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Formation of Dissipative Surface Structures during Friction Interaction of Solid Bodies in an External Magnetic Field

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The method of formation of the dissipative structures (DS) consisting of wear products obtained during the frictional interaction of solid bodies in a magnetic field (MF) is presented. A physical model of the local influence of MF on the mechanism of formation of the wear-surface DS of a ferromagnetic (steel 45) paired with a diamagnetic (glass) during sliding friction without lubrication is presented. The parameters of the movement and fixation of wear products on the worn surface depending on the direction of MF are determined. As established, the intensity of wear is subjected to the physical laws of the impact of MF on the magnets, which are on the path of its magnetic lines through the actual contact surface.

Key words: magnets, friction, magnetic field, nanostructure, wear products.

Представлено методику формування дисипативних структур (ДС), що складаються з продуктів зносу, одержаних під час фрикційної взаємодії твердих тіл у магнетному полі (МП). Вибудовано фізичний модель локального впливу МП на механізм формування ДС зношуваної поверхні феромагнетика (криця 45) у парі з діямагнетиком (склом) під час тертя ковзання без змащування. Визначено параметри переміщення та фіксації продуктів зносу на зношуваній поверхні залежно від напрямку МП. Вста-

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новлено, що інтенсивність зношування підпорядковується фізичним закономірностям впливу МП на магнетики, які знаходяться на шляху проходження його магнетних ліній через фактичну площу контакту.

Ключові слова: магнетики, тертя, магнетне поле, наноструктура, продукти зношування.

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1. INTRODUCTION

Any structure used in mechanical engineering is designed to perform a specific job of transmitting forces and loads. Therefore, it is always in an unbalanced tense state. This causes the need for additional energy costs with further reflection in the change of surface topography under the action of deformation components [1–3]. In this regard, energy support of the structure is necessary to ensure appropriate operating parameters.

The most stable and not subject to premature changes method of such support is the use of an external static magnetic field (MF). The energy state of the specified field practically does not change over time. It is stable in terms of internal parameters, but it has different effects on magnets in the area of its influence. With regard to such a design as a tribomechanical system, the action of the MF manifests itself in a change in the atomic structure of the magnets from which its triboelements are made, as well as the components of the specified structure. This is inevitably reflected in the conditions and parameters of the formation of dissipative structures (DS) in the zone of frictional interaction, which, in turn, ambiguously affect the structural components of magnets.

The effect of MF on the deformation parameters and wear products (WP) of the surface is most conveniently detected in sliding friction without lubrication.

From the energy point of view, the tribomechanical system refers to an open type relative to the environment, from which energy is supplied by mechanical, chemical (interaction with the environment), thermal (both from friction and from the outside) method, as well as activation using an external magnetic field in combination with the Earth's magnetic field (0.0005 T). The energy conditions of such a system are characterized by an increase in entropy, due to the contact spots of the actual contact surface (ACS), developed in the process of frictional interaction.

The basis of the conducted research was the development of a physical model of the tribomechanical system, which takes into account the location of its energy flows relative to the ACS. Research technology using a ferromagnetic–diamagnetic friction pair, in which the latter is transparent to the passage of light, and its characteristics are close to a completely solid body, is presented in the work [4]. This makes it possible to monitor the process of formation of DS in the air, as well as the influence of MF on the placement of WP in the zone of frictional interaction, which depends on the structure of protective tribological films.

The mechano-physicochemical process of the surface-film formation mechanism is determined in the scientific works of B. I. Kostetskyi [5], according to which, during friction, wear particles are dispersed with their subsequent sintering in the ACS zones.

At the same time, the geometric sizes of the particles acquire a wide spectrum of fractions from dozens of a micron to hundredths of a millimetre [6], from which their conglomerate clusters are subsequently formed (Fig. 1): the larger the size, the lower the surface energy of the particles during deformation of the conglomerate. Nanoparticles (up to 10 nm) in such a conglomerate have a higher surface energy [7].

Materials formed in the parameters of nanoparticles are characterized by significantly better physical properties compared to monolithic metal: magnetic, surface energy, anisotropy, *etc.* [8]. Particles of micron-sized materials can be compared to near-surface atoms, therefore, in such systems, excess surface energy appears, which leads to the appearance of a highly defective state of individual nanoparticles. Nanoparticles of ferromagnetic metals Fe, Co, Ni and alloys oxidize very quickly in normal atmospheric conditions, so they are protected by a coating comparable in thickness to the size of the particles themselves [9].

Thus, in the conditions of the applied research technology, it is necessary to take into account the chemical activity of nanoparticles, as a drawback of nanoclass materials.

