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Influence of orientation of zones of higher hardness of composite layers on their resistance to wear

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ABSTRACT

Purpose: Experimentally substantiate the influence of the orientation of zones of higher hardness on the wear mechanism of contact surfaces.

Design/methodology/approach: Forming of variable composition within the working surfaces of parts is a common way to solve the problem of uneven wear. The tests were aimed at determining the characteristics of the layers surfaced with the orientation of the zones of high hardness. For this different tests and measurements were done. Before the test, samples of 45 steel were surfaced with a preliminary application of titanium carbide paste.

Findings: As a result of researches it was found that different ways of the orientation of zones of higher hardness have different influences on the characteristics of a surface. The main conclusion is that the transverse orientation of such zones helps to increase the wear resistance of the surface and to save its original relief.

Research limitations/implications: The roughness, wear resistance, zonal hardness, and relief of layers surfaced with the orientation of zones of higher hardness were studied.

Practical implications: The results obtained are useful in the field of rolling production and mechanical engineering to avoid the uneven wear of parts and as a result to extend the term of their exploitation.

Originality/value: In this paper the model concepts of wear process of surfaces with variable composition and measurements of characteristics of surface considering its local hardening are proposed.

Keywords: Zones of higher hardness, Wear resistance, Roughness, Hardness

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PROPERTIES

1. Introduction

A lot of parts operating under friction conditions are subject to uneven wear. This leads to a change in the configuration of the work surface due to its significant loss of geometric dimensions in some areas. The consequence of this phenomenon is the acceleration of the time until the moment when the repair or replacement of such a part is necessary.

It is known [1-7] that a promising way to solve the problem of uneven wear of contact surfaces is the initial strengthening or restoration of surfaces with the formation of zones of variable composition and properties that are agreed on the actual loss of shape and size. In this case, the operating conditions can determine both the regulation of the chemical composition and mechanical properties of individual zones and the formation of areas that will differ, including by phase components. As a result, this will cause changes in the mechanism of destruction of the surface layers during contact.

The first successful attempt to form such surfaces is described in the work [1]. This method involved the application of zones of different compositions in a checkerboard pattern. The zones were formed by multi-electrode surfacing under a layer of ZhSN-5 doping flux. As an experience of forming surfaces of variable composition by multi-electrode surfacing, we can also mention the works [2,3]. In these cases, the goal lack was to form a common welding bath. The disadvantages of these methods are the questionable constancy of the volume of metal applied over the entire surface due to changes in the parameters of the surfacing mode, as well as the need for periodic replacement of the electrode material [1].

Another well-known principle of forming surfaces of variable composition is a method of surfacing with a change in the angle of the electrode. The complexity and inconvenience can also be called the disadvantage of this method (in the case of the complex shape of the treatment surfaces).

It should be noted that wear-resistant surfacing technology with the formation of the surface of the variable composition lacks sufficiently convenience and profitability in implementation. Because of this, it is important to propose a method with preliminary local application of reinforcing material with the use of common surfacing wires and with a constant surfacing mode. It is also important to check the effect of the direction of orientation of the zones of different hardness (transverse and longitudinal formations of such zones in relation to the direction of movement of the part during its operation were selected to ensure a fundamental difference in the conditions of destruction products removal from the contact zone) that are formed during the implementation of this method of applying hardener. Values that differed in the adjacent zones by at least 30-34 HB were taken as different levels hardness.

The literature data systematizes theoretical ideas about the process of friction. It is known from this research work [8] that friction can result from the follow:

- overcoming inequalities,
- overcoming the forces of molecular interaction
- one-time plastic embossing of the material
- repeated embossing of the material (re-deformation) and adhesion.

Some attention is given to the influence of adhesion as a factor in the process of friction [9-11]. Based on the literature data, it is possible to make assumptions about the harmful effect of adhesion on the performance of contact surfaces.

The disadvantage of such a factor as surface contamination is highlighted in the research work [12].

In addition to the consideration of theoretical concepts, researchers have covered the processes of destruction of specific parts [13,14]. The operating conditions of parts, as well as the influence of such external factors as water, soil, etc., are also taken into account.

The results of research of wear of stainless steels surfaces with added ceramics are given in [15]; and the results of research of the impact of different types of wear on the nature of the destruction are given in [16,17]. In particular, the formation of a tribo-oxide layer, which slows down wear, was recorded in the work [15], while studying structural transformations during the introduction of ceramics. Model ideas about the process of friction of surfaces during their forced heating are given in [16], and a conclusion about the influence of hydrogen saturation of separate zones of contact surfaces on the nature of their destruction is made in [17].

Analysis of literature data on the experience of forming surfaces of variable composition and properties shows that in terms of performance the most effective and most convenient is a method that involves pre-application of reinforcing materials locally, particularly on the periphery of the planned roller. The efficiency of this method is noticed in the better preservation of the material due to its placement at a distance from the epicentre of the heat flux that significantly reduces its burnout and increases the mechanical characteristics [4,18].

