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Surface Functionalization of AISI 316 Steel by Laser Texturing of Shaped Microcavities with Picosecond Pulses

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Abstract

Surface texturing is gaining interest in the field of surface engineering. Enhancements can be obtained by carefully creating textures with arrangement of 3D-cavities; such textures retain lubricant and enhancing the hydrodynamic effect, reducing therefore the friction coefficient and wear of sliding contact surfaces. 3D-cavities may have flat or curved shapes. In this investigation a picosecond pulsed laser with 1030 nm and 343 nm has been used to develop precise surface textures with triangular and flat shaped profiles. Tribological essays showed improvements in the tribological behavior of textured surfaces, triangular profile cavities obtained a friction coefficient < 0.03 doubling the wear resistance compared to reference surface without texture.

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Keywords: Laser Texturing; Picosecond; Wear

1. Motivation

Surface texturing is gaining interest in the field of surface engineering. Optimal textures allow enhancement of productivity and added value to a component subjected to friction and wear under lubricated conditions. A texture comprising a distribution of cavities or grooves with a flat or curved shape profile improves lubrication in the contact area.

The state of the art of surface modification for the improvement of tribological behavior has been mainly based on experimental investigations focus on simple textures formed by dimples, for which the results are analyzed assessing the influence of geometry, density and distribution of cavities arrangement. Typical manufacturing techniques used for surface texturing are mechanical, lithographic and high energy beam [2]. Laser texturing uses the energy of a focused laser beam to generate by ablation, a superficial texture [1]. Some studies on surface texturing consist of an array of circular cavities generated by a single

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or repeated laser shots and is performed by a nanosecond pulsed laser source. In this way textures reached $80\ \mu\text{m}$ of diameter and $50\ \mu\text{m}$ depth at ratios of $1\ \text{mm}^2/\text{s}$ [3].

In general tribological properties are improved by reducing friction coefficient and wear loss under lubricated conditions [4].

Picosecond laser sources are gaining interest in the field of laser micromachining. Flexibility, feasibility over a wide range of materials and precise ablation processes are great advantages. On the opposite, although are not cost effective systems for mass production nevertheless current systems allow small batch production, product design, functional prototypes and research.

2. Objective

Research on laser texturing is costly and requires intense experimentation due to numerous parameters related to texture design and fabrication process. The uses of computer modeling save efforts, allowing to evaluate multiple parameters and to establish a range of requirements for the optimization of the process.

In this work we consider cavity specifications obtained by computer modeling of surface textures for lubricated environments. In [5, 6] suggest designs with triangular distribution of cavities, these can have triangular or trapezoidal shape profiles. This cavity profiles provides better hydrodynamic effects of the lubricant layer, therefore it is suppose to achieve better tribological properties.

Main objective in this study is to explore the capabilities of laser surface texturing with a pulsed picoseconds laser to develop enhanced surfaces on AISI 316 substrates, comprising a distribution of microcavities with triangular and flat shape and to correlate textures with measured tribological properties such as friction coefficient and wear loss. The laser used in this study provides very fine machining and precision. For this purpose the machining procedure has been defined by conducting an intense experimental work to determine optimal parameters and machining sequence.

Furthermore, tribological essays under lubricated conditions have been performed to obtain friction coefficient and wear loss. The results established differences of texture performance as a function of the cavity profile.

3. Experimental setup

In this investigation a picosecond laser system was used. The system consists of a picoseconds pulsed laser, model Trumpf Trumicro 5050, with three wavelengths of emission: $1030\ \text{nm}$ (IR), $515\ \text{nm}$ (Green) and $343\ \text{nm}$ (UV), maximum output power of 50W , 30W and 15W respectively, pulse duration of less than $10\ \text{ps}$ and repetition rate up to $400\ \text{kHz}$. All cases $M^2 < 1.3$, the focusing optics produces from $17\ \mu\text{m}$ of diameter at $1030\ \text{nm}$ to $7\ \mu\text{m}$ at $343\ \text{nm}$ with focusing lens with $100\ \text{mm}$ of focal length.

Surface textures were a triangular distribution of flat and triangular microcavity profiles (see fig. 1).

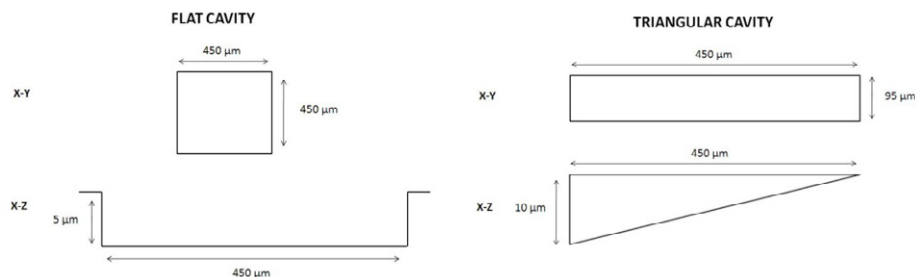


Fig. 1. (a) flat cavity specifications; (b) triangular cavity specifications

For profile measurements at micro scale level a confocal microscope, model Leica DCM3D, with lateral resolution of 140 nm and vertical resolution of 2 nm was used.

