

THE STRUCTURE AND MECHANOCHEMICAL PROPERTIES OF SOLID LUBRICANT MoS₂ USING VIBRATION WAVE TREATMENT

S. BOUTI¹, M. N. ANTONOVA², K. HAMOUDA¹, A. P. BABICHEV³, T. SAYAH¹

¹ University of Sciences and Technology, Bab Ezzouar, Algeria;

² Kamensky Institute (branch) of South Russian State Technical University (NPI) Kamensk-Shakhtinsky;

³ Don State Technical University, Rostov on Don, Russia

The obtained results from the investigations confirm the possibility of formation of a solid lubricant coating (SLC) using dry powder MoS₂ during exposure to wave vibration impact in steel beads medium, which trigger a deformation of the surface layer in the presence of MoS₂, and the formation of the corresponding coating. Based on the analysis of the investigation results of the vibration treatment characteristics in a metallic bodies environment, a model is developed for the formation of MoS₂ SLC during vibration treatment. Application of SLC in vibration treatment ensures a lower friction coefficient and an increase wear resistance. A physico-mathematical model for quantitative assessment of adhesive strength SLC MoS₂ is proposed.

Keywords: *mechanochemical solid film lubricant coatings, molybdenum disulfide, friction, wear, vibration treatment, adhesive energy.*

Solid lubricant coating (SLC) which are powder material based, with a layered structure deposited on metal surfaces, are widely used in the manufacture of parts for improved technical characteristics, friction reduction, increased durability and reliability of the machines and processes [1]. The SLC application methods vary depending on the operating conditions of nodes, friction mechanisms, structures of the processed parts, and necessary technical resources.

Analysis of work characterizing the conditions of SLC formation and features of interaction between the treatment medium with the treated parts surfaces showed that the promising trend is the formation of mechanochemical SLC, using wave vibration technologies [2, 3].

Great interest is given to molybdenum disulphide (MoS₂), with its layered structure containing both “strong” and “thick” layers, which are to a large extent quite separate from each other. The strong bond is present on the layer covering the friction surface, while the bond is weaker between the layers. Such properties ensure “slight” or limited slip of the interacting friction surfaces, contributing thus to the reduction of the friction coefficient and, consequently, to an increase in surface wear resistance of friction pairs of different mechanisms and machines [4].

The particle size and film thickness are important parameters that should be matched to the surface roughness of the substrate. Large particles may result in excessive wear by abrasion caused by impurities in the MoS₂, small particles may result in accelerated oxidation [5].

The aim of this work is to establish the laws governing the structure and anti-friction formation properties of mechanochemical SLC based on (MoS₂) during treatment of metal surfaces by wave vibration [6].

Corresponding author: K. HAMOUDA, e-mail: hamoudakhaled_2000@yahoo.fr

Materials and research methods. The MoS₂ powder dispersion was determined by Microtrac Bluewave analyzer, while the thermal stability was determined by differential scanning calorimetry method (DSC), using Mettler Toledo calorimeter DSC-1. It was conducted in a temperature range of 30...500°C, at a sample a heating rate of the 20°C per minute, and an air flow rate of 50 ml per min in a standard aluminum crucible.

A mixture of polished 100Cr6 steel 2.0 mm (HRC62) and naturally fine MoS₂ powder were used. The treatment time required to reach a solid MoS₂ film was around 60...90 min, with fluctuation amplitude and frequency $A = 2.5$ mm and $f = 33$ Hz. Three quarters of the working chamber were filled with steels beads (100Cr6), while MoS₂ the powder accounted for 10 g/l of filled beads volume.

Structural analysis of the formation of SLC during vibro-wave treatment.

The MoS₂ solid lubricating coating adhesive force is a result of the sum of adsorption and mechanical adhesion forces on the basis of micro and submicroshape of the coated surface. The adsorption component is characterized by the value of molecular adhesion between MoS₂ crystals and metal, and depends on the convergence of the surfaces before the occurrence of the inter-molecular attraction forces. Measurements have shown that these take effect at distances up to 0.04...0.1 μm.

During vibration treatment of the particles, the inflicted pounding with forces 30...120 N ensure the convergence of the processed material with the applied coating. The metal upper layer, which will be subjected to normal and tangential forces during impact or sliding, is deformed significantly. Plastic deformation causes accumulation of dislocation and voids in the surface layer, increasing thus the surface adsorption activity. The sliding blow triggers a destruction of the film, loosening of the surface, the formation of new areas, what lead to higher adsorption activity. The formation of lubricant film depends on the mechanical coupling between the metal crystals and MoS₂ caused by the roughness, i.e. available specific surface area.

