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Analysis of the directions of improving regular micro reliefs

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Abstract

The article analyzes the features of planar regular microreliefs with the shape of grooves, the axis of which lies in a plane that is parallel or coincident with the surface on which the microrelief is formed and can be described by a periodic function. It was established that the main parameter that determines the operational properties of a surface with regular microreliefs is the relative area of the microrelief. The hypothesis is put forward that the geometric shape of the grooves of the microrelief practically does not affect the operational properties of the surface. Microreliefs of groove axes that a periodic function can describe are technologically imperfect because when forming the tops of microrelief grooves, the tool must make stops to change the trajectory of movement. The complex geometry of microrelief grooves reduces the productivity of their formation, and the complexity of ensuring regularity ensures the surface's heterogeneous physical and mechanical properties. Directions for improving the forms of microreliefs are proposed, which will ensure an increase in the productivity of their formation and provide an opportunity to control the operational properties of the surface.

Key words: regular micro reliefs, operational properties, geometric parameters, surface engineering, periodic functions, friction pair

Introduction

Ensuring the operational properties of machine parts is an important task of modern engineering. For this purpose, technologies for processing responsible surfaces and methods for ensuring their geometric and physico-mechanical quality parameters are constantly being improved. The direction of engineering science aimed at ensuring the necessary operational properties of the working surfaces of machine parts is called surface engineering. In this direction, an important place is occupied by the technology of creating periodically repeating organized surface structures, which are called regular microreliefs. In the scientific literature, these organized structures are called "Surface Texture", "Surface topography " or " Regular Micro Relief (RMR)". The creation of new micro reliefs that would provide better operational properties is an important task for modern mechanical engineering.

Literature review

The work [1] gives the results of studies of the influence of different forms of grooves of regular microrelief, which was formed on the surfaces of the test sample, on the coefficient of friction, the temperature in the friction zone, and the ability of the surface to remove wear products. Reducing the coefficient of friction leads to a reduction in the consumption of energy resources that are spent to set mechanisms in motion, which can be very relevant both in the aviation industry and in any other field of transport.

In works [2, 3], the results of the research are presented, which indicate that the formation of a microstructure in the form of an ordered microrelief on the inner cylindrical surface of the cylinder liner contributes to the ability of this surface to retain an oil film. This property of the working surface of the hydraulic cylinder sleeve improves the operational properties of the surface and increases the resources of the unit as a whole.

A large number of studies have confirmed that the formation of an ordered microstructure on the working surface reduces the roughness of the treated surface and increases the surface microhardness [4, 5, 6].

To ensure the specified operational properties of the working surfaces, microreliefs with grooves of various shapes and sizes are formed.

For example, in [7], the authors conducted a comparative study of the operational properties of flat rotating surfaces of discs. Regular microreliefs were formed on these surfaces, the elements of which in the first case were periodically repeated spherical holes, and in the other, traces of segments of different lengths (chevrons) intersecting at acute angles in the range of 60° - 90°. The result of the study was the determination of the coefficient of friction of surfaces with formed microreliefs and the search for the optimal shape, sizes and mutual location of the elements of such a microrelief.

Studies similar in object were conducted in work [8]. The authors investigated surface structures with a depth of 8 nm, the traces of which in the vertical plane will be in the form of a circle, an ellipse, and a triangle. The influence of the shape of the texture on the coefficient of friction was studied. It was also established that, given the same area, the same area ratio, and the same depth, elliptical and triangular pits have a lower load-bearing capacity compared to a round pit.

Surface structures in the form of square holes and grooves were studied in [9]. The surface area covered by microrelief elements was 25%. After forming on the surface of the test samples a texture in the form of grooves and square holes with a depth of 20 nm, they were subjected to the action of friction with a similar surface, simulating the process of wear. Each sample carried out relative movements in the amount of 20 thousand cycles. After simulating the wear process, the samples were compared with a control sample with a flat surface without formed microrelief. The result of the research is the conclusion that surfaces with formed surface structures have better operational properties. Surface operational defects during the period of research were observed only on the surface without formed microreliefs.