In the conditions of sliding friction, a wide range of WP fractions is formed, but particles larger than 500 μm are filtered out due to the action of centrifugal forces, as well as the presence of filters in lubrication, fuel and hydraulic systems.

2. STATEMENT OF THE PROBLEM AND OBJECTIVE OF THE RESEARCH

The primary parameter that characterizes the conditions of operation of a tribomechanical system is the presence of DS in the contact zone capable of ensuring that it performs the relevant technical functions [10]. The determining factor in the formation of DS is the presence of a donor of its elements with the necessary properties. Donor elements must be subject to directed movement in the contact zone under the influence of external energy flows. During sliding friction without lubrication, the worn surfaces are subjected to the directed action of auxiliary energy flows and the deformation component in the unstable structure of the ACS.

The purpose of the study is studying the regularities of the formation of dissipative surface structures during the frictional interaction of solid bodies in an external magnetic field, which will contribute to increasing the wear resistance of the tribosystem.

The research hypothesis is based on the restoration of triboelements in the process of frictional interaction due to the formation of nanocoatings from wear products on their surfaces under the directed action of the energy flow of the external MF.

3. MATERIALS AND RESEARCH METHODS

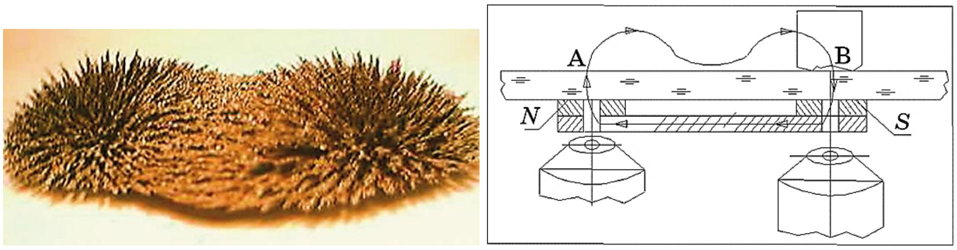
Two materials are used in the studied tribomechanical system: the first is a sample made of martensite-hardened ferromagnetic steel 45, the second is a counter-body made of diamagnetic glass. Using a solid transparent substance (glass), it is possible to monitor the kinetics and mechanism of wear and formation of DS on the surface of the ferromagnetic sample (Fig. 1). Tribological studies of the sample on the counter-body were carried out at a relative displacement speed of $V = 0.1$ m/s and a normal load of 1 N per sample area of 7.56 mm^2. The topography of the surface of steel 45 is shown in Fig. 1, on which present a significant deposit of a conglomerate of iron oxides [11].

Formatted during the relative movement of triboelements, WP are located in the gaps between their surfaces, forming DS from conglomerates that fill the depressions of the roughness on them.

3.1. Determination of Tribological Characteristics of Ferromagnetic WP Depending on the Direction of Influence of MF on the ACS Zone

The effect of MF and its direction in the process of friction without lubri-

Fig. 1. Friction surface of steel 45 in dynamic mode when moving on glass without the influence of a magnetic field.



a *b*

Fig. 2. Scheme: configuration of the magnetic field of the magnet used in the experiment (from the hard drive) (*a*), passage of ML through a bipolar magnet, glass and the body of a ferromagnetic sample (*b*).

cation was studied according to the method [4] on the tribological complex. The sample was placed in positions (A or B, Fig. 2, *b*) in such a way that the magnetic lines (ML) crossed the friction plane perpendicularly.

The results of determining the intensity of wear during tribocontact without lubrication of steel 45 on glass under conditions of sliding friction according to the finger-plane friction scheme are shown in Fig. 3 (curve *1*). In the same Figure, the curves characterizing the influence of the change in the direction of MF from the sample (MF-*SN* curve) and into the sample (MF-*NS* curve) on the wear intensity are presented.

Therefore, in the position of sample A (Figure 2), MF, which is directed into this sample and corresponds to MF-*NS* curve (Fig. 3), contributes to the minimum value of the intensity of wear. The position of sample B on

