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Wear Resistance Criteria for Various Types of Wear

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Abstract. The behavior of the material under cavitation and abrasive wear is considered. An analysis of easily determined wear resistance criteria is given. It has been shown that the resistance of metals to fracture under micro-impact loading is determined not by ordinary mechanical characteristics, but by the strength of individual micro-sections or structural components. And with cavitation erosion, corrosion makes a significant contribution, which is not taken into account when determining mechanical characteristics. The prospects for assessing the erosion resistance of materials using energy criteria are shown, since their specific values depend on factors characterizing the system that is under external influence: the stress state pattern of the wear layers, the deformation rate, the micro- and submicrostructure of the deformed volumes, as well as the cyclic of the external loading.

Keywords: abrasive (hydroabrasive) wear, cavitation erosion, wear resistance criterion, energy criterion, material destruction, structure of materials

Introduction

Cavitation, abrasive, and water-abrasive wear is one of the reasons for reducing the reliability of ship equipment, turbine blades of power plants, various pumping equipment, internal combustion engine parts and aircraft.

The criteria for the wear resistance of materials during cavitation, abrasive (water abrasive) wear are taken, both individually and in complexes, to be the mechanical, physicochemical and other properties of deformable volumes of materials, which (according to some scientists) best resist the destructive effects of the external environment on them [1-3] .When studying the patterns of these types of wear, numerous attempts were made to establish the relationship between wear and the properties of wear materials. At the same time, it was proposed to use a significant number of simple, easily determined and more complex parameters as a criterion for wear resistance.

Depending on the level of energy of external influence during wear, the wear resistance of samples with different hardness, even of the same grade of steel, not to mention materials with sharply different microstructures, can depend on various mechanical properties: hardness and the ratio of tensile strength to yield strength: H and $\sigma_u/\sigma_{0.2}$, elastic modules E and G, etc. However, none of these characteristics, as well as indicators of standard plastic properties, unambiguously determine the wear resistance of materials in a fairly wide range of changes in external energy levels. Considering the comparative simplicity of determining the standard mechanical properties of materials, such a characteristic as hardness H can be used as a particular criterion for assessing wear resistance for known levels of external loading energy for materials that are similar in microstructure and properties.

Studies have shown that in materials with different hardness and microstructure, the processes of accumulation of specific energy E_u, sufficient for the destruction of deformable volumes, have their own characteristics. Irreversible structural changes preceding the stage of preliminary destruction will occur through various mechanisms [4]. And the depth of the plastically deformed zone, according to modern physical and mechanical models, determines the large-scale levels of deformation and subsequent destruction (wear) of materials.

If we consider abrasive (water abrasive) wear and cavitation erosion, then they have a lot in common. Cavitation creates high pressures on wear surfaces and causes complex physical and chemical processes. What is common is the cyclical and dynamic nature of external loading, the locality of elastic-plastic deformations in zones of impact of abrasive particles and micro-jet of liquid, the random (stream) nature of external influence and the wave nature of energy transfer in deformable material objects.

1. Research methodology

A general criterion for wear resistance should take into account the characteristics of the destruction of materials under single and repeated external force, take into account the effects associated with the pulsed nature of loading, be sensitive to structural changes occurring in materials with different microstructures during wear and, finally, should reflect the uniform saturation of the wear layers internal energy. In this formulation of the problem, expressing the general criterion in analytical form is extremely difficult. However, modern achievements in metal physics, fracture mechanics of continuous media, dislocation theory and a number of other sciences, together with physical and mechanical research methods, now make it possible to approach the solution of this problem.

2. Results and discussion

In order to identify conditions sufficient for the onset of cavitation erosion, a series of samples made of soft materials ($\sigma_т \leq$ 300 MPa) were tested: steel 1010, 1015, alloys based on aluminum composition (Al + 5.4% Mg) and tin bronze composition (Cu +7% Sn+5% Zn) on impact erosion stand at a speed of impact of a water jet with the surface of the samples $\vartheta \leq$ 40 m/s. For the above materials, criterion dependence was established:

$$\vartheta_i \sim \vartheta_{cr} = 0{,}53\sqrt{\sigma_m}, \quad (1)$$

in which ϑ_{cr} is the jet speed, less than which there is no erosion on the surface of the material, and the jet pressure corresponds to the surface fatigue limit.

