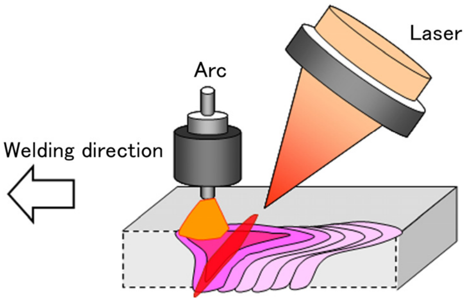
First Application of Hybrid Laser-arc Welding to Commercial Ships

Illustration of hybrid laser–arc welding



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Mitsubishi Heavy Industries, Ltd. (MHI) has been working to improve the accuracy of hull-block finishing and reducing the number of assembly operations for other blocks while mounted at the dock, aiming to establish a high-accuracy building method. One of the techniques we have introduced is hybrid laser-arc welding, which requires low heat and reduces welding deformation. In the past, this method has required a large initial investment, and it has not been popular in the shipbuilding industry, except at some European shipyards that specialize in passenger ships. We have developed a procedure that requires simple equipment and can be used while following conventional shipbuilding procedures. This method, which has already been applied to general commercial ships, is described below.

1. Introduction

A high-accuracy building method for general commercial ships is expected to reduce the time required to build a ship and improve the product quality. The method is expected to be an effective response to the intensifying competition from Korean and Chinese shipbuilders. To realize our goal, welding deformation needs to be reduced. We therefore considered the possibility of employing hybrid laser-arc welding in shipbuilding, which substantially reduces welding deformation. This welding method, which combines the advantages of laser welding and arc welding, was developed in the 1990s mainly by European ship builders and the Classification Society. It has been employed mainly by European shipbuilders that specialize in the construction of passenger ships and large yachts. The method makes use of low-heat welding, reducing the deformation of welded parts. However, it requires an initial investment in large-scale machinery equipment, and it has only been employed by a few shipbuilders, although they considered the possibility of introduction. We have developed a hybrid laser-arc welding method that does not require large-scale equipment and that can be used while following conventional procedures for butt welding steel plates. The welding method was approved by the Classification Society and has been applied to actual ships.

2. Challenges for Commercialization and Characteristics of Hybrid Laser-arc Welding

2.1 Investment in Large-scale Equipment

Hybrid laser-arc welding requires strict groove accuracy as well as machine cutting of grooves prior to welding because the quality is substantially influenced by the accuracy of the laser target during welding. Therefore, special large-scale equipment is required, including clamping equipment that prevents any shifting of the steel plates during welding. Furthermore, rustproof shop primers that are commonly used in the shipbuilding process and the temporary welding generally employed in the assembly process are issues in realizing quality welding. Therefore, it

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was believed that investment in large-scale equipment was unavoidable, and new processing stages had to be established in line with the introduction of the new equipment. However, we have developed and established a new method, thinking out of conventional hybrid laser-arc welding methods while relying on the advantages of conventional shipbuilding techniques.

2.2 Reduction of Welding Deformation

The process of cutting a part out of a steel plate, fitting the part, and forming a groove is important to ensure the accuracy of the groove. We decided to adopt hybrid laser-arc welding to take advantage of arc welding, which features a large tolerance for groove accuracy, is capable of absorbing small gaps, and uses a laser beam with a high energy density as the heat source. In this welding method, the narrow area at the end of the welding groove is penetrated deeply, reducing the heat input and the welding deformation.

The first stage of the development targeted butt-welded joints. The thickness of the steel plates was 4.5–13 mm, and the steel grades ranged from normal mild steel to high-tensile steel with a yield point of 36 kg. We conducted a survey of recent laser oscillator developments and selected a 10-kW fiber laser that featured a number of advantages such as high output and stable laser beam quality.

A numerical simulation was conducted to verify the effect of this welding method on reduction of welding deformation using a structure similar to actual ships. For the simulation, a model of the deck panel of a car carrier was used. Welding heat was input on the butt welding portion at the plate joint and the fillet welding portion on the longitudinal members to calculate deformation of the structure as a whole. Hybrid laser arc welding and arc welding were compared. **Figure 1** shows the calculated welding deformation. The deformation was reduced by about half by adopting hybrid laser-arc welding.

