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Multispot laser welding to improve process stability

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Abstract

Two studies about laser welding applying multiple spots in the process zone are presented. The first study aims to investigate how to control the dimensions of a weld pool by applying multiple spots on a row perpendicular to the welding direction. Examinations were performed as bead on plate experiments. The methods' ability to increase bridging and sensitivity to alignment tolerances were tested in a butt joint configuration with up to four parts in a single pass. The results showed that both the width and the depth could be controlled independently. The ability to bridge a gap was increased, and tolerances against alignment errors were good.
The second study was from a real production in which failures in form of impurities leads to blow outs, and failure in the final product. A study of the ability to perform inline repair welding with multiple spots was performed on specimens where an exaggerated blow out was caused by zinc powder. Results showed large improvements. Porosities were present after the welding which is concluded to originate from the heavy turbulence during the blow out.
Spot patterns were produced by splitting the beam from a single mode fiber laser into several spots with diffractive optics.
Keywords: Beamshaping; laser welding; weld geometry; inline repair welding; laser spot pattern; blow out;

1. Introduction

With the introduction of high power single mode fiber lasers it has been possible to reduce the spot size of a focused laser beam, while still maintaining a good depth of focus. The small spots have made it possible to place a number of spots close to each other in the same process zone. This has been utilized to perform two studies of multispot laser welding on two different joining geometries. Both joining geometries originate from joints in an actual production.

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2. Experiments and setup

The spot patterns have been produced by changing the phase of the collimated beam by a diffractive optical element in a flexible beam shaping unit. A 1 kW single mode fiber laser with a wavelength of 1.075 µm and a beam quality factor of $M^2 = 1.1$ were applied. This setup can produce spot patterns in which placement and power in the individual spots can be controlled, and where the individual spots had a diameter of 85 µm.

Two joining tasks were examined. The first one was a butt joint with multiple sheets as sketched in figure 1a. The task was to produce a joint between all 4 sheets in a single pass. For this it was necessary to produce a wide weld seam, in which the depth can be adjusted, as burn through should be avoided in the final production. During laser keyhole welding, normally the welding width cannot be controlled, and is usually quite narrow. In this work multiple spots were placed in a row perpendicular to the welding direction. Each spot had enough intensity and power to produce its own keyhole. The spots were placed with a distance so the material between each spot is melted. In this way one common weld pool were established. A parameter study covering spot distances, number of spots, travel speed, focus and laser power was performed as bead on plate experiments. Further tests with joining of 2-4 sheets were performed in which robustness towards assembly and fixture tolerances were examined.

The second joining task is also a butt joint. In this, a thin foil of 75 µm thickness were placed in between two sheets. In the current production, which is performed with a multimode laser, there are problems with local blowouts due to impurities. The task were to produce a weld which still was tight and with a good quality. To generate the blowout small amounts of zinc powder were placed locally between the foil and one of the sheets. The setup and one of the spot designs can be seen in figure 1b.

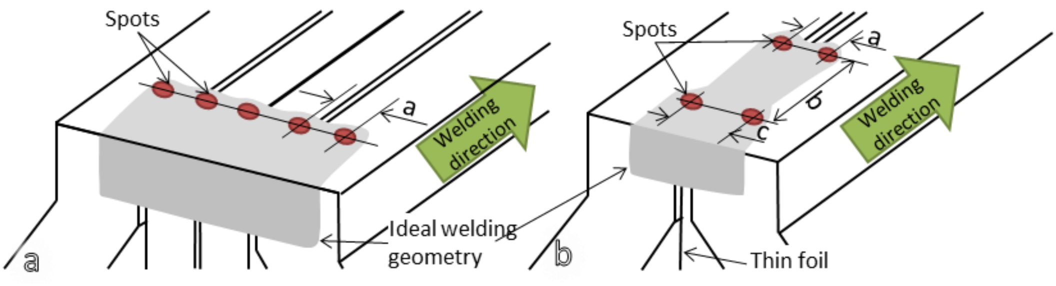

Fig. 1. (a) Joining task, ideal weld geometry and spot pattern placement for first study on control of welding width and depth. (b) Joining task for second study. Zinc powder is placed locally between the foil and the sheets.

3. Results

When multiple spots were placed in a row, perpendicular to the welding direction, they each formed an individual keyhole. Further, the material between the two keyholes was melted if the keyhole distance is close enough and the chosen travel speed was adequate. Figure 2 shows cross sections from a series of welds performed with different spot spacing. The center spots has 10-30% less power than the edge spots. This is due to limited resolution of the phase change in the design process.

