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ELECTROLYTE-PLASMA SURFACE TREATMENT OF 42XMFA (SIMILAR MATERIAL AISI 4140) STRUCTURAL-ALLOY STEEL, USED FOR THE MANUFACTURE OF CRANKSHAFTS OF KAMAZ-740 ENGINES

КАМАЗ-740 ҚОЗҒАЛТҚЫШТАРЫНЫҢ ИІНДІ БІЛІКТЕРІН ЖАСАУ ҮШІН ҚОЛДАНЫЛАТЫН 42ХМФА (АНАЛОГ AISI 4140) КОНСТРУКЦИЯЛЫҚ-ЛЕГИРЛЕНГЕН БОЛАТЫНЫҢ БЕТІН ЭЛЕКТРОЛИТТІК-ПЛАЗМАЛЫҚ ӨҢДЕУ

ЭЛЕКТРОЛИТНО-ПЛАЗМЕННАЯ ОБРАБОТКА ПОВЕРХНОСТИ КОНСТРУКЦИОННО-ЛЕГИРОВАННОЙ СТАЛИ 42ХМФА (АНАЛОГ AISI 4140), ПРИМЕНЯЕМОЙ ДЛЯ ИЗГОТОВЛЕНИЯ КОЛЕНЧАТЫХ ВАЛОВ ДВИГАТЕЛЕЙ КАМАЗ-740

Abstract. *Increased requirements for fatigue strength and wear resistance of the crankshaft require the development of technological processes for the repair and restoration of transport engineering. The surface hardening of the high loaded crankpin and main bearing journals of the crankshaft after grinding to the repair size is the most relevant. The technology of electrolytic-plasma processing for the KAMAZ-740 crankshaft samples during major repairs has been developed. There is a small acicular martensite and isolated areas of residual austenite on the surface microstructure of the sample. The measurement results indicate that the values of the surface microhardness of the part increased after the electrolytic plasma treatment. The local electrolyte-plasma treatment provides the required hardness and high wear resistance of the crankpin and the main bearing journals of the crankshaft, which significantly increases the service life.*
Key words. *Crankshaft; transport; wear resistance; electrolytic-plasma modification; microstructure; microhardness.*

Аңдатпа. *Иінді біліктің шаршау беріктігі мен тозуға төзімділігіне қойылатын талаптардың жоғарылауы көлік техникасын жөндеу және қалпына келтірудің технологиялық процестерін дамытуды талап етеді. Жөндеу өлшеміне тегістелгеннен кейін иінді біліктің ең көп жүктелген түбірлері мен шатундық мойындарының үстіңгі қатаюы ерекше өзекті болып табылады. Күрделі жөндеу кезінде Камаз-740 иінді білігінің үлгілерін электролиттік-плазмалық өңдеу технологиясы жасалды. Электролитті-плазмалық беріктендіруден кейін үлгіде ұсақ инелі мартенсит пен қалдық аустениттің оқшауланған түйіндерінің құрылымы байқалады. Өлшеу нәтижелері электролитті-плазмалық өңдеуден кейін үлгі бөлшек бетінің микроқаттылығы мәнінің жоғарылағанын көрсетеді. Жергілікті электролит-плазмалық өңдеу иінді біліктің негізгі және шатундық мойындарын қажетті қаттылығы мен жоғары тозуға төзімділігін қамтамасыз етеді, бұл қызмет мерзімін едәуір арттырады.*

Түйін сөздер: *Иінді білік; тасымалдау; тозуға төзімділік; электролиттік плазмалық модификация; микроқұрылым; микроқаттылық.*

Аннотация. *Повышенные требования к усталостной прочности и износостойкости коленчатого вала требует разработки технологических процессов ремонта и восстановления транспортной техники. Особо актуальным является поверхностное упрочнение наиболее нагруженных коренных и шатунных шеек коленчатого вала после шлифовки в ремонтный размер. Разработана технология электролитно-плазменной обработки образцов коленчатого вала КамАЗ-740 при проведении капитального ремонта. В образце после электролитно-плазменного упрочнения наблюдается структура мелкоигольчатого мартенсита и изолированных участков остаточного аустенита. Результаты измерений свидетельствуют о повышении значения микротвердости поверхности после электролитно-плазменной обработки. Локальная электролитно-плазменная обработка позволяет обеспечить требуемую твердость и высокую износостойкость коренных и шатунных шеек коленчатого вала, которая значительно повышает срок службы.*

Ключевые слова: *Коленчатый вал; транспорт; износостойкость; электролитно-плазменная модификация; микроструктура; микротвердость.*

Introduction. Road transport is a leader in the transport complex of the Republic of Kazakhstan and plays a significant role in the development of the country's commercial, industrial and passenger infrastructure. This is due to the fact that it is primarily available, multipurpose, flexible, and also mobile, because there are highways almost everywhere. Every year, hundreds of thousands of companies and organizations throughout the country are served by this type of transport.

