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Formation of sliding surface with texture by laser micromachining

Streszczenie. *W opracowaniu przedstawiono wybrane aspekty związane z technologią laserowego kształtowania tekstury powierzchniowej elementów z SiC współpracujących ślizgowo. W części opisowej analizowano cechy wiązki laserowej istotne z punktu widzenia wytwarzania tekstury. W części badawczej przedstawiono wyniki eksperymentów technologicznych i tribologicznych. Rezultatem pracy są wytyczne do technologii teksturowania przy wykorzystaniu lasera Nd:YAG. (**Kształtowanie powierzchni ślizgowej z teksturą poprzez mikroobróbkę laserową**).*

Abstract. *The study presented chosen aspects connected with laser technology which forms texture of SiC sliding ring co-operating. In the descriptive part there were analyzed qualities of the laser bundle that are essential from the texture production point of view. The research part of the study showed the outcome technological experiments that were. The end results were guidelines to the texture technology with the use Nd:YAG laser.*

Słowa kluczowe: mikroobróbka laserowa, teksturyzacja, opory tarcia.
Keywords: laser micromachining, texturing, friction resistance.

Introduction

Energy losses resulting from friction between contact surfaces in an internal combustion engine have been studied intensively by a considerable number of tribologists. Progress in this field has brought numerous economically effective solutions, which enable mass production of motor vehicles. Still, the automotive industry needs further improvements to reduce friction-related energy losses in engines and drive systems. For instance, the losses of energy generated in a piston-ring-cylinder system account for 45% of all the losses of energy due to friction in the whole engine. Numerous reports suggest that the problem can be solved by applying porous surfaces generated, for example, by laser surface texturing [1], [2].

The first publication on surface texturing appeared in Germany in 1995 [1]. It discussed the use of an excimer laser to texture elements of a magnetic memory disk drive with the aim of reducing friction at the start. Further experiments in this area involved texturing surfaces of punches applied to plastic forming. It was found that the process caused a 169% increase in the punch service life.

The current studies focus on the influence of texturing on the performance of various friction systems in internal combustion engines, e.g. precision bearing systems. Texturing is used to improve heat removal, vaporization, wettability, biological functions, absorptivity, etc.

Reference [3] compares results of tribological tests conducted by means of pin-on-disk devices, where the disk surfaces were polished, ground and textured (using three methods of texturing). The textured surface was covered with laser-generated pores, 4-6.5 μm in depth and 58-80 μm in diameter. Numerous tests show that texturing can be used to extend the ranges of load and sliding velocity within which hydrodynamic lubrication occurs. The hydrodynamic lubrication is observed when low- and high-viscosity lubricants are applied. Another finding is that the rough rims of cavities produced by laser beams need to be removed by lapping to ensure an optimal hydrodynamic effect. A comparative analysis was conducted to determine the friction coefficients for the polished, ground and textured surfaces. The effects of laser texturing were most visible when the values of sliding velocity were low, ranging between 0.075 and 0.3 m/s. Moreover, the high density of cavities was responsible for an increase in the friction coefficient. The results presented in the form of Stribeck curves illustrate that there was a significant reduction in friction for lubricated friction pairs operating in the boundary regime of friction.

The tests described in Ref. [4] aimed at determining the effect of laser texturing on the performance of a ring being in contact with a cylinder liner. Pores with diameters of 75-78 μm and depths of 7-9 μm covered the whole or parts of the ring surface. The pore area coverage ranged between 10 and 50%. The friction observed for textured surfaces was lower than that for non-textured ones. The greatest falls in friction were reported for a pore area coverage of 30%; they were 40-45% and 23-35% for a rotational speed of 500 rev/min and 1200 rev/min, respectively. It should be noted that the decrease in friction was greater for a partly textured ring. This reduction (12-29%) was observed in the whole range of loads and rotational speeds.

Reference [5], [6] discusses results of in-service tests conducted for face seals with textured carbide rings used in the petrochemical industry. The results were positive, because there was a decrease in the process temperature and an increase in the ring service life. Reference [7] illustrates that laser surface texturing caused an improvement in fretting fatigue life of steel tool elements.