Raising the right and left sides of the last relation to the third power and considering the proportionality

$$\vartheta_{cr}^2 \sim E_u \sim \sigma_{0.2}$$

to be valid, were E_u - specific energy intensity, we obtain the relations:

$$\Delta V \sim \vartheta_i^3 / \sigma_{0.2} \cdot \vartheta_{cr} \sim E_{in} \cdot \vartheta_i / E_u \cdot \vartheta_{cr}, \quad (2)$$

which indicate the prospects of using structural and energy criteria for the wear resistance of materials for any type of erosion.

The condition for the onset of cavitation-erosive wear during hydrodynamic cavitation, obtained earlier [5] in the form of a relation:

$$K_E = \rho_t / 0{,}5\rho_l \cdot \vartheta_x^2 = const, Re^{1/3} \ , \quad (3)$$

where K_E is the number of beginning erosion; ρ_l is the fluidity pressure of the material during cavitation pulses; Re is the Reynolds number, by analogy it is easily converted into a fairly accurate wear equation, which, in contrast to (1), takes into account the friction path of the fluid flow along the wear surface to the power of 0.5, i.e. $\sqrt{L_{fr}}$, which is consistent with the damped nature of the kinetic curves of cavitation erosion of materials observed in practice.

After taking into account the friction path, volumetric losses of materials are determined by the equation:

$$\Delta V \sim E_{in} \vartheta_i \, L_{fr}^{1/2} / E_U \vartheta_{cr} \ , \quad (4)$$

The validity of expression (3) is confirmed by the results of numerous experimental studies, in particular, works [6,7] and [5], which indicates the correctness of energy relations (2) and (3).

Attempts to connect the amount of cavitation wear with one of the mechanical characteristics of materials should be considered unsuccessful.This is explained, on the one hand, by the fact that the resistance to metal destruction under micro-impact loading is determined not by ordinary mechanical characteristics, but by the strength of individual micro-sections or structural components, and on the other hand, by the fact that during cavitation exposure in aggressive environments, along with the mechanical factor, the wear process can have a great influence on the corrosion factor, which conventional mechanical characteristics do not take into account.

Considering the direct dynamic penetration of a spherical abrasive particle into a less hard wear material and considering the volume of holes formed per unit time on a deformable surface to be directly proportional to the volume of wear products, it is not difficult to obtain an approximate expression for estimating volumetric wear.

$$\Delta V \sim \left(\frac{E_{in}}{p_Y}\right)^{3/2} \cdot \frac{(\pi D_a)^{1/2}}{A_N} \cdot N \ , \quad (5)$$

whereE_{in} - energy of an individual abrasive particle with diameter D_a;

p_Y– dynamicyield pressure of the material;

A_N– nominal contact area at maximum penetration particles;

N – number of impacts of abrasive particles.

The denominator of equation (5) contains the specific energy of deformation, which is proportional top_Y - dynamic yield pressure of the material. Therefore, the relative wear resistance of metals under the impact of abrasive particles can be determined by the relation:

$$k_{\Delta V} = \frac{\Delta V_{ref}}{\Delta V_i} = \left(\frac{E_{Ui}}{E_{Uref}}\right)^{3/2}, \quad (6)$$

whereE_u is the specific energy of deformation; indices *i*and *ref*to the test and reference material respectively.

Comparing the result obtained in Figure 1 with the experimental data given in [8-11], one can be convinced that the wear resistanceof carbon tool steel (0.7%C) and alloy wear-resistant steel during impact-abrasive wear depends on the specific energy intensity, to the power of 3/2.

