# High Speed Welding of Thick Plates using a Laser-Arc Combination System

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**Abstract**

*Combination welding was performed using a $CO_2$ laser and MIG arc under various conditions to investigate the effectiveness of combining these two welding methods for high speed welding of thick plates. The penetration depth of combination welding at a low welding speed was affected by the assist gas flow rate in a manner similar to laser welding. Penetration was governed by the laser, while the bead width was governed by the arc. Laser-arc combination welding enabled the joining of 12mm thick mild steel at a welding speed of 2000mm/min after proper selection of the assist gas flow rate and root gap.*

**KEY WORDS:** (Laser Welding)(Arc Welding)(Combination System)(High Speed Welding)(Thick Plate Welding)

## 1. Introduction

A laser beam can be finely focused on a material by optical means to produce an energy density of more than ten billion W/m$^2$, one hundred times higher than arc heat sources. Lasers are one of the best tools for heat processing, but high power lasers that provide deep penetration are large and expensive. In contrast, arc welding machines are very compact and inexpensive, but do not offer deep penetration or the high welding speed of lasers.

Recently, research into combining conventional arc welding and laser beam welding has been performed[1-4]. However, many difficulties still remain before such heat sources can be effectively combined for application to high speed welding of thick plates. This report describes fundamental research into the most effective method of combining a laser beam and conventional MIG arc for high speed welding of thick plates.

## 2. Experimental Methods

### 2.1 $CO_2$ laser and MIG arc welder

For this study, a model HPL-10(AVCO EVELETT Corp.) $CO_2$ laser oscillator and model DYNA AUTO XC500 (DAIHEN Corp.) MIG welder were used. The laser beam was multi mode. The focusing optic was a 70 mmϕ parabolic mirror with a focal distance of 700mm.

Figure 1 shows the experimental configuration of the laser welding nozzle, assist gas nozzle and MIG arc welding torch. The laser welding nozzle was set vertically. The assist gas nozzle was set at a 45 degree inclination to the laser nozzle. The MIG arc welding torch was set at a 60 degree inclination to the laser nozzle on the opposite side from the assist gas nozzle. All were aligned along the welding line. Helium was used as both the assist gas and the shielding gas for the arc.

### 2.2 Bead on plate welding

In order to determine the most effective method of

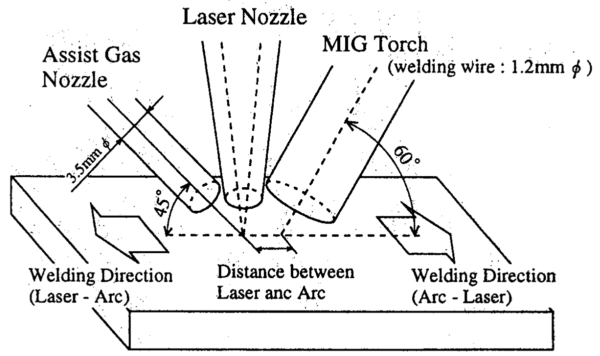


**Fig.1** Experimental configuration of an assist gas nozzle, a shield gas nozzle for laser and a MIG arc welding torch.

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combining a $CO_2$ laser and MIG arc, bead on plate welding was performed by varying the assist gas flow rate, the distance between the laser and the arc, the arrangement of the laser and arc, the laser power and the welding speed. The focus of the laser was at the surface of the specimen. A specimen of SS400 mild steel (50x100xt12mm) was used. The arc welding parameters were 200A and 25V with a welding wire of 1.2mm$\phi$.

### 2.3 Single V groove welding

In addition to bead on plate welding, the laser-arc combination high speed welding method was also investigated by performing single V groove welding and varying the assist gas flow rate, the distance between the laser and arc, the arrangement of the laser and the arc, and the root gap of the single V groove. The welding speed was 3000mm/min. The focus of the laser was 6mm below the surface of the specimen (i.e. the deepest point of the single V groove face). **Figure 2** shows the shape of the single V groove where the machined edge sides were butted with a root gap. The laser power was 7 kW. A specimen of SS400 mild steel (50x100xt16mm) was used. The arc welding parameters were 325A and 33V, with a welding wire of 1.2mm$\phi$.

