Development of Hot-wire Laser Welding Method for Lap Joint of Steel Sheet with Wide Gap*

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In this study, hot-wire laser welding was used to develop the welding method for the lap joint of 980MPa class high-strength steel sheets (thickness: 1 mm) with a wide gap. Detailed phenomena of wire melting and bead formation during welding were understood using the high-speed camera, and then the optimum welding condition and the mechanical properties of weld joints were investigated. The fiber laser with hot wire was used for welding the lap joint with the gap of 1 mm. The welding parameters such as the laser output of 3kW, spot diameter of 1.5mm ϕ , welding speed of 1.5m/min and the wire feeding speed of 3.8 m/min were fixed. The welding parameters of hot wire such as wire insertion angle, wire insertion position, and current of wire were varied. Moreover, shear test of the weld joints were done. As a result, upper and lower sheets with gap of 1 mm were well joined without weld defects in the welding parameters such as the wire insertion positions (from the laser spot center) of 3mm and the wire insertion angle of 70° and the wire currents of 102~116A. Moreover, the tensile shear strengths of weld joints were 500~600MPa regardless of the wire current.

Key Words: Laser welding, Hot-wire, Lap joint, Wide gap, high-strength steel

1. Introduction

There has been recent, the use of high strength / ultra-high strength steel sheets for an automobile body is widely investigated since the strong demand to reduce automobile body weight and energy consumption is increasing rapidly, moreover lap joints of high strength / ultra-high strength steel sheets by using laser welding for body construction is investigated to improve the body stiffness^{1~7)}. However it is difficult to predict and control precisely springback behavior during press forming of high strength / ultra-high strength steel sheets, then a large gap between lapped sheets is created. In general, laser welding has only small gap tolerance and the laser welding speed with a filler wire to fill the gap must decrease.

Hot-wire GTA welding has been developed to improve the deposition rate through energization of the filler wire⁸⁾. Shinozaki and Yamamoto *et al.* developed ultra-high-speed Gas Tungsten Arc (GTA) welding based on the above hot-wire system^{9~11)}. In their studies, the basic effects of different welding parameters on the welding phenomenon under the ultra-high welding speed condition have been obtained, and welding speeds up to 7 m/min under the bead-on- plate condition and 5 m/min under the fillet welding condition have been achieved.

In this study, the new laser welding process, which has a high

welding speed with feeding a filler wire and large gap tolerance, is proposed and investigated by combining laser welding and the hot-wire system which has the ability to control filler wire melting independently from the main heat input.

2. Experimental procedure

980 MPa class steel sheets (JIS-G3135-SPFCY, t: 1 mm) and a 590 MPa class filler wire (JIS-Z3312 YGW23, ϕ 1.2 mm) were used. 200 mm long and 50 mm wide specimens were used for basic investigation (see Fig. 1(a)), and 220 mm long and 100 mm wide specimens with a 30 mm lapped region were used for tensile tests (see Fig. 1(b)). A gap between lapped sheets was fixed as 1 mm by inserting shim tapes. The weld bead length was 180 mm and tensile specimens having 30 mm width were cut out in the above welded lapped sheets.

Table 1 shows the welding conditions employed in this study. A 3kW fiber laser oscillator, a laser head with a 400 mm focal length and a hot-wire heating system produced by Bab-Hitachi Industrial Co. were used. This hot-wire heating system uses pulsed current with a pulse frequency of 100 Hz in this study. The welding speed, the laser power, the filler wire feeding speed and the laser irradiation angle were fixed as 1.5 m/min, 3kW, 3.8 m/min and 5° respectively. The laser spot diameter, the wire feeding angle, the wire feeding position and the wire current were changed as experimental parameters. Filler wire was fed from backward into a welding region.

The in-situ observation was carried out using a high-speed camera to investigate filler wire melting and weld bead creation during hot-wire laser welding. The observation and evaluation of

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the bead surface and the cross section, and the tensile test were performed after welding.

3. Result and discussion

3.1 Concept of hot-wire laser welding for lap joint with wide gap

Figure 2 shows the schematic illustration of developed hot-wire laser welding on a lap joint with a wide gap. The penetrated hole initiates and weld metal does not fill the hole during laser welding without filler wire, then the sound bead and joint can't be created. Developed hot-wire laser welding can make stable wire feeding to fill the hole created by laser irradiation, and then the sound lap joint with a wide gap can be achieved by the proposed welding method. The following conditions are necessary to make stable filler wire feeding and the sound joint.

3.2 Effect of spot diameter

The suitable laser spot diameter and the welding speed which make the molten pool having a little larger width than the filler wire diameter are 1.5mm and 1.5 m/min respectively in this study under the 3 kW laser power condition. Figure 3 shows the cross sections when the laser spot diameter is 1.2 mm and 1.5 mm. When the 1.2 mm spot diameter was employed, the penetrated width of the upper sheet was about 1 mm which was smaller than the filler wire diameter of 1.2 mm, therefore the edge of filler wire touched and scratched the upper sheet, then the worse bead appearance was created. On the other hand, when the 1.5 mm spot diameter was employed, the penetrated width of the upper sheet was about 1.5 mm which was a little larger than the filler wire diameter of 1.2 mm, therefore filler wire was fed smoothly into the penetrated hole, then the sound bead could be created.

(a) Specimen for basic investigation.

(b) Specimen for tensile test.

Fig. 1 Sizes and configurations of specimens.

Table 1 Welding conditions.