Considering that the speed and impact energy are interrelated and at the same time, expression (5) with linear wear kinetics can be given the following form:

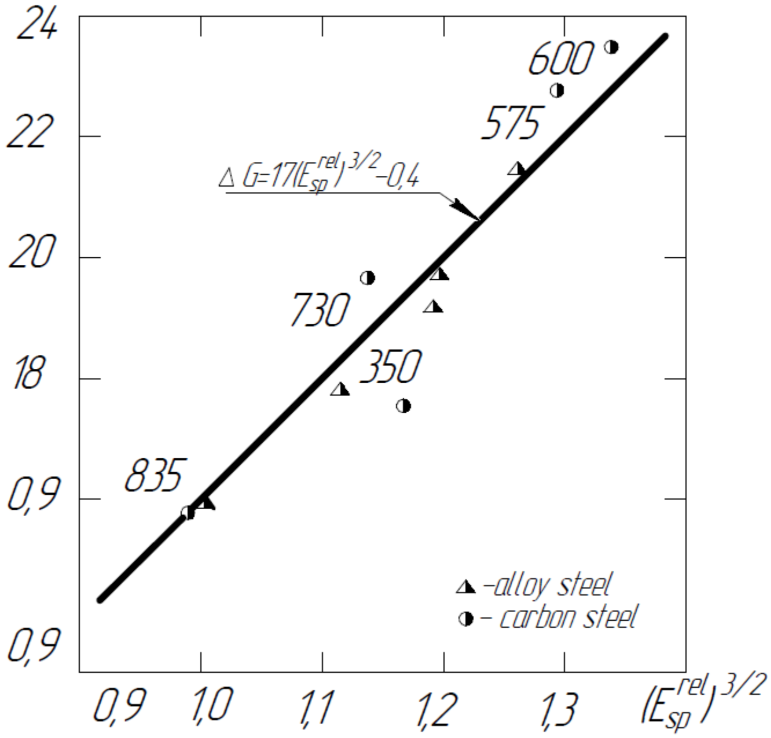
$$\Delta V = const_3 \frac{E_{in}\vartheta}{E_U \vartheta_{cr}} N, \tag{7}$$

whereϑ_{cr} - critical speed of blow causing destruction of material at N_{cr} = 1 in specific conditions of tests;

E_U – the critical strain power density characterizing wear resistance of materials;

N – number of external dynamic actions.

Wear ΔG^{-1},1|g



Specific energy intensity, $(E_U^r)^{3/2}$

Fig.1. – Dependence of wear resistance of steels during impact-abrasive wear of carbon tool steel when tested on the ST-4 sclerometer [6] and alloy wear-resistant steel on the MINE and GP installation [4]. Near the experimental points, the hardness of the samples is Vickers

Conclusions

Thus, an analysis of modern ideas about the criteria for wear resistance of materials and dependencies [5-7] indicate the prospects of developing a structural-energy model of water-abrasive wear.

It seems quite reasonable and promising to use specific energy intensity and latent energy of hardening as parameters that determine the wear resistance of materials, since their specific values depend on the pattern of the stress state of the wear layers, the rate of deformation, the micro- and sub microstructure of the deformed volumes, as well as on the cyclic of external loading.

Numerical values of the energy criterion for wear resistance of materials can be obtained in two ways:

- as a result of determining the limiting properties of materials and the degree of energy saturation of wear layers;

- when determining the properties of materials averaged by wear volumes, for example, micro hardness and degree of plastic deformation, reflecting the state of these volumes under specific external loading conditions with a steady wear process.

It should be noted that over the past few decades, the search for sufficiently physically based, objective and workable criteria for wear resistance and durability of materials has not been successful. This means that at present there are no reliable methods for calculating the behavior of materials under abrasive and cavitations' erosion. A similar situation occurs with other types of wear. These unsolved problems, as before, force us to use the results of labor-intensive and, as a rule, expensive laboratory and bench tests.

A general criterion for wear resistance should take into account the characteristics of the destruction of materials under single and repeated external force, take into account the effects associated with the pulsed nature of loading, be sensitive to structural changes occurring in materials with different microstructures during wear and, finally, should reflect the uniformity of saturation of wear layers internal energy.

It seems quite reasonable and promising to use a structural-energy model of cavitation and water-abrasive wear, the parameters of which depend on the pattern of the stress state of the worn layers, the rate of deformation, the micro- and sub microstructure of the deformed volumes, as well as on the cyclic of external loading.

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