Problems of Tribology, V. 29, No 1/111-2024, 25-31

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

DOI: https://doi.org/10.31891/2079-1372-2024-111-1-25-31

Study of Wear Resistance of Cylindrical Parts by Electromechanical Surface Hardening

D.D. Marchenko*, K.S. Matvyeyeva

Mykolayiv National Agrarian University, Mykolayiv, Ukraine
**E-mail: marchenkodd@mnau.edu.ua*

Received: 15 January 2024: Revised 30 January 2024: Accept 10 February 2024

Abstract

The work scientifically substantiates the use of an effective technology for increasing the wear resistance of cylindrical parts, using the example of protective sleeves of cantilever pumps, due to electromechanical surface hardening. A review of research was carried out and it was established that the achievement of the highest values of microhardness of the surface layer at a depth of up to 1.2 mm is possible during electromechanical processing of protective sleeves of cantilever pumps. The application of various modes and schemes of electromechanical surface hardening (EMSH) is accompanied by a change in structure and, as a result, an increase in the hardness of the surface layer of the bushings. The actual contact area of the tool roller with the processed surface and the depth of the temperature-deformation effect depend on the physical and mechanical properties of the materials and the pressing force. The formation of a temperature gradient in the hardened zone at a depth of up to 1.2 mm from the surface has been proven. Metallographic analysis of the surfaces of the sleeves treated by EMSH shows the formation of a white layer with reduced etchability and increased hardness in the hardening zones. The results of the X-ray structural analysis confirmed the formation of the martensite phase in the hardening zone. The microhardness of the hardened steel zone increased by 2.6...3.6 times compared to the initial values at a depth of up to 1 mm from the surface, depending on the materials. In the case of their overlap, the alternation of a fully hardened zone, a partially hardened zone, and a self-relief zone is observed. At the same time, the microhardness of steels along the surface depends on the hardening scheme.

Wear tests under friction conditions of parts of cantilever pumps paired with stuffing boxes showed that the wear resistance of protective sleeves after EMSH increased by 3.1 times for 45 steel, 1.9 times for U8 steel, 2.5 times for SHKH15 steel, for cast iron by 1.9 times compared to the initial values. The use of U8 steel samples after EMSH, instead of serial bushings made of steel 45, allows to increase the wear resistance of parts by 6.1 times, which allows us to recommend U8 steel for use in the manufacture of protective bushings for console pumps. On the basis of the research, recommendations are given for the application of EMSH for the formation of a surface layer with increased wear resistance of protective sleeves during their production and during repair of console pumps in workshops or service centers of agribusiness companies.

Key words: wear resistance, electromechanical hardening, durability, surface hardening, cylindrical parts

Introduction

In most cases, the structural characteristics and properties of the surface layer of parts have a decisive influence on the ability of materials to break. The failure of metals and alloys usually originates from the surface. The reasons for the violation of integrity can be: low quality of production of protective bushings of cantilever pumps, unreasonable choice of materials for their manufacture, ineffective technologies for their strengthening (34...40 HRC), not taking into account operating conditions and types of friction with packing stuffing. Increasing the hardness of the surface is one of the main measures to increase the durability by increasing the wear resistance of the surface layers of materials. Existing methods of strengthening and increasing surface hardness are associated with the use of methods of surface plastic deformation, thermal, chemical-thermal, laser, magnetic-pulse, thermomechanical and combined methods of increasing durability [1]. Today, the technology of processing surfaces with concentrated flows of electric energy is one of the most popular methods of reducing the manufacturing cost, strengthening and improving the quality of parts.

Electromechanical processing (EMP) provides: increase in hardness of steel surfaces up to 70 HRC (steels KhVG, U10...13A); hardening of low-carbon steels (steel 20) up to 42 HRC, cast iron up to 75 HRC; replacement of chemical and thermal treatment (cementation, nitrocementation...); increasing the limit of endurance by 30...80%; increase in wear resistance by 3...12 times; lack of oxidation and decarburization of the surface layer; lack of grooving of the product; reduction of production cost by 2.. 4 times; hardening in air and without the use of coolants, environmental cleanliness and safety; technological simplicity of processing methods.

