



# Influence Evaluation of the RVS Friction Geomodifier on Tribotechnical Parameters of the Contact in Non-Stationary Working Conditions

T.M.A. Al-Quraan<sup>a,\*</sup>

<sup>a</sup>Al-Balqa Applied University, Ma'an College - Technical Sciences Department, 19117 Al-Balqa, Jordan.

## Keywords:

Friction  
Wear  
Micro-hardness  
Surface topography  
Boundary lubricating films  
Tribotechnical contact

## ABSTRACT

*It has been found that empirical analysis provides a possibility to select the optimum concentration of the repair and restoring composition (RVS), addition of which to the transmission oil provides an increase in wear resistance of 42Cr4 steel under rolling and slip conditions. The structural adaptability of finely dispersed components of the friction geo-modifier RVS, boundary lubricating films and surface layers of metal under friction and under dynamic loading conditions contribute to reducing the wear of contact surfaces. It has been established that the addition of 1.5 % RVS to the lubricant provides a 17 % reduction in the wear of rolling friction pairs, provides hardening of the surface layers of the metal by 1.36 times, compared with the initial surface. The micro-hardness of the surface layers of the metal and its gradient depth distribution, the micro-geometry of the surface layer formed during friction, and the formation of boundary lubricating layers on the friction-activated contact surfaces are key indicators that increase the wear resistance in friction pairs.*

\* Corresponding author:

Tareq M.A. Al-Quraan   
E-mail: [tarjorggg@bau.edu.jo](mailto:tarjorggg@bau.edu.jo)  
[tarjor999@gmail.com](mailto:tarjor999@gmail.com)

Received: 30 August 2019

Revised: 23 October 2019

Accepted: 15 November 2019

© 2020 Published by Faculty of Engineering

## 1. INTRODUCTION

The efficiency of machines and mechanisms is largely determined by physical-mechanical and thermal-physical processes occurring in contact on the surfaces of friction pairs and in lubricating environment. Under dynamic loading, the surface layers of metals undergo significant plastic deformation, while the dislocation structure of the surface layer changes substantially, which is due to the occurrence of physicochemical processes in frictional contact. The resistance to deformation

and destruction of the metal surface under cyclic loading largely determines the reliability of friction pairs. In addition, one should take into account the existence of a relationship between the changes in the structure of the surface layers of solids and the lubricating environment under friction, as well as the kinetics of wear with structural changes in friction pairs.

A fundamental feature of the state of the surface of solids in friction is the existence at the points of contact of a stable grainy deformed structure of a dissipative dynamic nature. Energy, which is

expended on overcoming the rolling resistance, is absorbed by the surface layers of the metal and is expended on their intensive cyclic deformation. One of the directions for obtaining additional reserves for increasing the wear resistance of friction pairs is the ability to detect kinetic patterns of changes in micro-plastic deformation, to evaluate the elastic, relaxation properties of the material and other features of structural changes. An important direction of increasing the wear resistance of contact surfaces is the introduction into the lubricant of substances that are capable of repairing worn surfaces. Determining the conditions that facilitate the flow of mechanical and physicochemical processes in contact in the presence of repair and restoring compositions in the lubricant will contribute to a more accurate prediction of the friction unit's performance as a whole.

## 2. ANALYSIS OF LITERARY DATA AND FORMULATION OF THE PROBLEM

Investigations of structural changes in friction acquire great importance in connection with the development of engineering techniques for estimating wear depending on external factors and characteristics of fractionize objects. The analysis makes it possible to determine the wear mechanism, to obtain the data necessary for calculation, to estimate the degree of change in the properties of the surface layers in friction in comparison with the volume properties of materials. Increased wear both at positive and at negative temperatures often occurs in parts with a uniform, full-strength surface layer [1]. The formation of dispersed structures of increased wear resistance occurs with a certain thermodynamic action, taking into account the physicochemical properties of materials of tribo-unit materials. However, the correlation between the wear resistance and the uniformity of the surface layer is significantly different and depends not only on the loading dynamics, but also on the physicochemical properties of the material, which indicates the complexity of managing the synergetic processes [2]. The more wear-resistant under the specified test conditions is the material, the more structural self-organization takes place, and the complexity of the dynamic loading in the contact of the tribo-unit to its wear resistance has less affect.

According to the results [3], the catalysts present in the repair-restoring composition (RVS) initiate the physicochemical reactions of the transformation of the surface layer of the metal during the friction process. At the same time, new structures are formed that have a crystalline carcass with a more bulk crystal grid with the metal, which contributes to wear compensation. The thus formed cermet layer is a mono-crystal, which contributes to a significant levelling of the micro-relief in contact points of friction surfaces.

The main properties and parameters of the resulting modified layer [4]: coefficient of linear thermal expansion - 13.6...14.2; friction coefficient - about 0.007; micro-hardness of surfaces - 690...710 HB; impact strength - 50 kg/mm<sup>2</sup>.

