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Position welding using disk laser-GMA hybrid welding

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ABSTRACT

Purpose: Position welding technology was developed by using disk laser-GMA hybrid welding in this research.
Design/methodology/approach: The effect of hybrid welding parameters such as the shielding gas composition and laser-arc interspacing distance were investigated for the bead-on-plate welding. The pipe girth welding was implemented and the adequate arc welding parameters were selected according to the welding position from a flat position to an overhead position.
Findings: The optimized shielding gas composition and laser-arc interspacing distance for disk laser-GMA hybrid welding were 80% Ar- 20% CO_2 and 2mm, respectively for the bead-on-plate welding. The sound welds could be achieved even in the pipe girth welding, but the proper joint shape should be prepared.
Research limitations/implications: The laser-arc hybrid welding was implemented for pipe girth welding as a kind of 3-dimensional laser welding and the process parameters could be optimized according to the various target materials and sizes.
Practical implications: The optimized process parameters for the disk laser-arc hybrid welding can extend the application of the laser hybrid welding technology.
Originality/value: This research showed the possibility of the disk laser-GMA hybrid welding as new pipe girth welding technique. The behaviour of molten pool and droplet transfer could enhance understanding of the hybrid welding.

Keywords: Welding; Laser-arc hybrid welding; Position welding; Pipe girth welding

1. Introduction

Recently, in industries such as automobile, shipbuilding, and large-scale pipe operations, the development of highly-functional materials and high-speed welding technology has been required for cost reduction and enhanced productivity. Against this backdrop, research on laser-arc hybrid welding, which can produce synergetic effects by tapping into advantages of conventional methods such as laser welding and arc welding, has actively proceeded [1-9]. Various reports have been published on the laser-arc hybrid welding technology to demonstrate the advantages and limitations of the hybrid welding [10-14]. Most studies have addressed the influence of the fundamental process parameters – shielding gas, the angle between laser and arc, the distance between laser and arc, and groove shapes for the hybrid welding.

For pipe welding and other complex structure welding that require multiple welding positions, enhancing the performance of laser system—so that beam delivery can be made flexibly—makes it possible to apply laser welding or hybrid welding to the welding of a three-dimensional structure. S. Fujinaga et al. [15] applied a YAG laser welding with filler wire to SUS304 stainless steel pipe with a thickness of 5 mm and a diameter of 267.4 mm. Using a high-speed camera, they observed the behaviour of plasma and the molten droplet according to the welding position; they also evaluated weldability with the laser on continuous mode and on pulse mode.

There has been a wealth of studies for enhancing the fundamental understanding of hybrid welding, while a little research has been done on welding characteristics by welding position. In this research, the 3-dimensional laser-arc hybrid welding was implemented for actual application to large-scale pipes and 3-dimensional structures. To establish the hybrid welding parameters, welding characteristics are observed during bead-on-plate welding according to shielding gas composition and laser-arc interspacing distance. For each position from a flat position and an overhead position, welding characteristics and adequate welding conditions were investigated.

2. Experimental setup

A diode pumping disk laser with a maximum output power of 4 kW was used as the laser power source; an inverter welder with a rated output of 500 A was used as the GMA power source. The hybrid welding head was designed by combining a laser optic and GMA torch. For fine and accurate adjustment of the welding configuration during the experiment, a 3-axis guide was installed on the joint between the laser optic and GMA torch. The focal length of the disk laser was 220 mm; a push-pull GMA torch was utilized for smooth feeding of the welding wire.

In the experiment designed to identify the distance between the laser and arc and the optimal conditions for the shielding gas composition during hybrid welding, the hybrid welding head was fixed and the specimen was moved to carry out bead on plate welding. To observe the behaviours of the molten pool and plasma during hybrid welding, a high-speed camera and a CCD camera were used, respectively. A-grade steel for shipbuilding, with a thickness of 10 mm, was used as base metal. A six-axis robot and a position welding-purpose jig were utilized for position welding. The jig was designed to allow for welding experiments in all positions ranging from 0° to 360°.

