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FEATURES OF ESTIMATION WEARPROOFNESS TRIBOJOINTS BY WORK OF ELECTRON OUTPUT

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The wear is considered and power - producing state of a surface stratum exemplar after friction with a difficult dynamic loading. The estimation of work destruction and wearproofness tribojoints are analysed. It is shown that the change of character of loading tribojoints is determined the power - producing state of superficial layer and can be appraised in size works of electron output on a surface. The analysis of distribution magnitude work of electron output determines influence of conditions contact interaction to a wear resistance and condition of a superficial layer. It allows determining sites of a surface, which have received a different degree of plastic deformation

Keywords: wear, tribojoints, works of electron output, friction, superficial layer

Introduction

Despite the significant progress achieved in tribology, many problems related to improvement of wear resistance and reduction of friction losses are still not fully understood. This is due to the wide range of mechanical and physicochemical phenomena that occur in the contact zone. Simultaneous analysis of all such phenomena is hardly possible. It is advisable to consider a limited set of informative parameters, which may be sufficient to comprehensively characterize a tribosystem. Moreover, in testing on a friction machine, the tribocontact loading conditions should correspond as closely as possible to the real conditions of tribojoint operation. It is a matter of general experience that a variety of wear mechanisms exist. Variation in any given factor, or the appearance of a new one, can result in changes in the wear mechanism.

Functioning of tribojoints and exit on the optimal mode of wear is determined by the complex of external and internal factors. To the external factors, as is generally known, loading, speed of the relative moving, environment, physical and mechanical properties of materials belong. To internal, it is necessary to take the processes of electric nature. One of basic power-producing descriptions of metals is work of electron output (WEO). It is known that a sum volume and superficial constituents determine WEO. By volume, part of WEO depends on energy of Fermi this metal and very poorly change at deformation. The superficial constituent of WEO can suffer considerable changes at deformations, because determined by the local superficial gallops of potentials, variations of that depend on micro geometry and co-ordination of superficial atoms. Researches by means of the complex independent methods is showed, that changes of WEO were corollary of fatigue processes flowing in relatively thick subsuperficial layer and can be used for the analysis of kinetics flowing of processes fatigue destruction at a friction.

The surface is the most important component of metal parts and it is necessary to control its condition at all stages of the life cycle of the part - during its production, operation and repair. To carry out reliable non-destructive testing of metal parts, specially developed tools and methods for its use are necessary, including WEO [1, 2]. At the same time, it is possible to use both theoretical and experimental studies.

In obedience to a structural and energy theory, fundamental conformity to law of friction and wear shows up due to a main physical mechanism - phenomenon of structural and energy adapt of materials at mechanical and thermo mechanical processes. Initial period of work tribojoints from positions of structural and energy approach presents the process absorption energy of contact layers, as a result more power-hungry structure is formed as compared to initial one, but with less energy absorbing ability and higher dissipative properties [3, 4].

1. Theoretical part

Mechanical and chemical an effect most strongly shows up on the stage of the deformation workhardening, when intensive formation of dislocation accumulations in a metal, resulting in the height of thermodynamics and chemical potential, is. In thermodynamic chemical potential is energy that can be absorbed or disengaged because of change the number particles of this kind. Chemical potential plays an especially important role in physics of solid and closely related to conceptions of work output, energy of Fermi (or simply level of Fermi).

Essence of application laws classic thermodynamics to the non-equilibrium systems consists in supposition about a local equilibrium into the small elements areas of the system. An idea about a local equilibrium allows to study large number practically important non-equilibrium systems to that with the complete founding it is possible to take and tribojoints. Thus, all equalizations save the value in relation to small areas and community of the conformities to law described by them. So, equation of Gibbs, showing dependence of internal energy U on entropy S, volume V and chemical potentials μ components of the system consisting of different components, it is possible to write down for a small area in a form [5]

$$dU = TdS - pdV + \Sigma \mu dC, \quad (1)$$

where U, S, V pertaining to the small area (local values); C – concentrations of components.

However, there are difficulties at the calculations of local values of internal energy, entropies etc., because these values change depending on the coordinates of area and time.

