A Study on Laser-Arc Hybrid Welding of Butt Welded joints of Steel Plates for Hulls under the Condition of I-Gap with Zero Initial Gap

Kobayashi, Hiroo
Graduate School of Engineering, Kyushu University : Master course student

Uchimura, Tomoya
School of Engineering, Kyushu University : Technician

Ide, Akihiro
Sumitomo Heavy Industries, Ltd. : Researcher

Matsuda, Kazuki
Faculty of Engineering, Kyushu University : Associate Professor

他

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Hiroo Kobayashi*[1], Tomoya Uchimura[2], Akihiro Ide[3], Kazuki Matsuda[4], Koji Gotoh[5]

1) Master course student, Graduate School of Engineering, Kyushu University
2) Technician, School of Engineering, Kyushu University
3) Researcher, Sumitomo Heavy Industries, Ltd.
4) Associate Professor, Faculty of Engineering, Kyushu University
5) Professor, Faculty of Engineering, Kyushu University

Email: kobayashi.hiroo.601@s.kyushu-u.ac.jp (*Speaker)

Abstract

Laser-arc hybrid welding (LAHW) can significantly reduce weld deformation due to the lower heat input compared to conventional arc welding, which is the standard method used in the current hull construction stages. Because of its superior heat concentration, LAHW has a relatively larger plate thicknesses over which I-shaped groove joints can be fabricated than conventional arc welding.
One of authors reported that one-pass welding without backing material was possible for a 17 mm thick steel plate with I-shaped groove. However, it was necessary to insert a filler gauge into the groove face and set the gap across the weld line to 0.5 mm.
From the viewpoint of introducing LAHW into the construction stage of general merchant ships, this study examined the welding work conditions to fabricate sound welded joints by LAHW under the following conditions: (1) groove fabrication by plasma cutting and (2) I-shaped groove with zero initial gap width. With reference to our previous studies, a search was conducted for welding parameters (laser power, arc current and voltage, etc.) that would allow the joint to be fabricated by a single pass of construction. As a result, although welding conditions with good bead appearance were identified, hot cracking of the weld metal occurred in some of the joints. To prevent hot cracking, the number of welding passes was changed from one to two, the length of the molten pool formed in the first pass was shortened in the thickness direction, and the second pass was performed by arc welding alone to compensate for the insufficient reinforcement height. As a result, it was possible to fabricate welded joints with good bead appearance without hot cracking.

Keywords: Laser-arc hybrid welding, Flat Position, Butt welded joint, I-shaped groove, beveled by plasma cutting

1. Introduction

Shipbuilding industry has been engaged in fierce international competition, and there is a strong need to strengthen international competitiveness from the standpoint of economic development. Welding operations account for the majority of the hull construction stages, and improvements in welding technology have a significant impact on the productivity and quality of hull construction.
Laser-arc hybrid welding (LAHW), which is one of the advanced welding technologies that uses the advantages of laser welding and arc welding as a single molten pool. LAHW can significantly reduce weld deformation due to the lower heat input compared to conventional arc welding and its introduction into the hull construction process is expected to be expanded.

Takeshita et al.[1] reported that one-pass fabrication without backing was possible for steel plates of 17 mm in thickness. But there were two issues as follows.

(1) The beveling was performed by laser cutting, which is not commonly used in shipyards in Japan. In addition, there are still restrictions on the thickness of plates that can be beveled by laser cutting, and it is

not always possible to apply the method to plates equivalent to the exterior plates of general merchant ships. Considering that 80 to 90% of the cutting equipment currently used in shipyards in Japan is plasma cutting [2], it can be said that plasma cutting should be used in this study.

(2) The joint gap was controlled to 0.5 mm by inserting a filler gauge between the two steel plates before welding. The control of long and heavy steel plates that extend several meters in length in units of millimeters requires a great deal of time and labor, which is inefficient and requires improvement.