The specifics of the work of experimental and repair organizations that produce artificial products or parts in small batches do not allow them to maintain workshops and sites with equipment and qualified specialists capable of ensuring the quality of manufacturing machine parts only at the level of industrial enterprises. However, even machine-building enterprises do not guarantee the necessary quality of performance of executive surfaces for a wide range of parts, primarily in terms of hardness, roughness, structure and texture of metal fibers on one part, in various combinations, there may be seats for rolling and sliding bearings, slots and keyways, toothed profiles, holes, threads and grooves. Since the operating conditions and load schemes of the listed surfaces are not the same, their optimal performance cannot be ensured only by means of thermal or chemical thermal treatment [2]. Electromechanical surface hardening is one of the methods of processing products with concentrated energy flows, forming high quality indicators of the surface layer of steel and cast iron parts.

A feature of electromechanical surface hardening (EMSH) is the combination of surface plastic deformation and thermomechanical hardening in a single technological scheme for processing workpieces and the possibility of forming gradient hardened layers of metal with a finely dispersed structure on the surface. This makes it possible to significantly increase the wear resistance of cylindrical parts, including protective sleeves of console pumps.

Literature review

EMP refers to modern science-intensive technologies of impact by concentrated flows of energy on the surface of machine parts. EMP processes successfully compete with such classic technologies as: surface plastic deformation (SPD), heat treatment (HT) and thermomechanical treatment (TMT). By changing the technological modes of EMP (current density J, processing speed and pressure of the processing tool on the surface of the part) on the machine tool, it is possible to perform operations with hot SPD, surface TMT and surface maintenance.

The technology of EMP was developed at the Ulyanovsk Agricultural Institute. The founder of the EMP method is B.M. Askinazi. He investigated heat generation in the surface layer, the method of calculating the depth of the hardened layer, the peculiarities of thermomechanical processes in the surface layer; the nature and structure of the surface layer, the roughness and accuracy of the finished surface; internal stresses of the surface layer during EMP; the effect of EMP strengthening on the fatigue strength, wear resistance and corrosion resistance of parts; conducted research on the technology of restoration of parts with additional metal and without additional metal by electromechanical method; studied the processes of turning parts with a thread [3].

The activities of V.P. Bagmutova, I.N. Zakharova and their colleagues outlined the technological and physical foundations of EMP. The classification of EMP processes according to technological and energy criteria is given. Technological equipment and schemes of contact interactions of the electrode-tool with the surface of the part during EMP, calculation of optimal structural and technological processing parameters have been developed. The conditions of formation of surface layers of structural steels are described, their physical and mechanical properties and stress-strain state are determined [4]. Thermal processes and properties of the surface layer of steels are presented: strength, fatigue strength, wear resistance, corrosion and heat resistance after electromechanical processing. The influence of the structure and properties of the surface layer on the fatigue strength of hardened steels strengthened by combined electromechanical processing was studied [5]. In works [6, 7], the processes of strengthening of the surface layer of titanium alloys during EMP and strengthening by combined electromechanical processing are investigated.

Activities of V.V. Safronov developed, theoretically indicated and experimentally implemented an effective technological method of increasing the durability of cylinder-type steel parts by electromechanical processing. The nature of the influence of technological factors of EMP cylinders on the accuracy of processing, surface quality and heat distribution in the surface layer has been established. The dependence of the thickness of the hardened layer on the initial structure of the processed metal is theoretically justified and experimentally confirmed. An explanation of the increase in corrosion resistance of the surface layer after EMP is given on the basis of the electrode potential studies.

S.K. Fedorov investigated the peculiarities of work and the main defects of threaded joint parts under different operating conditions, substantiated and investigated the principles of electromechanical restoration of parts with external metric threads, developed a design and technological method of increasing the durability of remanufactured threaded parts connections Proposed a method of restoring the profile of the thread at the time of the initiation of defects due to the plastic redistribution of the material of the parts. Introduced EMP to improve the operational properties of parts [8].

In the work of N.G. Dudkina, the main regularities of the formation of the surface structure during electromechanical processing and the influence of the given structure of the white layer on the change in mechanical properties, kinetics of deformation and destruction of steel 45 under load were revealed; the nature of pressures during EMP is revealed, as a complex parameter of contact stresses from mechanical pressure on the tool and thermoelastic stresses arising during heating of the local microvolume. The regularities of changes in the physicomechanical properties and kinetics of microplastic deformations of steel 45 due to the structural inhomogeneity of the strengthened surface during EMP were established, and the regularities of changes in the cyclic strength of steel 45 due to different surface topography after EMP were determined. The properties of the surface layer were studied when EMP was combined with other methods [9].