The object of the research was to identify the effect of the application of composite layers with the formation of respectively oriented zones of higher and lower hardness on the nature and intensity of wear by building a physical model and its experimental test.

2. Physical model

It should be noted, however, there is a lack of systematic data on the wear of surfaces of variable composition and properties. That is why it seems important to form theoretical ideas about the wear of surfaces represented by zones of different hardness.

The expected effect from the use of this method is the control of the contact surface relief by different orientations of the zones of higher hardness (ZHH), when they are applied by arc surfacing. Orientation of such zones is possible transversely and longitudinally to the direction of rotation (rectilinear movement) of a detail at its subsequent operation. It can be assumed that the direction of the orientation of ZHH will influence not only the deformation of the surface but also the promotion of the destruction products. The transport factor of the destruction products in the area of contact of parts, in turn, can also affect the change of geometric dimensions.

Depending on the phase composition of the surface layers materials, different processes are expected. In the case of predominantly plastic phase composition in all areas of the surface layer, viscous destruction is expected to occur in the zones of lower hardness (ZLH) at the transverse arrangement of ZHH. Wear products will be displaced in the direction of rotation and will accumulate on the slope of the previous relief rise that corresponds to the location of the less destroyed ZHH (Fig. 1).

In the case when the surface layer is represented by harder and, therefore, more fragile phase components, similar processes will occur. The destruction products of the ZLH material will also be localized here and will be pushed away over time in the direction of rotation. These ZHH products will be poured to the depths between these zones; this corresponds to the location of zones of lower hardness. The difference will be in the destruction that will be most fragile over the entire surface.

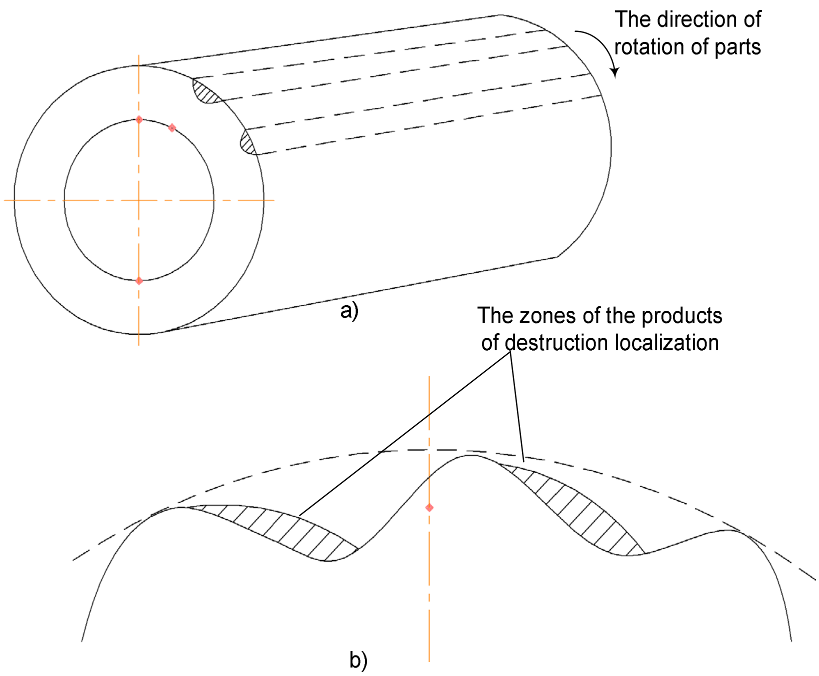

Fig. 1. The nature of the destruction of the surface at the transverse orientation of the zones of different levels of hardness: a) initial appearance of the part, b) localization of the destruction products during wear

The roughness factor and its connection to the phase composition of the surface should also be noted. In the case when the surface is represented by fragile phase components, there will be no viscous destruction in the ZLH and, most likely, there will be no furrows that will provide much lower geometric differences. According to this, lower roughness values will be observed in all areas of the contact surface. In the case of less hardness, on the other hand, adhesive bonds are possible in areas of lower hardness that will cause significant differences in zonal roughness.

Figure 2 shows the promotion of the destruction products at the longitudinally to the direction of rotation orientation of the zones of different hardness.

In the case of such orientation of ZHH and mainly plastic phase components in all zones of the surface layer, the nature of the destruction (regardless of the hardness of the material in the zones) will be preferably viscous. Unlike the transverse orientation, wear products will not accumulate in any way. Due to the absence of the obstacles on the way of friction as in the case of the transverse orientation of zones of different hardness, that would contain the removal of the destruction products. The surface roughness may increase in softer areas (due to the absence of the obstacles). This can be explained by the formation of adhesive bonds and consequently the ploughing of the metal. Ploughing can also result in a significant loss of geometric dimensions in diameter that will lead to the unserviceability of parts in general much faster.