The purpose of this study is to fabricate butt welded joints as hull plates of general merchant ships in one pass with I-shaped grooves, assuming that LAHW is introduced instead of multi-electrode submerged arc welding such as flux copper backing (FCB) or refractory flux (RF) [3] processes used in the joining process for hull plates. Therefore, we used steel plates beveled by plasma cutting to search for good welding conditions under the 0 mm gap condition, where two steel plates are simply butted together to reduce the gap control process.

2. Materials and Test procedure

The chemical compositions and the mechanical properties of the steel plates and welding wires used in this study are shown in Table 1 and Table 2. The thickness of the steel plate was 20.0 mm and the wire diameters were all 1.2 mm.

In order to suppress gap fluctuation during welding, laser welding was used as a tack welding method for the entire line before hybrid welding. The laser power and welding speed were 2 kW and 100 cm/min, respectively.

Table 1 Chemical compositions and mechanical properties of applied steel.

	Chemical compositions [mass %]					Mechanical properties		
	C	Si	Mn	P	S	Yield stress [MPa]	Tensile strength [MPa]	Elongation [%]
SS400	-	-	-	≦0.05	≦0.05	≧235	≧400	≧21

Table 2 Chemical compositions and mechanical properties of deposited material.

	JIS standard	Chemical compositions [mass %]					Mechanical properties		
		C	Si	Mn	P	S	Yield stress [MPa]	Tensile strength [MPa]	Elongation [%]
MG-50	JIS Z 3312 YGW11	0.08	0.51	1.1	0.01	0.01	490	570	31
MG-56	JIS Z 3312 YGW18	0.05	0.58	1.52	0.01	0.005	530	610	25
YM-60A	JIS Z 3312 G59JA1UM3M1T	0.06	0.35	1.45	0.008	0.003	580	650	30
MX-50K	JIS Z 3313 T49J1T15-0CAU	0.04	0.67	1.87	0.009	0.006	490	570	29
SF-60T	JIS Z 3313 T59J1T1-1CAGUH5	0.05	0.45	1.41	0.013	0.004	582	648	23

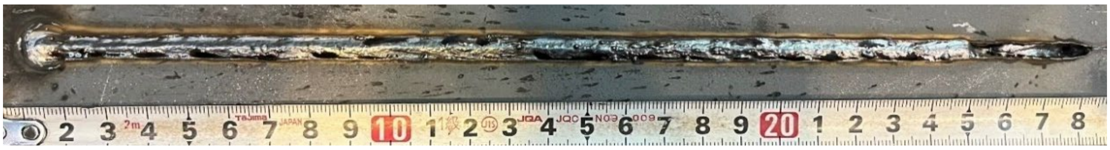
3. One Pass Welding

3.1. Welding Condition and Fabrication result

Referring the welding conditions for a plate thickness of 16.5 mm obtained in a previous study [1], the conditions that prevent the formation of defects on the bead surface were explored. Solid wire MG-50 was used in the test. Table 3 shows the two welding conditions obtained through this study. The bead appearances are shown in Figure 1 and the photographs of macroscopic observation of the cross-section samples are shown in Figure 2, respectively. As shown in Figure 2, hot cracking was observed in the weld metal under both conditions.

Table 3 Welding conditions of one pass welding.

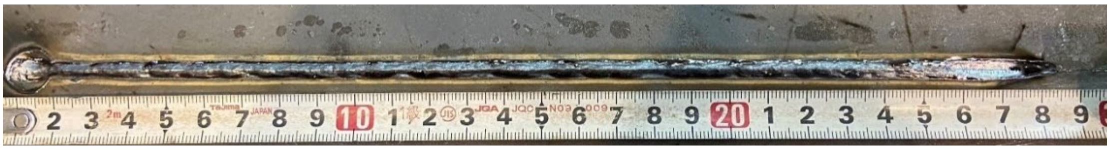
ID	A1	A2
Welding speed [cm/min]	120	150
Arc current [A]	260	350
Arc voltage [V]	26.5	26.5
Laser power [kW]	14.0	14.0
Defocused distance [mm]	-5.0	-5.0
Distance between laser radiation point and arc torch aiming point [mm]	2.0	2.0
Arc drag angle [degree]	40	40
Laser push angle [degree]	10	10