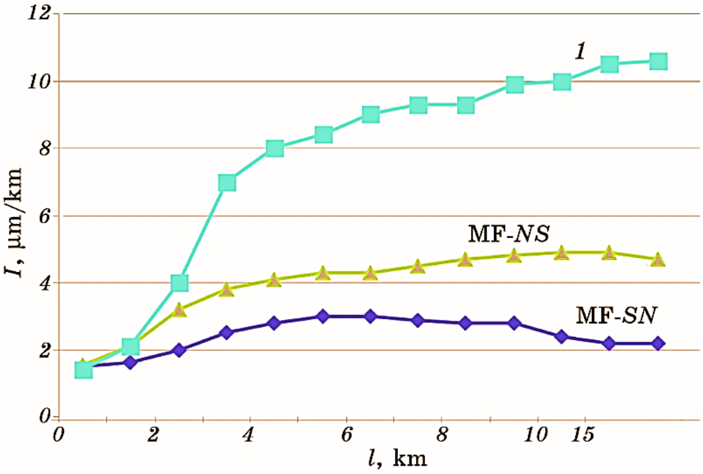
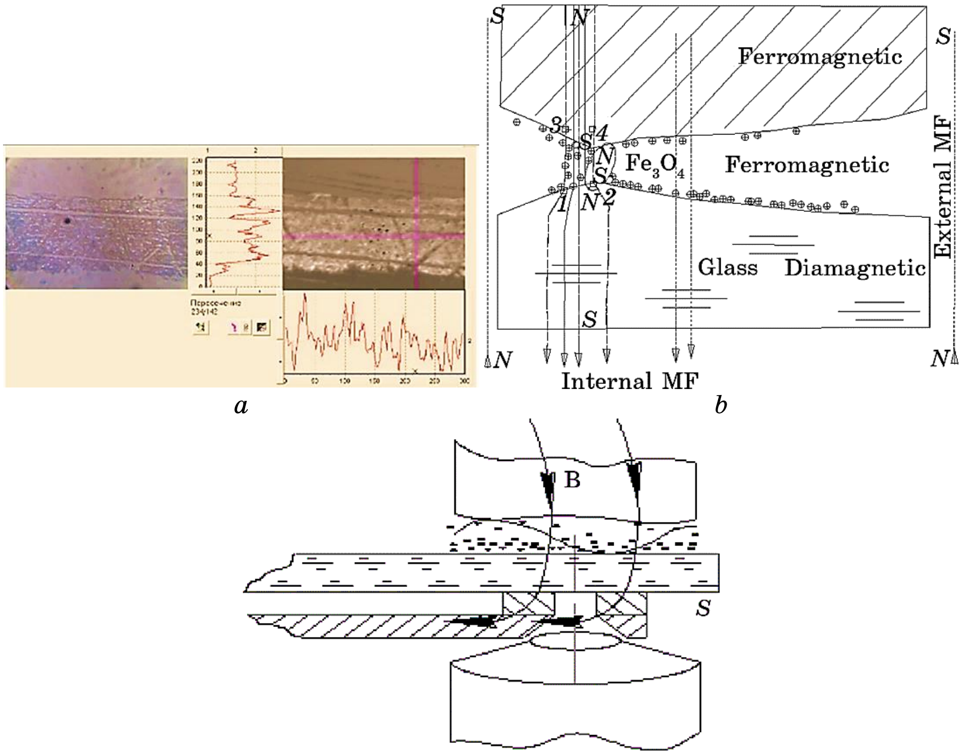


Fig. 3. Intensity of wear of steel 45 during friction sliding on glass: curve *1*—friction, without the influence of MF, MF-*SN* with *SN* direction, MF-*NS* with N_S referral.

the pole of *SN* magnet (Fig. 2) reflects the direction of MF from the sample in which the intensity of wear increases (Fig. 3, curve MF-*SN*).

The curve *1* is characterized by the greatest intensity of wear due to the action of the created oxide conglomerates (Fig. 1) [11] and rapid oxidation of FeO, Fe_2O_3, Fe_3O_4. The activation of oxygen in the contact zone is due to the following factors: increased energy state of the surface of iron nanoparticles, saturation of the contact zone with paramagnetic oxygen, which under the influence of MF concentrates in areas of the ACS.

Thus, the ferromagnetic sample forms a layer of nanoparticles of ferromagnetic DS based on iron oxide Fe_3O_4 between the surfaces of triboelements.



a *b*

c

Fig. 4. Profilogram of the friction track on the glass (see Fig. 2, plane B) and topography of the surface with the direction of the external MF in the direction of the *SN* glass (*a*), the scheme of the location of wear products in the directed MF on the pole *SN* corresponds to plane B of Fig. 2 (*b*), scheme-model of the transition zone of friction between the sample and the glass in the resulting MF (*c*).

3.2. Physical Model of the Mechanism of Tribomagnetic Contacting

The influence of MF on the formation of the structure under the action of dynamic loads and deformation movements is perceived by different materials individually. The passage of MF through a ferromagnetic medium significantly increases its induction due to the peculiarities of the structural structure of the crystal lattice and the presence of a significant number of free electrons, which by their excitations create an internal MF, which is much larger than the external MF. Due to this, the magnetic susceptibility of the material (χ) increases, which in Fig. 4, *c* in the *1–2–3–4* zone is represented by the concentration of ML, both in the metal and in DS zone. Since the ACS contact is always characterized by an elevated temperature up to the level of welding bridges due to a significant deformation component between the protrusions of the interacting surfaces.