A slightly different situation will occur for the surface layer represented by more solid phase components in all zones. The fragile nature of the destruction will be constant over the entire contact surface, the products of which will also not accumulate due to crumbling. Roughness reduction will make the difference, because the fragile destruction is characterized by a smooth fracture. There are also a possibility for much lower differences in the loss of geometric dimensions in the zones due to reduced wear at fragile destruction and the absence of significant adhesion.

It should also be noted that for any cases of ZHH orientation the described destruction processes will be supplemented by a periodic increase in the destruction rate and temporary alignment of the surface profile. This is because the material in the ZLH wears out faster in any case, so there will be periodic exposure of ZHH that will protrude above the surface and take on the main loads that will lead to this phenomenon.

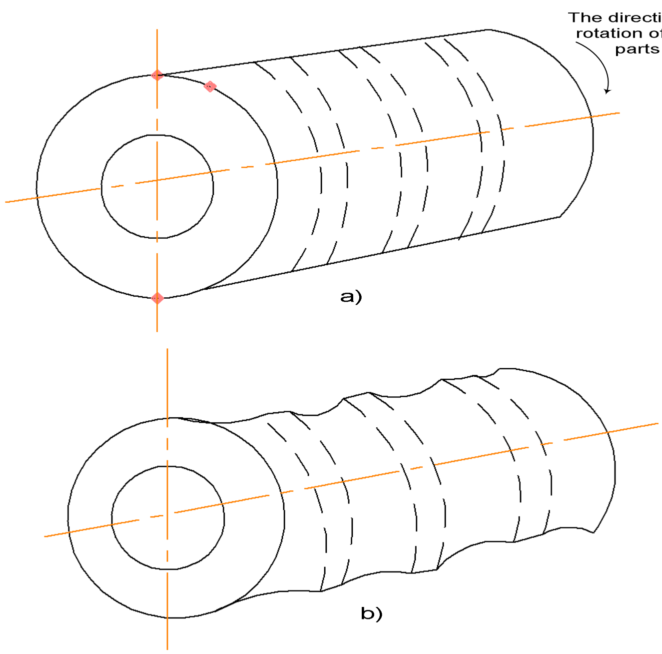

Fig. 2. The nature of the destruction of the surface at the longitudinal orientation of the zones of different hardness: a) the initial appearance of the surface; b) worn surface

3. Materials and methods

Samples of 45 steel (initial hardness 430-432 HB), 165 mm long, and 40 mm in diameter were prepared for an experimental test of the hypothesis. Surfacing was performed on the UD-209 installation, a universal surfacing machine designed for arc surfacing of flat surfaces and bodies of rotation. Following parameters of the mode were used: I = 140 A, U = 30 V, v = 30 m/h. The scheme of arc surfacing on a charge layer was taken as a basis [18]. As a modifying component was used Titanium carbide in powder form with the size of the particles, not more than 200 μm. To ensure uniformity of TiC penetration into the surfaced layers, a paste-like mixture based on GF021 primer was prepared. The primer is a suspension based on pigments and fillers in alkyd varnish. Importantly, it does not worsen the electrical conductivity and does not cause pores (at moderate amounts) in the case of deposition of metal layers [D13]. The mixture was applied in the form of strips with a 2 mm width, according to the width of the planned roller (~12 mm) and the direction of future surfacing (parallel to the rollers applied on their periphery). To do this, while surfacing, the electrode wire was installed with a corresponding N displacement (Fig. 3).

The mixture was applied in the form of 2 mm wide strips agreed to the width of the planned roller (12 mm) and the direction of future surfacing. The specific consumption was $1.6 \cdot 10^{-2}$ g/mm. Experimentally, this consumption is determined as the most appropriate, because there is a risk of pore formation at higher concentrations of the introduced material. To provide the maximum effect of the introduction of the hardener material into the surfaced layer, the highest (6 mm) density of the orientation of the strips was taken. This is the maximum distance allowed at which melting and mixing of metal of adjacent zones of different compositions can be avoided. Sv-08G2S wire with a diameter of 2 mm. was used as a surfacing material. Protection was provided by a gas mixture of 90% of Ar + 10% of CO_2. This mixture was chosen because it is universal for all types of high-speed welding and surfacing; it provides reduced spray formation, improved welded roller formation while minimizing metal oxidation and pore formation. Surfacing was performed in two stages, as a result, the thickness of the applied layer was 3.5 mm. The general area on which the metal layers were applied was ~20720 mm^2. The width of the zones of higher and lower hardness was approximately the same, so the mentioned zones occupied 50% of the area. Samples were also surfaced without modifying component introduction.

