



A Study on Optimization of Welding Parameter to Thick plates for Application Laser-Arc Hybrid Welding

Jeong Yeol Park^{1*}, Changwook Ji¹, Jooyoung Cheon¹ and Hyun Uk Jun¹

¹Korea Institute of Industrial Technology, Smart Forming Process Group, 44776 Ulsan, Republic of Korea

Abstract. Recently, there has been increasing interest in various welding methods to achieve automation and high-efficiency process design when applying welding to thick plates. Therefore, various studies are being conducted on new methods that can be automated rather than the existing welding methods. Among many new methods, the Laser-Arc Hybrid Welding (LAHW) method opens up the possibility of applying thick plates as the laser output increases, and can reduce deformation and heat-affected zone due to welding heat compared to existing welding methods. In addition, LAHW has high efficiency because welding can be performed in a single pass. There are studies related to humping that investigate the causes and mechanisms, but the analysis of the effects of each welding parameter is relatively insufficient. Therefore, in this study, we attempt to determine the cause and mechanism of occurrence by changing the welding process parameters applied during LAHW. Parameters being considered include laser output, arc output, welding speed, de-focusing, etc., and we would like to select parameters with the greatest influence by creating a process window. In addition, we derive optimal conditions which humping does not occur through analysis of each parameter.

1 Introduction

Recently, as the manufacturing industry faces the 4th Industrial Revolution, the demand for automation of the manufacturing process is increasing [1]. In particular, in the shipbuilding industry, research is continuously being conducted on welding automation, which accounts for most of the manufacturing process, to shorten manufacturing process time and improve quality. In the case of arc welding used in ship manufacturing, there are many limitations to automation depending on the welding technology, and the variables that determine quality are diverse. Therefore, interest in welding methods that are advantageous for automation is increasing, and among several new methods, laser-arc hybrid welding (LAHW) can reduce thermal deformation and the area of the heat-affected zone (HAZ) through high-density heat input compared to arc welding [2, 3]. In addition, when applying thick plates, there is an advantage that the welding process can be carried out in one pass, so various studies are being conducted [4]. I. Bunaziv et al. examined the feasibility of applying LAHW to 12mm and 15mm thick plate [5]. As a results, LAHW is susceptible to root humping due to unfavorable melt flow at the bottom of the weld pool. In addition, humping was mitigated by balancing certain arc and other process parameters. Y. Meng et al. performed a parametric study on the synergy effect of two heat sources during laser arc hybrid welding [6]. They said that the greater of the ψ (melting energy increment), the larger of the melting efficiency, and the stronger of the synergic effect.

LAHW, which has low thermal deformation, small HAZ, and can weld thick plates at once, is economically feasible in the production of liquefied natural gas (LNG)

storage tanks, and interest in the application of related materials is increasing. Low temperature materials used in LNG storage tanks have excellent fatigue and fracture performances at cryogenic temperatures, and representative examples include high manganese steel, aluminum, stainless steel, and 9% nickel steel. S. Gook et al. applied laser-arc hybrid welding to 9% nickel steel and performed analysis from a microstructural perspective. As a results, the microstructure of the weld root is ferritic-martensitic. In addition, the main volume of the filler material is concentrated in the top part of the weld. However, research on applying LAHW to 9% nickel steel from perspective process optimization is insufficient.

In this study, we aim to analyze problems that occur when applying LAHW to 9% nickel steel and identify the causes. For this purpose, process optimization was performed considering laser power, arc power, welding speed, and defocusing among the LAHW parameters. In addition, for humping conditions, which are representative defects that can occur, the temperature was measured using a thermal imaging camera and the maximum temperature was analyzed to confirm the difference from the optimized conditions. In addition, an impact test was conducted for each temperature of weld metal and confirm the possibility of replacing existing arc welding.

2 Experimental Set-up

2.1 Material

The steel used in this study is 9% nickel steel and has a thickness of 12 mm. Additionally, the welding material applied to 9% nickel steel is Inconel 625, and the

* Corresponding author: jypark08@kitech.re.kr

diameter is 1.2mm. Table 1 shows the chemical composition for 9% nickel steel and Inconel 625.

Table 1. Chemical composition of base metal (BM) and weld metal (WM).

	C	Si	Mn	P	S	Ni	Cr	Mo
B M	0.13	0.15- 0.40	0.90 Max	0.01 5 Max	0.01 5 Max	8.5- 9.5	-	-
W M	0.03	0.37	0.28	0.01	0.03	63.3	21.6	8.6

2.2 Equipment set-up

The welding equipment used in this study was installed as follows Fig. 1. In particular, the laser head and arc torch were prepared as shown in Fig. 2. The focal length was 250mm, the arc torch had an angle of 60°, and the laser head was set at an angle of 7°. In the case of D_{LA} , it was fixed at 3mm, the laser output was 5~6kw, the arc mode was standard, and the type of shielding gas and flow rate were 20% CO₂+Ar gas and 20L/mm.