In the work [10], the authors proposed an approach in which regular microrelief is considered from the standpoint of factors that determine its characteristics, in particular: size and shape and mutual placement of microrelief elements; orientation of microrelief elements relative to the surface on which it is formed; the relationship between microrelief parameters; hierarchical ranking. Examples of regular microreliefs in the form of ordered microstructures in the environment are given, the sizes of their constituent elements are given, and their orientation is shown. Factors affecting the functional properties of surfaces with regular surface structures are considered.

Article [11] is interesting from the point of view of carrying out classifications. The classification of directions of scientific research of textured surfaces is presented, in particular: technologies for creating regular microreliefs; input/output characteristics of such surfaces; modelling of their interaction and further research in this direction. This work also provides a classification of the main methods of creating textured surfaces, such as methods of thermal, mechanical, electrochemical interaction, micro- and nano-finishing and micro-casting. The article provides technological diagrams of the processes of formation of surface microstructures with justification of the main technological parameters. The result of the authors' research is a table describing the various tool materials, work materials and cutting parameters used in machining with a micro-textured tool and a table of texture generation methods along with the dimensions and geometry of the grooves.

The microstructure of the surface in the form of rectilinear grooves was studied in [12]. These microstructures with a depth of 80-120 nm at the angle of the grooves 0°, 45°, 90° were created by a laser beam. The authors studied the frictional properties of these surfaces. The research was carried out by applying a load that presses the ball to the test sample with a force of 20 to 100 N and performs relative cyclic movements in the amount of 10 thousand cycles, simulating wear. The obtained results of the change in the coefficient of friction were compared with a control sample with a surface without creating surface microstructures. The work also established a mechanism for filling the grooves with the products of surface interaction and searched for the optimal location of the grooves to remove them from the contact zone of the conjugated surfaces.

The technology of creating a regular microrelief is proposed in [13, 14]. The use of a special tool with an indenter in the form of a ball with the ability to adjust the interaction force on the surface creates a regular micro relief with sinusoidal grooves on the surface. In this way, a completely regular microrelief with hexagonal cells is formed on the surface. The article presents the results of the study of the influence of the main technological parameters on the geometric parameters of the created microrelief.

Studies confirming the ability of textured surfaces to hold liquids better are given in [15]. The authors conducted a study of the rolling speed of liquid drops from surfaces with different microreliefs. Test samples with nine types of regular microreliefs of different shapes were produced. It was established that surfaces with formed microreliefs, in particular longitudinal grooves, retain drops longer than flat surfaces and surfaces with other types of microreliefs.

Scientific articles [16, 17] are devoted to the classification and mathematical modelling of partially regular micro reliefs, the regularity of which is ensured only for certain geometric parameters formed on the end surfaces of the bodies of rotation. Such micro reliefs are created on the end surfaces of the bodies of rotation. At the same time, the axial step of the grooves gradually decreases as they approach the center of rotation. To ensure the regularity of this parameter, the concept of the angular step of the groove is introduced, which is the same for grooves placed at different distances from the center of rotation of the end surface.

One of the main characteristics of the regular microrelief formed on the surface is its relative area F_n - expressed as a percentage of the ratio of the area of the grooves of the microrelief to the total area of the surface on which it is formed. It is this parameter that several researchers consider to be the one that determines the operational properties of a surface with a regular micro relief [18, 20].

In [20] it is indicated that the relative surface area F_n is a parameter of a partially regular microrelief that most fully characterizes almost all operational properties of the surface and, first of all, the actual contact area of the conjugated surfaces.

Summing up, it can be concluded that in all cases, regardless of the schemes and modes of application of the "pattern", the optimal value of the area of the grooves of the micro relief F_n was within 25-45%. At lower F_n values, the oil capacity of the mating surfaces is insufficient, and at higher values, their bearing capacity is significantly reduced.