According to statistical data published by Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics, which conducts state statistical activities within the framework of the legislation of the Republic of Kazakhstan, 3287 million tons of cargo were transported by road in 2020, and cargo turnover amounted to 160 billion. t – km. Passengers were transported – 8377,7 million people, passenger turnover from this transportation amounted to 91 billion passenger – km [1]. Figure 1 shows the dynamic of the development of cargo transport in the Republic of Kazakhstan from 2018 to 2020 in the context of the total number of transported cargo, baggage, cargo baggage in million tons, as well as cargo turnover in billion t – km . There is a growing trend in cargo transportation.

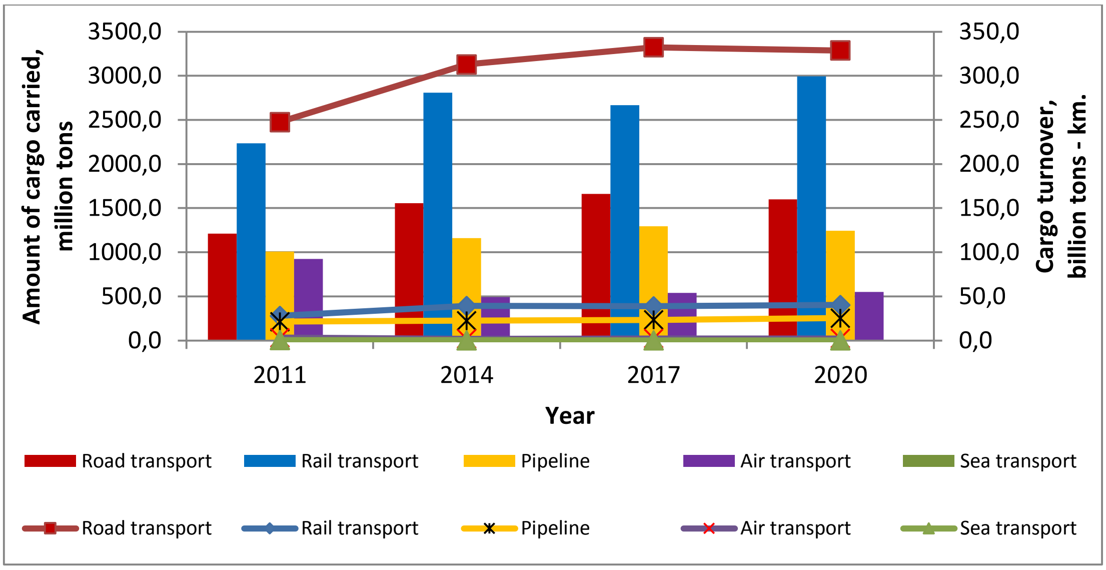


Figure 1. Dynamics of freight transport development

Figure 2 shows a similar picture. The growing trend of passenger transport in the Republic of Kazakhstan from 2018 to 2020 in terms of the total number of passengers carried in million people, as well as passenger turnover in billion people. - km. observed before the global crisis because of the COVID-19 pandemic. If it is considered that this factor is temporary and common, it can be assumed that the trend of growth in the demand for road transport as a means of passenger transportation is going to continue.

