Abstract of Dissertation (論文の要旨)

Title (題 目): Development of Vertical Welding Technology for Heavy-Thick and Ni 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およびニッケル鋼立向き溶接技術の開発）

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In recent years, the capacity of container shipbuilding has been greatly expanded with regard to a demand for the maximum loading capacity. The larger their structures are, the thicker steel plates become. Its thickness up to 100 mm can be found in the structures of a large-size ship, especially hatch side coaming. For vertical welding joints of the heavy-thick sections, electrogas arc welding (EGW) which is a single-pass vertical welding method is generally used in the field of shipbuilding. As a result of a large heat input welding process, the HAZ width becomes so wide; the microstructure of heat affected zone (HAZ) is coarsened and the properties of joints deteriorated. Steelmakers have developed a new technology which achieves high strength steel to reduce the designed thickness and high toughness in the HAZ to resist high heat-input welding processes. Consequently, a novel vertical welding process is strongly demanded to achieve higher efficiency and lower heat input for obtaining weld joints with higher strength and higher toughness.

Nowadays, the number of LNG-fueled ships is drastically increasing and more infrastructure projects are planned to replace the conventional oil-based fuel due to the particular emission regulations issued for the international maritime. Using the LNG removes SOx and particle PM emission completely and reduces NOx emission of up to 85%. For an increase in productivity of LNG tanks, weld joints strongly require the high-efficiency and high-quality welding process to decrease construction time and cost. Therefore, we would like to develop new welding processes instead of conventional arc welding processes in vertical welding using hot-wire laser method.

Firstly, a diode laser and a hot-wire system were applied for the novel single-pass vertical welding. The 6-kW diode laser as a heat source irradiated a controllable rectangular beam vertically fitting a thickness of steel plate and an-electrically heated filler wire up to its melting point as called hot-wire was used as deposited weld metal. A width of the beam was able to change to optimize power distribution. The width narrower than a 10-mm gap width was used with a weaving system to sweep the beam throughout the gap width. 2-mm and 4-mm beam widths with a 5-Hz exponential waveform having different power density were used. The 2-mm beam width had high power density on the groove surfaces that could not keep heating on the molten pool and some heat lost by high reflecting laser on above the weld pool. In other words, the 4-mm beam width could keep the molten pool and melt the base metal that was better than the 2-mm beam width. In addition, the beam could concentrate more power on the beam edges by using a high-edged energy beam type made by a particular optic lens that increased dilution and reduced lack of fusion on the groove edges. Consequently, the beam having the high-edged type and weaving system could optimal power distribution on the groove area. Then, 5%, 10% and 20% oxygen in argon shielding gas were studied in the effects of oxygen content on welds compared with argon shielding gas. The result showed that the better dilution could be observed by using 20% oxygen-added argon shielding gas rather than using argon shielding gas.

The novel vertical welding process could apply to a large size specimen similar to the fields. Due to the limited laser power of 6 kW, its thickness up to 28.5 mm could be applied. For the welded joint properties, the tensile strength met the requirement of the specification and the V-notch Charpy impact test result of notch location at weld metal showed high absorbed energy at -20^{0}C according to CTOD test results that exhibited the high resistance to brittle propagation at -10^{0}C. However, since grain boundary ferrite could be observed in the fusion line, the fusion line showed the unstable absorbed energy.

Then, twin diode lasers were employed to enhance the whole amount of laser power of 12 kW and the heavy-thick steel plate of 50 mm was used. In order to optimize power distribution on the groove, the first laser (LD1) irradiated a large rectangular beam stably which fitted the groove area with high energy density on both edges in its beam. The beam of second laser (LD2) was irradiated in three beam sizes in different power distribution as follows: a stable large rectangular beam, a narrow rectangular beam with weaving system having a beam width of 2 mm and 5 mm in order. Based on the adequate power laser and hot-wire system, the stable welding process could be observed during welding of three welding conditions. However, the cross-section of double stable laser beams showed very low dilution and narrow bead width and revealed the lack of fusion near the wire feeding side. Consequently, the stable beam with high-edged energy and both conditions of 2-mm and 5-mm weaving beams that achieved a sound joint could improve dilution on edges around plate surfaces and groove surfaces where the lack of fusion easily occurred.

To study the feasibility of using the novel vertical welding process for Ni steel plate, large specimens consisted of three different thicknesses 10 mm, 15 mm and 20 mm were used. At first, the welding conditions were optimized in each thickness such as laser power, a rectangular beam dimension, welding speed, etc. The proposed process achieved a stable weld pool formation and steady hot-wire feeding during welding in all specimens. The complete penetration could be obtained in the steady state and the cross-sections showed full penetration without lack of fusion. The joint properties of tensile test and Charpy impact test met the standard requirements. In case of the tensile strength, the breaking point was located at the weld metal due to the softer material, and Soft/Hard ration also affected the tensile strength result. The 10-mm specimen having higher Soft/Hard ration showed the least tensile strength value at the same gap width.