Hamilton's Principle for Search of Invariants at Creation, Evolution and Destruction of Nanomaterials

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Abstract— *It is shown that the kinetics of the evolution of a structure of materials under external influences occurs in accordance with the minimum production of entropy and is characterized by a lower absolute value of a free energy. Using the extinction contours, the local curvature of the dispersed crystal lattice of nickel, the stress values and the dislocation density were quantitatively evaluated. Based on the provisions of mesomechanics and nonequilibrium thermodynamics, the positions of the kinetics of physicochemical, mechanical and tribological properties of the metal interface under contact interaction are developed. The substantiation of the search for invariants in the creation, evolution and destruction of nanomaterials from the symmetry properties of space and time under various external influences is given, which has scientific and practical significance.*

Keywords— time, space, invariants, dislocation structure; kinetics of nanostructure.

I. INTRODUCTION

Accumulated experimental data base does not allow using it to the fullest. The experimental data given in various sources differ from each other. On the one hand, this can be explained by some difference in the regimes and technologies for obtaining nanomaterials, as well as the conditions for their testing, and on the other hand, the lack of scientifically based fundamental principles and, as a consequence, the measurement parameters. The absence of scientific schools, the fragmentation of the directions of fundamental research and the purely practical approach to solving momentary applied problems, unfortunately, do not allow concentrating efforts on the classification and systematization of data in the fields of metal physics, tribochemistry, condensed matter physics and nanomaterial science. The results of plastic deformation studies are often controversial, and sometimes contradictory. The current state of the problem of the creation of nanomaterials is characterized as a transitional period between the accumulation of experimental data and their interpretation in the categories of mechanics, physics, chemistry and the development of generalizing invariant criteria that do not depend on regimes, conditions and technologies for obtaining them.

Improving the wear resistance of metal surfaces it is directly related to the establishment of hardening mechanisms, evolution and destruction of the structural elements constituting the material or a conjugate pair. It is necessary to create conditions under which the injection of frictional loading energy into the interior of the material and the amorphization associated with it will not result in the creation of developed porosity and friability, but the creation and slippage of submicro and nanostructural elements relative to each other. The creation and slippage of submicro and nanostructured elements and mechanisms of formation of a "lock" or the coupling of nanostructures and their conglomerates with respect to each other will allow not only designing block nanomaterials, but also to reduce their fragility and improve operational properties. In this connection, direct experimental studies of the kinetics of the structure at various scale levels are of great importance: macro, micro, submicro, and nano [1].

Another reason for not studying this issue is the conservatism of thinking associated with the dominant role of the fatigue theory of fracture, which does not take into account the energy relaxation processes accumulated in the material by, for example, flake-like sheets separation of friction wear particles [2]. The method of ferromagnetic resonance (FMR) has proved to be effective for studying the mechanism of flake-like sheets separation of wear particles, since changes in the resonance curve of the FMR reflect the kinetics of the microstructure of a thin surface layer [3]. The observed cyclicity of the strength characteristics of surface volumes at a multi-cycle and low-amplitude effect can be explained from the point of view of dislocation representations. On the rise of each cycle, as a result of the action of plastic deformation factors, two opposite processes occur in the subsurface volume: hardening due to the generation of new dislocations and partial softening associated with annihilation of dislocations of the opposite sign, the formation of polygonal structures and the flow of defects to the surface of microcracks. Probably, in the region of the tops of cycles, these processes balance each other. The areas of recession are caused by the relaxation of elastic stresses due to intense cracking. At this stage of the test, a strong dispersion of the crystal lattice of the surface layer is observed due to the formation of numerous microcracks, pores and other discontinuities in the continuity of the material [4]. The growth of cracks and their fusion into closed contours promotes

peeling of the dispersed layer. This destruction has a local, in time, character. Further repetition of the cycle is associated with the rise of the underlying layer [1].

The phenomenological model of a time-localized fracture mechanism has been developed, resulting in a cyclical peeling of the deformation of the surface layer of a metal under frictional loading of surfaces [5, 6]. Priority determined that, in contrast to the usual contact methods (rolling, compression), in the case of friction, the cyclic nature of the change in the strength parameters [7]. This periodicity of structural changes is established by the method of ferromagnetic resonance (FMR), electron microscopy and electron diffraction, X-ray diffraction analysis, and wear rate [1]. A set of experimental results showed that deformation dispersion and subsequent selective destruction of surface layers of metals under frictional loading are multilevel processes occurring at meso- and macro-scale levels and are mainly determined by the kinetics of the dislocation structure [1, 8]. Damascus steel has a high plasticity, strength and sharpness of the cutting edge, which is possible only when the graded structural-phase states form on the surface of solids. A special role here is played by the joints and boundaries of the polycrystalline grains.