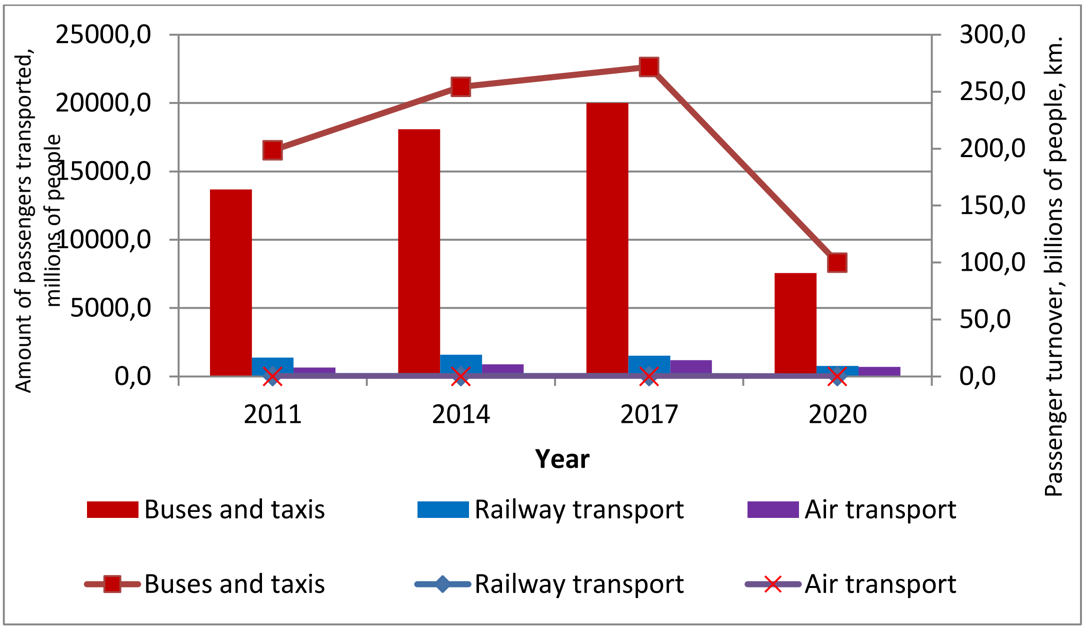


Figure 2. Dynamics of passenger transport development

Any vehicle has a maximum operating time set by the manufacturer, expressed mainly in the mileage units (kilometers). If the vehicles are serviced correctly and on time, they perform their functional tasks without any serious problems before the first major repair. Under real conditions, premature failure of car components often occurs [2].

The main goal of companies and organizations engaged in the commercial cargo and passenger transportation is to meet the needs of the population in a cost-effective way. In a competitive environment, this aspect can be realized by the greatest reduction in labor and material costs for maintaining the operability of automotive transport, which make up a significant part (up to 20%) of the transportation cost. After major repairs of the vehicle main units, the costs of maintaining its working condition in the first periods of the post-repair operation are comparable to the costs of operating a new vehicle, but, due to a decrease in reliability indicators, they change according to a more nonlinear relationship [3]. Downtime during the repair of transport units is also an important factor, which significantly reduces the economic indicators of the commercial activity. Hence the fact that the improvement of technological processes of repair and restoration of transport equipment is of particular relevance.

Materials and methods. The more common term of the electrolyte-plasma treatment method (hereinafter referred to as EPT) is "plasma electrolysis" [4]. Two main phenomena of this electrochemical process are typical. The first is the electrolysis of an aqueous solution when two electrodes with different electrical potentials are connected. One of the electrodes is the workpiece. An aqueous solution is called an electrolyte. The varieties of this process are: electroplating, electrochemical treatment, anodizing, etc. According to the simplified model describing electrode processes during electrolysis, the boundary between the electrode and the electrolyte is considered as a two-phase system (metal-electrolyte or oxide-electrolyte) [5].

For example, Figure 3 shows workpiece 2, which is connected to a negative potential and is a cathode. Anode 3 consists of a coating material that is destroyed during electrolysis. The electrodes are placed in bath 1 with electrolyte solution 4. When a potential difference is created between the electrodes using power supply 7, the electrolytic dissociation of the solution into cations 5 and anions 6 occurs. Thus, cations are deposited on the surface of the part, forming a coating.

