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# THE INFLUENCE OF EQUILIBRIUM QUALITY PARAMETERS OF A SURFACE LAYER ON THE WEAR RESISTANCE OF PARTS

## WPŁYW RÓWNOWAGI JAKOŚCIOWYCH PARAMETRÓW WARSTWY WIERZCHNIEJ NA ODPORNOŚĆ NA ZUŻYWANIE CZĘŚCI MASZYN

**Key words:**

wear rate, surface layer, quality parameters of the surface layer, stored energy

**Słowa kluczowe:**

intensywność zużywania, warstwa wierzchnia, właściwości warstwy wierzchniej, zmagazynowana energia

**Summary:**

The article describes the processes of hardening and softening of the surface layer of parts in the process of wear during the formation of the equilibrium state of work surfaces of friction units. Based on the energy approach to the

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problem of the determination of the relationship of the wear rate of the contacting surfaces of machine parts with the quality parameters of the surface layer, the equation for the calculation of the linear wear rate in the equilibrium state is shown. The equation contains the following variables of basic surface quality parameters: the roughness parameter, the degree of hardening of the surface layer, operating stresses in the surface layer of machine parts, and the depth of hardening. The possibility of determining the relationship of the wear rate with the technological conditions of machining is shown.

## INTRODUCTION

The main tasks during product design and production engineering of critical parts of high technology engineering products are to ensure the required accuracy of parts and products and to ensure the required quality of the surface layer of parts. An average drawing made by a designer contains requirements for the dimensional accuracy and relative positioning of surfaces, the surface roughness and hardness of the material, according to the specifications, and the hardness of the material that can be set in unreasonably wide range. Responsible assignment of parts and products needs to ensure high performance properties (wear resistance, contact stiffness, fatigue resistance, corrosion resistance, strength of joints with interference, etc.) as well as the higher requirements to the quality of surfaces. This problem is particularly relevant to work-surfaces of mating parts of machines, where often there is a causal link between the performance characteristics of parts **[L. 1]**.

## TASKS OF RESEARCH

It is known that all the products at the initial stage of operation pass a break-in procedure. The end of the break-in procedure, according to GOST 27674-88 is characterized by a decrease in the friction force, temperature, and wear rate. In this case, the initial parameters of the surface layer are changed to performance parameters that can be reproduced for a long period and, in this case, are called equilibrium parameters.

**Figures 1** and **2** are graphs showing the sequence of the formation of equilibrium surface roughness *Rz* of the steel of samples SH15 and the microhardness of the surface layer with rolling friction on the disc-disc scheme.

Analysis of the scientific work in this area shows that further research is needed to answer many questions, among which are the identification of the relationship between the parameters of roughness and mechanical properties of materials of mating parts, the development of recommendations on the choice

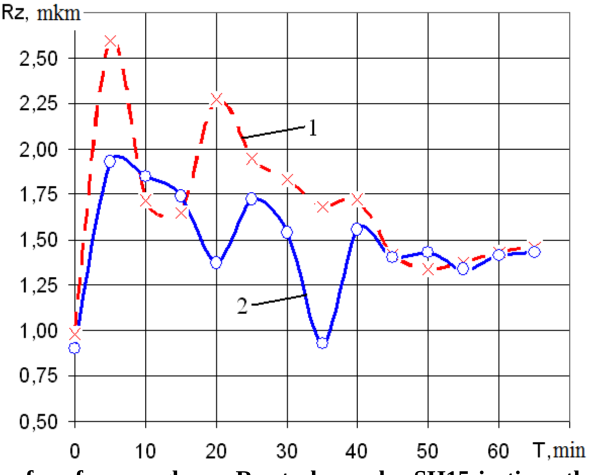


**Fig. 1. Formation of surface roughness Rz steel samples SH15 in time, the normal force of interaction of the contacting elements F = 784 N; 1 – 1st sample; 2 – 2nd sample**

Rys. 1. Zmiany parametru chropowatości powierzchni Rz próbek stalowych SH15 w funkcji czasu, siła normalna stykających się elementów: F = 784 N, 1 – pierwsza próbka, 2 – druga próbka