Tribological tests have been conducted with a cylinder-on-disk test under lubricated conditions. The counterbody used was a roller cylinder pin with diameter of 10 mm. All tests were performed with 10W-40 lubricant.

4. Experimental results

The laser process was optimized to obtain fine machining results in each cavity by adjusting parameters to obtain 1 μm of ablation depth per layer.

4.1. Laser micromachining of cavities

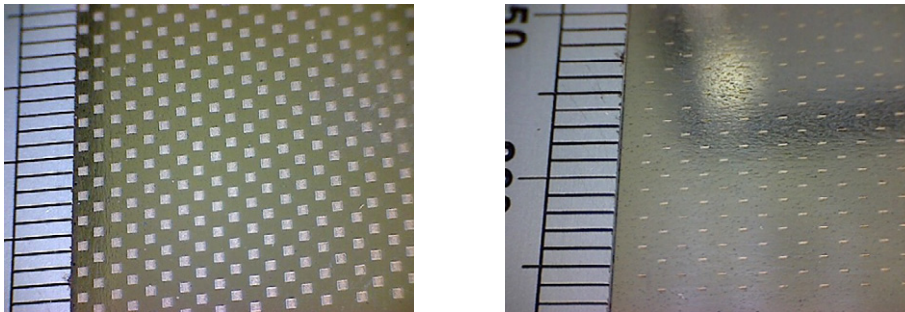


Fig. 2. (a) surface textured with flat cavities by laser ablation; (b) surface textured with triangular cavities by laser ablation

Precise flat cavities were obtained with third harmonic (343 nm), average power of 4 W, pulse duration of less than 10 ps, 400 kHz and 500 mm/s of scanning speed. To obtain smooth finish each layer was rotated 45 degrees. In fig. 2 and 3 it shows the textured surface obtained. Processing time reached 30 min for a sample containing a textured area of 25 mm x 25 mm.

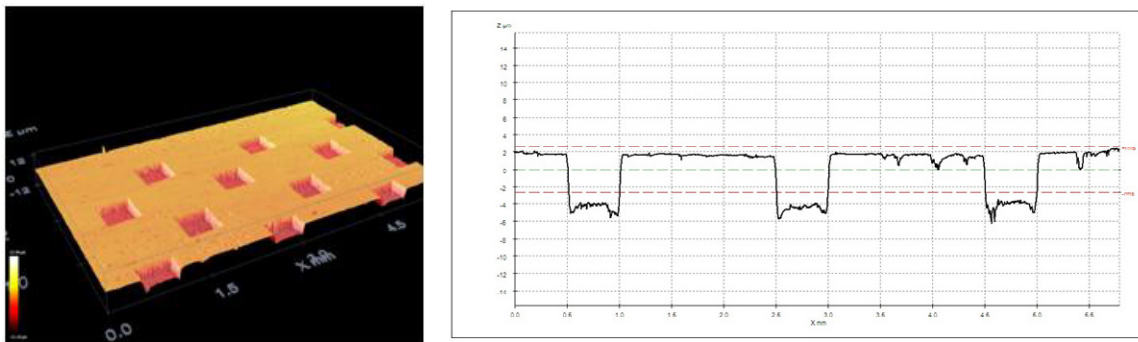


Fig. 2. (a) 3D texture topography measured with confocal microscope; (b) 2D profile; Width: 500 μm ; Depth: 6 μm

In a similar way textures with triangular profile were obtained. In this case the average power used was 2 W at 343 nm, with 400 kHz, pulse duration of less than 10 ps and 500 mm/s of velocity (see fig. 3 and 4). Total time was 40 minutes for 25 mm x 25 mm of textured area.

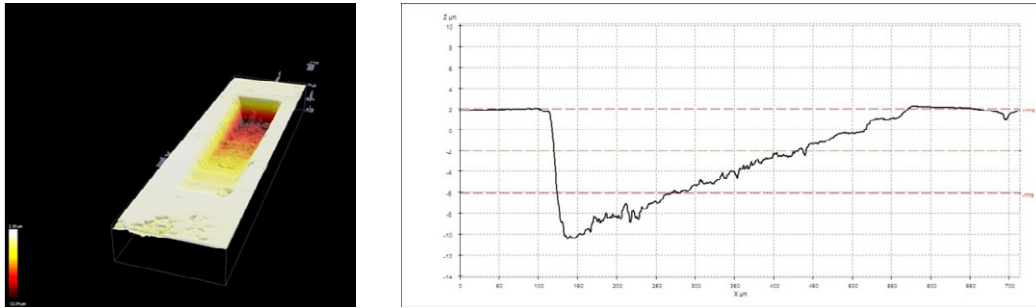


Fig. 4. (a) 3D profile of individual cavity with triangular profile; (b) 3D profile: 11 μm deep and 456 μm of width

4.2. Tribological test

All tests were conducted under lubricated conditions with conventional lubricant 10W-40. Stribeck test results performed with 10 N is shown in fig. 5 and Table 1. Textured samples showed better friction behavior than reference surface without treatment. Reference sample failed due to seizure at 350rpm as indicated in fig. 5, for textured samples the friction coefficient decreases when increasing rotational speed, typical behavior of Strickbeck curve shown in fig. 5.