During vibration treatment, as a result of roughness combs deformation caused by steel beads pounding, the surface roughness is changed. While microroughness height decreases, the curvature radius of the projections vertices and the actual area of contact between the coating and the metal surface increase.

In fact, coating adhesion does not occur to separate microroughness vertices, but across each bead's area of contact with the metal surface. Not only the roughness height and shape is taken into consideration, but also the orientation. Upon working medium particle impact, the working parts surface display marks of spherical drop shape as a result of a direct blow, generally referred to as oblique collision.

It is known that cross and transverse roughness the most effective, where of lubricating film formation occurs three times faster than the longitudinal roughness [2–4].

As a result of impact, and intermittent sliding and rolling friction, a convergence between MoS₂ crystals and pad is observed. At the time of sliding of the beads under load, lubricant particles in the contact area are crushed, which allows to a denser filling of microroughnesses. Anti-friction properties of the coating also depend on the particles orientation in the lubricating layer. Fig. 1 shows histograms of MoS₂ particle size distribution at the initial state and following the treatment. Under wave vibration, the number of sub-micron particles (<0.1 μm) decreases. This is associated with the particles packing in the coated surface roughness [8]. The initial powder is dominated micro-particles with sizes up to 10 μm.

During processing, as the dispersion of the powder increases, a tendency of particles to stick together is observed; agglomerates with sizes up to 30 μm are formed.

Upon achievement of SLC using vibration method, and as a result of working media particles sliding on the applied surface coating, the bedding occurs effectively during the application process, which in turn results in a mixing between the two. In order to produce solid lubricant coating layer during friction, it is necessary to achieve

a velocity up to 2 m/s, given the fact that with higher velocities the lubricant layer matter, in a number of cases, breaks off within the first minutes of contact.

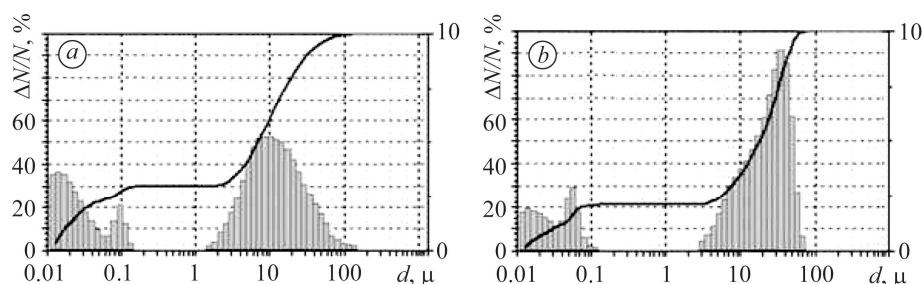


Fig. 1. MoS₂ powder microparticles size distribution: *a* – initial state; *b* – after vibration treatment.

The speed of circulation of the particles of the working medium as a function of the amplitude-frequency characteristic varies within 0.2...3.0 m/s [9].

In addition, with increasing pressure, the time of film formation decreases, and then stabilizes. The contact pressures resulting from vibration treatment are significantly higher than the yield strength. Instantaneous temperatures in the contact zone do not exceed 150°C. Thermal analysis of MoS₂ powder conducted using DSC method has shown that powder oxidation at the original state starts at temperatures of 396°C, while with vibration treatment at 329°C, which is explained by its high dispersion rate. As oxidation occurs at high temperatures. No changes to the anti-friction properties of the coating during treatment. The presence of cyclic movement of the working medium particles and parts allows a uniform distribution of the lubricant film of parts surface of any complex shape. Based on the above, vibration treatment of metallic objects provides all the required and favorable conditions for the effective application of a solid layered MoS₂ coating.

Mechanism of formation of a layer of SLC structure under friction. Analysis of the formation mechanism of the lubricant solid layer of the layered structure under friction [1] considering the characteristics of vibration treatment process in an environment of metal items allows the description of SLC molybdenum disulfide formation model through five steps as described below (Fig. 2).