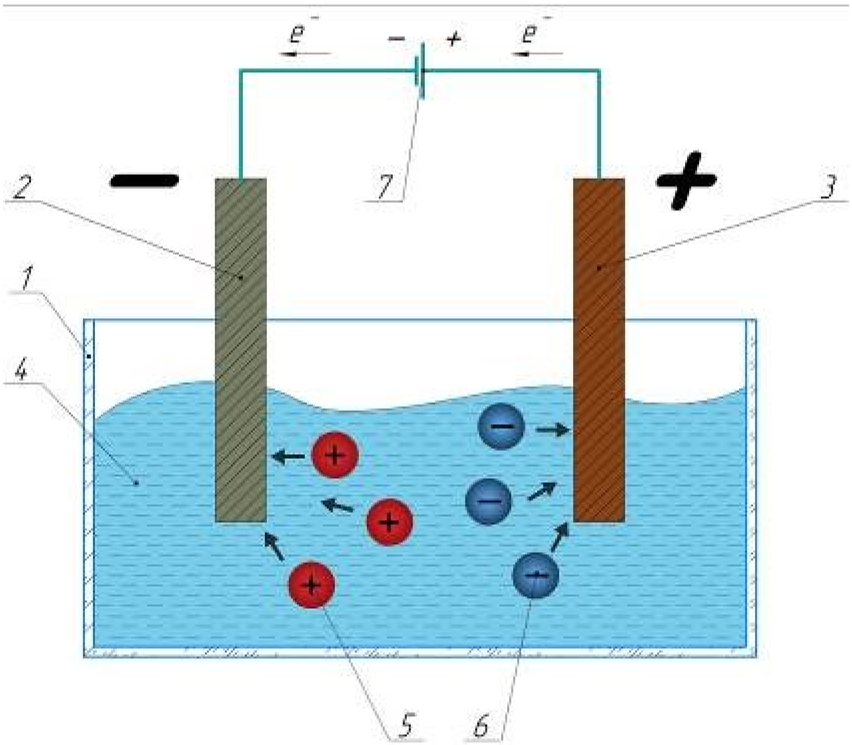


Figure 3. Diagram of the electrolysis process

The second phenomenon typical for plasma electrolysis is the formation of an electric discharge near the surface of the workpiece [6]. The process of electrolytic plasma treatment combines both of these phenomena, which makes it possible to produce local heating of the surface, i.e. heat treatment and its modification with other chemical elements. In the gap between the surface of the part (cathode) and the electrolyte electrode (anode), through of an electric discharge, a plasma layer is formed, which heats the electrolyte to the evaporation temperature [7]. The plasma is a partially or completely ionized gas with a huge reserve of thermal energy (temperatures can reach tens of thousands of Kelvin). As a result, the third phase is formed, which is called a gas-vapor barrier (Fig. 4, b). This phenomenon significantly complicates the understanding and control of the processes occurring in EPT.

The modification process (Fig.4a) consists of heating the surface of product 4, fixed on bracket 7 and placed in bath 5 with electrolyte 9 from a 10 % solution of sodium carbonate (Na_2CO_3), by electric discharges through the formed plasma, as well as mass transfer of chemical elements to it [8]. The centrifugal pump transports the electrolyte in a circle through pipe 10 and drain 1 to maintain an optimal temperature. The design has anode plate 3 made of stainless steel 12X18N10T GOST 5949-75 (similar material EURONORM 95 Grade X10CrNiTi1810 Steel) connected to positive potential 8 and nozzle 2. Through them, the electrolyte enters the surface of the workpiece, which is connected to negative potential 6.

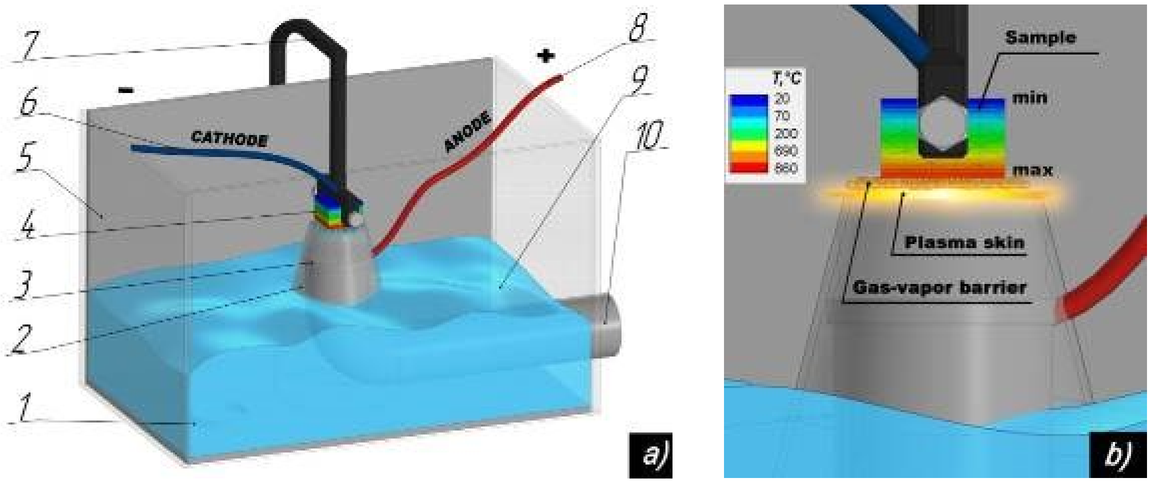


Figure 4. Electrolyte-plasma treatment of the sample
(a – diagram of EPT equipment; b – diagram of EPT process with scale of heating temperature)