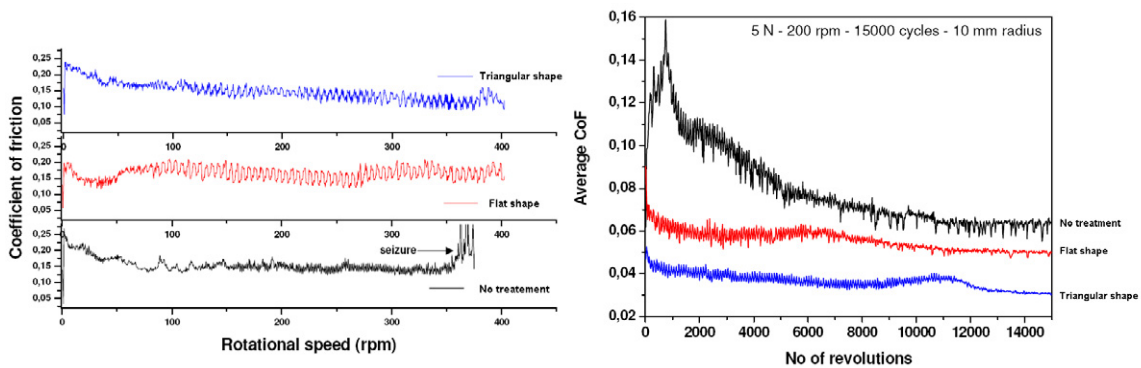


Fig. 5. (a) Stribeck test at 10 N (110 MPa) normal force. Speed ramped from 0 to 400 rpm in 10 minutes; (b) wear test results of textured surfaces and reference surface after 15,000 cycles

Table 1. Friction coefficient results referred to wear test (fig. 5). Test conditions: 5N , 200 rpm , 15000 cycles , 10 mm radius pin

Type of sample	Average Coefficient of Friction
AISI 316 no treatment	0.07
AISI 316 with flat cavities	0.05
AISI 316 with triangular cavities	0.03

Wear test were continued until failure. Both types of samples were tested in steps of 30,000 cycles. Flat cavities showed damage signs from the beginning, sample with triangular cavities did not show damage after 30,000 cycles. The test was repeated for another 30,000 cycles for the sample with triangular cavity profile. During this period, samples with triangular cavities started to wear off as indicated in fig. 6., reaching 75,000 cycles before fail, exhibiting even then lower wear rate than flat profiles.

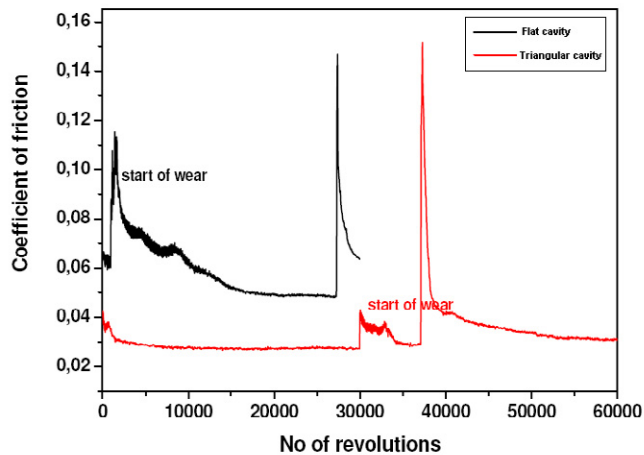


Fig. 6. Wear test extension until failure for textured samples.

5. Conclusions

We have demonstrated how to apply laser micromachining to evaluate complex textured surfaces improving wear resistance through a reduction of friction coefficient. It is fundamental disposing of flexible tool in terms of CAD/CAM, processing and feasibility over a wide range of materials. Micromachining systems with picoseconds pulsed laser sources offer such requirements. Although such systems are not cost effective for mass production it can be applied in early stages of product development and validation. This work is practical example of surface texture design. We have fabricated textured surface with reduced friction coefficient. The selection of design specifications were based in computer modeling approach selecting from complex cavity profiles such triangular cavity shape to more simple cavities with flat shape. Results showed a significant improvement of friction behavior under lubricate conditions reaching 0,03 average coefficient of friction for textures with triangular profile and 0,05 in the case of flat bottom shape cavities. Reference value corresponding to a non treated surface was established in 0,07. Furthermore the resistance to damage was compared obtaining that triangular profile cavity doubles the resistance of reference surface. Processing time was 20 mm²/min for flat cavities and 15 mm²/min for triangular cavities.

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