However, above the Curie temperature, the ferromagnetic properties changes dramatically to paramagnetic. Such structural transformations are formed in the areas of ACS during the relative movement of the surfaces even under insignificant loads and velocities.

At the same time, taking into account that the magnetic susceptibility of a ferromagnet is always significantly greater ($\chi_m >> 1$) than that of air ($\chi_m < 1$), therefore MF is concentrated in the sample at ACS transitions, which in the total area are realized on the plane of 0.1% of the total contact, on which ML are formed into a dense magnetic flux, the value of which is the sum of the ACS points of the contact (shown on the example of one touch ACS (Fig. 4, *b*) in the volume of space *1–2–3–4*).

So, at the point of contact *3–4* in Figure 4, *c* between steel and DS, the direction of MF does not change, however, a change in the specified direction is observed around the contact areas. This happens due to a decrease in the strength of the magnetic flux, as well as a smaller value of the magnetic permeability of paramagnetic air compared to a ferromagnetic. The change in the direction of the magnetic field can occur not only around ACS zones, but also near them [12]. If we take into account that the contact planes occupy 0.1% of the working plane, then a significant magnetic potential is concentrated on them [13], which can reach up to 30 Wb instantaneously. At the same time, DC are formed under the influence of a significant magnetic flux (Fig. 4, *b*, zone *1–2–3–4*), as well as the surface energy of nanoparticles. Small ferromagnetic particles (1–100 μm) are attracted to the glass and are located on the surface in the form of a track of magnetized conglomerates, which mechanically ‘are smeared’ in the direction of movement of the sample across the glass surface (Fig. 4, *a*) [14].

The directional MF affects the relative displacements of WP of the ferromagnetic, which at the transitions between the friction surfaces change their direction and location relative to the rough surface of the

Fig. 5. The friction surface: on the glass at *SN* pole (*a*), on steel 45 in the direction of *SN* magnetic field (*b*), ×100.

steel [14]. At the same time, the density and direction of ML changes depending on the magnetic permeability of the ferromagnetic material ($\mu >> 10^3$–10^6).

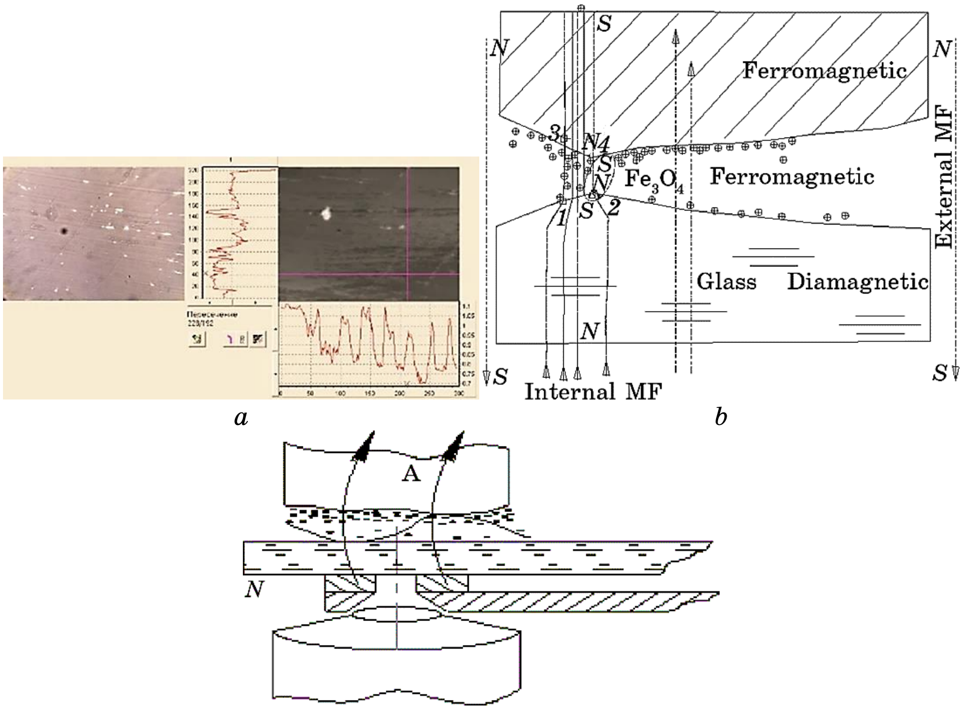
The ML direction vector and the magnetic susceptibility of steel and glass in their own way affect the location of the WP in the contact zone and around it.