## 3. Experimental Results and Discussion

### 3.1 Effect of laser irradiation on arc welding

*3.1.1 Effect of assist gas flow rate*

The effect of the assist gas flow rate on the penetration depth was investigated in order to compare the bead characteristics of MIG arc-laser combination welding with those of laser beam welding and MIG arc welding under bead on plate welding conditions. The assist gas flow rate was varied from 0 l/min to 50 l/min. In MIG arc-laser combination welding, the distance between the laser beam and MIG arc was varied from 7mm to 20mm. In this test series, the MIG arc preceded the laser beam. The laser power was 5kW and the welding speed was 600mm/min.

**Figure 3** shows the penetration depth's dependency on assist gas flow rate. The points marked squares and circles represent, respectively, the penetration depths of arc welding only and laser welding only. The penetration depth increased as the assist gas flow rate increased, reaching a maximum depth at a rate of 30 l/min. At assist gas flow rates over this value, the penetration depth decreased. This dependency is very similar to that of laser welding. **Figure 4** shows the bead width's dependency on the assist gas flow rate. As the assist gas flow rate increased, the surface bead

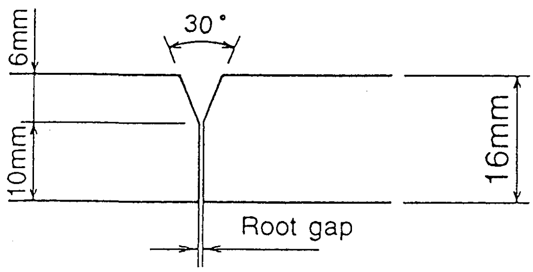


**Fig.2** The shape of single V groove used.

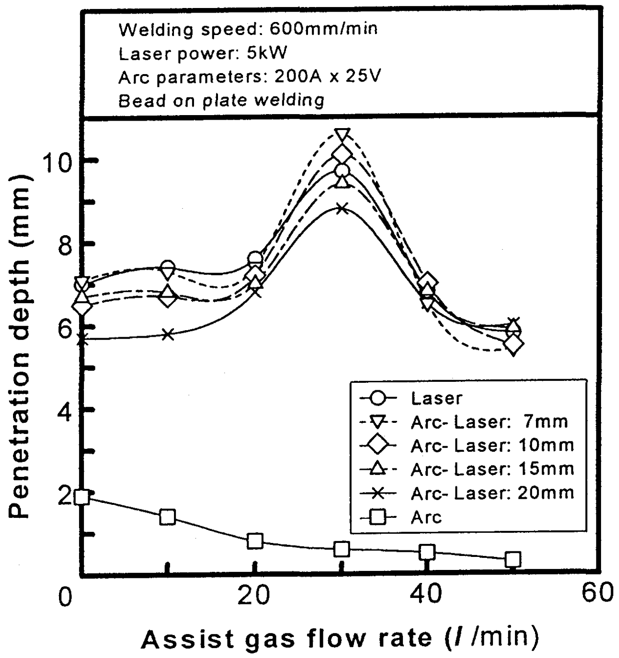


**Fig.3** Penetration depth dependency on assist gas flow rate.

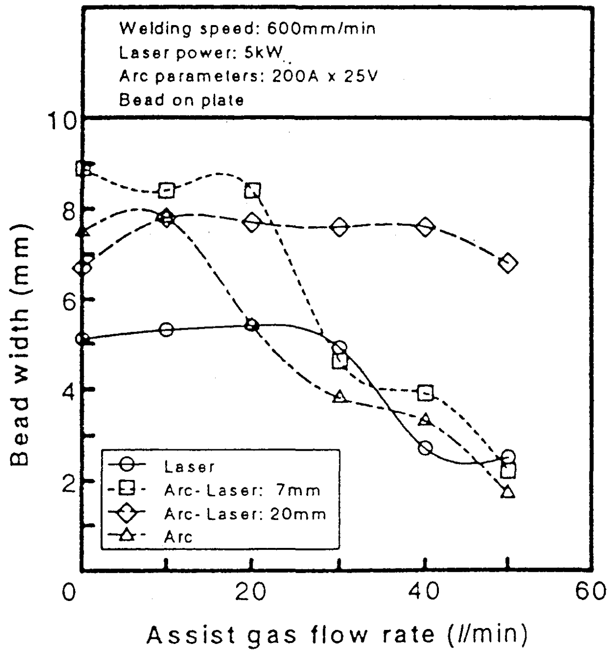


**Fig.4** Bead width dependency on assist gas flow rate.

width decreased. **Figure 5** shows sample cross sections of the weld bead produced by: (a)arc welding only, (b) laser welding only, and (c) arc-laser combination welding. These results indicate that the penetration depth is governed by the laser beam, and that the bead width is most affected by arc welding under these experimental conditions.

*3.1.2 Effect of the distance between the laser beam and MIG arc*