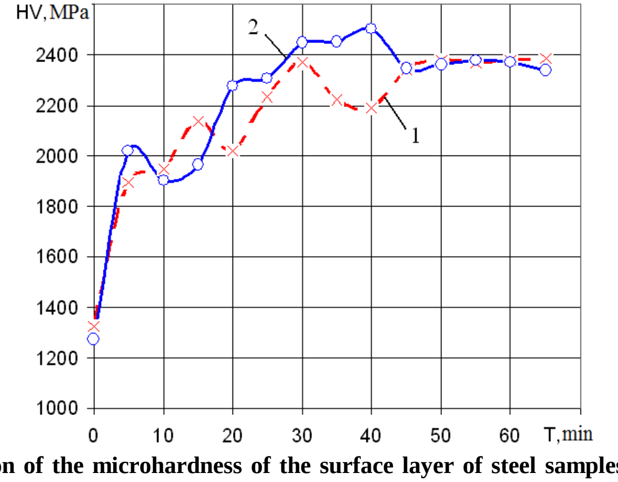


**Fig. 2. Formation of the microhardness of the surface layer of steel samples SH15 in time, the normal force of interaction of the contacting elements F = 784 N; 1 – 1st sample; 2 – 2nd sample**

Rys. 2. Zmiany mikrotwardości warstwy wierzchniej próbek stalowych SH15 w funkcji czasu, siła normalna stykających się elementów: F = 784 N, 1 – pierwsza próbka, 2 – druga próbka of the equilibrium degree of microhardness, and the hardening of the surface layer of parts, as well as the equilibrium residual stress of the surface layer of parts.

The aim of this work is to develop relationships between equilibrium quality parameters of the surface layer and the performances of the parts, in particular, the wear resistance and the ability to ensure parts' performances by technological methods and processing conditions.

## THE STUDIED PHYSICAL MODEL

The development of the relationship of the surface layer parameters (surface roughness, degree of hardening and the depth of machining after equilibrium voltages) and the intensity of wear of the contacting surfaces is as follows.

Tribosystems are open thermodynamic systems that exchange energy and matter with the environment. Friction is the process of converting the external mechanical energy into internal energy in the form of vibration and wave motion of particles of the tribosystem followed by thermal, thermionic, acoustic, and other phenomena. Most of this energy is converted into heat and is given to the environment; the other energy is spent to change the physical and chemical state of the surface layers of the material. The dissipation of energy corresponds to an increase of entropy (dS > 0).

In the basis of the thermodynamic approach to fracture and the wear of solids is the energy analogy of mechanical (during deformation) and thermal (in the melting or sublimation) physical destruction.

The energy balance of a tribosystem, according to the first law of thermodynamics, is described by the following equation:

$$W_{fr} = q + \Delta W \tag{1}$$

Where: $q$ – energy of heat exchange with the environment, $\Delta W$ – change of internal energy is the sum of the energy used to change the structure of the material and energy of heating.

The energy spent on the deformation and fracture of solid bodies is compared to one of the thermodynamic characteristics of the material (heat of sublimation, enthalpy of the solid and liquid state, latent heat of melting). In this case, it is assumed that thermodynamic properties are independent of the structure of the material. The body is treated as a solid, homogeneous, isotropic medium with statistically uniformly distributed structural elements.

The work of the friction force is the sum of the work of plastic deformation, hysteresis loss, and the elastic deformation of the dispersion.

As a result of the interaction of the interfaced parts, new surfaces are formed, which is followed by the energy release, $\gamma_{ef}$, consumed for its forming **[L. 2]**:

$$\gamma_{ef} = f(F, Rz, HV) \tag{2}$$

Where: $F$ – the normal force of friction pair elements interaction; $Rz$ – ten-point height of irregularities; $HV$ – a microhardness of a surface layer of an examined part at the specified depth **[L. 3]**.

Taking into consideration that expression, $V_W / S_{fr}$ ($V_W$ – the volume of the worn material, $S_{fr}$ – the friction track) represents the value of the wear rate $J_V$ **[L. 4]**, and changing of an internal energy is determined by the formula of specific energy of deformation $\Delta W$ accumulated in the material as a result of forming dislocation **[L. 5]**.

$$\Delta W = f(HV, HV_0, \alpha_0, G) \tag{3}$$

Where: $G$ – a displacement module of an examined material; $\alpha_0$ – a parameter of internal dislocation interaction; $HV$ – a microhardness of a surface layer of an examined part at the specified depth; $HV_0$ – a microhardness of an undeformed material.