Thus, the movement of the magnetized WP creates a DC on the surface of the model counter-body—glass (Fig. 4, *a*). The wear products of ferromagnetic steel 45, kept in the contact zone. They are pressed to the glass by the directed field from the ferromagnet (Fig. 4, *b*, *c*, zone *1*–*2*, Fig. 5, *a*) and, forming into conglomerates on its surface, reduce wear and the coefficient of friction [15]. At the same time, the surface of the sample is characterized by structured DS and the presence of local thin deposited zones (Fig. 5, *b*).

If the direction of the magnetic field is changed to the opposite, *i.e.* from *NS* pole of the magnet to the sample (Fig. 2), on which the near end will form *SN* pole, and the opposite one will take on the value of *NS*, then the character of the friction surface (Fig. 6, *a*) will take the form of curve MF-*NS* (Fig. 3).

In this position, WP are accumulated not only near the sample, but are also drawn into the contact zone, while the wear is reduced by approximately 2.5–3 times, compared to the wear (curve MF-*SN*, Fig. 3). This is explained by the forced retention of PW by the directed flow of the magnetic field (zone *1*–*2*–*3*–*4*, Fig. 6, *b*), which is directed into the body of the ferromagnetic from the surface of the steel 45.

At the same time, there is a significant decrease in the coefficient of friction to the level of 0.07–0.1 is observed. On the friction surface of the sample, WP is held by MF, followed by their dispersion to the finest fractions on the sample (Fig. 7, *a*). Larger particles (size 10–20 μm) repeatedly enter the friction zone and contribute to increased wear re-



a *b*

c

Fig. 6. Profilogram of the friction track on the glass (plane No. 3, Fig. 3) and topography of the surface with the direction of the external MF in the direction of *NS* glass (*a*), the scheme of the location of wear products in the directed MF near *NS* pole corresponds to plane No. 3 of Fig. 2 (*b*), scheme of the transition zone of friction between the sample and the glass in the resulting MF (*c*).

sistance [13]. Considering that WP conglomerates are oxides created under the influence of high local temperatures and pressures, they deposited on the glass, which is accompanied by the formation of protective oxide films on it (Fig. 7, *b*).

Further operation of the tribomechanical system during friction without lubrication on *NS* pole is accompanied by the formation of DS on the metal sample (steel 45). The dynamics of this process is shown in (Fig. 8), from which it can be seen that initially continuous protective films are formed (Fig. 8, *a*–*c*). After that, they are divided into separate areas, which are located on a significantly smaller plane (Fig. 8, *d*, *e*). This process ends with peeling of these films from their areas, and the appearance of dark oxide zones in their place, as well as powder from the products of their dispersion.

This mechanism of tribomagnetic contacting is subject to the laws of oxidative wear. When applying an external magnetic field directed from

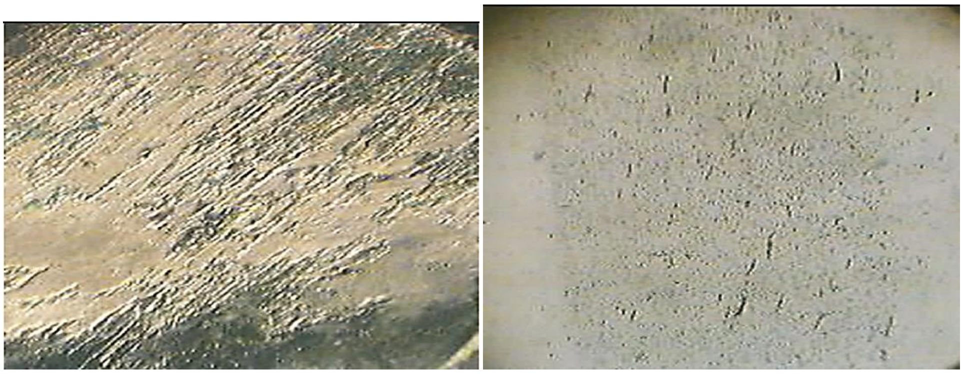


Fig. 7. Appearance of the friction surface on *NS* pole: on the sample (*a*), on glass (*b*). The speed of friction is 0.1 m/s, normal load $P = 0.1$ kg, ×90.

NS pole toward the surface of the sample, dense oxide-type tribological films prevail [15] due to the presence of paramagnetic oxygen, which is drawn into the zone of frictional interaction by the magnetic field.

Thus, the process of formation of surface films with structural adaptation under the influence of MF consists in the gradual formation of DS, which, under the influence of the magnetic plastic effect, reduce their strength and increase the deformation component up to 15% [16, 17].