A level of Fermi essentially is electrochemical potential of electron in a metal. In particular, in a zone theory the relative electrons and holes amount in a semiconductor is characterized by the level of energy of Fermi that makes sense chemical potential of electron in a semiconductor. What higher level of Fermi, the anymore stake of particles bearing a negative charge.

It is set [6, 7], that the coefficient friction of k is proportional to efficiency of destruction of contacts

$$k = C \cdot T \cdot \frac{A}{\mu} \cdot \overline{N}, \quad (2)$$

where A – work (energy) of destruction, T – temperature, μ – chemical potential of metal, $\overline{N}$ – middle number of elementary carriers destruction (is proportional to the number of contacts), C – permanent.

It ensues from equalization, that coefficient of dry friction the less, than anymore chemical potential. For clean metals chemical potential coincides with energy of Fermi. In addition, [8] it is educed, that wear proofness higher at those metals that have a large size of superficial energy, and the power state of surfaces metals suffers a substantial change during their work in the knots of friction. With that, a power (thermodynamics) surface tension is specific work of increase surface at her tension on condition of constancy temperature. In case of dry friction with introduction of coefficient proportion of C_0, for a surface tension an analogical formula is got [6, 7]:

$$\sigma = C_0 \cdot T \cdot \frac{A}{\mu} \cdot \overline{N} \,. \quad (3)$$

Formula that binds the size of work electron output to superficial energy of metal looks like [9]:

$$\sigma \cong 1{,}15 \cdot 10^3 \left(z \frac{D}{A} \right)^{5/6} \varphi \,, \quad (4)$$

where σ – superficial energy; z – an amount of valency electrons on an atom; D – density; A – atomic weight; φ – work of output.

However, general lack of mathematical models molecular - mechanical, molecular, atomic - molecular and other theories consists of that they do not take into account structural changes and related to this change of mechanical, physical, chemical, and other properties of superficial layer, influencing on tribotechnical descriptions of pair friction. Experimental data allow to suppose that accordance is between in size WEO and by the structure of superficial layer of metal, which characterizes the mode of friction set for these conditions. In the process of treatment surface details and at friction superficial layers change the structure and properties. These changes affect size of WEO as most structure - sensitive parameter [10], characterizing the level of superficial energy of solid.

In addition, to works of electron output the features of roughness surface influence substantially. As the preliminary conducted researches showed [11-13], complication of dynamics loading in tribojoints is characterized by the decline of roughness equilibrium. At a two - dimensional (blow with slipping) and three - dimensional loading (blow and slipping in two mutually perpendicular directions) with the increase of amplitude of the transversal slipping a from 0 to 0,2 mm grows by volume intensity of wear and the roughness of surface goes down, her homogeneity rises. The presence of the transversal slipping at a three - dimensional ladening results in formation of surface of less roughness without obvious longitudinal scratches of with a augmentation value WEO.

Taking into account the change of WEO by the friction of superficial layer with different structural state of and roughness equilibrium, we get the size of work destruction tribojoints:

$$A = C \cdot \varphi \cdot \gamma \cdot \frac{k}{T \cdot R \cdot \overline{\overline{N}}}, \tag{5}$$

where φ – works of electron output, γ – structure-sensitive coefficient, R – roughness of surface.

The set correlation between works of electron output, structural state of superficial layer, roughness and wearproofness of surface allows to offer the method of determination wearproofness steels and alloys. Because intensity of wear steels and alloys substantially changes depending on the terms of friction, determination of their wearproofness it maybe to conduct on the state a superficial layer. Thus, to produce the estimation of structural homogeneity of superficial layer on the change of size or distribution of WEO on the surface of details.

2. Experimental part

The state of the real surface of metals is related to forming on the surface of electric dipole moments that determine the size of electrostatic barrier in-process electron output. Because of the heterogeneous state of metallic surface, there is corresponding relief of electrostatic barrier that predetermines divergence works of electron output for the different areas of surface. Thus, for this surface of metal there are characteristic power relief and distribution of WEO on a surface. Comparison power relief of standard material with relief of material that is tested gives an opportunity to estimate the change of the structural state of superficial layer. Thus, as such material can be used the standard of the investigated steel or alloy with known wearproofness, state of superficial layer and conditions of loading in tribojoints. By the change of the structural state of superficial layer it's possible to determine wearproofness.

