***Problems of Tribology**, V. 29, No 4/114-2024, 6-13*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2024-114-4-6-13

Influence of the shape of abrasive soil particles on the regularities of destruction of structural steels during wear

V.I. Dvoruk

State University "Kyiv Aviation University", Kyiv, Ukraine
E-mail: vidvoruk@gmail.com

Received: 05 September 2024: Revised: 25 September 2024: Accept: 05 October 2024

Abstract

The article presents the results of studying the patterns of destruction and their influence on the wear resistance of structural steels: steel 45, steel 65G and steel 28MnB5 when moving in soils with different abrasive particle shape factors. The phenomenon of the presence of a critical abrasive particle shape factor (CPSF) was established, up to which the wear resistance of steels decreases. In the supercritical region, wear resistance is stabilized, and the differences between its values of the studied steels are significantly reduced. When forming wear resistance, the role of the particle shape factor is to regulate active deformation and fatigue phenomena by means of the level of external force action on the working surface and is realized through the rheological-fatigue parameter, which is controlled by the cyclic viscosity of steel deformation. In this regard, the choice of structural steel grade for the manufacture of machine parts intended for use in soils with different abrasive particle shape factors must be made based on its ranking by the rheological-fatigue parameter. It is shown that in the strength basis of the steel wear mechanism under sliding friction in soils with different particle shape factors, in addition to the resistance to the propagation of axial and radial fatigue cracks in the destructive deformation layer, an important role is played by the resistance to the initiation and propagation of lateral fatigue cracks at its boundary with the plastic-destructive deformation layer, and the mechanical component of the contact interaction is decisive. It is established that under wear in soils with different particle shape factors, the action of the softening process is more effective than the hardening process. In the supercritical region, the intensity of steel softening is significantly reduced due to the increase in the effectiveness of the hardening action due to the dispersion hardening of steel. However, no qualitative changes in the metal wear process are observed.

Key words: abrasive wear, soil, abrasive particle shape factor, fatigue, destructive deformation, plastic-destructive deformation, fatigue crack, wear resistance, rheological parameter, rheological-fatigue parameter, fracture toughness, size of the region of nonlinear effects, cyclic deformation toughness, softening, hardening, dispersion hardening.

Introduction

When machine parts and tools move in a soil environment containing an abrasive, intensive wear of the metal occurs, accompanied by a rapid change in their geometric dimensions and shape.

