# Part 1. Volumetric derivative of energy of a deformed solid, function of state of deformation and destruction. Thermomechanical potential of indentation, gradient of flux of specific power of irreversible processes during indentation and uniaxial tension, generalized and molar rheological power.

The abstract consists of 5 parts. In parts 1, 2, 3 physical methods of analysis of diagrams of kinetic indentation and uniaxial tension. In the 4th part using the concepts of molar volume, molar energy and power of processes of deformation and destruction, a solid is considered as a macroscopic (statistical) structural-energy corpuscular vortex wave system. As a result, a unified picture and a universal physical method of description of irreversible processes occurring in a deformed solid are proposed. Physical universal characteristics of internal processes, physical parameters of strength, plasticity, durability, brittleness of destruction of materials under different physical and mechanical conditions are substantiated.

**Physical macro-hardness (brief definition)** is the specific generalized power, the generalized rate of change of the density of dissipated energy in the process of irreversible shaping and structural transformations of a deformed solid. Specific energy or mechanical work of the indenter movement process (movement of the machine grips during stretching), spent over a certain period of time, for the irreversible formation of a certain area of the free macro surface and the inner surface (defects) and the movement of a unit of the activated volume of the material.

Let us consider the results of theoretical physical analysis of the force diagram F(h) of macro kinetic indentation (MKI) of materials of different hardness. This study and analysis were carried out using the methods of the physical theory of hardness (PTH) [1,2,3,4]. Briefly, the meaning of the physical theory of hardness and strength is reflected in the formula:

$$PH(V_p)=\frac{dA(V_P)}{dV_P}, \quad J/m^3 \qquad (1.1)$$

Where, $PH(V_p)$, $J/m^3$ , is the volume derivative of the thermomechanical potential A of the energy of the activated physical volume Vp of a solid. during its mechanical deformation. For UTM, this is the work of the sample stretching mechanism. Let us first consider the formulas for the case of KI.

A, J is the thermomechanical potential of the activated volume of a solid, it is equal to the mechanical work of the indenter KI or the energy dissipated in the volume Vp during deformation and internal structural transformations. This is the energy that is dissipated in the activated physical volume Vp during transformations and dissipation. Vp is the volume that, under the action of the external pressure force of the indenter F and other internal forces and factors, continuously arises and is formed in the thin corpuscular vortex and wave structure of the material during elastic-plastic deformation, displacement and its associated internal structural transformations.

$PH(V_p)$, $J/m^3$ - functions of the potential of the specific (volume) generalized power of the process of changing the shape of a solid body, a short term - physical hardness of the material

[1]. A - thermomechanical potential of the indented material, as well as the mechanical work of the indenter, which is spent on macro-shaping and micro-transformations of the fine structure of a solid body of volume Vp during the indentation process, etc. Further, all reasoning is presented for simplicity using the example of kinetic indentation.

Vp - physical activated volume of material, a solid body arising in the KI process [1]. For the case of macro kinetic indentation (MKI) by a sphere, we assume the equality $V_p \approx V(h)$, where V(h) is a function of the geometric volume of the material displaced (displaced) by the indenter in the direction of the coordinate axis x = h , Fig. 1b.

**PSB - physical solid body.**

**DBM - deformable body mechanic.**

Physical activated volume, **physical activated space (DAS - device activated space) of a deformed solid body (DBM). DAS** - scalar or vector torsion field, associated movement, transformation and interaction of quasiparticles, vortices, waves, as elementary flows of power of the internal energy of this solid body.

**DAS - physical model of DBM**. This model describes in space and time mechanical stresses, deformations, temperature field, vortex, wave processes, etc. These are processes of transmission and transformation of different forms of energy, power. In DAS, internal structural-energy processes of oscillation, rotation, wave movement, emergence, destruction and transformation of dissipative structures, translation of any stable form of the state of internal energy and power, movement of mass and formation of a new physical and material surface of this physical environment occur. This is a macro volume of PSB, in which there is a macroscopic set of elementary power flows of different magnitude, direction, frequency of parameter oscillations, rotation, etc. Vp is a physical volume (in some cases, physical space), a macroscopic sum of elementary vortex wave dipoles of energy. A dipole is an elementary energy monad (EM), and at the same time a source-sink of the movement of energy flows of a certain power, etc.

