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Influence of superimposed intensity distributions on the welding process and the spatter behavior during laser welding of steel

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Abstract

The influence of superimposed intensity distributions on the resulting melt flows, capillary shapes, and generated spatters during laser beam welding of mild steel was investigated using online high-speed X-ray imaging and visual high-speed imaging. The shape of the capillary changed for different superimposed intensity distributions and the size of the eddies in the melt pool changed for welds with different amounts of generated spatters. For a high number of generated spatters, a higher number of trajectories of the tracer particles leading to the upper part of the melt at the rear side of the capillary was observed, which was also the location of the generation of the spatters.

Keywords: laser welding; spatter reduction; online X-ray diagnostics; superimposed intensity distributions

1. Introduction

The occurrence of spatters in laser beam welding of steel can lead to a reduction in mechanical strength and contamination of the welded parts as well as contamination of the processing optics and is therefore an undesirable phenomenon, Nagel et al., 2016, Nagel et al., 2017.

Approaches to reduce the occurrence of spatters during laser beam welding of steel with solid-state lasers have already been demonstrated successfully. These approaches included a stabilization of the capillary opening, Fabbro et al., 2006, Kamimuki et al., 2002, defocusing of the laser beam, Weberpals, 2010, Li et al., 2014, Kawahito et al., 2017, welding at reduced ambient pressure, Börner et al., 2011, Rominger et al., 2012,

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and the use of superimposed intensity distributions, Nagel et al., 2016, Nagel et al., 2017, Speker et al., 2017, Speker et al., 2018, Jarwitz et al., 2018. However, for a detailed understanding of the underlying mechanisms, leading to this reduction of the spatter occurrence when using superimposed intensity distributions, further investigations are required.

In this proceeding the influence of superimposed intensity distribution on the resulting capillary shape, melt flows and generated spatters during laser beam welding of mild steel are presented.

2. Setup

A sketch of the experimental setup is shown in Fig. 1. Welding of mild steel was performed using a disk laser TruDisk 8001 with a wavelength of λ_{Laser} = 1.03 µm in combination with a TRUMPF BrightLine Weld system with a dual-core 2-in-1 fiber allowing to set the fraction of power in the inner and outer core arbitrarily. With this, the two intensity distributions could be superimposed on the work piece, Speker et al., 2017. The diameters of the inner and outer core were 100 µm and 400 µm, respectively. The collimation and focusing lens of the focusing optics that was used had a focal length of 200 mm each, leading to a focal diameter of 100 µm and 400 µm for the inner and outer core, respectively. The focal position was set 1 mm below the sample surface, the feed rate was v_{feed} = 7 m/min and the total power was always set to P_{total} = 5 kW. Partial penetration welds were produced with a length of 40 mm and the sample width (in the direction of the X-rays) was 4 mm. Visual high-speed (HS) imaging was performed in side-view with a frame rate of 8400 fps to characterize the generated spatters. For visualization of the capillary shape, online high-speed X-ray imaging in side-view was performed with a frame rate of 2000 fps. For the visualization of the melt flow, additional tungsten carbide tracer particles with a size of 400 µm were used.

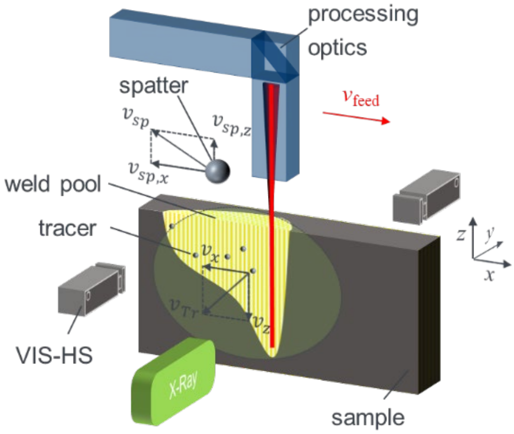

Fig. 1. Sketch of the experimental setup.

3. Results

All the presented results were evaluated within a length of 20 mm in the center of the generated weld seams. The fraction of power in the inner core $P_{\text{rel,core}} = P_{\text{core}}/P_{\text{total}}$ was varied during the experiments, where P_{core} is the power in the inner core (i.e. $P_{\text{rel,core}}$ = 100% all the power in the inner core and $P_{\text{rel,core}}$ = 0% all the power in the outer core). Fig. 2 shows the number of spatters generated per mm length of the weld seams as a function of the fraction of power in the inner core. The number of generated spatters could be reduced significantly to about 94% with $P_{\mathrm{rel,core}}$ = 70% compared to $P_{\mathrm{rel,core}}$ = 100%.

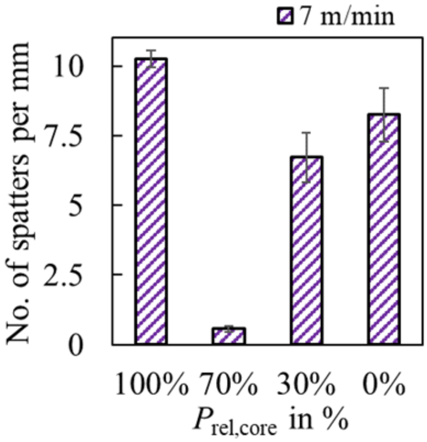

Fig. 2. Number of spatters generated per mm length of the weld seam as a function of $P_{\mathrm{rel,core}}$.

