Dynamic Observation of High Speed Laser-Arc Combination Welding of Thick Steel Plates

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Abstract

Leading Path Laser-Arc Combination (LPLAC) welding, which consists of laser-arc combination welding with a leading path for the laser beam, enables much deeper penetration than conventional laser-arc combination welding. It also allow higher speeds and more stable welding compared with conventional arc welding with a narrow V groove. To elucidate the reasons for this greater effectiveness, the behavior of the laser plasma, arc plasma, and the molten metal were observed during LPLAC welding using a high-speed video camera operating at 500 frames per second. It was found that the laser plasma stabilized the arc at an optimal distance between the laser and the arc, accounting for the very high speed and deep penetration of this method

KEY WORDS: (High-speed Photographs) (Narrow Gap Welding) (Laser-Arc Combination Welding) (Laser Plasma) (Arc Plasma)

1. Introduction

The coherence of laser beams allows them to be focused on a very small point, enabling a wide range of applications, particularly in the field of materials processing, including cutting, welding, surface treatment, ablation, rapid prototyping, etc. Laser welding has been mainly used for thin plates due to the high cost of the high-power lasers required for welding thick plates. During the past few years, however, the cost of high-power lasers has been decreasing and their cost/performance ratio has been improving, so they are being increasingly used for welding thick plates. Nevertheless, high-power lasers are still expensive and many problems remain with regard to the high-speed welding of thick plates.

A welding method involving the combined use of a laser beam and an electric arc has been studied for some time. This research has been pursued with the goals of reducing costs by attaining increased laser penetration through more effective utilization of the arc's heat [1], achieving better welding quality [2] and improving arc stability through the use of a laser [3].

To achieve these goals the authors developed a new LPLAC welding method -Leading Path Laser-Arc Combination (LPLAC) welding- in which LPLAC welding is performed with a leading path for the laser beam. This method exploits the interaction between the laser and arc plasmas, and achieves a penetration depth more than double that of conventional laser welding methods [4].

The principle features of the laser-arc combination high-speed welding method for thick plates are:

(1) The leading path for the laser beam is specially prepared to achieve much deeper penetration than conventional laser welding.
(2) The arc electrode supplies molten metal to the gap and the groove.
(3) The arc is stabilized by the laser plasma. This effect is particularly important for high-speed welding with a narrow groove.
(4) The laser plasma also leads the electrical pole of the arc to a deeper point in the groove in the base metal.

Figure 1 shows an example of a groove used in LPLAC welding.

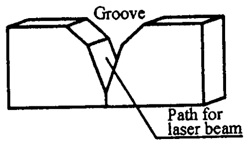

Fig.1 Example of a groove used in LPLAC high-speed welding of thick plates.

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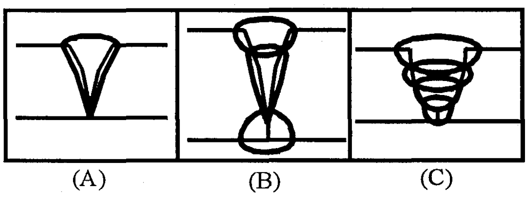
The LPLAC welding method was specifically designed for the high-speed welding of thick mild-steel plates. Thick plates can be welded using the welding methods shown in **Figure 2(A)** and **2(B)** at higher welding speeds compared to the multi-pass arc welding shown in **Figure 2(C).** Type A is suitable for full-penetration single-pass welding of medium-thick plates, while type B is suitable for the multi-pass welding of thicker plates. Both types achieve a deeper penetration depth with much lower input power than conventional laser welding.

Figure 3(A) shows a sample cross-section of the resulting weld LPLAC welding was used to perform full-penetration single-pass welding of medium-thick steel plates. The welding speed was 33.3mm/s (2m/min) and the penetration depth was 12 mm. **Figure 3(B)** shows a sample weld cross-section after just the first pass of multi-pass LPLAC welding of thicker steel plates. The welding speed was 83.3mm/s (5m/min) and the penetration depth was 8 mm. These results clearly indicate that much greater speeds and penetration depths were achieved compared with conventional laser welding. The purpose of this study was to reveal the reasons for the high degree of effectiveness of this method.