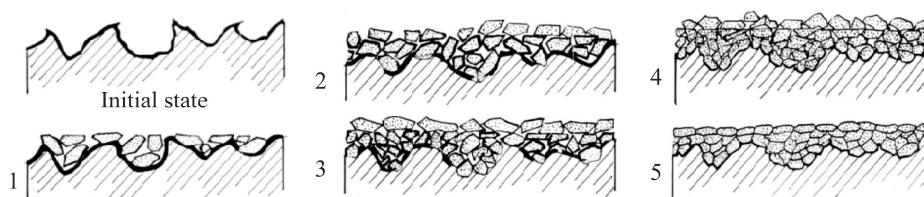


Fig. 2. Schematic model of MoS₂ coating formation during wave vibration treatment.

Mechanical contact and adsorption MoS₂ particles. At the time of external load application, and due to the force of impact of the steel beads with the surface of the processed material, elasto-plastic deformation in the contact zone occurs. Due to the convergence of the part coating with the powder particles are adsorbed on the metal surface.

Activation of the metal surface layer. Activation of the surface occurs as a result of plastic deformation and increase in density of dislocation, destruction of oxide films and formation of juvenile sections on the surface, increase in contact area and a temperature rise in the collision zone (temperature flash).

Formation of the boundary layer. This event occurs as a result of grinding MoS₂ crystallites, destruction of metal oxide films within micro relief depressions, and the

introduction of powder particles and their subsequent adsorption on to the surface layer of the activated metal.

Lubricant layer formation. This stage is characterized by the applied coating particles sealing, crystallites refining while converging to each other and the consequent formation of a solid coating.

Formation of surface coating layer. As a result of the working medium (beads) particles sliding relative to the processed surface, particles of the powder are oriented in base planes parallel to the friction surface.

Experimental studies of the friction coefficient and friction pairs wear resistance of various materials. Fig. 3 shows the results of the evaluation of changes of the friction coefficient (μ_F) through time (t), while Fig. 4 shows the results of the study of wear resistance.

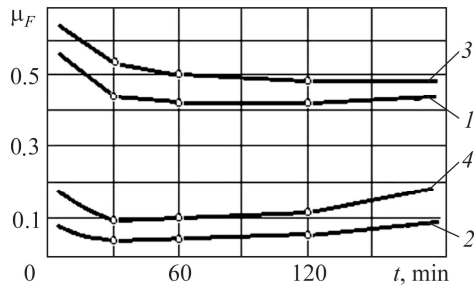


Fig. 3.

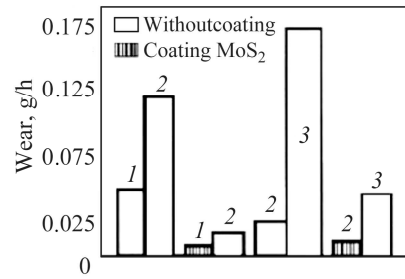


Fig. 4.

Fig. 3. Friction coefficient measurements through time: 1 – 100Cr6 and 37Cr4 steels (both original); 2 – 100Cr6 with MoS₂ coating and 37Cr4 steel (original); 3 – 37Cr4 steel and EN-GJL200 cast iron (both original); 4 – 37Cr4 steel with MoS₂ coating – EN-GJL200 cast iron (original).

Fig. 4. Wear resistance of original and coated samples:
 1 – 100Cr6 steel; 2 – 37Cr4 steel; 3 – EN-GJL200 cast iron.

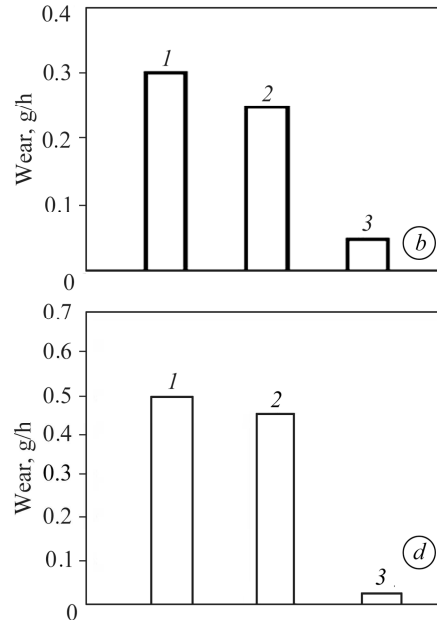
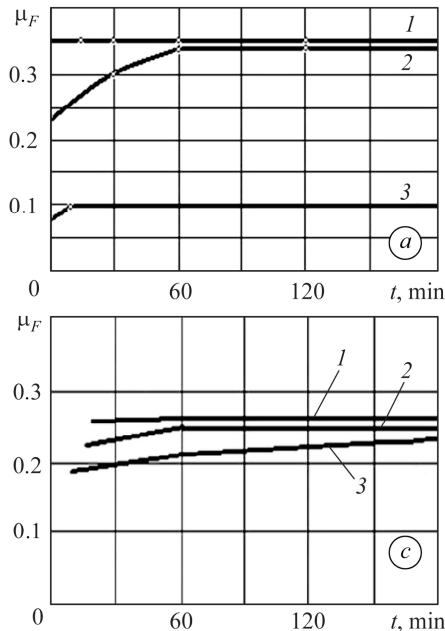