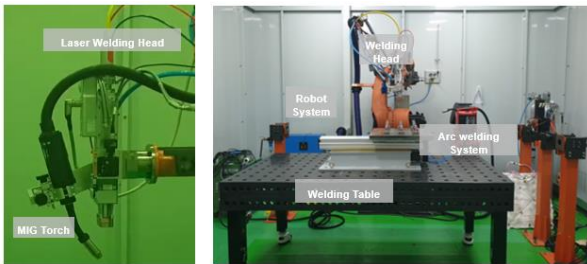


Fig. 1. Welding Machine

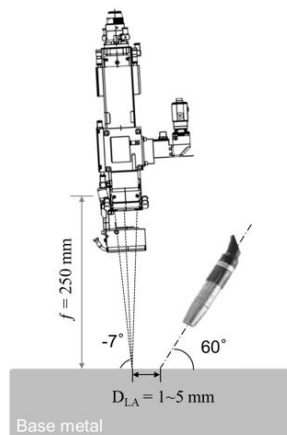


Fig. 2. Set up of laser head and arc torch.

The laser type applied in this study is an adjustable ring mode (ARM) laser, and the output of the center and ring parts can be adjusted. The advantages of ARM laser are stable temperature gradient due to the pre-heating effect of the ring beam and improvement of weld bead quality and mechanical properties (reduced spatter, improved seam quality and increased productivity) [8-9].

3 Results and Discussion

To optimize the LAHW process, a test plan for various heat input conditions was derived, and based on this, a process window for applying butt welding was created as shown in Fig. 3. As a result, conditions without partial penetration or humping were confirmed. Additionally, humping occurred at high heat inputs. As shown in Fig. 4, when humping occurred, it was confirmed that the quality of the root part was poor and that complete penetration did not occur in the face part. In addition, the optimized condition range had a higher heat input than the set test conditions and the range was very narrow.

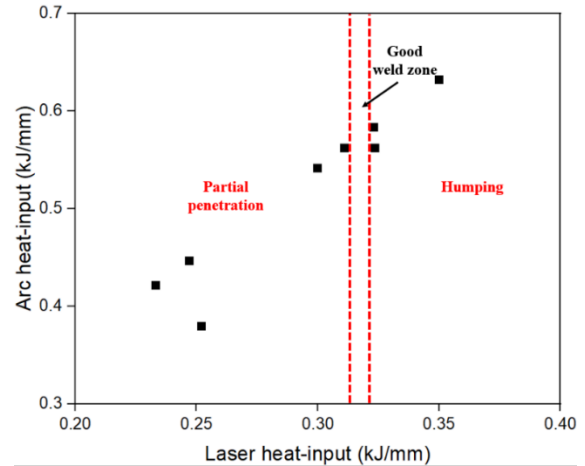


Fig. 3. Process window for butt weld

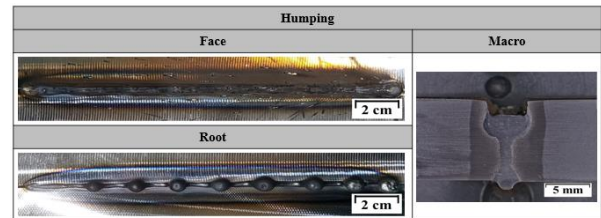


Fig. 4. Macro of humping condition

Therefore, it was necessary to derive process optimization conditions while reducing heat input. Accordingly, a butt test was conducted applying defocus conditions. When defocusing conditions were applied as shown in Fig. 5, optimized process conditions were derived under low heat input conditions. In case of Fig.5, when adjusting the laser beam focus in the thickness direction, the penetration depth increases. To confirm the presence or absence of defects under optimized conditions, the weld bead surface and macro were checked, and it was confirmed that the weld bead was formed without defects and humping, as shown in Fig. 6. In order to check thermal changes when humping and partial penetration occurred, real-time temperature changes were confirmed using a thermal imaging camera, and the results are shown in Fig. 7. As a result, under humping conditions, the synergy effect between the laser and the arc heat source was insufficient, and when the temperature of each heat source was measured, the maximum heat intensity and average heat intensity were measured to be high. Additionally, an irregular

temperature decrease occurred, which was presumed to be the effect of root humping.