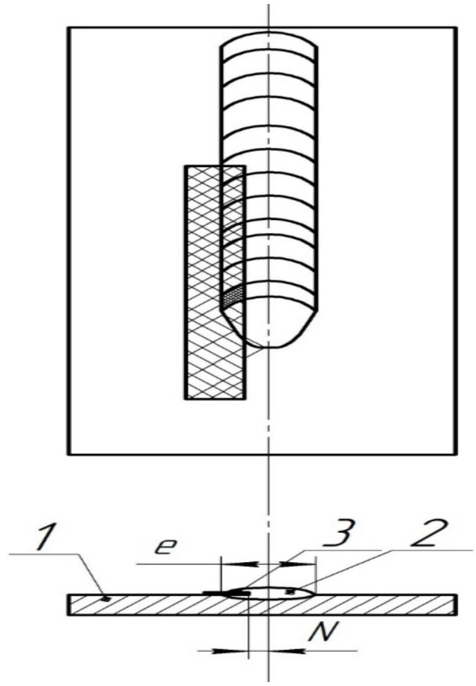

Fig. 3. Scheme of applying the layers of additional material: 1 – sample; 2 – surfacing roller; 3 – the layer of the mixture, *e* – the width of the roller; *N* – displacement

To provide a smooth cylindrical surface, machining of the welded samples was performed. The surface was treated to a roughness of 0.2 μm. 10 mm wide rollers were cut out from the surfaced samples. The study of wear resistance was performed on an MI-1M friction machine with a constant force of 100 N. MI-1M friction machine is designed to test antifriction materials for friction and wear during rolling, rolling with sliding, and sliding [15].

The tests were performed for 10 hours to check the changes in the microrelief of the surfaces and the nature of the destruction and the hardness of the surface over time. Hardness, roughness, and weight loss were measured every two hours. Weighing the samples was performed on laboratory scales; measuring the roughness was carried out on a profilometer; measuring the hardness was carried out on a TK-2 hardness tester. Measurements were performed according to the HRC scheme (diamond cone, 120°, rounding radius 0.2 mm, load 1.5 kN, duration of load application 10-15 s). The obtained hardness values, based on the obtained values, were converted into HB units.

Hardness and roughness were measured at 6 points (3 areas corresponded to lower hardness and 3 areas corresponded to higher hardness).

4. The results of experiments

4.1. Influence of transverse orientation of ZHH on relief and surface properties

Based on the constructed graphs of dependences, we will estimate regularities of the processes occurring during friction at various schemes of the orientation of zones of various hardness.

Figures 4 and 5 show the average picture of changes in roughness and hardness in areas of lower (a) and higher (b) hardness depending on the test time. The initial hardness of the metal in areas of lower hardness was 183-187 HB, and in areas of high hardness – 217-220 HB.