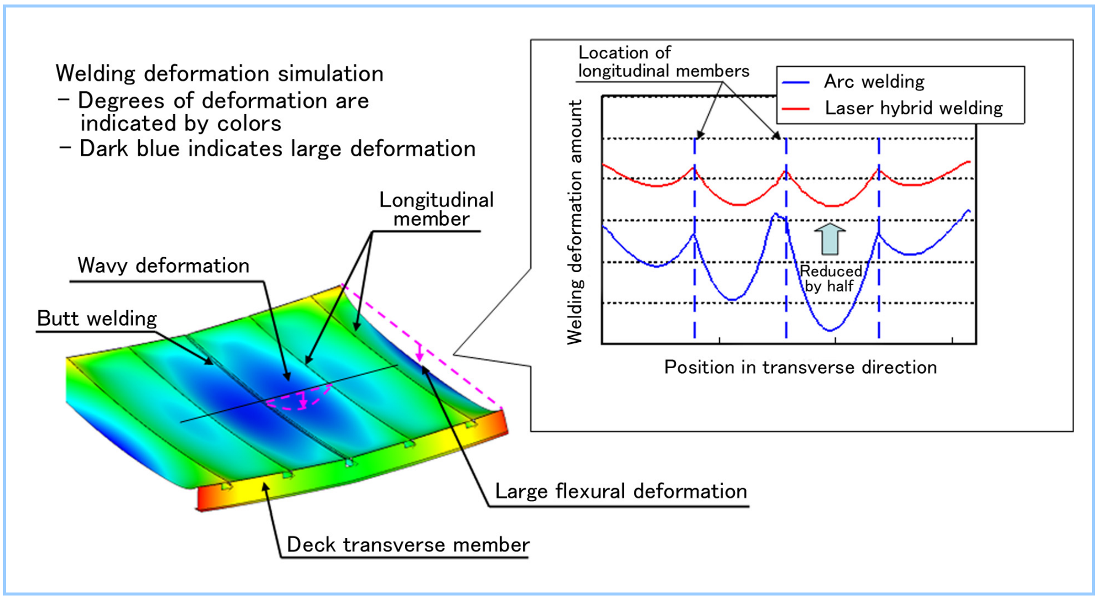


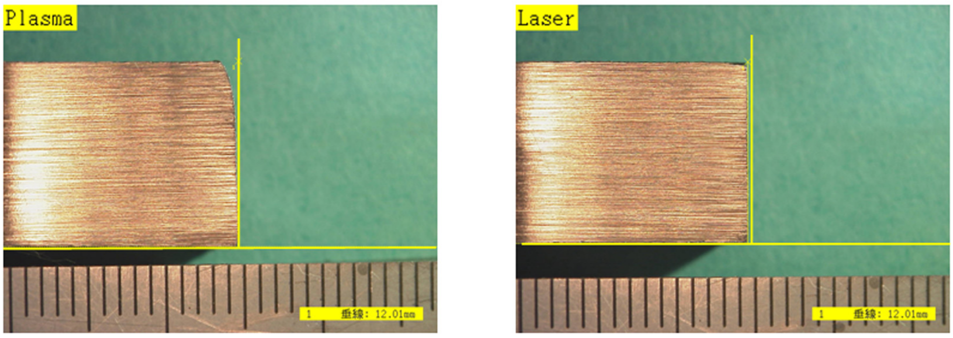
Figure 1 Calculation results of welding deformation

3. Development of the New Welding Method

3.1 Groove Treatment

For the groove treatment prior to welding, we considered existing equipment while comparing cutting accuracies by cutting the parts with the existing plasma cutter and a laser cutter so as to ensure adequate cutting accuracy. We also verified the influence of shop primers after cutting.

Figure 2 shows the groove surface difference between plasma cutting and laser cutting. The plasma cutting was inferior in terms of the flatness of the groove, and it generated oxide scale on the groove surface. In contrast, laser cutting created groove surfaces very high in flatness. To reduce the welding-heat input and consequently reduce the deformation, it is necessary to place the grooved surface closer to the weld so as to reduce the amount of welding metal to be filled. Judging from the results, and assuming that laser cutting will be employed, we decided to adopt hybrid laser-arc welding.