Table 1 shows the values of fixed parameters used in the experiment. The arc leading laser-arc hybrid welding—with arc preceding laser—was implemented, where the laser illumination was focused on the surface of the specimen.

To identify the influence of shielding gas on welding characteristics in hybrid welding, welding phenomena were observed using a high-speed camera and CCD camera under different shielding gas compositions. The distance between the laser and arc was set at 2 mm; mixed gas of Ar and CO_2 was used as a shielding gas and was supplied using the GMA welding torch.

In addition to shielding gas composition, the distance between laser and arc is as an important process parameter in hybrid welding. In order to determine the optimal welding conditions, the distance between the laser and arc was varied by 2 mm—from 0 mm to 10 mm—and the welding characteristics were identified using a high-speed camera.

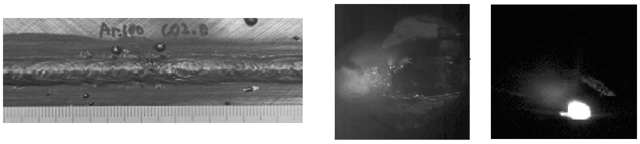
Table 1.
Welding conditions used

Laser power	4 kW
Angle between laser and torch	30°
CTWD	18 mm
Welding speed	1 m/min
Flow rate of shielding gas	30 ℓ/min
Arc current	320A to 400A
Wire feeding speed	11.0 m/min

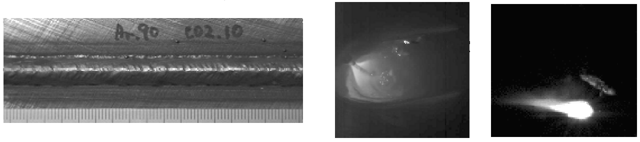
Using the jig and six-axis robot, position welding was implemented with adjusting the current and voltage of GMA welding for every 30° (from 0° to 180°). In this process, the distance between the laser and arc was set by considering the shape of the molten pool.

3. Results and discussion

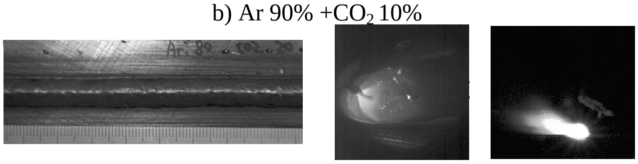
3.1. Shielding gas composition and laser-arc interspacing distance



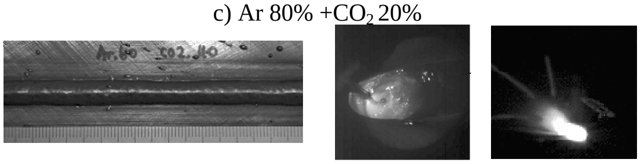
a) Ar 100% +CO_2 0%



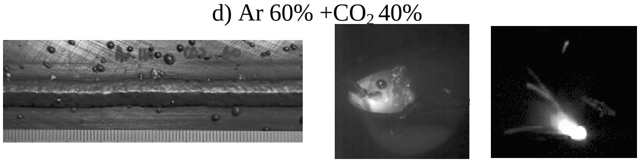
b) Ar 90% +CO_2 10%



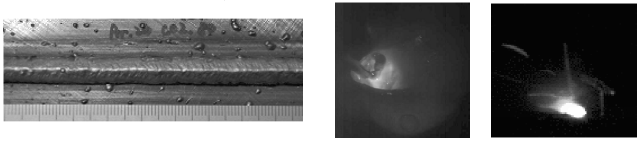
c) Ar 80% +CO_2 20%



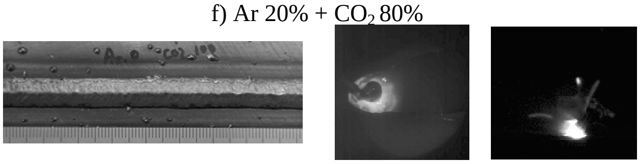
d) Ar 60% +CO_2 40%



e) Ar 40% +CO_2 60%



f) Ar 20% + CO_2 80%



g) Ar 0% +CO_2 100%

Fig. 1. Bead surfaces, droplet transfer and plasma behaviour for various shielding gas compositions (laser power: 4 kW; laser-arc interspacing distance: 2 mm)

