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Bead-on-plate weldability of Al 5052 alloy using a disk laser

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ABSTRACT

Purpose: The paper presents the effect of the laser welding parameters of the laser focal position and beam angle on the weldability of an Al 5052 thick plate using a 4kW disk laser.
Design/methodology/approach: Bead-on-plate welding was conducted on a 10mm-thick Al 5052 plate. Aspects of the bead, including the bead surface and cross sections, were evaluated with various laser welding parameters. The porosity formation was also examined in an X-ray transmission tests.
Findings: Although the penetration depth decreased as the focal point moves away from the surface, the appearance of the bead improved and the porosity decreased. The weldability according to the inclination angle of the laser beam was also investigated. It was found that a forward inclination of the laser beam (when the inclination angle is an acute angle) could enhance the weldability compared with a backward inclination.
Research limitations/implications: The results of the thick plate BOP welding experiments can be expanded to optimizing the Al alloy welding of thin sheets.
Practical implications: It is applicable as a ground technique for the laser welding of aluminium alloy to increase the productivity and quality using the recently developed disk laser.
Originality/value: The outcome of the research shows the influence of the welding parameters on weldability aspects in disk laser welding of an Al alloy.
Keywords: Welding; Laser welding; Aluminium alloy; Disk laser

1. Introduction

Laser welding is a popular method of welding currently as it has the advantages of deeper penetration, less thermal distortion and higher productivity [1]. The most versatile high-power lasers used presently are Nd:YAG and CO_2 lasers. Eventually, the disk laser and the fiber laser are expected to replace the conventional laser system [2]. Among recent lasers, the disk laser has a better beam quality compared to rod-type lasers as it reduces the thermal lensing effect by adopting the thin disk instead of a rod. Recently, a 25kW level of disk laser was tested [3]. Early studies of the characteristics of the beam quality have been reported for both disk and fiber lasers. However, at present, papers related to the welding applications for various workpieces as weld as the related physical phenomena are and its physical phenomena are typically appearing in the literature [4-15].

The 5xxx series of aluminium alloys are non-heat-treatable types which achieve high strength with the addition of a large amount of magnesium to a solid solution of aluminium. Therefore, they are applied in the auto bodies or structures due to their high strength and light weight. In this research, experiments regarding the bead-on-plate welding of Al 5052 alloys with a disk laser were conducted and the weldability was evaluated. In particular, the effect of the focal position from the surface and the incident angle of the laser beam were investigated. The weldability was verified by comparing the bead appearance, cross-sectional bead shape and the porosity formation in X-ray transmission tests.

2. Experimental setup

Table 1 shows the specifications of the disk laser used in the BOP welding experiments of the Al 5052 thick plate. The beam quality was validated by measuring the cross-sectional beam profile. Workpieces are Al 5052 alloys that are 10mm thick. The chemical compositions of the pieces are shown in Table 2. During the experiments, the nominal output power of the laser, the shielding gas and the welding speed are fixed. However, the position of the focal point and the incident angle of the laser beam varied, as shown in Table 3, to investigate their effects. Fig. 1 indicates the definition of the focal position and incident angle applied in the experiments. Fig. 2 shows the welding system, which consists of a 6-axis robot and optics

Table 1.
Technical data for the disk laser used

Gain material	Yb:YAG Disk
Max. output power	4.0 kW
Beam quality	8mm*mrad
Diameter of delivery fiber	200µm
Max. power consumption	21kW
Focal length	560mm

Table 2.
Chemical composition of Al 5052 alloy (weight, %)

Si	Fe	Cu	Mg	Cr	Al
0.08	0.27	0.01	2.69	0.18	Bal.

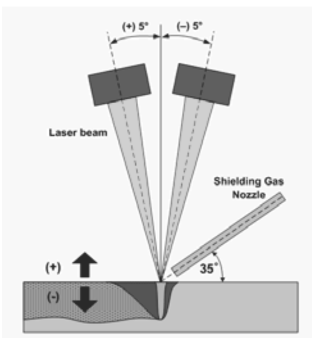


Fig. 1. Schematic diagram of experiment

Table 3.
Welding conditions used

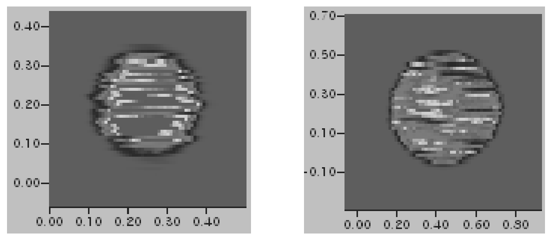
Laser output power, kW	4
Shielding gas composition	Ar 50% + He 50%,
Gas flow rate, l/min	20
Welding speed, m/min	1
Focal position, mm	0, -3, -6, -9, -12
Laser beam angle, Deg.	-5, +5

