The physical model of the thermodynamic conditions of the friction system of self-regulation

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Abstract

Abstra The control of the reliability of surfaces of strength under friction is nontrivial and turns out to be possible due to the achievements of the physical theory of self-organization. The paper describes the features of the physical model of the evolution of self-regulation processes of secondary structures based on the energy concept of friction. An attempt is presented to describe the process of ordering surface structures due to internal factors, the essence of which is reduced to natural phenomena of degradation and regeneration of secondary structures, which are subject to the laws of energy and entropy transformation - two integral fundamental (invariant) characteristics of systems with a physical structure. The basic concepts, expressed through a physical model, the theory of self-organization and structural adaptability of materials under friction, are presented, which have both cognitive and important applied significance for the formulation of problems of controlling the surface strength and reliability of machines and mechanisms.

Keywords

model, self-regulation, load, patterns, adaptability, secondary structures.

1. Introduction.

An attempt to present the patterns of manifestation of the features of tribological materials science, in particular, the representation of the role of structural adaptability due to the phenomenon of self-organization, proposed in the article, goes beyond the understanding of its usual canons and can be considered in the historical reality that is the object of dialectical study. It is noteworthy that the difficulty of detecting the material interaction of solids in nature did not lead to the inhibition of scientific research, but contributed to the emergence of new conceptual structures, which seem to be very essential for understanding the physical reality of the multiplicity and complexity of the manifestations of tribotechnical processes.

The classification of the processes of wear and damage under friction loading [1] makes it possible to determine that structural-thermal activation, which causes the interdependent flow of tribophysical and tribochemical reactions that stimulate the regularity and adequacy of the formation of secondary structures, exhibits eternal opposition and competition to the conditions of their dynamic equilibrium. Nevertheless, the phenomenon of structural adaptation of materials under friction established by fundamental physics, which is related to the phenomenon of self-organization, makes it possible to speak of the fundamental possibility of realizing the maximum permissible (theoretical) wear resistance.

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The regularities of self-regulation of processes of destruction and restoration of secondary structures consist in the ability of the thermodynamic friction system, starting from the end of running-in, to maintain a constant level of all tribotechnical parameters characterizing normal wear.

The aim of the work is to present a physical model of the evolution of self-regulation processes of secondary structures based on the energy concept of friction.

2. Simulation results.

As a result of studies of the manifestation of normal wear and the conditions for the occurrence of damage, it was found that the dynamic equilibrium of the processes of destruction and recovery of secondary structures is realized under the condition $V_p=V_b$, where V_p is the rate of destruction of secondary structures and V_b is the rate of their recovery.

The presentability of a quasi-stable state, as a consequence of dynamic equilibrium, is provided if $S_{ar}=$ const, where S_{ar} is the total area of the contact surface screened by secondary structures. Stability of dynamic equilibrium ($V_p=V_b$) in a certain range of friction parameters and environmental conditions is provided at: : p< $\varepsilon_{cr}^{V_i}$, C_i; V< $v_{cr}^{V_i}$ where, $\rho_{cr}^{V_i}$, C_i - critical values of the load for some fixed value of the speed V_i and friction parameters C_i; V_{cr}, C_i - critical values of speed for some fixed value of load and parameters C_i. Three main groups of friction passivation reactions can be distinguished, which are realized under strictly defined conditions, the first - when interacting with the active components of the medium, the second - with the counterbody material, and the third - due to the internal restructuring of the surface layers [2].

It is known that processes in the friction zone arise and develop as a result of the occurrence of the phenomena of activation and passivation: activation (an increase in the material's own energy) and passivation (a decrease in this energy), which are invariants. In accordance with the first law of thermodynamics, the work of the friction forces Afr, which is the source of the general activation of Gef, is mainly spent on thermal Q and structural ΔE activation: Afr= Q+ΔE= Gef

The main component of passivation Gpas is the energy dissipated by the friction unit Gdis, and the energy stored by the material of the system Gst: Afr= Gdis + Gst = Gpas

All types of structural changes in the materials of friction surfaces also have the same nature, due to the energetics of triboactivation and passivation of the materials of the parts. A necessary condition for the normalization of friction processes is the creation of a dynamic balance between the processes of activation and passivation, in which the effective energy of activation is within the range of values of the energy required for the formation of secondary structures: Gef= Gpas

The passivated state of the working surface, due to the ordered dynamics of the shielding structures, corresponds to the minimum values of the friction parameters and corresponds to normal mechanochemical wear. However, due to the influence of external conditions (plastic deformation, temperature, etc.), the dynamic equilibrium is shifted towards an increase in structural-thermal activation, which causes a change in conditions, and the wear process changes qualitatively [3].

The process taking place in the thinnest surface layers can be conditionally divided into three stages, the first is deformation and activation, the second is the formation of secondary structures, and the third is the destruction of secondary structures. Thus, structural-thermal activation determines the peculiar course of physical and chemical reactions and has a decisive influence on the occurrence and development of processes during external friction.

