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Determination of the 3D-Geometry of Cutting Fronts with High Temporal Resolution

Michael Sawannia[a*], Peter Berger[a], Michael Jarwitz[a], Rudolf Weber[a], Thomas Graf[a]

[a]*IFSW Institut für Strahlwerkzeuge, Pfaffenwaldring 43, Stuttgart 70569, Germany*

Abstract

The geometry of the cutting front was determined with a high temporal and spatial resolution during cutting of 10 mm thick stainless steel with a solid-state laser. The geometry was reconstructed using the information of the polarization state of the thermal radiation emitted from the process zone. This reconstruction of the geometry makes it possible to investigate the influence of process parameters on the geometry of the cutting front, including structures on the front and the global angle of inclination.

Keywords: Cutting front geometry; 3D surface reconstruction; thermal process emission; process diagnostic; laser cutting; solid-state laser

1. Introduction

During laser beam cutting of thick materials with solid-state lasers, the cut quality decreases with increasing cutting depth with regard to striations and dross formation, Arntz et al. 2017. These phenomena are mainly influenced by the locally distribution of the absorbed intensity and the resulting melt flow, Bocksrocker et al. 2018. For a better understanding of the processes leading to these phenomena, knowledge of the geometry of the cutting front during the cutting process is required with high temporal and spatial resolution. Information about the surface geometry can be obtained using the thermal process emission. From the polarization state of the emitted thermal radiation, the orientation of a local surface in 3-dimensional (3D) space can be determined. The 3D surface geometry of the cutting front can be reconstructed by aligning the measured local surfaces, Sawannia et al. 2018. The application of this principle was already successfully demonstrated for laser cutting of thin material, Sawannia et al. 2018.

In this proceeding the possibilities for the application of this principle to thick section cutting are presented.

* Corresponding author. Tel.: +49-711-685-636-850;
E-mail address: michael.sawannia@ifsw.uni-stuttgart.de.

2. Setup

A sketch of the experimental setup is shown in Figure 1. Cutting of 10 mm thick stainless steel was performed using an 8 kW thin disk laser (Trumpf, TruDisk 8001). The cutting head was a ProCutterET 100/150 from Precitec, which was connected to the laser by a 100 µm fiber. The EdgeTec module was used, which provides a ring-shaped intensity distribution of the focused laser beam with M^2 = 51. The calculated focus diameter was 824 µm and the Rayleigh length was 9.9 mm.

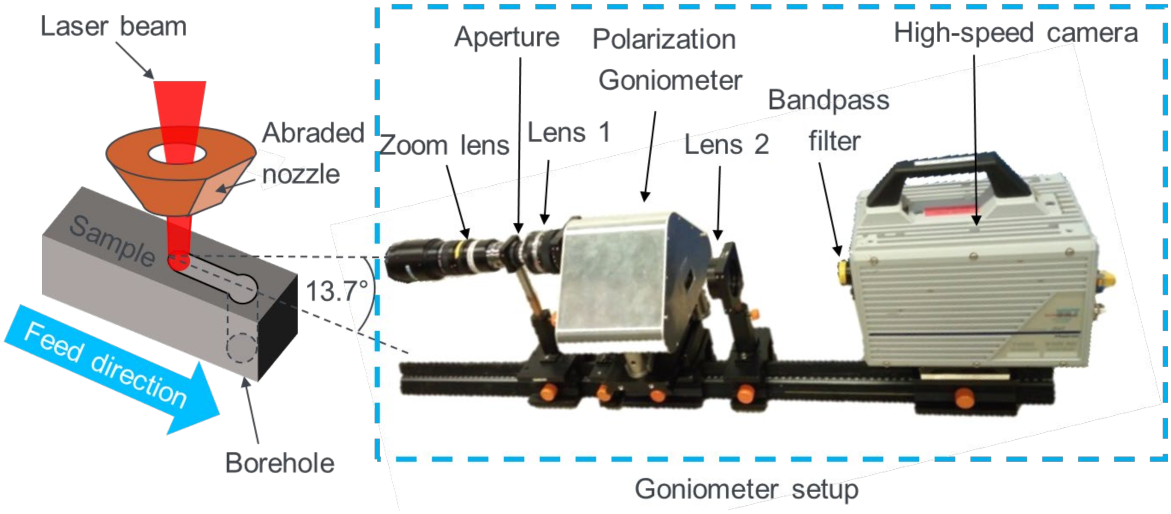

Fig. 1. Sketch of the experimental setup.