Plasma cutting   Laser cutting

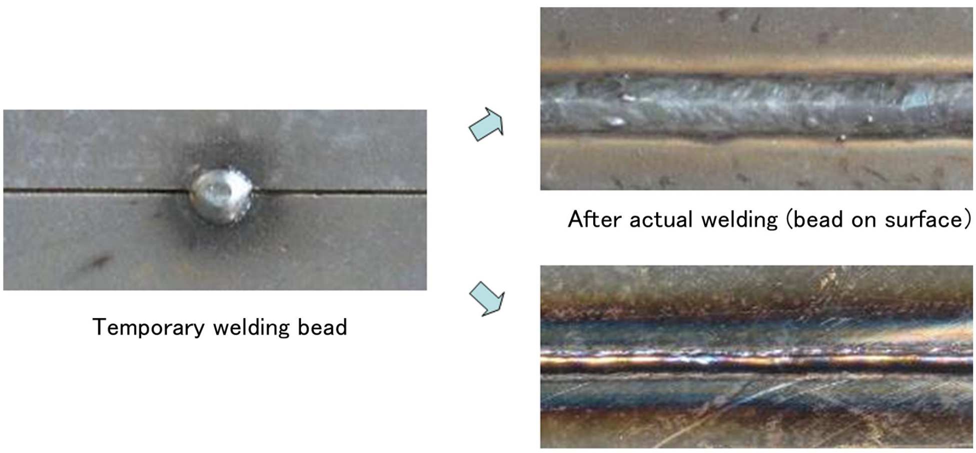
The flatness of the cut edge surface is higher for laser cutting than for plasma cutting

Figure 2 Verification of cutting methods and the cut edge surface

The steel plates were coated with shop primer, which was used to protect the material from rust until the final coating was applied prior to cutting. Shop primers generally tend to cause welding defects in arc welding when the coating film exceeds the allowable thickness. Because of this, European shipbuilders that have adopted hybrid laser-arc welding perform machine cutting after creating an appropriate processing environment to ensure the flatness of the grooved surface while simultaneously removing the shop primer. We have established a welding condition under which the laser cutting level remains the same as that used for general commercial ships. Unnecessary removal of slags from grooves and shop primer are avoided so as to expand the versatility of the technique.

3.2 Steel-plate Fixing Method

Steel plates are generally fixed by temporary welding. Conventional hybrid laser-arc welding requires large-scale clamping equipment to secure the whole area of the welded steel sheet because the temporary welding area actually increases the thickness of the plate, requiring increased laser output. Displacement of the steel plate due to thermal strain prevents the laser from accurately targeting the welding area. In developing our welding method, we employed temporary welding, and verified the welding conditions, with the aim of realizing appropriately welded joints. **Figure 3** shows the appearances of a temporary welding bead and surface, and the back side of an actual weld. We adopted the smallest possible point welding that could be melted easily by arc welding, which did not affect the laser welding. The bead surface of hybrid laser-arc welding was not affected by the temporary welding bead, and the weld metal was sufficiently melted. We also confirmed that the shape of the bead on the back side was free from influence of the temporary welding. We determined that sufficient welding quality could be attained by adopting appropriate welding conditions without using large-scale clamping equipment.



Temporary welding bead

After actual welding (bead on surface)

After actual welding (bead on back side)

Figure 3 Quality of actual welding at the temporary welding area

3.3 Groove Profile

The welding line is slightly displaced and deformed due to thermal stress caused by welding, and it is therefore not fixed at the same position throughout the welding process. Thus, a welding-line copying mechanism must be activated during the welding process. In addition, the gap of the groove does not always remain the same throughout the welding process, requiring the welding target to be kept constantly at an appropriate point. Therefore, we developed a system for real-time detection of both the profile and the gap of the groove, reflecting the detected value in the welding conditions. **Figure 4** shows the screen used to monitor the groove profile detected by a sensor. The welding line was copied while detecting the gap and unevenness of the groove so as to detect the optimal welding target and determine the optimal welding conditions.

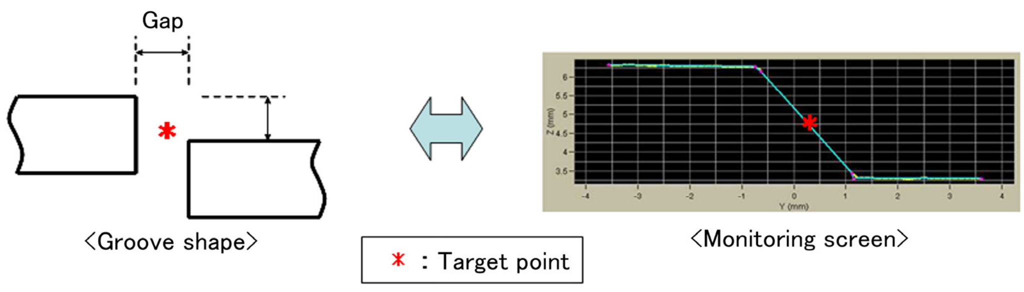
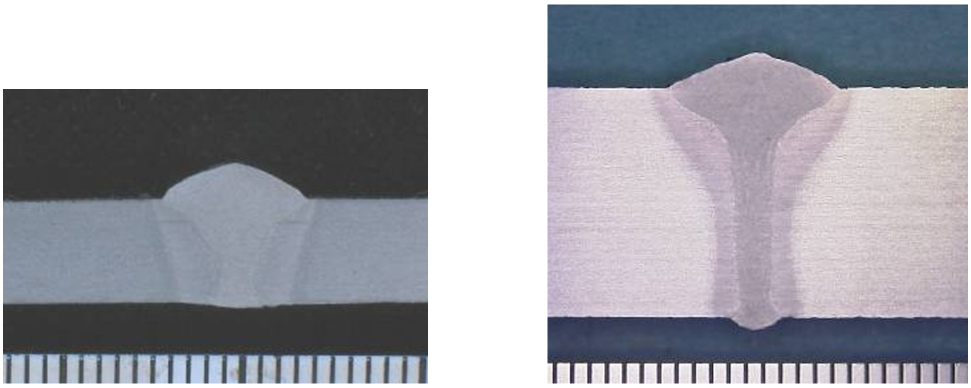