In particular, the terms of difficult dynamic loading in tribojoints result in formation of the certain structural state of superficial layer of details and level of his wearproofness. Tests of the friction unit model are not always possible due to the duration of the tests and the high cost of carrying out a full-cycle experiment. The required amount of information on wear resistance can be obtained in a shorter time in the methods of accelerated tests of friction pairs. Obviously, the test method for simulating full-scale conditions on a dynamic stand may be the most acceptable.

Techniques and a number of special instruments that allow the implementation of complex contact loading and test specimens in conditions close to full - scale were developed. Realization of the offered method of estimation wearproofness tribojoints we will consider on a concrete example with the use of standards 60S2A (XC60 - AFNOR) and alloy of KhTN-61(Standard of Ukraine), by the friction with a two-dimensional and three-dimensional loading on the special setting on the methodology presented in work [14-15]. The samples were plates 2 mm thick, 14 mm wide and 30 mm long. Friction of the end face of flat samples made it possible to provide constant contact conditions during tests with various dynamic loads. The volume of the worn-out material of the samples was determined through linear wear and the contact area.

Testing terms: amplitude of the transversal slipping a from 0 to 0,2 mm; amplitude of the longitudinal slipping is a 0,1 mm; frequency of the transversal slipping is 30 Hertzs; frequency of the longitudinal slipping is 66 Hertzs; normal loading 20 H, time of tests to 4 hours. The results of tests are presented in a table 1. Measuring works of electron output was conducted with the use of method dynamic condenser of

Kelvin, in that measuring of WEO is carried out on the difference of potentials, which arises up between a measureable surface and surface of electrode – standard [1].

Table 1. Results of tests at a two-dimensional and three-dimensional loading

Material of standard	A_{trs}, mm	V, mm^3	R_z, µm	R_{max}, µm	L, m	$I_v \cdot 10^{-3}$, mm^3/m
KhTN-61	0	0.041	6.5	11.0	960	0.04
	0.01	0.099	10.0	26.0	1164	0.09
	0.05	0.139	8.5	16.0	1368	0.10
	0.10	0.112	8.0	11.0	1056	0.11
60S2A	0	0.052	3.0	9.7	1920	0.03
	0.03	0.090	5.0	9.5	2496	0.04
	0.06	0.033	3.0	4.0	1104	0.05
	0.08	0.071	1.0	1.5	1920	0.05

Note: A_{trs} – amplitude of the transversal slipping; R_{max}, R_z – parameters of roughness; V – volume wear; L – way of friction; I_v – volume intensity of wear.

Thus, a measureable standard and electrode - standard form a flat condenser and does not contact inter se, but here possible is an effective exchange by electrons under the action difference works of electron output of the used metals. Between the surface of standard and electrode due to the pin difference of potentials the variable electric field is formed. Measuring of tension indemnification of this field allows to define difference of potentials between a standard and electrode, to obtain information about the state of layer of sub nanosize thickness.

Frequency of vibrations of electrode-standard from gold made 500 Hertzs, diameter 1,4 mm. Determined distribution WEO a scan-out with a step a 0,2 mm on one line in the center of working surface of standards within 1 meV. Standards before measuring wiped an alcohol and maintained during twenty-four hours to establishment thermodynamics of the equilibrium state of surface. The got distribution works of electron output is presented on Figure 1 and 2.

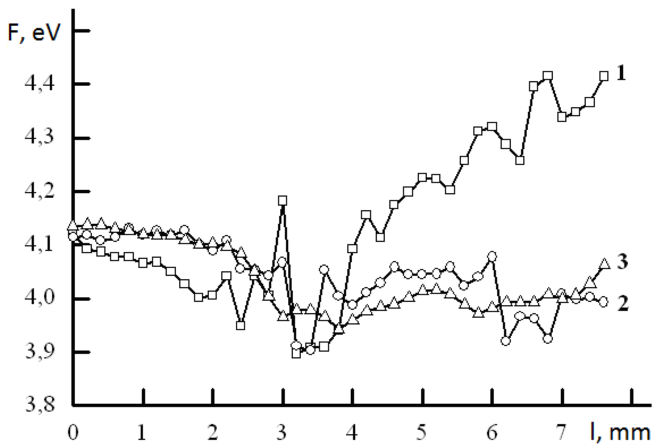

Fig.1. Distribution works of electron output along the surface of standards from the steel KhTN-61 after a wear with different amplitude of the transversal slipping: (*1*) A_{trs} = 0 mm; (*2*) A_{trs} = 0.05 mm; (*3*) A_{trs} = 0,1 mm.