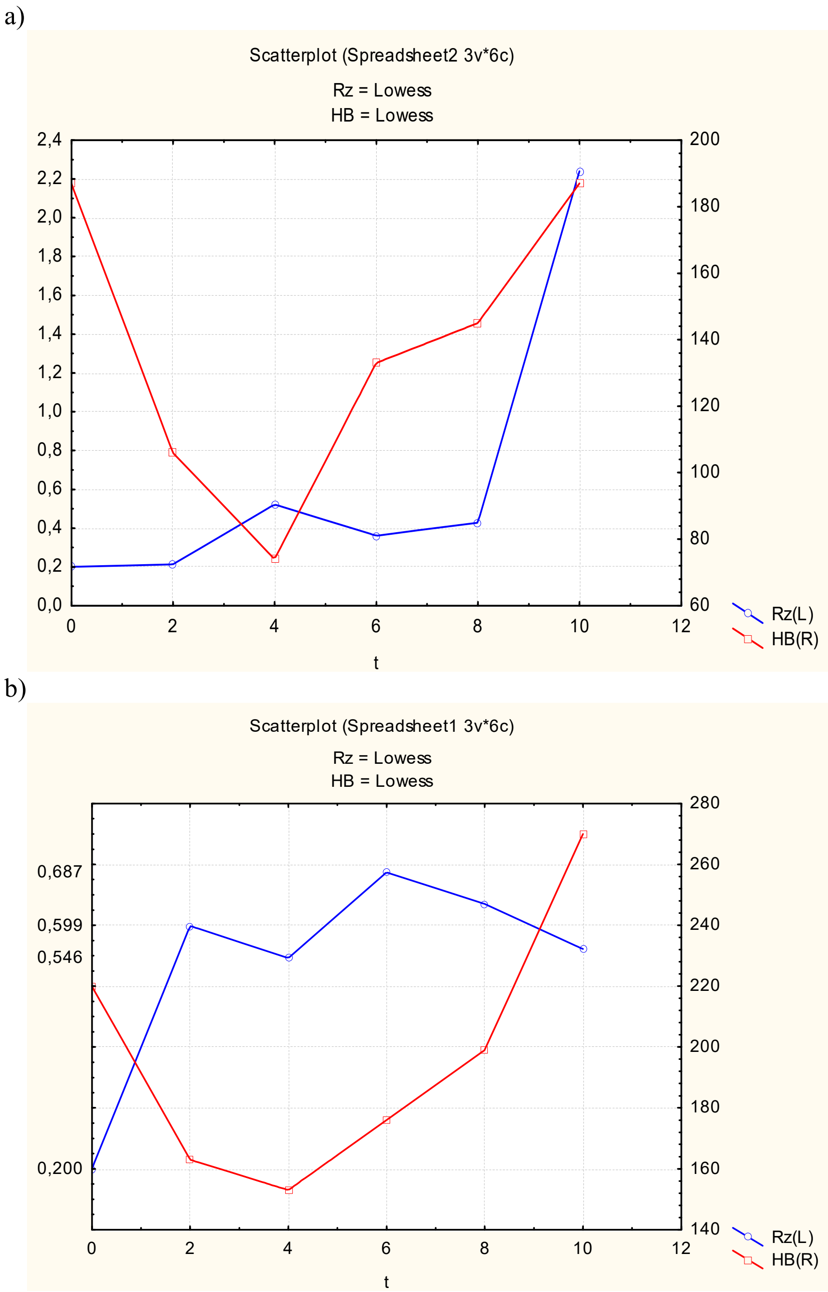

Fig. 4. Dependence of roughness Rz and hardness HB on time at the transverse orientation of ZHH: a) in zones of lower hardness, b) in zones of higher hardness

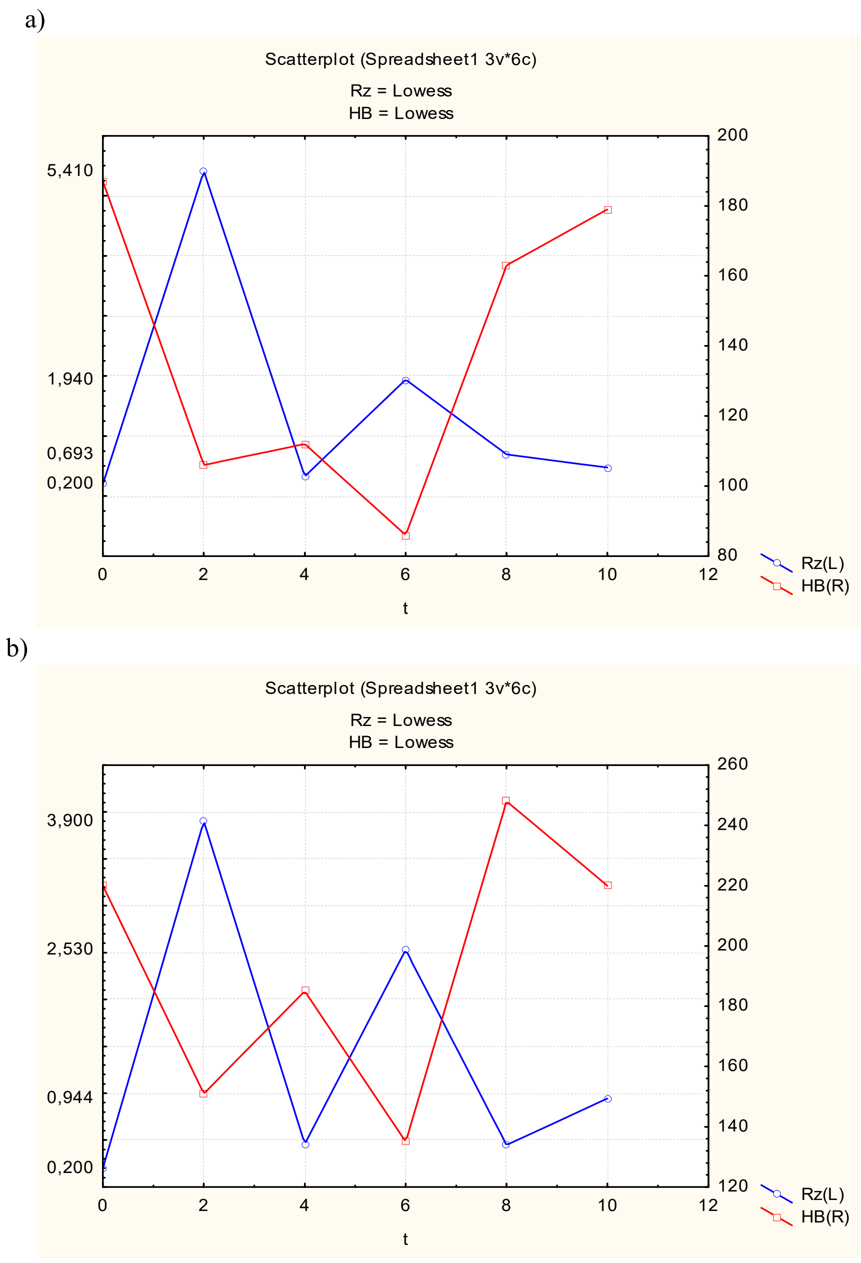

Fig. 5. Change in roughness Rz and hardness HB overtime at the longitudinal orientation of ZHH: a) in the zones of lower hardness, b) in the zones of higher hardness

Let's consider the processes occurring on the surface at the transverse orientation of zones of different hardness.

