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Deep drilling of metals with ultra-short laser pulses

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Abstract

A simplified model of the percussion drilling process to predict the achievable drilling depth was derived and systematically investigated for varying process parameters. The model allowed to design a process in such a way that microholes with an aspect ratio of around 125:1 (with respect to the focal diameter) and a drilling depth of 10 mm could be achieved. For this process, a ps-laser with a pulse energy of 3 mJ and a repetition rate of 30 kHz was used. In this paper, the simplified drilling model to predict achievable hole depths of laser percussion drilling processes is introduced. The application of a high-energy laser to achieve high aspect ratios and hole depths is discussed.

Keywords: USP laser; drilling; modelling

1. Introduction

Percussion drilling as a basic drilling process is ideally suited to perform fundamental experiments. For special drilling strategies like helical drilling, percussion drilling often is the first step to drill a hole through, before its final geometry is finally shaped by a more advanced strategy. Therefore, an important task on the way to find an ideally suited drilling process for a given demand is to design a percussion drilling process properly. In the following, a previously developed model to describe the aspect ratio of an achievable hole geometry by percussion drilling is used to design such a drilling process. For a given laser system, the optical system design is discussed and the findings are applied to finally produce a laser drilled hole with a depth of 10 mm.

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2. Designing a laser percussion drilling process

In order to enable the design of a drilling process, a previously developed drilling model is first discussed and adopted in section *2.1*. In section 2.2, a percussion drilling process is designed with respect to a given, specified laser source in order to achieve a drilling depth of 10 mm in stainless steel (AISI 304).

2.1. Analytical model

Förster et al. introduced a simplified model to estimate the achievable aspect ratio of a percussion drilling process as a function of the peak fluence Φ_0 and the ablation threshold Φ_{th}. The achievable aspect ratio, i.e. the ratio of the achievable hole depth z_{drill} and the focal radius w_0 is given by

$$\frac{z_{drill}}{w_0} = \sqrt{\frac{\Phi_0^2 - \Phi_{th}^2 \cdot ln^2\left(\frac{\Phi_0}{\Phi_{th}}\right)}{2 \cdot \Phi_{th}^2 \cdot ln\left(\frac{\Phi_0}{\Phi_{th}}\right)}} \quad . \tag{1}$$

Introducing the laser peak fluence $\Phi_0 = 2 \cdot E_P / \pi \cdot w_0^2$, the pulse energy E_P and the focal diameter w_0 as well as solving equation (1) for the drilling depth z_{drill} yields

$$z_{drill} = w_0 \cdot \sqrt{\frac{\left(\frac{2 \cdot E_P}{\pi \cdot w_0^2}\right)^2 - \Phi_{th}^2 \cdot ln^2\left(\frac{2 \cdot E_P}{\pi \cdot w_0^2 \cdot \Phi_{th}}\right)}{2 \cdot \Phi_{th}^2 \cdot ln\left(\frac{2 \cdot E_P}{\pi \cdot w_0^2 \cdot \Phi_{th}}\right)}} \quad . \tag{2}$$

2.2. Design of the drilling process

The governing parameters of a given laser system influencing the drilling process are the maximum pulse energy and the maximum repetition rate. Usually, both parameters can be easily adopted by introducing additional optics into the beam path and changing the parameters of the laser system electronically. Equation (2) states, that for achieving a deep hole, high pulse energies are needed. The repetition rate is not given in this equation, but has an influence on the processing quality. It has been shown before by Förster et al. in 2017 and Zahedi et al. in 2018 that when drilling holes with depths of several Millimeters, repetition rates below 100 kHz should be used.

Table 1. Specifications of the adopted laser system, originally set up by Negel et al.