Welding speed (m/min)	1.5
Laser power (kW)	3
Laser spot size (mm)	1.2, 1.5
Wire feeding speed (m/min)	3.8
Wire feeding angle (deg)	30 ~ 80
Wire feeding position (mm)	0 ~ 6
Wire current (R.M.S) (A)	98 ~ 120

Fig. 2 Schematic illustration of hot-wire laser welding on lap joint with wide gap.

Welding speed: 1.5m/min Sheet gap: 1mm Laser power: 3kW
Wire feeding angle: 70° Wire current: 104A
Wire feeding speed: 3.8m/min Wire feeding position: 3mm

Fig. 3 Cross sections when laser spot diameter changes.

3.3 Effect of wire current

Figure 4 shows the high-speed imaging output during hot-wire laser lap welding under the optimum welding condition. The adequate wire current which makes wire melting in the region from the upper sheet surface to the gap between the lapped sheets, 102 ~ 116 A in this study.

Fig. 4 High-speed imaging output during welding (optimum welding).

Figure 5 shows the cross-sections when the laser spot diameter is 1.5 mm, the wire feeding angle is 70°, the wire feeding position is 3 mm and the wire current is varied. When the wire current was too low (under 100 A in this study), the lower sheet melting was unstable, then a hole defect on the upper sheet initiated or filler wire penetrated into the lower sheet. When the wire current was high (118 ~ 120 A in this study), filler wire melted at the upper surface of the upper sheet, then the excess weld metal was formed but the serious defect was not created in the weld bead. When the wire current was too high (over 120 A in this study), filler wire was melted down before its tip reached the upper sheet surface, then the sound bead was not created. When the wire current was adequate (102 ~ 116 A in this study), stable wire melting was achieved and the sound bead with the adequate cross-section and the surface appearance could be created.

Fig. 5 Cross-sections when wire current is varied.

3.4 Effect of wire feeding position and feeding angle

The adequate wire feeding position is the anterior region of the molten pool crated posterior to the penetrated hole.

Figure 6 shows the cross sections when the wire feeding position from the laser spot center is varied as 0 ~ 6 mm, and the other optimum parameters are employed. When the wire feeding position is 3mm from the laser spot center, filler wire tip is located at the molten pool just behind the penetrated hole, and it is fed into the penetrated hole stably, therefore the sound appearance and cross-section of the bead are obtained. When the wire feeding position is 6mm from the laser spot center, filler

wire tip is located at the solidifying region behind the molten pool, and it makes the scratch on the bead surface as shown in this figure. When the wire feeding position is 0mm from the laser spot center, the laser beam irradiates on the filler wire tip directly, therefore the tip is melted down frequently. Although the bead appearance is good and enough weld metal and joint is created between the upper sheet and the lower sheet, filler wire melting is not steady.

Laser power:3kW Welding speed:1.5m/min Sheet gap:1mm
Laser spot diameter:1.5mm Wire feeding speed:3.8m/min
Wirecurrent:108A Wire feeding angle:70°

Fig. 6 Cross-sections when wire current is varied.

Figure 7 shows the effect of the wire feeding angle on the optimum wire current. When the wire feeding angle becomes too low (30° and 50° in this study), filler wire touches the upper sheet surface at the back of the molten pool, then stable wire feeding can not be performed. When the wire feeding angle is too high (80° in this study), the filler wire tip melts down frequently since the reflected laser beam irradiated unsteadily on its surface. When the wire feeding angle is 70° in this study, the filler wire tip touches stably the molten pool posterior to the penetrated hole, then the optimum wire current region becomes wider.

Fig. 7 Effect of wire feeding angle on optimum wire current.

Figure 8 shows the tensile shear test result when the wire current is varied from 102 A to 120 A. The laser spot diameter is 1.5 mm, the wire feeding angle is 70° and the wire feeding position is 3 mm based on the above investigations. The fracture path is in the base metal or the boundary between the base metal and the weld metal since the welded joint produced using the proposed hot-wire laser welding method has no serious defect in it. It is clear from the figure that the stable tensile shear strength can be obtained in the optimum wire current region.

Fig. 8 Tensile shear strength of lap welded joints.

4. Conclusions

The hot-wire laser welding was proposed for the lap joint of the high tensile / ultra-high tensile strength sheets with a wide gap, and its welding phenomenon was investigated precisely by using a high-speed camera, then the optimum welding conditions was obtained in this study. The obtained conclusions are as follows.

(1) The hot-wire laser system makes the penetrated hole and the molten pool by laser irradiation firstly, and then filler wire heated up through energization fills the penetrated hole in the proposed hot-wire laser lap welding method. The optimum conditions for the 1 mm gap are 1.5mm of the spot diameter, 3 mm of the wire feeding position, 70° of the wire feeding angle and 102 ~ 116 A of the wire current for 3kW of laser power, 1.5 m/min of the welding speed, 3.8 m/min of the wire feeding speed, 1 mm of the base sheet thickness and 1.2 mm of the filler wire diameter.

(2) The laser spot diameter and the welding speed which make the molten pool having a little larger width than the filler wire diameter, the wire feeding position and angle which is the anterior region of the molten pool crated posterior to the penetrated hole, and the wire current which makes wire melting in the region from the upper sheet surface to the gap between the lapped sheets are necessary for the stable welding phenomenon and sound bead creation.

(3) The stable and high tensile shear strength (500 ~ 600 MPa) can be obtained in the wide wire current region (102 ~ 120 A) using the optimum welding conditions based on the above investigation.

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