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Influence of a second heat source on the distortion behaviour during laser beam welding

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Abstract

Due to its several advantages like low heat input, high flexibility and welding speed, laser welding is an established process within numerous industrial fields such as automotive but also food and pharmacy industry.
A restricting phenomenon during laser welding of thin sheets is distortion, which can result in a change of the gap width between the welded parts and hence, highly affect the process performance itself and lead to reduced joint and component quality. The distortion is caused by thermally induced strains and the shrinkage in the weld, respectively.
By applying a second heat source positioned in a defined distance behind the main heat source, the shrinkage can be counteracted, hence optimizing the welding process. For this investigation, austenitic stainless steel 1.4301 sheets were welded with a CO_2 laser, and as a second heat source a diode laser was employed. Several parameters such as travel speed, power and position of the second heat source were varied to evaluate their effect on the process and the joint properties.
The influence of the second heat source on the welding process and the welding result is described. The application of a second heat source allows lower demands on the dimension accuracy and clamping devices in order to realize good welding results.

laser welding, autenitic stainless steel, distorion, CO_2 laser, diode laser

1. Introduction

Austenitic stainless steel is the distinguished material for sheet metal forming in order to realize complex 3D work pieces. Using suitable forming and joining processes, they show leak proof properties for liquids and

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gas and are used in order to realize pipes, reservoirs, boxes, and so on, which are commonly used in the chemistry, food, medical and automotive industry. Due to the high power intensity, laser beam welding is in comparison to TIG or GMA welding the favorable joining process. The thermal load into the work piece is reduced, which results in a reduced formation of the heat affected zone and distortion.

The high thermal expansion as well as the low thermal conductivity of austenitic steels is a trigger for unwanted deformations, which occur during butt welding using a laser. These deformations can either increase the gap between the welded sheets, cause them to be drawn closer together or to misalign and subsequently overlap. Oechsner et al., 2010 shows that a decrease of the welding speed of 1 m/min results in an increase of the deformation of around 10% for laser welding. The influence of high focusable laser sources on the distortion behavior is described by Hess, 2012. He shows that the welding speed can be increased using small spot diameters and therefore the thermal load can be reduced, which results in less deformation. But the reduction of the spot diameter leads to an increase of the tolerant demands. In general it can be said, that halving the tolerant grades leads to a quadruplication of the manufacturing costs, see Kirschling, 1988. The industry deals with this problem by using heavy jigs, fixings, clamps and other technologies, which restrict the relative movement of welded parts in different directions as well as increase the formation of residual stresses, see Nitschke-Pagel, 2002. While these mechanical adjustments might prove effectively, they require extra financial resources and can restrict the flexibility of changes regarding the product geometry. Tack welds are state of the art in order to obtain constant weld gaps. The distance between the tack welds is supposed to range from 20 mm to 40 mm for sheets of 1 mm thickness according to Rostfrei, 2007. However, even this method requires an extra production step, increasing the throughput time.

The objective of the investigation is to create temperature-induced strain, which would counter the displacements of the weld process and in turn maintain a constant gap width. This can be accomplished by a secondary heat source placed on the sheets behind the main laser source. The second heat source generates a temperature field, which results in a strain field. Due to the lever-mechanism, the opening movement can be counteracted. Previous investigation on this subject show the basic effects (Nagel et al, 2014) whereas this part of the investigation regards further boundary conditions such as varying welding speed.

2. Experimental procedure

The stainless austenitic steel X5CrNi18-10, also known as 1.4301, was used. Welding samples were separated out of material sheets by a laser cutting process. The dimensions of the sheets are 300 mm x 50 mm x 0,5 mm. The specimens were placed in a sample carrier and a clamping device fixed one plate of the two. Due to the air space of 0,1 mm between the second sheet and clamp, the motion along the X, Y and the rotation along the Z axis was made possible. The displacement of the unclamped sheet was detected with inductive measuring probes (P 2004 from Mahr GmbH) and the data was recorded using a Dewetron all-in-one instrument. Figure 1 shows the schematic illustration of the setup. Experiments were carried out using a DC025 CO_2 laser from Rofin-Sinar Laser with a wavelength of 10,6 µm and a handling system manufactured by SITEC Industrietechnologie GmbH. The circular spot diameter amounts 0,6 mm in defocused position, the power was set to 2 kW and the travel speed of the sample carrier was varied. A diode laser (LDM 3000, Laserline GmbH) was used as a second heat source. The wavelength amounts 0,98 µm and the elliptical spot amounts 5 mm x 8 mm in defocused position due to the setup. The location of the diode spot was varied relative to the CO_2 spot. The angle of incidence was adjusted to 45° for the diode laser and 90° for the CO_2 laser. A picture of the setup can be found in figure 2.

