MECHANICAL LOADING SYSTEMS SAFETY PROCESSES MODELING

To cite this article: Iurii Savchenko *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1164** 012070

MECHANICAL LOADING SYSTEMS SAFETY PROCESSES MODELING

Iurii Savchenko[1], Alexander Shapoval[2], Viktoriya Kozechko[3], Volodymyr Voskoboynik[4], Oksana Khrebtova[2], Sergii Shlyk[2]

1 Department of Cybersecurity and Information Technology, University of Customs and Finance, 2/4, Vladimir Vernadsky Street, Dnipro, 49000, Ukraine
2 Department of Manufacturing Engineering, Kremenchuk Mykhailo Ostrohradskyi National University, 20, Pershotravneva Street, Kremenchuk, 39600, Ukraine
3 Department Of Technologies of Mechanical Engineering and Materials Science, Dnipro University of Technology, Avenue Dmytra Yavornytskoho, 19, Dnipro, 49005, Ukraine
4 Department of Information Protection, Zaporizhzhya Polytechnic National University, 64, str. Zhukovsky, Zaporozhye, 69063, Ukraine

E-mail: alexshap.as@gmail.com

Abstract. Mechanical means which are directly related to the information support path (locators, observation stations, accompaniment, detection, localization, etc.) require special attention within the framework of the technical channels of receiving information. Their accurate and stable performance is of the utmost importance. Loss of the mechanical properties occurs during operation, that is material wear. To improve the quality of mechanisms and to ensure the stability of the radio-electronic means, the authors of the paper consider the possible mode of friction geoactivators in the friction unit parts of machines. The studies of the rubbing surfaces chemical composition after being processed by the geoactivator demonstrate that the components of the geoactivator diffuse into the surface layers of the material and form glass-crystalline layers, which are the solutions of the geoactivator components in the phase components of the surfaces steels and cast irons. The studies of mechanical properties have shown that the hardness and wear resistance of the surface layer increases and the roughness of contacting surfaces gets reduced.

1. Introduction

Mechanical means which are directly related to the information support path (locators, observation stations, accompaniment, detection, localization, etc.) require special attention within the framework of the technical channels of receiving information. Their accurate and stable performance is of the utmost importance. Loss of the mechanical properties occurs during operation, that is material wear. An essential obstacle to the increase of machines' and mechanisms' durability is the wear of their nodes during friction. The loss due to wear and the importance of the problem of increasing wear resistance and durability of machines can be demonstrated as follows: 80-90% of the machines failures are due to the nodes wear and the loss of funds in mechanical engineering reaches up to 5% of the national income.

To prevent the machines and mechanisms parts wear, a method of regenerating rubbing nodes, using friction geoactivators, was developed. This method is completely different from the current ones due to the fact that it not only reduced the friction coefficient but also allows to partially restore the functional condition of the worn surface on-the-job.

Geoactivator is a powder material, made on the basis of the domestic natural material – serpentinite, which contains a lot of chemical elements (32), with the highest of Mg (≈ 23%), Si (18 - 21%), and their oxides SiO2 (33,4 – 44,5%), MgO (25,6 – 38,0%).

Silicates play a key role in the processes which occur in the friction units. Silicates are sulfuric chemical compounds containing silica SiO2, which can create silician acid complexes of various forms (chains, hexagons, ribbons, etc.).

The properties of silicates are defined by their composition, the type of forces among the ions, the structure of crystalline lattices, and their defectiveness. Silicate hardness ranges from 1 (talc) to 6 ... 7 (forsterite) units on the Moos scale.

2. The main part of the article

The basis of silicates with small cations is a tetrahedral orthogroup [SiO4]4 with Si4 in the middle and 4O2 at the top of the tetrahedron with the ribs length of approximately 2,6 Å. Tetrahedrons in silicates can interconnect by common oxygen vertices to silica acid complexes. Every two neighboring tetrahedrons have a common vertex. At the decrease of the O/Si atomic ratio in the silicates, the number of tetrahedrons increases.