This analysis shows that the effects of laser texturing were measured at pre-determined parameters of performance of the sliding pair; the pore depth and diameter (or their ratio) and the pore area coverage were the most significant parameters of texturing. It was found that effective reduction in friction could be obtained also for partially porous surfaces. The problems to be solved in further research include determining precisely the relationships between the texturing parameters, ring geometry, and the parameters of performance of the friction system for which the desired reduction in friction occurs. The current research focuses on establishing the effect of laser surface texturing on the mechanical properties of materials, particularly their fatigue strength.

Laser surface texturing

The surfaces of the rings were textured using a diode-pumped Nd:YAG laser, designed for the production of printed circuit boards. The laser emits ultraviolet light, and the wavelengths are specially selected to assure the most effective machining of copper. The maximum power of the laser beam is 2W. The laser can be applied to drill microholes in laminates, for instance, copper-clad laminates, which are used for printed circuit boards. The device can be employed also to cut or drill holes in other materials; the maximum beam power, however, limits its application. It is suitable for cutting metal foils: steel and nickel up to 100 μm in thickness, and copper up to 200 μm in thickness. The maximum hit rate for this type of laser is more than 20000 holes per hour. The focal spot size is 25 µm.

The application of a laser beam causes laser ablation of the material. The photon energy is converted on the material surface into electron, thermal and mechanical energies. In consequence, the material in contact with the laser beam is vaporized and removed from the solid surface in the form of neutral atoms and molecules, and positive and negative ions.

A view of the ESI 5200 laser µvia drill used in the tests is presented in Figure 1. Table 1 illustrates the performance parameters.

Fig.1. A view of the ESI 5200 laser µvia drill

Table 1. Device performance characteristic

Producer	*Electro Scientific Industries*
Type of device	*Model 5200*
Type of laser	*diode-pumped Nd:YAG laser, UV [355 nm]*
Peak power	*>15 kW for 3 kHz*
Pulse width	*30 ns for 3 kHz*
Frequency	*100 Hz ÷ 20 kHz*
Field size	*533 mm x 635 mm*

Texturing methodology

Laser surface texturing is one of the most common and promising methods of surface roughening. Categorized as a metal removal process, laser texturing is usually performed at a power density of $10^6 \div 10^9$ W/cm^2. At present, it accounts for about 2% of all laser-based material processing processes used in the world. In laser surface texturing, a pulsed laser beam is focused on a material to melt a hole. The hole depth is dependent mainly on the power density and the pulse duration. The drilling debris is removed from a hole being drilled using compressed air or another inert gas.

The tests were conducted for SiC rings (certificate of material excellence) with the following dimensions: an outer diameter d_o of 35.3 mm, an inner diameter d_i of 25.1 mm, and a height h of 7 mm. The texturing was performed using an ESI 5200 Nd:YAG laser (pulse mode). The wavelength λ = 355 nm (the laser uses radiation at the third harmonic frequency).

The parameters of the laser surface texturing process were determined basing on the experimental results: the laser spot diameter d = 0.78÷150 μm; the laser power P = 0.37÷0.4 W; the laser beam velocity V = 15.7÷23.56 mm/s; the distance from the focus Δf = 0 mm; and the repetition frequency f = 6400 Hz.

The process of texturing was performed in two stages (two steps). In the first step, holes with a pre-determined diameter were drilled along a spiral path (Fig. 2). In the second step, the drilling debris was removed from each pore, with the number and frequency of pulses being strictly defined (Fig. 3).

The results of the laser surface texturing process are shown in Table 2.

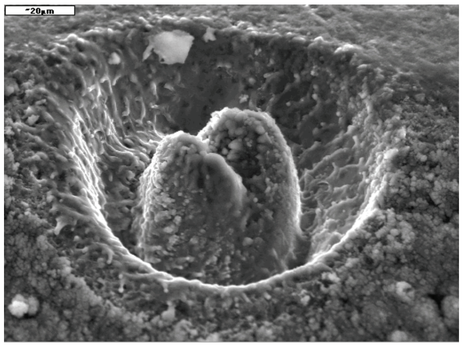

Fig.2. A pore produced in an SiC ring in the first step of the laser operation along a spiral trajectory (magnification 1000x)