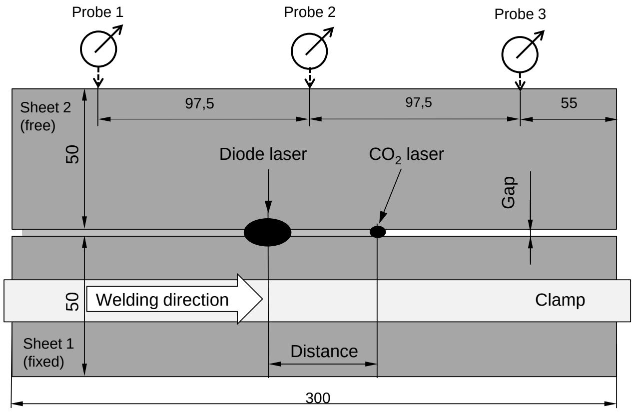

Fig. 1: Schematic illustration of the experimental setup

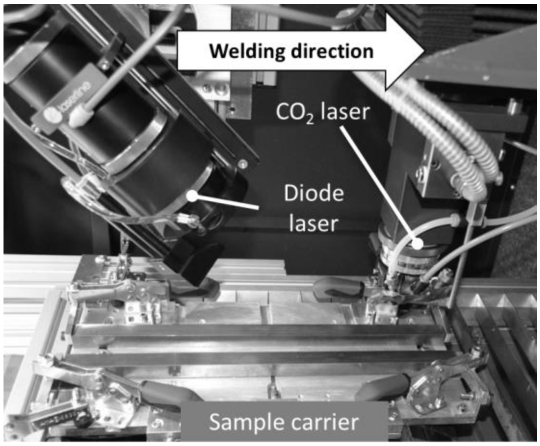

Fig. 2: Experimental setup (side view)

3. Results

3.1. Experimental results without a second heat source

In figure 3 the time depended results of the inductive measuring probes of the welding process can be observed. The control signal of the laser source shows when the laser is turned on or off. In order to estimate the gap, which occurs at the position of the laser spot, the calculated gap width is plotted as well. The welding process starts at time t_1. During t_2 and t_4 the increase of the probe signal can be identified. This means, that the gap between the sheets opens with increasing time. The different values of the probes demonstrate the lever mechanism of the shear movement. When a certain gap width is reached, the laser beam cannot penetrate the edge of the "free" sheet resulting in a process abort. This interruption is marked in this plot at $t = t_3$. This displacement value is named displacement abort. After the welding process ($t > t_4$) the signal decreases, which is explained by the shrinkage of the weld.

The influence of the welding speed on the weld length, the gap width at the moment of the process interruption and the displacement at the end of the weld (WE) is illustrated in figure 4. The displacement at the end of weld ($t = t_4$) reaches its maximum of 0,4 mm in average at a welding speed of 4 m/min. The samples were exposed to a high thermal load resulting in a high expansion and shrinkage. This behaviour decreases with increasing welding speed and the displacement amounts only 0,1 mm at a welding speed of 10 m/min. The weld length and gap width at the moment of the process interruption increases slightly up to a welding speed of 8 m/min. Thereby the maximum weld length amounts 213 mm in average. Further increase of the speed leads to a decrease of the gap width and weld length, which can be explained due to the lack of laser power.

The distance between the two curves of the displacement can be used as an indicator for the process stability up to the welding speed of 8 m/min. The higher the distance between the two curves the shorter is the weld length.

