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THE ANALYSIS OF THE INFLUENCE OF LASER HEAT TREATMENT OF THE CRANKSHAFT JOURNAL ON WEAR RESISTANCE OF THE BEARING

ANALIZA WPŁYWU LASEROWEJ OBRÓBKI CIEPLNEJ WARSTWY WIERZCHNIEJ CZOPU WAŁU KORBOWEGO NA ZUŻYWANIE SIĘ ŁOŻYSKA ŚLIZGOWEGO

Key words:

bearing, wear, laser treatment, cast iron

Słowa kluczowe:

łożysko ślizgowe, zużycie, obróbka laserowa, żeliwo

Abstract

The aim of the presented research was to evaluate wear effects of bearing elements in case of modification based on laser alloying with boron of journal surface layer. The research was performed on ZPG-IV tribology tester with journal-bearing friction pair. During the test load was applied progressively. SEM microscopes and non-contact 3D optical profilografometr was used to assess the test results. Study of the character of the wear process allowed to state, that after each increase of load during the test, rapid change of the value of oil temperature and the value of resistance in journal-pan contact was

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appeared. Then, the stabilization period was followed by. Some differences in the way of those processes between tested variants were noticed. Firstly, during the stabilization period larger thickness of the oil film at the journal-pan interface was notice in case of journal after laser treatment than in case of untreated journal. Secondly, it could be expected that oil temperature will be lower in case of longer time of tribological test for treated journal (than for untreated journal). It should favor better wear resistance of this kinematic node. Macro and microscopic observations of both types of surface after wear test allow to state, that journals after laser treatment were characterized by less wear effects, as cavities in the surface layer in comparison to untreated journals. More intensive wear of journals without treatment was confirmed by stereometric research and measurements of surface roughness parameters. This research allow to state positive laser treatment influence on the wear resistance of the journal. Although, there was no larger loss of the surface layer in case of pans after cooperation with hard journal after laser treatment (describe by the decrease of pans' thickness) then loss of the surface layer in case of pans after cooperation with softer untreated journal (nearly 5-times softer than the surface layer of treated journal), the microscopic observations and measurement of the parameters of stereometric structure of their surface showed more intensive wear of pan after cooperation with treated journal.

INTRODUCTION

Many machine parts are exposed to intense wear by friction, corrosion, and impact of high temperatures during their operation.

In the case of crankshafts (as well as camshafts) journals (main and connecting rods) cooperating with pans are expose to wear by friction [**L. 1–3**]. Intensive wear does not apply to the whole part, but only to a small element of it (this fact also concerns many other machine parts like cam of the camshaft, rocker arms, valves, etc.). The journal with a visible trace of seizure was presented in the **Figure 1**. The reason of the seizure process origin is interruption of lubricant film and growth of the adhesive interlocking [**L. 4**]. Therefore, journals should have a greater hardness of the surface layer.

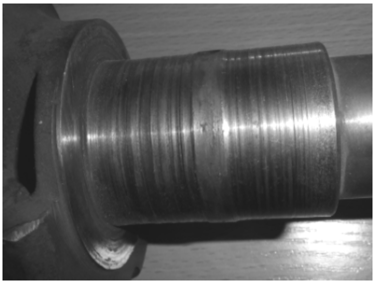

Fig. 1. Worn crankshaft journal with a trace of seizure
Rys. 1. Zużyty czop wału korbowego ze śladem zatarcia