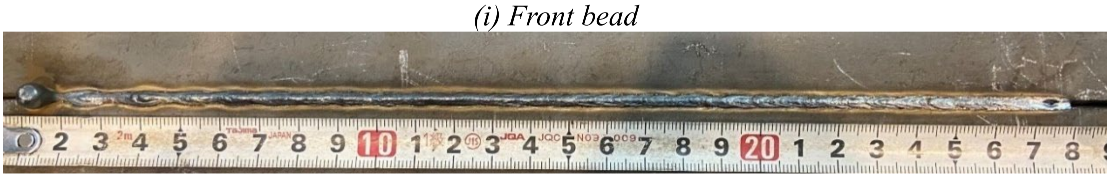
(i) Front bead

(ii) Back bead

(a) A1



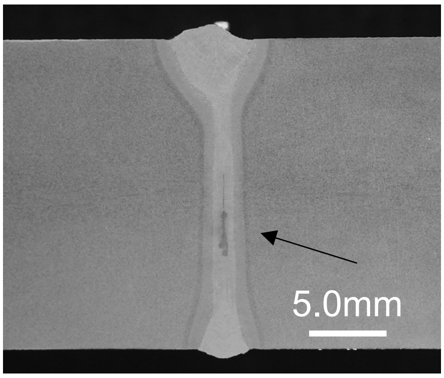
(i) Front bead

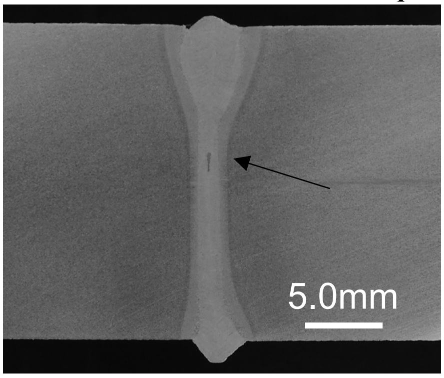


(ii) Back bead

(b) A2

Figure. 1 Photographs of bead appearance of one pass welding.





(a) A1 *(b) A2*

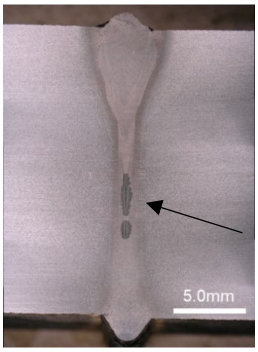
Figure. 2 Macroscopic observations of one pass welding.

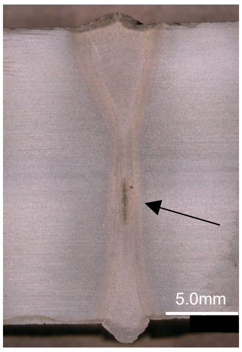
3.2. Preventing of hot cracking

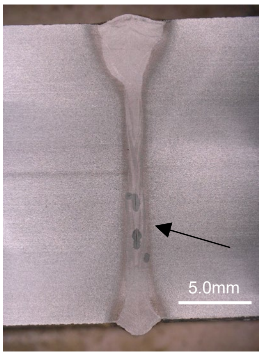
To prevent hot cracking, selection of welding wire and optimization of welding speeds were investigated.

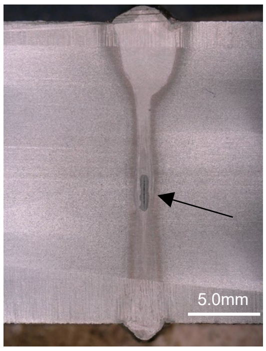
3.2.1 Wire changing

When the compounds with low melting point such as FeS and Fe3P are formed in solidification process, the melting point of the liquid phase decreases. This expands the brittle temperature range (BTR), which increases the risk of hot cracking [4]. Therefore, the eliminating hot cracking was attempted by changing the welding wire from MG-50 to the one with low S and P contents.
The wires used in this investigation were MG-56, YM-60A, MX-50K, and SF-60T. The chemical properties of each were listed in Table 2 above. Figure 3 shows the photographs of the cross-section obtained by the same conditions as those shown in Table 1. Hot cracking was observed in all conditions. Therefore, it can be concluded that the main cause of the hot cracking in this test was not due to chemical compositions that increase susceptibility to hot cracking such as S or P.