Plastic deformation of solids is realized at several interrelated structural levels, the scale of which is determined by the nature of the structural defects responsible for the shaping [9]. In most cases, the distribution of localization zones is ordered in space and time, and the type of localization is determined by the law of plastic flow. The consideration of a solid body as a multilevel hierarchically organized system consisting of 3D-crystalline and 2D-planar subsystems causes a sharp increase in the role of the curvature of the crystal structure in describing the behavior of solids in fields of external influences [10]. All types of deformation defects can be represented as solitons of curvature of the crystal structure. The type of deformation defect is determined by the scale level of the curvature soliton [11].

The aim of the work is to develop theoretical and practical aspects of the creation, evolution and destruction of nano and submicrocrystalline structures and lubricating films on the surface of metals under external influences in the presence of surface and chemically active substances contained in plastic lubricants and oils of various nature and functional purpose for establishing physico- chemical and mechanical properties and regularities of their kinetics from the point of view of scale invariance of deformation, which together determined the conceptual development of new fundamental directions: to search for invariants in the creation, evolution and destruction, including, and nanomaterials; to increase the safety margin, operational reliability and durability of metal surfaces of machine components and mechanisms.

II. EXPERIMENTAL DETAILS

Let's give the concrete example. It is known that the formation of nanostructures in 3D material occurs under conditions of high contact pressures ≈ 6-12 GPa, realized, for example, in the case of equal-channel pressing and intense plastic deformation of the material [12, 13]. The nickel surface is 2D planar subsystem where the atoms are not bonded as firmly as in 3D crystal lattice. The surface of a solid is a structural defect already because of the asymmetric nature of the attraction of the atoms of the surface. This determines the basic physical and chemical properties of the surface of the material, due to free energy. The question arises about the possibility of forming nanocrystalline structures at low contact pressures (≈ 100 kPa) under conditions of accumulation of free energy by the metal surface [14]. In other words, is it possible to obtain structures with a high degree of misorientation and, accordingly, possessing unique properties at a pressure differing by five orders of magnitude? If so, what are the conditions for implementing this process?

Transformation of dislocation structure in the near-surface layer of nickel under friction loading has been studied by means of electron microscopy and ferromagnetic resonance. Polycrystalline nickel with purity of 99.9 % has been examined. Samples in the form of thin disks (5 x 0.1 mm^2) were electrolytically polished and annealed in vacuum (0.133 MPa under 973 K) [1]. Friction test was carried out by means of a machine of type AE-5 with precision positioning of contact surface. Sliding friction was performed in pair Ni – Mo in air and lubricant CIATIM – 201 under load of 82.3 kPa and linear velocity of 0.5 m/s. Number of working operating strokes was in the range of $1 – 36 \cdot 10^3$. Average volume temperature of the sample didn't exceed 40 $^{\circ}C$. Range of ferromagnetic resonance was registered by means of method described in the monograph [1]. Electronic and microscopic researches of nickel were carried out by the instrumentality of microscope ЭМВ – 100АК and S-806 Hitachi by means of thin foils «for transparency». Foils were obtained by means of single-sided electrolytic thinning of disks at the opposite side of the friction surface at the installation of jet-stream polishing, equipped with sensitive photodiode bridge, which makes it possible to control transparency of areas at the depth of ≈ 0.1 micrometers from the friction surface [1].

III. RESULTS AND DISCUSSION

The principle of least action or Hamilton principle can be understood in a narrow and broad sense. In the narrow sense, this principle means energy advantage, i.e. the kinetics of the evolution of the structure of materials under the influence of

external influences, proceeds in accordance with the minimum production of entropy and is characterized by a lower absolute value of the free energy (Figure 1).