In the PSB theory, molecules, atoms, crystallites, blocks and other structural units are considered as stable dissipative elementary states of energy and power of a macroscopic system. All structural units with mass are considered as mediators, trajectories, pointers in the space-time structure of internal processes of motion and transformation of power and energy in a solid. In some cases, instead of the term dipole, we use the related term characteristic fluctuation CHFL of energy density. The term CHFL is present in the first works of the physical theory of strength. All elementary structural-energy states of a deformed body form the total macro potential of the internal energy of a macro volume, characterize its total specific power, volumetric energy density (J/m3), energy of a mole of elementary states and processes (J/mol) - molar energy density of a body, etc. [5,6].

In empirical methods of mechanics we traditionally consider trivial properties of DBM. In the ideal case, for example, for macro indentation, it is possible to ignore internal features and properties of physical irreversible processes in the fine structure of bodies. In this case we apply a simple physical model - the specific volumetric power of continuum transformations. Such a model integrally and simplistically displays the set of all transformations occurring in materials, ignoring the features of fine internal processes. For example, during macro indentation of a material by a sphere, it can be assumed that the activated physical volume Vp is equal to the value of the mechanically displaced, moved volume of material Va. The value of the geometric volume in three-dimensional coordinates Va (x=h) - the part of the indenter body immersed in the material is a function in Cartesian coordinates, the volume measure is m3. In this case, it is assumed that Va= Vp . Such a hypothesis of equality is not applicable in the combined micro-macro KI process $V_a \neq V_p$.

In the empirical model of hardness there are no subtle physical internal processes, the boundaries of elementary states on the external and internal surfaces (defects) are not considered. The surfaces of defects have a size, shape, quantity, etc. In empirical methods of analyzing the property of hardness there is no principle of measuring the physical activated volume of the material. The geometric Va and physical volume Vp of the activated body in the empirical analysis of the indentation process are a priori assumed to be the same. The empirical model of the KI process, like thermodynamics, can macro describe the parameters of the DBM continuum: temperature, pressure, elastic stresses, deformation, etc. These data are insufficient to construct the state function of the KI process.

In physical methods of analyzing KI processes [1,2,3,4], we study on simple models subtle processes of energy transformations in the volume and on the surface of a solid: structure, entropy of structural transformations, specific power, energy density, flow vector of elementary energy processes of energy absorption and transformation, the role of the surface, damage accumulation criteria, etc.

Fig. 1 shows the diagrams and the model of the physical process KI, the volume Vp for the case of a sphere. The process of growth of the geometric volume Va(h) = Vp is shown depending on the coordinate (axis) x = h. The volume Va in this case is equal to the volume of the immersed part of the sphere.

Some special notations and terms of the physical theory of hardness:

$PHI(V_p)$ - the function of the physical hardness of the material for the process of kinetic indentation. $PHUTM(V_p)$ - the function of physical hardness, it is also the generalized specific volumetric power of uniaxial tension (hereinafter UTM) of the material when testing in two different ways.

In the general case $PH(V_p)$ (1. 1) the function is a vector. We will consider the simplest case of a scalar function, assuming that it reveals the principles and general nature of simple forms of physical processes of deformation and irreversible internal changes in the material occurring at KI and UTM. In the 4th part of the abstract we will consider the specific molar power and molar energy density of a deformed solid for the case of UTM. These are new universal physical characteristics that display the properties and mechanism of irreversible structural-energy processes, mechanical parameters of material strength at KI and UTM [7,8], and characterize the micro and macro properties of the material.