RVS technology with the physical positions, that is, the restoration of the worn surface friction and enlargement of the protective layer [5]. The advantage of this hypothesis is the account of other important factors. However, the evidence of the elemental composition of HMT-coating shows the presence of a predominant (70-85 %) of the amount of carbon, a small (3-5 %) and similar to the amount of iron-silicon, in the absence of appreciable amounts of magnesium, which does not confirm the accuracy of the cermet.

According to [6], RVS technology is based on the atomic exchange reaction between the base material and the RVS component with the formation of a metal-ceramic coating. The RVS is a dispersive multi component mixture of additives, catalysts and minerals (serpentine, nephrite and schungite). The resulting layer of ferrosilicon is not separated from the base material. It is classified as a modified layer of the material (this is not a coating). The hardness of this layer is 63-70 HRC. Protection against wear is 5-6 times higher than when using special lubricants. The friction coefficient is very low ( $f = 0.003$ ).

When working with friction pairs using a repair-restoring composition on the basis of an oxidized lubricant, the formation of a metal-ceramic coating was also observed [7]. This coating provides a reduction in the temperature of the lubricant and the frictional force, a decrease in wear, an increase in the micro-hardness of the contact surfaces.

RVS geomodifiers have uncovered a mechanism for controlling the barrier effect of the near-surface dislocation density gradient (debris layer). It allows controlling the strength of the material compared with its initial state [8]. The use of RVS geomodifiers allows increasing surface hardness, wear resistance, reduce the coefficient of friction, restore the original geometry of the parts, as well as optimize the processes of friction and restoration of surfaces subjected to wear.

The addition of the REWITEC nano-coating to the lubricant provides a positive effect in terms of increasing the antifriction properties in contact. At the same time, a decrease in the frictional force can reach up to 22 % [9].

Geomodifiers of friction of a serpentinites class after addition in industrial hydraulic oil lead them to reduction of an adhesion of contact surfaces at work of friction pair. Geomodificators with average magnetic properties (AMP) showed the most effective influence on decrease of coefficient of friction and increase of wear resistance [10].

Simultaneously the process of connected surfaces micropolishing occurs, that leads to essential reduction of their roughness. A typical grain-oriented microrelief is formed on the friction surface. This microrelief has microcavities good in holding oil. Equal microhardness combined with low surface roughness leads to unique antifriction effect [11].

Based on the study of the structural features of the third body formed with the use of mineral friction modifiers, it is identified that the presence of the crystalline phase in the structure of the minerals included in the friction modifiers leads to an increase in their wear ability during the run-in [12]. The possibility of dry operation of metal surfaces in the presence of additives of this type is justified in the work. This effect, according to the study results, is due to the formation on the friction surfaces of a layer of a two-level structure: a mineral skeleton with a developed surface and a layer of tribo-polymerization products of a lubricant. At the same time, the patterns common to most tribo-systems are identified, which are typifying both for the friction of antifriction polymers and composite materials based on them, and for the

realization of selective transfer, and consisting in the formation of a multilayer antifriction coating on the friction surface.

The results of experiments aimed at studying the kinetics of formation of protective coatings using RVS Technology under conditions of elastic-hydrodynamic, boundary and dry lubrication regimes are presented in the work [13]. The results of the use of an additive RVS Technology to the lubricant have demonstrated that the effectiveness of this component reveals itself at contact voltages of Hertz of 300-860 MPa and depends on the lubrication regime in contact. In the boundary lubrication regime, the average roughness of the contact surfaces decreased from  $Ra=0.2 \mu m$  to  $Ra=0.05 \mu m$ . In dry lubrication mode, the time before setting the surfaces processed by RVS Technology are twice as longer as for untreated surfaces. Thus, the use of RVS Technology helps to increase the durability of tribo units.

Improving of the tribological properties of gearbox mechanisms and bearings of wind turbines has been established in work [14] using REWITEC Nano-coating. In particular, the smoothing of the surface of gear teeth, the reduction of acoustic characteristics (the number and levels of the speed peaks of the high-speed shaft of the reducer are decreased by approximately 20 %), and stabilization of wear and partial restoring of the worn surfaces ensure a longer durability of mechanical components.

Under conditions of contact cyclic loading in a thin surface layer of tribo-unit elements, the destruction of contact surfaces is associated with a change in the structure of materials. This occurs at high speeds, temperatures, loads and intense deformations concentrated in the local surface and subsurface volumes of the material of friction pairs. The solution to the problem of wear resistance of tribotechnical materials at the nano-level requires systematic research that would allow solving an important scientific and technical problem of minimizing wear and increasing the durability of the tribo-system. One of the directions in this area is the management of the processes of self-organization of secondary structures in the presence of a boundary layer of a lubricant and a repair-restoring composition.

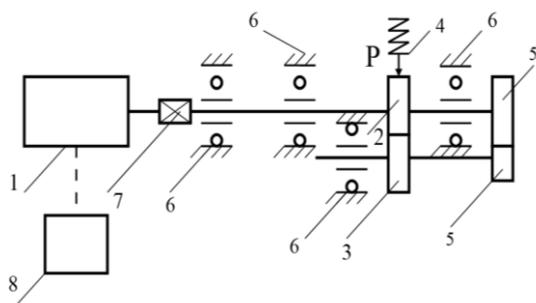
### 3. THE AIM OF STUDY

The aim of the work was to establish the wear mechanisms of steel 42Cr4 in non-stationary conditions of friction when the RVS repair-restoring composition is introduced into the lubricant.