Usually, hardness of the journal made of gray cast iron is increased by producing the white cast iron in their surface layer. Journals could be also surface hardened, carburized or nitrided (in case of diffusive chemical-heat treatments remaining areas of the part – not indicated for the treatment – are protected against the influence of the medium carrying the particular element which are implemented into the surface layer during this treatment). Therefore, useful solution for modification only selected area of machine parts is laser heat treatment (LHT). Additionally, this kind of treatment allows to achieve properties of surface layer which are not available to traditional surface treatments, such as obtaining a fine-crystalline microstructure, highly supersaturated solid solutions and metastable phases, even a vitrification. The strengthening of the surface layer is a result of [**L. 5–7**]: dissolution of additional atoms, effects of phase transformation and reduction of grain size. By laser implementation of alloy elements it is possible to obtain the microstructure and properties of surface layers similar to stainless and high-alloyed steels [**L. 8**]. Surface layer formed in such way favors achieving lower coefficient of friction [**L. 9**] better resistance to wear – not only adhesive [**L. 10**] and abrasives, [**L. 11**] but also fatigue [**L. 12, 13**]. Previously performed own research concerning nodular iron laser alloying with boron have shown that it is possible to obtain fine-grained microstructure of melted zone enriched with the hard phase of Fe_2B and to increase hardness and wear resistance of the surface layer of samples treated in this way. 3.5-times less the weight loss of such samples was noticed in comparison to samples after traditional hardening [**L. 10**]. In addition, less the weight loss of the steel rings working with such laser boronized samples was also observed [**L. 14**]. Results of the initial research of the wear test of journals after laser alloying have been already described in previous paper [**L. 15**]. Those research showed that value of the wear trace depth (in the area of cooperation with pan) after wear test in case of untreated journals was larger than in comparison to journals after laser treatment. Description of the surface layer microstructure produce by laser alloying (using raster method) and LHT treatment parameters selection for journals modification have been contained in papers [**L. 15, 16**].

The aim of the presented research was to evaluate wear effects of both kinematic node of the bearing in case of modification based on laser alloying with boron of journal surface layer and to compare the character of the wear processes for variant with the journal after laser treatment and with the untreated journal.

EXPERIMENTAL

Objects of the research were both kinematic node parts: journals (made of nodular iron characterized by spheroidal graphite in pearlite-ferrite matrix with hardness of ~250HV0.1) and pans (with the friction layer made of an aluminum alloy with tin). 3 journals without any treatment (i.e. with the same microstructures in the surface layer and in the core material), and 3 journals with modified surface layer (with fine microstructure enriched with iron borides in order to obtain hardness of ~1200HV0,1) achieved by laser alloying with boron using raster method were tested. The research was performed on the journal-bearing ZPG-IV tribology tester [**L. 17**]. During the test it was possible to measure: the torque of the driving shaft position M [Nm]; the shaft rotational speed n [rpm]; the pressure in the hydraulic system of the load p [bar] corresponding to the calculated values of the shaft pressure on the pan [MPa]; the temperature in the area under the pan T [°C]; the resistance in the journal-pan contact zone R [kΩ] (which is the equivalent of the presence of the oil film) [**L. 17**]. Wear test consisted on changing of the surface pressures from 0 to 2 MPa (initially the load was increasing by 0.2 MPa and next by 0.1 MPa). Every 15 minutes took place increase of the load node at constant shaft speed 1300 rpm.

To assess the surface of journals and pans JEOL/EO 0.1, JCM-6000 and Vega 5135 Tescan scanning electron microscopes and Sensofar non-contact 3D optical profilographometer were used.

RESULTS AND DISCUSSION

The characteristic of the wear process

During the wear test for both variants of studied journals changes in the value of friction, the oil temperature and the resistance in the area under the pan were noticed.

Every time when load of friction node was increased (expressed by increased pressure in the hydraulic system of the load) friction was raised, value of oil temperature was raised and value of resistance was decreased in the area under the pan. After some time of load change it was observed decrease and stabilization of the value of friction and the value of oil temperature, as well as increase and stabilization of the value of resistance. In case of laser treated journals the value of friction of analyzed pair decreased and stabilized more quickly than friction in case of untreated journals. The analysis of the oil temperature changes (under the pan) has shown that, right after increase of the load for laser treated journals, the increase of the temperature was higher (e.g. 8ºC) then for untreated journals (e.g. 5ºC during the same phase of the test). Nevertheless, it was notice also, that the following decrease of the temperature was faster (up to 2 times faster) in case of laser treated journal. The average value of the oil temperature under the pan after each stabilization of bearings work for both tested variants are shown in the **Fig. 2**. On the base of trend lines concerning the increase of the oil temperature value with increasing load during the test, it was stated that in case of higher values of the pressure on the pan (as a result of the longer time of the test) the lower values of the temperature in case of bearing with laser treated journal could be expected in comparison to bearing with untreated journal.

