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Process simulation and development for laser beam welding with rotating bifocal optics

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Abstract

Laser welding has been an established technology in industrial production. Nevertheless, there are many unsolved problems with cracks and pores when welding certain materials. New process or exposure strategies are therefore being developed to enable a controlled temperature field within the welding zone and thus deliver better welding results.

The aim of this study is to investigate a new type of processing optic that uses bifocal optics to split the laser beam into two partial beams and a fast rotation of these two partial beams. Optimum welding parameters for stainless steel were determined while varying the rotational speed and laser power. the same time, simulations were created with the FLOW 3D software, which agree very well with the experimental results.

Keywords: Bifocal Optics; Laser Welding; Stainless Steel;Disk Laser

1. Introduction

In the last few years, many papers have been published about laser welding applied to different materials with specialized technical applications. Laser welding is efficient and common process, due to high welding speed, smaller heat-affected zone (HAZ) area, reduced deformation, and other related matters [1].

The laser welding with rotating optics technique allows better temperature control of the welding part during welding. The beam passes near any point of the weld several times. The increase in temperature and cooling rates minimizes weld defects [3].

There are not many studies in the literature on bifocal optics, which offer an impressive weld quality visually and qualitatively. The aim of this study is to develop a new type of controlled welding process using rapidly rotating laser beams. The bifocal optics use the split of the combined laser beam into two partial beams.

This is designed to create a defined temperature field within the molten pool. While welding defects occur during the welding process, welding quality can be optimized with bifocal optics.

In current study, the welding process was carried out at LMB company, and the experiments were carried out in the Ruhr University Bochum laboratory. The aim was finding the optimum welding parameters for stainless steel while varying the rotational speed (RS) and laser power (LP). Welding speed (WS) is applied as 2000 mm/min for each sample. Geometry parameters such as weld depth (WD) and weld width (WW) are presented to define the weld properties. The results show that porosity formation and cracks reduced with optimum parameters.

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Simultaneously, simulations were created with FLOW 3D software. The WD and WW of the weld zone were measured in the Flow 3D Post Module. Comparison of the simulation results with the experimental results shows that the results are similar.

This can be advantage to optimize parameters before applying the welding process. This will be money and time saver for those who wants to study with bifocal optics [7].

Furthermore, this study shows that bifocal optics reduce pores and provides good connections to the heat affected area through uniform heat distribution with selected parameters [9]. This study will be a guiding light for researchers and companies seeking to improve welding quality.

2. Experimental setup and methodology

In this study, rotating bifocal optic is used, which enables the use of two beams formed from a basic beam.

The laser beam is split into two beams by using double wedge. These heads divide the laser power into two equal parts by using a double wedge, both beams rotate around a certain radius with same values. The great advantage of this method lies in the possibility of adapting the power distribution to the task at hand and regulating it depending on the process conditions, such as changing joining geometries or gap widths. This achieves a high degree of flexibility, quality, process reliability and efficiency.

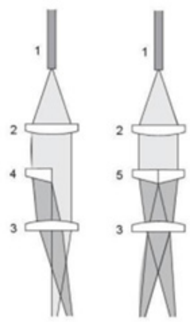

Fig. 1. Bifocal optics (1. Laser light cable, 2. Collimator, 3. Lens, 4. and 5. Wedges)

Using bifocal optics for welding brings is described to come with the following advantages:

- Achieving good mixing by a whisking effect,
- Good connections to the Heat-affected zone through a uniform heat distribution,
- Uniform heat input over the entire seam width,
- Reduction of pores due to suction effect, especially in the upper area.
- Easy adjustment of parameters on a disk laser (TruDisk 4001D).

The calculated path of the wobble laser on the sample can also be used to analyze the x and y paths of bifocal laser beam. The wobble laser can be considered as a single-beam version of the bifocal laser. Figure 2.(a) shows the movement of the wobble laser beam along the welding direction. And Figure 2.(b) shows the welding path of the laser beam.

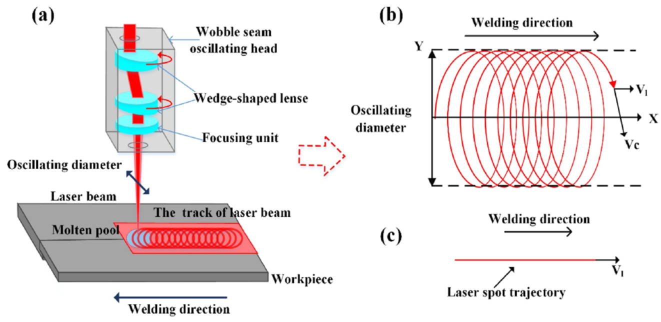

Fig. 2. (a) Oscillating head; (b) welding path; (c) welding direction [13].

