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Manufacturing of surface microstructures by two-stage laser ablation

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Abstract
For the series production of consumer products the replication of functional surface microstructures for example by injection molding has obtained great importance. Surfaces of molds and dies for replication processes can be modified by nanosecond laser ablation. Important target figures in laser ablation are the processing speed on the one hand and the resulting surface morphology on the other hand. However, these target figures are strongly connected to the pulse energy. For this reason, only a compromise between high processing speed and low surface roughness can normally be realized in the laser process.
The paper presents nanosecond laser ablation by a two-stage processing method that was developed and evaluated to overcome the current limits. In this procedure, the first processing stage with high ablation rate is followed by a second finishing stage for the achievement of a high surface quality with low roughness. The experimental investigation of this method was carried out under systematic variation of several process parameters in the finishing stage. The influence of these parameters on the resulting roughness value *Sa* was evaluated and described. It was shown that an appropriate choice of the parameters in the finishing stage is essential. A considerable reduction of the resulting surface roughness by 60 % compared to the one-stage standard method could be documented finally.

Nanosecond Laser Ablation, Surface Structuring, Surface Finishing, Mold Manufacturing

1. Introduction

Surface technology is a key factor for the functionality improvement of consumer products or technical parts. The adjustment of defined surface properties is often a challenge for the design and production of products. For the series production of surface finished parts replication processes are suitable in particular. In these processes the surface structure of a tool is transferred to the part finally.

For the microstructuring of replication tools, e. g. molds and dies, laser ablation is a common technology [1]. With this technology deterministic microstructures can be realized as well as stochastic surface structures. By the help of some process parameters the surface characteristics can be controlled in a wide range [2]. However, much potential for this design freedom is unused because of missing knowledge concerning parameter influences and processing strategies.

2. Experimental Investigations

2.1. Approach

Laser ablation processes are normally implemented as single step processes. This means that the target geometry or surface structure is processed with one single parameter set. As a consequence of this the ablation of large material volumes or large workpiece areas with high surface quality is very time-consuming and expensive. It is the approach of the present work to evaluate a two-stage laser processing strategy that is comparable to roughing and finishing in machining processes. By the help of this advanced ablation strategy a high ablation rate can be combined with a defined surface smoothing effect.

2.2. Laser Microstructuring

For the experimental investigations the high-strength aluminum alloy EN AW 7075 was used. The ablation of the material was realized by a nanosecond laser system from Spectra Physics® with the following specifications:

- Laser medium: Nd:YVO_4
- Wavelength: 532 nm
- Pulse duration: 10 ns
- Mean power: max. 13 W
- Focus diameter: ≈ 15 µm

During laser processing the material behavior depends significantly on the energy input to the surface. The energy input was changed in the experiments by the variation of three different parameters: the pulse frequency *f*, the focus position *Z* and the number of passes *n*. The corresponding parameter matrices are shown in Fig. 1.

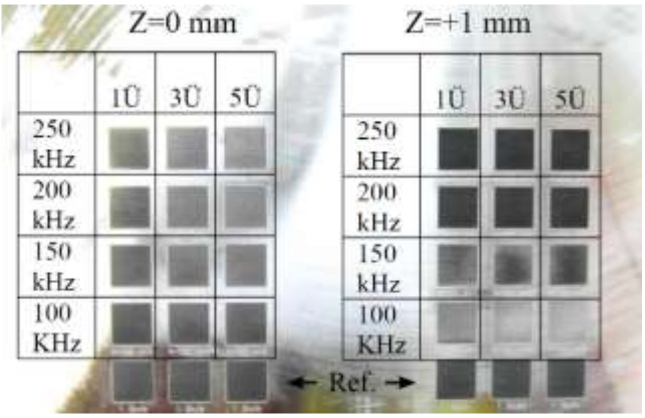

Figure 1. Parameter matrices for the surface characterization

All of the 30 parameter fields were at first ablated with the reference parameter set *f* = 100 kHz, *Z* = ±0 mm and *n* = 3. After that the second process stage was applied using the parameter variation illustrated in Fig. 1. In the last row of the matrices the reference surfaces are still apparent.

The laser power as well as the pulse and line spacing were held constant in both ablation stages at 13 W and 5 µm, respectively. The resulting pulse overlap of about 67 % was identified as suitable for the achievement of a low surface roughness in [2].

3. Surface Characterization

Surface measurements were carried out using the 3D-Laserscanning-Microscope Keyence VK-9700. The surfaces were characterized by the roughness value *Sa* [3] that was evaluated by four measured areas of 500 x 500 µm² each. The results of the measurements are shown in Fig. 2 exemplarily for the case of *Z* = ±0 mm in the second process stage.