The reason for the high aggressiveness of this type of wear is the specific process of contacting the abrasive, in which not every particle on the friction surface is capable of interacting with the metal, and the speed of relative movement of the particles is significantly less than the translational speed of the part. In addition, most of them have a rounded shape and, making a complex movement, can not only slide at high speed, but also rotate or roll along the friction surface until they take a more stable position in relation to it, as well as to each other. In this regard, it is advisable to consider the soil environment as a solid body with a very rough surface (where the role of irregularities is played by abrasive particles) and a mobile active layer [1]. Experiments have shown that when interacting with the friction surface, the abrasive particles of the active layer of such a body are pressed into the metal with a certain force and move progressively along its surface. Particular attention should be paid to the fact that both of these stages of interaction of the abrasive with the surface occur simultaneously, which significantly complicates its nature. The destruction of the surface is carried out both by the micro-cutting and deforming action of the particles. Micro-cutting particles directly produce wear, but there are relatively few of them (0.07 - 7% of the total). Deforming particles, the pressure of which on the contact area brings the worn metal to the yield point, are significantly more numerous. They do not directly produce wear, but multiple deformation of the same surface areas contributes to their fatigue destruction. Based on this, the leading form of abrasive wear of the friction surface when moving in the soil is mechanical fatigue by the mechanism of low-cycle and high-cycle fatigue [2]. The process of destruction from fatigue, which precedes the formation and separation of wear particles, includes the stages of nucleation and propagation of fatigue cracks in microvolumes of the deformed surface layer of the metal. Therefore, it should be considered as a kinetic process that predetermines the formation of two qualitatively different zones in the area of each crack: the zone of the inner surface of the crack and the zone of nonlinear effects in the vicinity of its tip. Based on the change in the stress-strain state with distance from the surface, the structure of the surface layer of the metal has a layered structure, including the following layers: a layer of destructive deformation, consisting of an outer (cracked) sublayer and an adjacent sublayer of nonlinear effects in the vicinity of the crack tips; a layer of plastic-destructive deformation; a layer of plastic deformation; a layer of elastic deformation, passing into undeformed metal [2]. The cracked sublayer contains the largest defects in the form of axial and radial microcracks, as well as the centers of their origin, i.e. the connection between individual microvolumes in it is weakened due to the violation of the continuity of the metal. The sublayer of nonlinear effects is a plastically deformed metal localized in the areas of crack propagation. Thus, the destructive deformation layer obeys not the laws of continuum mechanics, but the laws of solid-body fracture mechanics and, due to its "looseness", has the lowest strength. Inside the adjacent layer of plastic-destructive deformation, a rotational fragmented structure and rare microcracks, reflecting the disclination nature of deformation, predominate. In the deformation mechanism located below the layer of plastic deformation, the leading role is played by linear and point defects of the crystalline structure, forming a structure of predominantly dislocation type. In terms of its structure, the elastically deformed layer is practically no different from the undeformed metal bordering it.Such a structure indicates the simultaneous occurrence of two independent processes in each of the layers - deformation and destruction [3]. These processes are realized in dialectical unity: deformation does not happen without destruction, and destruction - without deformation. The relationship between them changes with an increase in the depth of the layer from the surface. Thus, in the layer of destructive deformation, destruction processes predominate, plastic-destructive deformation - large plastic deformations, plastic deformation - moderate plastic deformations, and elastic deformation - elastic deformations. The specified relationship is controlled by changes in the level of acting stresses as they penetrate deeper into the surface layer and depends on the physical characteristics of the metal, in particular the rheological-fatigue parameter [2]. Among the factors determining the destruction of the metal surface layer during wear in the soil, an important role is played by the shape acquired by the abrasive particles during the natural formation of sand. For the quantitative assessment of this factor, various variants of the shape coefficient K_F have been proposed [4-6] - a criterion whose values vary from 11 for rounded particles to 100 for acute-angled particles measuring 0.2 - 2 mm. The value of K_F, on the one hand, determines the probability of particle contact with the wear surface along a protrusion of a small radius of curvature, and on the other hand, the degree of deviation of its shape from spherical (the latter affects the degree of particle fixation in the mass of particles - its temporary retention in a motionless state with respect to the surrounding particles). The level of contact stresses and, consequently, the type of surface destruction depend on these indicators. Thus, at $K_F \leq 11.25$ direct destruction of the material does not occur. With further increase of K_F a gradual transition from plastic deformation to direct destruction of the material occurs, which occurs at $K_F \geq 45$. It has been established [4-6] that with increase of K_F the intensity of wear of metal in the soil environment increases. The initiation and propagation of fatigue cracks in metallic materials is caused by plastic deformation, the quantitative measure of which can be the width of the hysteresis loop (cyclic viscosity of deformation) per cycle of change of load at a given level of stresses [7]. The regularities of change of cyclic viscosity of deformation allow us to come to the conclusion that cyclically repeating alternating stresses during wear cause in each of the layers of the surface layer of metal two simultaneously proceeding opposite processes: strengthening and softening.

Materials and research methods

The objects of the study were structural steels: steel 45, steel 65G and steel 28MnB5, the chemical composition of which is presented in Table 1.