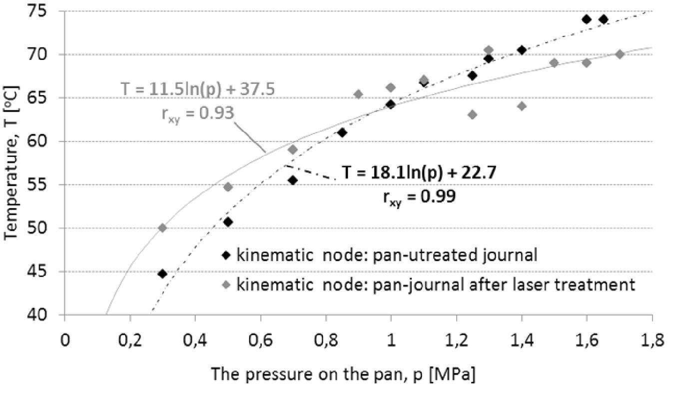

Fig. 2. The average value of the temperature after each stabilization of the bearings work for both tested variants (at the test measuring range)

Rys. 2. Średnie wartości temperatury po każdorazowym ustabilizowaniu pracy łożyska przy badanym zakresie pomiarowym dla obu badanych wariantów

On the other hand, the analysis of the value of resistance for both variants suggests that the oil film thickness in the pan-journal area in tested kinematic node in case of using laser treated journal is larger than in case of using untreated journal. The average value of resistance after each stabilization of the bearings work at the test measuring range for both tested variants are shown in **Fig. 4**. The existence of the lower values of the oil temperature in longer time of the test and the higher value of the oil film thickness under the pan cooperating with laser treated journal should favor lower wear of such modified journal.

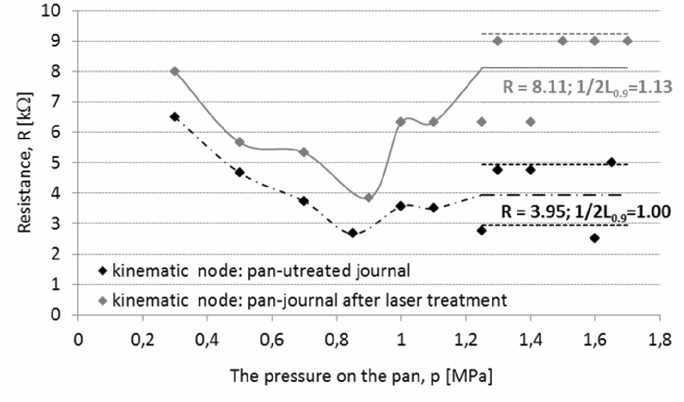

Fig. 3. The average value of resistance after each stabilization of the bearings work for both tested variants (at the test measuring range)

Rys. 3. Średnie wartości rezystancji po każdorazowym ustabilizowaniu pracy łożyska w badanym zakresie pomiarowym dla obu badanych wariantów

WEAR EFFECTS OF JOURNAL SURFACE

Except larger depth value of the wear trace (in area of cooperation with the pan) for untreated journals than for laser treated journals (noted already in paper [**L. 15**]) significant differences between wear intensity of both tested variants were revealed during the macroscopic study. On the base of observation, much larger number of wear cavities in the surface layer of untreated journals were revealed (**Fig. 4a**), than in the surface layer of laser treated journals (**Fig. 4b**).