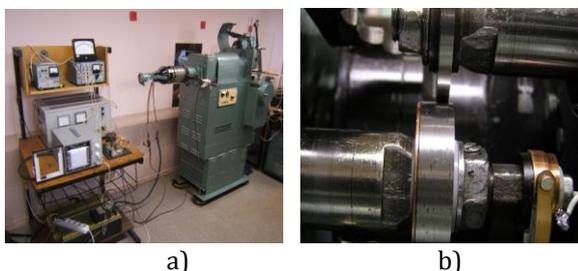
### 4. METHODOLOGY

The investigation of the lubricating properties of oils has been carried out on a laboratory single-contact installation SMC-2 in non-stationary conditions of friction (start-up-stationary operation-deceleration-stop).

The kinematic drive chain is a closed power circuit consisting of two branches connected at the contact point of the rollers. The drive of the power circuit is carried out from the aviation direct-current generator GSK-1500 ZH, the power control is realized through the converter digital unit (Figs. 1 and 2).



**Fig. 1.** Kinematic scheme: 1 - generator; 2, 3 - friction pairs; 4 - loading mechanism; 5 - replacement gears; 6 - rolling-contact bearings; 7 - shaft coupling; 8 - digital generator power control unit.



**Fig. 2.** a) Installation of SMC-2 for the investigation of the lubricating properties of oils; b) general view of the friction roller-roller assembly.

The investigations were carried out according to the roller-roller scheme ( $d=50\text{ mm}$ ) under conditions of rolling with 20 % slip. The maximum

speed for the leading surface was 800 rpm. The maximum contact voltage for Hertz is 450 MPa. Start-up cycles (2s) - stationary operation (3s) - deceleration (2s) - stop (3s) follow one after another, without interruption. The number of cycles in the experiment is  $N=3000$ .

The rollers were made of steel 42Cr4 (DIN) (HRC = 38,  $R_a=0.45\text{ }\mu\text{m}$ ,  $R_z=1.65\text{ }\mu\text{m}$ ) as the samples. The created test conditions are characterized by the kinematics of the contact of rolling with slippage, which is typical for gears. This kind of steel is used for gear manufacturing. Therefore, testing on friction pairs 42CR4 brings stand-testing closer to real-life conditions. Lubrication of contact surfaces was carried out by dipping the lower roller into a tray with oil. As a lubricant Okko GL-4 80w/90, mineral gear oil for mechanical gearboxes and main cars and trucks gears has been used. The oil volume temperature was 70 °C. The RVS repair and restoring composition of various concentrations was added to the lubricant. The geomodifier used in the work is RVS Technology T6a Automatic Transmission Treatment. For Transmissions with an oil capacity up to 6 Qt. Safe for All Automatic/Dual Clutch Transmissions (Manufacturer: RVS Technology Ltd., Finland). Unlike oil additives on the market, RVS Technology products produce a nanoceramic layer that integrates with the metal friction surfaces.

To determine the thickness of the lubricating layer, an electric method was used, based on measuring the voltage drop (proportional to the thickness of the layer) in the normal glow discharge mode with constant current strength between the contacting surfaces [15]. Lubricating properties (hydrodynamic and non-hydrodynamic components of the thickness of the lubricating layer) are determined by the method of voltage drop in the normal mode of glow discharge. According to this method, the voltage drop in the lubricating layer is measured at a current of 2 and 4 A, then the thickness of the lubricating layer is determined according to the calibration tables:

$$h = \frac{2U_{2A} - U_{4A}}{k}, \quad (1)$$

where  $U_{2A}$  and  $U_{4A}$  is the voltage drop in the lubricating layer at a current of 2 and 4 A;  $k$  - is the coefficient depending on the type of lubricant.

The total thickness of the lubricating layer was measured at the maximum rotational speed of the friction pairs; the thickness of the boundary layers was measured at a stop, when there is no hydrodynamic component of the thickness of the lubricating layer.

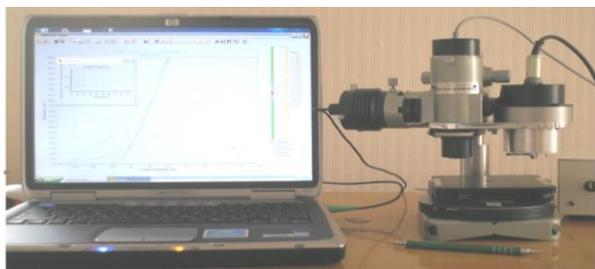


Fig. 3. "Micron-gamma" device.

The micro-hardness of the surface layers of metal and wear were measured with a multifunctional "Micron-gamma" device [16], designed to study the physico-mechanical properties of surface layers of materials by the methods of continuous indentation (Fig. 3).