Fig. 5. Change in friction coefficient measurements during work with BT-20 friction pairs and IX12H2VMF steel (*a, c*) and titan sample wear resistance (*b, d*) in dry (*a, b*) conditions and in kerosene (*c, d*): 1 – original; 2 – hardened by vibration; 3 – coated with MoS₂.

Therefore, the molybdenum disulfide coating of one of the friction pair samples in dry conditions reduces friction coefficient μ_F by 5 to 9 times. After 150 min, a slight increase of μ_F is noticed due to the destruction of MoS_2 film, reducing the wear from 13 to 20 times for steel and by 3.5 times for the cast iron in noticed.

Further research and testing of friction pairs were conducted of BT-20 titanium alloy and IX12H2BMF steel both in dry environment and in kerosene [7]. Fig. 5a, c shows μ_F dry test results, while Fig. 5b, d shows wear changes. It is noticeable that MoS_2 coating of the titanium alloy is accompanied by a decrease in μ_F 3.5 times, while the wear resistance increases about 20 times. Realistically, Titan BT-20 and IX12H2VMF steels both usually work in kerosene, so the tests were conducted in flowing kerosene environment. When working in kerosene, the MoS_2 coating generates a slight reduction in the friction coefficient. However, after a full abrasion of the coating, samples acquire a smooth, shiny surface, with no setting traces, that leads to a significant increase in wear resistance.

Further research was conducted using MoS_2 coating and investigating friction pairs in industrial oil environment. There was no noticeable wear within a period of three hours as shown in Table 1.

Table 1. Material wear in oil environment

Sample material	Surface at initial state	Wear, g/h
100Cr6 steel	polished	0.0026
37Cr4 steel	polished	0.0027
100Cr6 steel	coated with MoS_2	0.0000
37Cr4 steel	polished	0.0007
37Cr4 steel	polished	0.0101
EN-GJL200 iron	polished	0.0021
37Cr4 steel	coated with MoS_2	0.0000
EN-GJL200 iron	polished	0.0007

According to the results of the studies and tests, the orientation of the particles has a great influence on the antifriction properties of the MoS_2 coating. A minimum constant coefficient of friction is established at once, i.e. the effect of the coating is virtually non-existent.

Quantitative assessment of the mechanochemical solid lubricant coating MoS_2 adhesive strength during wave vibration treatment. In order to quantify the adhesive strength of SLC by developing a physical and mathematical model, we consider two solids $B_{(1)}$ and $B_{(2)}$ which come into adhesive contact. At the entry moment they occupy fields $V_{(1)}$ and $V_{(2)}$ bounded by limited surfaces $A_{(1)}$ and $A_{(2)}$. Contact occurs along the common portion to these surfaces $A_{(12)}$. While evaluating the adhesive contact process of these two bodies, the following stages its implementation.

The first stage – formation of the bodies themselves which happens initially mentally, and then instantly in realistic allocation of $B_{(1)}$ and $B_{(2)}$ to infinitely extended media $\Omega_{(1)}$ and $\Omega_{(2)}$, with the same properties as that of $B_{(1)}$ and $B_{(2)}$. It is assumed that the allocation of $B_{(k)}$ and $\Omega_{(k)}$ occurs simultaneously in time $t_{(0)} = 0$.

The second stage – the bodies bonding may also occur instantaneously at an instant $t^* = 0+0$ or after a finite time before $t^* > t_{(0)} = 0$. It is assumed that $t^* = 0+0$.

The third stage – after the entry into adhesive contact, a process of deformation, redistribution of mechanical and thermal energy of the material start to develop within the solids. Only the redistribution of mechanical energy is considered.