The EPT process is performed cyclically [9]. The first cycle (4 seconds) is the heating of the workpiece surface to the phase change temperature of ferrite into austenite, equal to approximately 860°C. After that, there is a cooling cycle for 4 seconds in the electrolyte flow and quenching. These cycles are repeated 30 times. The total processing time is 4 minutes.

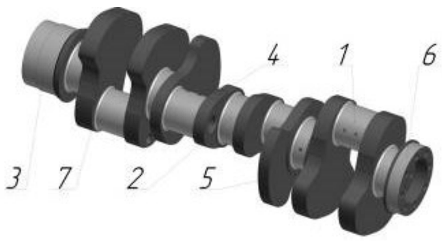
The studied sample (Fig.5) was cut out of the KAMAZ-740 crankshaft with constant cooling with water in order to prevent microstructural changes. The material of the sample is structural alloy steel 42XMFA TU 14-1-5520-2005 (similar material AISI 4140). Chemical composition are C (0,40-0,45%), Cr (1,00-1,30%), Mn (0,50-0,80%), Mo (0,35-0,45%), V (0,08-0,12%), Si (0,17-0,37%), Ni (≤0,3%), S (0,007-0,025), P (≤0,025%), Cu (≤0,3%), the rest is Fe.

Figure 5. Sample of the crankshaft, steel 42XMFA

The metallographic sample was prepared for studying by surface grinding and polishing on The Struers LaboPol-5 polishing machine and etching with a solution of 5% nitric acid and ethyl alcohol (5% HNO3 + C2H5OH), etching time = 10 s. An Olympus BX-51 optical microscope manufactured in Japan was used to study the microstructure of the sample surface.

Literature Review. The crankshaft is the main part in the design of the internal combustion engine. It is one of the most expensive and most loaded part, especially in large-sized diesels. The crankshaft perceives periodically acting high loads from the combustion of gases in the cylinder volume, as well as the inertial forces of the masses of the reciprocating motion of the crank mechanism during the operation [10]. This operation mode requires high fatigue strength and the crankshaft wear resistance.

Figure 6 shows the design of the KAMAZ-740 crankshaft. The main elements of the crankshaft are: crankpin journal 1, main bearing journal 2, pulley end 3, web 4, counterweight 5, flywheel flange 6, shaft journal radius 7.



Parameter	Value
Type of engine	diesel
Number of engine strokes	4
Number of cylinders	8
Cylinder arrangement	V-type
V-angle	90°
Firing order	1-5-4-2-6-3-7-8
Rotation direction	to the right
Engine displacement, l.	10,85
Nominal Power, kW (HP)	191 (260)
Maximum torque, N×m	931
Crankshaft speed, min^{-1}	
– nominal	2200±50
– at maximum torque	1200…1500

Figure 6. KAMAZ – 740 crankshaft

In 90 % of cases, the wear of the main bearing and crankpin journals is the main reason of the crankshaft's overhaul [11]. The wear of these elements occurs unevenly, the quality of the surface gets worse and defects are formed in the end. These are ovality, taper, bullies, scratches, dents and cracks. The main factors affecting the amount and rate of wear are the composition of the base material, the hardness and structure of the surface layer of the crankshaft journals, surface roughness, lubrication quality, engine operating mode and climatic exploitation conditions. The crankpin journals wear out 1.5 – 2 times more intensively than the main bearing journals . The reason is their more difficult operational conditions [12].

In practice, especially for large diesel vehicle, the cost of repairing a damaged crankshaft is significantly lower than replacing it with a new one. This is because its manufacture is complex and very metal-intensive.

Traditionally, the crankshaft journals are repaired by grinding to the repair size and polishing [13]. Each manufacturer gives its own range of sizes. Table 1 shows a number of repair dimensions for the KAMAZ-740 crankshaft.

