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Studying the effect of the electrolyte-plasma modification on the fatigue strength of the KamAZ-740 crankshaft after overhaul using finite element modeling

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Abstract. During the crankshaft overhaul, a hardened material layer is removed from the journal's surface. The resource and mechanical properties of such an engine have been shown to be considerably reduced when compared to the new one. The study proposes a method of electrolyte-plasma modification of the surface of the repaired journals of the KamAZ-740 crankshaft made of chromium-molybdenum-vanadium steel 42CrMoVA TU 14-1-5083-91 (analog AISI 4140) to restore and improve fatigue strength. The crankshaft was destroyed after overhaul and had a fatigue crack on the surface of the crankpin journal, which was examined. The microstructure revealed the formation of a phase of high-carbon martensite on the surface of the modified sample, as well as inclusions of carbides of alloying elements (Cr, Mo, V), and cementite (Fe_3C). Microhardness analysis of the samples using the Vickers method showed an increase in surface hardness from 356...380 HV (initial structure) to 592...624 HV (after modification). The behavior of the KamAZ-740 crankshaft when exposed to cyclic operating loads was modeled using the finite element method in the ANSYS Mechanical analysis software. The analysis showed that the greatest stresses of 91.673 MPa occur in the bearing fillets of the crankpin journal, and the maximum values of deformation of the neck body reach 11.829 microns. It was found that the ground crankshaft, without surface hardening, has a reduced number of operating cycles up to 163070, but after surface electrolyte-plasma modification, it can operate for an unlimited number of cycles. The method of electrolyte-plasma modification of the surface of the crankshaft journals makes it possible to increase the safety margin by 18... 38%. The results of this study are of practical importance for improving the quality of overhaul of steel crankshafts of diesel and gasoline engines and extending their service life.

Keywords: Crankshaft, electrolyte-plasma modification, fatigue strength, overhaul, engineering analysis.

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Introduction

Automotive vehicles with an internal combustion engine (ICE) hold a leading position in the transport sector of the Republic of Kazakhstan. It is the most popular mode of transport for freight and passenger transportation. The crankshaft is the main component of an internal combustion engine that drives everything from cars to ships and generators. Its main function is to convert the linear motion of pistons into rotational motion, which drives cars or mechanisms [1]. During operation, the crankshaft is exposed to high alternating loads from the combined action of gas pressure forces on the piston and inertia forces of reciprocating masses. As a result, mechanical vibrations (torsional and bending) occur. In addition, vibrations that occur during engine operation, as well as high temperatures, which are similarly variable, harm the crankshaft. Engine oil, fuel pollution, and combustion products create a corrosive environment in the engine, which degrades the surface quality and the integrity of the crankshaft [2]. All these processes increase the wear of the crankshaft and create conditions for the formation of fatigue cracks on the working surfaces. The manufacturer usually designs a new crankshaft with a safety margin that ensures its uninterrupted operation until the first overhaul of the internal combustion engine, if the conditions for proper operation are met.

The specified service life of the KAMAZ-740 engine before the overhaul of the main units is: category I – at least 500,000 km, category II – at least 450,000 km, category III – at least 400,000 km, category IV – at least 350,000 km, category V – at least 300,000 km [3]. The cost of the overhaul increases significantly if the crankshaft is replaced with a new one, especially for large diesel engines. For this reason, the worn-out crankshaft is repaired by grinding the crankpin and main journal to the repair size. During the grinding process, the surface hardened layer of the material is removed, which reduces its strength properties and resistance to loads [4]. After such repairs, the operating time of the crankshaft is significantly reduced. The study of the causes of crankshaft failure, as well as the improvement of technology and quality of repair, to restore and increase performance, is relevant these days.

The subject of the study is the mechanical properties of the crankshaft of the KamAZ-740 diesel engine. The design of the KamAZ-740 crankshaft is shown in Figure 1. The main elements of the crankshaft are: main bearing journals 1, crankpin journals 2, bearing fillets 3, webs 4, counterweights 5, flywheel flange 6, and pulley end 7.

Figure 1. Crankshaft of KamAZ-740

N. Nikolić, N. Tadić, and J. Dorić [5] analyzed the failures of crankshafts and found that most of them are formed in the main and crankpin journals, which operate under high variable torsion and bending loads. These failures have a fatigued character. Aleksandar Vencl and Aleksandar Rac [6] studying the tribological process during friction of crankshaft journals and bearing liners during the operation of diesel engines, and found that the main and most significant types of wear are abrasive, adhesive, and surface fatigue wear. In addition to loads, other factors affect the resistance of a part to fatigue wear. D. Arola and S.L. Williams [7] in their study indicate that the roughness and integrity of the surface formed during the mechanical processing of the material significantly affect the process of fatigue failure. Dimensional details are also of great importance. Large-sized crankshafts have low and variable stiffness and, as a result, high susceptibility to bending deformations [8]. V.P. Lyalyakin & D.B. Slinko [9] have shown that the main journals wear out more intensively than the crankpin journals. The authors also claim that increasing the hardness of the journal surface improves wear resistance. Shuailun Zhu and others [10] claim that abrasive wear of crankshaft journals occurs due to the ingress and accumulation of polluting particles of fine debris and migration of carbonaceous elements from lubricants to the contact surface between the journal and the bearing liner under the influence of friction and elevated temperatures. These accumulated particles also cause uneven stress distribution on the surface, increasing fatigue wear of the crankshaft neck. Park H., Ko Y., and Jung, S. [11] found that the fatigue strength of the surface of the crankshaft journals can be increased by nitriding by more than 60%. Yasutoshi Tominaga and others [12] investigated the effect of ultrasonic modification by nanocrystals on the surface of the crankshaft necks on its operational properties. The results of the study showed that the fatigue strength increased by 30%, the coefficient of friction decreased by 24%, and wear decreased by 85% after modification. Boris Tarasenko and others [13] used carbide powder and a soft base of copper-zinc alloy as a coating on the surface of the crankshaft journals to increase the reliability and durability of power plants.

After analyzing the experience of previous researchers, it was found that research in this area is not sufficient, because they have not fully identified and accurately determined the main factors influencing the increase in fatigue strength. They also did not offer a comprehensive technology that would simultaneously meet the requirements: the level of fatigue strength, economic efficiency, and manufacturability of crankshaft hardening methods.

