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Analysis of melting and melt expulsion during nanosecond pulsed laser ablation

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Abstract

Manufacturing with nanosecond pulsed lasers is one the most efficient ablation processes and frequently used in the field of micro production. The aim of this study is to analyse the amount of melt expulsion during the laser ablation process of aluminium sheets with a thickness of 200 µm. The amount of recast layer, which deteriorates the surface finish is supposed to be reduced. The influence of the laser parameters on the high speed ablation process are investigated and described. The amount of melt expulsion is analytically calculated and metallurgically obtained. Overall, pulse durations of 120 ns, lower repetition rates of 20 kHz and laser powers between 20 W and 30 W reduce the amount of melt expulsions and melting of the mesh structure surface area. Thus, for these parameters smaller amounts of recast on the mesh surface and higher web accuracies are obtained.

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Keywords: Laser micro machining; aluminium; microstructure; accuracy

1. Introduction

Laser ablation also called laser milling has been proven to be an effective tool for processing in micro applications [1]. Perforated and structured parts are used in vehicles, aircraft and medical as well as surface analysis devices [2]. Overall, laser micro machining has many advantages compared to conventional cutting processes namely high precision and contact-free machining [3]. For ablation processes mainly pulsed lasers within the micro and down to femtosecond range are used depending on the field of application. In general, longer pulsed lasers can

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achieve higher removal rates, but result in an inferior surface integrity and accuracy [4]. Laser ablation studies within the nanosecond range have been conducted by Campanelli et al. to determine the influence on surface integrity showing that defocusing and higher repetition rates as well as powers improve material accuracy[5].

Depending on the pulse duration, pulsed lasers interact different with the workpiece material. Experiments have been conducted by Yao showing that pulse durations have a great effect on the melting residues [6]. Three different types of ablation characteristics are identified such as cold ablation, warm ablation and melt expulsion, depending on the pulse duration and intensity of the laser beam [7]. These effects are caused by the differences in stimulation time of the pulse with the material respectively the phonon system [7].

During the nanosecond pulsed laser ablation process the interaction of beam causes energy consumption and heat transfer within the material [1]. The pulse duration time for energy consumption and the thermalisation of the electrons and phonon system is long and high enough, which transfers a lot of heat into the material [8]. Further heat accumulation can derive from higher pulse overlapping, which causes thermal expansion of the material. This results in warm ablation or also melting of the material [9]. An increase in surface temperature of the targeted material results in expulsive ejection of liquid melts and droplets. The pulse overlap *PO* is described as a function of frequency f_{rep}, beam diameter d_f and laser scanning speed v_s [4].

$$\mathrm{PO} = 1 - \frac{v_\mathrm{s}}{f_{rep} \cdot d_f} \tag{1}$$

An analytical approach to describe and understand the ablation process helps to identify the amount of the melt, which is created in the material and finally minimizing the melt during the ablation process. This can improve the surface integrity as well as the mesh structure [10].

2. Experimental setup and procedure

The investigations are conducted on a maintenance-free nano-second pulsed Ytterbium fiber laser belonging to the YLP-HP series from IPG. The YLP-HP laser delivers a 1065 nm laser beam. The laser system is combined with a galvanometer scanner and a plane field optic leading to a fast and highly precise process within an area of 100 mm * 100 mm. The laser beam is guided with a lateral resolution of 1 µm across the process field. The scanner is mounted on a twin-headed construction unit with an integrated CNC-control-system. For the experiments aluminium sheets with a thickness of t = 200 µm are processed. The focal position Δz is kept constant during each process. Further laser properties as well as the experimental range can be found in Tab. 1. The schematic view of the laser system and the mesh structure is shown in Fig. 1. Laser ablation experiments are performed under a protective gas atmosphere of Argon. During the experiments different scanning strategies and parameters are tested to generate laser ablated holes and determine material removal rates and the influence on melting. The scanning velocity v_s as well as the repetition rates and average powers are tested. Furthermore, different ablation strategies are analysed by changing the distance between the scanning lines l_s (0.02 mm and 0.04 mm) and the width of the holes w_h. Moreover, the material is processed with different focal positions of the laser (-0.6 mm to 0.2 mm). For hole as well as mesh structure analysis at least ten measurements with the optical microscope VK-9700 are evaluated.

Table 1. Nanosecond pulsed Ytterbium fiber laser parameters and experimental parameters.

	Repetition rates	Pulse duration	Average power	Pulse energy	Scanning speeds
Capability	20 kHz to 2000 kHz	30 ns to 240 ns	200 W	0.1 mJ to 1 mJ	3 m/s
Experimental range	20 kHz to 60 kHz	120 ns	20 W to 45 W	0.6 mJ to 1 mJ	1 m/s