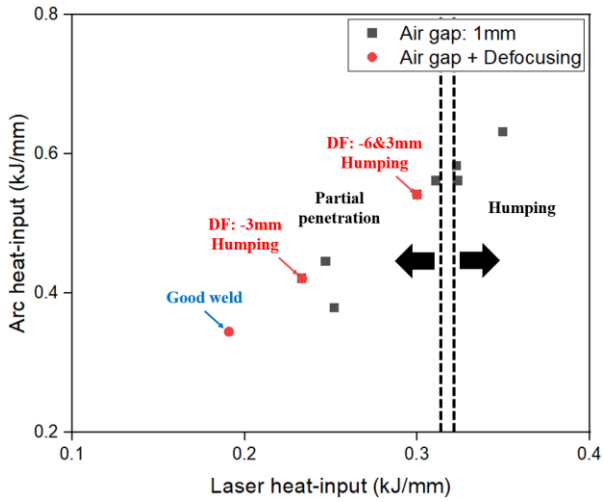


Fig. 5. Process window by effect of defocusing

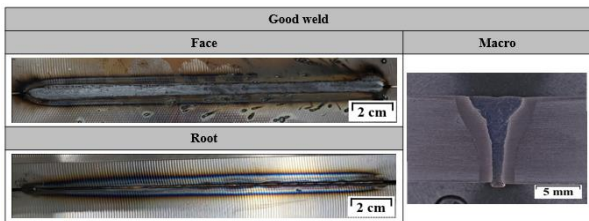


Fig. 6. Macro of good weld condition

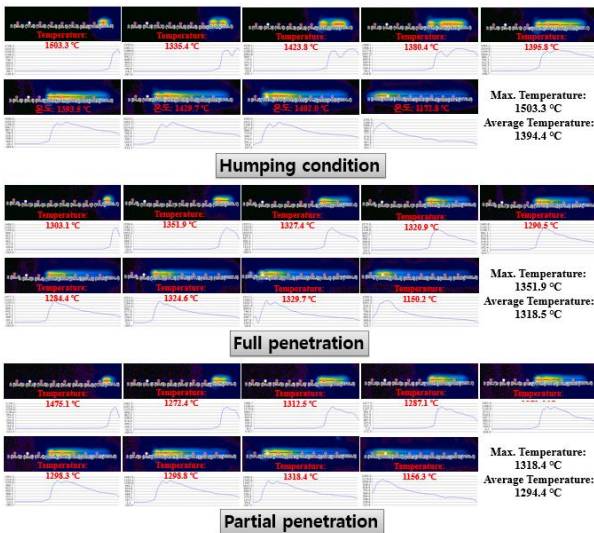


Fig. 7. Thermal image during LAHW

In the case of full penetration (without humping), the two heat sources, laser and arc, showed an appropriate synergy effect, and the heat intensity was also stable. In the case of partial penetration, the maximum heat intensity and average heat intensity are the lowest.

Impact test specimens were collected at WM for butt-welded plates according to optimized conditions [10]. The results of the impact test at 4 temperatures are shown in Fig. 8, and the results showed that the impact

toughness decreased as the temperature decreased. The impact toughness of the welded area at -196°C satisfied the design criteria, and the trend of reduction in impact toughness can be predicted as follows.

$$y=38.55-19.26/(1-0.19*x)^{(1/-0.23)} \quad (1)$$

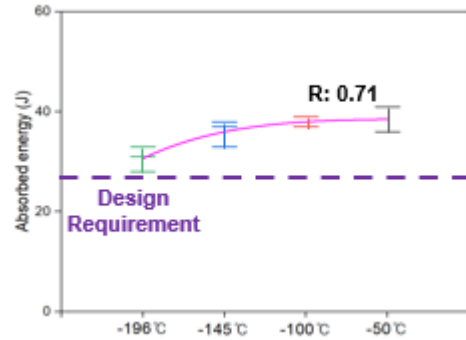


Fig. 8. Impact toughness test results [11]

4 Conclusion

- In order to achieve good welding quality at the root area with low heat input, an appropriate defocusing effect must be applied.
- As a result of comparing humping, full and partial penetration conditions through molten pool measurement results using a high-speed camera, when humping occurs, the flow of the molten pool has a high momentum in the center, does not flow from the surface to the side, and has a thin bead width.
- As a result of comparing the results of melt pool heat intensity measurement using a thermal imaging camera, the humping condition showed a lack of synergy effect between the laser and arc heat sources, resulting in high maximum heat intensity and average heat intensity and irregular temperature decrease.
- In order to reduce the root humping phenomenon, an appropriate synergy effect must be achieved and the momentum of the core of the molten pool behind the heat source must be reduced.
- Additional analysis will be performed by confirming the melt pool behavior using a high-speed infrared camera.

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