Robotic Welding System for Shipbuilding

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As a world-leading welding solution company, Kobe Steel began working on the automation of shipbuilding. A robotic welding system has been developed to be applied to the assembling processes in shipyards. The system includes a robot controller compatible with the small robot that enters hull blocks, a robot carrier for moving within blocks, and robot-program-preparation software allowing offline teaching using 3D models. This paper introduces our robotic welding system offering welding solutions, which integrates all the elements, including the development of optimum welding wires and welding techniques such as gap filling.

Introduction

Kobe Steel, a world-leading welding solution company, is promoting efforts to automate shipbuilding. Like other industries, the shipbuilding industry requires efficiency improvement, including multi-skill development and labor saving, due to the shortage and aging of welders. The lack of skilled workers is increasingly being felt.

This paper introduces a robotic welding system newly developed for ship assembly to improve productivity.

1. Advantage of robotic welding system for assembly

1.1 Robotic welding system

Large ships are built by a method called block building.[1] A shipyard has a block assembly shop, in which blocks of the partial hull are made through the steps of cutting, processing, assembling, etc. These blocks are eventually connected in a dock or on a bench to build a ship (**Fig. 1**, **Fig. 2**).

In order to make these blocks, a robotic welding system has been developed with the functions necessary for the assembling process.

In order to perform welding in a block, a robot must be installed in its space surrounded by other parts. The robot must be placed in a limited space, and the welding operation must be performed there smoothly. The robot must be a small one optimized for this purpose (**Fig. 3**).

The robot body is mounted on a compact, lightweight robot carrier designed for transportation, and in this state, it is suspended from a crane and moved from one block to another. When the robot carrier is lowered inside a block, the robot is fixed in position by an automatic positioning device. Then the target robot program is selected to start welding (**Fig. 4**).

Kobe Steel has developed a controller for such welding robots by exploiting its strengths, such as arc sensor technology enabling the tracking of thermally deformed welding surfaces, and vibration control technology. The newly developed controller is a dramatically improved version of

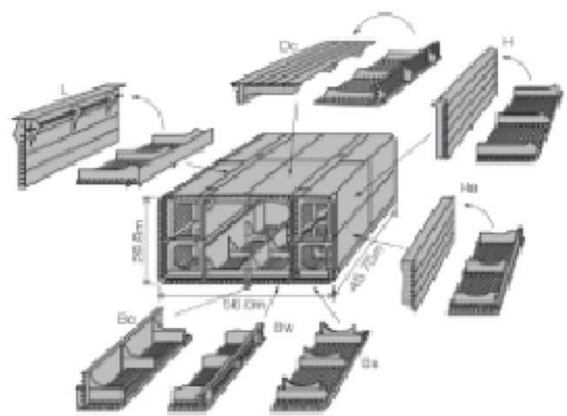


Fig. 1 Hull structure

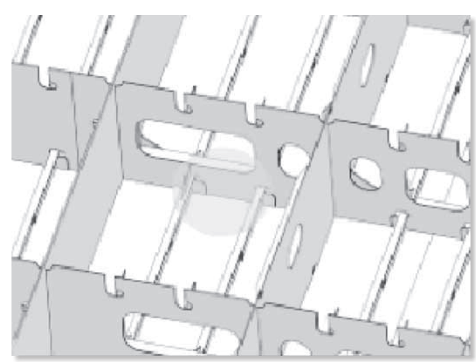


Fig. 2 Welding targets

Fig. 3 Small size welding robot

the conventional CB controller, in terms of (1) upgraded performance, (2) upgraded function, and (3) simplification, taking into consideration safety, maintenance, and system construction.

1.2 Locations where robot applies

A welding robot performs welding at locations between longitudinal elements and transverse elements between the two sides of a hull. **Fig. 5** shows the joints that are the targets of robotic welding.

1.3 Teaching software (SMART TEACHING™ note 1))

During the assembling stage, many members with similar linear shapes are arranged in the parallel part; however, it is not efficient to teach robots online using a real machine because the sizes of members vary.

Designing based on 3D models has been used in various fields.[2] In the field of shipbuilding it was used early on, as a large number of parts were involved, and 3D design was useful in checking such details as the placement of the parts.

Hence, Kobe Steel has developed an offline teaching system, "SMART TEACHING™," in which 3D models of shipbuilding blocks are used for teaching robots.