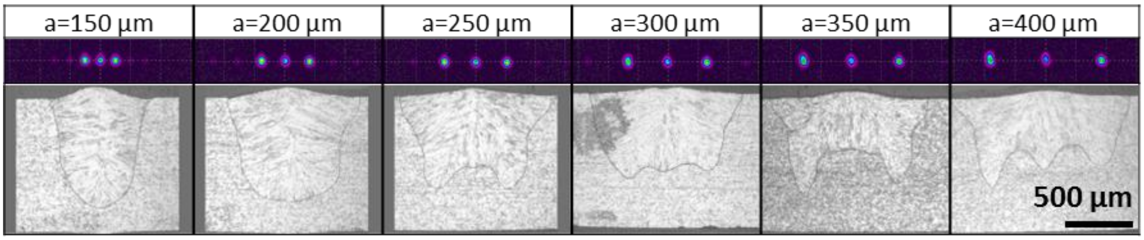

Fig 2: Top row: Measured spot pattern using an intensity sensitive CCD camera. Bottom row: The resulting cross-sections for different spot distances performed as bead on sheet, all with focus placed on top of the sheet. (F0). Travel speed has been kept constant at 50 mm/s. Power is set to average 200 W per spot. All figures have the same scale.

Figure 3 shows cross sections of the welds with 1-5 spots, and the spot pattern above each weld. The welds were performed with 300 µm spacing between each spot, travel speed of 50 mm/s, 200 W laser power in each spot and focus on the surface of the sheets (F0). The depth of fusion becomes constant, while the width scales linearly in incremental steps with the number of spots. When the spot spacing was increased, the individual keyholes in the cross sections became more distinct, and the bottom of the melt pool did not melt together. The same were observed when the travel speed was increased. The depth of fusion scales with the laser power. Similar results were achieved when focus was kept within +0.25/-0.5 Rayleigh length. Outside this range the shape was preserved, while depth of fusion was reduced.

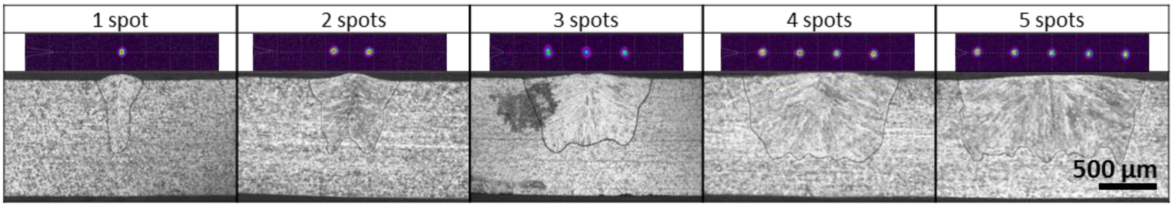

Fig. 3. Top row: Measured spot pattern using an intensity sensitive CCD camera. Differences in intensity between images are due to different power settings on the laser as the number of spots is increased. Bottom row: The resulting cross-sections

Figure 4 shows Experiments performed in a multi-butt-joint in which spot distances, sheet thickness and number of sheets are varied.

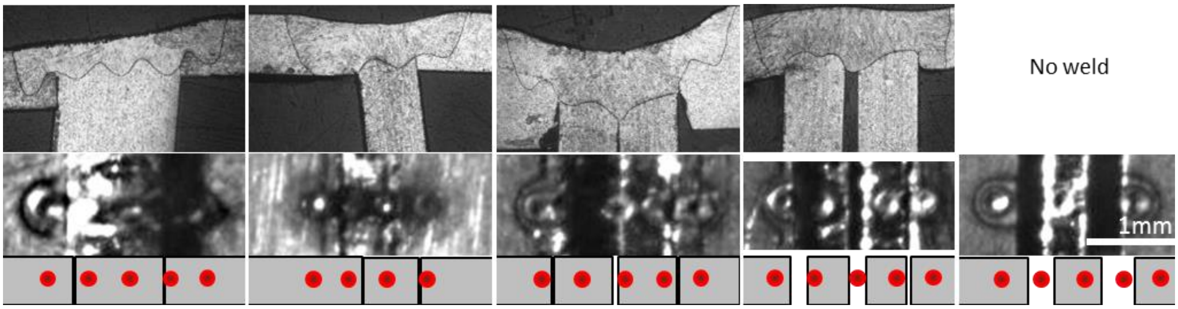

Fig. 4. Top row: Cross-sections of different welds on butt-joined parts. Middle row: Parts seen from above through the nozzle before welding. A short laser pulse with the applied pattern produced marks on the surface. Bottom row: Sketch of the parts where placement of the beams and gaps are shown. Distance between spots was 300 µm.

Figure 5 shows the results when gap distance (d_1) was varied in a butt joint configuration with two sheets. Spot distance was reduced to 250 µm, which increased the ability of the melt to bridge the gap. The power was 200 W per spot, travel speed 50 mm/s and focus was placed on the surface. For $d_1 \geq 450$ µm the edges do not bridge, and no joint is formed.