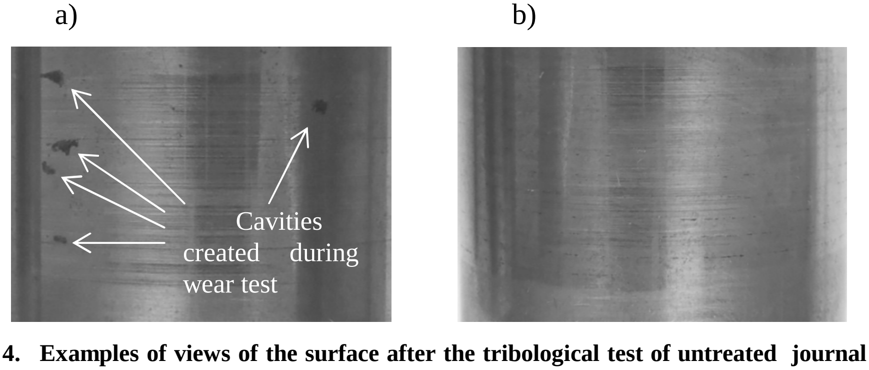

Fig. 4. Examples of views of the surface after the tribological test of untreated journal (a) and journal after laser treatment (b)

Rys. 4. Przykładowe widoki powierzchni czopu po próbie na maszynie zużyciowej: a) nieobrobionego; b) obrobionego laserowo

Microscopic study revealed, that cavities (formed during tribological test) in the surface layer of untreated journal were deeper (**Fig. 5 a, b**) than in the surface layer of laser treated journal (**Fig. 5 c, d**). In case of untreated journal, relatively not much greater hardness of its surface layer then the hardness of the pan could favor more intensive adhesive wear between them. The consequence of this kind of wear could be formation of deeper cavities. Whereas for laser treated journal (with nearly 5-times harder surface layer then the layer of the untreated journal) during tribological test plastic deformation of the pan by hard surface layer of the journal was more likely than adhesive processes between these cooperating surfaces.

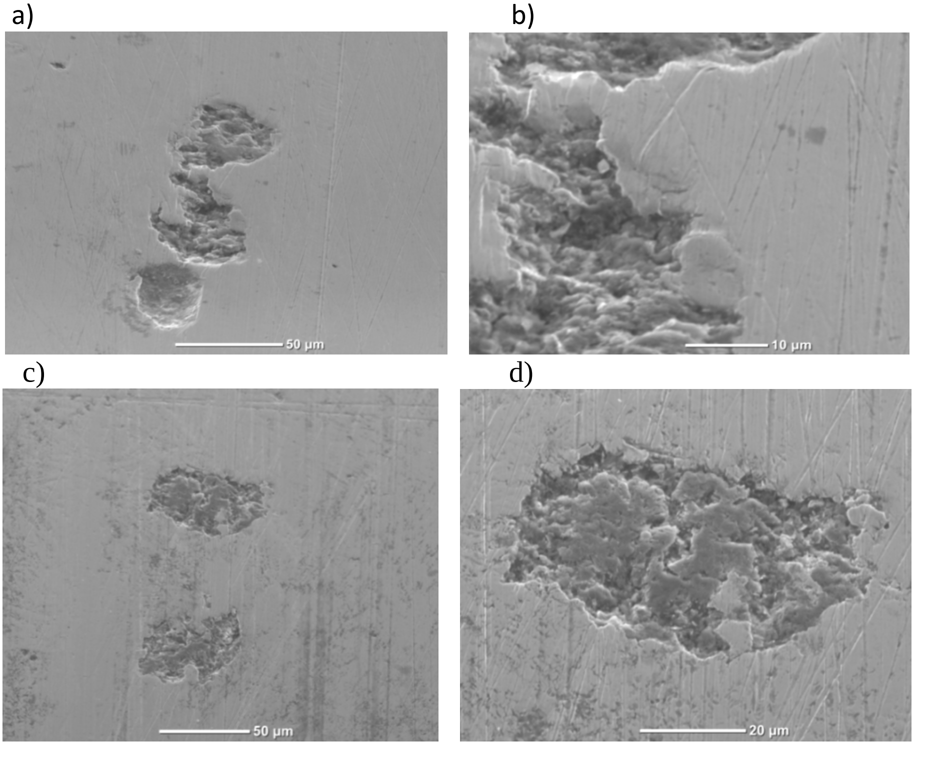

Fig. 5. Surface after tribological test of untreated journal (a, b) and laser treated journal (c, d), SEM