Table 1

Chemical composition of the investigated steel

Steel grade	Content, %									
	C	Mn	Si	P	S	Cr	Ni	Cu	B	As
65G	0,65	1,11	0,27	0,035	0,035	0,25	0,25	0,22	-	-
28MnB5	0,272	1,26	0,234	0,020	0,035	0,22	-	-	0,0023	-
45	0,46	0.65	0.27	0.035	0.04	0.25	0.25	0.25	-	0.08

Samples from the specified steels were made in the form of plates with dimensions of (70×70×6) mm and subjected to strengthening by heat treatment in the modes specified in Table 2.

The heating source during maintenance was an electric muffle furnace SNOL7.2/1300 (NPP Termoinzhenering, Kharkov).

Table 2

Mode of heat treatment of investigated steels

Steel grade	Hardening			Tempering	
	Heating temperature, °C	Holding time, min	Hardening environment	Heating temperature, °C	Holding time, min
65G	820	30	Oil	470	60
28MnB5	900	30	Oil	500	60
45	850	30	Water	550	60

The hardened samples were subjected to indentation and wear tests by friction in the soil.

Indentation tests were carried out using a universal hardness tester "NOVOTEST T-UD2" (OOO NTC "Industrial Equipment and Technologies", Novomoskovsk). As a result, the Rockwell hardness of steel in the initial state was determined.

Wear tests of steel by friction in the soil were carried out using a modernized "impeller" method on a test rig [8], the diagram of which is shown in Fig. 1

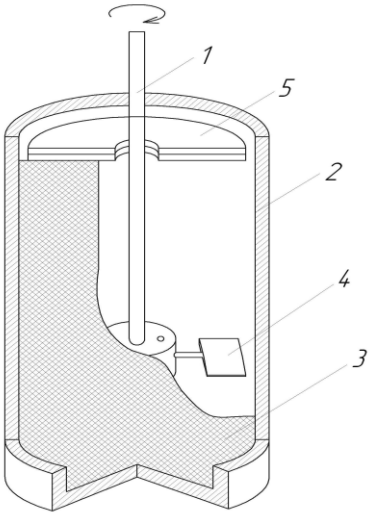

Fig. 1. Diagram of a setup for testing steel for wear when friction in soil: 1 - sample holder shaft; 2 - cylinder; 3 - soil; 4 - samples; 5 - mogosection disk

The essence of the tests consisted in rotating a steel sample immersed in the specified soil. The test mode is as follows: soil pressure on the sample P = 122.6 kPa, sample rotation speed V = 125.28 m/min, sample friction path L = 500 km. During wear, the friction force Ftr of the sample was measured. Sample wear G was measured by weighing on an electronic analytical scale CP 34001 S (Sartorius (Germany)). The measure of wear resistance ε was the reciprocal of wear G.

Quartz sand from three deposits in the Zhytomyr region of Ukraine - Tarasovskoye, Ignatpolsky and Irshansky - was used as soil, from which particles of a fraction of 0.5 - 1.0 mm were isolated by sifting through a sieve. The hardness of the particles was 1000 - 1300 kg / mm2. The particle shape coefficient K_F was calculated using the formula [6]. The geometric parameters of the particle required for this are shown in the diagram (Fig.2).

Для оценки указанных параметров частицы помещали под микроскоп «SIGETA CAM-03, фотографировали, после чего производили требуемые измерения с привлечением программы «КОМПАС-3D».

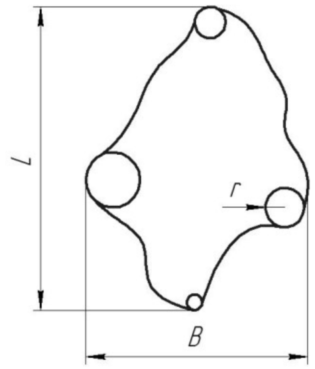

Fig. 2. Geometric parameters of the abrasive particle: L – the largest value of the longitudinal size; B – the largest value of the transverse size; r – protrusion

The analysis of the process of steel destruction during wear in soil was carried out using the following criteria: critical stress intensity factor (fracture viscosity) K_{1c}, size of the region of nonlinear effects in the vicinity of crack tips h_p, rheological parameter $R = K_{1c} / h_p$, cyclic deformation viscosity $\Delta\varepsilon$, as well as true deformation ε_{true}, which were determined by the methods [3, 9]. Using the specified characteristics, the rheological-fatigue parameter of the studied steels $R_f = R\ (\varepsilon\_{true} /2\ \Delta\varepsilon)^2$ [10] was determined. The obtained experimental results were processed using the methods of mathematical statistics.