In Fig.3 it can be seen that reducing the distance between the laser and arc increases the penetration depth. This is thought to be due to the fact that the laser must penetrate the solidified weld made by arc welding before it can penetrate the specimen. Thus as the distance between the laser and arc increases, the penetration depth of the laser inside the specimen decreases. On the other hand, when the distance between the laser and arc is small, the laser impinges on the still-hot weld and easily penetrates the specimen deeply.

The effects on the penetration depth of greatly shortening the distance between the arc and laser and the arrangement of the arc and laser were also investigated. The distance between the arc and laser was varied from 0mm to 7mm. The assist gas flow rate was 30l/min, with a laser power of 5kW and welding speed was 600mm/min.

**Figure 6** shows the dependency of the penetration depth on the distance between the laser and arc. The penetration depth virtually did not change above a distance of 0mm. At a welding speed of 600mm/min, changing the arrangement of the laser and arc had negligible effect.

*3.1.3 Effect of the arrangement of the laser and arc on the bead shape*

The bead shape was investigated to determine the effect of changing the arrangement of the laser and the arc. **Figure 7** shows the cross sections of the weld beads for the arc-laser arrangement (the MIG arc preceded the laser beam). When the distance between the laser and arc was 1mm, the bead shape was sound. The more the distance was increased, the more the weld bead surface was disturbed. **Figure 8** shows the cross sections of the weld beads produced by the laser-arc arrangement (the laser beam preceded the MIG arc). The bead shape was not disturbed when the distance between the laser and arc was in the range from 1mm to 5mm.

These results show that the laser-arc arrangement is superior regarding the bead shape compared to the arc-laser arrangement. It is thought that in the case of the arc-laser arrangement, the surface bead shape is disturbed by the assist gas blowing into the molten pool made by the arc. On the other hand, in the case of the laser-arc arrangement, since the assist gas does not affected the molten pool made by the arc, the bead shape is not disturbed within a relatively wide range of distance between the laser and arc.