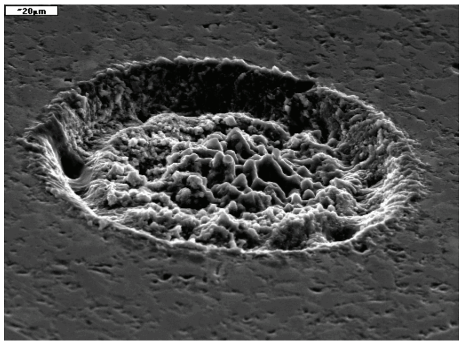

Fig.3. A pore generated in an SiC ring in the second step of the laser operation after cleaning the pore bottom (magnification x750)

Table 2. Parameter characterizing the geometrical surface texture on the face surface of a ring with d_o = 35.3 mm and d_i = 25.1 mm

Sample No	Pore diameter $2R$ [µm]	Distance between pores S_m [µm]	Pore area coverage [%]	Number of pores k [-]	Pore depth [µm]
1.	78	162	18.208	18440	13
2.	134	279	17.985	6216	13
3.	78	106	42.520	43060	13
4.	134	183	41.808	14450	13
5.	150	256	27.464	7383	13
6.	70	119	27.173	34170	13
7.	102	128	49.951	29530	13
8.	102	233	15.051	8913	13
9.	102	174	26.985	15980	13
10.	102	174	26.985	15980	13

The main stage of the process was drilling a pore with a predetermined shape, diameter, and depth. The material processed was particularly susceptible to the action of the laser beam. Ablation occurred at low beam energy.

A Joel JSM-5400 scanning electron microscope was used to study the effects of laser surface texturing. Selected SEM images are presented in Figures 2÷3 and 4. As can be seen, the surface structure after laser surface texturing is regular. The surface is covered by bumps and dimples resulting from phase and structural modifications and the accompanying specific volume changes in the laser affected zones.

Lapping and super finish are used to obtain hard flat areas transferring normal loads and areas of pores where the hydrodynamic forces are generated during fluid lubrication. Surfaces with such a texture can be applied, for instance, to sliding friction systems.

The microscopic analysis showed that the removal of the drilling debris was not complete when the laser beam was focused locally. This was probably due to insufficient power density. The action of the thermocapillary forces and the convective motion resulted in the formation of rims, whose structure consisted of molten and then crystallized SiC. The images in Figure 4 show textured surfaces of the ring after ultrasonic cleaning.

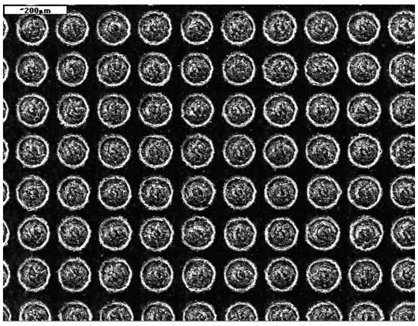

Fig.4. A view of a system of pores on a SiC ring; pore area coverage – 42% (magnification x100)

Pores generated with the aim of improving the tribological properties of the material were arranged regularly. In this analysis, we deal with a two-directional symmetry. It can be assumed that surface modelling involves producing blind holes in the shape of a cylinder or, more frequently, a truncated cone.

Tribologie properties

The tribological tests were conducted by means of a T-01M pin-on-disc device; however, the pin was replaced by a bearing ball with a diameter of 6.3 mm chamfered in such a way that the circular flat surface had a diameter of 4.5 mm. The ball was mounted in a fitting frame, which made it possible for the flat surface to be arranged parallel to the ring in contact. The extensive research described is now at the recognition stage.

Two series of tests were conducted, and the objective was to assess the suitability of the research method. The experiments involved observing the changes in the friction resistance during the comparative gears of the test machine using textured and non-textured rings.