Purpose

The problem of finding new types of regular and partially regular microreliefs is an important task for modern mechanical engineering.

Results

Regular micro reliefs [18] are periodically repeated grooves of the same depth, certain sizes and shape, the axial line of a continuous regular irregularity which is described by a periodic function. They are formed on the working surfaces of the parts and are characterized by the following constant parameters: amplitude A_k; step S_k which corresponds to the period of the periodic function; groove width b_k; the shape of the grooves - sinusoidal, triangular and other; by the type of microrelief, which determines the placement of rows of grooves between each other (I, II, III), which is determined by the interaxial step of the grooves of the micro relief S_o. The general appearance of the elements of the grooves of the regular microrelief is shown in Fig. 1.

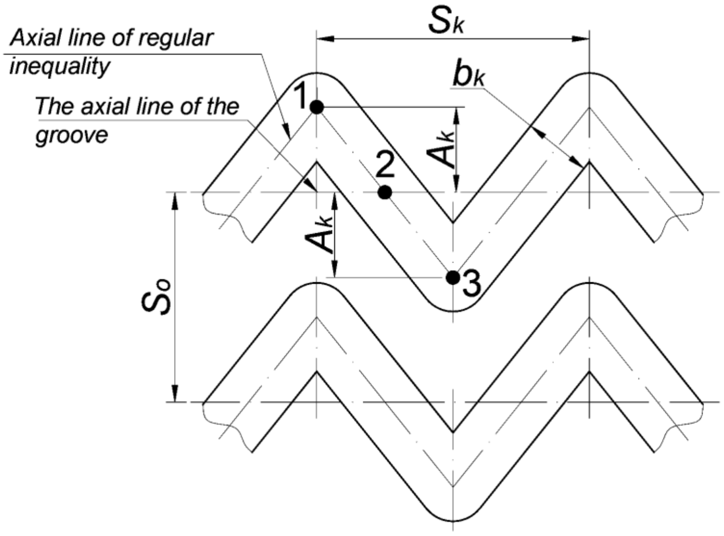


Fig. 1. Image of groove elements of regular type I microrelief (with grooves that do not touch) [18]

Since the depth of the grooves of such a microrelief is a constant value, and the change in the direction of the axial line of the grooves of the microrelief occurs in a plane parallel or coincident with the surface on which the microrelief is formed, it can be stated that such microreliefs are planar.

The creation of regular microreliefs on the working surfaces of machine parts ensures certain operational properties of these surfaces, in particular:

– reduction of the force of relative movement of conjugated surfaces;
– increase in the surface setting temperature under difficult operating conditions;
– increase in corrosion resistance of the surface;
- increase in oil capacity of the surface;
– increase in microhardness of the surface;
- increasing the fatigue strength limit of the surface and others.

Modern scientific research in the field of surface engineering is aimed at overcoming technical contradictions that arise when using regular microreliefs to ensure better operational properties of the working surfaces of machine parts.

The contradictions consist in finding a balance between the bearing capacity of the surface, which is greater with a larger contact area of the surfaces of the mating parts, and the area of the grooves of the microrelief, the growth of which provides the above advantages.

The classification of current areas of scientific research, in particular, forming technologies, tools, forming properties, process modelling, and others is given in the work [19].