The geoactivators comprise of different forms of the magnesium silicates with a common formula of nMgO·mSiO2 or with the substitution Mg2+ ↔ Fe2+ (3Mg2+ ↔ 2Fe3+), (Mg, Fe)2[SiO4] (to be more precise, considering constitutional or crystallization water n(Mg, Fe)O·mSiO2·kH2O).

These silicates can form solid solutions of limited and unlimited solubility, as the result of substitutions of the Mg2+ lattice cations by other cations engaged in similar packaging spaces from large ions O2-. It is also possible to replace the Mg2+ cations with cations of greater valence (Al3+, Fe3+) with the occurrence of cationic vacancies. Vacancies, distortions in lattices due to differences between the ion radii of mutually replaced cations, the location of the portion of the latter in the interstices of the lattice, dislocations are the defects of silicate lattices which can change the diffusion rate, accelerate chemical reactions, increase sintering and other physicochemical characteristics.

Natural silicates which are the components of the geoactivators contain all possible phases in one way or another. Of these, forsterite and enstatite at about 50% concentration.

Forsterite has a rhombic crystal lattice with the following parameters a = 4,770 Å, b = 10,260 Å, c = 5,990 Å. Forsterite is stable within the entire temperature range with the hardness of 7 units on the Moos scale. The most important quality of the forsterite is the ability to form solid solutions.

Enstatite has a structure consisting of infinite chains of various types with a general formula of Mg2[Si2O6]. Enstatite has two polymorphic forms - enstatite and clinoestatite. The structure of main construction materials – steels and cast irons, has carbon in the form of cementite (chemical compound Fe – Fe3C) practically at any concentration, according to the Fe – C (Fe – Fe3C) state diagram. When the carbon is less than or equal to 0.8%, cementite is part of perlite, when carbon is more than 0.8% - cementite is also observed in free form.

Pic. 1 demonstrates cementite lattice. Cementite has rhombic lattice with the following parameters: a = 5,077 Å, b = 6,776 Å, c = 4,515 Å. The comparison of the cementite and forsterite lattices (table 1) showed almost complete parameters coincidence over two axes.

Geoactivator particles that lubricated in the friction zone are exposed to contact pressure, which in the micro-block of the contact spot may reach up to 1000 MPa. As a result, the destruction of geoactivator crystals and the formation of active radicals occurs. The similarity of cementite and forsterite latices allows silicate compounds to be formed on the steel surface at no significant distortion of their latices, which is very important for the diffusion processes.

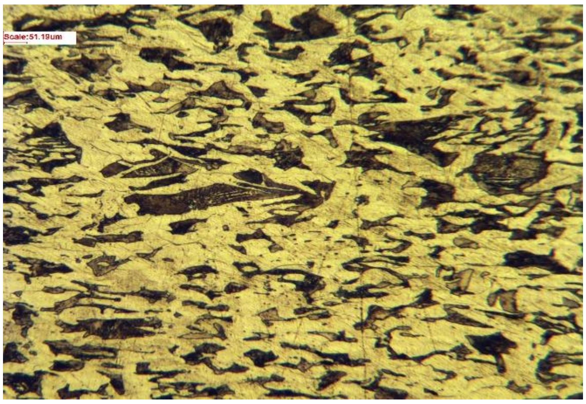
At the same time, geoactivator crystals having higher hardness than the material of the part, micro polish the friction surfaces and remove oxide films, preparing the contacting surfaces to be processed by the geoactivators. At the same time, the roughness of the surface decreases along with its activation.

Under the contact loads (at the material flow limit level), the substitution of Mg crystals cations in the geoactivator crystals to the Fe cations to form solid solutions takes place. As a result of these processes, a glass-crystalline layer is formed at the friction surface, firmly merged to the surface of the part, and consisting of various compounds (from endless layers and chains to the amorphous phase), interconnected and capable of further phase transformations.