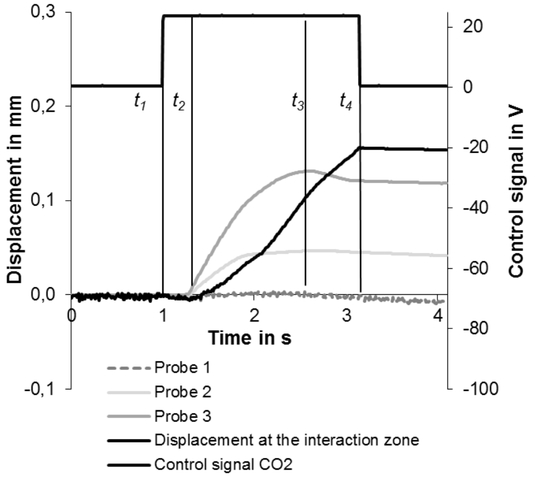

Fig. 3: Displacement of the free sheet during welding, P = 2 kW, v =8 m/min

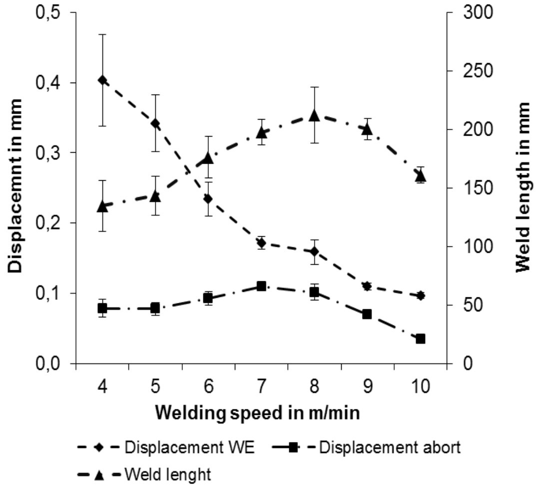

Fig. 4: Influence of the welding speed in the weld length and displacement, P = 2 kW

3.2. Experimental results with additional hot Spot

The impact of the second heat source on the motion of the free clamped sheet is plotted in figure 5. In comparison to the result in figure 3, the curve of the displacement is different. It can clearly be seen, that the occurring gap closes at the moment when the second laser is turned on ($t = t_2$). Due to the temperature field in the area of the cooling weld seam, the shrinkage is compensated and because of the lever mechanism, the gap closes. Afterwards, the gap opens again due to the shrinkage in the weld, but the values are lower in comparison to the values in figure 3. After the laser sources are turned off ($t = t_5$) the values decrease due to the general shrinkage in the cooling weld seam.

Figure 6 shows the influence of the laser power on the plotted curve of the calculated displacement for the interaction zone for a welding speed of 7 m/min. The use of 300 W leads to an increase of the gap width during the welding process and therefore to shorter weld lengths. The use of 700 W and 900 W leads to a decrease of the gap width and the welding process was stabilized. These results are similar for the welding speed range from 5 m/min to 9 m/min.

Figure 7 and 8 show the impact of the distance between the two laser sources on the gap curve and the resulting weld length at the welding speed of 8 m/min. The average weld length amounts 126 mm at the lowest setup of 30 mm, which is a reduction of 70 mm in comparison to the trail without a second heat source. The increase of the distance leads to an increase of the weld length up to the possible maximum of 285 mm. This maximum was achieved for the travel speed range from 6 m/min till 9 m/min (see figure 8). It can be assumed that the interaction of the main process parameters compensates the shrinkage movement of the cooling weld seam thoroughly. A further increase of the distance results in a reduction of the seam length. Hereby, the second hot spot interacts too late and the positive influence cannot be accomplished.

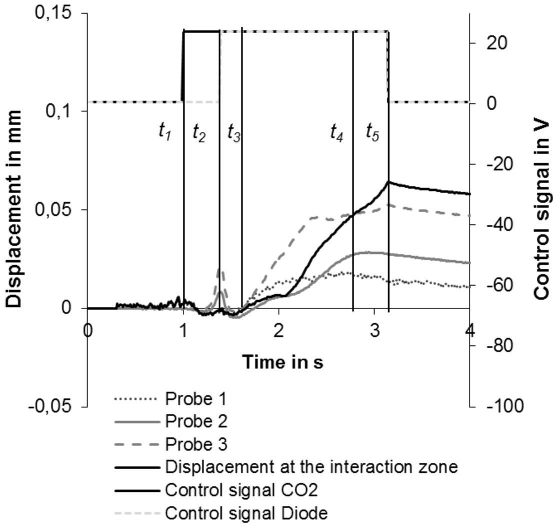

Fig. 5: Signal curve with second heat source, v = 8 m/min, P_{Diode} = 900 W, a = 50 mm,