Rys. 5. Widok powierzchni czopu po próbie zużyciowej nieobrobionego (a, b) i obrobionego laserowo (c, d), SEM

The differences between analyzed surfaces were also evident in the images of stereometric structure (**Fig. 6**). On the base of these images, values of roughness parameters (**Tab. 1**) and curves of load capacity were estimated. Although the majority of the amplitude and hybrid surface roughness parameters (like: arithmetic mean deviation of the assessed profile Sa**,** maximum height of the profile Sz**,** maximum profile valley depth Sv**,** maximum profile peak height Sp**,** root mean square slope of the assessed profile Sdq) was similar values for both tested variants, it has to be into account that these parameters averaged roughness characteristics pretty much.

a) b)

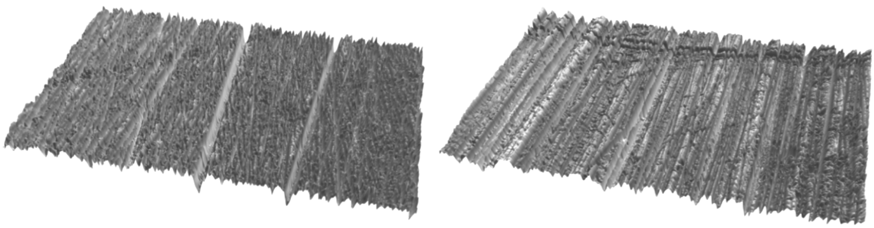

Fig. 6. The stereometric structure of surface of the untreated journal (a) and laser treated journal (b)

Rys. 6. Struktura stereometryczna czopu nieobrobionego (a) i obrobionego laserowo (b)

Table 1. Chosen 3D roughness parameters of surface of the untreated journal (a) and laser treated journal (b)

Tabela 1. Wybrane parametry struktury geometrycznej powierzchni 3D czopu nieobrobionego i obrobionego laserowo

Parameter	Untreated journal	Treated journal	Parameter	Untreated journal	Treated journal
Sq [·m]	0.1010	0.1073	Sdr [%]	0.5333	0.4175
Ssk	-1.8156	-0.9542	Sk [·m]	0.1818	0.2400
Sku	8.0090	4.5813	Spk [·m]	0.0417	0.0495
Sp [·m]	0.3083	0.3034	Svk [·m]	0.2106	0.1661
Sv [·m]	0.8646	0.9467	Sr1 [%]	6.5700	5.8125
Sz [·m]	1.1730	1.2500	Sr2 [%]	83.6270	83.3625
Sa [·m]	0.0714	0.0841	Sa1 [$\cdot m^3/\cdot m^2$]	0.0014	0.0014
Sdq	0.1038	0.0919	Sa2 [$\cdot m^3/\cdot m^2$]	0.0172	0.0138

For a more detailed analysis such parameters as asymmetry of surface deviations about the mean plane Ssk (skewness) and the peakedness or sharpness of the surface height distribution Sku (kurtosis) allow. On the base of the value of Ssk parameter for laser treated journal (0.95) it could be stated the presence of single valleys with high depth (Sa, Sq and Sz parameters do not identify such valleys due to their specificity mentioned above). Whereas, the presence of more flattened tops of the surface profile in the case of laser treated journal was stated due to value of Sku parameter equal to 4.58 (in case of untreated journal surface the value of Sku was 8.01).

Such character of the surface is confirmed by the value of core roughness depth Sk and reduced valley depth Svk. For laser treated journal the value of Sk was larger (0.24 μm) than the value for untreated journal (0.18 μm). In case of Svk parameter was inversely. The value of reduced valley depth was lower (0.17 μm) for laser treated journal, than for the value of untreated journal (0.21 μm). Higher Svk parameter indicates the existence of larger cavities in the surface layer of untreated journal created during the wear test. It was confirmed by microscopic observation (**Fig. 5**).