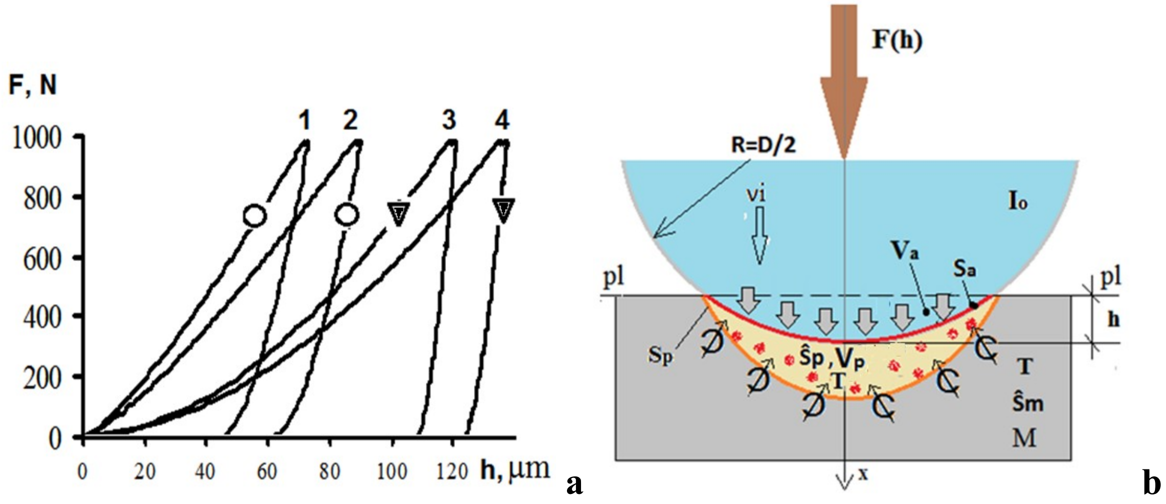

Fig1. F(h) diagrams and the MKI process model of the material: a). Indentation diagrams F(h), UTM - 20HT installation, Brinell sphere D2.5mm [9], 1.3 - steel 15X2HMFA. 2.4 - steel C45, O - sphere, ▼ - Vickers pyramid. according to ISO 14577-1.2002, b.) Physical model of the thermomechanical indentation system and the process of growth of the activated volume Vp for a sphere.

Physical model of the thermomechanical indentation system. Fig. 1b shows the elements of the physical energy model of the kinetic process of shape change and growth of the activated physical volume of a solid, the diagrams in Fig. 1a from [9], macro indentation with a sphere.

Designations: F(h) is the force on the indenter, Io is the indenter sphere with diameter D and radius R, M is the initial material, pl is the surface plane, T is the temperature, P is the conventional pressure, Sa is the contact surface of the sphere and the activated material created, generated by the indenter Io. Sp is the conventional physical surface, the outer boundary of the volume Vp, pl is the surface plane of the material. $S_m$ are the entropy of the structure of the deformed body and $S_p$ the entropy of the activated body. We assume that when the indenter moves, the activated volume Vp is continuously formed and grows with new high proper parameters T, Vp , $S_p$ the quasi-equilibrium state of the material. When the indenter moves with a certain low speed $\upsilon_i = dh/dt$ , a quasi-equilibrium process of continuous exchange arises between all elements of the system, the translation of structural (dissipative) states of the energy of waves-vortices-quasiparticles. We assume that the physical state in the volume $V_p(h)$ is completely characterized by the values of its parameters. All changes and relaxation of the parameters of the activated new state of the material occur in a certain thin layer, it is designated by the symbols ø, in front of the surface Sp (orange line), Fig. 1b.

We assume that the stage of transformation and relaxation of the initial state of the material body structure occurs continuously, in a short time in this small boundary region. The formation of stable parameters is completed under the condition h >>ho, where ho is a certain small depth for the relaxation period of the activation process. This small boundary region is the volume of structural-energy transformations of the material and the formation (generation) of the activated volume Vp. On the surface Sp, all irreversible processes of translational-rotational transformations of the initial structure of the material occur, the latent energy of the initial structure of the material is released. In the volume $V_p(h)$, there are new physical parameters of the state of the material, they are marked with an asterisk "*" and a subscript "p". In the works [1,2,4], more detail is given on the modeling of the physical process MKI and the construction of the equation of the physical process in the volume Vp.