Research results and their discussion

The valuesof the shape coefficient of abrasive particles of the studied soils are presented in Table 3.

Table 3

Shape coefficient of abrasive soil particles

Sand deposit	Irshanskoe	Tarasovskoye	Ignatpolskoe
Shape coefficient	98,71	114,18	153,72

Data on changes in the tribomechanical and rheological properties of the studied steels in soils with different shape factors of abrasive particles are presented in Table 4.

Table 4

. Dependence of tribomechanical and rheological properties of steels on the shape factor of abrasive particles

Steel grade	Sand deposit	Shape coefficient, K_F	Tribomechanical properties		Rheological properties	
			Hardness, *HRC*	Wear resistance, ε, kg^{-1}	Rheological parameter *R*, GPa	Rheological-fatigue parameter R_f, TPa
45	Irshanskoe	98,71	8	58,8	1,82	20,5
	Tarasovskoye	114,18	8	46,5	1,82	16,27
	Ignatpolskoe	163,72	8	35,1	1,82	12,3
65G	Irshanskoe	98,71	40	133,3	4,94	126,5
	Tarasovskoye	114,18	40	71,4	4,94	67,63
	Ignatpolskoe	163,72	40	42,6	4,94	40,12
28MnB5	Irshanskoe	98,71	50	200	6,9	265,24
	Tarasovskoye	114,18	50	100	6,9	132,37
	Ignatpolskoe	163,72	50	55	6,9	74,23

By comparing the shape factor K_F and wear resistance ε, the following inversely proportional correlation dependence was established (Fig. 3): with an increase in the particle shape factor, the wear resistance of the steels under study decreases. Moreover, in stronger steels (steel 28MnB5, steel 65G) this occurs much more intensively than in the less strong steel 45

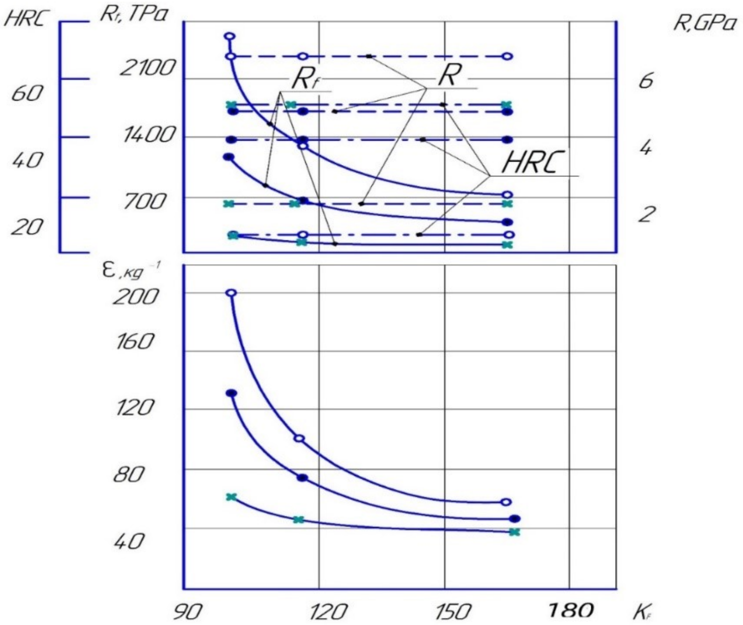

Fig. 3. Comparison of wear resistance (ε) with hardness (*HRC*), rheological parameter (*R*) and rheological-fatigue parameter (R_f) of steels after wear in soils with different shape coefficients of abrasive particles ($К_F$): × - steel 45; ● - steel 65 G; ○ – steel 28MnB5