After 2 hours of testing the roughness in the ZLH increases from the initial 0.200 μm to 0.231 μm. This indicates the gradual start of the destruction of ZLH that is accompanied by reducing in hardness from 187 HB to 106 HB. At the same time, the roughness also increases significantly (from 0.200 μm to 0.599 μm) in ZHH. It can similarly be explained by the destruction of the zone. The hardness of the zone is reduced from 220 HB to 163 HB. At this time there is a slight accumulation of the destruction products.

After 4 hours of testing the increase in roughness in the ZLH from 0.231 μm to 0.450 μm is noted. The hardness decreases from 106 HB to 74 HB, apparently due to destruction. General weakening of the surfaced metal (that is essentially low-carbon, based on the carbon content in the surfaced wire), as well as the maximum accumulation of the destruction products in these areas, are observed. The accumulation of the destruction products becomes more significant. In ZHH the decrease in roughness is insignificant: from 0.599 μm to 0.546 μm. This is due to the loss by the zone of its geometric dimensions due to prolonged perception of the main loads.

After 6 hours the roughness in the ZLH begins to decrease from 0.450 μm to 0.250 μm. This can be explained by the accumulation of the destruction products in the volume that is sufficient to level the surface relief that occurs due to the pressing of these products. In addition, hardness begins to increase from 74 HB to 133 HB, apparently due to strain hardening. The destruction and occurrence of a geometric difference are fixed in the ZHH again; that is confirmed by the increase in roughness from 0.546 μm to 0.687 μm.

After 8 hours roughness in the ZLH begins to increase again from 0.250 μm to 0.425 μm. The hardness also increases due to heating and strain hardening. At the same time, the zone is destroyed; the pressed destruction products are removed. In ZHH the roughness decreases from 0.687 μm to 0.617 μm. At this time, both zones take on the main loads and lose their geometric dimensions. This difference in the change in roughness in the same period can be explained by the different intensities of wear in the zones.

After 10 hours roughness in the ZHH decreases even more significantly (from 0.617 μm to 0.550 μm) due to a significant reduction in the intensity of destruction of the zone. At the same time, there is a displacement of the pressed destruction products and wear of the zone itself in ZLH. This confirms the increase in roughness from 0.425 to 2.41 μm.

It should be noted that the destruction products accumulating between the ZHH are compressed during friction, thereby levelling the geometric differences between the sections. However, after 10 hours of testing there are a shift of the destruction products and additional wear of the zones of lower hardness that causes a difference in roughness. The latter indicates the cyclicity of alternating destruction of zones of higher and lower hardness, even after the onset of running-in of contact surfaces. Following the recordings of the roughness and hardness, the time of accumulation and compression of friction products varies within 2-4 hours.

4.2. Influence of longitudinal orientation of ZHH on the relief and properties of surfaces

Figure 5 can trace the cyclical process of destruction of surfaces with a longitudinal orientation of ZHH more clearly.

The same processes will occur in both zones, but with different levels of intensity taking into account the fact that the zones of high hardness do not play the role of obstacles to the destruction in this case. After 2 hours of testing, there is significant destruction of the zones of lower hardness: the roughness increases from 0.20 μm to 5.41 μm. At this time more preserved ZHH begins to take on the main loads and be more intensely destroyed. This causes an increase in roughness from 0.2 μm to 3.87 μm.

After 4 hours significant destruction in the ZLH does not occur due to the perception of the main loads by the zones of higher hardness; that is confirmed by a decrease in roughness (from 5.41 μm to 0.198 μm). In the ZHH the roughness also decreases (from 3.87 μm to 0.540 μm) due to a certain alignment in the profile with the ZLH.

After 6 hours there is a re-destruction of the zones of lower hardness. However, the destruction and the geometric difference are much less significant (from 0.215 μm to 1.94 μm) because of the strain hardening, due to which the hardness increases. In the ZHH re-destruction also begins (from 0.540 to 2.53 μm) after levelling the relief.

During the next 2 hours ZHH takes on the main loads again; as a result, these zones begin to collapse, and the roughness decreases (from 1.94 μm to 0.693 μm). At the same time the ZLH is destroyed insignificantly; as a result, roughness decreases (from 2.53 μm to 0.517 μm), but in this case because of the strain hardening.