During adhesion of two solids, the atomic grid of one of them extends the grid of the other body. For the solid body, this means that in the simplest case of adhesion,

with this type of linear contact, prior to deformation, to the fiber crossing contact surface maintains its integrity and smoothness upon deformation.

Assume $\vec{u}_{(k)}(\vec{r})$ is the particle k movement vector field; and $\vec{u}_{\alpha(k)}(\vec{r})$ is the movement field of particles adjacent to the adhesive contact surface. $\vec{n}_{(k-l)}$ is the unit vector normal to the this surface, oriented towards $B_{(l)}$ from $B_{(k)}$ side; $\nabla = d/d\vec{r}$ is the Hamilton differential operator expressing derivative of the radius-vector \vec{r} of the material point. Then, the kinematics coupling conditions of displacement fields in the state of adhesion of the bodies will have the following form:

$$\vec{u}_{\alpha(1)} = \vec{u}_{\alpha(2)}, \quad \vec{n}_{(2-1)} \cdot \nabla \vec{u}_{\alpha(1)} = \vec{n}_{(1-2)} \cdot \nabla \vec{u}_{\alpha(2)}. \quad (1)$$

One of the quantitative characteristics of the adhesive bonding strength is the adhesion energy F_a . For bodies $B_{(1)}$ and $B_{(2)}$ it is equal to the change in free energy occurring in the reverse isothermal process of their entry into adhesive contact along $A_a \equiv A_{(1,2)}$, occurring per unit area. The value of F_a is calculated by the formula:

$$F_a = W_{p(1,2)} - (W_{p(1)} + W_{p(2)}), \quad (2)$$

The subtrahend on the right side of formula (1) is the amount of available surface energy from the contact of bodies $B_{(1)}$ from $B_{(2)}$ and; agglutinate surface energy of the system.

Surface energy W_p is equal to the change in the free energy of the body in question, in an isothermal reverse formation process of its free surface unit area A . There exist methods for calculating the values of F_a , W_p . However, their use for realistic materials and their complex chemical composition and structure is complicated. This was the main driver for evaluating the values of F_a , W_p based on the theory of elasticity of solid media.

Attention is immediately drawn to the fact that the surface layer thickness of bodies $B_{(1)}$ and $B_{(2)}$, in which surface and adhesion energies accumulate, is in the order of several interatomic distances. This is much lower in length and width than surfaces $A_{(1)}$ and $A_{(2)}$. On the inside edge of such layers, perturbation distribution of the bulk density $w(\vec{r})$ of the free energy, caused by then re-structuring of their atomic structure is equal to zero. Therefore, this distribution as well as the distribution of the displacement fields $\vec{u}_{(k)}(\vec{r})$ can be regarded as one-dimensional occurring along coordinates x , considered in the opposite direction of $\vec{n}_{(k-l)}$. At the same time (considering the asymmetric tendency to zero) it is convenient to suppose $0 \leq x < \infty$ in the calculations. Based on these simplifications, it can be assumed that bodies $B_{(j)}$ occupy the region:

$$\begin{aligned} B_{(1)} : 0 < x \equiv x_1 < +\infty, \quad -\infty < x_2, \quad x_3 < +\infty \\ B_{(2)} : -\infty < x \equiv x_1 < 0, \quad -\infty < x_2, \quad x_3 < +\infty, \end{aligned} \quad (3)$$

where in

$$W_{p(j)} = \int_0^{\infty} w_{(j)}(x) dx, \quad (4)$$

$$F_a = \int_{-\infty}^{+\infty} w_{(12)}(x) dx - \int_{-\infty}^0 w_{(1)}(x) dx - \int_0^{+\infty} w_{(2)}(x) dx. \quad (5)$$

It is believed that the free energy changes occurring during the formation of the free surfaces of bodies $B_{(j)}$, as well at the entry into adhesive contact, are equal to their elastic energy of $B_{(j)}$ deformations taking place during these processes.

The classic condition for coupling displacement fields during rigid contact of bodies $B_{(1)}$ and $B_{(2)}$ is to resolve only the first of the two Eq. (1). This is since the basis of the classical description of elastic body kinematics of the is to use only the first dis-

placement gradient $\nabla \bar{u}$. The need to satisfy the second condition in Eq. (1) requires, along with the first displacement gradient $\nabla \bar{u}$, consideration of the second gradient $\nabla^2 \bar{u}$.