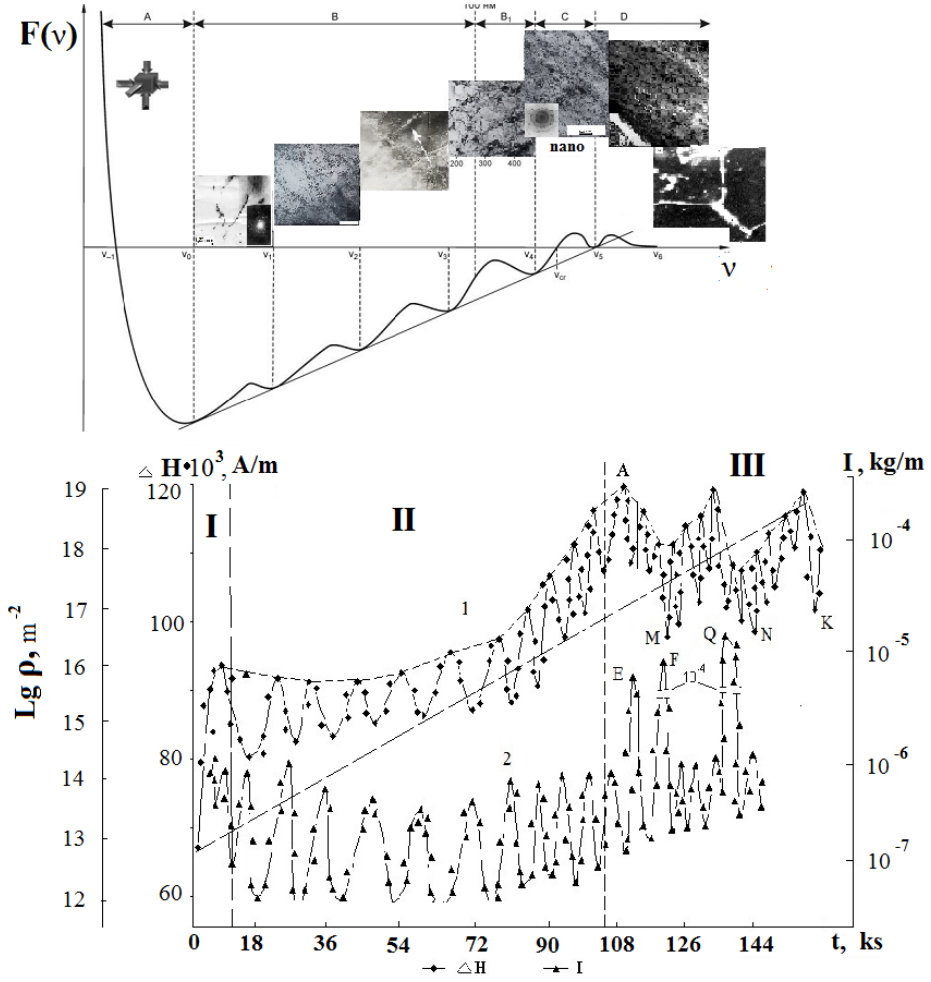


FIGURE 1. Dependences of the Gibbs potential (F(ν)), dislocation density (ρ) and wear (I) on the friction time (t).

A distinctive feature of the appearance of nanocrystalline structures (Fig. 2) with friction (≈ 84 kPa) from the occurrence of intense plastic deformation (6–12 GPa) is that they are already beginning to form at a relatively short time t = 0.6–0.9 ks (Fig. 1) at the stage of the first cycle of surface hardening in the presence of surface and chemically active substances contained in the lubricant CIATIM-201.

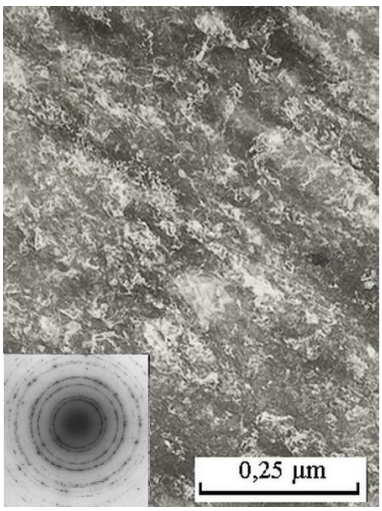


FIGURE 2. Nanostrucrure (t = 0.9 ks)

The primary flows of structural transformations in a deformed polycrystalline of nickel develop in a 2D planar subsystem in which there is no translational invariance. The distribution of normal stresses in the boundary of disoriented polycrystalline grains is described by a sinusoidal function that is, alternating regions of tensile and compressive stresses [15, 16]. With this development of grain boundary sliding in the zones of tensile normal stresses, clusters of positive ions arise which are shielded by an electron gas from the nearest environment in the border zone of the 3D crystalline grain. A decrease in the concentration of free electrons between ions causes an increase in their interionic distance and the appearance of a localized gap in an electron-energy spectrum [17]. This is equivalent to the appearance in the system of a quantum dot, which creates its own "impurity" electronic states in the local energy gap of an electron-energy spectrum. As a consequence, bifurcation minima of the multiparticle interaction of potential arise in interstices.