In the physical theory of hardness and strength (1.1) $PH(V_p)$ - specific volumetric generalized physical power, a characteristic of a simultaneous irreversible and reversible process during shaping of solids. For the analysis of the physical specific power of irreversible processes of solid body shaping, the theory also uses conjugate functions, their designations, and terms:

**PHKI(V),** J/m3 - specific generalized volumetric physical power, physical hardness of the material, in the process of kinetic indentation (KI). Physical hardness is divided into three types of KI power:
**PHKIMA,** J/m3 - physical volumetric macro power KI (MKI);
**PHKICOMBI (PHCM),** J/m3 – combined (COMBI) power of the nano-micro-macro process KI;
**PHKINA,** J/m3 - physical volumetric power of nano and micro KI;

**PHUTM,** J/m3 - generalized specific volumetric power of an irreversible process during uniaxial stretching of the material. All the above types of power are based on the concept of a continuum, thermodynamics of the medium, i.e. the properties of the microscopic structure and the fine structure of the body are ignored.
**PHGr,** J/sec - rheological, molar power of the irreversible process UTM. This function uses the physical concepts of the structural-energetic kinetic theory of strength (SET). In SET [6,7] the function is designated as Ir, J/sec – inre (from the Latin in fact). In SET, dependencies are obtained for describing the processes of corpuscular vortex wave motion and the transformation of internal energy, equations for the specific molar power of destruction of DBM, etc. are obtained. The generalized power is the main characteristic of the physical and mechanical state of DBM and is based on the model of a solid body as a continuum (there is no internal structure, etc.).

The molar power function PHGr (also Ir, J/sec) takes into account the internal structure of solids, rheological properties of solids, processes at the nano and micro levels, etc.
Special new functions of the power of the material deformation process will allow analytically combining the usual mechanical characteristics, properties and parameters of materials (standard parameters of strength, durability, fatigue, elasticity, plasticity, brittleness, destruction) on uniform physical principles. Physical functions and parameters are based on the application of the theory and dependencies of the properties of corpuscular wave vortex energy (CVWDE) DBM, complement the classical theoretical methods of mechanics with new possibilities, but do not contradict the methods of mechanics. For analytical analysis of the function of physical hardness, the specific power of material transformations (1.1), the full thermomechanical potential A of the activated volume of a solid body is represented as the sum of its three components:

$$A = AS + AV + At \text{ , J} \quad (1.2)$$

Where, AS is the component reflecting the work spent on the formation of a new free surface of the external and internal (defects). is the component of the work of the process of irreversible change in the shape of the volume Vp, transfer - mass flow, translation and transformation of the structural-energy states of the physical activated volume of the material. At is the component responsible for irreversible rheological processes in the material at constant parameters Sa, Va. For example, irreversible processes in the structure of the material after reaching a certain value of force F(h), fixed position of the indenter at a given depth h=const, etc. Work and power of the internal process of relaxation of stress energy arising from the load F.
According to ISO 14577 and [10], the full thermomechanical potential A of the activated volume of a solid can be found from the integral:

$$A(h)=\int_0^{h_{\max}} F(h)dh \quad \text{J} \quad (1.3)$$

Where, F(h) is a function of the force acting on the indenter from the depth of movement h.

The physical theory of hardness and strength of materials (PTHS) is based on the analysis and generalization of experimental data of physical processes of kinetic indentation (KI) in different ranges [3], analysis of the results of physical processes and diagrams of uniaxial tension of material (UTM) [11]. Known dependencies and experimental data of the kinetic concept of strength, formulas of Zhurkov [12] and Sanfirova [13], vector field theory, etc. are used. A deformed solid (DBM) is considered as a macroscopic rheological, quasi-equilibrium thermomechanical system (TMS). DBM is presented as a physical field of a macroscopic set of associated elementary corpuscular vortex wave states of motion and energy transformation (CVWDE). This set, a field of elementary dipoles "source - drain" of energy, forming a torsion macro field of energy CVWDE. In small volumes of this macro field, fluctuations in energy density, specific power, rotation of vectors of micro power flows occur, dissipative microstructures (molecules, lattices, blocks, clusters, etc.) arise and are destroyed. Under the influence of external forces, temperature, time, small structural units of the TMS volume change their own geometric, thermodynamic, internal structural-energy parameters and the potential of the density of dissipated energy. As a result, the macro potential of the power of the associated CVWDE flows changes. We consider the interconnected stress field, temperature field, etc. of the processes in the CVWDE field. In a deformed body, over time, the micro and macro physical, thermodynamic and mechanical, structural-energy (molar) parameters, the density and power of energy flows change, the shape of the activated volume of the body, its surface area changes. In PTHS, using new physical models of processes, their simplest cases are considered and analytical dependencies are proposed. On this basis, new physical methods have been proposed for solving engineering and scientific problems, calculating the parameters of strength, plasticity, hardness, durability, fatigue, brittleness and destruction of materials[11].