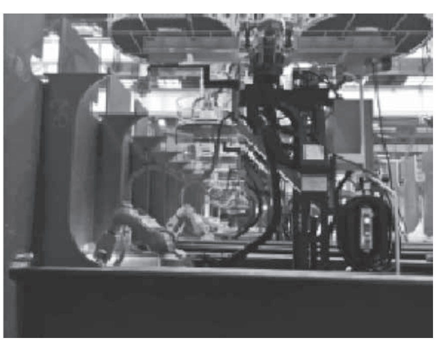


Fig. 4 Application of welding robot to ship assembly

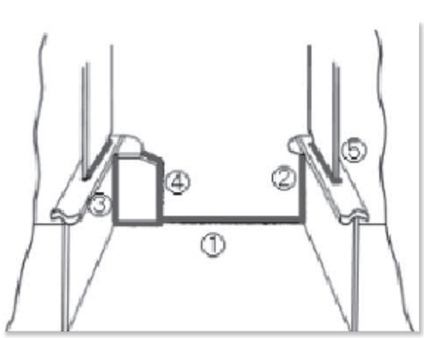


Fig. 5 Robotically welded joints

1) Reading of 3D model data

The 3D models used for this system are compatible with the general-purpose data format (STEP format). Thanks to this, it is possible to read data from various CADs without depending on any one specific CAD.

2) Automatic extraction of welding lines in blocks

The general-purpose format carries no information unique to a specific CAD (e.g., welding information). Hence, the graphic information included in the model shapes has been used to identify the shapes of the members constituting each shipbuilding block so that the intersections between the members are recognized as the positional information of welded joints. For example, it recognizes horizontal fillet joints where transverse elements and shell plates intersect and vertical fillet joints where longitudinal elements and collar plates intersect.

These coordinate data and the data on member shapes are collected and extracted as welding information data (**Fig. 6**).

3) Preparation of robot teaching program

The welding information data has been used to recognize the start/end positions of welding lines and to determine the robot motion to perform the welding. Then the motion corresponding to the member shapes, such as sensing, and the welding conditions corresponding to the member shapes and welding position were assigned to prepare the robot teaching program (**Fig. 7**).

The position matching between the instruction program and the actual work pieces (calibration) is not done by software, but by the positioning device on the robot carrier. Once the teaching program is sent to each robot, welding can begin.

1.4 Welding work

Among the welding stages of shipbuilding, the

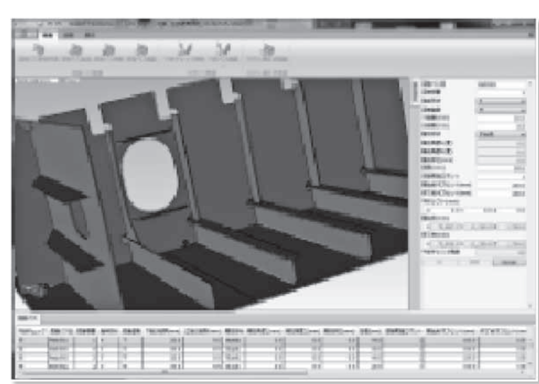


Fig. 6 Software to detect welding lines

note 1) SMART TEACHING is a registered trademark of Kobe Steel (No. 05645545).

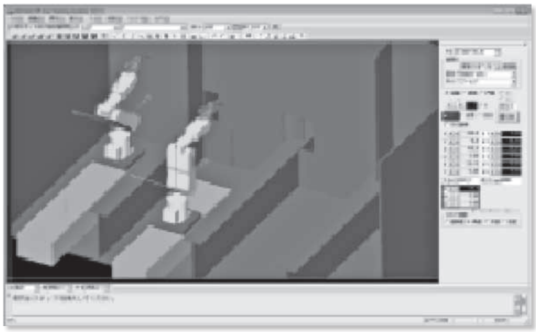


Fig. 7 Robot teaching simulation

Table 1 Wire Evaluation

Welding position	Evaluation item	Wire	
		DW-100	DW-100V
Vertical upward	Bead appearance	○	◎
	Welding speed	○	◎
	Gap tolerance	○	◎
Horizontal fillet	Bead appearance	◎	△
	Welding speed	○	○
	Boxing weld	○	△

*1) Wire evaluation ◎ : excellent ○ : good △ : normal

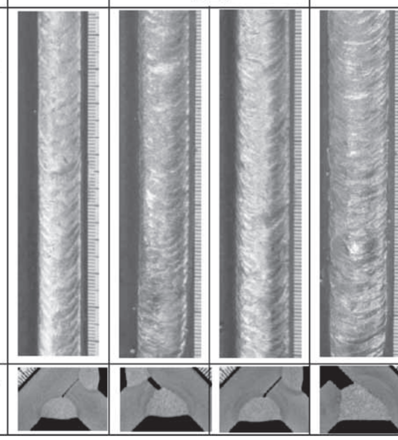
Wire	DW-100			
Welding currents (A)	220	220		200
Welding Speed (cm/min)	16	12		6
GAP (mm)	0	3⇒0 (shift)		5
Bead appearance				
Macrostructure				

Fig. 8 Gap tolerance for vertically upward welding

assembly stage occupies the greatest ratio, using more than half of all the welding consumables. Most of the welding done in assembly employs flux-cored wires (FCW). Typical wires for shipbuilding include FAMILIARC™ note 2) DW-100, which can be used in all positions, and FAMILIARC™ DW-100V, which has excellent gap tolerance and enables highly efficient welding in the vertically upward direction.