After 10 hours there is an increase in roughness in the ZHH (as evidence of the resumption of the destruction of the levelled surface layer in this zone) and a decrease in roughness in the ZLH (as a result of the strain hardening).

In general, from the graphs of dependences show us that the process of destruction, regardless of the orientation of the zones of different hardness, is characterized by a cyclical process. This is due to the more intensive ZLH wears out; that is why ZHH periodically takes the main loads on. The role of the destruction products in the alignment of the geometry of the surfaces can be called the main difference in the course of processes. At the transverse orientation, the temporary levelling of the surface is facilitated by the accumulation and compression of the destruction products. At the longitudinally, it is facilitated by the directly alternate destruction of zones. The cyclicity of the processes is confirmed by the results of measurements of roughness and hardness, the results of which are shown in Tables 1-4. In Tables 2 and 4 the first value corresponds to the hardness in the zone of lower hardness, and the second one corresponds to the hardness in the zone of higher hardness.

We also studied the wear of samples that were surfaced without the introduction of a modifying component (TiC). It was found that the total weight loss after 6 hours of wear is 4.4715 g if the applied layer of TiC is absent (that is 3.0561 g more compared to the longitudinal location of ZHH and 2.0347 g more compared to the transverse location of such zones). Taking into account that the continuous application of TiC costs at least double, the formation of oriented zones of lower and higher hardness seems more appropriate: the saving of modifying components provides a favourable nature of the wear products removal and long lifetime of friction pairs.

Table 1.
The results of measurements of the roughness of the samples at the transverse orientation of the ZHH

Test time, h	Roughness measurement zones					
	Rz_1 (ZLH)	Rz_2 (ZHH)	Rz_3 (ZLH)	Rz_4 (ZHH)	Rz_5 (ZLH)	Rz_6 (ZHH)
Initial	0.2	0.2	0.2	0.2	0.2	0.2
2	0.045	0.546	0.397	0.774	0.197	0.476
4	0.351	0.358	0.374	0.507	0.842	0.772
6	0.375	0.736	0.221	0.390	0.486	0.936
8	0.282	0.223	0.255	0.604	0.744	0.442
10	0.290	0.092	2.19	0.942	4.24	0.650

Table 2.
Hardness differences and the level of wear at the transverse orientation of the ZHH

Test time, h	Hardness values (in ZLH...in ZHH) HB	Difference ΔHB	Δm, g
Initial	187…220	33	-
2	106…163	57	2.3158
4	74…153	79	0.0488
6	133…176	43	0.0722
8	145…199	54	0.0800
10	187…270	83	0.0916

Table 3.
The results of measurements of the roughness of the samples at the transverse orientation of the ZHH

Test time, h	Roughness measurement zones					
	Rz_1 (ZLH)	Rz_2 (ZHH)	Rz_3 (ZLH)	Rz_4 (ZHH)	Rz_5 (ZLH)	Rz_6 (ZHH)
Initial	0.2	0.2	0.2	0.2	0.2	0.2
2	0.814	4.10	8.99	2.61	6.44	4.99
4	0.038	0.330	0.519	0.309	0.431	0.737
6	0.281	0.684	5.04	6.25	0.509	0.668
8	0.398	0.789	0.876	0.362	0.804	0.192
10	0.342	0.329	0.839	0.544	0.240	1.96

Table 4.
Hardness differences and the level of wear at the longitudinal orientation of the ZHH

Test time, h	Hardness values (in ZLH… in ZHH) HB	Difference ΔHB	Δm, g
Initial	183…217	34	-
2	106…151	45	0.1553
4	112…185	73	1.1665
6	86…135	49	0.0936
8	163…248	85	0.1007
10	187…270	83	0.6264