On the base of performed analysis of both variants of surface the positive influence of laser treatment on the wear resistance of journals could be stated.

WEAR EFFECTS OF PANS SURFACE

Macroscopic study after the tribological test did not revealed obviously differences in wear effect between pans after cooperation with untreated journals and pans after cooperation with laser treated journals (**Fig. 7**). Additionally, the measured thickness of pans after cooperation with untreated journals and pans after cooperation with laser treated was similar. The thickness was smaller than the thickness of the new pan of approx. 0.024 mm (**Fig. 8**).

a) b)

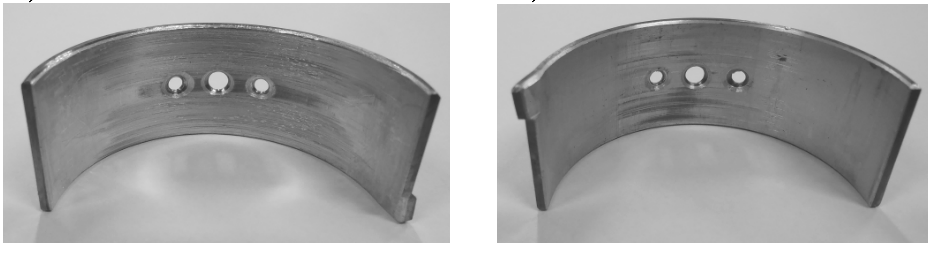

Fig. 7. Examples of views of the surface after the tribological test of pan cooperating with untreated journal (a) and pan cooperating with laser treated journal (b)

Rys. 7. Przykładowe widoki panwi po próbie zużyciowej współpracujących z czopem: a) nieobrobionym laserowo; b) obrobionym laserowo

In spite of the lack of differences in size of the loss in the surface layer between pans after cooperation with untreated journals and pans after cooperation with laser treated journals (**Fig. 8**) the study of their surfaces revealed the influence of the hardened surface layer achieved by laser heat treatment of the journal on the intensity of the pan wear. Primarily, the presence of larger grooves in the pan after cooperation of a hard surface layer of laser treated journal than in case of pan after cooperation with untreated journal indicating on more intensive wear (**Fig. 9** and **10**).

The roughness parameters measured on the base of 3D stereometric surface study are presented in **Tab. 2**. 10-times higher parameter of the volume of the deep valleys Sa2 for the pan after cooperation with laser treated journal (equal to 0.11mm^3/mm^2) indicates their larger material loss during tribological test than the loss of material of the pan after cooperation with untreated journal. Higher value of reduced valley depth Svk (1.56 μm) for the pan after cooperation with laser treated journal (for the pan after cooperation with untreated journal was 0.22 μm) suggests that in this case a grooving (an abrasive wear by plastic deformation of softer pan by harder surface layer of laser treated journal) was dominating. It is also confirmed by the valleys depth of the pan after cooperation with laser treated journal which were up to 1.5 μm (the valleys of depth of the pan after cooperation with untreated journal was 40 nm).