The path of the rotating laser beam on the sample in the x-direction,

$$x = -a(\cos 2\pi f t) + \upsilon t + a \quad (1)$$

And the path it follows on y,

$$y = -a(\sin 2\pi f t) \quad (2)$$

In Equation (1) and Equation (2), rotation diameter is denoted by a, frequency by f , velocity by v and time by t [3]. The equations can be used for the creating simulation.

For bifocal optics, these x and y path can be considered as beam path. The difference is that the wobble laser beam has a single beam, but for bifocal optics two beams with a distance of 0.8 mm from each other must be used. This means that there must be two x and y paths where every parameter is the same, with a distance of only 0.8 mm between the first laser beam and the second laser beam.

2.1. Parameter optimization and samples inspection

The high energy density laser beam is charged on the surface of the samples and the vaporized materials in the area cause the keyhole to rapidly form and develop. The weld seam is formed under unstable keyhole behaviours and complex multiphase flows involved in the welding process. Weld geometry characteristics play an essential role in the mechanical properties and performance of joints. Weld quality is usually evaluated based on weld seam geometry, mechanical properties, and distortion [5].

Laser power, rotation speed, welding speed can be adjusted to reduce porosity and achieve better penetration in laser welded stainless steel [4]. This laser beam parameters have a significant effect on the results of numerical models of the laser beam welding process. AISI 304 stainless steel is a superior absorber of laser light [11]. Parameters should be determined taking this information into account.

The aim of this study is to find the optimum welding parameters for stainless steel to obtain the best beam quality and mechanical properties by varying RS and LP.

The experiments were designed with stainless steel to weld with TruDisk 4001D laser. Bifocal distance was chosen as 0.8 mm, fibre diameter as 0.1 mm and dot size as 0.1 mm. The size of the plate taken for welding trials are of 50 mm long and 50 mm width with thickness of 15 mm.

The experimental variables and their values are summarized below.

WV: 2000 mm/min
WP: 2 kW / 4 kW
RS: 2500 rev/min – 5000 rev/min

The laser welded specimens were successfully sanded and polished before etching process. Then microscope images were taken to investigate WD and WW.

2.2. Simulation with Flow 3D software

In this study Flow 3D was used as software to create a simulation. It provides powerful insights into laser welding processes to reach process optimization. The process can be controlled to minimize porosity, control heat affected zones and control microstructure evolution.

It is possible to capture a realistic representation of the laser keyhole welding process by simulation [6].

Simulation of the laser beam welding has proven to be highly efficient for research and application. Besides experimental studies, numerical studies provide information about the weld pool and its relationship with the weld parameters (welding speed, laser beam intensity, workpiece thickness, etc.) and can be used to reduce experiment expenses [10].

To obtain the closest results to the experimental results, the same mathematical model for the beam path was used in the Flow 3D weld module. And all the parameters in the experiment were entered into the software program identically. The material properties for stainless steel have also been precisely selected.

3. Results and discussion

3.1. Experimental results comparation

Two samples group were examined under the microscope. Group 1 was welded with 2 kW power and Group 2 was welded with 4 kW power. Their parameters are shown in Table 1 and Table 2. The same welding speed (WS) of 2000 mm/min was applied to both Groups.

Table 1. Welding parameters (Group 1)

Samples	RS (rev/min)	LP (kW)
C1	2500	2
C4	3000	2
C7	4000	2
C10	5000	2

Table 2. Welding parameters (Group 2)

Samples	RS (rev/min)	LP (kW)
C3	2500	4
C6	3000	4
C9	4000	4
C12	*5000*	4

Table 3 and Table 4 show the effects of power and rotational speed on depths (WD) and widths (WW).

Table 3. Values of results (Group 1)

Samples	Width (μm)	Depth (μm)
C1	2279,29	2294,77
C4	2319,56	1811,.66
C7	2367,89	1924,39
C10	2392,05	1912,31

Table 4. Values of results (Group 2)

Samples	Width (μm)	Depth(μm)
C3	3269,04	3382,70
C6	3205,51	3357,61
C9	3422,97	3168,39
C12	3157,18	2926,84