In physical theory, atomic, molecular and other geometric models of strength, atomic, ionic, covalent and other models of "mechanical structures" of connections between structural units are not applied explicitly. Pair potentials, coordination numbers, dislocations and vacancies and other geometric, spatial virtual structures of the internal microstructure of a solid are not applied. PSB is a macroscopic CVWAE system. PSB is a physical space of associated interaction of different forms of internal energy of a solid, which we present in three idealized forms (triad): CORPUSCULAR VORTICAL WAVE ASTIR (astir - in motion) ENERGY

(CVWAE) [5,14]. In the physical theory of strength, a model of the structural-energy associated dissipative process of vortex wave motion and transformation of specific power flows of internal energy PSB is analytically formed. The theory uses macro parameters and other characteristics of CVWAE: V, m3 - physical and geometric volume of the body, Sh, m3/mol - molar volume, S, m2 - physical area of the external and internal vortex wave surface of the body, PVA, J/m3 - density of scattered (dissipation) energy, WL, J/mol - molar density of scattered energy, derivatives of these functions, etc.

The theory considers physical and mathematical idealized models of the processes of motion, transformation, oscillation, rotation, etc. These are processes of changing the physical parameters of the specific power of internal energy flows CVW. The theory obtained equations, dependencies that display the rheology of changes in thermomechanical and thermodynamic macro parameters, processes of transformation of shape, volume, surface, temperature. stresses, etc. DBS is a field of elementary flows and oscillations of the power of sources and sinks of the internal energy of space and volume of a solid. Thus, PSB is a physical spatio-temporal structure, a multi-level torsion field of associated corpuscular vortex wave motion, oscillations and transformation of energy density CVWDE. The field contains many different associated forms of energy - the sum, the alliance of matrices of dissipative structures formed from a set of elementary states of energy (each has its own parameters: physical and mechanical, rheological, dissipative, molar, etc.). In this theory, first of all, an ideal inelastic (plastic) solid physical body (PSB), which simultaneously has an elastic energy density (idealized reversible processes, an ideal body in mechanics), is considered. But the theory is based on a simplified physical model of associated elementary processes in a spatial macroscopic system CVWD, using which we study the physical model of a real (inelastic) body of finite dimensions, etc.

In PTHS, theoretical and experimental methods for assessing the initial boundary physical universal parameters of the material state have been developed, an analytical relationship has been established between new physical and conventional empirical standard parameters of strength, hardness, etc.

Using the dependencies and parameters of PTHS, it is possible to analytically determine the initial mechanical empirical parameters of materials: yield strength, tensile strength, fatigue limit, plastic deformations, their rate, time to brittle failure of the material, etc. [7, 8]. For a simple case of a uniaxial stress state, a method has been developed for calculating the changed (damaged) values of the physical and mechanical parameters of the material under the influence of stress, temperature, time, and other factors (analytical assessment of accumulated damage).

Physical theory studies recognized phenological concepts, empirical and mechanical models of strength and failure of solids, and allows them to be consolidated on a single physical theoretical basis. The theory analytically allows one to describe the experimental properties of strength and plasticity of materials that could not be modeled before. The theory models the physical process of changing the shape and destruction of solids, and has opened up new possibilities for solving practical problems.