In line with the requirement of a mathematical model of an elastic medium, which is expected for use in surface and adhesion energy calculation, the ability to describe energy changes occurring on the surface layers of the newly formed free surfaces is required, together with their variation during the event of adhesion. In view of this, it is assumed that the bodies $B_{(1)}$ and $B_{(2)}$, which formed initially through mental then realistic release of the internal body parts $\Omega_{(1)}$ and $\Omega_{(2)}$ of much bigger than $B_{(1)}$ and $B_{(2)}$ size, meaning infinitely extended homogeneous isotropic media $\Omega_{(1)}$ and $\Omega_{(2)}$. $B_{(1)}$ and $B_{(2)}$ materials have an initial stress state, which disappears upon approach to the free surface. These stresses are described using non-classical stress tensor.

$$P_0^{(2)} = T_0 \cdot \bar{E} , \quad (6)$$

where $T_0 = \pi_0 \delta_{ij} \delta_{kl} \bar{e}_i \bar{e}_j \bar{e}_k \bar{e}_l$; δ_{ij} – Kronecker symbol; \bar{E} – vector, normal to the equipotential surfaces of the field. On the body surface \bar{E} matches the external unit normal \bar{n} ; \bar{e}_p ($p = 1, 2, 3$) are the basis vectors of the Cartesian coordinate system $x \equiv x_1, x_2, x_3$.

Kinematics of the material is described by the small deformations tensor $g_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$ and deformation unevenness tensor $Z_{ijk} = u_{k,ij}$ (the index after comma denotes differentiation with respect to the coordinate with the corresponding number). The bulk density elastic deformation energy is given by:

$$w = \mu g_{ij} g_{ij} + \frac{\lambda}{2} g_{kk} g_{ll} + \frac{2\mu + \lambda}{2} (b^2 Z_{ijk} Z_{ijk}) + \pi_0 \delta_{ij} E_k Z_{ijk} . \quad (7)$$

Two of the stress tensor is defined by:

$$P_{ij}^{(1)} = \frac{\partial w}{\partial g_{ij}} , \quad P_{ijk}^{(2)} = \frac{\partial w}{\partial Z_{ijk}} , \quad (8)$$

where π_0, b – is additional to the classic λ, μ (Lame coefficients) physical constants. They should be determined based on direct or indirect experiments.

In general, the equilibrium equations are:

$$\nabla \cdot (P_{(j)}^{(1)} - \nabla \cdot P_{(j)}^{(2)}) = 0 \quad (\bar{r} \in V_{(j)}) . \quad (9)$$

Under defined boundary conditions free from external influences surface areas:

$$\bar{n}_{(j)} \cdot (P_{(j)}^{(1)} - \nabla \cdot P_{(j)}^{(2)}) - \nabla_A \cdot P_{(j)}^{(2)} = 0, \quad (\bar{n}_{(j)} \bar{n}_{(j)}) \cdot P_{(j)}^{(2)} = 0 \quad (\bar{r} \in A_{(j)}) . \quad (10)$$

On the adhesive contact surface the specified conditions (1), as well as the conditions of coupling of stress fields are laid:

$$\bar{n}_{(2-1)} \cdot (P_{\alpha(1)}^{(1)} - \nabla \cdot P_{\alpha(1)}^{(2)}) - \nabla_S \cdot P_{\alpha(1)}^{(2)} + \bar{n}_{(2-1)} \cdot (P_{\alpha(2)}^{(1)} - \nabla \cdot P_{\alpha(2)}^{(2)}) - \nabla_A \cdot P_{\alpha(2)}^{(2)} = 0 \quad (11)$$

$$(\bar{n}_{(2-1)} \bar{n}_{(2-1)}) \cdot P_{\alpha(2)}^{(2)} = (\bar{n}_{(1-2)} \bar{n}_{(1-2)}) \cdot P_{\alpha(2)}^{(2)} . \quad (12)$$

Here, ∇_A is the gradient along the surface, the point (\cdot) is the scalar product (convolution) and two points are the double convolution.

Assumptions about the dimensionality of the surface layers deformation of the material and the infinity of their thickness allows to obtain accurate solutions for the displacement field in the surface layers of bodies $B_{(1)}$ and $B_{(2)}$ and their respective fields $w_{(j)}(x)$, then use the formulas (3) and (4) to calculate the surface and adhesion energy.