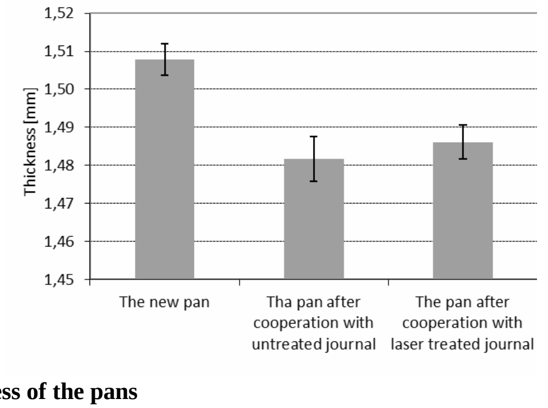

Fig. 8. The thickness of the pans
Rys. 8. Grubość panewek

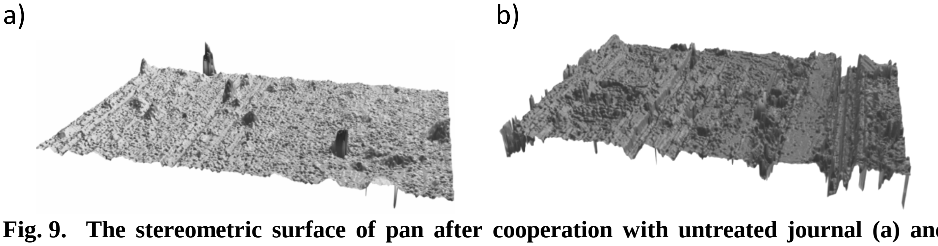

Fig. 9. The stereometric surface of pan after cooperation with untreated journal (a) and pan after cooperation with laser treated journal (b)
Rys. 9. Struktura stereometryczna panwi po współpracy z czopem nieobrobionym (a) i obrobionym laserowo (b)

No larger loss of the surface layer (assessed by measuring of the pan thickness) in case of pans after cooperation with hard laser treated journal then loss of the surface layer in case of pans after cooperation with softer journal without treatment could be because of too short time of performed tribological test – approx. 30h. Hence, it can be expected that the longer time of the test will cause their faster damage.

a) b)

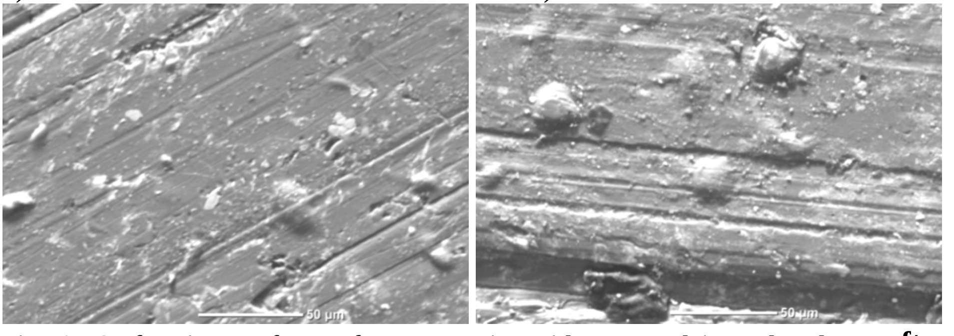

Fig. 10. Surface image of pan after cooperation with untreated journal and pan after cooperation (a) with laser treated journal (b), SEM

Rys. 10. Widok powierzchni panewki współpracującej z czopem nieobrobionym (a) oraz czopem obrobionym laserowo (b), SEM

Table 2. Chosen 3D roughness parameters of surface of pan after cooperation with the untreated journal (a) and pan after cooperation with laser treated journal (b)

Tabela 2. Wybrane parametry struktury geometrycznej powierzchni 3D panwi współpracującej z czopem nieobrobionym i obrobionym laserowo

Parameter	Pan after cooperation with the journal		Parameter	Pan after cooperation with the journal	
	without treatment	after treat-ment		without treatment	after treat-ment
Sq [·m]	0.2434	0.6631	Sk [·m]	0.2955	1.1703
Ssk	3.7589	-1.3667	Spk [·m]	0.4917	0.4484
Sku	39.8764	6.0447	Svk [·m]	0.2195	1.5614
Sp [·m]	4.3241	2.7075	Sr1 [%]	16.1835	10.9600
Sv [·m]	4.1179	4.5616	Sr2 [%]	89.2835	86.1600
Sz [·m]	8.4420	7.2691	Sa1 [·m^3/·m^2]	0.0398	0.0246
Sa [·m]	0.1395	0.4631	Sa2 [·m^3/·m^2]	0.0118	0.1080

CONCLUSION

The following conclusions can be drown from the carried out research.

Study of the character of the wear process allowed to state, that after each increase of load during the test, rapid change of the value of friction, oil temperature and resistance in journal-pan contact was appeared. Then, the stabilization period was followed by. During the stabilization period larger thickness of the oil film at the journal-pan interface was notice in case of use of laser treated journal than in case of untreated journal. It was also stated that, for laser treated journal it could be expected that oil temperature will be lower (than for untreated journal) in case of longer time of tribological test. It should favor better wear resistance.