A standard cutting nozzle was used with a diameter of 2.5 mm. The standoff distance was 1 mm. In addition, the nozzle was abraded on the outer contour to allow view to the cut front. The process gas used was nitrogen at a pressure of 12 bar. The focal position of the laser beam was 1 mm below the sample surface. A stainless steel sample (AISI 304) with the dimensions 150 mm x 6 mm and a thickness of 10 mm was used. The cutting process was initiated in a mechanically applied borehole to avoid the piercing process at the beginning of the cut. From there a 40 mm long cut was carried out by moving the sample under the cutting head (blue arrow). The laser power was fixed at 8 kW for the experiments and the feed rate was 2 m/min.

The shown goniometer setup of the IFSW in Figure1 was used to record the thermal process emission from the cutting front. The goniometer setup records the emission of the surface in four images, each filtered with a linear polarizer with a different orientation of 0°, 90°, -45°, and 45°. The four images are recorded with a high-speed camera in a single frame. In the following, the four images are referred to as single images with the respective polarizer orientation. The measured emission is spectrally limited by a bandpass filter which allows the assumption of a constant emissivity for the selected spectral range. If the emissivity is known, the four measured single images can be used to calculate the orientation of an emitting surface relative to the angle of observation of the goniometer setup. The inclination and rotation angles are calculated for the part of the image on each pixel of the recorded cutting front image and serve as the basis for the 3D reconstruction of the whole cutting front. A more detailed description of the setup of this goniometer can be found in Sawannia et al. 2018. The goniometer setup was arranged under 13.7° to the sample surface in feed direction. The central wavelength of the bandpass filter was 857 nm with a bandwidth of 30 nm. The high-speed camera was a Photron FASTCAM SA5. The Recordings were made with frame rates up to 75000 fps.

3. Results

For the following results, a framerate of 7000 fps was used with an exposure time of 66 µs. Figure 2 (a) shows the four single images of the cutting front. Only the lower 8 mm of the 10 mm thick sample are shown, since the upper 2 mm were covert by the nozzle.

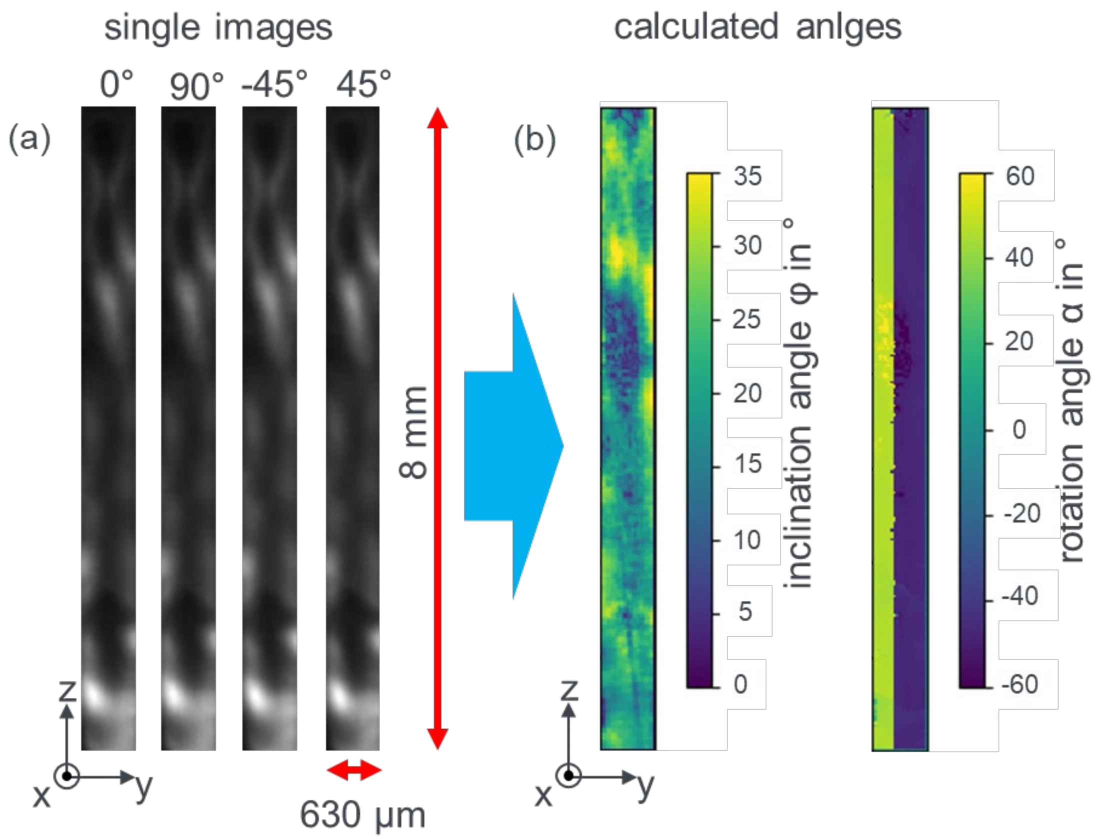

Fig. 2. (a) Four measured single images in a single camera after the linear polarizers with the orientation of 0°, 90°, -45° and 45°; (b) Calculated inclination and rotation angle for each image pixel in observer direction