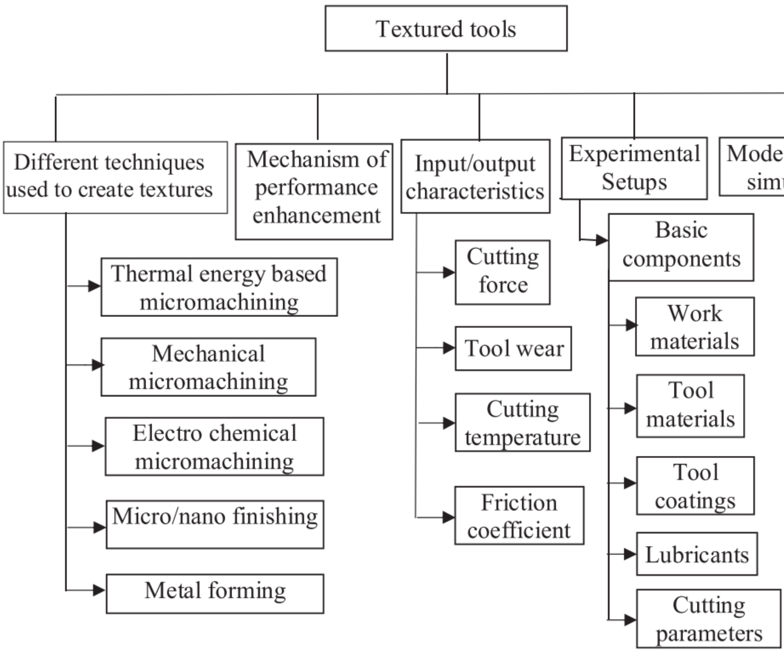


Fig. 2. Classification of areas of scientific research in the field of formation of regular micro reliefs [19]

To ensure the specified operational properties of the working surfaces, microreliefs with grooves of various shapes and sizes are formed. For example, in [19], the authors conducted a comparative study of the operational properties of flat rotating surfaces.

The analysis of scientific publications in the direction of the geometry of regular microreliefs allows us to identify the following directions for improving the geometry of regular microreliefs.

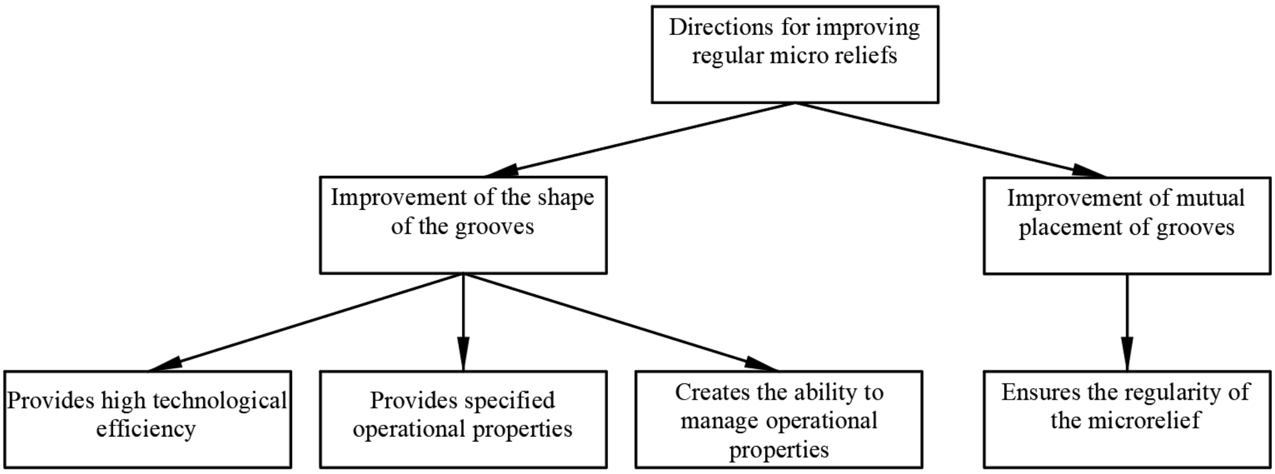


Fig. 3. Directions for improving the geometry of regular microreliefs

Most of the scientific research in this field is currently focused on ensuring the specified operational properties of surfaces with regular microreliefs and the regularity of microrelief grooves. The classic approach to this problem involves further gradual deterioration of the operational properties of the surface during operation.

In our opinion, the perspective lies in finding such a geometry of microrelief grooves, which would provide an opportunity to control the operational properties of the surface during its operation.