Welding performance was confirmed by the aspect shown in **Table 1** to find out which wire is more suitable for robotic welding. As a result, FAMILIARC™ DW-100 was adopted; it can be used in all positions.

In order to introduce a robot into the actual production line, preparation must be made for various welding situations. The following describes the three points involved in the preparation for the introduction of a robot into the production line.

1) Welding with gaps in vertical positions

Because of the structure, in which transverse elements are inserted in longitudinal elements, there are inevitable gaps between the transverse elements and longitudinal elements in an assembly. The gaps created are not uniform, ranging from approximately 0 mm to 4 mm.

Hence, the welding conditions corresponding to each gap dimension have been developed as shown in **Fig. 8**. At that time, arc tracking performance, the basic performance of a robot,[3] was also confirmed. This has enabled the tracking of welding lines during vertical position welding even with thermal deformation occurring during the welding and/or when transverse elements are tilted.

2) Welding of collar plates

For each target workpiece, welding conditions must be established not only for vertical position welding and horizontal fillet welding, but also for the oblique welding of collar plates, where the welding switches from a vertical position to that of horizontal fillet welding, and for the corner parts of collar plates of different shapes so as to smooth the appearance of their beads.

This time, the positions at which switching from vertical welding positions to oblique joints or to corner parts takes place are judged by the dimensions of gaps in the teaching software so as to optimize the welding conditions for each joint and to realize a smooth bead appearance as shown in **Fig. 9** and **Fig.10**.

3) Corner filling and intersection between horizontal fillet and vertical position welding

There are gaps opening in the corners before welding, and welding conditions must be established to close these openings. Also, welding conditions must be devised to achieve a favorable appearance at locations where horizontal fillet welding and vertical position welding intersect. The shape of each gap is like a triangle, widest at the bottom and gradually narrowing upwards. Therefore, the weaving width of the welding

note 2) FAMILIARC™ (FAMILIARC™) is a trademark of Kobe Steel.

Fig. 9 Robotic welding result A

Fig.10 Robotic welding result B

robot has been changed to match the shapes and to fill the gaps. Subsequently, the vertical position welding continues without stopping the arc, so as to eliminate bead connections. In the case of horizontal fillet welding, a backstep operation has been applied so that the gap is overlapped on the bead after filling before applying the main welding conditions. This has enabled a favorable bead appearance to be made at each intersection (**Fig.11**).

2. Current work

2.1 Development of FCW designed for welding robots

Currently, works are being done to improve the efficiency of robotic welding. One of them is a study being conducted to improve the efficiency from the aspect of welding consumables.

In the target portions of robotic welding, vertical position welding occupies much of the welding time. The efficiency improvement essentially requires the improvements in efficiency and quality of vertical

Fig.11 Intersection of hull member after welding

position welding.

As described in Section 1.4, there is FAMILIARC™ DW-100V, an FCW realizing high efficiency in vertical position welding. This consumable, however, has a slight disadvantage in the horizontal fillet bead shape and welding condition tolerance.

Since horizontal fillet welding and vertical position welding are mixed in a series of tasks, a robot, which cannot distinguish welding consumables, must perform both welding jobs with one welding wire.

Hence, the wire design has been reexamined on the premise of using the wire with welding robots. An FCW, "FAMILIARC™ DW-100R," designed for robotic welding, has been developed to be used in combination with a robot to realize both horizontal fillet welding and vertical position welding at high efficiency.

FAMILIARC™ DW-100R can produce weld metal with adjusted viscosity and slag generation, etc., and also can be optimally controlled when combined with the CB controller. As a result, the workability in the vertically upward direction has been improved while maintaining the same fillet welding workability as that of FAMILIARC™ DW-100.

Fig.12 shows the bead appearance and cross-sectional macrostructure of horizontal fillets. It is shown that FAMILIARC™ DW-100R has achieved the same bead appearance and shape as that of FAMILIARC™ DW-100 with an undercut smaller than that of FAMILIARC™ DW-100V.