Figure 4 Welding target point detected by a welding profile sensor

4. Welding Procedure and Verification of the Weld Joint Quality

4.1 Welding Procedure

In hybrid laser-arc welding, the amount of welding heat is determined by four parameters: the welding current, welding voltage, welding speed, and laser output. When carrying out the welding procedure, the laser output and arc welding heat input were adjusted depending on variations in the accuracy of the grooves. **Figure 5** shows magnified cross-sectional views of the butt-welding beads for 5-mm AH36 and 13-mm AH36 material, as application examples of a this method on high-tensile steel. The welding conditions determined by the plate thickness and groove accuracy were automatically adjusted so that the width of the welding beads remained the same throughout the process.



5-mm AH36 material

13-mm AH36 material

Figure 5 Bead cross-sectional views for hybrid laser-arc welding

4.2 Verification of the Weld Joint Quality

We verified the quality of the weld joints prior to application of this method to actual ships. We selected arc-welding materials that matched the grades of steel to be used, and carried out every possible verification to obtain approval for the welding technique from the Classification Society. In addition to visual inspections, nondestructive inspections, tensile strength tests, flexural strength tests, hardness tests, macro tests, and Charpy V notch impact tests, which are generally required for welding approval, we also conducted fatigue tests and large-product fracture toughness tests.

Figure 6 shows the results of the Charpy V notch impact tests of an area joined by hybrid laser-arc welding. The method we have developed fully satisfied all of the values required by the tests shown above, and the weld joint quality was sufficient for application to actual ships. The method was approved by Nippon Kaiji Kyokai and Lloyd's Register of Shipping and is currently being adopted for construction of actual ships.

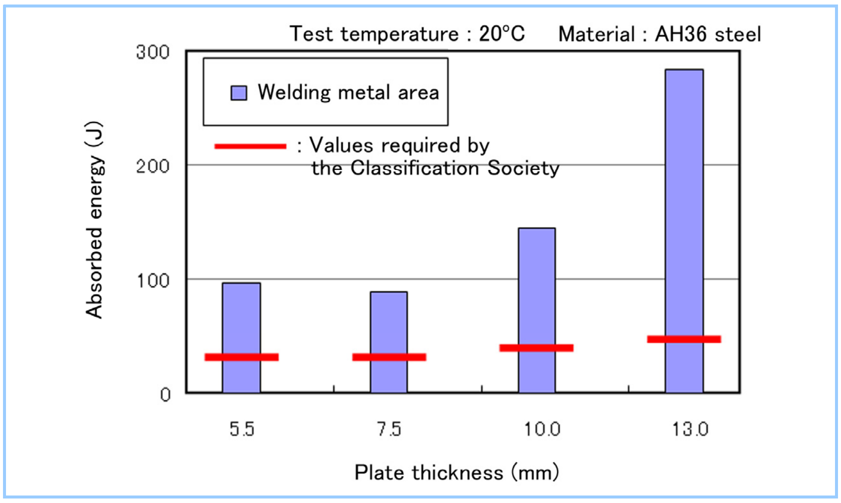


Figure 6 Results of impact tests on welding metals

5. Application to Actual Ships

5.1 Configuration of the Welding Equipment

Much of the welding equipment is mounted on large gantries, and simple welding equipment is rarely commercialized. Some of the European shipbuilders that construct large passenger ships have adopted large-scale equipment and use it in plants that exclusively build passenger ships. However, it is difficult for shipbuilders that construct general commercial ships to invest in equipment that can only be used for this task. Therefore, we decided to utilize a welding dolly that is commonly used for butt welding and focus on the standard butt-welding method. Our aim was to adopt the same processing method that is currently employed for the welding procedure as much as possible. An outline of the equipment is shown in **Figure 7**. A laser-welding torch, an arc-welding torch, and a wire-feeding device for arc welding were mounted on the welding dolly. A laser sensor to copy the welding line was also mounted on the dolly. The dolly moved on the rail that ran along the welding line to carry out the welding.