As follows from a Figure 1, state of superficial layer standards alloy of KhTN-61 before the friction approximately identical and WEO is determined about 4.1 eV. As a result of friction with different amplitude of the transversal slipping the state of superficial layer standards changed. A friction with a two-dimensional loading (A_{trs} = 0) results in the receipt of superficial layer with enhanceable and large variation of WEO from 3.90 to 4.40 eV. It is possible to suppose that the new structural state of surface, near to amorphous, attended with the increase of WEO, is.

A presence and increase amplitude of the transversal slipping result in diminishing of size and variation of WEO. At tests on a friction with A_{trs} = 0,05 mm of WEO droningly diminishes from 4.10 to 4.00 eV, variation in the values of WEO here makes the interval of 3.90…4.10 eV. Superficial layer of standards after a friction with a three-component loading with A_{trs} = 0,1 mm provides WEO from 3.95 to 4.05 eV. The increase amplitude of the transversal slipping results in diminishing dispersion of WEO specifies on the increase homogeneity of the structural state superficial layer, which is accompanied by the decline of wearproofness.

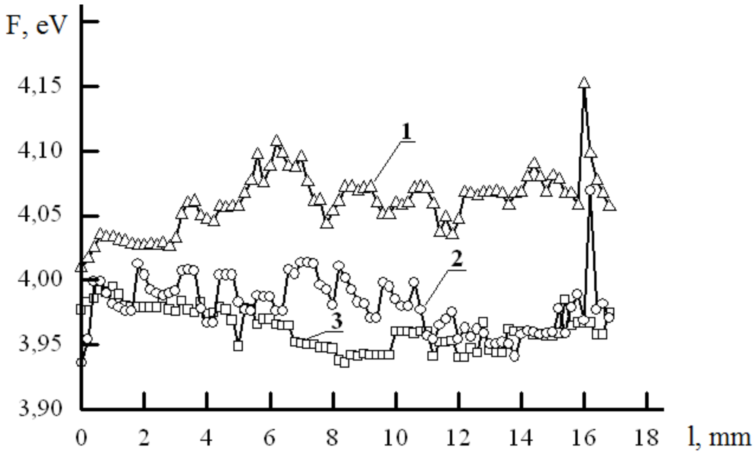

Fig.2. Distribution works of electron output along the surface of standards from the steel 60S2A after a wear with different amplitude of the transversal slipping: (*1*) A_{trs} = 0 mm; (*2*) A_{trs} = 0.06 mm; (*3*) A_{trs} = 0,2 mm.

Analogical results were got for standards from steel of brand of 60S2A (see Figure 2). Enhanceable by volume intensity of wear is marked at presence of the transversal slipping and characterized by the increase of homogeneity superficial layer, decline size of WEO.

Decline of WEO at the increase amplitude of the transversal slipping it is possible to explain as follows. At tests on a friction under act of external variables tensions takes place origins of dislocations that move in the systems of skidding. Part from them outcrops metal and dislocation steps appear. It is known that these steps carry an electric charge and, consequently, form electric doublets. The increase of amount doublets distributions results in diminishing of WEO and decline wearproofness of the investigated surfaces. In the deformed material at a difficult dynamic loading a basic role is played by interaction of dislocations that appear at the shock loading and as a result of cyclic deformation. It results in difficulty of plastic deformation and conditions are created for the facilitation of origin of fragile crack.

Conclusions

Presently plenty of different technological methods to increase resource and reliability of work parts of machines are used in practice. However, their application is not always possible. Most often, the expected efficiency is not ensured due to the lack of formation of optimal parameters of the surface layer during the manufacture or operation of parts.