The average flow fields in the melt pool were determined from tracking of the tracer particles in the high-speed X-ray images and are shown in Fig. 3 together with the averaged X-ray images for $P_{\mathrm{rel,core}}$ = 70% and $P_{\mathrm{rel,core}}$ = 30%. Each of the lines represents the trajectory of a single tracer particle tracked during the process with the color of the lines indicating the velocity of the particles. The average velocity of the melt flow in the upper eddy was found to be almost the same with about 0.5 m/s, but the size of the eddies (indicated by the dashed orange lines) in the upper part was larger for $P_{\mathrm{rel,core}}$ = 70%, when less spatters were generated. In the case when more spatters were generated ($P_{\mathrm{rel,core}}$ = 30%), a higher number of trajectories leading to the upper part of the melt at the rear side of the capillary was observed, which coincides with the location where the spatters were generated.

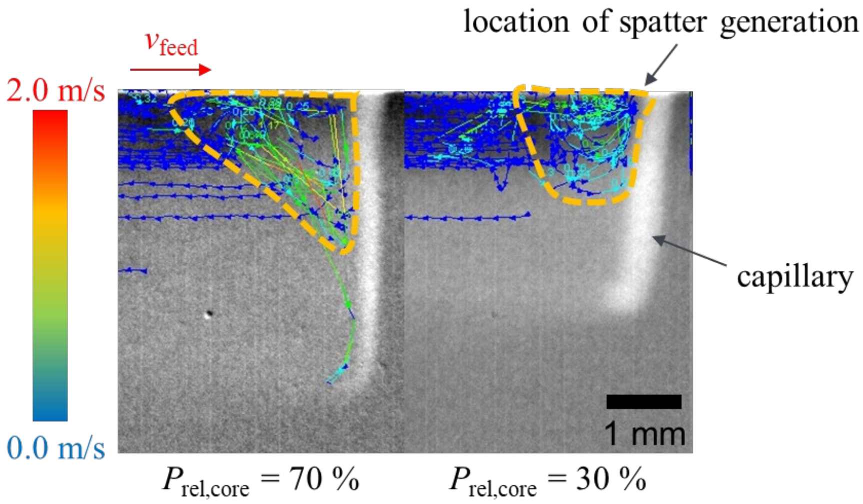

Fig. 3. Flow fields in the melt pool together with average images from X-ray videos for $P_{rel,core}$ = 70% (left) and $P_{rel,core}$ = 30% (right).

The average shapes of the capillary were obtained from the high-speed X-ray images and are shown in Fig. 4 as a function of $P_{rel,core}$. At $P_{rel,core}$ = 100%, the average capillary shape is vertical with a small width in the upper part. The inclination and width in the upper part of the capillary increase and its length decreases slightly at $P_{rel,core}$ = 70%, while the lower part remains vertical. At $P_{rel,core}$ = 30% and $P_{rel,core}$ = 0%, the length is further decreased and the width and inclination of the entire capillary increase. Furthermore, a bulge at the tip of the capillary forms.

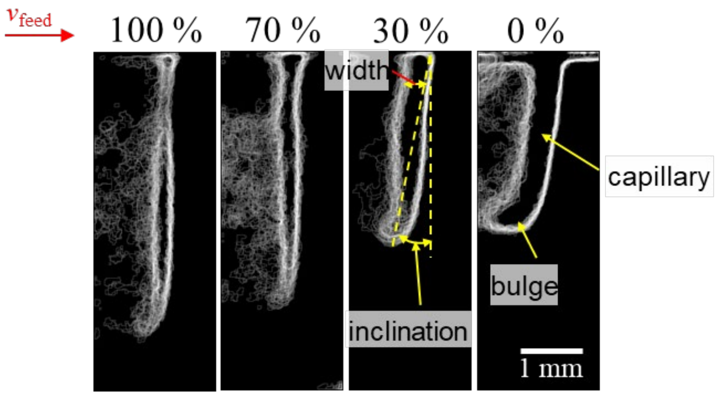

Fig. 4. Average shapes of the capillary from X-ray videos for different $P_{rel,core}$.

4. Summary

The influence of superimposed intensity distributions on the capillary shape, melt flows and generated spatters was investigated for laser welding of mild steel, using visual and X-ray high-speed imaging. A significantly reduced number of generated spatters was observed for $P_{rel,core}$ = 70%. It was found that the width and the inclination of the capillary increased with a decreasing fraction of power in the inner core. The average velocities of the melt flow in the upper eddy were found to be almost the same, but the size of the eddy changed. When a low number of spatters was generated, the eddy was larger in size, whereas for a high number of generated spatters, a higher number of trajectories of the tracer particles leading to the upper part of the melt at the rear side of the capillary was observed. The ejection of the spatters mainly occurred at this location.

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