	Value	Unit
Pulse energy	**3**	**mJ**
Maximum repetition rate	300	kHz
Set Repetition rate	**30**	**kHz**
Average power	**90**	**W**
Pulse duration	8	ps
Polarization	circular	-
Wavelength	1030	nm

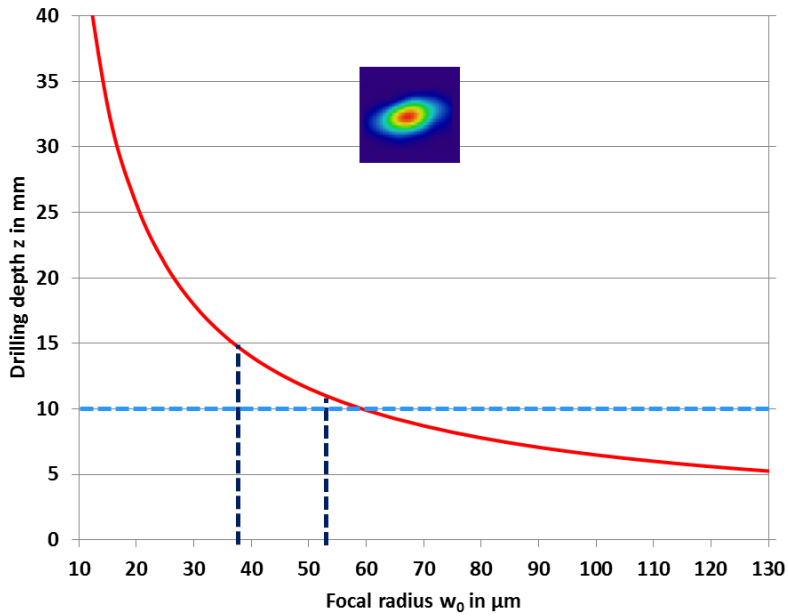

Fig. 1. Achievable hole depth z_{drill} as a function of the focal radius w_0 following equation (2) for laser system parameters given in table 1

To avoid heat accumulation effects, the repetition rate of the high-power picosecond laser was decreased to 30 kHz. Further parameters of the available system are given in table 1. In order to design a drilling process, according to equation (2) the focal radius as an important parameter has to be taken into account. In Figure 1, z_{drill} is given as a function of the focal radius w_0 for the given laser parameters. The hole depth of 10 mm is given as a blue dashed line. The drilling depth for given laser parameters could be only achieved for focal radii below 59 µm. Since the beam profile was of elliptical shape (cf. Fig 1, top), it was finally decided to focus the beam to a focal radius of 53 µm (1/e² major semi-axis) and 38 µm (1/e² minor semi-axis). The cross section of the achieved hole is given in Fig. 2. No thermal effects due to heat accumulation can be observed.

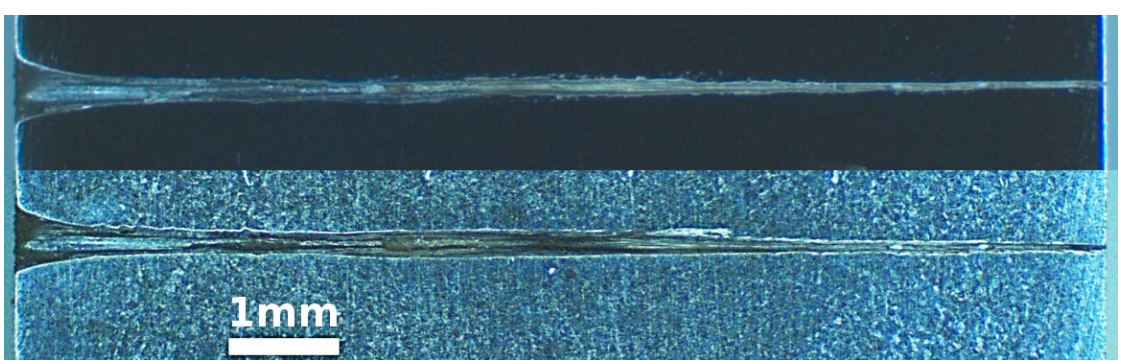

Fig. 2. Polished (top) and etched (bottom) cross sections of the percussion drilled hole, hole depth: 10 mm.

3. Conclusion

It has been shown that a simplified model of the percussion drilling process can be used to design a process resulting in a 10 mm deep hole free of thermal damage and irregularities due to heat accumulation.

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