Electrolyte-plasma modification (EPM) opens up great opportunities for repairing and improving crankshaft performance, offering a new approach to solving problems such as wear, fatigue, and surface damage. This innovative technology uses a combination of electrochemical and plasma processes to change the surface properties of metal components, including crankshafts, and improve their performance, strength, and durability [14]. EPM can also cause compressive residual stresses in the surface layers of the crankshaft, effectively slowing down the initiation and spread of cracks and increasing the fatigue strength and resistance of the part to mechanical damage [15]. EPM can effectively harden the surface of crankshafts, increasing their resistance to wear and fatigue. If the crankshaft is exposed to a controlled plasma discharge in an electrolytic solution, it is possible to modify the surface layers with alloying elements or transform them into hardened phases, which increases the strength of the part and extends its service life [16]. EPM can change the surface topography and chemical composition of these critical areas, creating a protective layer that reduces friction, minimizes wear, and improves lubricant retention. These factors increase the efficiency and reliability of the crankshaft [17].

The methodology

Samples were cut and prepared (Fig.2) from the journals of the KamAZ-740 crankshaft made of steel 42CrMoVA TU 14-1-5083-91 (analog AISI 4140) to study the mechanical properties. It is a type of alloy steel that has high strength, toughness, and excellent hardenability. This steel belongs to the group of chromium-molybdenum-vanadium steels and is often used in areas requiring high mechanical properties and resistance to wear and fatigue [18].

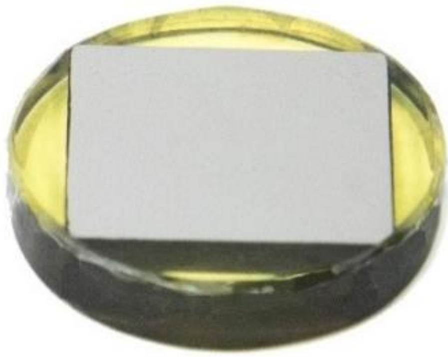

Figure 2. Crankshaft sample made of 42CrMoVA Steel TU 14-1-5083-91 (analog AISI 4140)

Chemical composition of steel 42CrMoVA TU 14-1-5083-91 (analog AISI 4140): (0,40 – 0,45)% C; (1,00-1,30)% Cr; (0,50 – 0,80)% Mn; (0,35 – 0,45)% Mo; (0,08 – 0,12)% V; (0,17 – 0,37)% Si; ≤0,3% Ni; (0,007 – 0,025)% S; ≤0,025% P; ≤0,3% Cu; Fe – Rest.

The mechanical properties of heat-treated (quenching and tempering) steel 42CrMoVA TU 14-1-5083-91 (analog AISI 4140) are shown in Table 1.

Table 1. The mechanical properties of steel 42CrMoVA TU 14-1-5083-91 (analog AISI 4140)

The mechanical properties							
$\sigma_В$	$\sigma_Т$	δ	Ψ	KCU	HB	σ_{-1}	τ_{-1}
835	716	12	42	78,4	255-277	389	233

$\sigma_В$ – Tensile strength, [MPa];
$\sigma_Т$ – Yield strength, [МПа];
δ – Relative elongation, [%];
Ψ – Relative narrowing, [%];
KCU – Impact strength, [J / cm^2];
HB – Brinell hardness, [MPa];
σ_{-1} – Endurance limit for a symmetrical cycle of normal stresses, [MPa];
τ_{-1} – Endurance limit for a symmetrical tangential stress cycle, [MPa].

The surfaces of the samples have been modified by the electrolytic plasma method. The surfaces of the samples were modified by the electrolytic plasma method. In the modification process, the sample surface mounted on a bracket and placed in an electrolyte bath from a 10% solution of soda ash (Na_2CO_3) was heated by electric discharges of the resulting plasma. In this case, carbon is mass-transferred to the treated surface and cemented [19]. The electrolyte was constantly circulated using a centrifugal pump to maintain an optimal temperature. The design had a nozzle through which the electrolyte enters the surface of the workpiece, and an anode plate made of stainless steel 12Cr18Ni10Ti GOST 5949-2018, connected to a positive potential. The processed product was connected to a negative potential. The EPM process was performed cyclically [20]. The first cycle (4 seconds) is heating the part's surface to the temperature of the phase transformation of ferrite into austenite, equal to approximately 860°C. Next, a cooling cycle took place for 4 seconds in the electrolyte stream and quenching. These cycles were repeated 30 times. The total processing time was 4 minutes.

The microstructure of the samples before and after modification was examined using an Olympus BX51 optical microscope, which allows detailed observation and analysis of changes in the surface structure. The microhardness was measured on a DuraScan 20 hardness tester using the Vickers method, which provides high accuracy.

Experimental research and mechanical tests were carried out at the “Smart Engineering” laboratory and the “Mechanical Engineering” scientific and production complex of the NJSC “D. Serikbayev East Kazakhstan Technical University”.

The hardening process and its effect on fatigue strength were modeled using the finite element method in the ANSYS Mechanical automated engineering analysis software package.

Findings/Discussion

The investigated crankshaft of the KamAZ-740 engine had a developed fatigue crack (Fig. 3) extending from the surface deep into the material. The initial crack formation zone was localized in the bearing fillet region of the second connecting journal, where maximum stress concentrations were observed. The fatigue crack developed gradually, spreading from the stress concentration zone to the main body of the shaft and further to the nearest web. The fracture occurred after the crack length reached a critical value and the load-bearing capacity of the structure was disrupted.

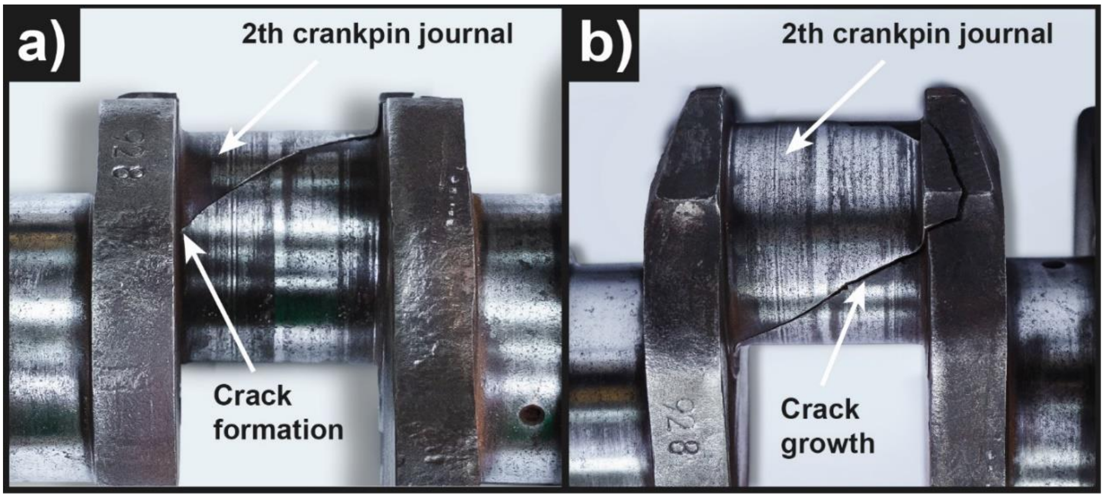

Figure 3. Fatigue crack of the KamAZ-740 crankshaft
a – the beginning of cracking; b – crack development