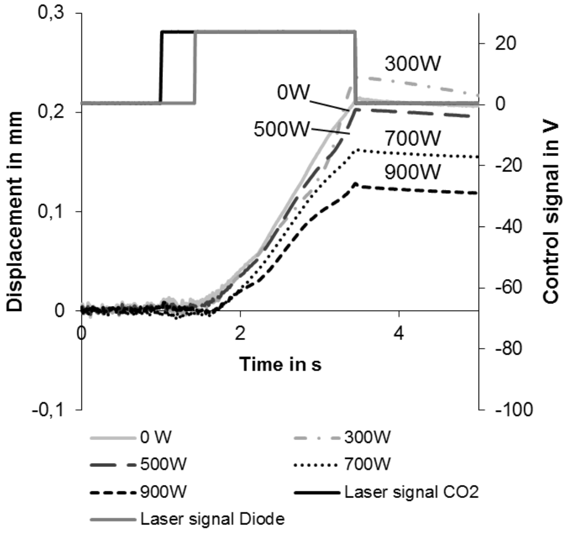

Fig. 6:Influence of the laser power on the displacement for 7 m/min, a = 50 mm

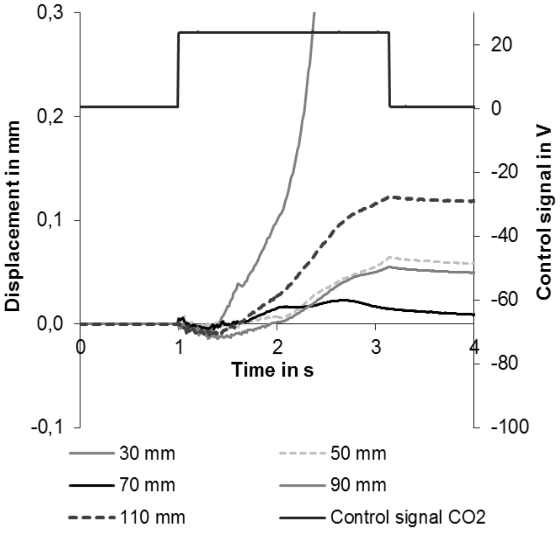

Fig. 7: Influence of the distance between the two laser spots, v = 8 m/min, P_{diode} = 900 W,

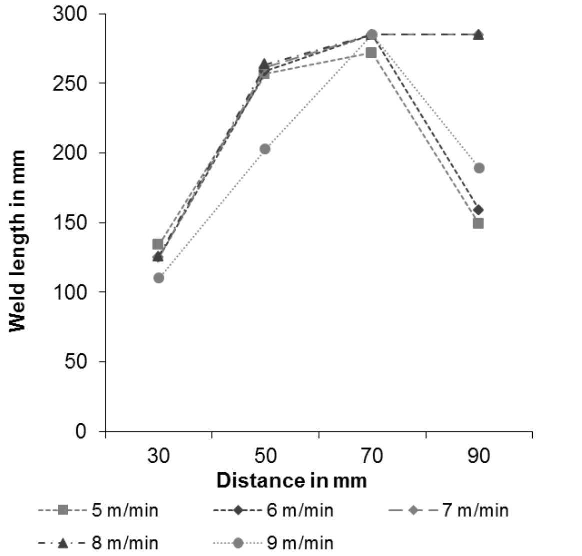

Fig. 8: Influence of the distance between the two laser spots on the weld length , P_{diode} = 900 W