3.3. Analytical Substantiation of the Results of Tribological Research

Friction conditions are realized in the process of molecular-mechanical interaction in the surface layers of contacting bodies. The density of the energy balance is concentrated in the thin surface layers, therefore the properties of the deep layers of the material differ significantly, both structurally and energetically.

As the load increases, ACS, which takes part in the process of frictional interaction of the surfaces, expands, but its value does not exceed 0.1% of the total contact area. Energy costs are spent on overcoming the deformation components of the surface layers and creating an intermediate film with a defect-free structure at a minimum thickness [19]. In the contact zone, DS (Fig. 8, *a*) [20] are constantly being developed, which are sprayed on the friction surface, forming protective structures on it (Fig. 8, *b*–*e*). Further enrichment of the surface film with a fine fraction of DS ferromagnetic steel (Fig. 8, *f*) together with paramagnetic oxygen initiates chemical reactions, as a result of which, under the influence of frictional deformation and elevated temperature, different phase iron oxides are formed.

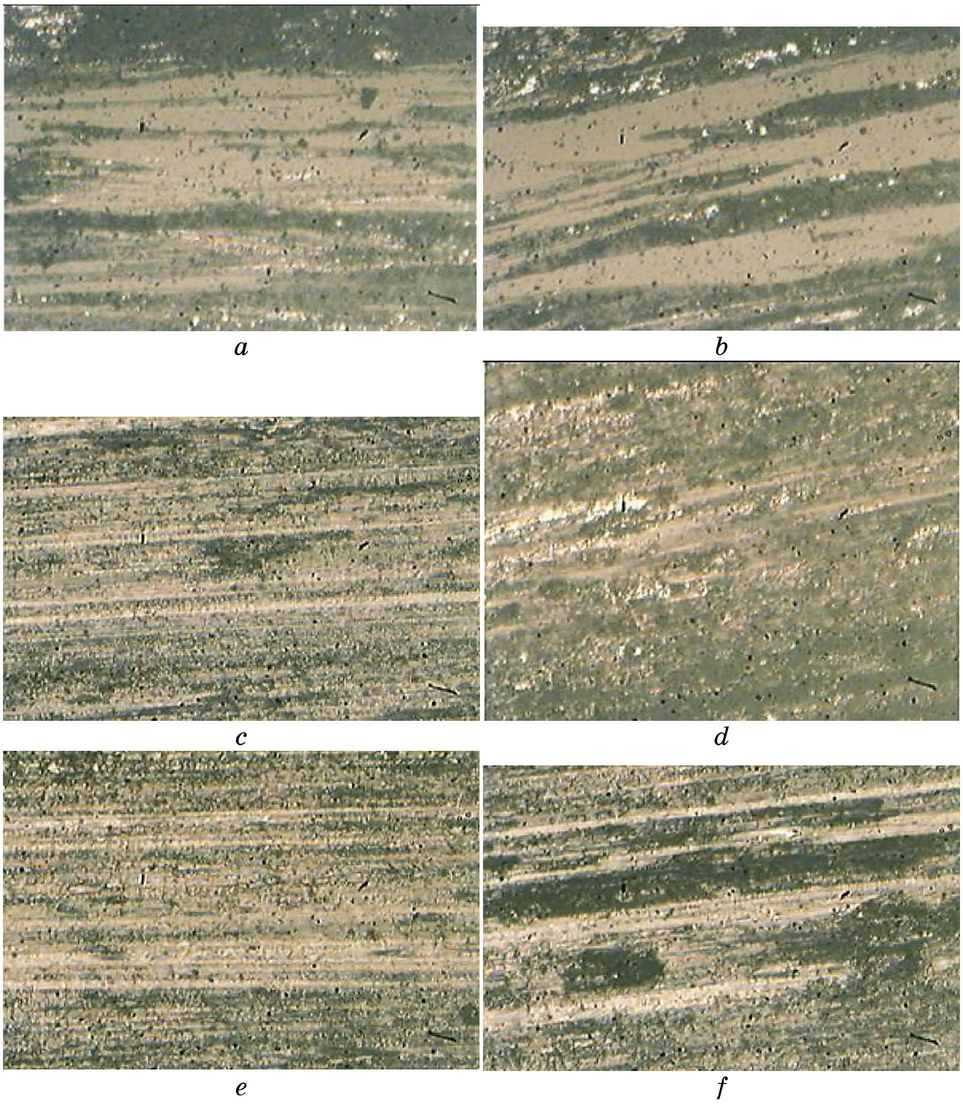


Fig. 8. Step-by-step formation of a protective oxide film on the surface of steel 45, when rubbing against a (model) counter body—glass, ×500 (photos taken in dynamic mode).