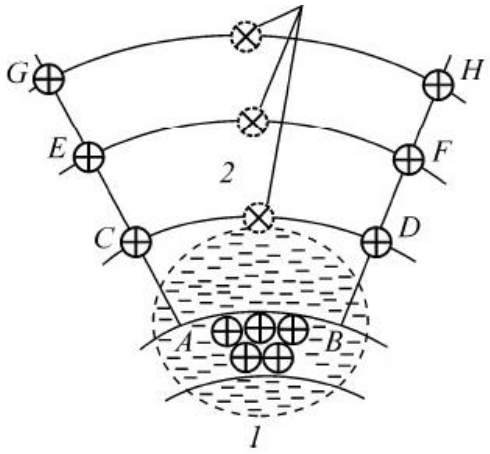


FIGURE 3 – Generation of bifurcation interstitial structural states in the zone of local curvature of the crystal lattice, where AB are clusters of positive ions on the grain boundary 1 and 2

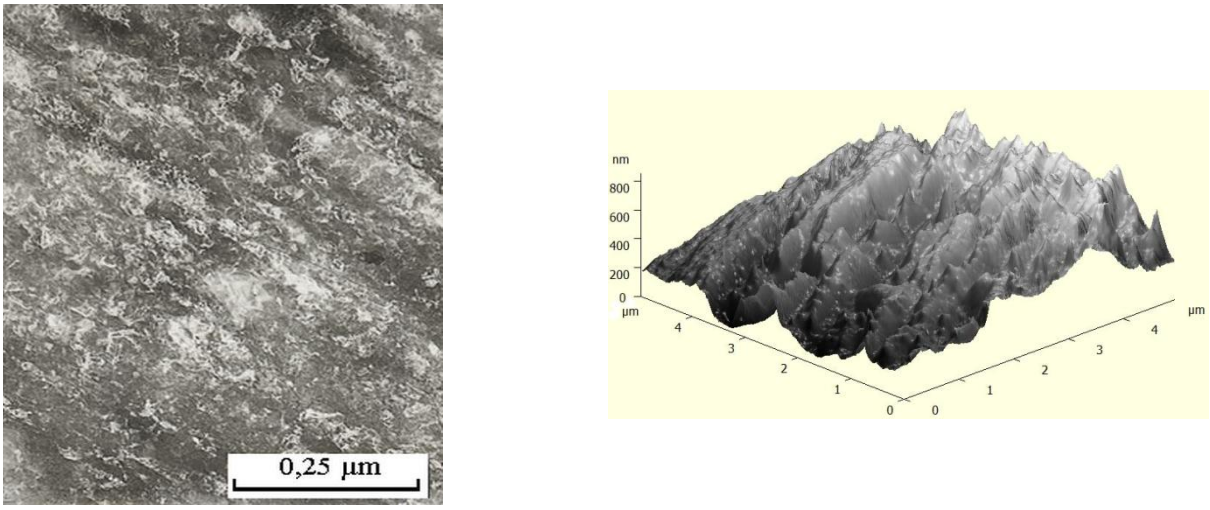
Displacement atoms in the vapor during the development of the shear deformation will be accompanied by plastic distortion in the region of the bifurcation of interstitial minima multiparticle potential that causes a local plastic flow vorticity. The expression for the vorticity of a localized plastic shear was obtained in [18] and has the form:

$$\chi_{\nu}^{\beta} = \varepsilon_{\mu\chi\delta}\,\partial/ox\left(E_{\nu}^{\beta} - P_{\nu}^{\beta}\right)\frac{C_{\alpha\beta}^{\mu\nu}}{E} \tag{1}$$

where $\varepsilon_{\mu\chi\delta}$ – is Levi-Civita symbol, the expression representing the relaxation of shear stresses by the mechanism of plastic distortion P_{ν}^{β} in the zones of local curvature of the crystal lattice is presented in parentheses. Taking into account the curvature of the crystal lattice in the entire volume of the deformed solid body necessitates the construction of a nonlinear mechanics of plastic deformation and fracture.

The formation of bifurcation interstitial structural states and the development of the effects of plastic distortion are enhanced under conditions of intense plastic deformation, when the curvature of the crystal structure is strongly pronounced [19–21]. Particular attention is paid to the problem of wear of materials by papers in the field of grinding the structure of materials with their equal-channel angular pressing [21] and friction welding with mixing [21]. Under conditions of equal channel angular pressing, the curvature of the crystal structure is formed throughout the cross section of the preform, in the interstitial spaces of which plastic distortion processes develop with the formation of a large concentration of vacant sites of the crystal lattice. Their multilevel coalescence causes fragmentation of the initial structure at the meso- and nanoscale structural levels. The formation of a submicrocrystalline structure (0.1–0.5 μm) obtained by intense plastic deformation, for example, equal-channel angular pressing, extrusion causes a significant increase in the stress of cyclic hardening, the endurance limit under multicyclic loading, and a decrease in the characteristics of cyclic crack resistance [22]. This is due to an increase in the density of dislocations and a decrease in the grain size. In view of the high gradient of the properties of the two-phase (crystal and its boundaries) nanocrystalline state, the formed structures are nonequilibrium with a high concentration of defects and their properties are described from the standpoint of nonequilibrium thermodynamics and nonlinear mechanics [23]. It should

