Abstract of Dissertation

題　目　Development of Vertical Welding Technology on Thick Steel Plate Using Hot-Wire Laser Welding Method
(ホットワイヤ・レーザ溶接法による厚鋼板立向き溶接技術の開発)

氏　名　WARINSIRIRUK　EAKKACHAI

Recently, larger container ships have been built for more efficiency of maritime transportation, consequently by the thicker of steel plates that have been used for its structure. Generally, “electrogas arc welding” (EGW) process, a single-pass vertical welding process having very high efficiency, has been used to join heavy-thick steel plates on the vertical direction in a ship building industry, especially in the part of a container ship structure such as a hatch side coaming. However, the EGW process causes very high heat input, which affects seriously on toughness deterioration of a welded joint, since it makes grains coarse and a heat affected zone (HAZ) width wide. Therefore, the novel vertical welding process with lower heat input is strongly demanded to join heavy-thick steel plates having high strength and high toughness.

The present research proposes the novel vertical welding process for thick steel plates, using the laser diode as a heat source in combination with the hot-wire method, in order to achieve much lower heat input compared with the EGW process. This proposed welding process with low heat input should prevent grain growth and widening HAZ width and maintain toughness of a welded joint. In addition, the proposed process needs high efficiency by single-pass welding for thick steel plates in the vertical direction as with the EGW.

In the proposed welding process, a high-power laser diode is used as a main heat source and the hot-wire method is used for efficient deposition. A large rectangular spot shape of a laser beam, which fits a groove width (gap) and plate thickness, is employed. The laser is irradiated continuously from the above the joint into the groove to create and keep a molten pool during welding. A reflected laser on a molten pool surface is utilized for melting groove surfaces efficiently. Filler wires are fed from both sides of the groove, and filler wires are heated up to its melting point by Joule heating using the hot-wire system before entering the molten pool. YP-47 steel material for hull structure was used as base metal to joining for this research.

Firstly, feasibility study of welding phenomena of the proposed process was performed. The Initial melting of base metal was observed by in-suite observation during the stationary laser beam irradiate and hot-wire feeding. It was verified that the reflected laser beam form the molten pool really affected initial melting of the groove surfaces. Melting phenomena were investigated by basic experiment of single-pass vertical joining by hot-wire laser method. Gap width size of 5 mm with base metal thickness of 26 mm was joint dimension to study. The high-speed observation shows

the result of stable weld pool formation during the vertical joining. The power density of laser irradiation is principle parameter to obtain an adequate fusion of the base metal. The critical power densities which depended on welding speed were successfully determined with 25 and 35 W/mm^2 for welding speed of 1.7 and 3.3 cm/min, respectively. Therefore, it was idealized for design and provide an appropriate laser irradiating method to maintain high power density of laser beam to obtain the sound joint.

Laser irradiating methods were investigated on melting phenomena. Gap dimension of 10 mm (width) x 26 mm (thickness) was used as a target for joining. The couple parameter of power density is ratio of laser beam width per groove width, namely W_L/W_G ratio was used to investigate the joining ability. For the length dimension of the beam is almost equal base metal thickness. The stationary laser beam with W_L/W_G = 1.0 was used, but irradiated by low power density (23 W/mm^2) has a result of low melting amount, more accumulated imperfections of incomplete fulfill, and lack of fusion. It was revealed that joining by the low-power-density laser beam does not provide an adequate reflected laser energy to create the initial melting of the base metal. On the other hands, the final fusion of the weld joint that was formed by weld pool heat conduction.

Consequently, the weaving laser irradiating method was used instead of the stationary laser beam method in case of the laser power source is a limitation of the maximum power irradiation. Methodology of the weaving laser beam is an irradiation of the narrow-width long-length laser spot-shape to maintain high power density (higher than the critical power density) and sweep this beam along the groove width direction. The appropriate weaving frequency and waveform was obtained; it is 5 Hz exponential wave to set for the weaving condition. The weaving irradiating condition was optimized by varies 2 beam width sizes of 2 mm and 4 mm over gap width of 10 mm and W_L/W_G = 0.2 and W_L/W_G = 0.4. The wide laser spot size of W_L/W_G =0.4 could maintain a high temperature weld pool and result on a larger melting volume (larger weld bead size). Meanwhile, laser beam size of W_L/W_G = 0.2 was resulted on larger difference of liquid weld pool energy when laser beam moving, although narrower laser beam width irradiated by higher power density. It was mentioned that using long-length laser beam size for joining resulted in much lower energy on the beam tails (edge region). Frequently imperfection of incomplete fulfill or lack of fusion was occurred on this region. An important idea of this problem is a compensation of laser energy on the both tails for troubleshoot the occurring of imperfection.

Therefore, the twin laser method was performed to improve welded joint quality for sound weld achievement. Twin laser method has been successfully applied on one pass vertical joining. Imperfection on edge region could be fixed by compensate laser power on the edge region. For one side of compensate laser power, laser power levels strong affected the melting amount of base metal. At 3 kW compensate laser power provided complete fulfill weld metal and complete fusion of welded joint under fixed welding speed of 3.33 cm/min (2 m/h). It was performed to study of welding speeds effects to optimized welding parameters. The optimized welding speed for twin laser with one side compensation is 5.00 cm/min (3 m/h). It provided complete fulfill and adequate weld penetration. From the information of this chapter, it can be suggested that homogenizer for create laser beam shape should distribute higher energy on the edge tails on the laser beam. The center region can irradiate by lower energy since during joining heat conduction from both tail sides can provide adequate energy for fusion base metal.

The weld metal properties were studied. Cooling transformation time of Δt8/5 were obtained and related with microstructure and toughness. The cooling characteristic of the twin laser method has Δt8/5 range of 84 to 200 second. The selected filler metal of JIS3312 G78AUMN5C1 M3T provided martensitic-bainitic base of microstructures transformation. The increasing of welding speed resulted in cooling time became short and resulted in the fine martensite phase formed. On the other hand, long cooling time by lower welding speed resulted in coarse upper bainite formed. The finest microstructure of cooling time of 84 second was performed on the Charpy V-notch test. Absorbed energy more than 100 Joule at test temperature of -20 °C could be obtained by high-speed condition.

According to the main proposes of low heat input delivered to base metal, heat input effects on HAZ's characteristics was investigated. Heat input of twin laser method was controlled by welding speed ranges. Increasing welding speed resulted in heat input was decreased thereby grain size on CGHAZ became smaller. CGHAZ width of the proposed process has narrower to 1,600 micron and could become narrower than 700 micron by using the welding speed of 5.00 cm/min which was optimized welding speed for sound weld condition. Compare HAZ's characteristics of the proposed process with two electrode VEGA, the proposed process has an advantage of both of grain size and CGHAZ over two electrode VEGA. It was clearly evidence that the proposed process provide low heat input welding for single-pass vertical joining. The requirement of heat input of the proposed process has the lower level of heat input when comparatively compared with other vertical welding processes.