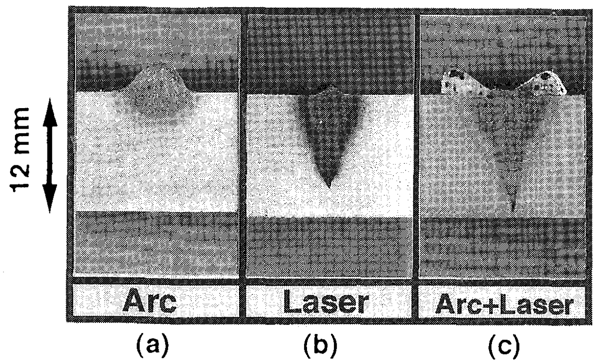


**Fig. 5** Typical bead shapes for (a) arc welding, (b) laser welding and (c) arc welding with laser beam.

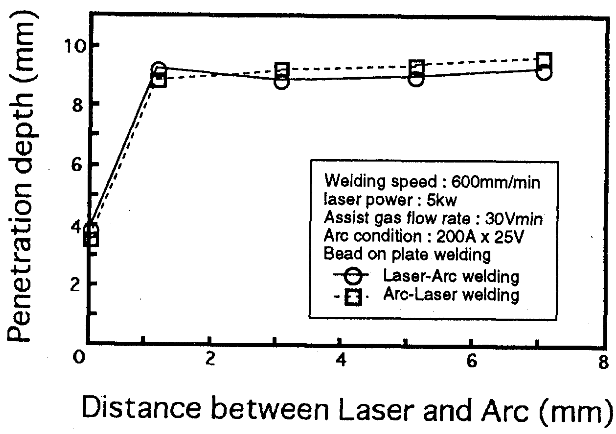


**Fig. 6** Effect of distance between laser and arc on penetration depth.

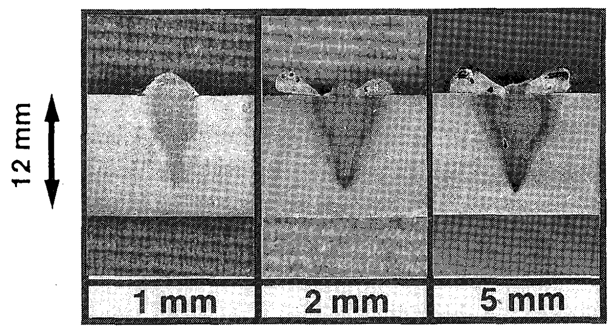


**Fig. 7** Typical bead shapes for each distance between the laser and arc in the Arc-Laser arrangement.

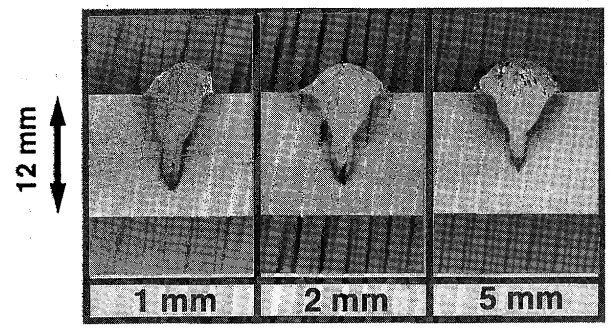


**Fig. 8** Typical bead shapes for each distance between the laser and arc in the Laser-Arc arrangement.

## 3.2 High speed laser-arc combination welding of thick plates

*3.2.1 Penetration depth dependency on welding speed*

High speed laser welding of thick plates was investigated by performing bead on plate welding and varying the assist gas flow rate, laser power and welding speed. The assist gas flow rate was varied from 10l/min to 40l/min. The laser power was varied from 3kW to 7kW, and the welding speed was varied from 1000mm/min to 3000mm/min.

**Figure 9** shows the relation between the welding speed and penetration depth. The penetration depth decreased rapidly as the welding speed increased and the laser power decreased. **Figure 10** shows the relation between the assist gas flow rate and the penetration depth for a constant laser power of 7kW. At a welding speed of 1000mm/min the assist gas flow rate affected the penetration depth, but did not affect the penetration depth at welding speeds over 2000mm/min. **Figure 11** shows cross sections of typical weld beads produced at welding speeds of 1000mm/min and 3000mm/min. The weld bead shape varied from a deep wedge to shallow and rounded. These results mean that even at an output power of 7kW, the laser beam used for these experiments did not have a high enough energy density for high speed welding over 2000mm/min.

*3.2.2 Narrow gap laser welding*

Root gap welding is generally used for the arc welding of thick plates. In order to achieve deep penetration with a low energy density laser beam, root gap welding was investigated through the high speed laser welding of thick plates. Single V groove welding was performed, varying the assist gas flow rate and the root gap. The welding speed was 3000mm/min. The assist gas flow rate was varied from 20l/min to 30l/min. The root gap was varied from 0.0mm to 0.6mm.