(A) Full penetration single pass welding of the Laser-Arc combination welding.
(B) Multi pass welding combination the Laser-Arc combination welding and arc welding.
(C) Multi pass arc welding.

Fig.2 Typical application of LPLAC welding and conventional arc welding of thick plates.

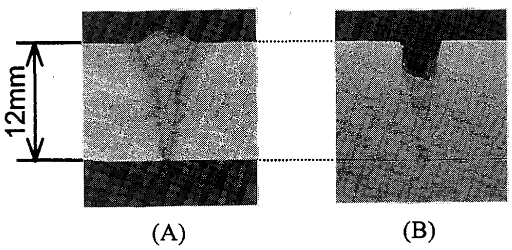


Fig.3(A) Single-pass full-penetration welding.
Welding speed : 33.3mm/s (2 m/min)
Laser power : 7 kW
Arc power : 7 kW
(B) Welding of the center of thicker steel plates in multi-pass LPLAC welding.
Welding speed : 83.3mm/s (5 m/min)
Laser power : 7 kW
Arc power : 9.6 kW

2.Experimental Details

Figure 4 shows the configuration of the equipment used to conduct the experiment. The front torch is a CO_2 laser and the rear torch is a MIG arc. Helium assist gas was supplied from the front of the laser torch. A copper vapor laser (511 nm, 578 nm) was used to illuminate the welded portion in order to permit clear observation of the molten metal, as well as the laser plasma and arc plasma. An ND filter and a band pass filter (580 nm) were installed to suppress the intense light emitted by the arc and laser plasmas. Welding phenomena were recorded via a long distance microscope (Questar QM1 MkIII) on video tape using a high-speed video camera operating at 500 frames per second.

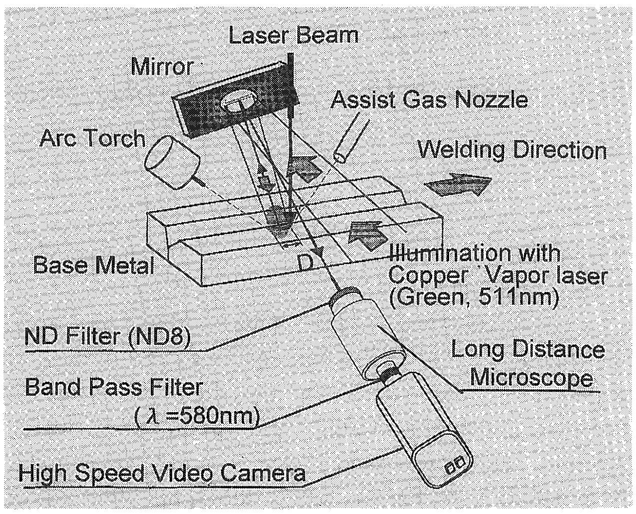


Fig.4 Configuration of the LPLAC welding experiment and the observation method.

3.Results and Discussion

3.1 Influence of the Root Gap and the Assist Gas Flow on the Penetration Depth

Laser welding alone was performed to simplify the welding conditions in order to investigate the influence of the root gap and the assist gas. The relationship between the penetration depth, the assist gas flow rate and the root gap are shown in **Figure 5**. Cross-sections of the weld are shown in **Figure 6**. When the root gap was 0 mm, the penetration depth was almost constant despite a varying assist gas flow rate. This indicates that the laser plasma which reduces laser input power to the specimen is sufficiently minimized. In the presence of a root gap, the penetration depth increased as the assist gas flow rate increased. This means that in addition to eliminating the laser plasma, the assist gas flow in the root gap permits deeper penetration. The penetration depth also increased as the root gap increases, except for