Table 1. A range of repair sizes of KAMAZ-740 crankshaft journals

Name of the crankshaft journals	Identification of the repair size							
	Nom.	P1	P2	P3	P4	P5	P6	P7
	Journal diameter, mm							
Crankpin journal	80	79.5	79	80	79.5	79	78,5	78
Main bearing journal	95	94.5	94	95	94.5	94	93.5	93

After grinding of journals, new sliding bearings are installed in the cylinder block bearing surface for a specific repair size, which compensate for the change in the diameter of the crankshaft or the block.

At the manufacturing plant, usually after machining of the crankshaft, technologies of surface hardening of the journals is used to increase wear resistance, hardness and fatigue strength. There are quenching with high frequency currents (HDPE), chemical and thermal treatment (cementation, nitriding, nitrocementation, cyanidation), etc. When grinding to the repair size takes place, a hardened layer of material is removed from the journal surface, which reduces the operational properties of the crankshaft. Higher repair dimensions form a surface with a hardness that does not meet the technical requirements. Also, when a layer of material is deposited and cracks of the part are welded, there is a significant thermal effect on the material and, as a result, its temper, which is an additional negative factor [14]. Such journals have reduced wear resistance and a shorter service life. For these reasons, some services do not repair crankshafts with the factory surface hardening. Therefore, during the repair and restoration, it is necessary to ensure the required hardness and high wear resistance of the main bearing and crankpin journals of the crankshaft.

One of the most relevant methods of surface hardening is the method of electrolyte-plasma treatment (EPT), which allows creating a product surface with high functional properties.

Results and discussion. If we examine the initial microstructure of the surface of the 42XMFA steel sample (Fig. 7), we can notice the presence of predominantly perlite and ferrite phases. This is due to the fact that there is a small amount of alloying elements in the composition of steel. The surface microstructure of the sample is fine-grain. At the boundaries of perlite and austenite, the presence of phases of cementite (Fe_3C), as well as other chemical compounds based on alloying elements of chromium, molybdenum, vanadium are observed.

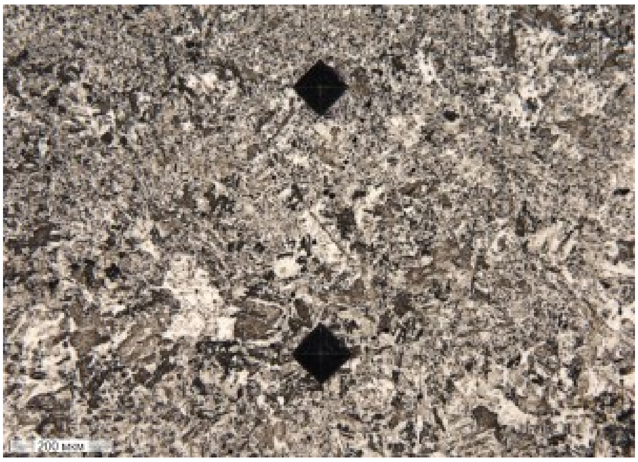


Figure 7. The initial microstructure of the steel 42XMFA sample surface

Cementite particles have a very high hardness approaching diamond and increase the deformation resistance, as well as reduce the ductility and viscosity of steel. Carbide-forming elements Cr, V, Mo create an obstacle to the growth of austenite grains, so that the carbide particles can maintain high dispersion and increases the strength of steel. The steel with the above microstructure has good plastic properties, but because of the large grain size, it does not have high hardness and strength [12].

The structure of acicular martensite and isolated areas of retained austenite is observed on a sample hardened by the EPR method, Figure 8. Usually, such structure is provided by hardened steels with a carbon-modified surface during the cementation process. This phenomenon is due to the fact that the emission of atomic carbon, its adsorption by the steel surface and diffusion deep into the metal occurs during the electrolytic dissociation of soda ash solution and the occurrence of chemical reactions [15].

Figure 8. Microstructure of the 42XMFA steel sample surface after EPT

It can be concluded that the percentage of carbon on the part surface is higher than in the core, therefore, the hardness and wear resistance increase [14].

Figure 9 shows a graph of measuring the microhardness of samples measured before and after electrolytic plasma treatment.