Welding experiments were conducted with different shielding gas compositions in laser-arc hybrid welding. The weld bead appearance, droplet transfer and plasma behavior were observed, as shown in Fig. 1.

In Ar 100% shielding, the arc and droplet transfer were unstably formed, and thus inconsistent bead shapes and large-scale spattering were observed. When the proportion of CO_2 gas was at 10% or at 20%, consistent bead width and appearance were obtained, with a stable arc being formed and little spatter generated. As the CO_2 gas proportion exceeded 40%, the amounts of generated large-scale spatter became greater again, and the bead width and appearance became inconsistent, because the droplets shower globular transfer. It was seen that as the proportion of CO_2 gas increased, the arc length gradually declined and droplet transfer became unstable, resulting in large-scale spatter.

In subsequent hybrid welding conducted with varying laser-arc distance, the shielding gas composition was set at 80% in Ar and 20% in CO_2. When the distance between the laser and arc was 0 mm, an undercut was found in the weld bead. With the distance being 2 mm, a relatively good bead appearance was demonstrated. When the laser-arc distance was longer than 4 mm, however, the bead width was inconsistent. Each of the different penetration depths is graphically depicted in Fig. 2. Depending on the laser-arc distance, penetration depths differed by approximately 1.5 mm at maximum. The deepest penetration was achieved at the distance between the laser and arc of 2 mm.

In arc leading hybrid welding, a molten pool was created owing to the leading arc. The location where the laser beam was irradiated on the molten pool differed by the distance between the laser and arc. As the distance between the laser beam and arc became longer, the laser beam was irradiated on the molten pool formed above the surface of the specimen. Therefore, the depth of penetration became shallower even when a laser beam with the same level of output power was irradiated. However, when the laser-arc distance was too short, droplet transfer obstructed the irradiation of the laser beam, leading to decreased penetration.

The experiment results showed the following: Deep penetration could be obtained if the laser beam was irradiated on a location where there was no droplet transfer or laser beam interference and where the height of the molten pool was the lowest. Unlike in the case of applying a shielding gas, the distance between the laser and arc had little influence on the weld bead appearance or spatter generation.

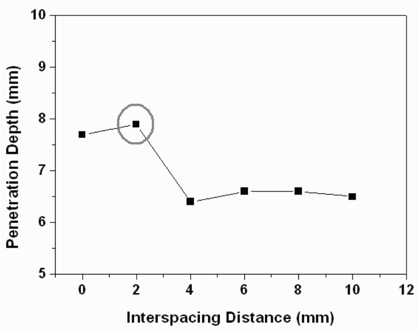


Fig. 2. Penetration depths according to the laser-arc interspacing distance (laser power: 4 kW; shielding gas: Ar 80% + CO_2 20%)

3.2. Position welding

As described in Fig. 3, an I-type groove and V-type groove were used in the experiment, and 2-pass welding was conducted. In the preliminary experiment, the mixture ratio of protection gas was 80% in Ar and 20% in CO2; the distance between the laser and arc was fixed at 2 mm.

First, vertical down welding, where change in the molten pool shape was expected to be mostly affected by gravity, was performed using a V-type groove specimen. Full penetration, however, could not be achieved, as the molten pool ran down due to gravity, disturbing the irradiation of the laser beam. Considering the shape of the molten pool that streamed down during vertical down welding, the distance between the laser and arc was changed several times during the experiment so that deep penetration could be achieved at the interspacing distance of -1mm.