(i) MG-56 *(ii) YM-60A* *(iii) MX-50K* *(iv) SF-60T*

Figure. 3 Use of low impurity wire.

3.2.2 Reducing welding speed

It is known that high-speed welding tends to form a teardrop in the molten pool, which promotes the development of columnar crystals, resulting in occurring the segregation of alloy elements and hot cracking [4]. Therefore, by reducing the welding speed and changing the molten pool to elliptical shape, the formation of columnar crystals and resulting segregation of constituents were suppressed.
The appearances of welding bead whose welding speed of 90 cm/min are shown in Figure 4. Weld metal was drooped on back surface. The cause is considered to be that the cooling rate of the molten metal was decreased as the welding speed reduced, and a large amount of molten metal flowed into the backside. In order to reduce the flow of molten metal into the backside, the wire feeding rate was reduced. Resulting in insufficient

reinforcement height of the front bead and a bead appearance that satisfied the criteria of the welding procedure qualification test [5] could not be obtained. It was concluded that it is difficult to achieve both a beautiful bead and suppression of hot cracking of the weld cross-section in one-pass welding of I-shaped steel plates with a thickness of 20.0 mm.

(i) Front bead

(ii) Back bead

Figure. 4 Welding at low speed.

4. Two Pass Welding

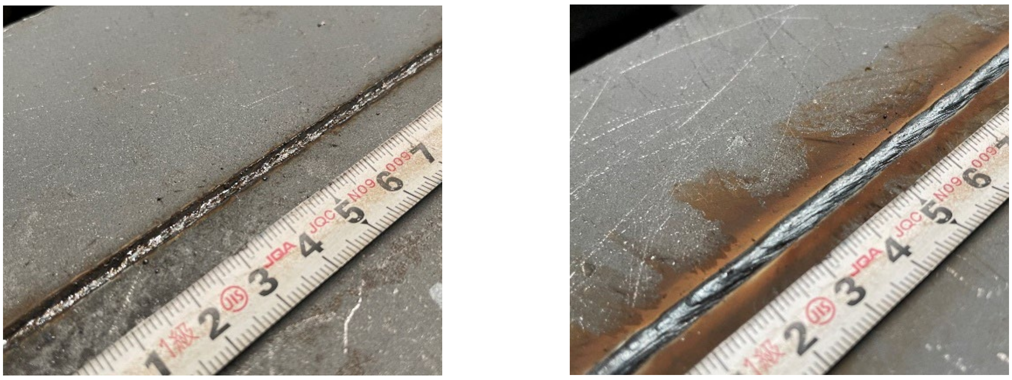
Mori et al. reported [4] that the larger the aspect ratio (length in the thickness direction / melt width) of the weld metal shape in the cross-section, the more likely hot cracking is occurred.
Therefore, to reduce the aspect ratio, the research policy was changed from one-pass welding to two-pass welding. In the first layer, the aspect ratio is lowered by welding such that the back bead is good, and the front bead is insufficient to prevent hot cracking, and the insufficient front bead is welded by arc welding alone in the second layer.

4.1. First layer

In the welding of the first layer, the optimal conditions were explored with emphasis on the formation of a sound back bead, while allowing for a lack of reinforcement height of the front bead.
At first, the welding speed of 60 cm/min was conducted, afterwards increasing by 10 cm/min for each test. As a result, the welding speed of 80 cm/min was selected as the optimal condition. Table 4 shows the optimal welding conditions, and Figure 5 and Figure 6 shows the bead appearances and the photographs of cross-sectional macroscopic observations, respectively. As shown in Figure 6, hot cracking was prevented in all samples. The reasons for this result are thought to be the reduction of aspect ratio of weld metal and the suppression of columnar crystal growth by the reduction of welding speed.