The reduction of the relative movement force is ensured by the reduction of the actual contact area of the conjugated surfaces with regular microreliefs, which is confirmed by numerous studies in this field [21] The relative area of the micro relief parameter shows a decreased in the share of the contact area of the conjugated surfaces of the friction pair.

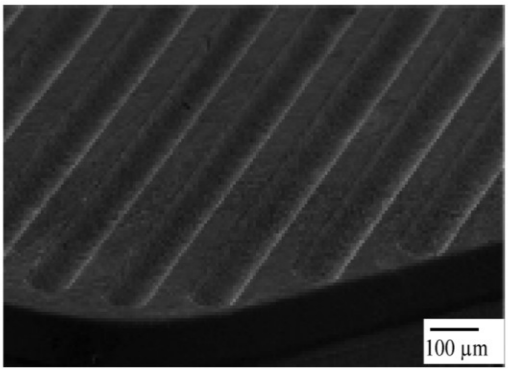
The parameter related to the relative area of the microrelief is the relative reference area of the profile element – the ratio of the reference area of the profile elements to the base area of the surface elements, which is determined as a percentage [18]. As the relative area of the microrelief increases, the relative support area will decrease. An increase in the relative area of the microrelief increases the ability of the surface to hold an oil film, which improves its oil capacity. So finding a balance between the relative area of the microrelief and the relative support area is an important task. The relative bearing area can be increased by treating the surface of the friction pair with PPD methods. Therefore, an approach that provides full surface treatment by PPD methods with subsequent formation of microrelief grooves is promising. This idea is based on the fact that in the process of operation, the contact of the friction pair is carried out precisely by plane surfaces, and the formed microrelief only provides certain properties. Such properties include a reduction in the force of the relative movement of the coupled surfaces of the friction pair, an increase in the oil capacity of the surfaces, and others. We also put forward the hypothesis that the shape of the groove of the microrelief does not have a significant effect on the operational properties of the surface. One of the main parameters that determines the operational properties of a surface with regular microreliefs is the numerical value of the relative area of the microrelief.

We substantiate our proposed direction of improvement of regular microreliefs, which concerns the simplification of the shape of the grooves to a rectilinear one, that is, the improvement of their manufacturability. To form a profile of a microrelief with the shape of grooves, the axis of which lies in a plane that is parallel or coincident with the surface on which the microrelief is formed and can be described by a periodic function, the vibration method is used (usually on general-purpose machines) with special devices that ensure the oscillatory movement of the deformable element (usually a ball) of the tool, during which it performs reciprocating movements by the amplitude A_k with simultaneous longitudinal movement along the longitudinal axis of the microrelief groove. Also, for the formation of PMR, machines with CNC are often used, which perform the formation of the groove profile by the calculated coordinates of the control program.

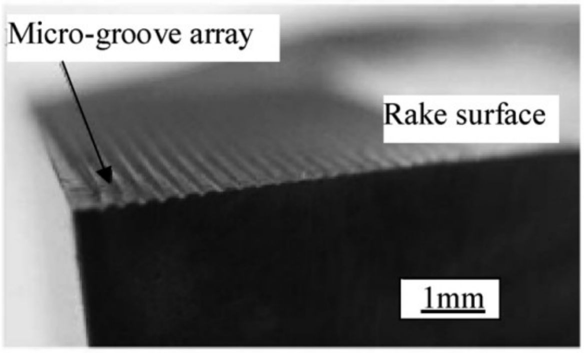
The rate of deformation of the surface material by the deforming element during the formation of the micro relief is important since it determines the amount of plastic deformation, the surface structure of the formed groove, and its physical and mechanical properties. Experimental studies [22, 23] established that the optimum from the point of view of ensuring the overall roughness of the surface with a regular microrelief is the deformation speed of 1000 mm/min.

