Development of welding method for wide gap lap joint of steel sheet using laser welding with hot-wire†

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1. Introduction

In recent years, high strength / ultra-high strength steel sheets are widely used for an automobile body since the 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. 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. 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-Z3321 YGW23, ϕ 1.2 mm) were used. 200 mm long and 50 mm wide specimens were used for basic investigation, and 220 mm long and 100 mm wide specimens with a 30 mm lapped region were used for tensile tests. 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. A 3kW fiber laser, a laser head with a 400 mm focal length and a hot-wire heating system produced by Bab-Hitachi Industrial Co. were used. 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 backwards into a welding region.

(1) The adequate laser spot diameter and the welding speed which make the molten pool having a little larger width than the filler wire diameter, 1.5mm for the spot diameter and 1.5 m/min for the welding speed in this study.
(2) The adequate wire feeding position and angle which are the anterior region of the molten pool created posterior to the penetrated hole, 3mm for the feeding position from the laser spot center and 70˚ for the wire feeding angle in this study.
(3) 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.

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

The in-situ observation was carried out using a high-speed camera to investigate filler wire melting phenomena and weld bead creation phenomenon during welding. The observation and evaluation of the bead surface and the cross section, and the tensile test were performed after welding.

3. Result and discussion

Figure 1 shows the high-speed image output during hot-wire laser lap welding under the optimum welding condition. **Figure 2** shows the schematic illustration of welding phenomenon during developed hot-wire laser lap welding. A penetrated hole initiated and weld metal could not fill the hole during laser welding without filler wire, then the sound bead and joint could not be created. The developed hot-wire laser welding method can make stable wire feeding to fill the hole created by laser irradiation, and then the sound joint with a 1 mm gap could be created by the proposed welding method. The following conditions are necessary to make stable filler wire feeding and the sound joint.

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Fig.1 High-speed image during welding (optimum welding).

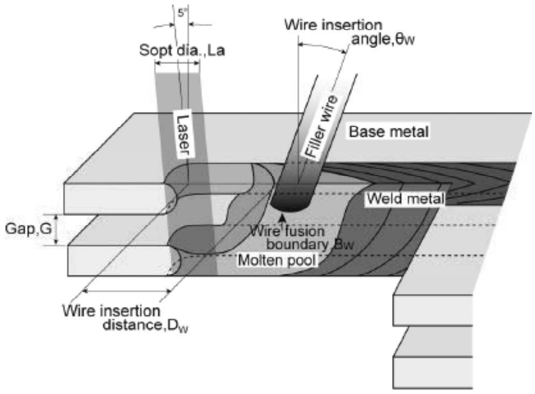

Fig.2 Schematic illustration of hot-wire laser welding.

Figure 3 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 a 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 adequate cross-section and surface appearance could be created.

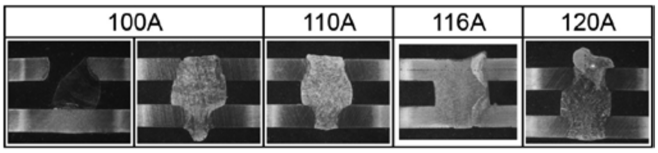

Fig.3 Cross-sections when wire current is varied.

Figure 4 shows the effect of the wire feeding angle on the optimum wire current. When the wire feeding angle became too low (30˚ and 50˚ in this study), filler wire touched the upper sheet surface at the back of the molten pool, then stable wire feeding could not be performed. When the wire feeding angle was too high (80˚ in this study), the filler wire tip melted down frequently since the reflected laser beam irradiated unsteadily on its surface. When the wire feeding angle was 70˚ in this study, the filler wire tip touched stably the molten pool posterior to the penetrated hole, then the optimum wire current region became wider.

Figure 5 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.

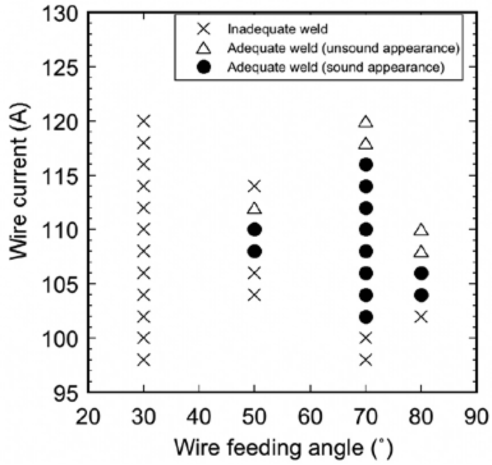

Fig.4 Effect of wire feeding angle on optimum wire current.

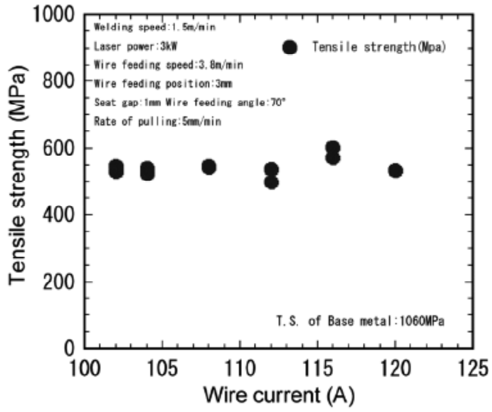

Fig.5 Tensile shear strength of lap welded joints.

4. Conclusions

The hot-wire laser welding method 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 were 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 by 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 created 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 over the wide wire current region (102 ~ 120 A) using the optimum welding conditions based on the above investigation.