Subproject A8

Title
In-situ diagnosis and control of the melting and solidification dynamics during laser beam cutting

Project management/-processing
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Task definition
The primary task of this sub-project is the identification, experimental implementation and testing of new methods for increasing the precision of oxide-free laser beam fusion cutting of sheet materials by using improved in-situ diagnostic methods.

The tasks for 2018 also include the further development of a more detailed understanding of the cause-and-effect relationships of the dominant
sub-processes and the affected primary process variables, which have so far been insufficiently sensory assessed. An essential basis for this is the identification of the process dynamics by analyzing the response of process variables to modulation of the laser parameters. The determination of the time constants of the dynamic sub-processes involved is of fundamental importance for the later design of the compensation methods and requires extensive serial investigations.

Procedure

Cold-rolled 1.4301 stainless steel sheets with a thickness of 6 mm are used for the investigations. Linear cuts are made with a fiber-guided disk laser (Tru-Disk 12002) at a laser power of 5 kW, a focus diameter of 500 µm and a Rayleigh length of 6.5 mm. The process parameters focus position, cutting speed and cutting gas pressure are varied. The analysis of the process dynamics is performed by means of in situ visualization and de-tection of the melt film forming on the cutting front and at the transition to the cutting edge during the process. For this purpose, on the one hand the cutting method (at real incisions) with a high-speed camera aligned parallel to the cutting direction is used, and on the other hand the trimming method with laterally rotated observation direction is used. (Picture 1)

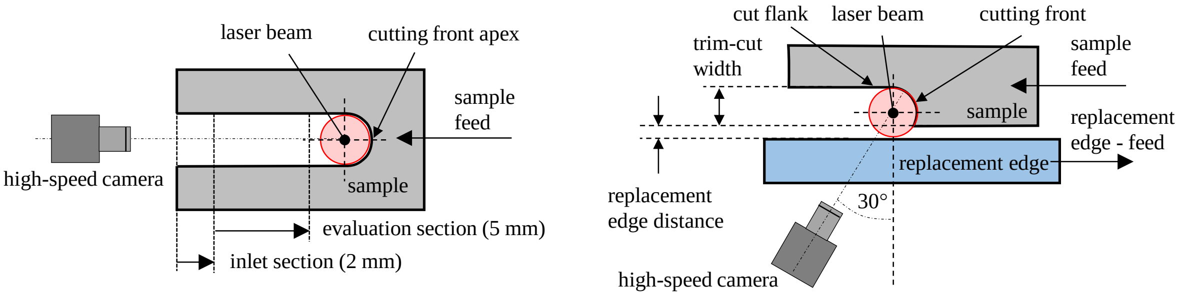

Figure 1: Principle of in situ diagnosis. Camera orientation for the cutting (left) and trimming (right)

In both cases the thermal process light is visualized with a local resolution of 20 µm/px and a recording frequency of 100 kHz. The evaluation of the process recording is carried out with the incision method with an evaluation length of 5 mm after an incision length of 2 mm. This ensures that a stable process area is analyzed. A longer evaluation distance is not possible because the vertical parallel cutting gap (< 1 mm) acts as an aperture, which reduces the contrast of the recording as the cutting length increases.

The melt film on the cutting front is characterized by, among other things, highly dynamic downward, towards the joint exit, moving brightly shining melt waves. For quantitative analysis of the melt waves, the differences in brightness are evaluated along a vertical analysis line. (picture 2)

The data used are those generated by the cutting method. Both the number and the speed range of individual melt cells are counted and determined. The evaluation of velocity distributions is carried out over the complete cutting depth as well as in discrete cutting depth ranges.