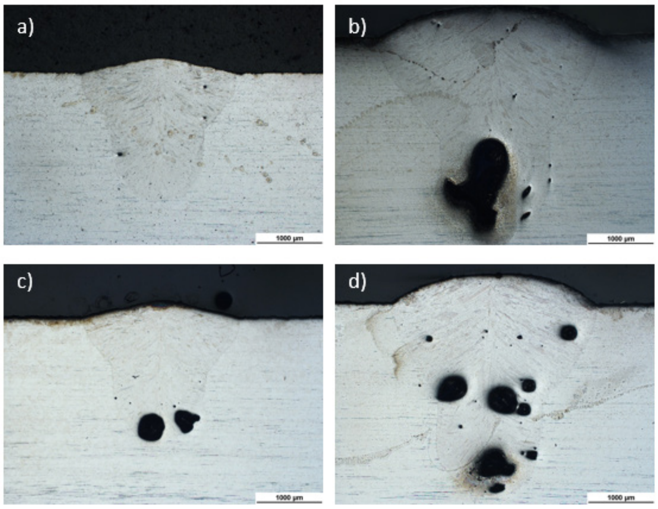

Fig. 3. Experimental results (C7, C9, C10 and C12)

In Figure 3. Respectively, a, b, c and d microscope images belong to samples C7, C9, C10 and C12. When comparing a and b, the weld depth increases with increasing power. In addition, when comparing the samples with the same power applied at 4000 rpm and 5000 rpm rotational speeds, more pores are observed in the weld zone at rotational speeds higher than 4000 rpm.

Experiments show that if the power increases, the weld depths, and widths increase. Since it was seen in this study that an increase or decrease in rotation speed cannot be defined with a general judgment, an optimum value was tried to be found. Increasing the rotation speed up to 4000 rpm reduced pore formation. The values of C7 specimen identified it as the most non-porous specimen.

3.2. Simulation and experimental results comparation

This research has been done numerically and experimentally. Flow 3D Software was used for numerical simulation [8].

Cross-sections of the weld were used to analyse the morphologies of the heat affected area. Then samples which have different parameters were investigated under microscope. Simulation was carried at the same time with the same parameters to compare experimental and simulation results. In Figure 4, the values for welding and simulation are WP 1kW, RP 2000 rev/min and WS 2500 mm/min.

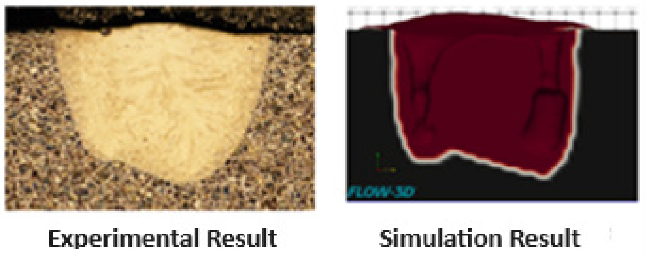

Fig.4. Cross-sectional comparison of experimental and numerical results

Comparison of experimental and numerical results shows that close welding forms can be obtained by simulation.

Figure 5 shows the results of the simulation and experiment for C7 sample. Depth a is the value measured from the depth to the top and depth b is the value measured from the depth to the surface.

As a result of the simulation, values of 2300 μm, 2120 μm and 1900 μm were obtained for width, depth a and depth b respectively. And as a result of the experiments, 2367,89 μm, 2161,91 μm and 1924,39 μm values were obtained for width, depth a and depth b, respectively.

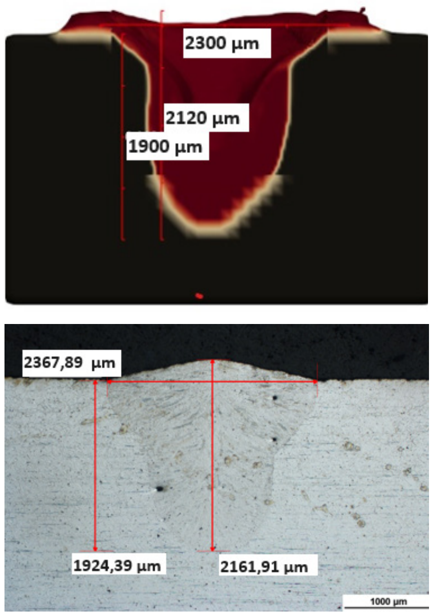

Fig. 5. Measurements of experimental and numerical results (C7)

After comparison, it can be said that very close results were obtained. All the simulated weld pool shapes are like the experimentally measured weld pool shapes. It should be noted that the WD and WW values will vary from point to point when measurements are taken.

Since the results are very similar, simulation can be considered as a useful tool for the prediction of weld geometry and thermal distributions for various parameters such as laser beam power, welding speed, properties of the weld material and rotation speed [12].

4. Conclusions

Bifocal laser beam welding experiments on stainless steel were carried out using variable parameters for parameter optimization. In the meantime, simulation was carried out to compare the results.

The simulation results are found to be in satisfactory agreement with experimental measurements. Simulated weld pool shapes are similar to the experimentally measured.

As a result of this study 4000 rev/min rotational speed and 2 kW power were selected best parameters for this research. With these parameters, the results show that porosity formation and cracks are reduced. Further investigations with other parameters will be carried out.

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