A significant decrease in wear resistance is observed until the shape factor reaches a value of the order of $K_F \approx 140$-150, after which a clear tendency towards stabilization of the indicated pattern is observed. In addition, with an increase in the particle shape factor, a gradual convergence of the wear resistance of steels takes place. For example, if at $K_F = 98.71$ the wear resistance of steel 28MnB5 was 3.4 times higher than that of steel 45, then at $K_F = 153.72$ - 1.6 times. Consequently, during wear in soils with different shape factors of abrasive particles on the working surfaces of steels, the phenomenon of the presence of a critical shape factor of abrasive particles (CPSF) is realized, the value of which is 140 - 150.

Analysis of the obtained results showed that the characteristics of resistance to deformation (hardness HRC) and destruction (rheological parameter R) under static loading do not show sensitivity to the formation of wear resistance of steels when moving in soils with different shape factors of particles. At the same time, between the characteristic of resistance to destruction under fatigue loading - the rheological-fatigue parameter R_f and wear resistance ε as K_F of particles increases, the following correlation is established: the higher the particle shape factor, the lower the rheological-fatigue parameter and wear resistance of steel. Consequently, the wear resistance of steels when moving in soils with different shape factors of abrasive particles is controlled by the rheological-fatigue parameter.

Based on the above, it can be stated that in the strength basis of the mechanism of steel wear under sliding friction in soils with different shape factors of abrasive particles, in addition to the resistance to the propagation of axial and radial fatigue cracks in the destructive deformation layer (see above), an important role is played by the resistance to the initiation and propagation of lateral fatigue cracks on its boundary with the layer of plastic-destructive deformation. In this case, the mechanical component of the contact interaction is decisive.

Lateral cracks originate from the boundary of these layers and then grow towards the surface. Their intersection with radial cracks leads to the formation of wear particles [11].

Along with lateral cracks, axial and radial cracks originate at the same boundary, which propagate in the opposite direction - towards the layer of plastic-destructive deformation, thereby gradually transforming it into a destructive layer. It finally becomes destructive after the complete destruction of the layer preceding it. In this way, layer-by-layer destruction of the metal occurs, the result of which is its wear. The immediate cause of localization of the origin of the system of lateral, axial and radial fatigue cracks at the boundary of the destructive and plastic-destructive layers is the state of plane deformation, which occurs here during contact interaction with the abrasive and contributes to an increase in the effective maximum stresses to a level three times greater than at the boundary of the cracked sublayer with the sublayer of nonlinear effects in the vicinity of the cracks [10]. Along with the maximum, residual stresses simultaneously arise and act in the metal due to the unevenness of its deformation. The superposition of these stresses under cyclic action determines the actual load level at the specified boundary. Consequently, the stress distribution curve from the boundary of the cracked sublayer along the depth of the surface layer has a non-monotonic character with a maximum at the boundary of the destructive and plastic-destructive layers.

Based on the proposed mechanism of destruction, it is advisable to rank the wear resistance of structural steels under the conditions under consideration by the rheological-fatigue parameter.

Since the rheological-fatigue parameter includes a number of physical quantities, the patterns of their change during wear, as well as the role of each of them in the formation of steel wear resistance with varying the shape factor of abrasive soil particles, are of scientific and practical interest.

Fig. 4 and 5 show the patterns of true deformation ε_{true} and cyclic viscosity of deformation $\Delta\varepsilon$ (Fig. 4), fracture viscosity K_{1c} and the size of the region of nonlinear effects in the vicinity of crack tips h_p (Fig. 5) of steels with a change in the particle shape factor K_F.

From this it is evident that the true deformation ε_{true} (Fig. 4), fracture toughness K_{1c} (Fig. 5) and the size of the region of nonlinear effects h_p (Fig. 5) of the studied steels are insensitive to changes in the particle shape facto K_F, while the cyclic deformation viscosity $\Delta\varepsilon$ (Fig. 4) increased with the latter.