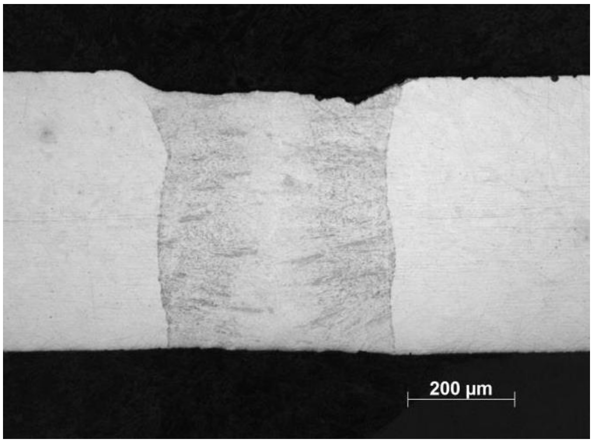

Fig. 9: Cross section, v = 8 m/min, without second hot spot, middle position

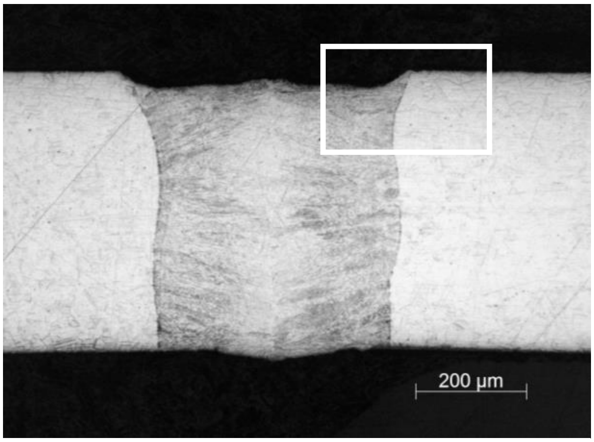

Fig. 10: Cross section, v = 8m/min, P_{diode} = 900W, a = 70mm, middle position

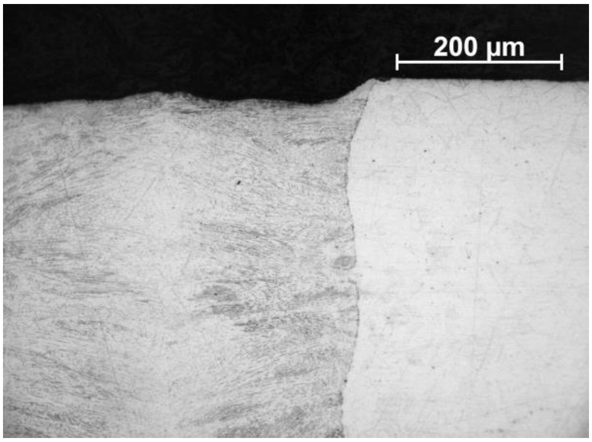

Fig. 11: Detail view of figure 10

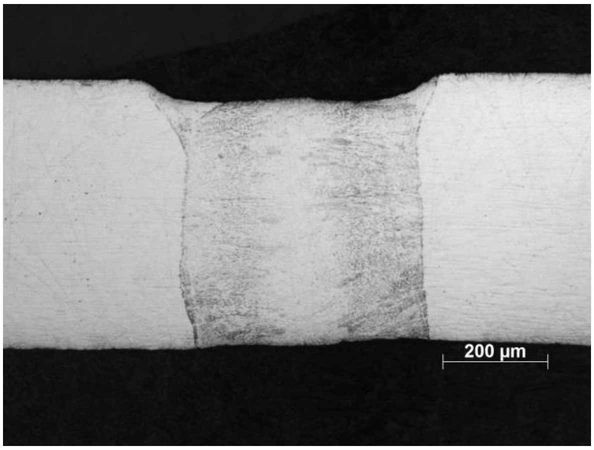

Fig. 12: Cross section, v= 8m/min, P_{diode} = 900W, a = 70mm, end position

Figure 9 and 10 show the cross section taken 148 mm from the beginning edge of the sheet using a second hot spot and not. A slight undercut in the top layer can be determined in both cross sections. A negative influence of the second hot spot on the metallurgical properties of the top layer is not noticeable (see figure 11). Figure 12 shows the cross section from the same sample as figure 10 (273 mm from the beginning). Because the widths of the seams in the cross sections do not show major differences, it can be assumed, that the welding process is perfectly stabilized and endless welds could be realized.

The investigations show that a weld length of maximum 200 mm (see figure 4) can be obtained with this type of clamping and without using a secondary heat source. The welding speed has an influence of the sheer motion during the welding process and therefore an influence on the weld length. The application of a second heat source has a significant influence on the welding process. The use of optimal parameters leads to an increase of the weld length from 200 mm to 285 mm. The cross sections and the plotted curves show the tendency, that endless welds can be expected using this strategy.

Acknowledgements

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