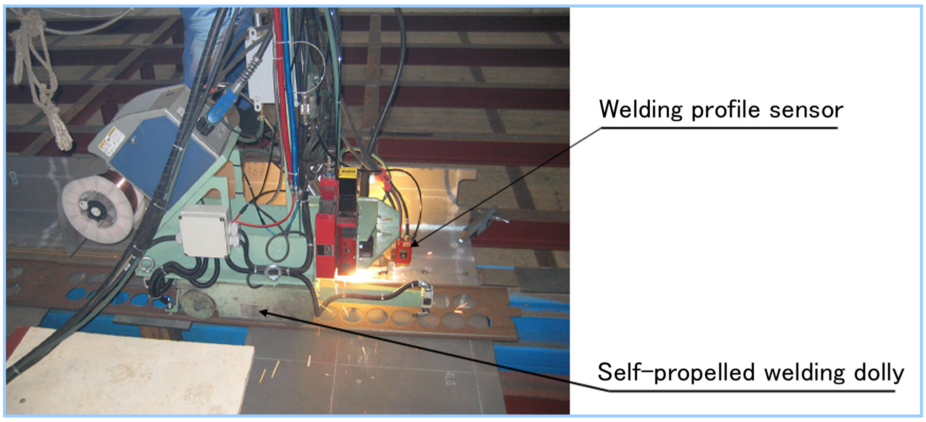


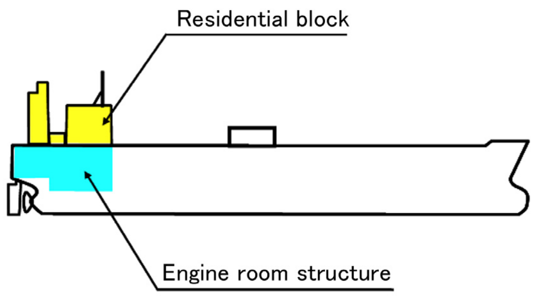
Figure 7 Appearance of the dolly used for hybrid laser-arc welding

5.2 Application to Actual Ships

This welding method has been applied to general commercial ships since February 2010. This method is intended for very large crude carriers (VLCCs), container vessels, and cryogenic carriers (LNG or LPG carriers). The welding method has been applied to butt-weld joints of comparatively thin steel plates that are used in the upper structures of the hull and walls of the engine room and are 13 mm or less in thickness, after considering the plate thickness and the steel grade.

The areas where this method has been adopted in an actual ship are shown in **Figure 8**.

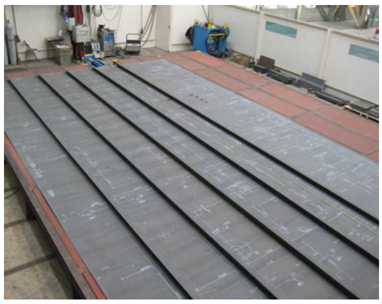
Figure 9 shows how butt welding is actually processed on the upper structure. The deformation after welding was limited, and the method has proven effective for constructing high-accuracy blocks, which was the goal of this project. We plan to further expand the areas where this technique can be used in the future.



Applied to butt-welded joints of comparatively thin steel plates in areas such as the residential block and the engine room structure.

Figure 8 Areas where the method has been applied in an actual ship

Welding operation



Condition after welding

Figure 9 Application to block butt-welded joints

6. Conclusion

Hybrid laser-arc welding has long been confirmed as an effective technique for shipbuilding. However, its adoption has been limited to some European shipbuilders specializing in passenger ships; it is not popular among builders of general commercial ships, and its use is hindered by the initial equipment investment. Hybrid laser-arc welding developed by MHI and used in actual ships does not require an initial investment in large-scale welding equipment or any new processes. We have confirmed that this method can be used in the same manner as conventional welding.

We are planning to expand the application of hybrid laser-arc welding to fillet welding based on our experiences gained in butt welding, and we expect to obtain approval from the Classification Society for this in the near future.

If the majority of butt-welding and fillet-welding procedures, which are necessary for block manufacturing, can be done by low-heat welding methods such as hybrid laser-arc welding, deformation after welding will be reduced, reducing strain release operations, and the accuracy of block building will be improved, providing a large step toward establishing a high-precision shipbuilding method.

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