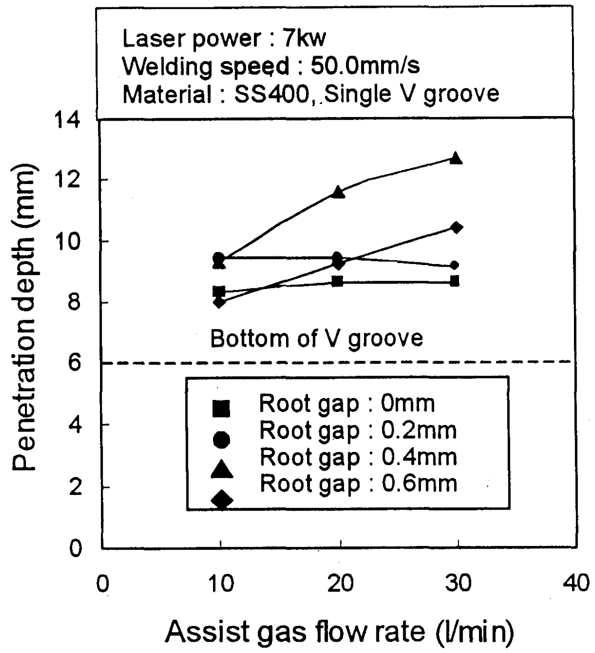
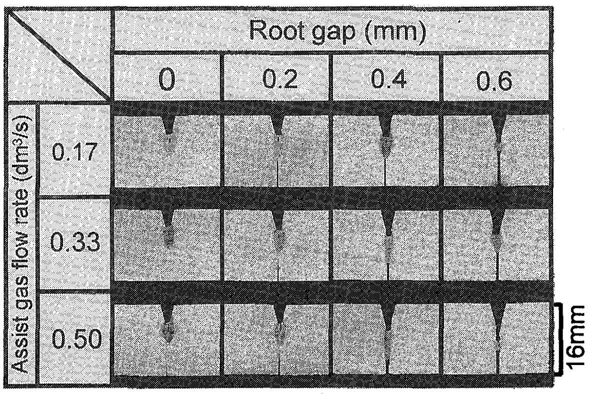


Fig.5 Relationship between the penetration depth, assist gas flow rate and root gap.



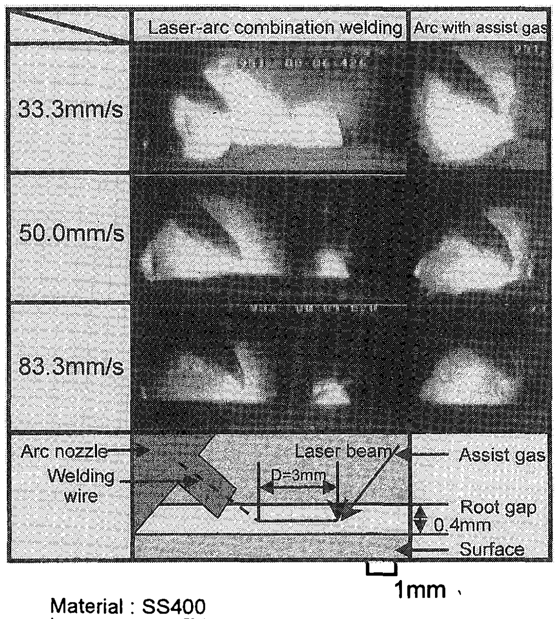
Laser power : 7kW, Welding speed : 50mm/s (3m/min)
Material : SS400, Assist gas : He
Nozzle diameter : ϕ3.5mm, Nozzle angle : 45°
Assist gas flow rate : Var., V groove

Fig.6 Cross-section of beads using LPLAC welding for various assist gas flow rates and root gap.

root gaps greater than 0.6 mm. This is because when the root gap is too wide, the laser beam passes through the specimen without interacting with it.

3.2 Influence of Welding Speed on Arc Plasma

Figure 7 shows high-speed photographs of the laser and arc plasmas during LPLAC welding conducted at various speeds. The right-hand column shows the arc plasma when arc welding alone is performed with assist gas under the same conditions used for LPLAC welding. As the photos indicate, when arc welding was performed alone, the arc plasma moved backward as the welding speed increased. The left-hand column shows the laser and arc plasmas produced during LPLAC welding.