The technological imperfection of these microreliefs is that the real rate of deformation of the groove material will be reached only in the central part of the groove at point 2 (Fig. 1), and at points 1 and 3 (Fig. 1) the deforming element of the tool will change the direction of movement, respectively its speed will be zero. Accordingly, the planned physical and mechanical properties of the surface will also be obtained only in the central part of the groove of the microrelief, i.e. in the vicinity of point 2. Near the tops of the groove - points 1 and 3, the surface properties will be different, and the overall structure of the surface will be heterogeneous.

Therefore, to ensure the calculated rates of formation of microrelief groove surfaces and deformation of the surface material, the shape of the groove elements mustn't have tool stop points. This form can be grooves in the form of straight lines (Fig. 4) or grooves in the form of trochoids, cycloids and elements of circles.



a



b

Fig. 4. Regular microrelief with rectilinear grooves

Shape of linear texture created using Micro EDM [24] (a) **Diagonal texture created on the rake surface of the carbide tool [25] (b)**

Another technological difficulty in the formation of planar microreliefs, the axial line of a continuous regular unevenness described by a periodic function, is ensuring the regularity of the grooves of the microrelief. Violation of the regularity of the grooves of the microrelief is manifested in the change in the mutual arrangement of the elements of the grooves in a row and the rows of grooves of the microrelief between each other. The reason for this phenomenon on machines with mechanical gearboxes is the probabilistic nature of tool feed. This causes an increase in the value of the accumulated error and, accordingly, the pitch of the groove of the microrelief S_o (Fig. 5).

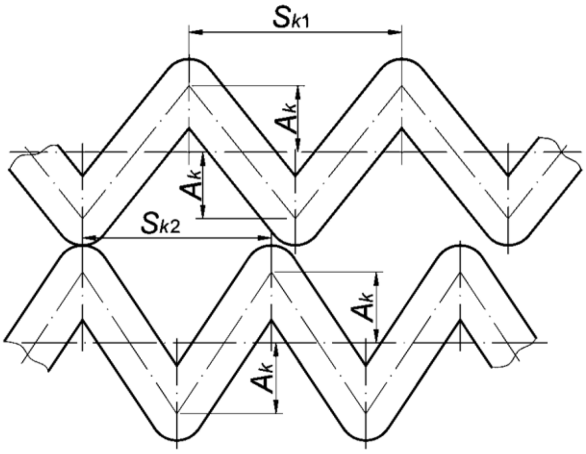


Fig. 5. Irregularity of microrelief grooves formed due to the difference in steps S_{k1} and S_{k2}

From the point of view of providing the necessary numerical value of the relative area of the microrelief, the violation of regularity is not a significant problem, since the regularity does not affect the value of the relative area of the microrelief. However, the violation of the regularity of the grooves of the microrelief creates heterogeneity of the physical and mechanical properties of the surface and its operational properties. It should be noted that when using CNC machines to form regular microreliefs, the problem of irregularity of the grooves is not observed.

Researchers are conducting other properties of textured surfaces. Studies confirming the ability of textured surfaces to hold liquids better are given in [26]. The authors conducted a study of the rolling speed of liquid drops from surfaces with different microreliefs. Test samples with nine types of regular microreliefs of different shapes were produced.

The results of these studies indicate that surfaces with formed microreliefs, in particular longitudinal grooves, can retain drops longer than flat surfaces and surfaces with other types of microreliefs.

Research studies in the direction of determining the optimal geometry of microrelief grooves that provide the minimum friction coefficient are given in [28].

The authors conducted a very important experiment to find the optimal geometry of the microrelief to ensure the minimum coefficient of friction. For comparison, 6 test samples with microrelief grooves of different geometric shapes were made.