This process continues until the entire surface of the metal is saturated with a geoactivator. The process ends with the formation of the stable crystal structure of the surface layer and adjacent to the surface layers of the metal. The completion of the surface saturation process with the geoactivator is accompanied by a sharp decrease of the friction coefficient and the temperature of the friction node.

Thus, the processes occurring in the friction zone during processed by the geoactivator can be divided into four stages:

- surface activation;
- absorption of the geoactivators by the top layers of the metal;
- diffusion of the geoactivator from the top layer into the metal;
- regeneration of the friction surfaces and roughness decrease.



Picture 1 – Microstructure of the surface layers, x 300

The studies of the chemical composition of the friction surfaces made of 45 and 45 XH steel after processing with a geoactivator for 15, 20, and 40 hours of uninterrupted operation have been conducted. Metallographic oblique grinds were made for the study.

Table 1 – Cementite and forsterite latices parameters

	The parameter value, Å		
Forsterite	a = 4,770	b = 10,260	c = 5,990
Cementite	c = 4,515	2 a = 10,154	b = 6,726
Parameters deviation, A	0,255	0,106	0,736
Parameters deviation, %	5	1	11

The study of the friction surfaces chemical composition processing by the geoactivator showed that the components of the geoactivator diffuse into the surface layers of the material and form glass-crystal layers, which are the solutions of the geoactivator components in the phase components of steels and cast irons. The penetration depth is 0,1…0,2 mm.

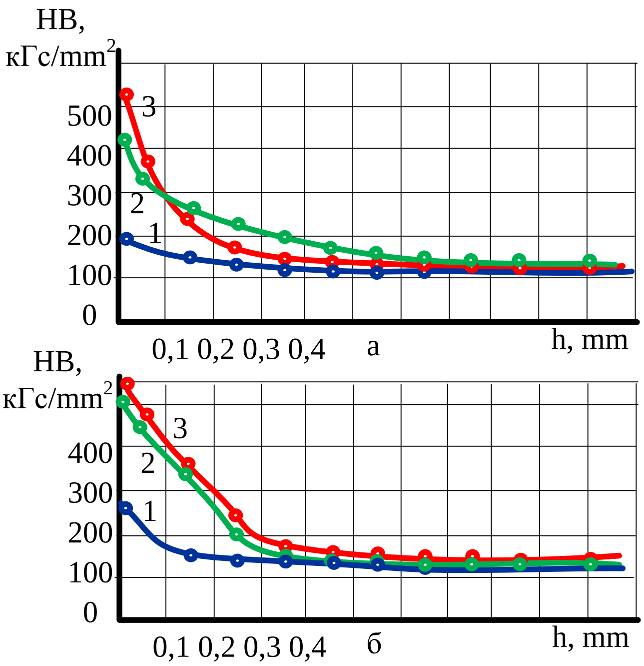
The mechanical properties of contacting surfaces are investigated: microhardness, roughness, wear resistance.

Microhardness was measured with help of the PMT-3 tool according to GOST 9450-76 at the load of 50 and 100 kg/mm2. The microhardness study at different depths of the metal surfaces treated with geoactivators allowed us to establish a certain dependency. The hardness of the surface layer revealed on the micro slice in the form of a light strip, differs from the initial hardness of the processed material and, as a rule, significantly exceeds it (Pic. 1).

The microhardness of the metal equals the initial microhardness of the metal at the depth of 0,2 mm and above. This can be seen by the microhardness and layer depth dependency curves, presented on the Pic. 2. Consideration of these curves shows that the maximum increase in hardness is observed at the depth (up to 0.04 mm), where the lower part of the modified layer ends and the subsurface layer begins.

The mechanical properties studies demonstrated that the hardness of the surface layer gets increased by 1,5…3,5 times, wear resistance gets increases 4…5 times, roughness o the contacting surfaces decreases 2,5…10 times (table 2).

Thus, the effect of geomodifiers leads to the occurrence of a unique tribological effect.