Laser treated journals were characterized by surface with less wear effects, as cavities created during tribological test in the surface layer in comparison to untreated journals. More intensive wear of journals without treatment was confirmed by stereometric research and measurements of surface roughness parameters. For instance, the value of Sku parameter for laser treated journal was lower (4.58) than for untreated journal (8.01), which allow to state the presence of more flattened tops of the surface profile in the case of laser treated journal. Confirmation of less intensive wear of laser treaded journal was its higher value of core roughness depth Sk. Whereas, higher value of reduced valley depth Svk for untreated journal (in comparison to laser treated journal) indicates the existence of larger cavities in the surface layer of untreated journal created during the wear test.

In spite of no larger loss of the surface layer in case of pans after cooperation with hard laser treated journal then loss of the surface layer in case of pans after cooperation with softer untreated journal (the thickness of pans were similar) the microscopic and stereometric examination of their surfaces showed more intensive wear of pans after cooperation with laser treated journal.

Positive effects of wear test of journals allow to state that application of laser alloying of such machine parts like crankshaft should increase their life and durability and should contribute the replacement of steel shafts by shafts made of cast iron and diffusive surface treatment by laser treatment.

Acknowledgments

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Streszczenie

Celem prezentowanych badań była ocena skutków zużywania się elementów węzła kinametycznego łożyska ślizgowego w przypadku zastosowania modyfikacji warstwy wierzchniej czopu za pomocą

stopowania laserowego borem. Badania zostały przeprowadzone na stanowisku do badań tribologicznych ZPG-IV z węzłem ciernym czop–panewka. Podczas badania obciążenie zwiększane było stopniowo. Do oceny stanu powierzchni został zastosowany elektronowy mikroskop skaningowy (SEM) oraz bezstykowy optyczny profilografometr 3D. Na podstawie analizy przebiegu procesu zużywania stwierdzono, że po zwiększeniu obciążenia następowała nagła zmiana wartości temperatury oleju oraz rezystancji w strefie styku czopa i panewki, a następnie ich stabilizacja. Stwierdzono również pewne różnice w przebiegu tych procesów pomiędzy badanymi wariantami. Po pierwsze podczas okresu stabilizacji odnotowano występowanie większej grubości filmu olejowego w strefie styku czop-panewka w przypadku zastosowania czopu obrobionego laserowego niż w przypadku czopu nieobrobionego. Po drugie na podstawie analizy procesu zużywania stwierdzono, że przy dłuższym czasie próby dla czopu obrobionego wartość temperatury oleju w miejscu styku czopa i panewki będzie mniejsza (niż dla czopu nieobrobionego), co powinno sprzyjać zwiększeniu odporności na zużywanie przez tarcie tego węzła kinematycznego. Na podstawie wykonanych badań makro- i mikroskopowych powierzchni obu rodzajów czopów po przeprowadzonej próbie zużycia zaobserwowano, że czopy obrobione laserowo charakteryzowały się mniejszą ilością efektów zużycia w postaci ubytków w warstwie wierzchniej w porównaniu z czopami nieobrobionymi laserowo. Mniejsze zużycie czopów obrobionych laserowo potwierdziły pomiary parametrów struktury geometrycznej powierzchni. Badania te pozwoliły na stwierdzenie pozytywnego wpływu obróbki laserowej na odporność zmodyfikowanej w ten sposób warstwy wierzchniej czopów. Pomimo że nie odnotowano większego ubytku warstwy wierzchniej panewek (wyrażonej przez zmniejszenie ich grubości po próbie zużyciowej) współpracujących z twardym obrobionym laserowo czopem od panewek współpracujących z blisko 5-krotnie bardziej miękkim od czopu obrobionego laserowo czopem nieobrobionym, to obserwacje mikroskopowe i pomiary parametrów struktury geometrycznej powierzchni wskazały jednak na intensywniejsze ich zużycie.