3. Results and discussion

3.1. Beam properties of disk laser used in this study

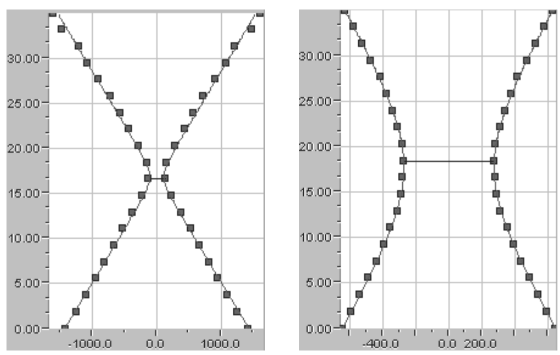
In order to clarify the beam properties at the focus of the disk laser, the beam diameter and beam profile were measured, as illustrated in Figs. 3 and 4, respectively. The laser optics used in the experiment had focal lengths of 220mm and 560mm. As shown in Figs. 3 and 4, the diameter and shape of the beam change depending on the optics system. For a head with a focal length of 560mm, as used in the experiment, the diameter of the beam on the focus was measured as 0.54mm, indicating that the beam quality is excellent.

Fig. 2. Robot laser welding system



(a) 220mm (b) 560mm

Fig. 3. Measured diameters of focused laser beams for different focal lengths



(a) 220mm (b) 560mm

Fig. 4. Beam geometries for different focal lengths

3.2. Evaluation of weldability

In the laser welding of aluminium, beams are irradiated at an inclined angle to prevent the damage to the optics that can be caused by the beam if it is reflected by the aluminium surface. In the experiments, two incident angle parameters of +5° and -5° were applied along the welding direction. Fig. 5 and Fig 6 show the bead appearance and the results of X-ray transmission tests, respectively, for the measured range of the experimental parameters.

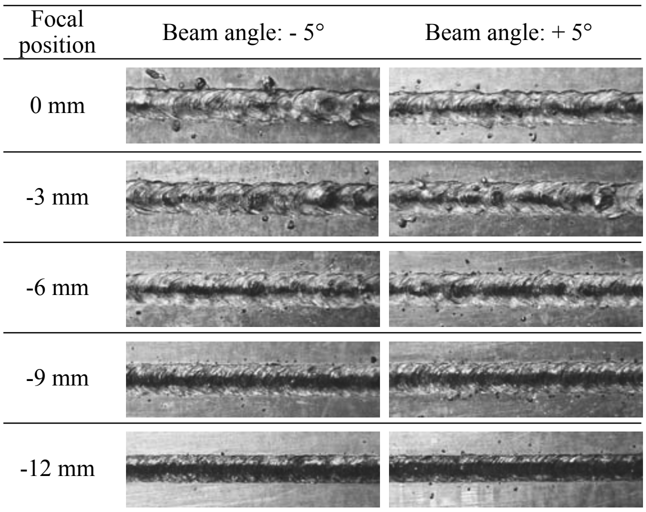


Fig. 5. Bead surface for various welding parameters

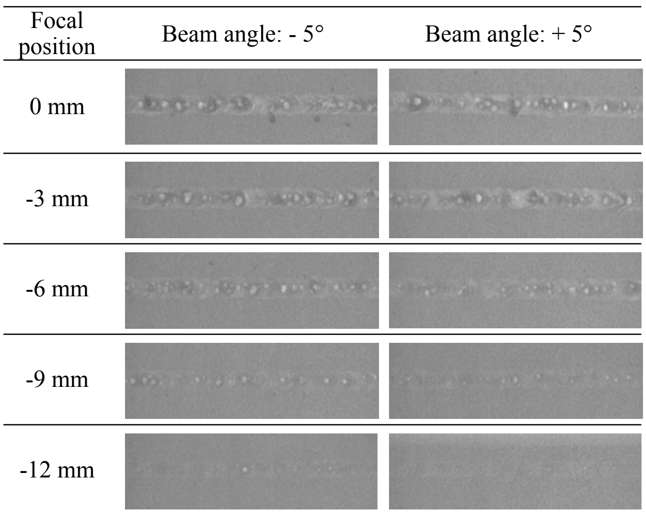
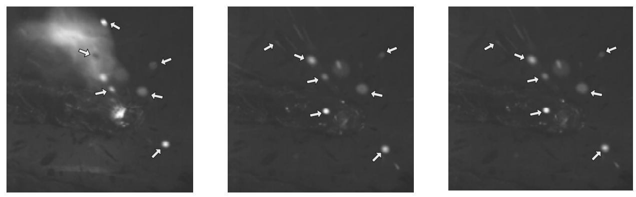