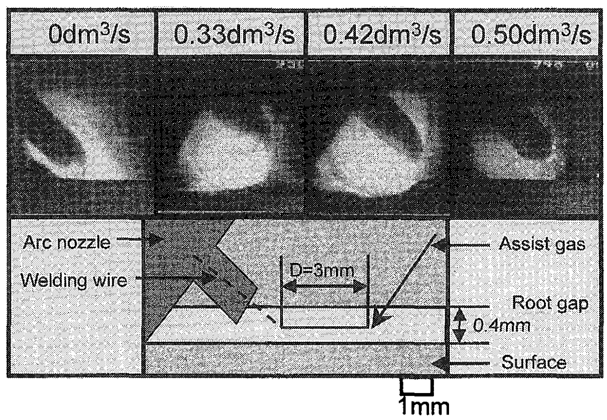
Material : SS400
Laser power : 7 kW, Arc power : 9.75 kW
Assist gas : He, Assist gas flow rate : 0.42dm³/s
Shield gas : He, Shield gas flow rate : 0.33dm³/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
V groove

Fig.7 Laser and arc plasmas of the LPLAC welding at various welding speeds.

Both plasmas seem to merge into a single plasma at a welding speed of 33.3mm/s (2m/min), and to separate again as the welding speed increases. The arc plasma during LPLAC welding remained under the arc torch even at a welding speed of 83.3mm/s (5 m/min), whereas it shifted increasingly backward when arc welding alone was performed.

3.3 Influence of Assist Gas Flow Rate on Arc Plasma

Figure 8 shows high-speed photographs of the



Material : SS400, Welding speed : 50mm/s
Arc power : 9.75 kW, Assist gas : He
Shield gas : He, Shield gas flow rate : 0.33dm³/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
V groove

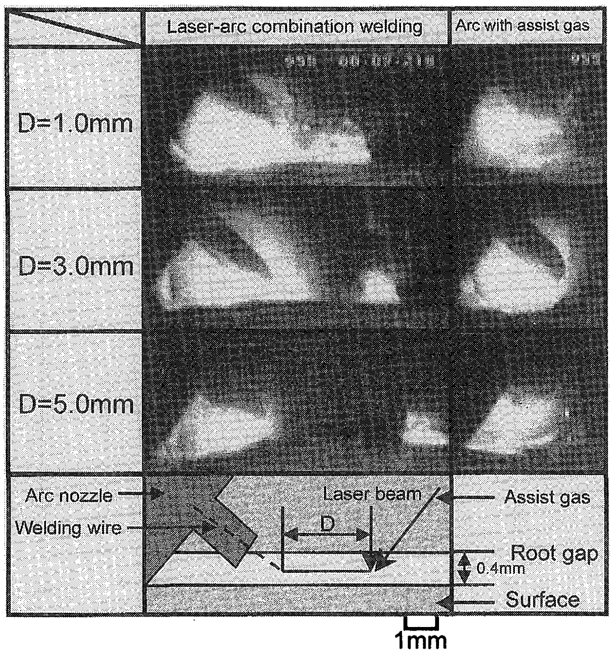
Fig.8 Arc plasma produced during arc welding at various assist gas flow rate.

plasma produced during arc welding alone with a varying assist gas flow rate. When assist gas was not supplied, the arc was in front of the electrode. However, as the assist gas flow rate increased, the arc shifted backward. **Figure** 9 also shows high-speed photographs of the arc and laser plasmas produced during LPLAC welding at gas flow rates of 0 to 0.42dm^3/s (25l/min). When assist gas was not supplied, the laser and arc plasmas merged to form a single plasma. With an assist gas flow rate of 0.42dm^3/s they seemed to separate, although there was still a slight interaction between the plasmas because the arc plasma did not shift backward, whereas the arc plasma in arc welding alone was blown backward by the assist gas.