## 5. THE RESEARCH RESULTS AND DISCUSSION

### 5.1 Selection of the Optimum Concentration of the RVS Additive to Improve the Tribological Properties of the Contact

At the first stage, study was carried out to select the optimal concentration of RVS. The main tribotechnical indexes for assessing the effectiveness of tribo-units were the antifriction and anti-wear properties of the transmission oil mixture and the RVS additive. It was identified that the best anti-wear properties are characterized by a mixture of oil with the addition of 1.5 % RVS (Fig. 4).

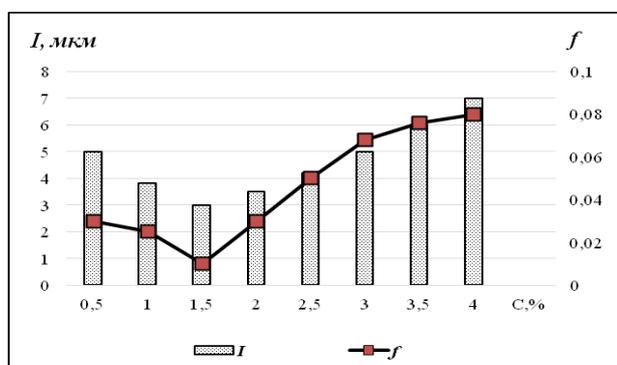


Fig. 4. The effect of the concentration of the additive RVS (C, %) on the coefficient of friction (f) in contact and the overall wear of the leading and trailing surfaces (I).

At a lower concentration of the RVS additive, the boundary layer of the lubricant is used to reduce the wear of the contact surfaces. Since friction occurs under unsteady conditions, with the dominance of the boundary or semi-dry lubrication regimes, frequent changes in the boundary layers of the lubricant occur. On the average, a direct metallic contact of the friction pairs in the parking lot in 40 % of the cycles is established, which indicates the destruction of the boundary films of the lubricant.

With an increase in the concentration of the RVS additive from 2 to 4 %, the total wear of the leading and lagging surfaces increases 1.17 and 2.33 times, respectively. First of all, this is due to the high content of solid particles in the lubricant, which act as an abrasive, increasing wear on contact surfaces.

Similar qualitative changes were established for the coefficient of friction in rolling conditions with slip (Fig. 4). This indicator increases by 3 and 8 times with the concentration of the RVS additive of 0.5 % and 4 %, compared to the mixture of oil with 1.5 % RVS.

Further studies were aimed to establish mechanisms of increasing the tribotechnical properties of the transmission oil composition with the addition of RVS at a concentration of 1.5 %.

### 5.2 The Micro-Hardness influence of Contact Surfaces on Their Wear Resistance in Presence of Repair Material (RVS) in Lubricant

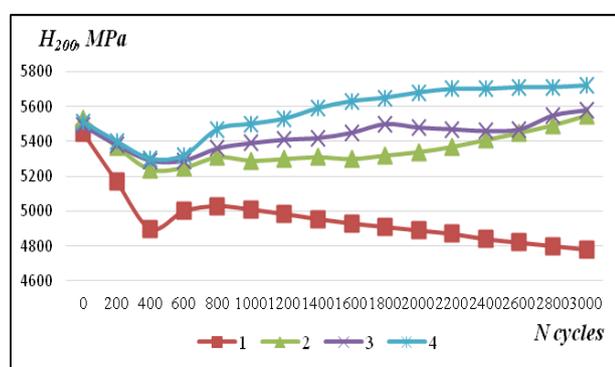
When lubricating contact surfaces with Okko GL-4 80w/90 oil without the addition of RVS, a significant difference in linear wear for the advanced and lagging surfaces, - 2.541 and 1.805 microns respectively, has been established during the experiment. The maximum wear is characteristic for the run-in period, with  $N \leq 500$  cycles (the total wear rate of the samples was  $(7,648 - 4,134) \cdot 10^{-8}$ ). It was during this period that a frequent breakdown of the lubricating layer was identified and a metallic contact of the surfaces was established. With the adaptation of the boundary adsorption layers, the wear rate decreases to  $(0.601 - 0.751) \cdot 10^{-8}$ .

Investigations of the change in the micro-hardness of the surface layer of the advanced

and lagging samples under dynamic load conditions have been carried out and the effect of the change in this parameter on the wear value has been established.

The highest wear, fixed at  $N \leq 500$ , is due to softening of the surface layer of the metal both on the leading and on the lagging surfaces (Fig. 5).

At this stage of deformation, the structural elements are fragmented and dislocations are accumulated. Changes in the magnitude of the shift along the slip tracks are especially pronounced in the first alternating cycles, characterized by an intensive decrease in the plastic component and an increase in the destructive component. The first stage of micro-plastic deformation is characterized by a more facilitated formation and movement of dislocations in the near-surface layers of crystalline materials [17]. According to Smekal's hypothesis, in real crystals there are voids that increase the chemical activity of nearby atoms and provide enhanced adsorption action [18]. Due to the activation of surface layers in the regime of frequent start-stop, boundary adsorption films are formed on contacting surfaces with thickness up to  $1.2 \mu\text{m}$ .