In work [10], an improved EMP method is given in relation to the strengthening of the previously obtained profile of the metric thread and fundamentally new methods of restoring the defective screw surface are developed due to the plastic thermodynamic redistribution of the metal of the distorted areas, squeezing the material from the base and moving it in the desired direction with the simultaneous formation of a cavity and side surfaces. The conditions for the formation of the profile of thread turns with a hardened surface and a viscous core have been determined. The sophisticated possibility of electromechanical restoration of the worn thread profile. The dependence of the pressure in the contact zone on the geometrical parameters of the tool and on the physical and mechanical properties of the metal was established [11].

In the work of G.D. Fedotov, approximate analytical equations for the distribution of temperature fields in the tool from a constantly operating normal-circular heat source in the part, when the heat source moves along a helical line, were obtained. The possibility of using tungsten-free tool materials with low thermal activity during EMP is shown in order to increase the efficiency of EMP operations due to a greater strengthening effect on the surface layers of the processed parts with equal heat release in the contact zone of the tool with the part; the use of hard alloys with high electrical resistance makes it possible to achieve an even strengthening effect with lower energy costs and obtaining compressive residual stresses in the surface layers of the processed parts. A.V. Morozov investigated the improvement of the operational properties of thin-walled steel bushings by electromechanical mandrel (EMM). He proposed mathematical models of the EMM process, which allows studying the influence of EMM modes on the depth and structure of the strengthened layer, roughness, wear resistance of the inner surfaces of the bushings [12]. Selected EMM modes that allow obtaining a high-quality connection with tension along the outer diameter of a thin-walled steel sleeve with simultaneous surface hardening and a reduction in the roughness of the treated hole. Edigarov V.R. improved the processing method with preliminary application of antifriction material on the surface of the part followed by electromechanical processing (AFEMP). AFEMP of the surfaces of steel parts of tribosystems with preliminary application of a thin anti-friction layer made of various solid lubricants to the surface of the processed parts, which allows to change the structure of the surface layer, increase its wear resistance and operational characteristics, especially anti-friction due to the reduction of the friction moment of the tribopair samples. In A.V. Pavlov developed a method and technological equipment for electromechanical strengthening of shafts using three-phase current. He studied the influence of processing parameters when using three-phase current on the depth and hardness of the hardened layer, the wear resistance of the surface after EMP. Based on the analysis of the methods of manufacturing and restoration of threaded joint parts, in [13] a method of finishing and strengthening electromechanical processing of parts with an external metric thread to increase the fatigue life of threaded joints is proposed. The optimal values of current density, force in the contact zone and processing speed and their influence on the depth of hardening were determined. V. A. Petrushenko developed a method for calculating EMP modes for the production of various standard sizes of metric threads; calculated the contact temperature to ensure the specified depth of hardening; established the relationship between the temperature in the contact zone of the tool and the workpiece with technological modes of EMP and geometric parameters of the tool. S.M. Parshev studied the technological hardening by pulse electromechanical processing (PEP). The effect of PEP on the wear resistance of medium-carbon structural steels under conditions of abrasive wear and limit friction, the issue of accuracy during electromechanical processing, the stability of the cutting edges of blade tools when strengthened by the PEP method was studied.

In [14], he developed a method of improving the operational properties of threading parts of lifting mechanisms based on electromechanical processing. At the same time, mathematical models were obtained that establish the relationship between the technological modes of electromechanical processing and the depth of the hardened layer for screws made of 35, 45, 18KHT steels. It was established that the maximum hardness is achieved at a depth of 0.05...0.15 mm from the surface, and an increase in the carbon content in steel leads to an increase in the depth of the hardened layer.

Purpose

The purpose of the research is to increase the durability of console pumps by increasing the wear resistance of the executive surfaces of protective sleeves by electromechanical surface hardening.

Research methodology

Samples for bench tests were made of steel 40G, 40X, 45, U8, SHKH15 and cast iron SCH35 of the following sizes: outer diameter 25 mm; hole diameter 15 mm; height 20 mm. The roughness of the surfaces of the studied samples before EMSH corresponded to Ra3.2 μm according to DSTU 2789.