Comparison of the cyclic deformation viscosity Δε (Fig. 4) with the rheological-fatigue parameter R_f and wear resistance ε (Fig. 3) of steels with variations in the particle shape factor K_F shows the presence of an inversely proportional correlative relationship between them: with an increase in the cyclic deformation viscosity, the rheological-fatigue parameter and wear resistance decrease.

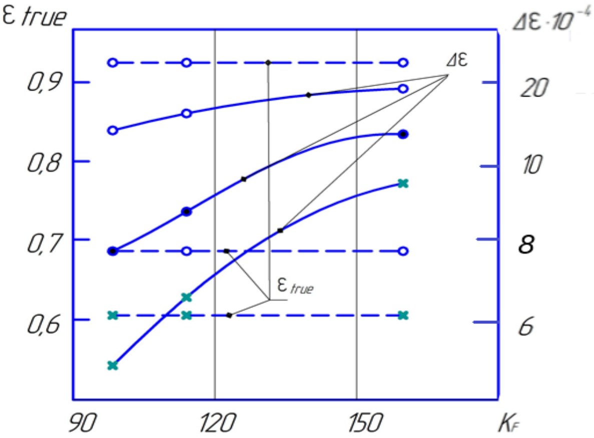

Fig. 4. Change true deformation (ε_{true}) and cyclic deformation viscosity (Δε) of steels after wear in soils with different shape coefficients of abrasive particles (K_F): × - steel 45; ● - steel 65 G; ○ – steel 28MnB5

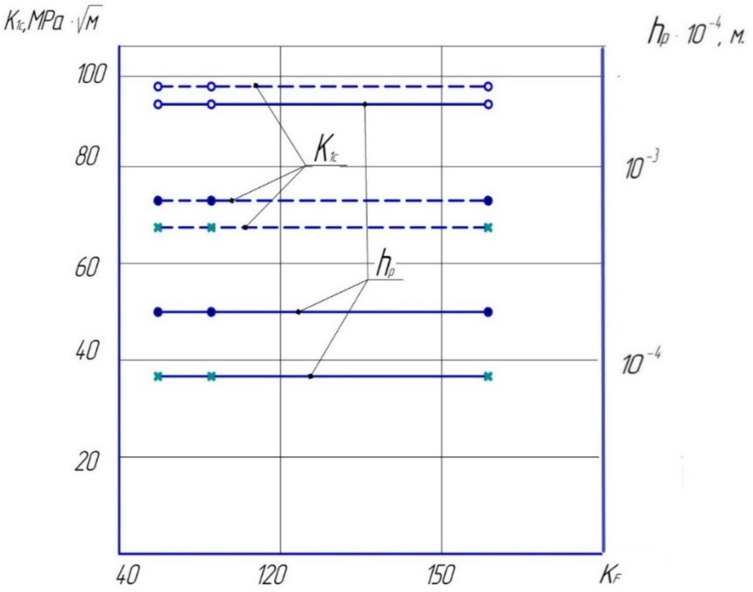

Fig. 5. Change in fracture toughness (K_{1c}) and the size of the area of nonlinear effects in the vicinity of the crack (hn) steels after wear in soils with different shape coefficients of abrasive particles (K_F): × - steel 45; ● - steel 65 G; ○ – steel 28MnB5

Consequently, the leading role in the formation of the rheological-fatigue parameter and wear resistance of steels when moving in soils with different shape factors is played by the cyclic viscosity of deformation, which characterizes the ability of the metal to absorb the supplied energy in an irreversible form and is determined by the parameters of the hysteresis loop, in particular, its width Δε.