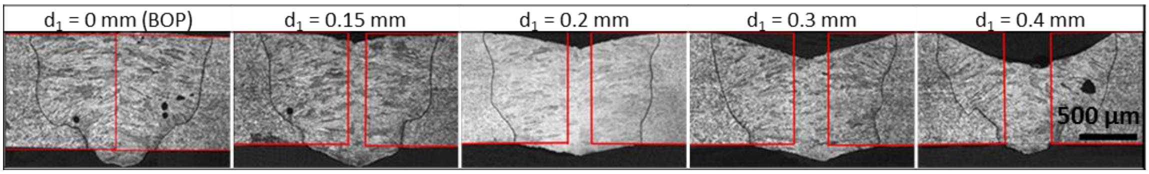

Fig. 5. Cross sections from experiments in a butt joint design with different gaps.

Figure 6 shows the relationship between power ratio and distance to a trailing spot in a multispot pattern like the one shown beneath the graph in figure 6. The power ratio P2/P1 indicates the ratio where the trailing spot has the same depth of fusion as the two main spots. P1 is the power in one of the main spots and P2 is the power in the trailing spot.

The results from these experiments were used to design spot patterns for performing the butt joint design sketched in figure 1b. Results from welding with a dual spot pattern are shown in figure 7. “Dual spot” is a design identical to the pattern design in figure 3, with two spots. This design produced good looking welds, as long as no zinc powder was present (Figure 7a and b). Figure 7c and d shows the result when the zinc powder was present. Here, the whole melt pool has been removed, and no joint is formed.

Figure 7e, f and g show the results from welding with a double dual spot pattern, like sketched in figure 1b. The surface where the zinc caused the expulsion of the melt pool is not as good as when no zinc has been present, but the weld is repaired, with some undercut. In general, porosities were found in the areas where zinc had caused expulsion of the melt pool. In the areas where no zinc had been present the weld looks good, without porosities and a with a small weld head with no undercut.

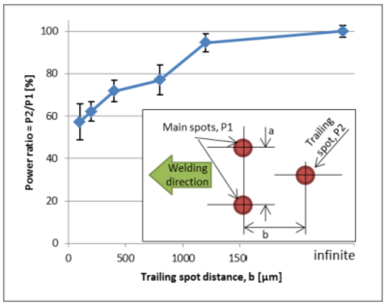

Fig. 6. Distance and required power to penetrate the weld pool for a trailing spot for different distance of trailing spot (b).

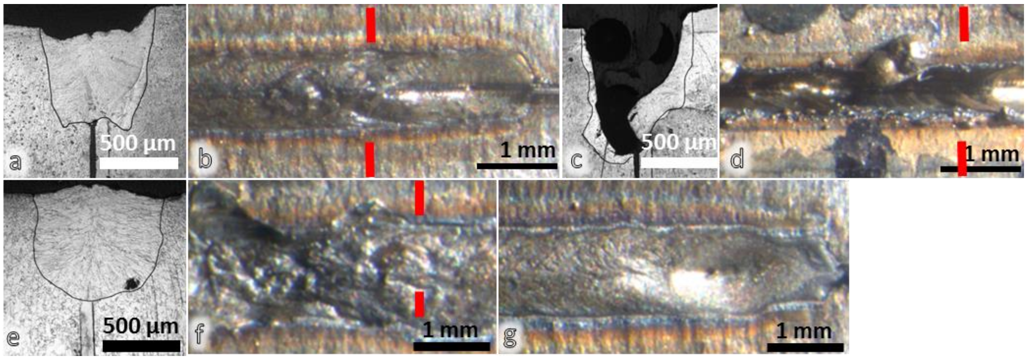

Fig. 7. Result from dual spot welding. a) Cross-section, no zinc has been present. b) Surface of cross-section with indication of approximate position of cross-section. c) Cross-section where zinc has been present d) Surface where zinc has been present with indication of approximate position of cross-section. (e) Weld performed with spot pattern shown in figure 1b with a = 800 µm, b = 200 µm, c = 400 µm, power in the trailing spots at 80% of the power in the main spots. Small amount of zinc powder between disc and foil. (f) Surface of weld with indication of approximate position of cross-section. (g) Surface where zinc has been present.

4 Discussion and conclusion

Two studies in which multispot welding were applied shows promising results regarding increased process stability. Welding with multiple spots in a line has shown it is possible to control the welding width and depth of fusion independent from each other. The process has increased robustness regarding tolerances compared to welding with a single beam. In welding situations where blowouts can occur, a double dual spot pattern, in which the trailing spots melts additional material and hereby repair the blowout, has shown promising results for improvement of process stability. The imperfect energy distributions of the energy in the spot patterns arise from insufficient resolution of the flexible beam shaping unit, and would not be a real problem if the spot patterns were produced by a DOE in a substrate inserted in the collimated part of the beam.

5 References

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