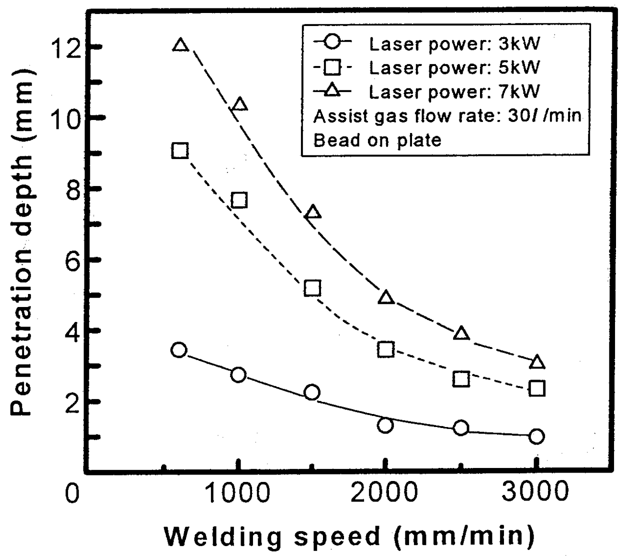


**Fig. 9** Effect of welding speed on penetration depth.

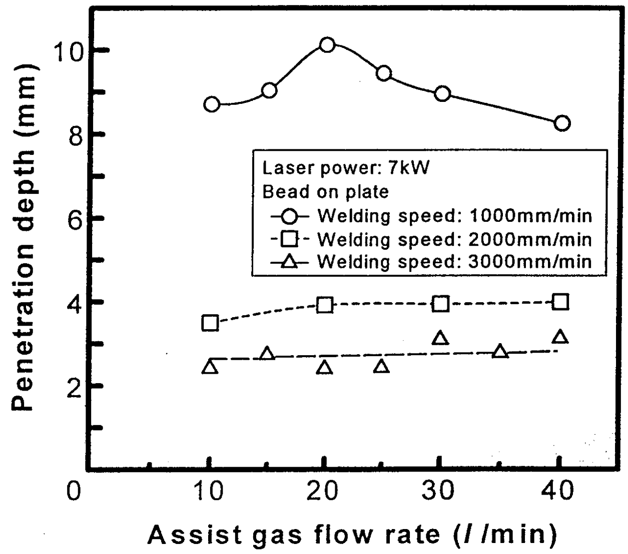


**Fig. 10** Effect of assist gas flow rate on penetration depth at high welding speed.

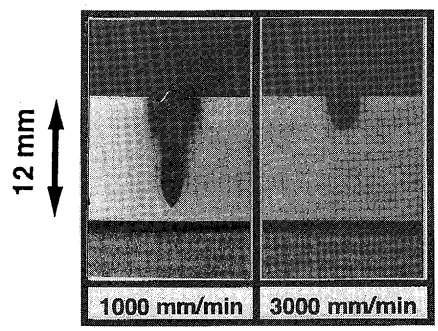


**Fig. 11** Effect of welding speed on bead shape at laser power of 7kW.

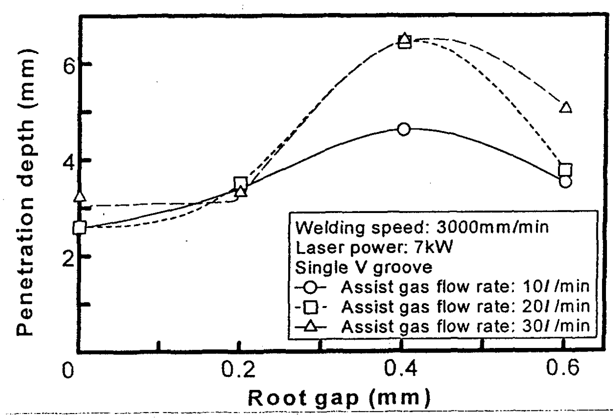


**Fig. 12** Effect of root gap on penetration depth at a welding speed of 3000mm/min.

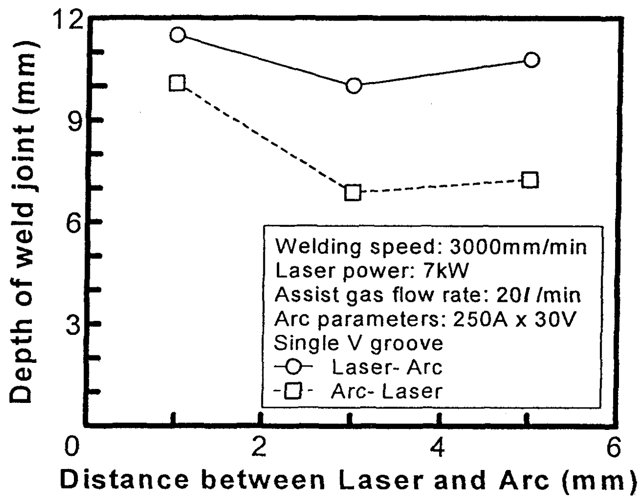


**Fig. 14** Effect of the distance between the laser and arc on depth of weld joint.

**Figure 12** shows the relation between the root gap and penetration depth. The penetration depth increased with the root gap, reaching a maximum depth of 6.5mm (2.5 times deeper penetration than butt welding) at a root gap of 0.4mm. **Figure 13** shows cross sections of the weld beads produced with root gaps of 0.0mm , 0.2mm, 0.4mm and 0.6mm, respectively. The weld bead shapes varied from shallow and rounded to a deep wedge. These results indicate that it is possible to use a low power density laser for high speed welding of thick plates, In this experiment, the optimum root gap was 0.4mm.

*3.2.3 Narrow gap laser-arc combination welding*

The characteristics of laser-arc combination welding for the high speed welding of thick plates were investigated by performing single V groove welding and varying the assist gas flow rate, the distance between the laser and arc, and the arc and laser arrangement. The assist gas flow rate was varied from 10l/min to 30l/min. The distance between the laser and arc was varied from 1mm to 5mm. The root gap of the single V groove was 0.4mm.