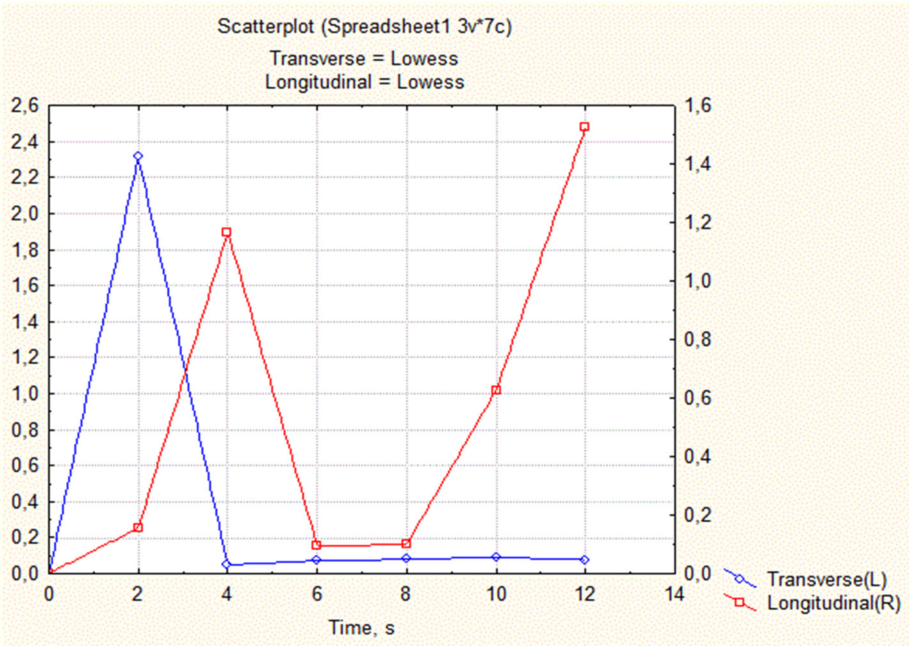

Fig. 6. Change of the level of wear overtime at the transverse orientation of the and the longitudinal one

When tests are carried out for more than 10 hours, it is expected that the sequence of phenomena accompanying the wear of the composite layer will be repeated until its final wear. Additionally, the operating time will be longer than in the case of wear of a layer that is constant over the entire surface of the metal composition. The reason for this increase is that the presence of zones of different roughness and fixed undulation of the contact surfaces will prevent mutual slippage of parts that intensifies wear.

When it comes to reducing the amount of wear is best to perform tests in a time interval of more than 2…4 hours for transverse orientation and 4…6 hours for longitudinal one. This can be explained by the beginning of surface running-in and adaptation to loads [D18].

5. Discussion

From the values of roughness given in the table the cyclic destruction of surface layers is traced regardless of hardness. The difference is in the time of the predominant abrasion of the relief on zones. Moreover, the duration of these cycles depends on the orientation at surfacing zones of high hardness.

In the case of the transverse orientation of the ZHH, there is a tendency (that occurs for a longer period (4… 6 hours)) roughness reduction (destruction is almost absent). In the ZLH the growth of roughness is fixed during this time; that indicates intensive material destruction in this zone.

In addition, the values of hardness in the zones of higher and lower hardness periodically change. At the transverse orientation of the ZHH, the increase in hardness difference also lasts longer. This can be explained by the lower impact of strain hardening and, possibly, taking on fewer loads by ZHH due to the specifics of the process.

The cyclic change of values is also distinctive for the level of surface wear. In both cases, during the first 4 hours of testing there is a decrease in weight loss, and then in its increase (see Fig. 5).

Figure 6 shows that the increase of the level of wear at the transverse orientation is much less significant than at the longitudinal; it confirms the higher resistance to wear of such surfaces.

From the above data, we can conclude that the orientation of ZHH has a great effect on changing the nature of wear and geometry of the surface. Their transverse orientation can be considered more effective in terms of preserving the geometry and wear resistance of the ZHH location scheme. This confirms the appearance of the surface after prolonged wear (see Fig. 7), as well as the difference in THE values of roughness.

It should be assumed that as distance between ZHH in both cases of orientation increases the intensity of wear will increase.

6. Conclusions

Taking into account the uneven wear of a significant proportion of real friction pairs, the formation of composite metal layers within the contact surfaces consisting of zones of lower and higher hardness has a potential. The most convenient and effective in terms of preservation of the material that can be implemented is a method that provides pre-application of appropriately oriented strips of hardener for electric arc surfacing.

During the course of the research, the cyclicity of wear of composite layers that remains for a long time is discovered. This is confirmed by measurements of roughness and hardness. The difference is in the duration of increasing roughness periods, the magnitude of which can indicate the time of intensive alternating wear of zones of lower and higher hardness. Reduction of roughness in zones of higher hardness at their transverse orientation lasts for 4...6 hours which is longer than at longitudinal orientation (~2 hours). This indicates a higher resistance to wear of the surfaces that were surfaced according to this scheme.

a) b)

Fig. 7. Appearance of the surface of the samples with the transverse orientation of ZHH (a) and longitudinal (b) after 10 hours of testing

The higher wear resistance of surfaces with the transverse orientation of the zones' higher hardness is confirmed by wear measurements. At the transverse orientation, the final value after 10 hours of tests is almost 7 times less than a longitudinal one. This can be explained by the ploughing prevention and intensive material crumbling out in the weakened zones by the nature of surface configuration.

In the case of the transverse orientation of the zones of higher hardness, a decrease in the intensity of destruction of the zones of lower hardness is fixed. The difference in the values of ΔHB hardness in the zones at the transverse orientation is lower (58 HB vs. 62 HB at the longitudinal orientation) which indicates a lower loss of strength in the ZLH.

Temporary levelling of the relief is distinctive for the wear process of the combined layers. In the case of the transverse orientation of ZHH, this is the result of accumulation and compression of the destruction products, and in the case of longitudinal orientation, this is the result of the direct destruction of zones of higher hardness.

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