Table 4 Welding conditions in the first layer of two pass welding.

ID	B1
Welding speed [cm/min]	80
Arc current [A]	125
Arc voltage [V]	16.0
Laser power [kW]	12.0
Defocused distance [mm]	-5.0
Distance between laser radiation point and arc torch aiming point [mm]	2.0
Arc drag angle [degree]	40
Laser push angle [degree]	10

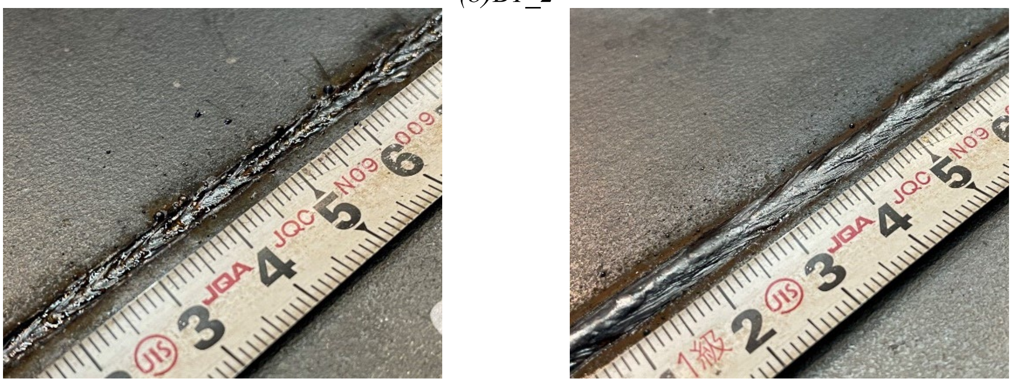


(i) Front bead (ii) Back bead

(a) B1_1

(i) Front bead (ii) Back bead

(b)B1_2



(i) Front bead (ii) Back bead

(c)B1_3

Figure. 5 Photographs of bead appearance of first layer.