arc decreased, reaching its maximum depth at a distance of 1mm. Figure 14 also shows the effect of using the laser-arc versus the arc-laser arrangement. The laser-arc arrangement was found to be superior with regard to weld joint depth for high speed single V groove welding.

**Figure 15** shows the relation between the assist gas flow rate and the depth of the weld joint in laser-arc combination welding. At a welding speed of 3000mm/min, the depth of weld joint increased as the assist gas flow rate increased. **Figure 16** shows cross sections of the weld beads produced at assist gas flow rates of 0l/min, 10l/min, 20l/min, 30l/min and 40l/min.

**Figure 14** shows the effect of varying the distance between the laser and arc on the depth of the weld joint using welding wire of 1.2mm$\phi$. The depth of the weld joint increased as the distance between the laser and

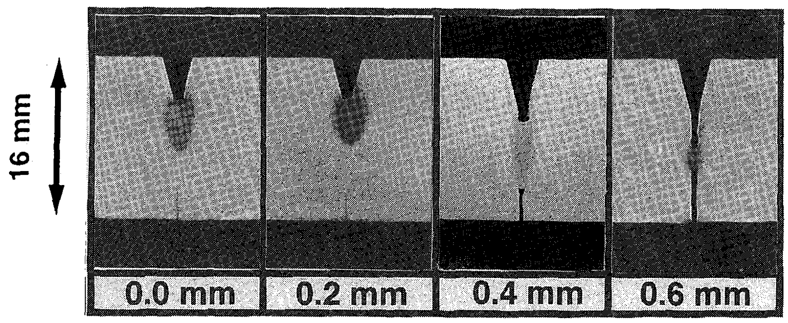


**Fig. 13** Effect of root gap on bead shape at an assist gas flow rate of 30l/min.

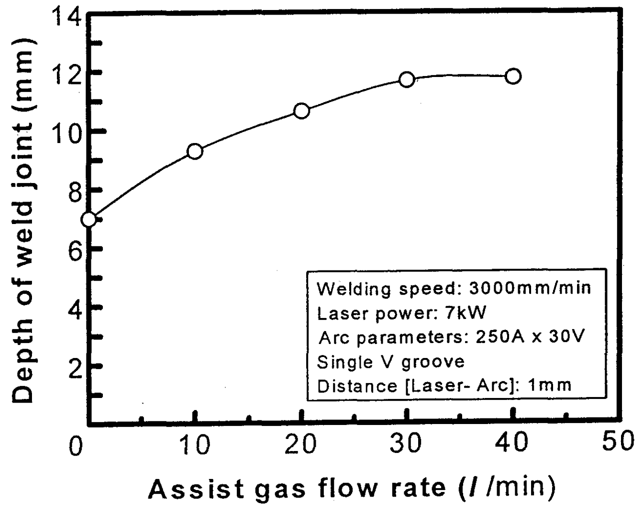


**Fig. 15** Effect of the assist gas flow rate on depth of weld joint.

These results indicate that it is possible to apply laser-arc combination welding for the high speed welding of thick plates by selecting the proper assist gas flow rate and root gap. **Figure 17** shows the groove shape used for high speed laser-arc combination welding at 2000mm/min. An example of the cross section of weld bead is shown in **Fig. 18**.