During the study, the microstructure and microhardness of the crankshaft samples were studied before processing (Fig.4a) and after the electrolyte-plasma modification (Fig.4b). It was found that in the initial state, the microstructure of the material consisted of a finely dispersed mixture of ferrite and carbides phases, as well as small sections of perlite. This is typical for the structure of alloy steel subjected to quenching and high tempering. No martensite phases, inclusions of CrN, FeN, VN nitrides, iron, and nitrogen compounds such as the ε-phase (Fe_2N_3) and γ'-phase (Fe_4N) characteristic after nitriding were found near the surface. This indicates that when the crankshaft was ground to the repair size, the surface hardened layer was completely removed. After treatment by the method of electrolyte-plasma modification, the formation of high-carbon martensite from carbon-supersaturated austenite was observed in the structure of the material [21]. Finely dispersed carbides of alloying elements (Cr, Mo, V) and cementite (Fe_3C) were also found.

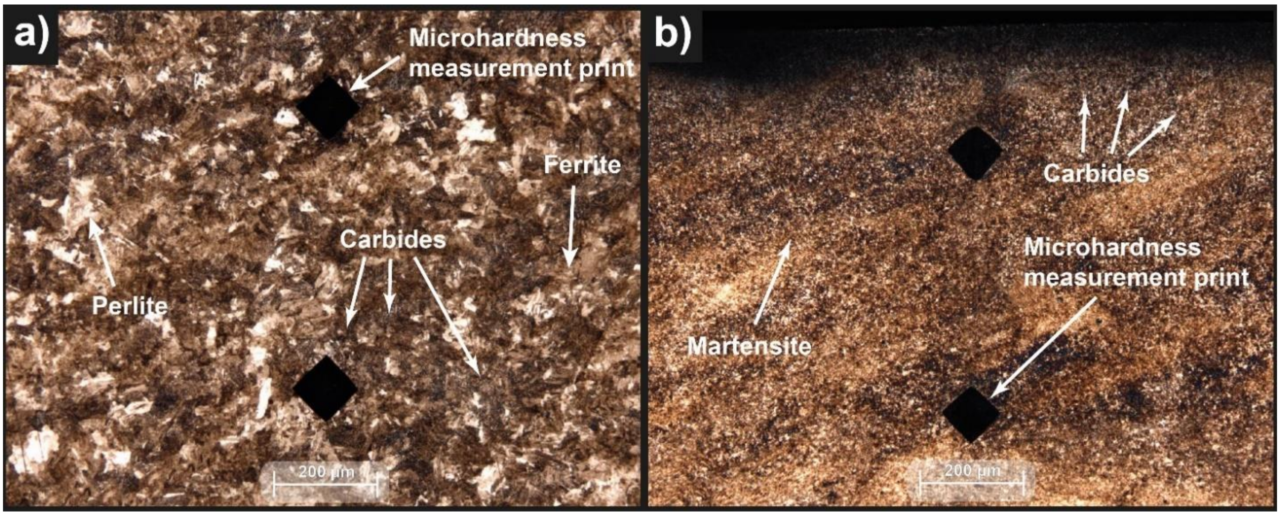

Figure 4. Microstructure of 42CrMoVA Steel
a – initial sample; b – after EPM

Measurements of the microhardness of the surface of the samples showed an increase in values after electrolyte-plasma modification from 356...380 HV (Fig.5a) to 592...624 HV (Fig.5b). This has a positive effect on the strength characteristics of the material. As noted earlier, the high hardness due to the fine structure of martensite contributes to a significant increase in the fatigue strength of the material due to resistance to the development of microcracks [22]. Fine-dispersed martensite ensures uniform distribution of internal stresses, which reduces local load concentrations and increases the durability of the part.

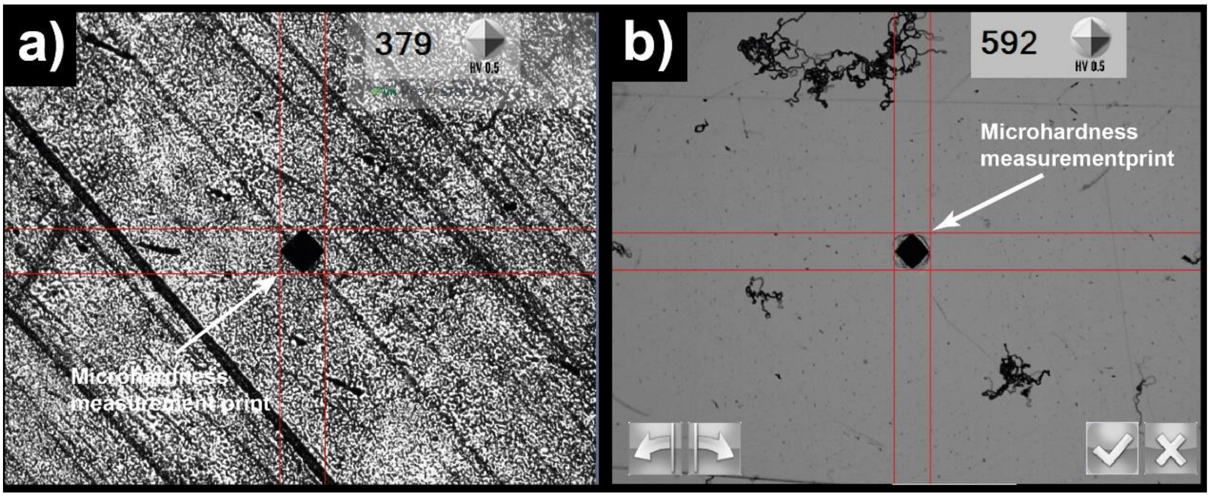

Figure 5. Measurements of surface microhardness: a – initial sample; b – after EPM