**Fig. 5.** Change of micro-hardness ( $H_{200}$ ) of surface layers of metal depending on the cycles number of operating time ( $N$ ) for Okko GL-4 80w / 90 oil (1, 2) and its composition with the addition of RVS (RVS at a concentration of 1.5 %) (3, 4): 1, 4 - surface; 2, 3 - lagging surface.

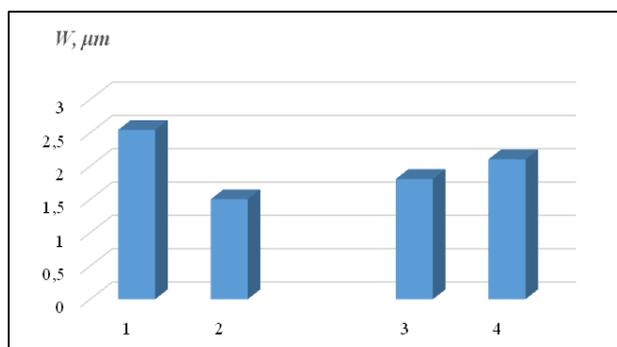
The different nature of the change in micro-hardness and wear on lagging and advanced surfaces is due to the complex stress state of the surface layer material, which results from the combined effect of contact stresses from normal loading to tangential forces. As the boundary layer forms and adapts, the hydrodynamic friction regime begins to dominate in the

contact. The effect of lubrication on contact endurance manifests itself through the peak of the hydrodynamic pressure in the exit zone of the surfaces from the contact, which creates a pronounced stress concentration: the resulting frictional forces in contact increase the stresses in the surface layer of the material on the lagging surface and reduce them on the leading surface [19]. According to the data given in [19], an increase in the stress in the surface layer on the lagging surface reduces its contact endurance during rolling with slippage. However, when lubricating with Okko GL-4 80w/90 mineral gear oil, the opposite effect is identified: the linear wear of the leading sample is twice as large as for the lagging one. The mechanism of this process is as follows: the influence of tangential alternating cyclic stresses on the metal surface is weakened with the formation of boundary adsorption layers at  $N \geq 500$ , the degree of hardening decreases. As softening of the leading surface occurred more intensively ( $H_{200}=4880 \text{ MPa}$  - leading,  $H_{200}=5250 \text{ MPa}$  - lagging surface; the micro-hardness of the initial surface is, on average,  $5500 \text{ MPa}$ ), thus the increase in wear is due to increased abrasion of the less hardened layer of the leading sample.

Adding 1.5 % RVS additive to the test lubricant results in an increase in wear rate during the run-in ( $N \leq 500$ ) by 15 %, compared to Okko GL-4 80w/90 pure oil. This is primarily due to dominance in contact at the initial stage of experiment of the abrasion wear, since the components of the used additive are relatively large particles of 1-10 microns in size. The introduction of such particles into the surface of the friction pairs increases the initial linear wear during the running-in of both the leading and lagging surfaces, and also results in the synchronized softening of the surface layers of the samples due to the permanent abrasion of the metal in the zone of tribological contact. On average, the micro-hardness of both the leading and lagging surfaces during the run-in period is reduced by  $200 \text{ MPa}$  (Fig. 5).

With the further run of  $N \geq 600$ , granular particles are introduced into the surface layers of the metal, the mechanochemical processes intensified between the components of the mixture of the minerals and catalysts of the RVS additive and the activated metal surface. These processes frame an increase in the micro-

hardness of the surface layer of the samples and a decrease in the wear rate to  $0.48 \cdot 10^{-8}$ . The total linear wear of friction pairs with the RVS additive in the transmission oil is reduced, on average, by 17 %, compared to the oil without the additive (Fig. 6). On the contact surfaces, the boundary adsorption layers of the lubricating material are formed up to  $1.15 \mu\text{m}$  thick.



**Fig. 6.** Linear wear ( $W$ ) of the leading (1,2) and lagging (3,4) surfaces in the friction of steel 42Cr4 in the environment of pure gear oil (1,3) and its suspension with the addition of RVS (2,4).

When introducing the RVS additive into the lubricant, not only the quantitative index of wear of friction pairs changes, but also an interesting pattern appears in the qualitative characteristic of the wear resistance of contact surfaces. The wear of the leading surface is 1.4 times less than the wear of the lagging surface. Correlation of this parameter with micro-hardness of contact surfaces— $H_{100}$  on the leading surface is identified and, on average,  $225 \text{ MPa}$  higher than the similar parameter identified for the lagging surface (Fig. 5). The determining effect of the micro-hardness of contact surfaces on their wear was as well established in the other works [20,21].