This is based on an energy-based approach to the problem of defining the relationship of the wear rate of work surfaces of machine parts with quality parameters of the surface layer. The wear rate as a functional relationship with geometrical (roughness) and physico-mechanical (degree of work hardening) parameters of surface layer of machine parts during normal operation can be represented as follows:

$$J_V = 20 \cdot \left( \frac{\sigma_B}{\sigma_{0.2} \cdot \delta} \right)^{-4,14} \frac{fF 3\pi S_{fr} Rz_{bal} 2 \cdot 10^{-3} \cdot [HV_0 (N_{bal} + 1)]^{1,19} - 4F^2}{\frac{3\pi}{\alpha_0^2 G} S_{fr} Rz_{bal} \cdot 2 \cdot 10^{-3} \cdot [HV_0 (N_{bal} + 1)]^{1,19} [0,32 \cdot HV_0 \cdot N_{bal}]^2} \tag{4}$$

Where: $J_V$ – the wear rate; $F$ – the normal force of friction pair elements interaction; $f$ – a friction coefficient; $S_{fr}$ – the friction track; $Rz_{bal}$ – the balanced roughness of the interfaced surfaces of the components; $\sigma_{0,2}$ – the yield strength conditional with the tolerance of 0.2% for the value of the plastic deformation at stressing; $N_{bal}$ – the balanced degree of hardening; $HV_0$ – a microhardness of a undeformed material; $\sigma_B$ – ultimate stress limit of a treated material; $\delta$ – extension strain.

Further studies in this direction have developed the following relationship of the linear wear rate with the quality parameters of the surface layer of parts:

$$J_h = \frac{10\alpha_0^2 G}{A_T \cdot S_{fr} HV_0{}^2 N_{\mathrm{bal}}^2} \left[ F_{\mathrm{fr}} S_{fr} - \frac{4F^2}{3\pi Rz_{bal} \sigma_F} - A_T \left( h_C \sigma_{\mathrm{bal}} + C\rho h_T (\theta_K - \theta_0) \right) \right] \tag{5}$$

Where: $J_h$ – the linear wear rate; $Rz_{bal}$ – the balanced roughness of the interfaced surfaces of the components; $N_{bal}$ – the balanced degree of hardening; $\sigma_{bal}$ – operating (equilibrium) stress in the surface layer of parts; $HV_0$ – a microhardness of a undeformed material; $S_{fr}$ – the friction track; $A_T$ – nominal contact area of the mating surfaces of the elements; $\alpha_0$ – a parameter of internal dislocation interaction; $G$ – a displacement module of an examined material; $\alpha_0$ – a parameter of internal dislocation interaction; $F_{fr}$ – friction force; $F$ – the normal force of friction pair elements interaction; $\sigma_F$ – actual contact pressure in the friction zone; $C\rho$ – volumetric heat capacity of the surface layer parameters of material of part; $\theta_0$ – the initial temperature of the surface of part; $\theta_K$ – the average temperature in the contact zone working surfaces of parts tribo-mating; $h_C$ – depth of the surface layer parameters of part to the conditional boundary of the elastic and plastic deformations; $h_T$ – depth of the surface layer parameters of part, heated to a temperature $\theta_K$.

The presented mathematical model of the relationship of the linear wear rate with the equilibrium parameters of the friction units of the surface layer of parts considers the impact force (normal force interaction of the elements of the friction pair) and the temperature (the temperature in the friction zone) factors in the process of wear.

Using the formula for correlation between surface roughness, depth, and the rate of mechanical hardening, residual stresses, and technological requirements of machining **[L. 6]**, the correlation between wear rate and technological requirements of machining is formulated as follows:

$$J_h = f\left(f, F, S_{fr}, \alpha_0, r, HV_0, h_c, \sigma_B, \sigma_{B_E}, p_1, t, \tau_p, B_{Cr}, \gamma\right) \tag{6}$$