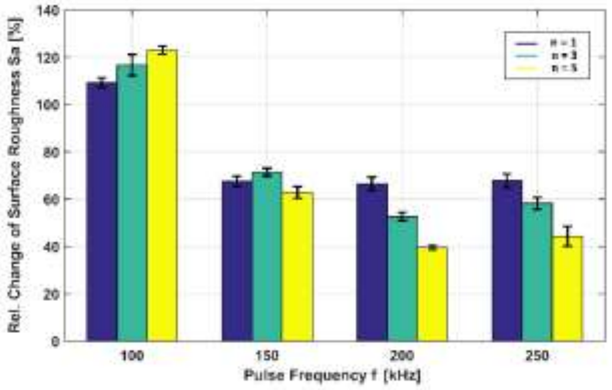

Figure 2. Measurement results of the experiments (Z = ±0 mm)

The diagram in Fig. 2 makes clear that the surface roughness can be influenced in a wide range by the additional second process stage. It could be observed that the roughness *Sa* was reduced to approximately 40 % of the initial roughness by the parameter combination *f* = 200 kHz, n = 5 and *Z* = ±0 mm. The roughness increases in the first case because the laser parameters are equal to the reference set.

For the test ablations with focus position *Z* = 0 mm the smoothing effect occurs primarily at high pulse frequencies. Using the focus position of *Z* = +1 mm the surface roughness is only reduced considerably using the low pulse frequency of *f* = 50 kHz. Regarding these experimental results on the one hand and the published results of Steyn et al. in [4] on the other hand it becomes clear that the change of roughness is correlated to the energy input in the second process stage. According to this a defined energy input for the melting and the rearrangement of material on the surface seems necessary for an effective surface roughness reduction. Using the calculated mean energy density of the laser spot on the surface in the second ablation stage a value of about 105 MW/mm² was the optimum case in the conducted experiments. Higher values as well as lower values of the energy density leaded to increasing roughness.

Beside the roughness values the optical surface appearance changed as well. In this context the occurrence of resolidified material on the surface clearly maintains brightening of the surface color (cf. Fig. 1). The surfaces after the first stage and the second process stage are shown in Figs. 3a and 3b.

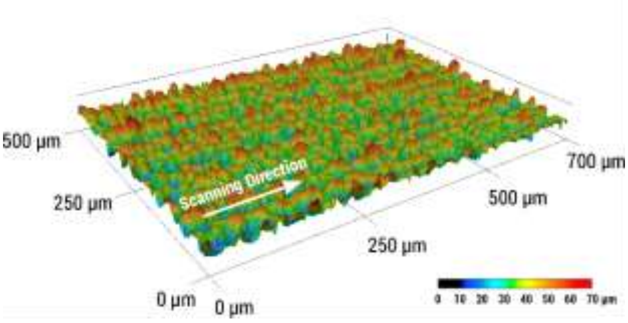

Figure 3a. Surface microstructure after the first process stage

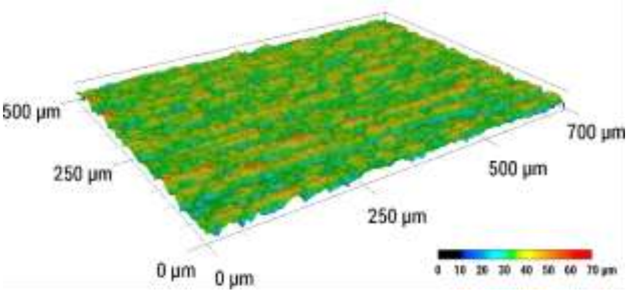

Figure 3b. Surface microstructure after the second process stage

The additional effort with regard to the second process stage must be justified by increased process speed. In the regarded case in Figs. 3a and 3b the process time of the second stage still amounts to 45 % of the overall ablation time. However, for the machining of practical structures the ablation depth is usually much larger than in the conducted parameter tests. For these applications, the two-stage process using the combination of a high ablation rate with the additional finishing stage has great potential to reduce process times significantly.

5. Summary and Conclusions

In the present study a two-stage laser process that consists of a first stage with high ablation rate and a second stage for surface finishing was evaluated experimentally. A selection of laser parameters of the finishing stage, namely the pulse frequency, the focus position and the number of passes, were varied in a wide range and the obtained surfaces were characterized using the roughness value *Sa*. The yielded results showed that this value could be reduced by 60 % compared to the surface obtained after the first process stage. It is the aim to validate the method further by using practical surface microstructures with a relevant ablation depth.

References

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