EMSH of the samples was performed on a lathe and screw-cutting machine with the modes: hardening speed 1.2 m/min; the current in the secondary circuit is 1600 A; secondary circuit voltage 3; force of adjustment of the tool 400 N; tool feed 2.5 mm/rev.

For carrying out wear tests, a stand was developed and manufactured, which allows simulating the operating conditions, the load pattern and the nature of the wear of the protective bushings.

The wear of the samples was determined by weighing on analytical balances AND GH-252 before and after the tests with a maximum weighing mass of 250 g with an accuracy of 0.00001 m. Before weighing, the samples were wiped with acetone, blown with air and dried in a muffle furnace at a temperature of 60 °C.

Research results

The formation of the structure of the strengthened zone of the surface layer during EMSH is a set of processes associated with the simultaneous influence of heating, plastic deformation and high cooling rate. This effect is accompanied by plastic deformation by grinding the grain and increasing the density of dislocations, and by hardening by changing the structure of the material.

The study of the microstructure of the samples after EMSH was performed on an metallographic microscope. The results of studies of the microstructure of steel and cast iron samples indicate the formation of a white layer with increased hardness and reduced corrosion in the hardening zones, even with large increases [15]. Depending on the original structure and modes of strengthening, the thickness of this zone can be different.

Studies of the structure of the surface layer after EMSH have shown that the structure of the white layer, observed in an optical microscope, looks like a continuous, uniform light field. This is due to the fact that with EMSH the process occurs instantly, phase transformations are combined with plastic deformations.

The specific properties of the white layer are explained by the occurrence in it of a special structureless martensite [16], which is characterized by a large dispersion of the structure, significant concentration heterogeneity and significant distortions of the crystal structure. In addition, the reason for reduced etchability and high hardness is changes in the electronic structure and chemical bonds of individual elements as a result of action in the processing zone of extreme temperatures and pressures. The white layer formed on the surface of the metal under the action of concentrated energy flows inherits both the heterogeneity of the composition and properties of austenite, which originates, generally speaking, under abnormal conditions, and the close to critical fineness of its structure.

The kinetics of austenite formation in pre-eutectoid steel during heating is characterized by certain features associated with the presence of structurally free ferrite in it. With high-speed heating of pre-eutectoid steel under EMSH conditions, independent transformation of structurally free ferrite into carbon-free iron becomes possible, i.e. e. without interaction between it and carburized austenite. With an increase in the heating rate, the dissolution of excess ferrite into austenite is gradually "suppressed", as a result of which most of the ferrite is overheated to higher temperatures, at which thermodynamic prerequisites are created for its diffusion-free transformation into austenite, typical for pure iron (at temperatures above 905°C), the subsequent (upon cooling) formation of low-carbon martensite in such areas. In addition, in the transition zone there is an area of incomplete hardening, as a result, when such an area is heated, the process of austenite formation does not proceed completely, and when it cools, an inhomogeneous structure is formed in it (Fig. 1). As the white layer is removed from the fragment, the temperature in the zone of thermal influence decreases, which leads to the formation of transitional structures. Their presence in the surface layer improves the surface quality of the protective sleeve.

After EMSH, the microhardness of the surface layer of steels increased by 2.6...3.6 times compared to the initial values. This hardness is much higher than the initial one and is 700...940 HV depending on the brand of material. The microhardness of cast iron SCH35 after EMSH is high (943 HV), but the depth of hardening is not great (0.2...0.3 mm).

For example, for U8 steel, the increase in microhardness at a depth of 0.05 mm from the surface was 3.6 times. Gradient layers with increased values of microhardness are observed at a depth of up to 1 mm under these regimes.