Where: $p_1 = f\left(a_1, b_1, c\rho, \theta, \rho_1, a, \lambda_p, \beta, \varepsilon, V, \lambda, \alpha, \tau_p, b, a_2, B_{Cr}, b_2, \gamma, x, \delta_1\right)$; $h_c$ – depth of a mechanical hardening; $V$ – a cutting speed; $t$ – a cutting depth; $\tau_p$ – plastic displacement resistance of the treated material; $\lambda$ and $\lambda_p$ – thermal conduction of treated and tool materials; $\theta$ – a melting temperature of a treated material; $\alpha$ and $\gamma$ – rear and front angles of the cutter; $\varphi$ и $\varphi_1$ – principal and auxiliary angles of the plane; $\beta$, $\varepsilon$ – cutter pointing angle and vertex angle of the plane; $r$ – radius at a cutter tip of the plane; $\rho_1$ – radius of a rounding of a cutting edge of a cutter; $\delta_1$ – value of wearing of a cutter on a rear surface; $\sigma_B$ – ultimate stress limit of a treated material; $a$ – temperature conduction of a treated material; $\sigma_{B_E}$ – ultimate stress limit of electric steel taken as a standard sample; $c\rho$ – specific volume thermal capacity of a treated material; $a_1$ – thickness of cut; $b_1$ – width of cut; $b$ – the summary length of cutting edges; $V_{Cr} = \frac{cB_{Cr}^{x} D_{Cr}^{z}}{G_{Cr}^{y}(1-\sin\gamma)^{0,73}}$ – dimensionless group; $B_{Cr} = \frac{Va_1}{a}$ – dimensionless group; $G_{Cr} = \frac{\lambda_p}{\lambda}\beta\cdot\varepsilon$ – dimensionless group; $D_{Cr} = a_1/b_1$ – dimensionless group; $a_2$, $b_2$, $c$, $\xi$, $\chi$, $x$, $y$, $z$ – the values depending on properties of treated and tool materials.

Implementation of the equations obtained in the development of specialized software products and their integration with the knowledge bases of CAD / CAM / CAE systems makes it possible to control the formation of the quality and accuracy of parts at the stages of design, pre-production, production, and maintenance products.

## RESULTS AND DISCUSSION

The paper presents the equations of wear rate and cutting modes that allow one to analytically calculate the wear rate for the selected cutting steel for SH15

$$J_V = 3{,}71\cdot 10^{-8} S^{0,054} V^{0,85} t^{-0,12} r^{-0,069} \varphi^{-0,69} F^{0,95} \tag{7}$$

And for steel 30KhGSA

$$J_V = 2{,}945\cdot 10^{-8} S^{0,024} V^{0,428} t^{-0,046} r^{-0,077} \varphi^{-0,909} F^{0,907} \tag{8}$$

Where: $S$ – feed, mm/rev. Equations adequately describe process at $S$ = 0.05...0.08 mm/rev; $V$ = 0.1...0.2 m per sec.; $t$ = 0.25...0.4 mm; $\varphi$ = 45 … 60°; $r$ = 0.3 … 1 mm; $F$ = 100 … 500 N; a dry friction; elastic character of interaction; contact temperature no more than 120°C.

## CONCLUSIONS

1. On the basis of the energy approach to the problem of defining the relationship of the wear rate of the contacting surfaces of machine parts with the quality parameters of the surface layer, a generalized equation of the relationship of the linear wear rate with the equilibrium parameters of roughness, the depth and degree of work hardening of the surface layer of machine parts, equilibrium stresses in the surface layer are obtained.

2. In the design phase, the equilibrium calculation of quality parameters of the surface layer makes it possible to provide high performance properties that will provide high durability of parts, hence increasing the reliability of the product or unit as a whole.
3. From a technology standpoint, the assurance of equilibrium quality parameters of the surface layer allows one to use optimal cutting speeds during machining, where a minimum tool wear is obtained, thus increasing efficient tool life.
4. From the standpoint of process operation parameters the assurance of equilibrium quality of the surface layer makes it possible to provide maximum durability of parts, thus enhancing the reliability of the product or unit as a whole.

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**Streszczenie**

**W artykule opisano proces utwardzania i odpuszczania warstwy wierzchniej elementów w procesie tarcia podczas tworzenia się stanu równowagi powierzchni roboczych elementów trących. Bazując na podejściu energetycznym do problemu określenia zależności pomiędzy intensywnością zużywania współpracujących powierzchni a jakością warstwy wierzchniej, zaprezentowano równanie dla obliczania liniowej intensywności zużywania w stanie równowagi. Równanie zawiera następujące zmienne charakteryzujące jakość powierzchni: parametr chropowatości, stopień zgniotu warstwy wierzchniej, występujące naprężenia w warstwie wierzchniej obrabianych materiałów i głębokość zgniotu. W pracy została zaprezentowana możliwość określenia zależności intensywności zużywania od parametrów technologicznych obróbki.**