The second side of this most complex interaction in nature is associated with the fact that the state of self-organization of matter in hidden systems is as fundamental as the spontaneous transition of closed systems to an equilibrium state with maximum entropy [4]. During self-organization, materials and systems counteract the increase in entropy, which opens up the reserves of their scientific and applied application. At the same time, it should be noted that the possibilities of achieving self-organization are not unique, since the states of stability and metastability of materials are realized, of which there are much more than equilibrium ones.

One of the illustrative examples of self-organization during friction is running-in - quasi-relaxation of the tribosystem structure from an equilibrium to a stable state, the former being subject to the condition of a minimum of free energy, and stability is controlled by a minimum of entropy production [5].

To consider the mechanism of self-regulation of the processes of destruction and restoration of secondary structures, the physical model of normal wear is presented by a structural diagram (Fig. 1), in which the following designations are adopted: S - is the total contact area, S_{ar} - is the area covered with a film, S_p – is the part of S_{ar}, subject to destruction , S_b is the part of the juvenile surface on which the film was restored, Z - is the film thickness, $i=kZS_p$ - is the wear rate, k - proportionality factor; ε- mismatch equal to the area of the juvenile surface at each moment of time, that is $\varepsilon = S_p - S_b$; load p and sliding speed V are combined into one vector (g) [6].

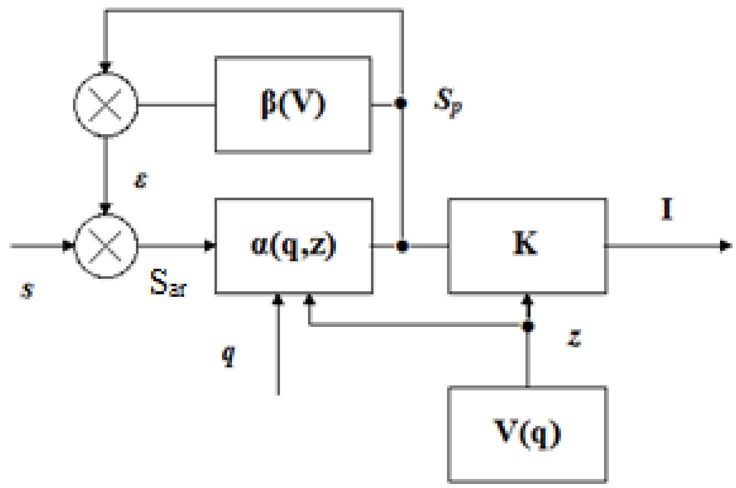

Figure 1: Structural diagram of self-regulation of processes during wear of metals

As a result of deformation, the activated layer and the active components of the medium (in particular, oxygen) present at the point of friction form secondary structures during physicochemical interaction. As a result of multiple loading and the presence of internal stresses in the film of secondary structures, the formation, accumulation and development of microdefects occurs, and on the interface between the film and the base metal, bonds are weakened and peeled off . Subsequent mechanical influences (vector g) cause destruction and wear of the film fragments. In the juvenile areas of the friction surface, the process is repeated. Moreover, the area on which the destruction occurred depends on the strength and thickness Z of the film, therefore: $S_p= \alpha(g, z)S_{ar}$ (block α (g, z).

At each elementary section, the moments of destruction and restoration of the film are separated by a nonzero time interval, which is dictated by the discreteness of the contact and the finiteness of the sliding speed. In other words, at each moment of time, the film is restored only in the area of the juvenile surface. So, considering, for example, the parameter characterizing the discreteness of the contact at steady-state wear, constant, we get: $S_B=\beta(V)S_p$ $\beta(V)\leq 1$ (block β (V)). The state is thermodynamically stable when the entire contact surface is covered with a film; therefore, $\varepsilon \rightarrow 0$. However, due to the delay in the restoration of the film, only the condition $\varepsilon=\varepsilon_0>0$ is satisfied, which corresponds to the dynamic equilibrium of the processes of destruction and restoration of secondary structures. The thickness of the destroyed film is a function of the vector g (block V (g)).

The structural diagram corresponds to the following system of equations: $S_{ar}=S-\varepsilon$; $\varepsilon=S_p-S_b$; $S_p=\alpha_i(q)S_{ar}$; $S_B=\beta(V)S_p$; $i=kzS_p$; $z=\gamma(g)$, где $\alpha_1(g)=\alpha[q,z(g)]$.

Therefore, we can write: $i=[kS_\gamma(q_1c)\alpha_1(q_1c)]/1+\alpha_1(q_1c)[1-\beta(v,c)]$.

The expression contains an explicit vector C, the components of which are the parameters of materials and working environments.

Self-regulation as a frictional phenomenon is a logical expression of the universal phenomenon of structural adjustment. In fact, new phases appear on rubbing under conditions of adaptability (as a result of mass transfer with the medium and structural-chemical transformations), while friction acts as the creator of new materials that are extremely resistant to fracture during friction (surface structures).

