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High-speed X-Ray Imaging of the Cutting Process during Laser Beam Cutting of Aluminum

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Abstract

The online X-ray diagnostics system at the IFSW was modified for laser beam cutting allowing for the analysis of the temporal behavior of the local inclination of the cutting front. The cutting front of 10 mm thick aluminum samples was recorded during the process with a framerate of 1000 Hz. When increasing the feed rate, it was observed that the inclination of the cutting front with respect to the laser beam increased until loss of cut.

Keywords: laser beam cutting; cutting front; aluminium; online high-speed X-ray imaging

1. Introduction

The cutting quality which results from laser beam cutting of thick materials with solid-state lasers is frequently unsatisfactory. This is mainly expressed in dross adherence and a large surface roughness at the cutting kerf resulting from the generated striations, Wandera and Kujanpää, 2011. Both features strongly depend on the melt flow and the ejection behavior of the melt, Bocksrocker et al., 2017. This is governed by the locally absorbed intensity, which depends on the local inclination of the cutting front, Petring, 2016, Bocksrocker et al., 2019. Therefore, knowledge of the local geometry of the cutting front is crucial for improving the resulting cutting quality for cutting of thick materials. However, the in-process observation of the geometry of the cutting front is difficult to realize with conventional diagnostics. Approaches to measure the cutting front during the process have already been demonstrated successfully. These approaches included the cutting behind glass, Arntz et al., 2017, Riveiro et al., 2011, the use of thermal radiation, Phi

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Long et al., 2016, Bocksrocker et al., 2015, or the use of high-speed cameras, Pocorni et al., 2017. Furthermore the applicability of high-speed X-ray imaging for laser cutting was already demonstrated for cutting 4 mm thin mild steel sheets, Ozaki et al., 2016. However, for cutting of thick materials, further investigations of the melt flow and the cutting front are necessary for a detailed understanding of the resulting cut quality.

In this proceeding, the investigation of the cutting front during laser beam cutting of 10 mm thick aluminum as a function of the feed rate is presented, using online X-ray imaging.

2. Setup

A sketch of the experimental setup is shown in Fig. 1. Cutting of aluminum was performed using a disk laser TruDisk 8001 with a wavelength of λ_{Laser} = 1.03 µm in combination with a PRECITEC ProCutter cutting head. The focal lengths of the collimating and focusing lenses were 100 mm and 150 mm, respectively. In combination with the 100 µm fiber used, this resulted in a focus diameter of 150 µm. The cutting nozzle with an outlet diameter of 2.5 mm was positioned 1 mm above the 10 mm thick aluminum sample. The selected laser power was 8 kW, the focus position was 1 mm below the sample surface and nitrogen was used as cutting gas with a pressure of 12 bar. The feed rate was variated between 2 m/min and 4 m/min. Cuts with a length of 40 mm were produced and the sample width (in the direction of the X-rays) was 6 mm. For visualization of the cutting front, online high-speed X-ray imaging in side-view was performed with a frame rate of 1000 fps.

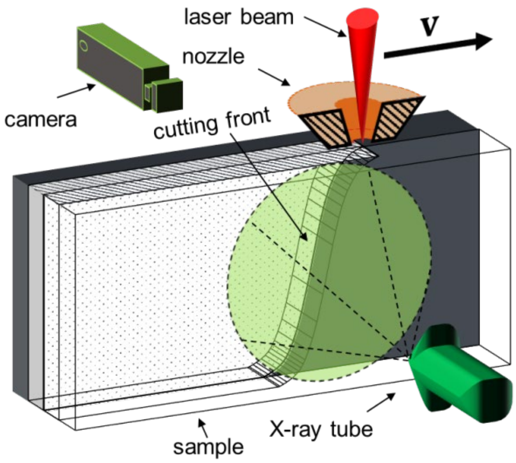
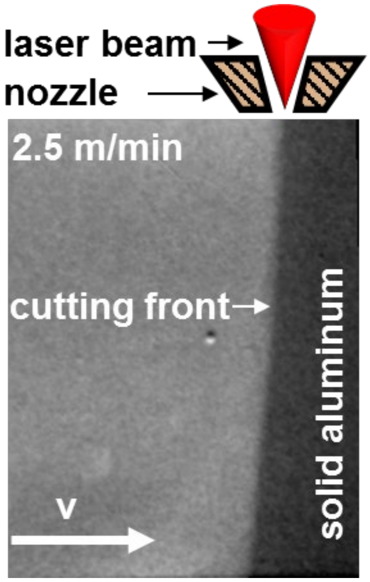


Fig. 1. Sketch of the experimental setup.

