracy with observance of the following standardized test conditions [17].

1. Provision of conditions of boundary friction.

2. Equilibrium of conditions of heat formation and heat dissipation.

3. Equilibrium of conditions of formation and failure of secondary structures.

The frictional system must provide accurate measurement of the coefficient of friction and the surface temperature [17].

The energy principles of calculation and prediction of the life of frictional pairs, based on criteria of the specific work of failure and the thermal energy content of the frictional system, are described in [17].

Therefore, the most indisputable result of the whole development of the science of friction and wear is the conclusion that external friction is a thermodynamically irreversible dissipative process, the rules of which in principle depend upon the rates of cooperatively occurring processes. The role of the medium is also determining and the lubricating medium plays an important role since it on a par with solid bodies forms the material structure of the zone of friction.

A criterion of the reliability and value of the modern theory of friction and wear may be its conformity to the rules of thermodynamics and mechanics of continuums and the use of material science concepts.

The basis of the structural and energy approach in the problem of external friction and wear (surface strength) is the generalized classification of the forms of friction and surface failure, the general rule of friction and wear, and the universal phenomenon of structural adaptability of materials in friction. Based on these concepts problems of control of friction, lubricating action, and wear in machines have been formulated and are being solved and methods of soundly based tribology tests and engineering calculations are being developed.

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