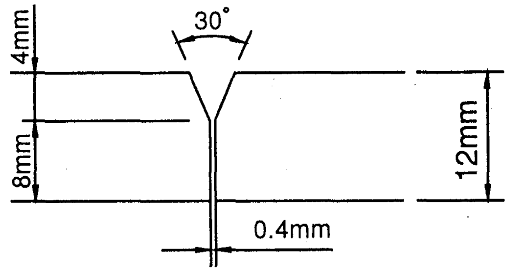


**Fig. 17** Groove shape used for the high speed laser-arc combination welding at welding speed of 2000mm/min.

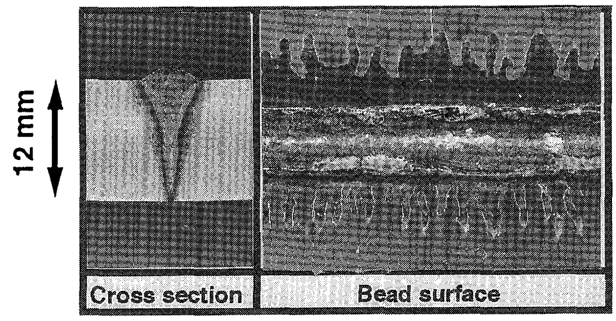


**Fig. 18** Typical bead shape produced with high speed laser-arc combination welding at welding speed of 2000mm/min.

## 4.Conclusion

The effectiveness of combining $CO_2$ laser welding with MIG arc welding was investigated by performing combination welding under a variety of conditions, at a low welding speed of 600mm/min and at a speed as high as 3000mm/min to examine the possibility of applying combination welding to the welding of thick plates. The main results obtained are as follows:

(1) At a low welding speeds, the penetration depths of combination welding are affected by the assist gas flow rate in a manner similar to laser welding. As the assist gas flow rate increases, the penetration depth increases and reaches a maximum depth at a gas flow rate of 30l/min. The penetration of combination welding is governed by the laser, while the bead width is primarily governed by the arc.

(2) Using root gap welding makes it possible to employ a low power density laser for the high speed welding of thick plates. In these experiments, the optimum root gap was 0.4mm.

(3) Laser-arc combination welding can be used for the high speed welding of thick plates by selecting the proper assist gas flow rate and root gap. Laser(7kW)-arc(7kW)combination welding achieved a full penetration weld of 12mm thick steel at a welding speed of 2000mm/min.

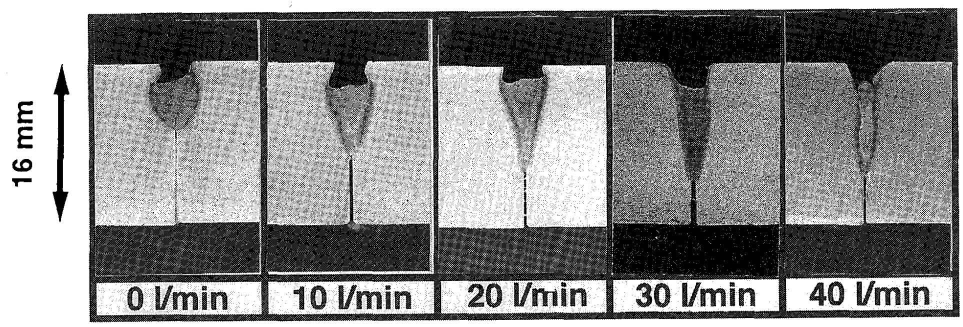


**Fig. 16** Typical bead shape of laser-arc combination welding at welding speed of 3000mm/min.

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