be noted that dynamic recrystallization occurs under conditions of high curvature up to 1000 deg / μm of the crystal lattice and high local stress microconcentrators and their gradients. Fragmentation of the crystal lattice into nano- and ultrafine-grained structural states is realized by collective dislocation-disclination relaxation of the micromoentions by mutual shifts and rotations as a whole of meso- volumes larger than 1 μm. The realization of the collective rotational mode of deformation is carried out at several scale levels and includes the following basic mechanisms: the formation of the fragment boundaries, namely, submicrogerene with variable misorientation vectors or high density of partial disclinations as a result of the relaxation of micromotions; the formation of localization bands of non-crystallographic shear with high-angle misorientations at the boundaries of meso-volumes; the formation of elements of the nanocrystalline structure in the zones of intense shear and rotations [23].



(A) (B)

FIGURE 4. A - nanostructure; B - AFM image of the surface of nickel with nanostructured formations.

Nanocrystalline structures have a size of ≈ 5–50 nm with a high-angle misorientation of the cell boundaries ≈ 5–10° [24]. It can be assumed that under conditions of nonequilibrium deformation and nonlinear dynamics of structure formation, when the rate of increase in stresses exceeds the rate of their relaxation, the formation of dislocations on the surface of nickel during friction and the facilitated exit to the surface in the presence of surface and chemically active substances are present. The high dislocation density $\rho \approx 10^{16}$ m^{-2} ensures their convergence and splitting, which is accompanied by an increase in the local curvature of the crystal structure.

It can be argued that these nanostructures are formed not only in the presence of high contact pressures, causing intense plastic deformation, but also in conditions of nonequilibrium deformation (region I in Fig. 1), where the sources of failure, namely slip bands, microcracks, twins, pores, vacancies are not present. There are no mechanisms of energy relaxation yet. The only possible mechanism for splitting dislocations and the formation of nanostructures on the surface of nickel are realized. There is a principle of least action or the greatest energy efficiency at the maximum possible result namely the formation of nanostructures (Figure 4) [14].

Consider the transition of the system from one equilibrium state to another (Figure 1). For example, the material under the influence of external influences passes from the state "A" (the original crystal of the metal, which has the translational invariance of the crystal lattice) to the state "B" (the nanostructured state), while the necessary condition for the transition to a new structural state is that, that the value of the energy difference $\Delta H = H_{max} - H_{min}$ should be sufficient to create a new structural state. The material structure passes from one state, for example, "A" to state "B" (Figure 5) in accordance with the principle of least action [25]. Once the amount of energy injected into the system (material) is sufficient to form a new structural state, it is formed in accordance with the principle of least action.

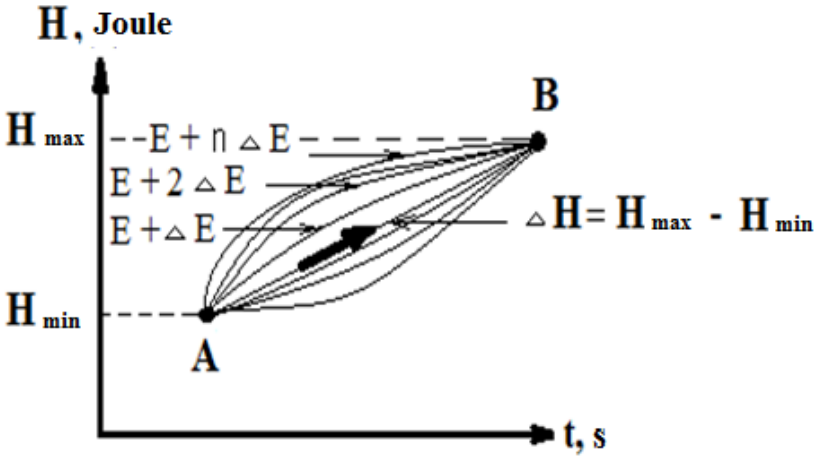


FIGURE 5. Kinetics of the transition of a system from one structural state (A) to another (B) in accordance with the principle of least action.

The system or material tends to move to a new structural state in accordance with the principle of least action, characterized by a decrease of free energy.

In a broad sense, the use of the principle of least action means the search for invariants in the creation, evolution and destruction, including, and nanomaterials.

It is known that the principle of least action (S) at moving a material point from one position to another during a time interval $\Delta t = t_2 - t_1$ can be written in the form [25]:

$$\delta S = \delta \int_{t_1}^{t_2} L\,(x, v, t)\,dt = 0\,, \tag{2}$$

where x – is the generalized coordinate, v – is the generalized velocity, t – is time, and L (x, v, t) is the Lagrange function.