To simulate the behavior of the material under cyclic loading of the KamAZ-740 crankshaft and identify areas prone to fatigue cracks, fatigue strength was calculated using the finite element method by the ANSYS Mechanical automated engineering analysis software package with the ANSYS Structural Fatigue module. This module allows you to evaluate fatigue life, damage caused by fatigue load, safety factors, and variable stresses [23]. During the fatigue analysis, the most severe modes of operation of the internal combustion engine were taken as design modes. Figure 6 shows a graph of changes in the specific forces (in MPa) of inertia P'_j and gas pressure P'_g depending on the angle φ of rotation of the crankshaft in the maximum torque mode. The total value of the specific forces of gas pressure and inertia is their algebraic sum:

$$P_s = P_g + P_j \tag{1}$$

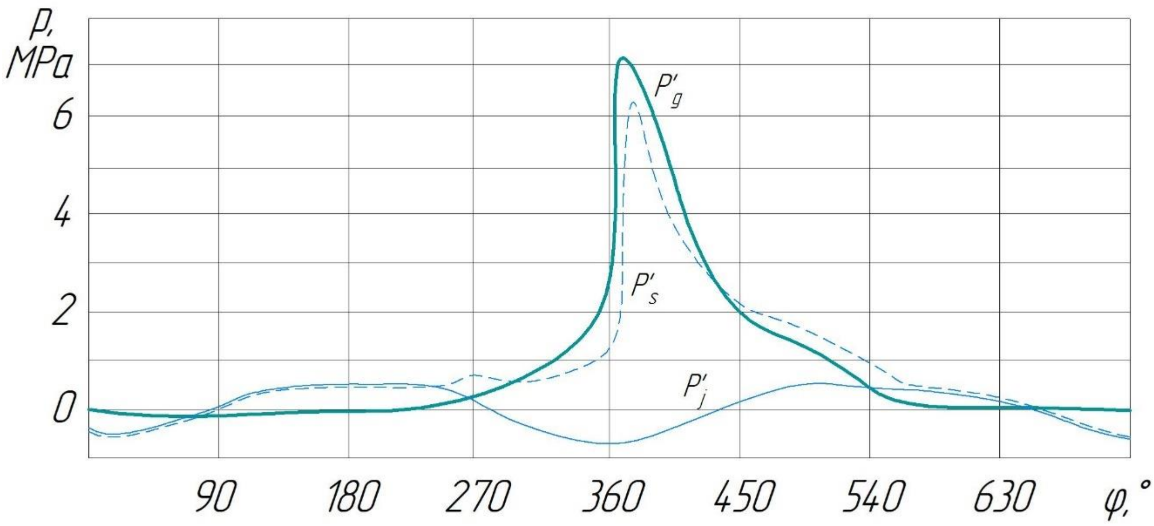

Figure 6. Graphs of the specific forces of the reciprocating internal combustion engine $P_s = P_g + P_j$ by the angle of rotation of the crankshaft in the maximum torque mode

In most cases, all of these loads do not cause critical elastic and plastic deformations of the crankshaft material, and the resulting stresses are significantly lower than the yield strength. Nevertheless, all these loads are alternating in nature and cause fatigue failure of the part. As noted earlier, the fatigue strength of the material is affected by the following factors: the design and dimensions of the part, the nature of the loads, surface roughness after machining, surface hardening, and corrosion resistance. All these parameters are determined by the coefficient of reduction of the endurance limit K [24, 25], which is taken into account when calculating fatigue strength. In turn, ANSYS Mechanical uses the fatigue strength factor K_f, which has an inverse relationship with K:

$$K_f = \frac{1}{K} \tag{2}$$

During operation, the crankshaft experiences the combined effect of tension compression, bending, and cyclic torque loads. In the case of tension compression, or bending, K is determined by the following formula:

$$K = \left(\frac{K_\sigma}{K_{d\sigma}} + \frac{1}{K_{F\sigma}} - 1\right) \cdot \frac{1}{K_v \cdot K_A} \tag{3}$$

K during torsion:

$$K = \left(\frac{K_\tau}{K_{d\tau}} + \frac{1}{K_{F\tau}} - 1\right) \cdot \frac{1}{K_v \cdot K_A} \tag{4}$$

where K_σ,K_τ are the effective stress concentration coefficients (take into account the design parameters and dimensions of the crankshaft): $K_{\sigma t}$ – during tension compression, $K_{\sigma b}$ – during bending, K_τ – during torsion;

$K_{F\sigma}$,$K_{F\tau}$ are the surface roughness coefficients (roughness of crankshaft journals after grinding Ra0,32 (Rz1,6)): $K_{F\sigma}$ – during tension compression, bending, $K_{F\tau}$ – during torsion;

K_v are the coefficient of surface treatment;

K_A are the anisotropy coefficient.

The anisotropy coefficient is K_A =1, because the KamAZ-740 crankshaft workpiece is obtained by forging and the material has a uniform structure in all directions.

The coefficient of surface treatment K_v is determined experimentally. For surface cementation, K_v is in the range from 1.2 to 2.0, without surface treatment, K_v equal to 1. To determine the effect of cementation by the electrolyte-plasma modification on the fatigue strength of the crankshaft, the conditions were modeled at surface treatment coefficients K_v equal to 1.0, 1.2, 1.6 and 2.0.

The obtained values of the coefficients associated with K are shown in Table 2, the coefficients K_f in Table 3.

Table 2. Coefficients K

Coefficients	$K_{\sigma t}$	$K_{\sigma b}$	K_τ	$K_{d\sigma}$	$K_{d\tau}$	$K_{F\sigma}$	$K_{F\tau}$	K_v	K_A
Value	1,574	1,571	1,404	0,823	0,760	0,972	0,984	1.0…2.0	1

Table 3. Coefficients K_f

Sample	Value K_f		
	Tension compression	Bending	Torsion
Initial	0,515	0,516	0,533
Modified K_v=1.2	0,618	0,619	0,640
Modified K_v=1.6	0,824	0,826	0,853
Modified K_v=2.0	1,030	1,032	1,066

At the first stage of the fatigue strength calculations in ANSYS Mechanical, the loading parameters were set. Cyclic loads during crankshaft operation are asymmetrical. Figure 7a shows the constant loading amplitude of the KamAZ-740 crankshaft. For forged parts made of high-quality alloy steel, the most acceptable theory of medium stress correction is the Soderbergh theory (Fig. 7b).