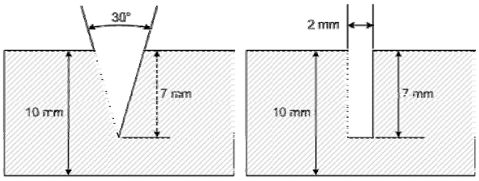


Fig. 3. Groove types used a) V-groove, b) Square groove

For the V-type groove specimen, the root pass and the second pass welding were conducted for various arc welding parameters. For the root pass welding, the sound beads and full penetrations were achieved for the root pass. For the second pass welding, molten pool ran down more easily, owing to the effects of the groove surface—which was enlarged further through root pass welding—and gravity; running down by arc pressure, the molten pool tended to spread out widely. Consequently, underfill and inconsistent bead appearance were observed, as shown in Fig. 4.

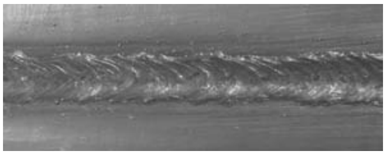


Fig. 4. Hybrid welding of vertical position with V groove

Also, for the I-type groove specimen, the current and voltage of the GMA welder were adjusted so that good bead appearance and full penetration could be achieved in all welding positions during root pass welding. Unlike the V-type groove, the I-type groove had a narrow groove surface, and hence the molten pool did not run down easily from it even when second pass welding was conducted after root pass welding. Thus, good bead and full penetration were achieved, as shown in Fig. 5. The experimental conditions for welding variables by angle are summarized in Table 2.

4. Conclusions

This study has investigated welding characteristics according to welding position and process parameters—ranging from flat position welding to overhead position welding—in the position welding of disk laser-arc hybrid welding.

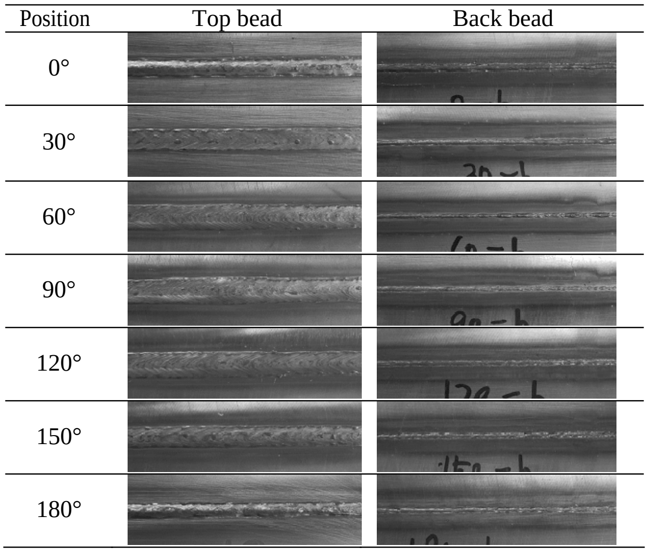


Fig. 5. Bead shapes for square groove welding

Table 2.
Welding conditions for square groove welding

Angle (Deg.)	Pass	Voltage (V)	Current (A), Wire feeding rate (m/min)
0°	1 pass	22.7	194. 6.5
	2 pass	23.3	194. 6.5
30°	1 pass	22.7	194. 6.5
	2 pass	23.3	194. 6.5
60°	1 pass	22.7	187. 6.0
	2 pass	23.3	194. 6.5
90°	1 pass	22.7	187. 6.0
	2 pass	23.3	194. 6.5
120°	1 pass	22.7	187. 6.0
	2 pass	23.3	194. 6.5
150°	1 pass	22.7	187. 6.0
	2 pass	23.3	194. 6.5
180°	1 pass	22.1	187. 6.0
	2 pass	24.2	200. 7.0

First, the influences of process parameters (i.e. the mixture of protection gas components, the distance between laser and arc) on disk laser-arc hybrid welding were observed. With the composition of shielding gas being adjusted, it was shown that a stable arc, decreased spatter, deep penetration, and good bead appearance could be achieved when the mixture ratio was 80% in Ar and 20% in CO_2.