Picture 2 – Relationship of the microhardness parameter against the depth of the layer:
a – steel 45; б – steel 40XH; 1 – tests without geoactivator; 2 – tests with geoactivator №1; 3 – tests with geoactivator №2.

3. Conclusions

The results of the conducted studies demonstrated that adding geomodifiers based on the natural material – serpentine leads to the increase of reliability and durability of the treated friction nodes by 2…3 times, the hardness of the surface layer gets increased by 1,5…3,5 times, wear resistance gets increases 4…5 times, roughness of the contacting surfaces decreases 2,5…10 times.

The obtained results allowed us to establish the nature of the wear and disclose the mechanism of the wear-resistant layer formation with applied friction geoactivators, a change in the mechanical properties of materials, the geometric characteristics of the friction surfaces, and the operation modes of mechanisms on the wear and restoration of parts with applied geoactivators.

Table 2 – Mechanical properties of steels

Material	Mechanical properties		
	Hardness HB, kg/mm²	Roughness R_a, mcm	Wear resistance
Steel 45, initial state	179	2,5	$2{,}1\cdot10^{-11}$
Steel 45, processed by the geoactivator	550	0,8	$0{,}6\cdot10^{-11}$
Steel 40XH, initial state	200	1,25	$1{,}5\cdot10^{-11}$
Steel 40XH, processed by the geoactivator	585	0,2	$0{,}4\cdot10^{-11}$

The approach proposed by the authors will improve the quality of the radio-electronic equipment mechanical products manufacturing, will increase its durability, reduce the level of lateral deviations and ensure the reliability of the information transmission channels.

4. References

[1] Savchenko Iu, Gurenko A and Naumenko O 2016 The cutting-edge industrial technology of mining tool manufacturing *Mining of Mineral Deposits* **10 4** 105–110
[2] Bast J, Gorbatyuk S M, and Kryukov I Yu 2011 Horizontal hcc-12000 unit for the continuous casting of semifinished products *Metallurgist* **55(1-2)** 116-118
[3] Surianinov M and Krutii Y 2018 To the solution of the problem of bending of a cylindrical shell by the boundary elements method *MATEC Web of Conferences* **230**