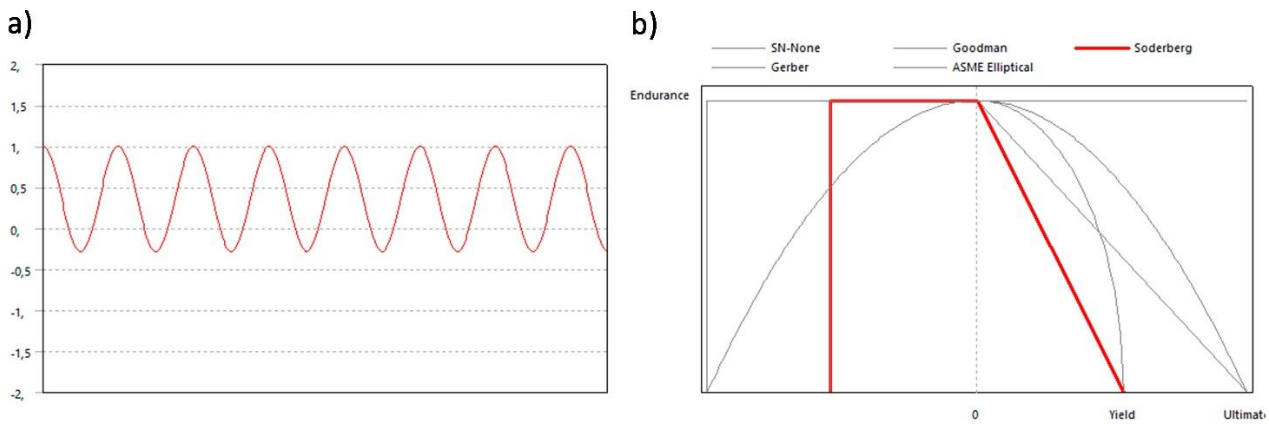

Figure 7. Load parameters of the KamAZ-740 crankshaft
a – constant loading amplitude of the crankshaft; b – Soderberg curve

Figure 8a shows equivalent (according to Von Mises) stresses that occur in the crankshaft when exposed to loads. Places of significant stress are marked in red: in the bearing fillets around the crankshaft, near the main and crankpin journal. The maximum stress is 91.673 MPa in the bearing fillet area. The complete deformations under loading are shown in Figure 8b. The maximum deformation of the crankshaft occurs in the area of the center of the connecting crankpin journal by 11.829 microns. The biaxial index is defined as the ratio of the lower main strength to the higher main strength, while the main strength close to zero is ignored. A value of 0 indicates a uniaxial strength. A value of -1 means a pure shift and a value of 1 corresponds to a purely biaxial state. Figure 8c shows a graph of the biaxial indication for the 42CrMoVA material of the KamAZ-740 crankshaft.

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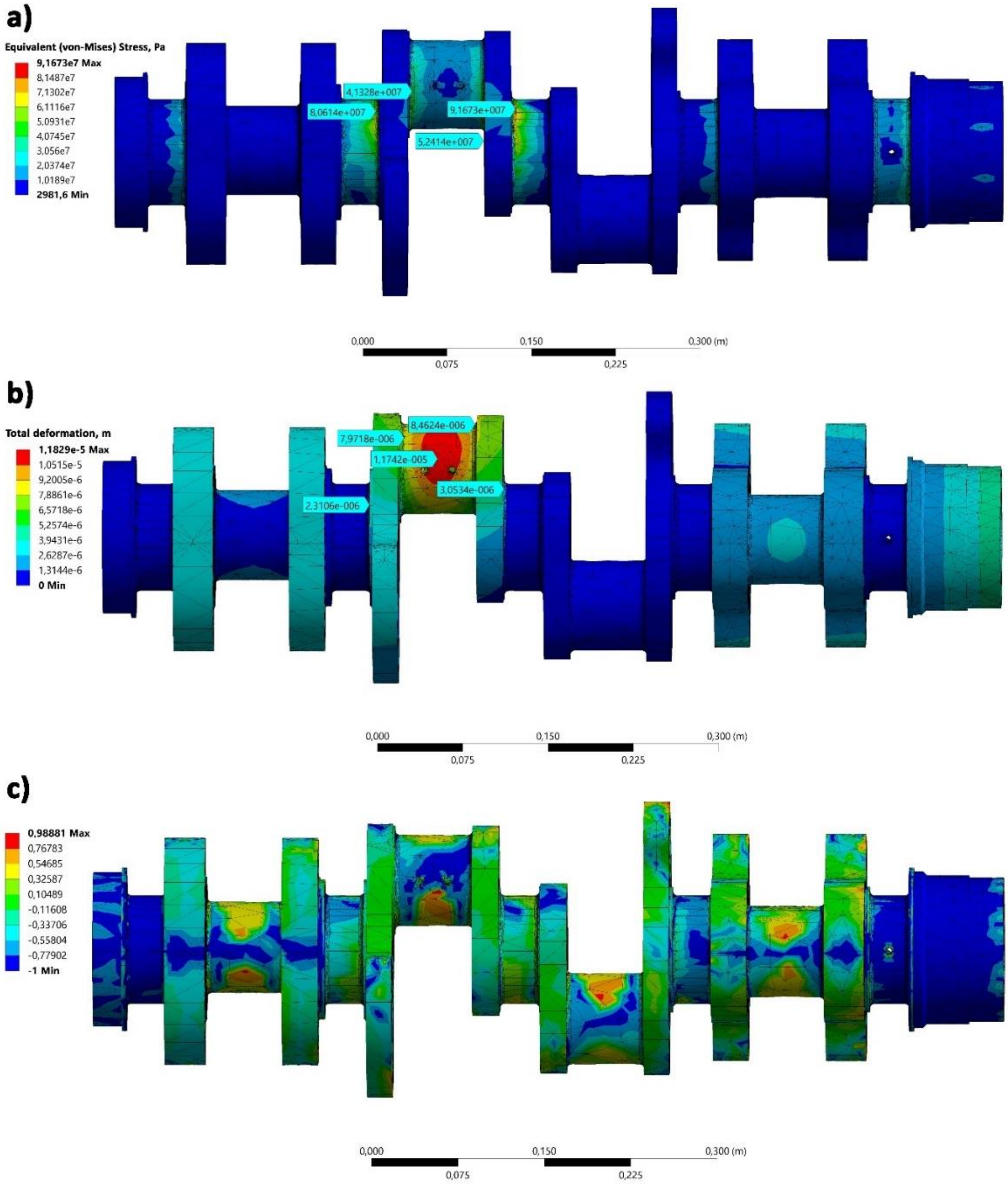


Figure 8. Stresses in the material of the KamAZ-740 crankshaft
a – Equivalent stresses according to Von Mises, b – complete deformations, c – biaxial stresses

Figure 9 shows the results of modeling the number of available cycles of the crankshaft, with calculated variable loads. In Figures 9a (K_v=1) and 9b (K_v=1.2) it can be observed that there are areas with reduced available cycles on the crankpin journal bearing fillets (min 163070 and 445350 cycles, respectively). This fact indicates that in these places, upon reaching the set values, a fatigue crack will form and the crankshaft will begin to collapse. At K_v=1.6 и 2.0 (Fig. 9c), the entire area of the part satisfies the fatigue strength condition. This means that the crankshaft can continue to operate indefinitely.

