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Selection of Laser Ablation Parameters on the Basis of Accuracy of Performing a Single Texture Element

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Abstract. Laser surface texturing is currently the most developed technique of producing microcavities in a completely repetitive way on the surface of machine elements. The article shows the method of a selection of laser micromachining parameters such as beam trajectory, power and radiation frequency to obtain the right quality of the canopy shape microcavities.

Introduction

Laser surface texturing is used in modern machines for various purposes, including lubrication intensification, intensification of heat exchange, stimulation of microflows and increased chemical activity of the surface. The subject of the study focuses on the selection of laser micromachining parameters with picosecond pulses in order to achieve the highest possible efficiency and accuracy of the implementation of a single element of texture. The development of technology places very high demands on the reliability and durability of machine components [1, 2]. One of the ways to meet these requirements is the action consisting in shaping microgeometry of selected surfaces of machine elements. Laser ablation is the removal of material from the substrate by direct absorption of laser energy. This is the most efficient technology for surface development [3, 4]. The ablation starts above the threshold fluence (energy amount per unit area), which depends on the absorption mechanism, properties of particular material, microstructure, morphology, the presence of defects and laser parameters such as wavelength and duration of the pulse.

Microsecond and nanosecond pulses are called long, picosecond and femtosecond pulses are called short or ultra-short. The mechanism of long pulse ablation is called photothermal (due to the HAZ) and ultra-short ablation is called photochemical or cold ablation [5, 6].

Laser surface texturing exceeds chemical, electrical and mechanical methods, because it allows localized changes with a high degree of control over the shape and size of the resulting elements and enables greater size diversification. Different textures can be produced in a strictly defined way by controlling process parameters such as beam intensity, spatial and temporal profile, wavelength and environmental selection. Basic dimensions of surface features are usually determined by the shape and size of the beam. However, secondary characteristics in the microscale and even at the nanoscale may be formed around the LST irradiance area due to the variety of mechanisms involved, including post-ablation melting, re-solidification, or spattering of surface fluid due to recoil pressure [7, 8].

Experiment

The research aiming at achieving the highest possible accuracy in the performance of a single texture element was carried out using a laser micromachining station equipped with a TruMICRO 5000 5325c picosecond laser with an average power of 5W max, pulse energy up to 12.6μJ and M^2 radius quality <1.3. The maximum pulse frequency equals 400kHz and can be modified by entering the pulse divider assuming values of 200kHz, 133.33kHz, 100kHz, 80kHz, 66.66kHz, etc. The radiation wave length of the TruMICRO 5325c laser is 343 nm. The TruMICRO 5325c laser has been equipped with a SCANLAB "galvo" scanning head with a square machining area of 90 mm side and scanning speed (laser beam through material feed) in the range of 100 - 5000 mm/s and with a lens with a focal length of 160mm. The micro-machining of 100Cr6 bearing steel was the subject of interest.

In order to determine the optimal method of producing microcavities in the form of a canopy, three possible trajectories of the laser beam offered by the laser software were examined. Each of the beam guidance methods produced different results. In the case of a spiral trajectory, the machine software allows you to determine the number of coils and their mutual distance. Unfortunately, it is not possible to program the closure of the spiral at its center point, which resulted in insufficient removal of the material in the middle of the microforming. The outer spiral coil propagates in relation to the central point at a given angle, which resulted in poor representation of the preset shape in the workpiece - the microcavity produced was not completely circular. In the case of a trajectory of parallel lines, a microcavity of a suitable shape was created, but its edges and slopes were very ragged. This is caused by a software limitation that does not allow the laser to get the desired power from the beginning of the line. The power increase to a given value occurs exponentially over a period of time and is called a ramp. The best results were obtained using the trajectories of concentric circles. Microcavities produced with this trajectory possessed the desired geometry with smooth undamaged edges and a smooth bottom. Further investigations were carried out using this trajectory of the beam.

During the production of samples for the tests, the range of average laser power from 5W to 1.5W and the frequency of laser pulses 400 kHz, 200 kHz, 133.33 kHz, 100 kHz, 80 kHz, 66.66 kHz were examined. For average power of less than 1.5W and frequencies lower than 66.66k Hz, the fluence F was less than 1.33 J/cm^2; no significant influence of the treatment on the material and loss of ablation mass was observed. Thus, it can be considered that 1.33 J/cm^2 is the threshold fluence for the 100Cr6 steel. All the ninety test samples were made with a constant scanning speed of 100 mm/s. The set diameter of the microcavity equalled 100 µm. The surfaces of the samples were prepared before laser processing on a polishing machine (Ra=0.392÷0.694 µm, Rz=1.336÷1.919 µm).

To determine the geometry of the created microcavities, a Talysurf CCI optical profiler by Taylor Hobson was used (using a 2.2mm coherent correlation-based interferometry and a 0.01nm resolution lens with an x50 magnification to measure the area of 330 µm x 330 µm and a slope of up to 27.7°). Three measurements were made for each sample, concentrating on the size of the deviation of the obtained diameter from the set one - Δø.