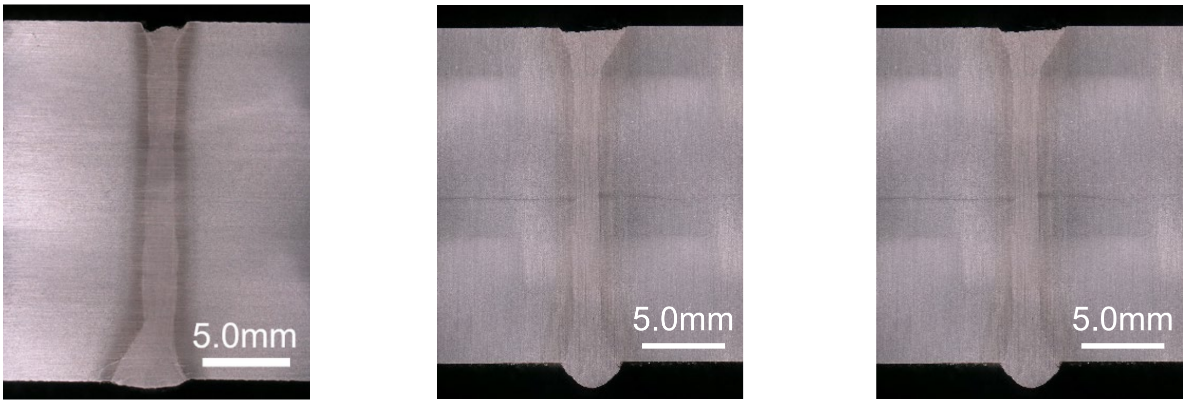


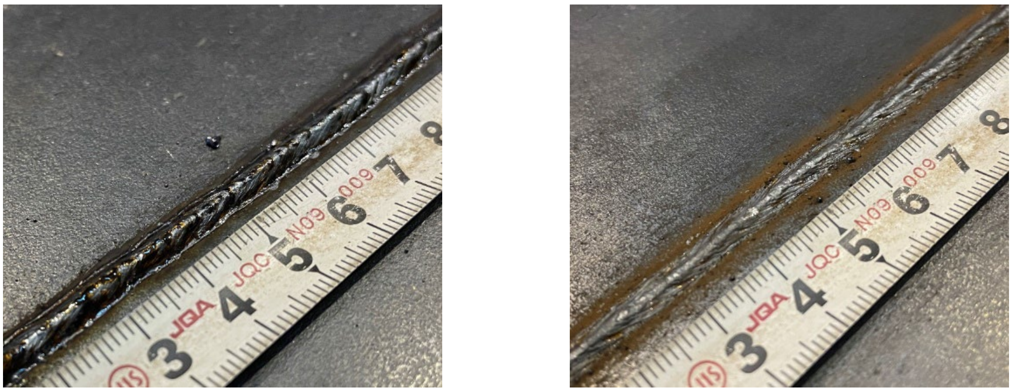
Figure. 6 Macroscopic observations of first layer.

4.2. Second layer

In order to compensate for the insufficient reinforcement height of the front bead in the first layer, arc-alone cosmetic welding was performed in the second layer. The welding conditions is shown in Table 5, the bead appearance is shown in Figure 7, the photographs of cross-sectional macroscopic observation are shown in Figure 8, respectively. As shown in Figure 8, there are no defects in all cross-sections.

Table 5 Welding conditions in the second layer of two pass welding.

ID	C1
Welding speed [cm/min]	80
Arc current [A]	150
Arc voltage [V]	18.0



(i) Front bead *(ii) Back bead*

Figure. 7 Photographs of bead appearance of two pass welding.

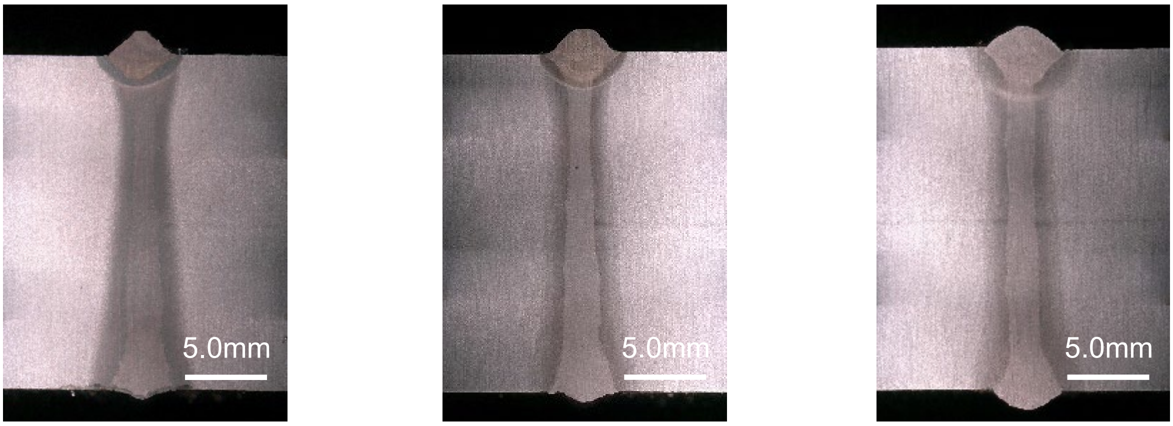


Figure. 8 Macroscopic observations of two pass welding.

5. Conclusion

In this study, welding conditions using plate thickness of 20 mm with I-bevels cut by plasma cutting were explored. Changing welding wire or reducing welding speed could not satisfy both to achieve a sound bead appearance and to suppress the hot cracking at the same time.

Based on the hypothesis that the aspect ratio of the penetration shape of the weld cross-section contributes to suppress the hot cracking, two-pass welding was investigated. Finally, both hot cracking prevention and sound bead appearance were achieved.

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