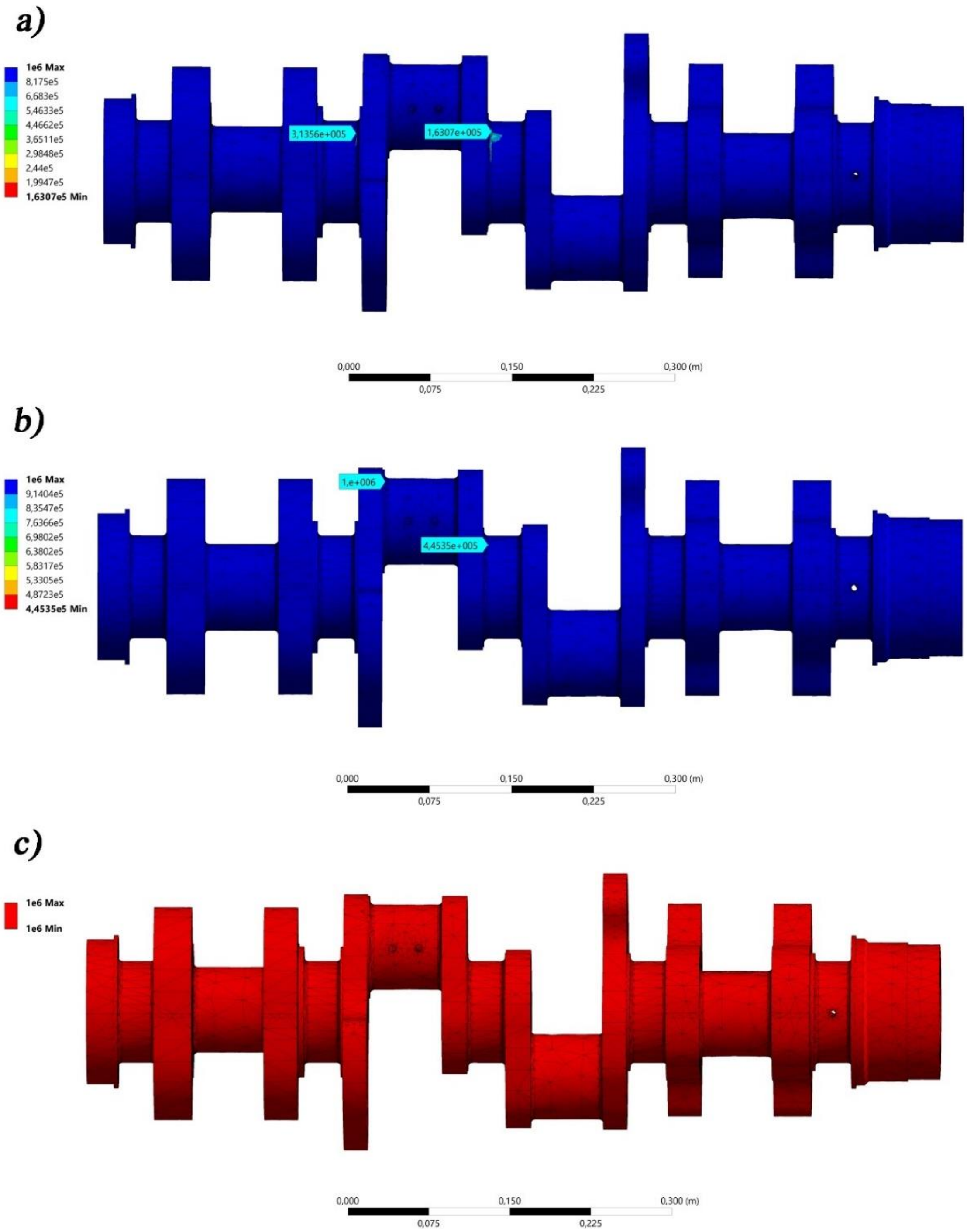
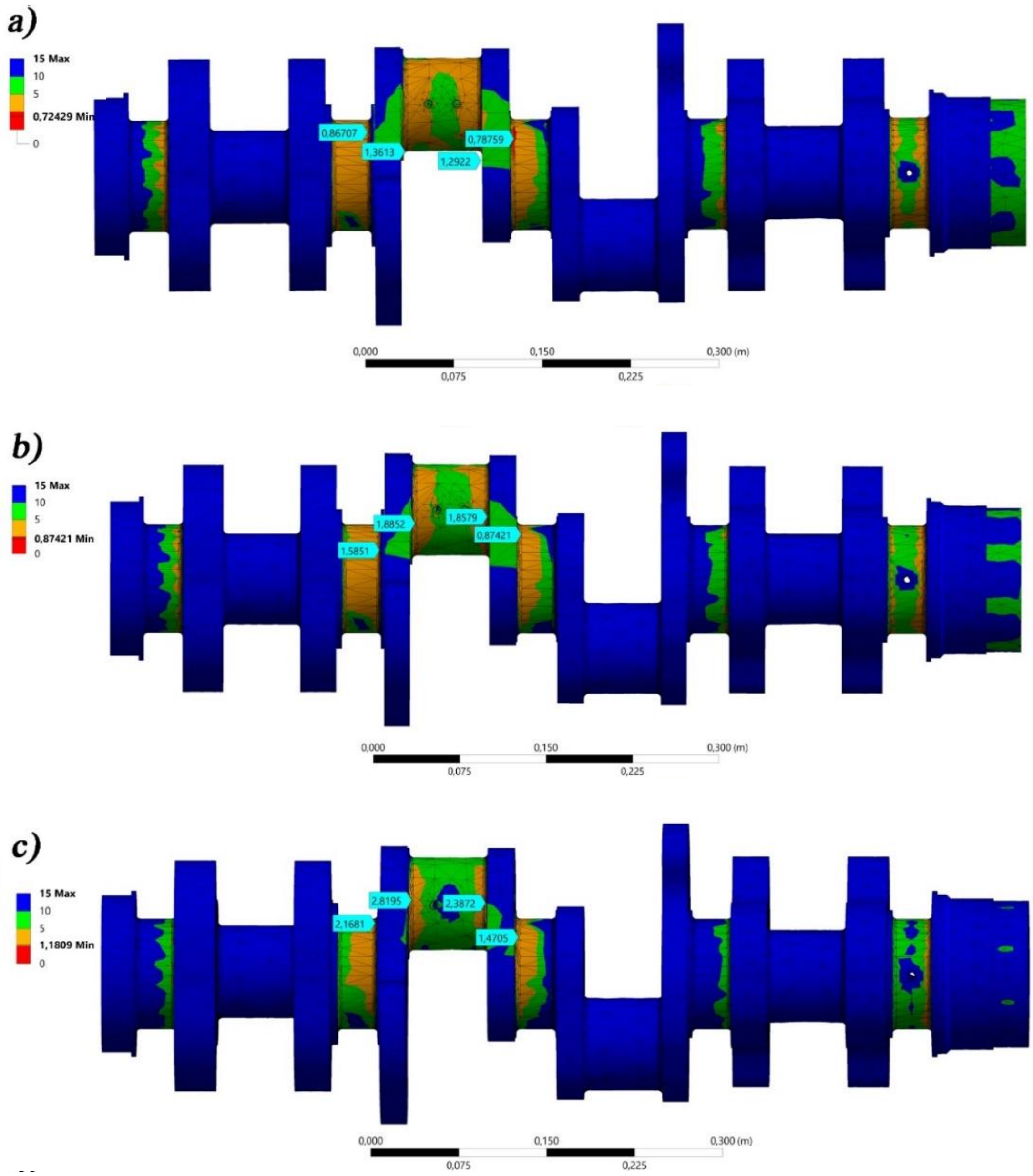