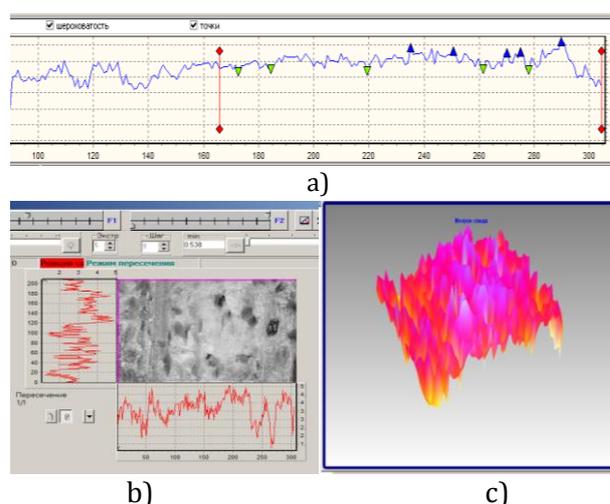
### 5.3 Effect of the RVS Additive on the Equilibrium Roughness and Gradient Distribution of Micro-Hardness over the Depth of the Metal

During friction are accompanied by plastic deformation of the surface layers. Thus, a study on structural changes near the friction surface is of the greatest interest. When determining the qualitative side of wear, it is necessary to investigate all the stages of the transformations that occur on the surface and in the near-surface layers of metal.

An important stage in the operation of contact surfaces under dynamic loading conditions is the

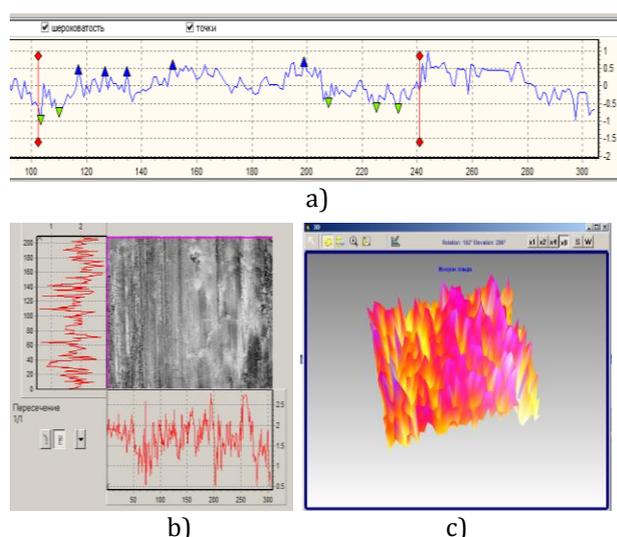
self-organization of dissipative structures, the effectiveness of which largely determines the wear resistance of friction pairs. One of the integral components of the process of self-organization is the establishment of an equilibrium (operational) roughness of contact surfaces in the process of friction. The change in this parameter is significantly affected by the load, temperature, lubricant and other parameters. Since only the composition of the lubricant changed under the experimental conditions, the study considers its effect on the formation of the micro-geometry of the friction surface.

The analysis of topography was carried out on a lagging surface with the help of a contactless 3D profiler "Mikron-gamma" [16]. When using pure transmission oil as a lubricant, there are following micro-geometry parameters of the surface layer of the sample:  $R_a=0.35 \mu\text{m}$ ,  $R_z=1.341 \mu\text{m}$  (Fig. 7). In comparison with the initial surface ( $R_a=0.45 \mu\text{m}$ ,  $R_z=1.65 \mu\text{m}$ ), the main parameters of the roughness decrease insignificantly. First of all, this is due to the effective lubricating properties of the oil being examined. It is the adsorption activity of lubricant components and the activation of friction contact surfaces that provide an effective structural adaptability that manifests itself in the formation of boundary adsorption layers on contact surfaces. These layers exhibit effective shielding properties, preventing direct metallic contact of friction pairs, which provides insignificant changes in the initial micro-geometry.



**Fig. 7.** Topography of the lagging surface after 3000 cycles of operating time in the rolling condition with slip (lubrication - transmission oil Okko GL-4 80w/90): a) scan route; b) 2D surface under different illumination with longitudinal and transverse profile-grams; c) 3D model of the surface.

When the repair and restoring composition (RVS) is introduced into the lubricant, the micro-geometry of the contact surfaces changes significantly. After 3000 operating cycles in non-stationary friction conditions, the roughness parameters studied were  $Ra=0.26\mu m$ ,  $Rz=1.217\mu m$ . A decrease in the average arithmetic deviation of the profile within the base length, on average in 2 times compared with the initial surface, indicates a smoothing of the friction surface in the longitudinal and transverse directions (Fig. 8).



**Fig. 8.** Topography of the lagging surface after 3000 cycles of operating time in rolling condition with slip (lubrication - transmission oil Okko GL-4 80w / 90 + 1.5 % RVS): A) - scanning route; B) - 2D surface under different illumination with longitudinal and transverse profile-grams; C) - 3D model of the surface.

The main factor ensuring the formation of a smoother surface is the presence in the lubricant of a finely dispersed additive, the components of which intensifying the elastic-plastic deformation of the surface layers of the metal, pressing into the surface, and interacting with it. Due to the deformation changes, the hardening of the surface layers of metal occurs and their wear resistance increases. Thus, at the initial stage, the energy-congested local contact zones are destroyed, and the formation of a new micro-relief provides a reduction in the level of dissipative processes.