Fig.13 shows the bead appearance and cross-section for vertical position welding. FAMILIARC™ DW-100R is capable of welding with a higher electric current and higher welding speed comparable to those of FAMILIARC™ DW-100 in the vertically upward welding and results in a favorable bead appearance and cross-sectional shape.

Furthermore, it has an improved gap tolerance and enables welding with a small leg length at a

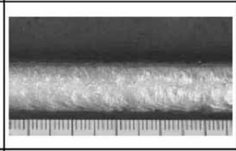
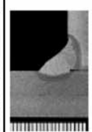
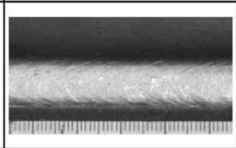
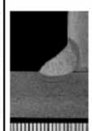
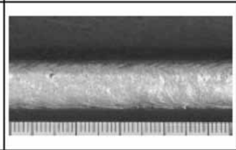
Wire	Bead appearance	Macro structure	Under cut (mm)
DW-100R			0.09
DW-100			0.09
DW-100V			0.14
*1) Welding by robot system *2) Leg length (Target) : 6mm *3) Welding current: 260A Travel speed: 40cm/min *4) Wire dia.: 1.2mm			

Fig.12 Bead appearance and macrostructure of horizontal fillet welding

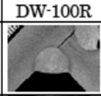
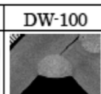
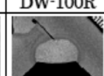
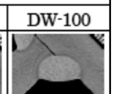
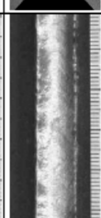
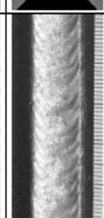
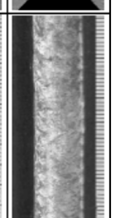
Leg length (Target) (mm)	6		8	
Wire	DW-100R	DW-100	DW-100R	DW-100
Macro structure				
Bead appearance				
Welding current (A)	240	220	240	220
Welding speed (cm/min)	25	23	18	16
*1) Welding by robot system *2) Wire dia.: 1.2mm				

Fig.13 Bead appearance and macrostructure of vertically upward welding

high welding speed in a wider gap range. **Fig.14** shows the bead appearance of vertical position welding at a gap width of 5 mm.

FAMILIARC™ DW-100R is acquiring shipping approval equivalent to that of FAMILIARC™ DW-100, even in semiautomatic welding, besides shipping approval in fully automatic welding, so that it can be used for the rework after robotic welding and areas other than robotic welding.

2.2 Work toward Internet of Things (IoT)

The Internet of Things (IoT) is attracting

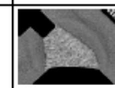
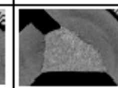
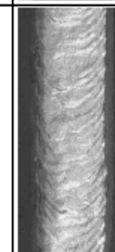
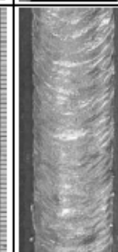
Wire	DW-100R	DW-100
Macro structure		
Bead appearance		
Welding current (A)	200	200
Welding speed (cm/min)	8	6
Leg length (mm)	10	13
*1) Welding by robot system *2) Wire dia.: 1.2mm		

Fig.14 Bead appearance and macrostructure of vertically upward welding (Gap: 5mm)

Fig.15 Example of IoT

worldwide attention, including Industry 4.0 proposed by Germany, the Industrial Internet Consortium (IIC) established by five US companies and the IoT Acceleration Consortium in Japan. Sensors are installed in machinery or equipment, and the data is collected via a network to be analyzed for improving the efficiency of operation while reducing the cost of maintenance. Machines are controlled and operated remotely to achieve labor saving. These are a few examples of the developments seen in various organizations.

In Kobe Steel, welding robots are connected to production-support PC software (AP-SUPPORT™) to promote information visualization via the robots. The visualization of the operation data and error status can prevent short time breakdown and improve productivity. In the CB controller, an arc monitor is used to collect welding status data to check any trouble-causing phenomena, and a production monitoring camera is used in parallel for grasping more detailed status (**Fig.15**).

Conclusions

This paper introduces a welding robot that can enter narrow, limited spaces inside a workpiece to perform welding work and newly developed teaching software incorporating optimum welding conditions and motions. A robotic welding system incorporating the above for the assembly process in shipbuilding is also introduced. This system can be operated by a few workers and contributes to improving the production efficiency of the welding stage.

As a welding solution company, Kobe Steel will continue to strengthen the product lineup for each welding stage in shipbuilding blocks, from single-sided submerged arc welding apparatuses for the plate splicing processes to robotic systems for the sub-assembling and assembling processes. At the same time, the company will continue to work on the development of automated welding solutions, including strengthening the lineup of welding consumables.

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