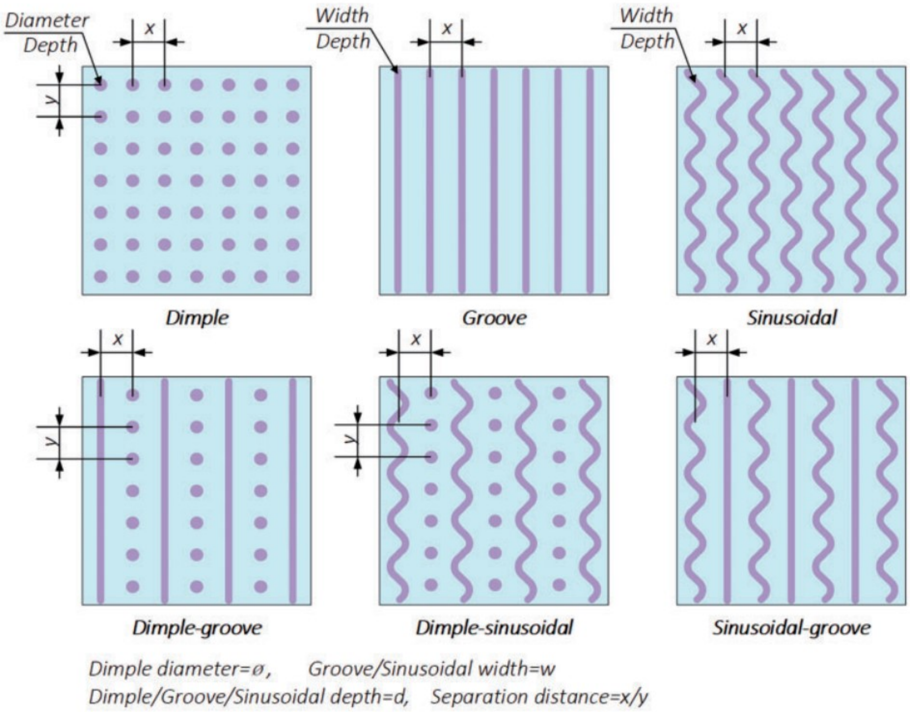
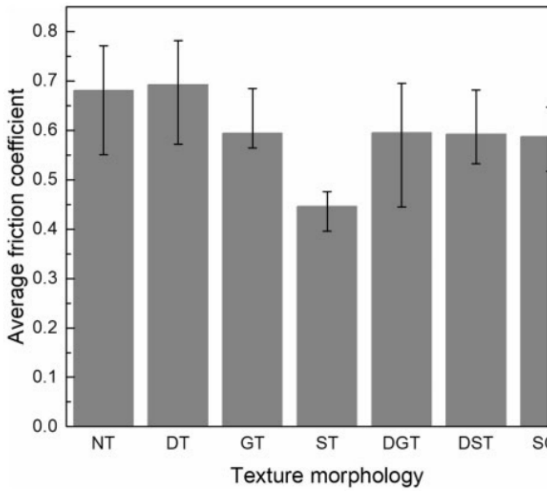
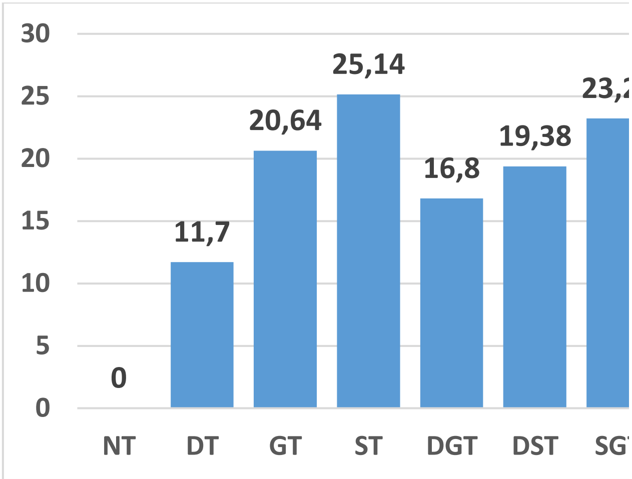


Fig. 6. Test samples with different geometries of grooves for determining the coefficient of sliding friction [28]

The results of research on the effect of the shape of the microrelief grooves on the friction coefficient are shown in Fig. 8 and indicate that the minimum friction coefficient is provided by the sample with the sinusoidal shape of the microrelief grooves. However, the authors of this study made a false conclusion regarding the optimal shape of the microrelief, since the test samples, although they had the same dimensions, had different contact areas due to the different relative areas of the grooves of the microrelief.