Assume that the kinetic structural change material, with the transition from state «A» to state the structure of the structure «B» can be written as:

$$\delta S = \delta \int_{t_1}^{t_2} L\,(x, \chi, t)\,dt = 0\,, \tag{3}$$

where x – is the generalized coordinate, χ – is the curvature of the crystal lattice, and t – is the time.

The analysis of literary data in the field of tribology, condensed matter physics, and nanomaterial science testifies mainly about their experimental character. The level of our understanding is currently aimed at solving applied problems and does not allow us to develop fundamental principles for meaningful evolutionary development, both in the field of condensed matter physics, tribology, and in the development of nanomaterials.

Conservation laws are invariants in physics [25]. An invariant is a property that remains unchanged under transformations of a certain type. In kinetic processes, an invariant is a physical quantity whose value in some physical process does not change with time. They are performed in a closed reference system or where the projection of their vector quantities is stored in the field of action of forces on the direction, where their magnitude does not change.

Processes of contact interaction of solids and the creation of nanomaterials under external influences proceed in the same space-time continuum, with the same properties (from the homogeneity of time, the law of conservation of energy follows, from the homogeneity of space - the law of conservation of momentum, from the isotropy of space - law conservation of the angular momentum) and are accompanied by heat exchange [25]. Does this mean that since the system is not closed, then the conservation laws and invariants in it are absent or are all forms of energy dissipation and the fulfillment of the energy balance not only possible but also an objective reality? Therefore, the existence of invariants when acting on a tribosystem or material follows from the fact that it itself is part of a space-time continuum with certain properties. Since the modern stage

of understanding the processes occurring at the interface between metals and materials under external influences does not allow us to fully clearly formulate invariants, we can only assume the direction of their search and the ways of development.

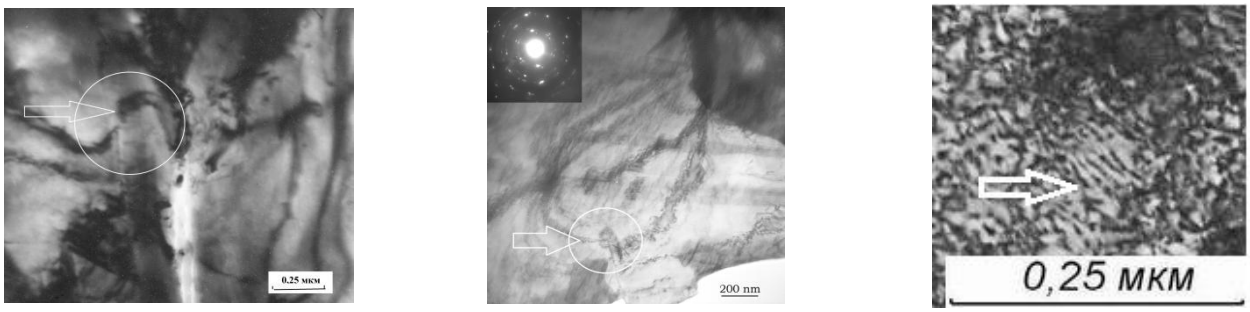
The homogeneity of space and the law of conservation of momentum it will correspond to the invariant associated with the geometric parameters of the material structure when it is *created*, for example, the conservation of the scale invariance of the curvature of the crystal lattice of the metals, a particular manifestation of which is the formation of an equilibrium roughness in the friction of conjugated bodies in accordance with the Le-Satelier–Brown [26].

It is known that initially nickel has a translationally invariant crystal lattice with a low dislocation density $\rho = 10^{12}$ m^{-2} and a curvature of the crystal lattice $\chi \approx 0$ degrees / nm. Each half-cycle of hardening corresponds to a half-cycle of destruction (Figure 1), and the region of compression of the material corresponds to a stretching area similar to a chessboard [15, 16]. Like Heisenberg's uncertainty principle in quantum mechanics in nanomaterial science (the smaller the size of the nanostructure, the larger the size of the amorphous "coat" surrounding it), we can assume that the product of two physical parameters is a constant value [27]. As one physical parameter, the curvature of the crystal lattice χ can be chosen, which increases in proportion to the dislocation density (Fig. 1), and as another parameter one can choose a parameter that decreases accordingly, that is, it is in antiphase. In this particular case (Figure 1), this is the rate of destruction (this may be the area of pores, discontinuities, cracks, etc.) or wear. Then we can assume that the product of these two parameters has the form:

$$\left(\sum_{i=1}^{N} \chi_i\right) \times I = const \tag{4}$$

where χ_i – is the local curvature of the crystal lattice at the i-th mesoscopic level, and I – is the wear rate.