Work of electron output can be used for research of electronic structure of surface. Deformation of metals at a friction with the different terms of contact results in structural alterations, certain microgeometries of surface, and accordingly to the change of power relief of surface. Comparing initial power relief before deformation with relief after deformation it is possible to define areas surfaces that got different degree of plastic deformation.

Expansion of practical application of results estimation size of WEO domain maybe by control of wearproofness tribojoints, which exploited in the conditions of difficult dynamic loading with the presence of vibrations operating in different directions. Possibility to promote efficiency appears of estimation wearproofness with to confront the change of the structural state of superficial layer of details tribojoints.

This makes it possible to purposefully develop (or choose from among the existing ones) highly efficient structural and technological methods of increasing the performance of parts in extreme conditions, to create designs of new friction devices and significantly reduce the time of their production.

In this case, it is possible to derive and analyze the friction and wear characteristics of a pair’s materials, evaluate friction pairs by comparison, and physically model the processes in actual tribocouplings.

Our further work will consist in the development of a technique for measuring the WEO on the surface of machine parts.

REFERENCES

1. Makeeva O.V., Oleshko V.S., Fedorov A.V., Yurov V.M. Development of a device for determining work electron output. *Eurasian Physical Technical Journal*. 2020. No.1, pp. 127 – 131.

2. Yurov V.M., Oleshko V.S. The impact of the environment on the contact potential difference of metal machine parts. *Eurasian Physical Technical Journal*. 2019. Vol. 16, No.1 (31), pp. 99 – 108.

3. Kim V.A. *Self organization of is in the processes work - hardening, friction and wears of toolpiece.* Vladivostok, Dalscience, 2001, 203 p. [in Russian]

4. Shejko S., Sukhomlin G., Mishchenko V., Shalomeev V., Tretiak V. Formation of the Grain Boundary Structure of Low-Alloyed Steels in the Process of Plastic Deformation. *Materials Science and Technology Conference and Exhibition, MS and T,* 2018, Part 1, pp. 746 – 753.

5. Mashkov Yu. T. *Tribophysicist of metals and polymers*. Omsk, OmGTU, 2013, 240 p. [in Russian]

6. Eremin E.N., Yurov V.M., Guchenko S.A. Wear resistance and tribological properties of high entropy coatings CrNiTiZrCu. *Eurasian Physical Technical Journal*. 2020. No.1, pp. 13 – 18.

7. Yurov V.M., Laurinas V.Ch., Gurchenko S.A., Vertyagina E.N., Zavatskaya O.N. *Structure and properties of multiphase ion-plasma coverages*. Karaganda, 2012, 148 p [in Russian]

8. Markov A.A. Change work of electron output at a friction. *Electric phenomena at a friction, cutting and greasing of hard tel*. 1973. pp. 28-34. [in Russian]

9. Zadumkin S.N., Egiev V.G. Work of output and superficial energy of metals. *Physicist of metals and physical metallurgy*. 1966**.** Vol. 1, No 2, pp. 121-122. [in Russian]

10. Shpenkov G.P. *Physikochemistry of friction*, Minsk, BGU, 1978, 208p. [in Russian]

11. Tsyganov V., Ivschenko L., Byalik H., Mokhnach R., Sakhniuk N. Creation of wearproof eutecticum composition materials for the details of the high temperature dynamic systems. *MS and T 2019 - Materials Science and Technolog*. 2019. pp. 450-456.

12. Tsyganov V., Naumik V., Ivschenko L., Byalik H., Mokhnach R. Steel-copper nano composited materials. *MS and T 2019 - Materials Science and Technology*. 2019. pp. 439-443.

13. Tsyganov V.V., Mokhnach R.E., Sheiko S.P. Increasing Wear Resistance of Steel by Optimizing Structural State of Surface Layer, *Steel in Translation*. 2021. Vol.51, No.2, pp.144-147.

14. Tsyganov V.V., Sheyko S. Features of engineering the wear-resistant surface of parts with the multicomponent dynamic load, *Wear*. 2022. 494-495, 204255.

15. Ivshenko L.I., Tsyganov V.V., Zakiev I.M. Features of the wear of tribolojoints under three-dimensional loading, *Journal of friction and wear*. 2011. Vol. 32, No.1, pp.8–16.

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