3. Results

All the presented results were evaluated within a length of 3 mm in the middle of the 40 mm long cuts. The X-ray videos were post-processed with a flat-field correction and Kalman filtering, Harvey, 1989. Fig. 2



shows an example of an averaged image of the recorded X-ray single frames during one cutting process. During their propagation through the cutting sample, the X-rays are absorbed as a function of the thickness of the sample material. Thus, a clear contrast between the solid material (dark, high absorption of X-rays) and the material which contains the cutting kerf (light, low absorption of X-rays) is visible in the grey value images. This grey value contrast provides temporal and spatial high-resolution information about the geometry of the cutting front.

Fig. 2. Average image from X-ray videos.

Fig. 3 (a – c) shows the averaged cutting fronts as a function of the feed rate.The workpiece was completely cut at feeds from 2.0 m/min to 3.0 m/min. For feed rates of 4 m/min and above, the energy, which is required for a complete cut, was not provided, so that a loss of cut occurred which can be clearly seen in Fig. 3 (c).

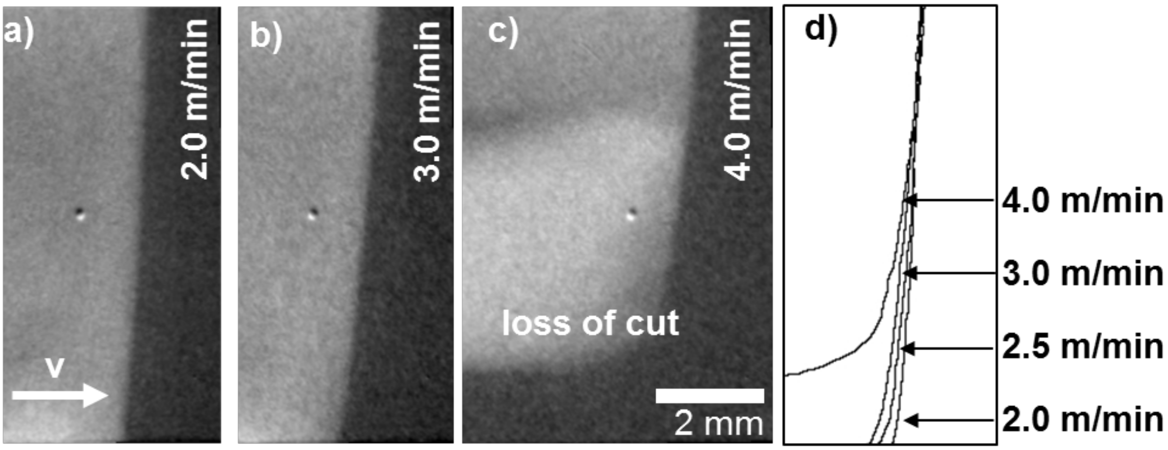


Fig. 3. Average images from X-ray videos for different feed rates (a-c). Extracted geometries of the cutting front for different feed rates (d).

By using image processing filters, the contours of the respective cut front can be extracted. These contours are compared in Fig. 3 (d) for different feed rates. This clearly shows that inclination of the cutting front with respect to the laser beam was increasing with increasing feed rates.

4. Summary

The online X-ray diagnostics system at the IFSW was successfully modified for laser beam cutting allowing for the analysis of the temporal behavior of the local inclination of the cutting front. The cutting front could be identified in-process due to the grey value contrast between the material containing the kerf and the solid material in the X-ray video. It was seen that the inclination of the cutting front with respect to the laser beam was increasing with increasing feed rates. The online X-ray diagnostic system proved to be a promising tool for investigating the cutting process.

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