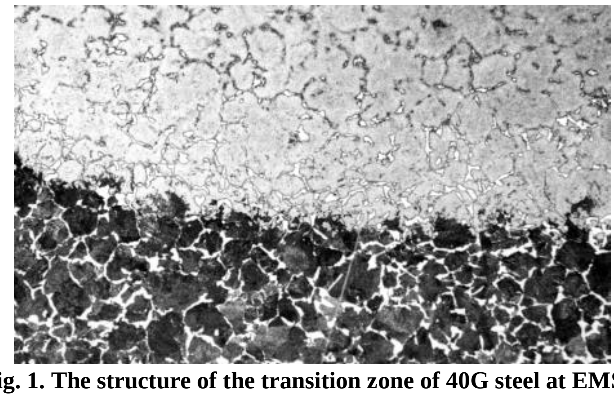

Fig. 1. The structure of the transition zone of 40G steel at EMSH

With removal from the surface, the microhardness decreases to the initial values. The transition zone has a microhardness lower than that of the white layer zone. This is explained by the presence of very high local heating temperatures at a high cooling rate, but insufficient for hardening these volumes.

The undulating change in microhardness values is associated with the specifics of electromechanical processing. If necessary, by choosing the appropriate processing parameters, you can possibly minimize this effect.

Reheating the previous track when the next one is applied leads to the release of previously formed martensite. An area of repeated hardening with heating close to the maximum temperature of heating for hardening, upon cooling, martensite, which has high microhardness, forms again in this area [17].

Analysis of the phase composition of steel was performed on a DRON-4-07 X-ray phase diffractometer in the following modes: Shooting step, gr. 0.050; tube mode BSV-27(Co) 20 mA, 35 kV; beta - filter - Fe; shooting method: according to Bragg - Brentano - w/2t; combined t=3000 s, V=4.0 g/min.

In the Table 1 and Fig. 2 presents the results of wear of the surfaces of the studied samples before and after EMSH.

Table 1

The results of wear measurements of samples before and after strengthening

Sample type	Wear, g			
	45	U8	SHKH15	SCH35
Initial	0,04199	0,01308	0,01696	0,02295
EMSH	0,01371	0,0068	0,0081	0,01222

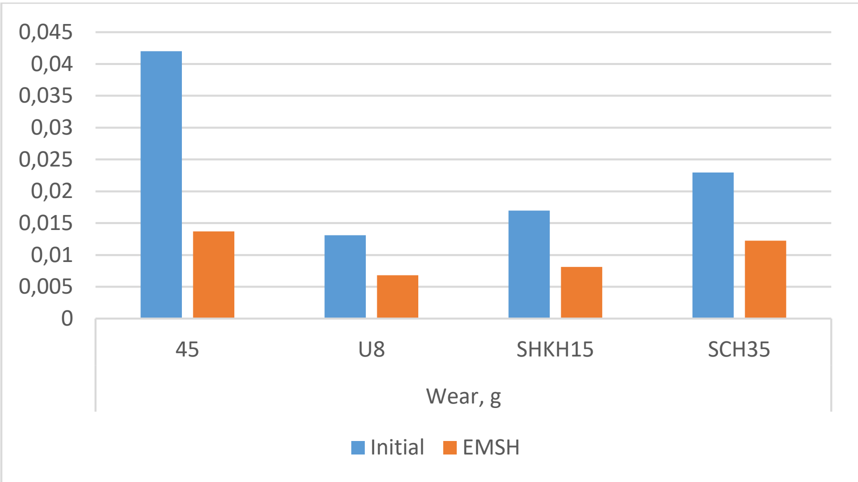

Fig. 2. Results of wear tests

The results of the research showed that in the conditions of contact between the protective sleeve and the oil seal in the friction zone of the abrasive during 30 min of tests, the wear resistance of the surface layer of steel 45, U8, SHKH15 and cast iron SCH35 after EMSH increased for steel 45 by 3.1 times, for steel U8 - by 1.9 times, SHKH15 steel - 2.5 times, cast iron - 1.9 times compared to the initial values. At the same time, the use of U8 steel samples after EMSH, instead of serial bushings made of 45 steel, allows to increase the wear resistance. details by 6.1 times.

Conclusions

1. An overview of modern methods of strengthening, their advantages and disadvantages allows recommending the technology of electromechanical processing and, in particular, electromechanical surface hardening, as one of the effective ways to increase the wear resistance of protective sleeves of cantilever pumps. The development of a mathematical model allows you to determine the temperature field in the contact zone, to get a visual picture of the change in the depth of hardening depending on the processing modes, with the possibility of its application to other materials.

It was established that the achievement of the highest values of microhardness of the surface layer at a depth of up to 1.2 mm is possible during electromechanical processing of the protective sleeves of cantilever pumps. The use of different modes and schemes of EMSH is accompanied by a change in the structure and, as a result, an increase in the hardness of the surface layer of the bushings.