Fig. 6. X-ray transmitted images for various welding parameters

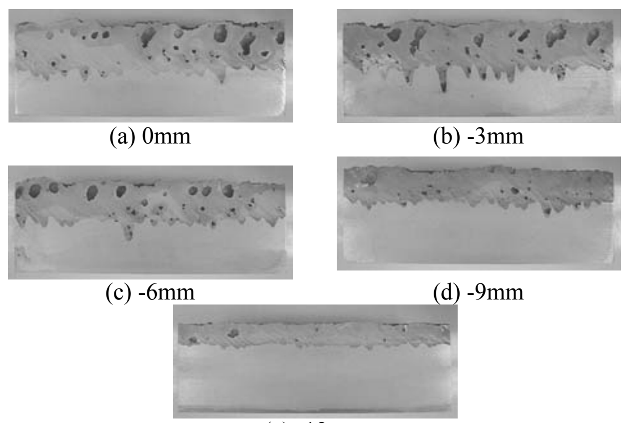
By analyzing the bead appearance in Fig. 5, it was found that the farther the focal position moves from the surface, the narrower the bead width becomes. However, the bead quality improves and the severity of spatter is reduced. As shown in Fig. 4, the power density becomes lower beyond the focal point. At the focal point, the beam spot diameter was measured as 0.54mm and when the position was 12mm apart from the focal point, it was 0.96mm. Therefore the power density at the focal point is 3.2 times higher than that at a position of 12mm away from the focal point. For a high power density at the focal point, an aluminium surface quickly evaporates, resulting in more spatters compared with the defocused cases shown in Fig. 5. Figure 7 shows the pictures captured by a high-speed camera of the vicinity of the keyhole during the welding process. As a volatile element, the magnesium included in the Al 5052 alloy is rapidly vaporized as its boiling point is lower than that of aluminium. It is inferred that when this magnesium vapor escapes from the molten pool, it causes spatters as well as a poor bead appearance. However, with defocused laser beam welding, spatters are noticeably reduced as the power density is lower than that of focused laser welding, indicating that less concentrated energy is transferred to the alloy.

For the effect of the incident angle of the laser beam, it was found that the positive angle shows a better weld quality than the negative angle when their porosities are compared. This is shown in Figs. 5 and 6. As is well known, the shape of keyhole affects its stability and ultimately influences the quality of the weld. If the incident angle is maintained positively, as in this research, the keyhole becomes more vertical than the negative case. Therefore the keyhole is reasonably stabilized [16, 17] which leads to lower porosity and fewer spatters [18].



(a) 1/1500 s (b) 2/1500 s (c) 3/1500 s

Fig. 7. Spatters generated during welding



(a) 0mm (b) -3mm (c) -6mm (d) -9mm (e) -12mm

Fig. 8. Longitudinal cross sections for various focal positions (beam angle; +5°)

Fig. 8 shows pictures of longitudinal cross sections of the weldments for various focal positions with a positive incident angle. As the focal point moves away from the surface, it is clear that the porosity is reduced.

4. Conclusions

In this research, feasible experiments involving the BOP welding of an Al 5052 thick plate were using a disk laser. During this process, the effects of the focal position and the incident beam angle were analyzed. When the focal point was set directly on the surface, the disk laser had a good beam quality but much spatters along with many pores were generated, indicating a low weld quality.

The results were different using a defocused beam. Although the penetration depth was decreased, the number of pores and the amount of spatter were noticeably reduced.

Regarding the effect of the beam incident angle of the laser, it was found that a better welding quality could be achieved with a positive angle compared to a negative angle. It is inferred that the positive beam angle causes the beam mainly to hit the front keyhole, which affects the stability of the keyhole. As a result, the fewer pores and spatters are produced.