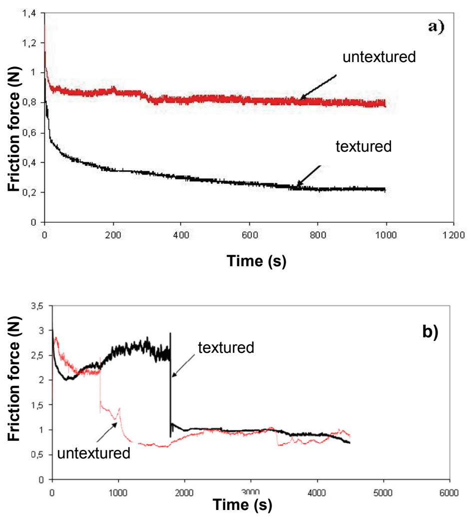

Fig.5. Results of tribological tests obtained for specimens with and without texture: a) v = 0.6 m/s and Q = 25 N, b) v = 1 m/s and Q = 15 N

The first series of tests performed at various rotational velocities (v_1 = 0.3 m/s, v_2 = 0.6 m/s and v_3 = 1 m/s) and various loads (Q_1 = 10 N, Q_2 = 25 N and Q_3 = 40 N) involved continuous wick lubrication with a paraffin oil (Fig. 5a). In the second series, the sliding velocity was v = 1 m/s and the load was Q = 15 N. The test gear included a dry mode followed by a wet mode. A drop of lubricant – cosmetic kerosene or paraffin oil – was applied on the ring raceway only once. It was necessary to measure the time after which the value of the friction coefficient increased (Fig. 5b).

The results show that the method used in the tests is suitable for assessing the effectiveness of the geometrical surface texture of sliding pairs under mixed friction.

Surface texturing improves lubrication conditions, and according to Refs. [5, 6, 7, 8], this improvement is due to the hydrostatic and hydrodynamic effects. The analysis studied only the influence on the friction processes. The texture cavities were used as microcontainers of the lubricant. Their influence on the friction process was determined.

Conclusions

1. The process of laser surface texturing performed by means of an ESI 5200 Nd:YAG laser µvia drill can be applied to produce predetermined pore patterns on sliding surfaces. Pores on metallic materials are reproducible in shape and depth; for SiC, reproducibility may reach a value of the order of several dozen µm.
2. The software of the ESI 5200 Nd:YAG laser µvia drill can be used for texturing flat surfaces. Special-purpose equipment and software need to be applied to texture cylindrical and other curvilinear surfaces.
3. The pore shape is limited by the software used. Standard procedures allow drilling circular holes. Specially developed programs are necessary to drill holes other than circular.
4. Different values of the coefficient of friction and the load-carrying capacity were reported for friction pairs with textured working surfaces. These were dependent on the texture parameters. It is possible to design the surface texture of a friction pair so that the required value of the load-carrying capacity is achieved for a given load.
5. From the experiments it is clear that the positive effect of texturing is more visible for greater diameters of cavities and a greater degree of blackening. The measurements of the variability of the input factors show that the cavity diameters should range 138-150 µm and the degree of blackening 42-50% .

REFERENCES

[1] Etsion I., State of the Art in Laser Surface Texturing", *Transaction of the ASME*, January 2005, Vol. 127
[2] Yu X.Q, He S., Cai R.L., Frictional characteristics of mechanical seals with a laser textured seal face, *Journal of Materials Processing Technology*, 129(2002), 463-466
[3] Kovalchenko A., Ajayi A., Erdemir A., Fenske G., Etison I., The effect of laser surface texturing on transitions in lubrication regimes during unidirectional sliding contact, *Tribology International*, 38(2005), 219-225
[4] Etsion I., A laser surface textured hydrostatic mechanical seal, *Sealing technology*, March 2003
[5] Erdemir A., Review of engineered tribological interfaces for improved boundary lubrication, *Tribology International,* 38 (2005), 249-256
[6] McGeough J.A., Rasmussen H., A theoretical model of electrodischarge texturing, *Journal of Materials Processing Technology*, 68 (1997), 172-178
[7] Volchok A., Halperin G., Etsion I., The effect of surface regular microtopography on fretting fatigue life, *Wear* 235 (2002), 509-515
[8] Wakuda M., Yamauchi Y., Kanazaki S., Yasuda Y., Effect of surface texturing on friction reduction between ceramic and steel materials under lubricated sliding contact, *Wear* 254 (2003) 356-363

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