2. The actual contact area of the tool roller with the treated surface and the depth of the temperature-deformation effect depend on the physical and mechanical properties of the materials and the pressing force. The calculation of the temperature field at the EMSH was carried out. The formation of a temperature gradient in the hardened zone at a depth of up to 1.2 mm from the surface has been proven.

3. Metallographic analysis of the surfaces of the sleeves treated by EMSH indicates the formation of a white layer with reduced corrosion and increased hardness in the hardening zones. The results of the X-ray structural analysis confirmed the formation of the martensite phase in the hardening zone. The microhardness of the hardened steel zone increased by 2.6...3.6 times compared to the initial values at a depth of up to 1 mm from the surface, depending on the materials. In the case of their overlap, the alternation of a fully hardened zone, a partially hardened zone, and a self-relief zone is observed. At the same time, the microhardness of steels along the surface depends on the hardening scheme.

4. Wear tests under friction conditions of parts of cantilever steam pumps with gland packing showed that the wear resistance of the protective bushings after EMSH increased by 3.1 times for steel 45, for steel U8 by 1.9 times, for steel SHKH15 by 2.5 times, for cast iron by 1.9 times compared to the initial values.

5. The use of U8 steel samples after EMSH, instead of serial bushings made of steel 45, allows to increase the wear resistance of parts by 6.1 times, which makes it possible to recommend U8 steel for use in the manufacture of protective bushings for console pumps.

References

1. Edenhofer, B. An overview of advances in atmosphere and vacuum heat treatment / B. Edenhofer // Heat treatment of metals. – 1999. – № 26. – P. 1–7.

2. Kula, P. New vacuum carburizing technology / P. Kula, J. Olejnik, J. Kowalewski // Heat treatment progress. – 2001. – № 1. – P. 57–65.

3. Felice Rubino. Thermo-mechanical finite element modeling of the laser treatment of titanium cold-sprayed coatings / Felice Rubino, Antonello Astarita, Pierpaolo Carlone // Coatings. – 2018. – P. 1–17.

4. W. Cheng, F. Dai, S. Huang, and X. Chen. Plastic deformation behavior of 316 stainless steel subjected to multiple laser shock imprinting impacts. Opt. Laser Technol. – 2022. – 153. doi: 10.1016/j.optlastec.2022.108201.

5. H. Liu. Effect of laser surface texturing depth and pattern on the bond strength and corrosion performance of phosphate conversion coating on magnesium alloy. Opt. Laser Technol. – 2022. – 153. doi: 10.1016/j.optlastec.2022.108164.

6. J. Jones, P. McNutt, R. Tosi, C. Perry, and D. Wimpenny. Remanufacture of turbine blades by laser cladding, machining and in-process scanning in a single machine. – 2012.

7. Rahito D. A. Wahab and A. H. Azman. Additive manufacturing for repair and restoration in remanufacturing: An overview from object design and systems perspectives" – 2019. – Processes, 7(11). MDPI AG. doi: 10.3390/pr7110802.

8. M. S. Alam and A. K. Das, Advancement in cermet based coating on steel substrate: A review," Mater. Today Proc. – 2022 – 56, pp. 805–810. doi:10.1016/j.matpr.2022.02.260

9. O. Lymar, D. Marchenko, "Prospects for the Application of Restoring Electric Arc Coatings in the Repair of Machines and Mechanisms", Proceedings of the 2022 IEEE 4th International Conference on Modern Electrical and Energy System, MEES 2022. https://doi.org/10.1109/MEES58014.2022.10005709.

10. R. Ranjan and A. K. Das. A review on surface protective coating using cold spray cladding technique. Mater. Today Proc., 56, pp. 768–773, (2022). doi: 10.1016/j.matpr.2022.02.254.

11. Marchenko, D., & Matvyeyeva, K. (2022). Increasing warning resistance of engine valves by gas nitrogenization method. Problems of Tribology, 27(2/104), 20–27. https://doi.org/10.31891/2079-1372-2022-104-2-20-27.