Determination of phase changes of the friction surface under the influence of MF was carried out by the method of quantitative phase analysis of the formation of the percentage content of the α-Fe phase in the ferrite-pearlite structure of steel 45 before and after exposure to MF (Table 1).

Depending on the direction of the field, changes in the atomic struc-

TABLE 1. Phase composition, texture coefficient and lattice periods of steel 45 after friction in a magnetic field.

No.	Material	Quantitative phase composition (% by mass), texture coefficient τ and period of the crystal lattice phases (nm)					Direction of MF (Fig. 2, *b*)
		α- Fe ferromagnetic component		f.c.c./γ- Fe paramagnetic component			
		a, nm	% mass	*a*, nm	τ	% mass	
1	St 45	0.2868	59.36	0.3701	0.48	40.64	N
2	St 45	0.2866	52.11	0.3693	0.49	47.89	*N*/*S*
3	St 45	0.2867	73.42	0.3694	0.40	26.58	*S*
4	St 45	0.2871	100				Without MF
5	St 45	0.28708	100				Without MF
		Volume-centred crystal lattice		Cubic face-centred lattice			

ture of steel 45 are observed in the zone of its active deformation and the effect of high temperature in the process of friction on the glass (Table 1).

In addition, under the influence of MF under conditions of magnetostriction, the parameter of the crystal lattice decreases in comparison to without MF $a = 0.28708–0.2872$ nm to $a = 0.2866–0.2868$ nm

The crystal lattice is formed from magnetically dependent elementary particles that are part of each atom. According to the Pauli principle, the spin of an electron (atom or molecule) in the quantum mechanical state always appears near the source of rotation [21]. Electrons occupy only specific discrete orbital positions around the nucleus, creating the atomic shell. The closer the electrons are to the nucleus, the stronger they are attracted to it, so more energy is needed to move them to other orbits.

The orbital closest to the nucleus can accommodate only two electrons with oppositely directed spins, which provides them with different quantum states. In the absence of an external magnetic field, the electron spins of the same level compensate for the total electric charge. The influence of the magnetic field directed parallel to the spin magnetic moments reduces the potential energy of the electron compared to the opposite direction of the field. As a result, the first electron will be in an energetically more stable state than the electron paired with it [22].

Since entropy ΔS is always positive, MF increases the energy of the system. The placement of the electron at the appropriate level must satisfy the condition of minimum potential energy. Due to this, the orbital radius decreases: the more energy a common pair of electrons has, the closer they must be to the nucleus of the atom, which, in turn, contributes to reducing the distance between lattice nodes. What, in particular, is indicated by the results of the analysis of the α-Fe phase composition (Table 1).

When the temperature increases ($T > 0$ K), the internal structure of a real crystal differs significantly from the ideal one. Defects can disrupt both the short- and long-range order of the crystal lattice (Fig. 8, *e*, *f*). The appearance of defects in a real crystal is explained by thermodynamic factors.

The stable state of the system is characterized by the minimum Gibbs energy: $\Delta G = \Delta H - T\Delta S$ at a certain concentration of defects in the crystal structure (depends on the material and environment). A certain amount of energy (ΔH) is spent on heating a defect-free crystal, which increases its Gibbs energy, which indicates the formation of defects on the friction surface (Fig. 8, *d*, *e*). Therefore, the enthalpy factor does not contribute to an increase in the number of defects. On the other hand, single vacancies in lattices (concentration of vacancies $\cong 10^{23}$ per 1 mole of substance) lead to a decrease in the total energy of the system and an increase in the entropy ΔS of the crystal. This is due to the presence of a significant number of nodes of the crystal lattice, where vacancies of this type can appear. The mathematical relationship between entropy and the probability of the formation of a vacancy is expressed by the formula $S = k\ln W$, where W is the probability of the formation of a single vacancy, which is proportional to the number of nodes of the crystal lattice of a given type, k is the Boltzmann constant. That is, the entropy factor ($T\Delta S$) at a temperature above 0 K leads to a decrease in the Gibbs energy of the crystal and contributes to the formation of defects in the crystal structure. Bearing in mind that it far exceeds the enthalpy factor, in which the energy is spent to form a single vacancy, the overall quantitative entropy parameter dominates, increasing the entropy of the crystal.