Figure 9. The number of available cycles of the KamAZ-740 crankshaft before fatigue failure
a – with the K_v=1.0; b – with the K_v=1.2; c – with the K_v=1.6 и 2.0;

It is also important to determine the fatigue strength safety factor of the KamAZ-740 crankshaft material during fatigue calculation. The minimum safety factor (Fig.10 a,b) of fatigue strength is observed at the bearing fillets and reaches values less than one, which indicates insufficient fatigue strength of the part under specified operating conditions. The value of the safety factor greater than 1 (Fig.10 c,d) indicates the available margin of fatigue strength, which makes it possible to compensate for inaccuracies in the manufacture and processing of the crankshaft, specified operating conditions, and other factors.



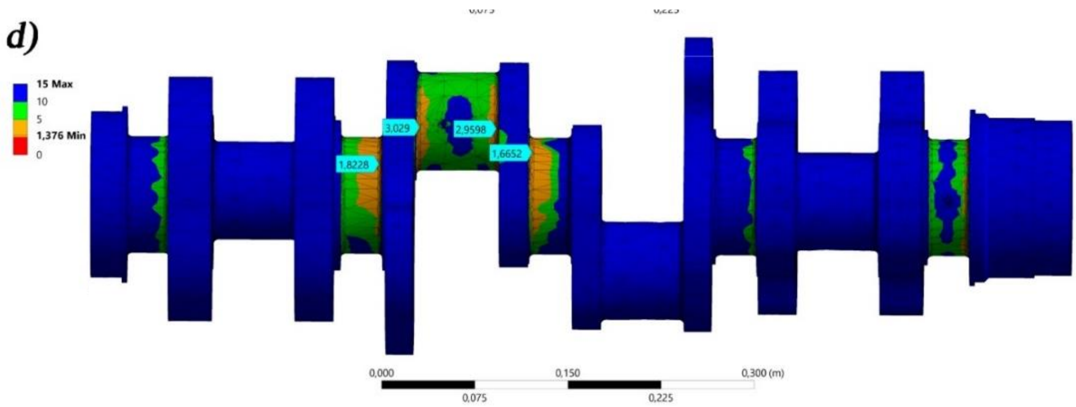


Figure 10. Fatigue strength safety factors
a – with the K_v=1.0; b – with the K_v=1.2; c – with the K_v=1.6; d – with the K_v=2.0;

After analyzing the results calculations for fatigue strength using the finite element method by the ANSYS Mechanical, a fatigue sensitivity diagram was constructed (Fig. 11). In this diagram, you can observe differences in the values of the number of available cycles of loading the KamAZ-740 crankshaft. At K_v=1 (surface without treatment), correct operation of the crankshaft is ensured at a load not exceeding 72% of the maximum, at K_v=1.2 the load should not exceed 87% of the maximum. With coefficients K_v=1.6 and 2.0, its correct operation is guaranteed at maximum calculated fatigue loads and has a margin of 18% and 38%, respectively.

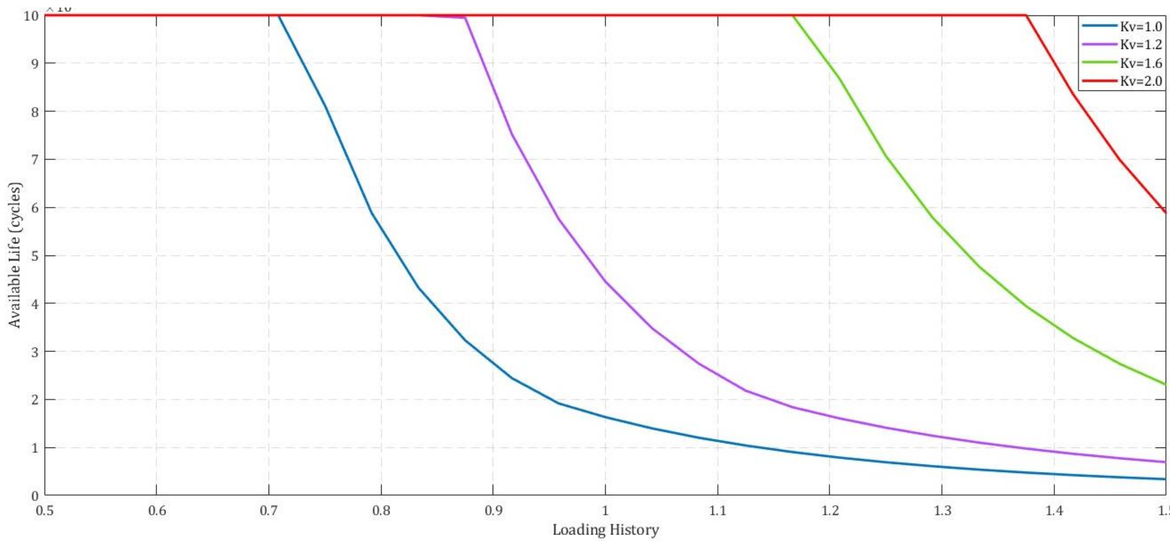


Figure 11. Fatigue sensitivity diagram

Conclusion

The effect of electrolyte-plasma modification on the fatigue properties of the KamAZ-740 crankshaft made of high-quality chromium-molybdenum-vanadium steel 42CrMoVA TU 14-1-