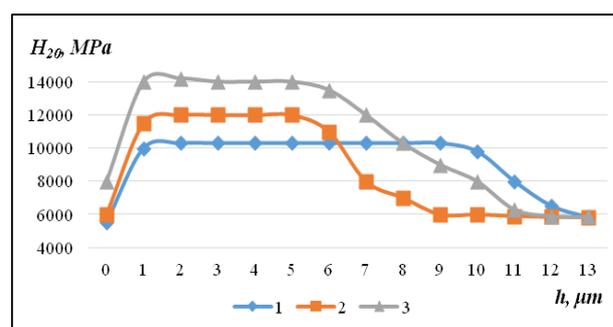
However, the structural adaptability of the investigated lubricants and the material of contact surfaces are manifested not only in the formation of stable boundary lubricating films and in the change in the micro-geometry of the

surface. The mechanism of this phenomenon is wider and is affecting the underlying layers of the metal.

The metallographic studies carried out revealed the dispersion of the structure of the initial steel after hardening of 42Cr4, which is difficult to differentiate under the microscope. The structure is similar to the troostite-martensite or bainite (needle troostite or intermediate transformation product). The gradient of mechanical properties up to  $2\mu m$  is positive. The micro-hardness of the near-surface layers is  $H_{20}=10300 MPa$  at a distance of up to  $10\mu m$  in depth; at a distance of  $12-13\mu m$  the micro-hardness is  $5800-6000 MPa$ , which corresponds to the micro-hardness of the base material (Fig. 9).

When lubricating with pure mineral gear oil on a lagging surface after 3000 cycles under dynamic loading conditions, a significant increase in micro-hardness at a depth of  $1-5.6\mu m$  was identified (Fig. 9).

The addition of the RVS repair- restoring composition provides even more hardening of the near-surface metal layers - their micro-hardness increases on average by 1.36 times, compared to the initial surface, and the depth of the hardened layer covers up to  $10\mu m$  as shown in (Fig. 9).



**Fig. 9.** Addition of change of micro-hardness of near-surface layers of metal in depth (lagging surface): 1 - initial material, 2 - after 3000 operating cycles in lubrication environment Okko GL-4 80w / 90, 3 - after 3000 operating cycles in lubrication environment Okko GL-4 80w / 90 + 1.5% RVS.

Thus, the presence in the lubricant of the repair-restoring composition RVS intensifies the elastic-plastic changes not only in the surface layers of the material, but also affects the near-surface layers of the metal. It was established in [22] that during the abrasive wear process, a significant

part of the energy is converted into a metal in the potential deformation energy of the near-surface layers. The greater the ability of the materials in storing the energy, the higher is their durability. Similar patterns are identified in the case under study. The increase in the deformation component of the surface metal layers in the lubricating medium with the addition of RVS activates diffusion processes in the friction zone, which is manifested in an increase in the mechanical strength of both surface and near-surface layers of the metal. These structural changes contribute to an increase in wear resistance of the contacting pairs.

The studies of the degree of hardening have established a positive gradient in the variation of this parameter in the near-surface layers, which positively influences the working capacity of the contacting pairs, according to the molecular-mechanical theory of friction.

## 5. CONCLUSION

The conducted study allows concluding that the introduction of RVS in the transmission oil in a concentration of 1.5 % provides an increase in wear resistance of the contact surfaces by 1.45 times in the rolling with slippage conditions. The introduction of fine particles of the test additive causes the intensification of mechanochemical processes in tribotechnical contact, which manifests itself in an increase in the microhardness of the surface layers of the metal, hardening the surface layers of the metal to a depth of 10  $\mu\text{m}$ , and forming boundary lubricating material films that are stable to dynamic loading conditions. If RVS is present in the lubricant, the microhardness of the surface layers increases by 900 and 30 MPa for the leading and lagging surfaces, respectively, which helps to reduce wear by 1.4 times for the leading surface. These processes reveal the structural adaptability of structural materials under study, the consequence of which is a qualitative and quantitative change in the microgeometry of the friction surfaces. By optimizing the concentration of the RVS additive, it is possible to control the dissipative processes in contact and to increase the wear resistance of materials in friction.