For additional material constants, Equations:

$$b_{(j)} = \frac{3W_{p(j)}}{4k_{(j)}^2 A_{(j)}}, \quad \pi_{0(j)} = \frac{W_{p(j)}}{k_{(j)}}. \quad (13)$$

Here,

$$A_{(j)} = \frac{E_{(j)}}{2} \frac{1 - \nu_{(j)}}{(1 + \nu_{(j)})(1 - 2\nu_{(j)})}.$$

For the surface energy of materials in contact, a valid assessment is empirically well established in the SI system:

$$W_{p(j)} = 8E_{(j)} \cdot 10^{-12}. \quad (14)$$

For the adhesion energy, the following expression is obtained:

$$F_a = \frac{W_{p(1)}W_{p(2)}(k_{(1)} + k_{(2)})^2}{W_{p(1)}k_{(2)}^2 + W_{p(2)}k_{(1)}^2}, \quad k_{(j)} = \frac{\nu_{(j)}}{1 - \nu_{(j)}}, \quad j = 1, 2. \quad (15)$$

Here and above: $\nu_{(j)}$ – Poisson coefficient of material number j .

The calculation is performed based on Eq. (14) and reference data on material properties presented in Table 2. In this case, the surface energy was estimated by Eq. (13).

Table 2. Mechanical properties of the studied materials

Property	Sulphur	Molybdenum	37Cr4 steel
Young's module, N/m ²	$0.8 \cdot 10^{10}$	$28.5 \cdot 10^{10}$	$21.4 \cdot 10^{10}$
Surface energy, J/m ²	0.064	2.28	1.71
Poisson's coefficient	0.25	0.30	0.26

Calculation results of the material pairs adhesion energy involved in the solid lubricant treatment are presented in Table 3.

Table 3. Adhesion energy of pairs of materials involved in the process of solid lubrication of MoS₂ and steel 37Cr4

Material bond	S–Mo	S–37Cr4	Mo–37Cr4
Adhesion energy, J/m ²	0.064	2.28	1.71

Results and discussion. The obtained numerical results allow to draw the following conclusion on the effect of the solid Lubrication of 37Cr4 steel using MoS₂ under the influence of friction forces. Friction forces cause relative displacement of the lubricant layers themselves, and also for the lubricant layer from the coated surface, if they exceed the value of the corresponding adhesive forces.

The obtained numerical results allow drawing the following conclusion on the effect of the solid lubrication of 37Cr4 steel using MoS₂ under the influence of friction forces.

Assuming a development shear stresses τ on the lubricating layer, which cause such elastic deformations on both MoS₂ layers as well as the 37Cr4 steel layer, to which corresponds an energy w per unit of area of contact. Stratification occurs when the amount w exceeds the value corresponding to the adhesion energy. Conversely, this would not happen if $w < F_a$.

CONCLUSION

If MoS₂ particle is in contact with the 37Cr4 steel layer through the Mo layer, then it can adhere to the steel surface, while the sulphur layer would slip over the molybde-

num layer, since $F_{a(Mo-37Cr4)} > F_{a(Mo-S)}$. In this case, molybdenum should appear on the steel surface after removal of traces of lubricant. Moreover, if MoS₂ particles get in contact with the 37Cr4 steel through the S layer, then due to the fact that $F_{a(Mo-S)} > F_{a(Mo-37Cr4)}$, MoS₂ particle will be sliding along the surface of 37Cr4 steel.

Similar results may be obtained by analyzing the interaction of the lubricating layer with an indenter, similar results can be obtained by analyzing the interaction of the lubricating layer with an indenter, from the effect of which the lubricant protects the steel surface.

РЕЗЮМЕ. Показано перспективність використання механохімічного твердомасляного покриття дисульфіду молибдену під час віброхвильової обробки для створення антифрикційних матеріалів. Досліджено коефіцієнт тертя і зносотривкість пар тертя з різних матеріалів під час нанесення покриття. Виявлено механізм утворення твердого мащення шаруватої структури покриття під час тертя. На підставі теорії пружності суцільних середовищ запропоновано фізико-математично модель кількісної оцінки адгезійної міцності покриття.

РЕЗЮМЕ. Показана перспективность использования механохимического твердосмазочного покрытия дисульфида молибдена при виброволновой обработке для создания антифрикционных материалов. Проведены испытания коэффициента трения и износостойкости пар трения из различных материалов при нанесении покрытия. Выявлен механизм образования твердой смазки слоистой структуры покрытия при трении. На основании теории упругости сплошных сред предложена физико-математическая модель количественной оценки адгезионной прочности покрытия.

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