5083-91 (analog AISI 4140) was investigated. Samples were made and modified for experimental work. Changes in the microstructure of the samples after EPM were recorded. The results showed the presence of a quenching structure of high-carbon martensite on the surface of the modified samples, as well as inclusions of carbides of alloying elements (Cr, Mo, V) and cementite (Fe_3C). The microhardness study showed a 64% increase in HV values after treatment. The simulation of cyclic loading by the finite element method in the ANSYS Mechanical system showed that the strength characteristics of the KamAZ-740 crankshaft without surface heat treatment do not meet the specified requirements and ensure correct operation only at loads not exceeding 72% of the maximum. The method of electrolyte-plasma modification of the surface of the crankshaft journals allows for a margin of safety in the range of 18% and 38%. The study showed that the electrolyte-plasma modification has a positive effect on the service life of the KamAZ-740 crankshaft after overhaul, significantly increasing its durability and reliability.

Acknowledgment, conflict of interests

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The contribution of the authors.

I.D. Gridunov – significant contribution to the concept and design of the work, methodology, resources, data collection, writing a text, modeling, visualization, interpretation of results, and editing.

K.K. Kombayev – methodology, resources, interpretation of results, critical review, approval of the final version.

Y. Y. Tabiyeva – analysis, writing a text, and resources.

A.S. Kizatov – analysis, writing a text, and resources.

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Күрделі жөндеуден кейін КамАЗ-740 иінді білігінің шаршау беріктігіне соңғы элементтерді модельдеуді қолдана отырып, электролит-плазмалық модификацияның әсерін зерттеу

Аңдатпа. Иінді білікті күрделі жөндеу кезінде мойынның бетінен материалдың қатайтылған қабаты алынып тасталады. Мұндай қозғалтқыштың ресурсы мен механи-калық қасиеттері жаңасымен салыстырғанда айтарлықтай төмендейді. Зерттеу шаршау беріктігін қалпына келтіру және жақсарту мақсатында 42ХМФА ТУ14-1-5083-91 (AISI 4140 аналогы) хромдымолибдендіванадий болатынан жасалған КамАЗ-740 иінді білігінің жөнделген мойын бетін электролиттік-плазмалық модификациялау әдісін ұсынады. Күрделі жөндеуден кейін бұзылған Камаз-740 дизельді қозғалтқышының мойын бетінде шаршау жарықшасы бар иінді білігі зерттелді. Микроқұрылымды зерттеу өңделген үлгінің бетінде жоғары көміртекті мартенсит фазасының түзілуін, сондай-ақ легирлеуші элементтер карбидтерінің (Cr, Mo, V) және цементиттің (Fe_3C) қосындыларын анықтады. Виккерс әдісімен үлгілердің микроқаттылығын талдау бетінің қаттылығының 356...380 HV (бастапқы құрылым) мәндерінен 592 … 624 HV (модификациядан кейін) дейін жоғарылағанын көрсетті. ANSYS Mechanical бағдарламалық кешеніндегі соңғы элементтер әдісімен КамАЗ-740 иінді білігінің жұмыстық циклдік жүктемелерге ұшыраған кездегі әрекеті модельденді. Талдау көрсеткендей, ең жоғары кернеулер 91,673 МПа байланыстырушы өзек галтельдерінде пайда болады, ал мойын денесінің деформациясының максималды мәні 11,829 мкм-ге жетеді. Тегістелген иінді білік, кейіннен беттік қатайтусыз, жұмыс циклдерінің саны 163070-ке дейін төмендегені анықталды, бірақ беттік электролиттік-плазмалық модификациядан кейін шексіз циклдар бойы жұмыс істей алады. Иінді біліктің мойын бетін электролиттік-плазмалық модификациялау әдісі оның қауіпсіздік шегін 18...38%-ға арттыруға мүмкіндік береді. Осы зерттеудің нәтижелері дизельді және бензинді қозғалтқыштардың болат иінді біліктерін күрделі жөндеу сапасын арттыру және олардың қызмет ету мерзімін ұлғайту үшін практикалық маңызы бар.

Түйін сөздер: иінді білік, электролиттік плазмалық модификация, шаршау беріктігі, күрделі жөндеу, инженерлік талдау.

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Исследование влияния электролитно-плазменной модификации на усталостную прочность коленчатого вала КамАЗ-740 после капитального ремонта с применением моделирования методом конечных элементов

Аннотация. При капитальном ремонте коленчатого вала, с поверхности шеек снимается упрочненный слой материала. Ресурс и механические свойства такого двигателя значительно снижены по сравнению с новым. В исследовании предлагается метод электролитно-плазменной модификации поверхности отремонтированных шеек коленчатого вала КамАЗ-740, изготовленного из хромомолибденованадиевой стали 42ХМФА ТУ 14-1-5083-91 (аналог AISI 4140), с целью восстановления и улучшения усталостной прочности. Был исследован, разрушенный после капитального ремонта коленчатый вал дизельного двигателя КамАЗ-740, имеющий на поверхности шатунной шейки усталостную трещину. При исследовании микроструктуры было выявлено образование фазы высокоуглеродистого мартенсита на поверхности обработанного образца, а также включений карбидов легирующих элементов (Cr, Mo, V) и цементита (Fe_3C). Анализ микротвердости образцов по методу Виккерса показал увеличение твердости поверхности со значений 356…380 HV (исходная структура) до 592…624 HV (после модификации). Методом конечных элементов в программном комплексе ANSYS Mechanical было смоделировано поведение коленчатого вала КамАЗ-740 при воздействии на него рабочих циклических нагрузок. Анализ показал, что наибольшие напряжения 91,673 МПа возникают в галтелях шатунной шейки, а максимальные значения деформации тела шейки достигают 11,829 мкм. Было установлено, что отшлифованный коленчатый вал, без последующего поверхностного упрочнения, имеет сниженное количество циклов работы до 163070, но после поверхностной электролитно-плазменной модификацией может работать неограниченной количество циклов. Метод электролитно-плазменного модифицирования поверхности шеек коленчатого вала позволяет увеличить запас прочности на 18…38%. Результаты данного исследования имеют практическую значимость для повышения качества капитального ремонта стальных коленчатых валов дизельных и бензиновых двигателей и увеличения их срока эксплуатации.

Ключевые слова: Коленчатый вал, электролитно-плазменная модификация, усталостная прочность, капитальный ремонт, инженерный анализ.

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