## REFERENCES

- [1] L. Ivschenko, V. Tsyganov, M. Frolov, *The structural self-organization of details of tribocoupling in the conditions of the complicated thermodynamic loading*, Visnyk Chernihiv State Technological University, vol. 59, no. 3, pp. 5-11, 2012. (in Ukraine)
- [2] L.I. Ivshchenko, V.V. Tsyganov, I.M. Zakiev, *Features of the wear of tribojoints under three-dimensional loading*, Journal of Friction and Wear, vol. 32, iss. 1, pp. 8-16, 2011, doi: [10.3103/S1068366611010065](https://doi.org/10.3103/S1068366611010065)
- [3] T.B. Fedorovich, S.E. Aleksandrovich, *Physical Basis of the Innovative Technologies of Processing Machines and Mechanisms*, Scientific Journal of KubSAU, vol. 2, no. 86, pp. 1-24, 2013. (in Ukraine)
- [4] Presentation of RVS-technology. ZAO "NPK Russpromremont". St. Petersburg, available at: [www.rvs-tech.ru/eng/rvs\\_description.html](http://www.rvs-tech.ru/eng/rvs_description.html), accessed: 29.08.2019.
- [5] S.N. Sharifullin, A.V. Dunayev, *On the mechanism of the formation of wear-resistant coatings on the friction surfaces of technical products in the presence of these drugs*, IOP Conference Series: Materials Science and Engineering, vol. 134, pp. 1-4, 2016, doi: [10.1088/1757-899X/134/1/012025](https://doi.org/10.1088/1757-899X/134/1/012025)
- [6] B. Skrbek, V. Nosek, M. Kysel, P. Sláma, *The solution of the modern pair of guide and valve of piston engines*, in 1th international conference about Resent Trends in Structural Materials, 25-26 November, 2010, Dobruany, Czech Republic, pp. 60-69, ISBN 978-80-254-8683-2.
- [7] R.G. Nigmatullin, V.Yu. Sholom, L.Sh. Shuster, I.M. Nigmatullin, *The increase of the efficiency of lubricants with friction geomodifiers*, Vestnik UGATU, vol. 46, no. 1, pp. 51-56, 2012, (in Russian)
- [8] St. Bill, *Improving the Friction Power of Gears and Bearings*, Gear Solutions - CFD Simulation of Power Losses and Lubricant Flows in Gearboxes, pp. 43-45, 2018.
- [9] A.A. Bainov, S.V. Firstov, *RVS-IP1 for in-place repair of equipment*. in Welding. Renovation. Tribotechnology: abstracts of the VIII Ural Scientific and Practical Conference. - Nizhny Tagil: Ural Federal University, pp. 116-120, 2017, (in Russian)
- [10] K.N. Dolgoplov, D.N. Lyubimov, A.G. Ponomarenko, G.G. Chigarev, M.V. Boiko, *The structure of the lubricating layers appears during friction in the presence of additives of mineral friction modifiers*, Journal of Friction and Wear, vol. 30, p. 377, 2009, doi: [10.3103/S1068366609050134](https://doi.org/10.3103/S1068366609050134)

- [11] M.A. Skotnikova, N.A. Krylov, V.V. Medvedeva, *Influence of the Magnetic Component of Geomaterials on Properties of Friction Pairs*, *Procedia Engineering*, vol. 150, pp. 612-617, 2016, doi: [10.1016/j.proeng.2016.07.053](https://doi.org/10.1016/j.proeng.2016.07.053)
- [12] R.P. Didyk, P.B. Aratskiy, *Increase of Mining and Smelting Equipment Life on the Way of Tribological Barrier Overcoming*, *Metallurgical and Mining Industry*, vol. 3, no. 2, pp. 67-72, 2011.
- [13] A. Grossl, *Development of Powertrain and Drive Line Components without Liquid Lubrication*. Technical Report Work-package 5 Phase Transition Lubrication. OFP - Oil-Free Powertrain, FZG, Technical University of Munich-Germany. Contract No: IPS-2001-CT-98006, 2004.
- [14] St. Bill, H. Fritsch, *Reconditioning and Durable Wear Protection for Gear Boxes and Bearings and Wind Turbines*, *VGB PowerTech Journal*, vol. 9, pp. 1-5, 2009.
- [15] T.M.A. Al-quraan, *A Manifestation of Non-Hydrodynamic Factors in Steady-State Conditions of Friction*, *Journal of Mechanical Engineering*, vol. 14, no. 2, pp. 111-126, 2017.
- [16] S.R. Ignatovich, I.M. Zakiev, D.I. Borisov, V.I. Zakiev, *The technique for studying the physico-mechanical properties of surface layers of materials during fatigue with the use of the multifunctional device "Micron-gamma"*, *Aviation and space engineering and technology*, vol. 16, no. 8, pp. 163-166, 2004. (in Ukraine)
- [17] L.M. Rybakova, L.I. Kuksenova, *The structure and wear resistance of metal*, M. Mashinostroenie, 1982. (in Russian)
- [18] B.I. Kostetskiy, *Wear resistance of machine parts*, Kiev-Technics, 1950. (in Ukraine)
- [19] K.A. Krylov, M.E. Haymzon, *Durability of air craft friction units*, M. Transport, 1976. (in Russian)
- [20] T.M.A. Al-quraan, O.O. Mikosyanchik, R.G. Mnatsakanov, *The Effect of the Slippage Degree at Rolling with Slipping on the Wear Resistance of Contact Surfaces*, *Mechanical Engineering Research*, vol. 6, no. 2, pp. 48-61, 2016, doi: [10.5539/mer.v6n2p48](https://doi.org/10.5539/mer.v6n2p48)
- [21] O.A. Mikosyanchik, R.G. Mnatsakanov, *Tribotechnical characteristics of cast iron with a steel coating in lubrication medium under unsteady modes*, *Journal of Friction and Wear*, vol. 38, iss. 4, pp. 279-285, 2017, doi: [10.3103/S1068366617040109](https://doi.org/10.3103/S1068366617040109)
- [22] V.S. Popov, N.N. Brykov, *Metallurgical aspects of wear resistance of steels and alloys*. Z: VPK Zaporizhzhya, 1996. (in Ukraine)