Lasers in Manufacturing Conference 2019

Laser welding –control of microstructure with wobble technique

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Abstract

Laser beam wobble is a recently developed technique for welding application, in which the beam oscillates across the process zone at high frequency. This technique has shown the capability to weld without defects materials that are difficult to weld such as aluminium and copper. In this contribution, another advantage of this technique will be presented which is the capability to control the microstructure of welded materials. The welding experiments were performed on Ti6Al4V alloy and the microstructures were investigated by optical microscopy. It is shown that the microstructure can be modified by tuning the wobble parameters without affecting the dimension of the bonded area.

Keywords: Laser welding; wobbling; microstructure.

1. Introduction

Laser welding is one of the most common applications of laser technology in industrial production. It involves rapid melting of the materials by an intensive laser beam, followed by very fast re-solidification at the end of the irradiation (Katayama 2013; Kou 2002). Recently, laser beam wobbling has been proposed as a promising approach for welding of materials that are difficult to weld with conventional technique. In this approach, the laser beam is oscillated at high frequency, and hence, high velocity, across the process surface (Hagenlocher et al. 2019). Defect-free welding of copper with this technique has been demonstrated (Grupp et al. 2017). In this contribution, another advantage of wobble welding will be presented, which is the capability to alter the microstructure of the weld. This topic has been of great interest since the weld microstructure has a dominant influence on the performance of the weld joints.

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2. Experimental setups

The laser welding experiments were made with a single mode fiber laser source StarFiber 150P (Coherent, Switzerland) with a 1070 nm wavelength. The laser system was operated in continuous-wave mode. The emitted Gaussian beam was transmitted through a 12 µm diameter single – mode optical fiber to a wobble laser head (Coherent, Switzerland). The laser beam was guided by the optical system within the laser head and then focused on the sample surface by a focusing lens with a focal length of 170 mm. The diameter of the laser spot at the focus was approximately 30 µm at 1/e2 of the beam's maximum intensity. This small diameter allowed keyhole formation even at low laser power. The wobble behavior of the laser beam is controlled via an external waveform generator, which allows a wobbling frequency up 3 kHz and a great variety of wobbling trajectory. In the present work, only the results with circle wobbling, will be presented.

The experiments were performed on 2 mm thick Ti6Al4V alloy. The samples were placed on a linear stage M-663.5U (Physik Instrumente, Germany), providing the linear movement of the samples during the process. The tested laser and wobbling parameters are listed in Table 1. It is worth emphasizing that the parameters were chosen so that the heat input, conventionally defined as laser energy per trajectory length, was kept at a constant value ($7.96*10^{-5}$ J/mm). Additionally, the ratio between linear velocity of the sample and the wobbling frequency was also constant. This ensures similar overlapping of the laser beam scanning trajectory for all the experiments.

Table 1. Laser parameters used for wobble welding in the present work.

Laser power (W)	Linear velocity V_l (mm/s)	Wobbling amplitude (mm)	Wobbling frequency (Hz)
25	10	0.5	200
50	20	0.5	400
100	40	0.5	800

The microstructure of the welds was observed from the top surface with an optical microscope AxioPlan Zeiss.

3. Results and discussion

Optical images of the weld lines are displayed in Figure 1. There are two notions that can be made based on this figure. Firstly, unlike the other two samples, individual laser tracks can be clearly seen on the surface of the sample welded at 25 W (Figure 1a). It implies that the melt pool size obtained in this case was too small to obtain a sufficient overlapping of the welded regions. Secondly, the grain size of the weld, as observed in Figures 1b and 1c, was different even though the heat input remained constant for all the experiments. In particular, the grain size obtained at 100W laser power, 40 mm/s linear velocity and 800 Hz was the biggest. The results might be explained by fact that as the intense laser beam was wobbled across the sample surface at very high speed, it allowed increasing the average temperature in the process surface while decreasing the temperature gradient. The former behavior enhances laser absorption by the metallic surface, leading to bigger melt pool size (Katayama 2013), while the latter allows bigger grain size after the solidification (Hagenlocher et al. 2019). It is worth emphasizing that at 800 Hz wobbling frequency, the material was re-heated by the laser beam after every 1.25 ms, which is sufficiently fast compared to the heat dissipation rate. Therefore, this wobble welding process might allow better energy efficiency than conventional linear laser welding. It might be also useful for welding of material such as aluminium or copper, which have very high thermal conductivity. In fact, in a previous work from the present authors, it was shown on an aluminium alloy that the resolidification process would take several milliseconds, which is completely within the range of wobble frequency achievable (Le-Quang et al. 2018).