The homogeneity of time and the energy conservation law associated with it will correspond to a certain structural state formed under external influences. Here it is necessary to note the special role of time in the *evolution* of the material at the formation of highly excited energy states, namely, how long this material will be in this state. The definite content of the exciton material corresponds to a definite form expressed in the elements of plastic distortion. The transition of atoms to the interstices of the crystal lattice under external action and the formation of bifurcation states by them provides the spectrum of excited states of the electronic subsystem and nuclei [28]. The definite content of the exciton material corresponds to a definite form expressed in the elements of plastic distortion. Using the method of electron transmission microscopy, it is established that after the expiration of a time period of forty years, extinction circuits (fig. 6, a, b, arrows) with high stresses (up to 300 GPa) and plastic distortion elements are clearly preserved and do not dissociate (fig. 6, c, arrow). But does this form correspond to its energetic state or content? On the one hand, there is superplasticity and amorphous (like liquid) state of the material, expressed in plastic distortion elements, for example, circles on the water, and on the other hand circles on the water (or elements of plastic distortion) completely relax in time, which cannot be said about the elements plastic distortion (fig. 6, c, arrow).



(A) (B) (C)

FIGURE 6. A) and B) The extinction circuits at curvature of the crystal lattice of the metals; C) The elements plastic distortion

The plastic components of the amplitude of internal stresses in bending and torsion are calculated by formulas [29, 30]:

$$\sigma_{11,n\prime} = E\sqrt{b\chi_{11,n\prime}} \tag{5}$$

$$\sigma_{12,пл} = E\sqrt{b\chi_{12,пл}} \quad (6)$$

where E – is the modulus of elasticity; b – is the Burgers vector, and χ – are the components of the curvature-torsion tensor of the crystal lattice.

The width of the contour can be represented in terms of the components of $\Delta L_{пл}$ and, respectively, on the OX and OY axes of the Descartes coordinate system. The plastic components of the curvature-torsion gradient at the bending and torsion χ of the crystal lattice, respectively, are determined by formulas:

$$\chi_{11,пл=}\frac{\Delta\varphi}{\Delta L_{ox,пл}} \quad (7)$$

$$\chi_{12,пл=}\frac{\Delta\varphi}{\Delta L_{oy,пл}} \quad (8)$$

where Δφ – is the angle of misorientation on the width of the contour ΔL; ΔL – is the width of extinction contour.

The quantitative estimation of the local curvature of the crystal lattice of the nickel surface, the plastic components of the internal stress amplitude for bending $\sigma_{11} \approx 0.6 \cdot 10^{11}$ Pa and torsion $\sigma_{12} \approx 0.9 \cdot 10^{11}$ Pa is comparable with the magnitude of the nickel elasticity modulus $\approx 2 \cdot 10^{11}$ Pa, which indicates a loss elastic properties, the accumulation of energy deformation and the destruction of the surface.

I estimated the dislocation density using expression [31]:

$$\rho = \frac{1}{b}\chi \quad (9)$$

where b – is the Burgers vector of dislocations, χ – is the disorientation gradient equal to the curvature-torsion of the crystal lattice. The dislocation density is $\rho + - \approx 10^{18} - 10^{19}$ m^{-2}.

Fragmentation of the initial structure of the material causes a strong thermodynamic disequilibrium of the surface layer of the material during the contact interaction. When the stresses are reached $\approx 1 \cdot 10^{11}$ Pa, the nickel crystal lattice loses its resistance to shear $\approx 0.77 \cdot 10^{11}$Pa. The amorphous layer with unique physicomechanical properties is formed.

It is of interest to determine the contribution of the hardening mechanisms by the formula [31]:

$$\sigma_{\Sigma} = \sigma_{тр} + \sigma_{тв} + \sigma_{з} + \sigma_{Op} + \sqrt{(\sigma_{д}^{2} + \sigma_{л}^{2})} \quad (10)$$

where $\sigma_{з}$ – grain boundary hardening. where $\sigma_{тр}$ is the frictional stress of dislocations in the Ni crystal lattice; $\sigma_{тв}$ – hardening of the Ni sample by the atoms of the alloying elements (C, Mn, V, etc.); $\sigma_{л}$ – hardening by forest dislocations, which cut sliding dislocations; $\sigma_{Д}$ – hardening by internal long-range stress fields; σ_{Op} – hardening by incoherent particles when they are traversed by dislocations by the Orovana mechanism (dispersive hardening); $\sigma_{з}$ – hardening due to grain boundaries.