The measurement was carried out at 10 points, from a cross-section of the sample, in a measurement step of 250 microns. An increase in microhardness from the core to the surface modified by the EPT method at the site of acicular martensite and at the border of cementite can be observed. The maximum value of microhardness in the range of 550-600 HV, which is equivalent to 55-59 HRC [16], is observed at a depth of up to 0,65 mm, where the modification by carbon ions from the decomposition of the electrolyte has obviously occurred. At a depth of 0,65 mm to 1,40 mm, the phase transformations from high plasma temperature occur, which is also fixed by a high microhardness in the range of 420-500 HV. The microhardness value smoothly transitions to the initial state at a depth of more than 2 mm. In the initial state after factory heat treatment, the part has an average microhardness of 250-300 HV. There is also an increase in the microhardness to the surface at a depth of about 0,8 mm and is in the range of 350-400 HV, which is equivalent to 35-40 HRC.

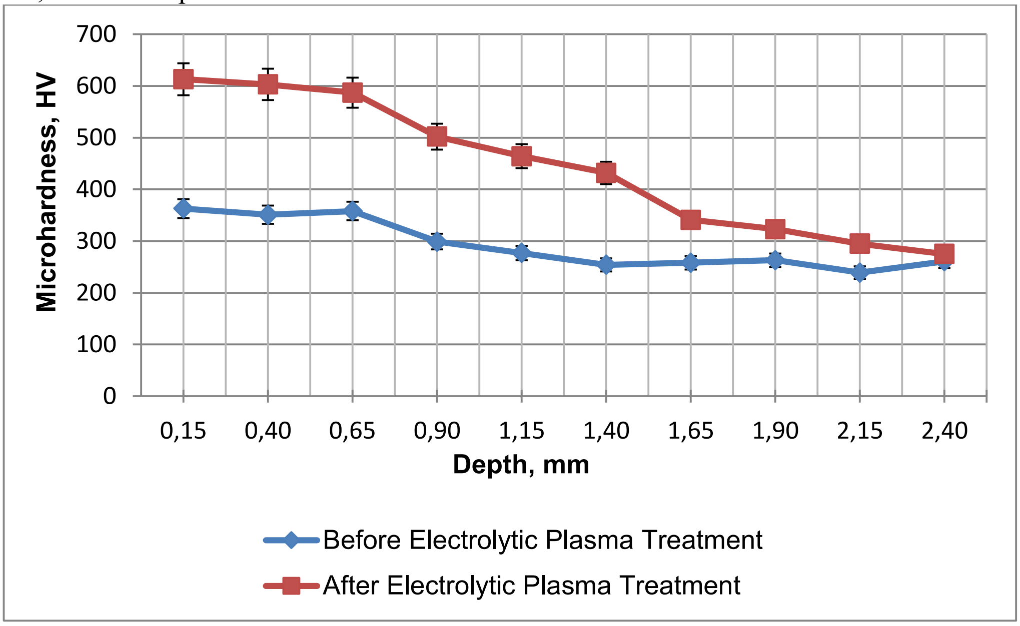


Figure 9. Graph of the 42XMFA steel samples microhardness comparison

If we analyze these graphs, it can be concluded that the values of the sample surface microhardness increase by 1,5-2 times after electrolytic plasma treatment. High hardness is the main factor in increasing the wear resistance and fatigue strength of crankshaft journals, which will directly increase the service life of a transport vehicle after major repairs.

Conclusions. The technology of local electrolytic plasma surface treatment of crankshaft samples during major repairs has been developed.

1) After electrolytic-plasma treatment, phase transformations occur in the sample and a structure of acicular martensite and residual cementite is formed on its surface.

2) The results of measuring the surface of the sample after electrolytic plasma treatment indicate that the microhardness increases by 1,5-2 times relative to the initial state. The local electrolyte-plasma treatment allows providing the required hardness at a depth of up to 1,5-2 mm and high wear resistance of the main bearing and crankpin journals of the crankshaft, which significantly increases the service life.