3.4 Influence of the Distance between the Laser and Arc on the Arc Plasma

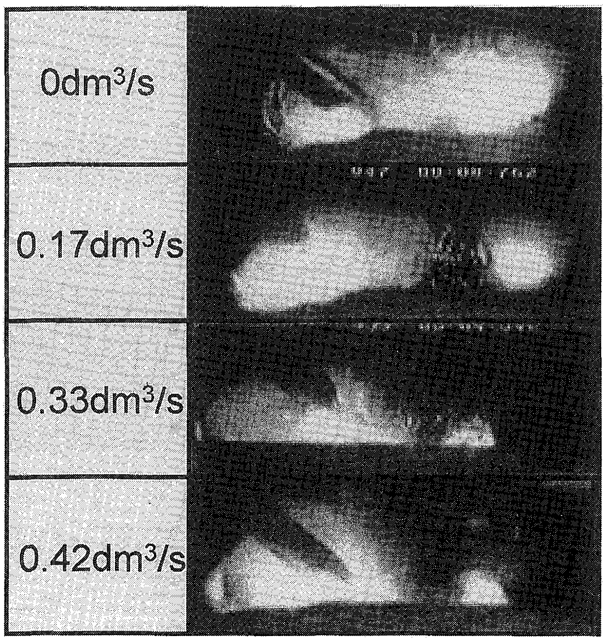
Figure 10 shows high-speed photographs of LPLAC welding with the distance between the laser and arc varying from 1 mm to 5 mm. At a distance of 1 mm, the arc and laser plasmas merged to form a single plasma. As the distance increased, they separated and the arc plasma shifted backward. It is thought that the influence of the laser weakens as the distance between the laser and arc increases.

Figure 11 shows high-speed photographs of the



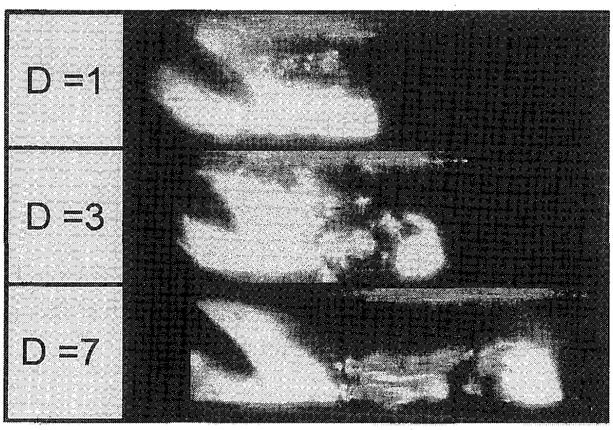
Material : SS400, Welding speed : 50mm/s
Laser power : 7 kW, Arc power : 9.75 kW
Assist gas : He, Assist gas flow rate : 0.42dm^3/s
Shield gas : He, Shield gas flow rate : 0.33dm^3/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
V groove

Fig.10 High-speed photographs of LPLAC welding with varying distances between the laser and arc.



Material : SS400, Welding speed : 50mm/s
Laser power : 7 kW, Arc power : 9.75 kW
Assist gas : He
Shield gas : He, Shield gas flow rate : 0.33dm^3/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
V groove

Fig.9 High-speed photographs of LPLAC welding with a varying assist gas flow rate.

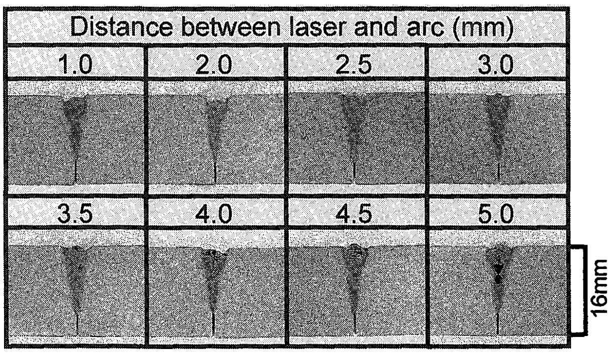


Material : SS400, Welding speed : 50mm/s
Laser power : 7 kW, Arc power : 9.75 kW
Assist gas : He, Assist gas flow rate : 0.42dm^3/s
Shield gas : He, Shield gas flow rate : 0.33dm^3/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
V groove