Cyclically repeating stresses during abrasive wear cause two simultaneously occurring opposite phenomena in the metal: strengthening and softening. From the established pattern of change in the cyclic viscosity of deformation (Fig. 4), it is evident that with an increase in the shape factor of the abrasive, the value of $\Delta\varepsilon$

continuously increases. This allows us to consider the effect of softening during wear to be more effective than strengthening. The softening process, in this case, occurs as a result of cyclic deformation of the surface layer, leading to the occurrence and development of structural defects, embrittlement of the material, an increase in internal stresses and the opening of microcracks, while hardening is associated with the work hardening factor - the formation of obstacles in the metal that slow down the movement of dislocations.

Noteworthy is the noticeable decrease in the intensity of softening of the metal after reaching the value of the form factor of the order of $K_F \approx 140\text{-}150$. This effect is especially clearly manifested in strong steels 28MnB5 and 65G. It is explained by an increase in the effectiveness of the hardening action due to factors that complement the work hardening. For steel 45, such a factor is most likely dynamic strain aging (DSA) - blocking of dislocations due to diffusion of carbon and nitrogen atoms to them, and for steels 28MnB5 and 65G - dispersion hardening (DH), caused by partial decomposition of martensite, as well as white layers of thermomechanical origin, consisting of martensite and its decomposition products, residual austenite, carbides, nitrides, oxides.

Due to the high hardness of the martensite base, plastic deformation of strong steels during wear cannot be significant, as a result of which, it is not capable of causing significant strain hardening and dynamic strain aging. Therefore, the main type of strengthening of steels 28MnB5 and 65G, in all likelihood, is dispersion hardening. Despite the decrease in the intensity of destruction under the influence of the indicated factors of additional strengthening, qualitative changes in the wear process of steels are not observed (Fig.3).

Conclusions

1.When worn in soils with different abrasive particle shape factors on the working surfaces of low-alloy steels, the phenomenon of the presence of a critical abrasive particle shape factor (CPSF) is realized, up to which the wear resistance of steels decreases. With a further increase in the particle shape factor, the wear resistance stabilizes, and the differences between its values of the studied steels are significantly reduced.

2. The role of the particle shape factor in the formation of wear resistance lies in the regulation of active deformation and fatigue phenomena in the surface layer by changing the level of external force action on the working surface.

3. The influence of the soil particle shape factor on wear resistance is carried out through the rheological-fatigue parameter in the following relationship: the higher the rheological-fatigue parameter, the higher the wear resistance of the steel.

4. In the strength basis of the steel wear mechanism under sliding friction in soils with different particle shape factors, in addition to the resistance to the propagation of axial and radial fatigue cracks in the destructive deformation layer, an important role is played by the resistance to the initiation and propagation of lateral fatigue cracks at its boundary with the plastic-destructive deformation layer, and the mechanical component of the contact interaction is decisive.

5. When selecting a grade of structural steel for the manufacture of machine parts operated in soils with different abrasive particle shape factors, it is necessary to be guided by its ranking by the rheological-fatigue parameter.

6. The role of the particle shape factor in the formation of the rheological-fatigue parameter is carried out mainly through the cyclic viscosity of deformation in the following relationship: the higher the cyclic viscosity, the lower the rheological-fatigue parameter of steel. The effect of the softening process during wear in soils with different particle shape factors is more effective than the hardening process. In the supercritical region of the abrasive shape factor, the intensity of softening of steels is significantly reduced due to the increase in the effectiveness of the hardening action due to the dispersion hardening of steel. However, no qualitative changes in the process of metal wear are observed.

References

1. Dvoruk V. I., Borak K. V., Buchko I. A. Destruction of Steel, by the Work-Hardened Speed Electrothermal Treatment at Wear by Friction of Skidding at the Non-Rigid Envisaged Abrasive // Journal of Friction and Wear, 2022, Vol. 43, No. 3, pp. 255–264

2. Dvoruk V. I., Borak K. V., Buchko I. A., and N. A. Kirienko N. A. Influence of Soil Type on Breaking of Low-Alloy Steels during Wear // Journal of Friction and Wear, 2022, Vol. 43, No. 6, pp. 383–390

3. Dvoruk V. I. Scientific bases for increasing abrasive resistance of machine parts. — Kyiv: KMUHA, 1997. 101 p.

4. Tadolder Yu.F. Influence of the geometry of the abrasive grain on the intensity of metal extraction in the flow of abrasive particles. Proceedings of the Tallinn Polytechnic Institute, Ser. A.1966. 237. P.15-22.