We determined the relative area of the microrelief grooves of each of the grooves shown in Fig. 7 test samples and it was established that the test sample with sinusoidal grooves (ST) has the largest value of the relative area of the microrelief (Fig. 8). This explains the minimum value of the coefficient of friction since the contact area of the mating surfaces was minimal due to the maximum area of the grooves of the micro relief.





NT: non-textured ; DT: dimple-textured ; GT: groove-textured ; ST: sinusoidal-textured ; DGT: dimple – groove-textured ; DST: dimple – sinusoidal-textured ; SGT: sinusoidal – groove-textured

Fig. 7. Average friction coefficient of non-textured and textured surfaces [28]

Fig. 8. Value of the relative area of microrelief grooves on the surface of the test samples

This study confirms our hypothesis that the numerical value of the relative area of microrelief is decisive in the formation of operational properties of a surface with regular microrelief. The pattern of microrelief grooves does not have a significant effect on the friction coefficient of the mating surfaces. Taking this into account, it is advisable to apply such a form of a groove, which is more technologically simpler and will provide higher labour productivity when forming a surface with regular microrelief and the possibility of controlling the operational properties of the surface.

Conclusions

1. To ensure the improvement of the operational properties of the working surfaces of parts of machines and mechanisms, it is advisable to use surface regularization methods, and the geometric characteristics of the created microrelief should be determined depending on the specific operating conditions.

2. Analysis of planar regular microreliefs with the shape of grooves, the axis of which lies in a plane that is parallel or coincident with the surface on which the microrelief is formed and can be described by a periodic function, allows us to state that they are technologically imperfect. This is manifested in the fact that the formation of periodically repeated vertices of elements in their geometry requires periodic stops of the tool, which leads to a decrease in productivity.

3. The analysis of the operational properties of surfaces with regular microreliefs established that these properties are provided mainly by the optimal value of the relative area of the microrelief and the uniform placement of the grooves of the microrelief on the surface. The shape of the grooves of the microrelief does not significantly affect the operational properties of the surface.

4. More optimal forms of grooves of microreliefs are proposed, which are technologically easier to manufacture (straight-line, cycloid, trochoid) and provide the possibility of controlling the operational properties of the surface by changing the geometry of the groove in the plane perpendicular to the surface on which they are formed. Pre-treatment of the surface by PPD methods followed by the formation of PMR will allow to increase in the relative support area of the friction pair.

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В.О. Дзюра Р.О. Бица. Аналіз напрямків вдосконалення регулярних мікрорельєфів.

В статті проведено аналіз особливостей площинних регулярних мікрорельєфів із формою канавок, вісь яких лежить в площині, що паралельна чи співпадає із поверхнею на якій формують мікрорельєф і її можна описати періодичною функцією. Встановлено, що основним параметром, який визначає експлуатаційні властивості поверхні з регулярними мікрорельєфами є відносна площа мікрорельєфу. Висунута гіпотеза про те, що геометрична форма канавок мікрорельєфу практично не впливає на експлуатаційні властивості поверхні. Мікрорельєфи вісь канавок яких можна описати періодичною функцією є технологічно недосконалими, оскільки при формуванні вершин канавок мікрорельєфу інструмент повинен здійснювати зупинки для зміни траєкторії руху. Складна геометрія канавок мікрорельєфу зменшує продуктивність їх формування, а складність забезпечення регулярності забезпечує неоднорідні фізико-механічні властивості поверхні. Запропоновано напрями вдосконалення форм мікрорельєфів, які забезпечать підвищення продуктивності їх формування та нададуть можливість керувати експлуатаційними властивостями поверхні.

Ключові слова: регулярні мікрорельєфи, експлуатаційні властивості, геометричні параметри, інженерія поверхні, періодичні функції, пара тертя