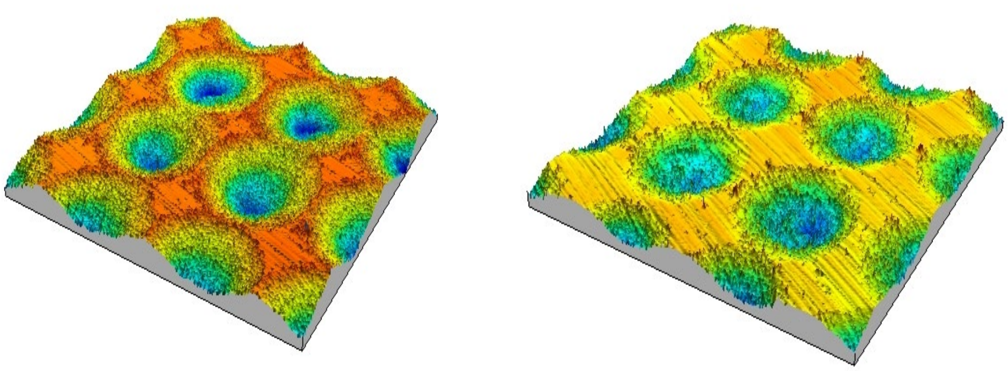

Fig. 1. Isometric views of samples made with fluences of: left - 3, 75, right 2,31 J/cm^2

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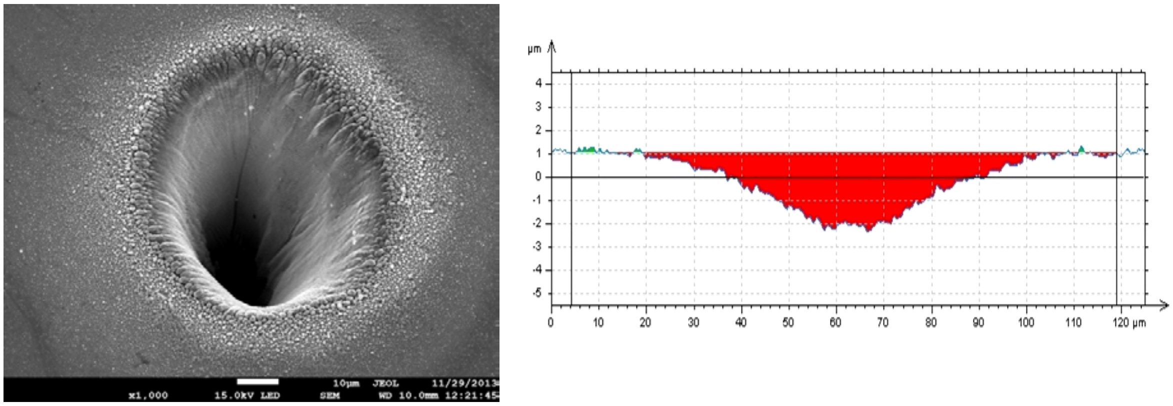

Fig. 2. View of sample made with the fluence of 2,31 J/cm^2:
left – microscopic view, right – geometry measurement

Analysis of results

In order to determine the effect of fluence on the geometry of a single microclimate, the analysis of the dependence of quantitative variables was used. The analysis was performed in the SAS System version 9.4, determining the mathematical dependence of the factors considered. The evaluation of the quadratic parameters of the regression function, determined by the least squares method, leads to the following equation describing the relationship between F and Δø:

$$\Delta ø = 0{,}282F^2 + 2{,}273 \quad (1)$$

Figure 1 presents an estimation of the square regression function in a graphical form, estimated by the least squares method. The cut off of the apex of the parabola, slightly smaller than 3, determines the value of F, for which the smallest Δø is observed.

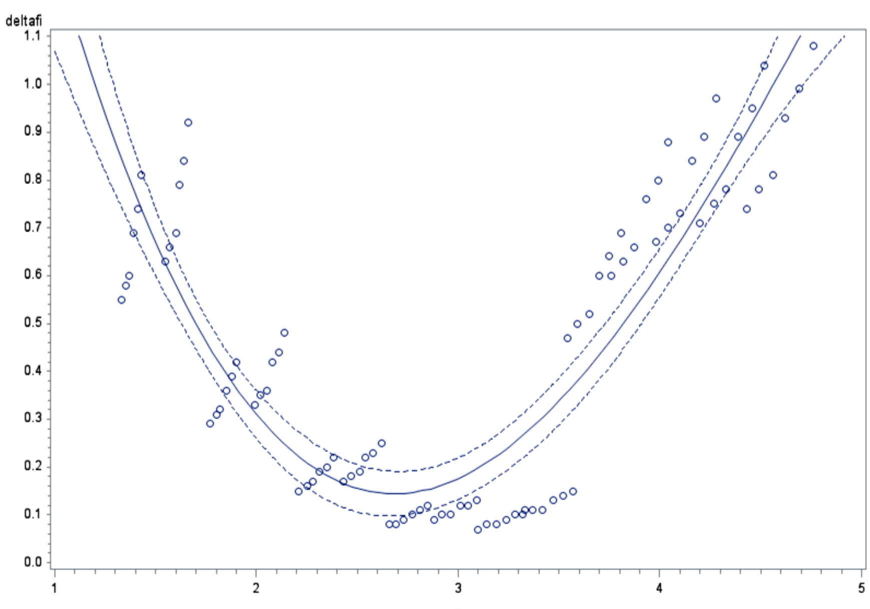

Fig. 1. Dependence of F and ΔøSummary

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The analysis of the dependence of the quality of the implementation of a single texture element on the fluence of laser radiation showed a strong influence of the laser processing parameters on the shape and quality of the microfusion. The highest accuracy of microcubber performance was obtained for fluence from the range of 2.62 to 3.57. For the fluence values below 2.62 J/cm^2, we observe insufficient quality of a single texture element caused by the insufficient amount of energy delivered to the work surface. Micro cavities made at these fluence values were not precisely made, and their diameter was much smaller than the set one. For machining with fluence greater than 3.57 J/cm^2, we observe microcavities of irregular shape resulting from remelting material. The diameter of the microcavities made with the fluence values higher than J/cm^2 was greater than the set value.

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