Since the temperature in ACS zones significantly exceeds point *A*1 (Fe–C state diagram), there is a change in the micro- and macrostructure of the steel, in particular, as a result of ferrite (α-Fe)–pearlite (α-Fe + Fe_3C) hardening the structure becomes martensitic. However, the energy state of the martensitic structure is lower than that of austenite (γ-Fe) [20]. The transition of α-Fe to γ-Fe begins when the steel 45 is heated to about 810°C and continues up to a temperature of about 1450°C, where the austenite structure is maintained. This indicates a significant energy advantage of the free energy in γ-iron over α-iron, which depends on the temperature level.

During the frictional interaction of surfaces in ACS zones, a sharp increase in temperature and high-speed deformation of the surface layer occur in an instant. The rupture of the zones during the movement of the surfaces leads to their rapid cooling by removing heat into the metal matrix and the environment, which is accompanied by the creation of a structure with a tetragonal crystal lattice—martensite. Under the influence of MF and the processes of cooling and deformation of the rough steel surface, a more energy-intensive structure of austenite (γ-Fe) is formed in it at the level of *Ra* parameters.

When the magnetic field direction is changed, the ratio of the phase composition on the friction surface changes and the largest proportion of γ-Fe is observed in the bifurcation zone of ML at the position of sample B (see Fig. 2, *b*) (Table 1, position No. 2, N/S f.c.c./γ-Fe = 0.49), which indicates the most unstable structural state of the surface under the influence of the energy of the external MF.

Bearing in mind that friction is the relative movement of triboelements, and MF is imposed on both of their materials, it is necessary to create conditions under which the mechanical and chemical interaction of surfaces would have the least impact on the tribosystem. Investigating the kinetics of the formation of tribomagnetic films on friction surfaces, we come to the conclusion that the dynamics of the gradual build-up of surface films must be formed under the conditions of the influence of MF on a single material. That is, with a significant difference in the magnetic susceptibility of MF materials. Diamagnetic (glass) reduces the effect of magnetic field on the contact zone when paired with steel. The chemical interaction of iron with oxygen occurs in three stages. First, iron oxide FeO is formed, which contains 22.7% oxygen and also has the ability to dissolve in iron. Further accumulation of oxygen forms iron oxide Fe_2O_3 with an oxygen content of 30.06%. A mixture of FeO and Fe_2O_3 in MF has paramagnetic properties. The next stage takes place with the use of atomic oxygen to create Fe_3O_4 oxide, which contains 27.7% oxygen and acquires ferromagnetic properties in MF. Mechanochemical processes during rubbing of steel and glass under the influence of MP cause active deformation of the surface and accumulation of oxygen in the contact zone, which significantly affects the formation of surface protective films, the presence of which, according to the classification of B. I. Kostetskyi, corresponds to oxidative wear.

When the external MF is removed, the wear products are removed from the zone of frictional interaction. Under such conditions, steel wear occurs by the mechanism of friction without lubrication by the smooth surface of the glass.

The scientific novelty of the article lies in the disclosure of the wear mechanism of a ferromagnetic sample paired with glass (diamagnetic material) under the directed action of an external magnetic field. The effect of MF on the structural hierarchy of nanocoatings on the glass surface was determined. The basis of the structural transformations is the directed effect of MF on the deformation component, the mechanism of the formation of WP and the formation of servo-vital films of a thin structure of tribological origin.

Practical Significance: monitoring of worn surfaces and restoration of the tribomechanical system; creation of conditions for reducing the wear of the tribomechanical system during operation.

4. CONCLUSIONS

1. An improved physical model of magnetic influence on the contact zone is characterized by the location of wear products around the friction zone and opens up the possibility of using them in the wear process to change the mechanism of formation of tribological protective nanocoatings. The location of nanocoatings is observed at the transitions between environments and materials of different magnetic nature along the direction of the magnetic field lines. On the basis of the analysis of the mechanism of impact of MF on the contact zone located perpendicular to the passage of the lines of force, the process of placement of wear products on the surface of the glass in the direction of MF from the sample to the glass in *SN* pole is considered.
2. The direction of the magnetic field affects the ratio of the phase composition of the friction surface, and the largest fraction of γ-Fe is observed in the bifurcation zone of the magnetic field lines (N/S f.c.c./γ-Fe $= 0.49$), which passes during an unstable state of the surface structure under dynamic by changing the energy of the external MF. In this way, the parameters of the crystal bed are reshaped from volume-centred α-Fe to face-centred γ-Fe (zone of the austenite structure). The rearrangement of the crystal bed takes place due to the rapid heating of the friction surface at the points of ACS with subsequent, rapid cooling (more than 1000°C/s) of the contact zone and the influence of the mobility of dislocations when the electronic structure changes under the influence of MF. The created formation of a finely dispersed structure significantly increases the tribological parameters of the surface.
3. The conditions of influence of MP on the tribological properties of ferromagnetic materials require further research.

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