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References

1. Editor-in-chief Aidapkelov N.S., Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics, Transport in the Republic of Kazakhstan/Statistical collection/in Kazakh and Russian/119 pages, 010000, Republic of Kazakhstan, Nur-Sultan, 8 Mangilik el avenue, House of Ministries, 4th entrance.
2. Aleksanyan I.M., Dubenko O.Ya. Wear of engine parts of transport and technological machines: monograph. – Rostov n/A: RSUPS, 2015. – 139 pages.
3. A.S. Grebennikov, S.A. Grebennikov, A.V. Kosareva Unaccounted factors in the standards of technical operation of vehicle (on types of repairs and the impact of downtime on the economy), World of Transport and Technological Machines No. 3(54) 2016 July - September, I.S. Turgenev OSU.
4. Pogrebnyak, A. D., Kaverina, A. S. Electrolytic plasma processing for plating coatings and treating metals and alloys. Prot. Met. Phys. Chem. Surf. 50, pp. 72–87,2014.
5. Pogrebnyak, A.D., Kaverina A.S., Kylyshkanov M.K. Electrolytic plasma processing for plating coatings and treating metals and alloys. Protection of Metals and Physical Chemistry of Surfaces, 2014, 50, pp. 72-87, https://doi.org/10.1134/S2070205114010092.
6. Vitthal R. Jumbad, Arvind Chel, Updesh Verma, Geetanjali Kaushik, Application of Electrolytic Plasma Process in Surface Improvement of Metals: A Review, Letters in Applied NanoBioScience Platinum Open Access Journal (ISSN: 2284-6808), Volume 9, Issue 3, 2020, 1249-1262.
7. Patent RK 23178. Method of electrolyte-plasma hardening of drill bit parts. M.K. Kylyshkanov, K.K. Kombaev, A.D. Pogrebnyak. Registered on 09/20/2010, MPK C21D1 / 78 (2009.01), C21D 1/34 (2009.01). https://kzpatents.com/3-ip 23178
8. K. K. Kombayev, M. V. Doudkin, A. I. Kim, M. Mlynczak, B. K. Rakhadilov. Surface hardening of the aluminum alloys Al3 by electrolytic-plasma treatment. News Of the national academy of sciences of the republic of Kazakhstan. Series of geology and technical sciences. Volume 4, Number 436 (2019), pp. 222 – 229, https://doi.org/10.32014/2019.2518-170X.117.
9. Kozha E., Smagulov D.U., Akhmetova G.E., Kombaev K.K. Laboratory installation for electrolytic-plasma treatment of steel. NEWS of national academy of sciences of the republic of Kazakhstan. 2017, 4(424), pp. 219-225.
10. I.M. Aleksanyan, A.E. Khachkinayan, Research of wear of crankshafts and connecting journals of engines of transport and technological machines, Transport. Transport Facilities. Ecology, No. 2, 2021, Rostov State University of Railway Engineering, Rostov-on-Don, Russia.
11. Rakhadilov B.K., Sagdoldina Zh. B., Ocheredko I.A., Kombaev K.K. Khassenov A.K. Impactresearch of electron beam processing on the structure and properties of PA6 polyamide//Eurasian Physical Technical Journal, Materials science, 2019, Vol.16, №2 (32), pp 43-47. DOI 10.31489/2019No2/43-47. ISSN1811-1165(Print); 2413-2179 (Online). https://doi.org/10.31489/2019 No 2 / 43-47.
12. Mikhail Doudkin, Kuat Kombayev, A.I. Kim, Bagdad Azamatov, ZhanerkeAzamatova. Research of cutting temperature reducing of titanium alloy grade 5 below polymorphic transformation depending on calculation of cutting modes. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 10, Issue 2, Apr 2020, pp. 747–758, https://doi.org/10.24247/ ijmperdapr202074.
13. Mikhail Doudkin, Kuat Kombayev, A.I. Kim, Bagdad Azamatov, ZhanerkeAzamatova. Research of cutting temperature reducing of titanium alloy grade 5 below polymorphic transformation depending on calculation of cutting modes. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Vol. 10, Issue 2, Apr 2020, pp. 747–758, https://doi.org/10.24247/ ijmperdapr202074.
14. Kuat Kombayev, Alina Kim, Daniyar Yelemanov, Gulden Sypainova, Strengthening of Low-Carbon Alloy Steel by Electrolytic-Plasma Hardening, International Review of Mechanical Engineering (I.RE.M.E.), Vol. 16, N. 2, February 2022 (ISSN 1970-8734)
15. S.H. Alavi, C. Dehghanian, P. Taheri. Investigation of corrosion behaviour of carbon steel coated by pulsed plasma electrolytic boronising technique in 35 wt-%NaCl aqueous solution. Surface engineering, 2011, No 27, pp. 509-514.

16. ASTM E1558-09(2014), Standard Guide for Electrolytic Polishing of Metallographic Specimens, ASTM International, West Conshohocken,PA, 2014,www.astm.org