In the process of thermal and mechanical processing of materials in the surface layer of parts, a high density of crystal structure defects is achieved, which leads to a high density of the internal energy of the system. Arising during operation details, even insignificant disturbing influences lead to the transfer of the system to a new energy and structural state at a higher level of stability. As a result, the wear resistance of the processed materials is mainly determined by the possibility of self-organization of the structure of the surface layers of the part in relation to the current scheme of the stress-strain state, that is, the ability to have triboenergetic adaptability. The durability of tribotechnical materials is ensured if the excess energy accumulated under the external temperature-force effect has time to dissipate before it reaches a critical level, which causes destruction of the surface material of the friction pair part.

To describe the regularity of the phenomenon of structural adaptability, which consists in the fact that in a certain (for a given combination of materials and boundary conditions of scale, external temperature, physical and chemical medium) range of loads and displacement velocities, all types of interactions are localized in a minimum volume and such a spectrum of dissipative of metastable structures and such a distribution of their volumes and dissipative fluxes between them, at which the total production of entropy would be minimal [6], a physical model of self-regulation is proposed, which is shown in Fig. 2.

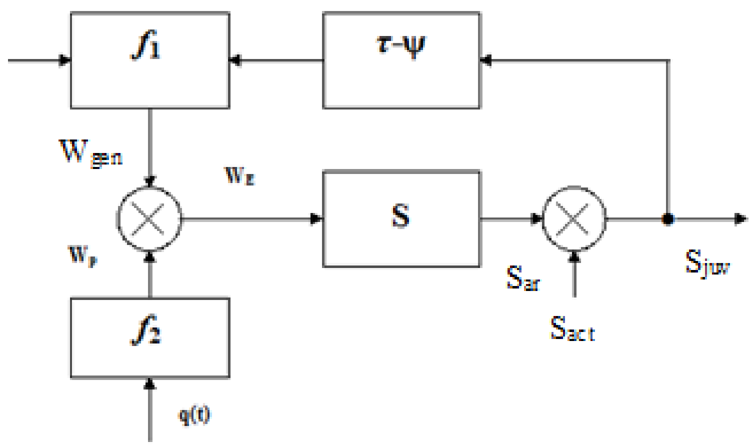

Figure 2: Dynamic model of self-regulation of metals and media in the friction zone

To describe the model under consideration, the following designations are accepted: S_{act}- is the area of actual contact, S_{juv}- is the area of juvenile areas on the surface of actual contact formed as a result of destruction and wear of the films, W_p - is the rate of destruction of the films (decrease in the area of the films per unit time), W_{gen} – is the rate of formation films (increase in their area per unit time), $g(\tau)$ is a generalized loading parameter depending on the value of the specific load $p(\tau)$, f_1 and f_2 are functions expressing the dependences of the rates of formation and destruction of films of secondary structures on the corresponding parameters, ψ is the time between the moments of destruction and wear of the films (formation of juvenile areas) and the appearance of new films in these areas. The parameter ψ is mainly characterized by the penetrating ability of the medium and the rate of physicochemical interaction between the medium and the juvenile surface of the metal. The considered physical model corresponds to the following dependencies: $dS_{ar}/d\tau=W_{gen}(\tau)-W_p(\tau)=W_E(\tau)$; $W_{gen}(\tau)=f_1[V(\tau),S_{juv}(\tau-\psi)]$; $W_p(\tau)=f_2[g(\tau)]$; $S_{juv}(\tau)=S_{act}-S_{ar}$.

The rate of formation of films is proportional to the speed of sliding and the area on which their formation is possible and can be written as $W_{gen}=kW(\tau)S_{juv}(\tau-\psi)$ where k - is the coefficient of the intensity of film formation. Taking into account the independence of the mechanical effects of the specific load and the speed of movement, it can be written that $W_p[g(\tau)]=a_1(V(\tau)+a_2p(\tau)$, where a_1 and a_2 are coefficients that depend on the strength of the films [7].

3. Conclusions.

Thus, the process of formation and destruction of secondary structures is described by a first-order differential equation with a lagging argument $dS_{ar}/d\tau + kV(\tau)S_{ar}(\tau-\psi)= V(\tau)(kS_{act}-a_1)-p(\tau)a_2$, which at p, v=const describes the state of self-regulation and stationarity of processes of destruction and formation of films of secondary structures.

The mechanism of self-regulation of processes of destruction and restoration of secondary structures is described, the main principles of stability of their dynamic equilibrium and the presence of conditions that implement the processes of passivation during friction are presented.

It is shown that the conditions of self-organization are accompanied by the destruction of old and the emergence of new structural forms with the same properties. It was noted that the time between the moments of the formation of new films depends on the penetrating ability of the medium and the rate of physicochemical interaction between the external environment and the juvenile surface.

It is noted that the rate of formation of protective films of secondary structures is proportional to the speed of sliding, load and area of their formation.

It was found that the process of formation and destruction of secondary structures is described by a first-order differential equation with a lagging argument.

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