References

[1] R.L. O'Brien, Welding Handbook. Vol. 2-Welding Processes,. Eighth Edition, American Welding Society, 1991.

[2] N. Ahmed, New Developments in Advanced Welding, Woodhead Publishing, Cambridge, 2005.

[3] R. Brockmann, K. Mann, Disk lasers enables industrial manufacturing, Laser Technik Journal 4-3 (2007) 50-53.

[4] I. Miyamoto, Ultra-fine keyhole welding with single-mode fiber laser, Proceedings of 2nd international WLT-conference on „Lasers in Manufacturing" LIM2003, Munich, Germany, 2003, 221-228.

[5] A. Russ, W. Gref, M. Leimser, F. Dausinger, H. Huegel, High speed welding of metal sheets with thin disk laser, Proceedings of 2nd International WLT-conference on „Lasers in Manufacturing" LIM2003, Munich, Germany, 2003, 229-234.

[6] F. Vollertsen, C. Thomy, Welding with fiber laser from 200 to 17000W, Proceedings of 24th International Congress on „Applications of Lasers and Electro-Optics" ICALEO2005, Miami, Florida, US, 2005, 254-263.

[7] G. Verhaeghe, P. Hilton, The effect of spot size and laser beam quality on welding performance when using high-power continuous wave solid state lasers, Proceedings of 24th International Congress on „Applications of Lasers and Electro-Optics" ICALEO2005, Miami, Florida, US, 2005, 264-271.

[8] C. Thomy, T. Seefeld, F. Vollertsen, Application of high-power fiber lasers for joining of steel and aluminium alloys, Proceedings of 3rd International WLT-conference on „Lasers in Manufacturing" LIM2005, Munich, Germany, 2005, 27-32.

[9] G. Verhaeghe, P. Hilton, Battle of sources – using a high-power Yb-fiber laser for welding steel and aluminium, Proceedings of 3rd International WLT-conference on „Lasers in Manufacturing" LIM2005, Munich, Germany, 2005, 33-38.

[10] J. Weberpals, A. Russ, F. Dausinger, H. Huegel, Influence of the focus diameter in laser welding with thin disk laser, Proceedings of 3rd International WLT-conference on „Lasers in Manufacturing" LIM2005, Munich, Germany, 2005, 39-42.

[11] J. Weberpals, C. Deininger, F. Dausinger, Laser welding with thin disk lasers up to 6kW, Proceedings of 4th International Congress on „Laser Advanced Materials Processing" LAMP2006, Kyoto, Japan, 2006.

[12] E. Beyer, B. Brenner, A. Klotzbach, S. Nowotny, Laser macro procssing – today and tomorrow, Proceedings of 4th International Congress on „Laser Advanced Materials Processing" LAMP2006, Kyoto, Japan, 2006

[13] K. Kinoshta, M. Mizutani, Y. Kawahito, S. Katayama, Phenomena during high-power fiber laser welding, Proceedings of 4th International Congress on „Laser Advanced Materials Processing" LAMP2006, Kyoto, Japan, 2006.

[14] G. Verhaeghe, C. Allen, P. Hilton, Achieving low-porosity laser welds in 12.7mm thickness aerospace aluminium using a Yb-fibre laser, Proceedings of 4th International WLT-conference on „Lasers in Manufacturing" LIM2007, Munich, Germany, 2007, 17-24.

[15] F. Abt, F. Dausinger, Focusing of high power single mode laser beams, Proceedings of 4th International WLT-conference on „Lasers in Manufacturing" LIM2007, Munich, Germany, 2007, 321-324.

[16] R. Fabbro, S. Slimani, F. Coste, F. Briand, Study on keyhole behavior for full penetration Nd:YAD CW laser welding, Journal of Physics, Part D: Applied Physics 38 (2004) 1881-1887.

[17] R. Fabbro, S. Slimani, I. Doudet, F. Coste, F. Briand, Experimental study of the dynamic coupling between the induced vapor plume and the melt pool for Nd-YAG CW laser welding, Journal of Physics Part D: Applied Physics 38(2006) 394-400.

[18] C. Deininger, P. Gaertner, J. Weberpals, F. Dausinger, Diagnostics of welding with high brightness laser, Proceedings of 4th International WLT-conference on „Lasers in Manufacturing" LIM2007, Munich, Germany, 2007, 289-293.