[4] Krutii Y, Suriyaninov M and Vandynskyi V 2018 Analytic formulas for the natural frequencies of hinged structures with taking into account the dead weight *MATEC Web of Conferences* **230**
[5] Markov O E, Gerasimenko O V, Shapoval A A, Abdulov O R and Zhytnikov R U 2019 Computerized simulation of shortened ingots with a controlled crystallization for manufacturing of high-quality forgings *Int J of Advanced Manufacturing Technology* **103(5–8)** 3057–3065
[6] Shapoval A, Savchenko I and Markov O 2021 Determination coefficient of stress concentration using a conformed display on a circle of a single radius *Solid State Phenomena* **316** 928-935
[7] Zagirnyak M, Mamchur and Kalinov A 2010 Elimination of the influence of supply mains low-quality parameters on the results of induction motor diagnostics *The XIX International Conference on Electrical Machines - ICEM 2010*
[8] Zagirnyak M, Maliakova M and Kalinov A 2015 Analysis of electric circuits with semiconductor converters with the use of a small parameter method in frequency domain", *COMPEL – The international journal for computation and mathematics in electrical and electronic engineering* **34 3** 808-823
[9] Lutsenko I 2015 Identification of target system operations Development of global efficiency criterion of target operations *Eastern-European Journal of Enterprise Technologies* **2 2** 35–40
[10] Lutsenko I, Vihrova E, Fomovskaya E and Serdiuk O 2016 Development of the method for testing of efficiency criterion of models of simple target operations Eastern-European Journal of Enterprise Technologies 2 4 42–50
[11] Gorbatyuk S, Shapoval A, Mos'pan D and Dragobetskii V 2016 Production of periodic bars by vibrational drawing *Steel in Translation* **46 7** 474-478
[12] Kurpe O, Kukhar V, Puzyr R, Burko V, Balalayeva E and Klimov E 2020 Electric Motors Power Modes at Synchronization of Roughing Rolling Stands of Hot Strip Mill. *CONFERENCE 2020, PAEP* **510**
[13] Kukhar V, Grushko A and Vishtak I 2018 Shape indexes for dieless forming of the elongated forgings with sharpened end by tensile drawing with rupture *Solid State Phenomena* **284** 408–415
[14] Grushko A, Kukhar V and Slobodyanyuk Y 2017 Phenomenological model of low-carbon steels hardening during multistage drawing *Solid State Phenomena* **265** 114–123
[15] Haikova T, Puzyr R, Savelov D, Dragobetsky V, Argat R and Sivak R 2020 The Research of the Morphology and Mechanical Characteristics of Electric Bimetallic Contacts *CONFERENCE 2020, PAEP* **579**
[16] Shapoval A, Drahobetskyi V, Savchenko I, Gurenko A and Markov O 2020 Profitability of production of stainless steel + zirconium metals combination adapters *Key Engineering Materials* **864** 285-291
[17] Zarapin A, Shur A and Chichenev N 1999 Improvement of the unit for rolling aluminum strip clad with corrosion-resistant steel *Steel in Translation* **29(10)** 69-71
[18] Artiukh V, Mazur V ahd Adamtsevich A 2017 Priority influence of horizontal forces at rolling on operation of main sheet rolling equipment *MATEC Web of Conferences* **106**
[19] Savchenko I, Shapoval and Gurenko A 2020 Modeling dynamic parameters of hard alloys during shock wave regeneration *IOP Conference Series: Materials Science and Engineerin*. **969(1)**
[20] Zagirnyak M, Kalinov A, Melnykov V and Kochurov I 2015 Correction of the operating modes of an induction motor with asymmetrical stator windings at vector control *International Conference on Electrical Drives and Power Electronics* **259**
[21] Hrudkina N, Aliieva L, Markov O, Marchenko I, Shapoval A, Abhari P and Kordenko M 2020 Predicting the shape formation of hollow parts with a flange in the process of combined radial-reverse extrusion *Eastern-European Journal of Enterprise Technologies* **4 1 (106)** 55-62.
[22] Shvab'yuk V, Krutii Y and Sur'yaninov M 2016 Investigation of the Free Vibrations of Bar Elements with Variable Parameters Using the Direct Integration Method *Strength of Materials* **48(3)** 384-393