With the measured intensities in the single images, the angle of inclination φ and the angle of rotation α can be calculated, plotted in Figure 2 (b). With these angles, the surface normal for each pixel can be calculated by tilting the surface normal in the xz plane by φ, followed by a rotation in the yz plane by α. An algorithm is used to align the individual surface elements to each other and to reconstruct the cutting front. The reconstructed 3D geometry resulting from the four single images is shown in Figure 3 (a) and (b).

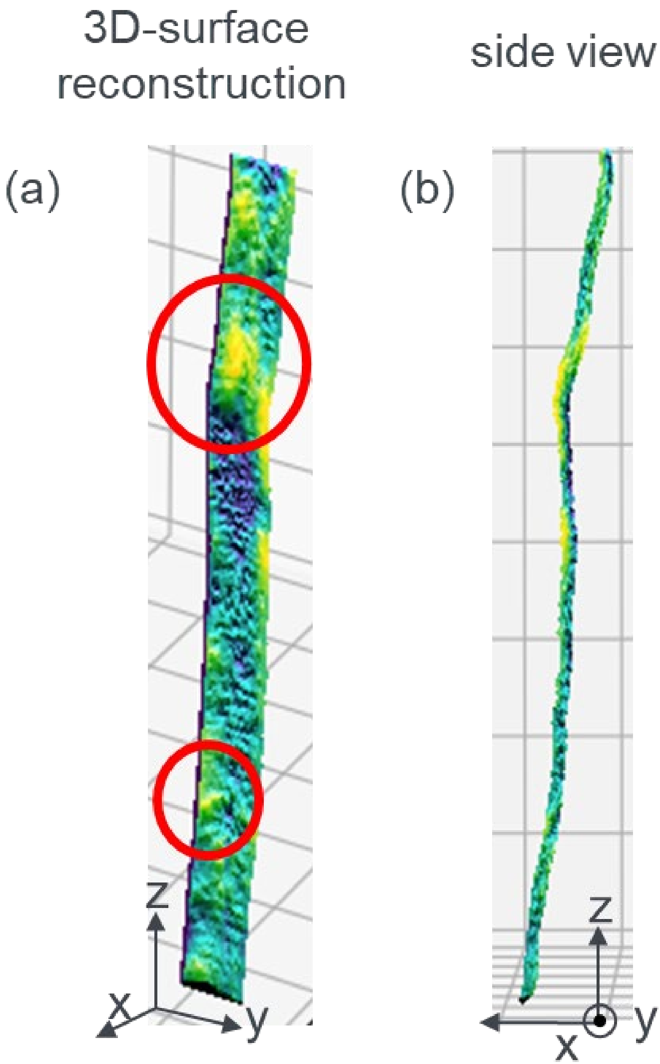

Fig. 3. (a) Reconstructed 3D surface of the cutting front. The color corresponds to the local inclination angle; (b) Side view of the reconstructed surface

The color corresponds to the angle of inclination φ. The reconstruction allows to determine the global inclination angle of the cutting front, noticeable in Figure 3 (b) and its fluctuation during the cutting process.

In Figure 3 (a), Structures can be identified on the reconstructed surface. Two of these structures are marked with a red circle. The size and velocity of these structures can be determined from image to image. It is noted that these structures do not necessarily match the bright spots in the recorded images with the four different polarizations. This verifies, that the information about the intensity of the emitted thermal radiation is not sufficient to reliably determine geometrical features on the processing front. However, as shown above, geometrical features can be detected if the polarization state of the emission is considered

4. Summary

The goniometer setup was used to reconstruct the 3D-surface of the cutting front during laser cutting of 10 mm thick stainless steel with a solid-state laser. The surface reconstruction provides the global inclination angle of the front from each single frame of the high-speed camera. Structures on the front can be tracked over several images. The setup allows analyzing cutting front geometries with frame rates of up to 75000 fps and high spatial resolution. It was noted, that the information about the intensity of the emitted thermal radiation is not sufficient to reliably determine geometrical features on the processing front. To determine them, information about the polarization state of the emission is required.

Future work will include investigations on the influence of the cutting parameters on the geometry of the cutting front, e.g. raytracing to calculate the local absorption.

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