The laser-arc distance was identified to be an important parameter for achieving deep penetration. In the flat position welding experiment, the deepest penetration was obtained when the laser-arc distance was 2 mm. In vertical down welding of the welded part of a V-type groove, on the other hand, the deepest penetration was achieved when the distance was -1 mm, owing to downward movement of the molten pool.

The arc welding current and voltage were adjusted for the V-type and I-type grooves to conduct 2-pass position welding. In the V-type groove welding, the molten pool streamed down as the welding position approached vertical down welding, and hence it was impossible to determine welding conditions that would guarantee good quality for the second pass welding. In the I-type groove, in contrast, downward streaming of the bead decreased in the second pass, resulting in arc welding conditions that yielded good top and back beads.

References

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

[2] N. Abe, M. Hayashi, Trends in laser arc combination welding methods, Welding International 16 (2002) 94-98.

[3] C. Bagger, F.O. Olsen, Review of laser hybrid welding, Journal of Laser Applications 17 (2005) 2-14.

[4] P. Zeyffarth, J. Hoffmann, Laser technologies in shipbuilding reality and prospects, The Paton Welding Journal 75/12 (2001) 9-15.

[5] S. Herbert, Laser-Hybrid Welding of Ships, Welding Journal 83/6 (2004) 39-44.

[6] H. Staufer, H. Hackl, Laser-MIG process for automotive industry, The Paton Welding Journal 75/12 (2001) 26-28.

[7] H. Staufer, M. Ruhrnossl, G. Miessbacher, Hybrid Welding for the Automotive Industry, Industrial laser solutions for manufacturing 16 (2003) 7-10.

[8] G. Sepold, C. Thomy, T. Seefeld, M. Schilf, R. Vollertsen, R. Hoffmann, CO_2-Laser GMA hybrid welding-aspects of research and industrial application, Proceedings of 2nd International WLT-conference on „Lasers in Manufacturing” LIM2003, Munich, Germany, 2003, 149-156.

[9] S. Kaierle, K. Bongard, M. Dahmen, R. Poprawe, Innovative hybrid welding process in an industrial application, Proceedings of 19th International Congress on „Applications of Lasers and Electro-Optics” ICALEO2000, Dearborn, US, 2000, Section C 91-98.

[10] C. Bagger, L.C. Sondru, F.O. Olsen, Laser/TIG hybrid welding of pot for induction heater, Proceedings of 23rd International Congress on „Applications of Lasers and Electro-Optics” ICALEO2004, San Francisco, US, 60-69.

[11] C.V. Hyatt, K.H. Magee, J.F. Porter, V.E. Merchant, J.R. Matthews, Laser-assisted gas metal arc welding of 25mm thick HY-80 Plate, Welding Journal 80 (2001) 163-172.

[12] T. Hayachi, S. Katayama, N. Abe, A. Omori, High-power CO2 laser-MIG hybrid welding for increased gap tolerance. Hybrid weldability of thick steel plates with a square groove, Welding International 18 (2004) 692-701.

[13] W.R. Edward, J.S. Michael, A.M. Darlene, Joining pipe with the hybrid laser-GMAW Process, Welding Journal 85/6 (2006) 66-71.

[14] G.S. Booth, D.S Howse, R.D Howard, A New Technique for Girth Welds in Land Pipelines: Hybrid Laser-Arc welding, Proceedings of 2nd international WLT-conference on „Lasers in Manufacturing” LIM2003, Munich, Germany, 2003, 145-148.

[15] S. Fujinaga, R. Ohashi, T. Urakami, S. Katayama, A. Matsunawa, Development of an all-position YAG laser butt welding process with addition of filler wire, Welding International 19 (2005) 441-446.