Fig.11 Photographs of the molten metal and laser and arc plasma produced during LPLAC welding taken with a high-speed video camera and a long distance microscope.

molten metal and the laser and arc plasmas during LPLAC welding. They were taken using a high-speed video camera through a long distance microscope, with an ND filter and a 580-nm band pass filter. The molten metal can be seen between the laser and arc plasmas. As the distance between the laser and arc increased, the height of the molten metal decreased, and the point of interaction between the laser and the specimen shifted downward.

Figure 12 shows cross-sections of welds performed using LPLAC welding with the distance varying between the laser and arc. At a distance of 1 mm, the bead has a wine-cup shape. For short distances, the electric pole of the arc is thought to be at the upper point because of the high height of the molten metal, as shown in Fig. 12. Therefore, the heat supplied to the upper portion of the specimen increased and the upper portion of the weld became wider, resulting in the wine-cup shape. At a distance of 3 mm, the metal melted by the laser and the arc properly merged and the bead became wedge-shaped. As the distance increased further, blow holes appeared. This is thought to be due to the fact that as the distance increases, the metal melted by the laser begins to cool before the metal melted by the arc reaches it. This reduces the solidification time, thereby causing the blow holes. At a distance of 5 mm, the portions of metal melted by the laser and the arc were completely separate, and the deposited metal was also separated.



Material : SS400, Welding speed : 50mm/s
Laser power : 7 kW, Arc power : 9.75 kW
Assist gas : He, Assist gas flow rate : 0.42dm^3/s
Shield gas : He, Shield gas flow rate : 0.33dm^3/s
Wire dia. 1.2mm, Nozzle dia. 3.5mm
Single V groove, Root gap : 0.4mm

Fig.12 Cross-section of welds performed using LPLAC welding at various distances between the laser and arc.

4. Conclusion

The Leading Path Laser-Arc Combination (LPLAC) welding method developed by the authors has four main features:

(1) Preparing the leading path for the laser beam achieves a much greater penetration depth than conventional laser welding
(2) The laser plasma makes the arc stable.
(3) The laser leads the electric pole of the arc to a deeper position in the groove.
(4) The gap of the leading path for the laser and the groove is filled by the metal melted by arc welding.

The fundamental characteristics of LPLAC high-speed welding of thick plates were observed using a high-speed video camera operating at 500 frames per second and a long distance microscope. The behavior of the laser and arc plasmas and the molten metal was analyzed to reveal the influence of the root gap, the assist gas flow rate and the distance between the laser and the arc.

It was found that:

(1) The width of the leading path for the laser beam, the assist gas flow rate and the distance between the laser and the arc all influence the penetration depth, bead shape and weld defects.
(2) As the assist gas flow rate increases, the penetration depth increases. This is caused by the assist gas flowing in the root gap reducing the laser plasma.
(3) The distance between the laser and the arc influences the interaction of the laser and arc plasmas. This affects the creation of weld defects such as blow holes and cracks.
(4) The behavior and amount of molten metal between the laser and the arc is an important factor determining weld quality.

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References

1) J. Alexander and William M. Steen, Proc. of Int. Conf. on Welding Research in the 1980's, Osaka, 1980, 121.
2)T. Ishide, Y. Hashimoto, T. Akaba, and T. Nagashita, Proc. of 41st Laser Materials Processing Conf., Osaka, 1997, p.99.
3)J. Matsuda, A. Utsumi, M. Yoneda and M. Katsumura, ibid., p.73.
4)N. Abe, Y. Agano, M. Tsukamoto, T. Makino, M. Hayashi and T. Kurosawa, Proc. ICALEO'96, 1996, p.D64