The most significant contribution to hardening of the nickel surface is made by hardening due to the interaction of long-range stress fields ($\sigma_{д}$). The magnitude of the stress $\sigma_{л}$ corresponds to a charged dislocation ensemble of dislocations and is estimated by electron microscopy using flexural extinction contours [31]:

$$\sigma_{д} = m \cdot \alpha_{c} \cdot G \cdot b \cdot \sqrt{\rho_{+-}} \quad (11)$$

where α_{c} = 0,5 – is the Strunin coefficient; m – is the orientational factor, or Schmid factor [31], m = 2.2; α – is a dimensionless coefficient that varies within the range 0.05–0.6, depending on the type of dislocation ensemble (we shall take it equal to 0.25 [31]); G = 78 GPa – is the shear modulus of the matrix material, b = 0.35 nm – is the lattice constant of nickel; ρ – is the average value of the scalar density of dislocations.

The external contact action on the nickel surface at a very long friction time t = 108 ks and more in the presence of surfactants contained in the plastic lubricant CIATIM-201 leads to the formation of a highly developed dispersed submicrostructure, which causes the interaction of long-range dislocation fields (≈ 70 nm) polarization of the dislocation structure, which is reflected in the appearance of extinction loops. The quantitative estimation of the curvature-torsion

parameter from the analysis of the images of the extinction loops in Figures 6, a and b shows that it is up to $\chi = 3$ degrees / nm at a voltage up to $\approx 3 \cdot 10^{11}$ Pa.

The oscillating kinetics of hardening and destruction of amorphous layer takes place at superplastic.

I estimated the energy density using expression [30]:

$$\Delta U = \frac{1}{4E}[(1-\nu)]\sigma_{11}^2 + 2\sigma_{12}^2 \quad (12)$$

where ν – is Poisson's coefficient, and the remaining parameters correspond to the parameters described above in expressions 3 and 4.

Accumulated energy under friction in local areas with a large curvature of the crystal lattice reaches $\approx 17 \cdot 10^9$ Joule. Coalescence of nano and submicropores into micropores leads to a viscous destruction of the surface layer of the material. There is a time-localized selective mechanism for the destruction of the surface layer, the fundamental role in which is determined by the multilevel curvature of the crystal structure of the surface layer [5, 6].

The isotropy of space and the law of conservation of angular momentum associated with it can be compared the invariant associated with the mechanisms of deformation and *fracture* of the surface of tribosystem or material at all mesoscopic structural-scale levels of deformation [27]. A possible implementation mechanism will be implemented through intergranular shift, relative rotation and slip [1, 6]. According to the law of conservation of the angular momentum, the macro-rotation must be compensated by the sum of all rotations in the hierarchy of mesoscale levels of deformation. This law is defined by the expression [28, 32]:

$$\sum_{i=1}^{N} rotJ_i = 0 \quad (13)$$

where I_i - fluxes of defects at the i-th mesoscopic level. The formation of defect fluxes I_i is a kinetic process that requires a periodic crack stop to bring the material state before the crack tip to the critical level of the nanostructured states.

It is necessary to note the dominant role of the nanostructural level in the hierarchically organized phenomenological model of destruction [33]. The output of dislocations on the surface of metals in the form of steps leads to the rise of the Kelvin probe, which causes an increase in the contact resistance [33]. The dependence of the tunneling conductivity on the nanometer thickness of the boundary lubricating layer makes it possible to diagnose the operating modes of the rolling and sliding bearings, which increases the reliability of their operation [34, 35].

IV. CONCLUSION

Thus, on the basis of mesomechanics and nonequilibrium thermodynamics, as well as the properties of space and time, the positions of the kinetics of the physicochemical, mechanical and tribological properties of the interface of metals under contact interaction have been developed, namely:

- Each stable state of the metal interface will have its own structure with a certain value of free energy and, accordingly, with the kinds of its redistribution between the elements of the boundaries and within the structural formation;
- The system tends to occupy a position or form a structure of the interface, which corresponds to the minimum thermodynamic potential of Gibbs;
- If the effect of the load-velocity parameters or external action exceeds a certain critical value that has entered the energy system, it goes into a new structural state with a minimum production of entropy and is characterized by a lower value of the free energy;
- The system tends to shift to a new structural state in accordance with the scaling of the local curvature of the crystal lattice at all structural-scale levels of plastic deformation and destruction of the metal surface;
- based on the analysis of the basic properties of space and time, the principle of least action is proposed for analyzing the kinetics of structure formation and the search for invariants in the *creation*, *evolution* and *destruction* of

nanostructured materials under various external influences and the determination of kinetic regularities and their physicochemical and mechanical properties that have scientific and practical value.

The proposed approach requires further development and reflection.

ACKNOWLEDGEMENTS

Thanks to professor V.G. Pinchuk and academician of RAS, professor V.E. Panin for research support.

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