12. R. Ranjan and A. K. Das. A review on surface protective coating using cold spray cladding technique. Mater. Today Proc., 56, pp. 768–773, (2022), doi: 10.1016/j.matpr.2022.02.254

13. Marchenko, D., & Matvyeyeva, K. (2022). Study of the Stress-Strain State of the Surface Layer During the Strengthening Treatment of Parts. Problems of Tribology, 27(3/105), 82–88. https://doi.org/10.31891/2079-1372-2022-105-3-82-88.

14. X. Hu. Rolling contact fatigue behaviors of 25CrNi2MoV steel combined treated by discrete laser surface hardening and ultrasonic surface rolling" Opt. Laser Technol., 155, (2022) doi: 10.1016/j.optlastec.2022.108370.

15. Dykha A.V., Marchenko D.D. Prediction the wear of sliding bearings. International Journal of Engineering and Technology (UAE). India: "Sciencepubco–logo" Science Publishing Corporation. Publisher of International Academic Journals. 2018. Vol. 7, No 2.23 (2018). pp. 4–8. DOI: https://doi.org/10.14419/ijet.v7i2.23.11872.

16. Marchenko, D., & Matvyeyeva, K. (2023). Increasing the Wear Resistance of Restored Car Parts by Using Electrospark Coatings. Problems of Tribology, 28(1/107), 65–72. https://doi.org/10.31891/2079-1372-2023-107-1-65-72.

17. Marchenko, D., & Matvyeyeva, K. (2023). Research of Increase of the Wear Resistance of Machine Parts and Tools by Surface Alloying. Problems of Tribology, 28(3/109), 32–40. https://doi.org/10.31891/2079-1372-2023-109-3-32-40.

Марченко Д.Д., Матвєєва К.С. Дослідження зносостійкості циліндричних деталей електромеханічним поверхневим загартуванням

У роботі науково обґрунтовано застосування ефективної технології підвищення зносостійкості циліндричних деталей, на прикладі захисних втулок консольних насосів, за рахунок електромеханічного поверхневого загартування. Проведено огляд досліджень і встановлено, що досягнення найбільш високих значень мікротвердості поверхневого шару на глибині до 1,2 мм можливо при електромеханічній обробці захисних втулок консольних насосів. Застосування різних режимів та схем електромеханічного поверхневого загартування (ЕМПЗ) супроводжується зміною структури і, в результаті, підвищенням твердості поверхневого шару втулок. Фактична площа контакту інструментального ролика з оброблюваною поверхнею і глибина температурно-деформаційної дії залежать від фізико-механічних властивостей матеріалів та зусилля притискання. Доведено утворення температурного градієнта у зміцненій зоні на глибині до 1,2 мм від поверхні. Металографічний аналіз поверхонь втулок, оброблених ЕМПЗ свідчить про формування в зонах загартування білого шару зі зниженою травимістю і підвищеною твердістю. Результати рентгеноструктурного аналізу підтвердили утворення фази мартенситу в зоні зміцнення. Мікротвердість зміцненої зони сталей збільшилася в 2,6...3,6 рази порівняно з вихідними значеннями при глибині до 1 мм від поверхні в залежності від матеріалів. У випадку їх перекриття спостерігаються чергування повної загартованої зони, часткової загартованої зони і зони самовідпустки. При цьому мікротвердість сталей вздовж поверхні залежить від схеми зміцнення.

Випробування на зношування в умовах тертя деталей консольних насосів у парі з сальниковою набивкою показали, що зносостійкість захисних втулок після ЕМПЗ збільшилася для сталі 45 в 3,1 рази, для сталі У8 в 1,9 рази, для сталі ШХ15 у 2,5 рази, для чавуну в 1,9 рази порівняно з вихідними значеннями. Використання зразків зі сталі У8 після ЕМПЗ, замість серійних втулок із сталі 45, дозволяє підвищити зносостійкість деталей у 6,1 разів, що дозволяє рекомендувати до впровадження сталь У8 при виготовленні захисних втулок консольних насосів. На основі проведення досліджень дані рекомендації по застосуванню ЕМПЗ для утворення поверхневого шару з підвищеною зносостійкістю захисних втулок при виготовленні їх на виробництві та при ремонті консольних насосів в майстернях або сервісних центрах компаній АПК.

Ключові слова: зносостійкість, електромеханічне закалювання, довговічність, поверхневе зміцнення, циліндричні деталі