[23] Markov O, Gerasimenko O, Aliieva L and Shapoval A 2019 Development of the metal rheology model of high-temperature deformation for modeling by finite element method *EUREKA, Physics and Engineering* **(2)** 52-60
[24] Puzyr R, Shchetynin V, Arhat R, Sira Yu, Muravlov V and Kravchenko S 2021 Numerical modeling of pipe parts of agricultural machinery expansion by stepped punches *IOP Conference Series: Materials Science and Engineering* **1018**
[25] Shapoval A, Kantemyrova R, Markov O, Chernysh A, Vakulenko R and Savchenko I 2020 Technology of production of refractory composites for plasma technologies *Proceedings of the 25th IEEE Int. Conf. on Problems of Automated Electric Drive Theory and Practice* **9240830**
[26] Kondratenko V, Sedykh L, Mirzakarimov A and Aleksakhin A 2020 Static analysis and strength calculation of drive shaft of large-scale cone crusher *E3S Web of Conferences* **193**
[27] Malinov L, Malysheva I, Klimov E, Kukhar V and Balalayeva E 2019 Effect of Particular Combinations of Quenching *Tempering and Carburization on Abrasive Wear of Low-Carbon Manganese Steels with Metastable Austenite. Materials Science Forum* **945** 574–578
[28] Khrebtova O, Zachepa N, Zachepa I, Mykhalchenko G and ProkopenkoV 2020 Formation of Starting Torque of Double-Fed Induction Motor *Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice* **9240786**
[29] Khrebtova O 2020 Forming the induction motor torque when starting *Technical Electrodynamics* **(5)** 40-44
[30] Bogoboyashchii V, Vlasov A and Izhnin I 2001 Mechanism for conversion of the conductivity type in arsenic-doped p-CdxHg1-xTe subject to ionic etching *Russian Physics Journal* **44(1)** 61-70
[31] Markov O, Kukhar V, Zlygoriev V, Shapoval A, Khvashchynskyi A and Zhytnikov R. 2020 Improvement of Upsetting Process of Four-Beam Workpieces Based on Computerized and Physical Modeling *FME Transactions* **48(4)** 946–953
[32] Khrebtova O, Shapoval A, Mos'pan D, Dragobetsky V, Gorbatyuk S and Markov O 2021 Automatic temperature control system for electrocontact annealing of steel welding wire. *Metallurgist* **65 (3-4)**
[33] Zagirnyak M, Maliakova M and Kalinov A 2016 Analysis of operation of power components compensation systems at harmonic distortions of mains supply voltage *Joint International Conference – ACEMP 2015: Aegean Conference on Electrical Machines and Power Electronics, OPTIM 2015: Optimization of Electrical and Electronic Equipment and ELECTROMOTION 2015: International Symposium on Advanced Electromechanical Motion Systems* **355**
[34] Bogoboyashchii V and Inzhin I 2000 Mechanism for conversion of the type of conductivity inp-Hg1-xCdxTe crystals upon bombardment by low-energy ions *Russian Physics Journal* **43 8** 627-636
[35] Belas E, Bogoboyashchyy V, Grill R, Izhnin I, Vlasov A and Yudenkov V 2003 Time relaxation of point defects in p- and n-(HgCd)Te after ion milling *Journal of Electronic Materials* **32 7**
[36] Zagirnyak M, Prus V and Nikitina A 2006 Grounds for efficiency and prospect of the use of instantaneous power components in electric systems diagnostics *Przeglad Elektrotechniczny* **82 12** 123-125
[37] Prus V, Nikitina A, Zagirnyak M and Miljavec D 2011 Research of rnergy processes in circuits containing iron in saturation condition *Przeglad Elektrotechniczny* **87 3** 149-152
[38] Zagirnyak M, Mamchur D and Kalinov A 2012 Comparison of induction motor diagnostic methods based on spectra analysis of current and instantaneous power signals *Przeglad Elektrotechniczny* **88 12** 221-224
[39] Zagirnyak M, Mamchur D and Kalinov A 2012 Induction motor diagnostic system based on spectra analysis of current and instantaneous power signals *IEEE SOUTHEASTCON 2014* **1**
[40] LutsenkoI, Fomovskaya E, Oksanych I, Koval S and Serdiuk O 2017 Development of a verification method of estimated indicators for their use as an optimization criterion *Eastern-European Journal of Enterprise Technologies* **2 486** 17-23

[41] Salenko Y, Puzyr R, Shevchenko O, Kulynych V and Pedun O 2020 Numerical Simulation of Local Plastic Deformations of a Cylindrical Workpiece of a Steel Wheel Rim *Simulation and Manufacturing III. DSMIE 2020* **1** 442 – 451
[42] Haikova T, Puzyr R and Levchenko R 2020 Experimental Studies on the Stress-Strain State under Drawing Aluminum–Copper Bimetal Parts Rectangular in Plan *Russian Journal of Non-Ferrous Metals* **61 4** 404–412
[43] Zagirnyak M, Zagirnyak V, Moloshtan D, Drahobetskyi V and Shapoval A 2019 A search for technologies implementing a high fighting efficiency of the multilayered elements of military equipment *Eastern-European Journal of Enterprise Technologies* **6/1 (102)** 33–40
[44] Dragobetskii V, Savchenko I, Pavlenko O, Parschina E, Gurenko A and Markov O 2020 Comparative Assessment of Multilayer Waveguide Manufacturing Technologies *Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice* **9240865**