Another advantage of laser wobble technique that has not been presented in the present work is the flexibility with the beam trajectory, which affects the heat distribution in the process zone. By carefully adjusting the trajectory, desired distribution of microstructure in the joints can be achieved.

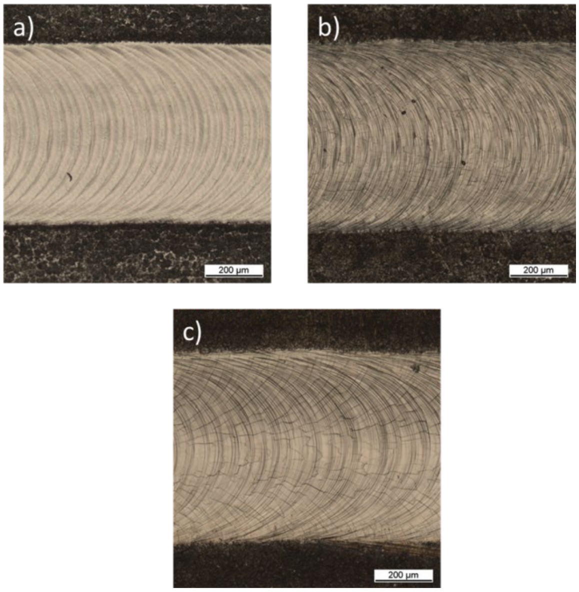

Fig. 1. Top view optical images of weld lines produced with

a) 25W laser power, 10 mm/s linear velocity and 200 Hz wobble frequency;

b) 50W laser power, 20 mm/s linear velocity and 400 Hz wobble frequency;

c) 100W laser power, 40 mm/s linear velocity and 800 Hz wobble frequency.

4. Conclusion

In this contribution, the authors show that wobble welding allows the possibility to alter the microstructure of the weld. In particular, even though the heat input was kept constant, different grain sizes and structures were achieved by adjusting the scanning parameters. Another advantage of the laser beam wobbling, which is not shown here, would be the flexibility with the beam trajectory, which has the dominant influence on the heat distribution in the process zone.

References

Hagenlocher C., Sommer M., Fetzer F., Weber R., Graf T., Optimization of the solidification conditions by means of beam oscillation during laser beam welding of aluminum, Materials & Design, Volume 160, 2018, Pages 1178-1185, ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2018.11.009.
Katayama S., ed., Handbook of Laser Welding Technologies, Woodhead Publishing, 2013. DOI:10.1016/B978-0-85709-264-9.50025-8.
Kou S., Welding Metallurgy, Second edition, John Wiley & Sons Inc., 2002, DOI: 10.1002/0471434027.
Grupp M. and Reinermann N., Copper Welding with High-Brightness Fiber Lasers Process stabilization by high dynamic beam deflection, Laser Technik Journal, 2017.
Le-Quang, T., Shevchik, S.A., Meylan, B., Vakili - Farahani, F., Olbinado, M.P., Rack, A., Wasmer, K., 2018. Why Is In Situ Quality Control Of Laser Keyhole Welding A Real Challenge?” Procedia CIRP, 74, p. 649, https://doi.org/10.1016/j.procir.2018.08.055.