5. Tenenbaum M.M. Resistance to abrasive wear, 1976. 271 s.

6. Bernshtein D.B., Kysetova N.Y., Sorkyna E.M., Sheko Y.B. Macrogeometry and wearing capacity of soil abrasive particles. Friction and wear. 1992.13, No2. P. 333-339.

7. Ivanova V.S. Fatigue failure of metals. 1963. 272 p.

8. V.I. Dvoruk.A method for examining materials and rotating them for wear resistance and determining the coefficient of wear and tear of an abrasive mass.: pat. 142596 Ukraine, G01N 3/00; № u2019 02358; publ. 25.06.2020. Biul. № 12

9. Dvoruk, V. I. (2018). A method of abrasive wear is for determination of superficsal energy of crystals. Problems of Tribology, 90(4), 22–31. https://tribology.khnu.km.ua/index.php/ProbTrib/article/view/686

10. Dvoruk, V. (2015). Modeling of metals wear when driving in abrasive mass. Problems of Tribology, 75(1), 77–85. https://tribology.khnu.km.ua/index.php/ProbTrib/article/view/449

11. Lown B.R. A model for the wear of brittle solids under fixed abrasive conditions // Wear, 1975, Vol.33, No.2, pp. 309-372

Дворук В.І. **Вплив форми абразивних частинок грунту на закономірності руйнування низьколегованих сталей при зношуванні**

Наведено результати вивчення закономірностей руйнування та їх впливу на зносостійкість конструкційних сталей - сталі 45, сталі 65Г і сталі 28MnB5 при русі в ґрунтах з різним коефіцієнтом форми абразивних частинок. Встановлено явище критичного коефіцієнта форми абразивних частинок (CPSF), аж до якого зносостійкість сталей знижується. При формуванні зносостійкості роль коефіцієнта форми частинок полягає в регулюванні активних деформаційних та утомних явищ за допомогою рівня зовнішнього силового впливу на робочу поверхню та реалізується через реолого-утомний параметр, який контролюється циклічною в'язкістю деформування сталі. У зв'язку з цим вибір марки конструкційної сталі для виготовлення деталей машин, призначених для експлуатації в грунтах з різним коефіцієнтом форми абразивних частинок необхідно проводити, виходячи з її ранжування за реолого-увтомним параметром. Показано, що в міцністному підгрунті механізму зношування сталі при терті ковзання в грунтах з різним коефіцієнтом форми частинок, крім опору поширенню осьових та радіальних утомних тріщин в шарі деструкційного деформування, важливу роль відіграє опір зародженню і поширенню бічних втомних тріщин на його кордоні з шаром деструкційного деформування, а механічний компонент контактної взаємодії є визначальним. Встановлено, що при зношуванні в ґрунтах з різним коефіцієнтом форми частинок дія процесу знеміцнення є більш ефективною, ніж процесу зміцнення. В закритичній області коефіцієнта форми абразивних частинок інтенсивність знеміцнення істотно зменшується через зростання інтенсивності зміцнення внаслідок дисперсійного тверднення сталей.

Ключові слова: абразивне зношування, грунт, коефіцієнт форми абразивних частинок, утома, деструкційна деформація, пластично-деструкційна деформація, утомна тріщина, зносостійкість, реологічний параметр, реолого-утомний параметр, в'язкість руйнування, розмір області нелінійних ефектів в околі трішин, циклічна в'язкість деформування, знеміцнення, зміцнення, дисперсійне твердіння