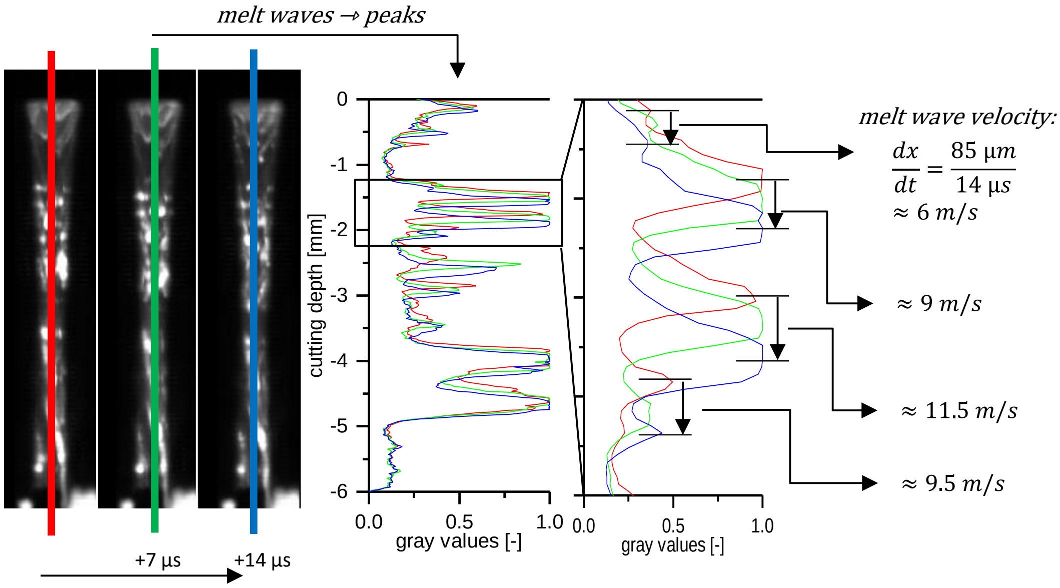

Figure 2: Principle presentation: Analysis of the melt film dynamics, detection and evaluation of melt waves

The correlation of the velocity distribution with the cutting flank roughness depth, the dominant quality-determining properties of the cutting flank besides the formation of dross, becomes possible. The quantitative analysis is complemented by the qualitative analysis of single image sequences, which are recorded by means of cutting and trimming methods. Picture 3

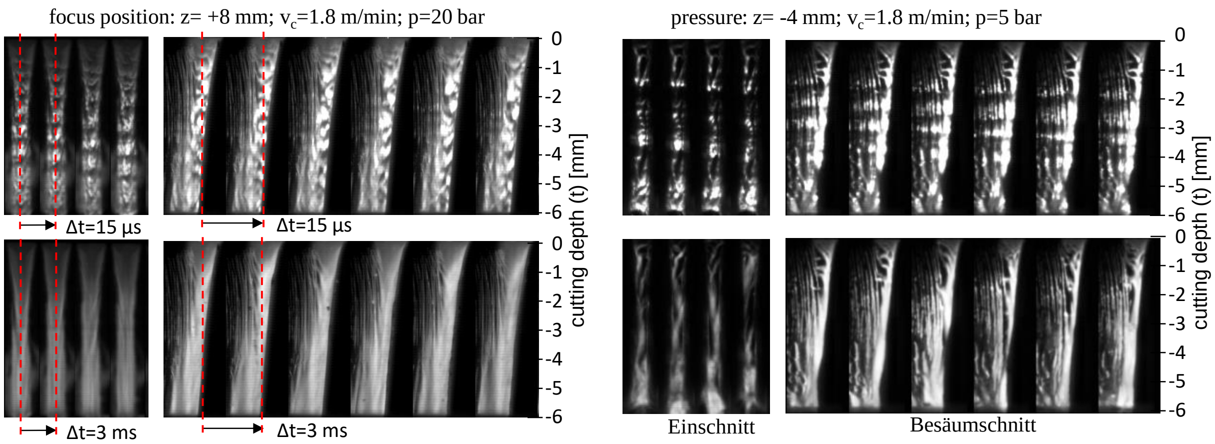

Figure 3: Single image analysis with different cutting parameters; divided into single cuts (each left), trim cuts (each right), unprocessed single images (each top) and time-averaged single images (each bottom)

Results

The reduction of surface roughness correlates positively with the number of detected melt waves when considering the total cutting depth, with few exceptions. The single image analysis of the in-situ diagnosis allows the observation of two effects, which have a significant influence on the number of detected and counted melt waves at the cutting front vertex:

- The number of counted fusion waves decreases if the fusion waves do not slide strictly vertically downwards, but laterally from the analysis area at the cutting front vertex to the transition to the cutting edge. In this case they are no longer detected by the analysis method used, as only areas close to the cutting front vertex are evaluated. This effect occurs when the melt flow narrows laterally to individual melt strands. (see Fig. 3, right)
- With a stable melt film, the number of counted melt waves can increase further if melt waves with lower vertical expansion are formed. Or, if the surface of melt waves is not smooth, but another finer, still recognizable surface structure is formed.Niedrige Werte der gezählten Schmelzwellen können daher auf das Auftreten eines verengten instabilen Schmelzfilms hinweisen. Das Auftreten eines instabilen Schmelzfilms korreliert positiv mit einer erhöhten Oberflächenrautiefe.

With positive focus positions and an increase of the cutting speed a stabilization of the melt film as well as an acceleration of the melt waves can be observed and a reduction of the cutting edge roughness can be measured.

Summary and Conclusion

The in situ diagnostic methods used in combination with automated evaluation procedures allow the quantitative and qualitative analysis of the melt film dynamics during laser cutting. A correlation between cut edge quality and melt film dynamics is possible. A uniform melt film on the cutting front vertex as well as on the transition to the cutting edge is necessary but not sufficient for a reduced cutting edge roughness depth. Furthermore, an accelerated melting film is necessary. With the new findings, the dyna-mic of the melt film can be clearly identified as a quality-determining property and compensation methods for quality improvement can be derived. The targeted excitation of the enamel film dyna-tics thus clearly represents the next working point of the sub-project.

Publication

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