Robotic Welding System with New Equipment for Steel Structures

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Abstract

A state-of-the-art welding robot system has been developed for architectural steel frames, featuring the latest technology such as the ARCMAN™ A60 manipulator and the SENSARC™ RA500 welding power source. The system is aimed at increasing productivity and has a reduced cycle time compared with the previous model. This paper provides an overview of the system's components, highlighting the technology that has contributed to the reduction in cycle time. Specifically, the REGARC™ process is covered in detail, which has been improved by the new welding power source, and the welding wire, which now benefits from surface treatment for improved feedability. These advancements have resulted in highly efficient welding conditions, improving the welding current and speed compared with conventional welding techniques, as outlined in this paper. Additionally, the development technology used to create the system equipment is described.

Introduction

Recent years have witnessed a consistent annual demand for steel in architectural frames in Japan, stabilizing at approximately 4.6 million tonnes per year [1]). This demand is anticipated to endure, as there is a pressing need to replace buildings erected during the high economic growth period. However, this scenario poses a challenge due to a shortage of welding technicians, highlighting the imperative for enhancements in both productivity and welding quality. Consequently, there are ongoing initiatives to automate the welding process in the domain of architectural steel frames.

The automation for the welding process of architectural steel frames can be broadly categorized into two primary types: in-factory welding automation and construction site automation. These approaches further break down into automation using vertically articulated robots and automation employing simplified portable robots.

This paper specifically concentrates on in-factory welding automation within the facilities of steel-frame fabricators and introduces a welding robot system that utilizes a vertically articulated robot, known for its benefits of prolonged continuous operation and high productivity.

1. Background of system development

The robotic automation of welding processes for the in-factory settings of architectural steel frames presents challenges due to the unique distinctive feature of each welded structure and the great thickness of the plates involved. The evolution of such robotic automation has involved incorporating mechanisms for automatically generating programs through software technology, enhancing robot functions for multi-layer welding, and integrating equipment to facilitate unmanned operation.

Steel frame fabricators, undertaking the installation of new robot systems, aim not only to introduce cutting-edge equipment but also to modernize existing systems, increase production volume, and reduce labor requirements. In response to such needs, Kobe Steel has been conducting product development to reduce cycle times and contribute to increased productivity. As for cycle time reduction, efforts have been made to shorten both welding and non-welding times. For welding time, a specific focus has been placed on developing welding conditions for cold-formed angular steel columns (hereafter referred to as "columns").

2. System Advantages and Configuration

The advantage of Kobe Steel's welding robot system for architectural steel frames lies in its ability to facilitate robot welding for workpieces, each unique and distinctive, without the need for manual teaching of welding paths or conditions on the actual machine. This comprehensive system comprises a welding robot, welding power source, welding wire, a positioner for mounting and posturing workpieces to be welded, a transfer device with a robotic manipulator to expand the range of motion, equipment associated with continuous operation, and steel frame software that automatically generates robot programs. **Fig. 1** displays an exemplary welding robot system for architectural steel frames.

This system introduces newly developed

Fig.1 Structural steel large assembly welding robot system

robotic functions, such as the capability to rectify discrepancies in root gaps that may occur during workpiece assembly and an arc-sensor function to monitor workpiece deformation during welding. Additionally, the system ensures seamless robotic rerun for grooved multi-layered welding by incorporating standard devices for exchanging short/long nozzles, an automated slag remover, a wire cutter, and torch cleaner.

The steel frame software encompasses multiple welding conditions categorized by target joints. Users can access specific welding conditions for each joint by inputting relevant joint information. Two types of welding conditions are offered: one for constant voltage welding and the other for welding utilizing the low-spatter REGARC™ process, which ensures stable globular transfer through pulse waveform control.

The REGARC™ process significantly reduces spatter generation during welding, compared with the constant voltage welding method, thanks to its combination of pulse waveform control and dedicated welding wire. Consequently, the spatter adhering to the base material surface is minimized, reducing the need for spatter removal work in subsequent processes.

The following sections delve into the enhanced performance of the REGARC™ process, made possible by a new power source, welding wire, high-efficiency welding conditions resulting from their use, and technology developed for the system equipment.

3. Welding work [2), 3)]

3.1 Improvement of REGARC™ process

3.1.1 Stability improvement of droplet transfer against changing wire extension length

The REGARC™ process alternately outputs two pulse waveforms with different peak currents to stabilize droplet formation and detachment, thereby achieving low spatter during globule transfer in carbon dioxide arc welding. However, a challenge has been the instability of droplet transfer and increased spatter due to the variation in wire extension length, which changes during welding, causing fluctuations in arc length.

The primary joint shape of welding structures for architectural steel frame is a single bevel groove with a gap. During the welding process, a weaving operation is performed to ensure a sound joint, including penetration. However, this weaving operation causes the wire extension length to change at both ends of the groove. This change in wire extension length leads to spatter generation, and in particular, spatter generated on the groove side may adhere to the vertical surface of the workpiece.

Fig. 2 illustrates an example of the mechanism where changes in wire extension length result in the instability of droplet transfer and the generation of spatter. When the wire extension length changes during welding, the base period of the pulse is modulated to track current changes. The base period that has become shorter due to modulation results in insufficient energy, preventing the droplet from adequately growing, leading to insufficient squeezing and weight of the droplet itself. This causes the droplet to be unable to detach with appropriate timing. The droplets that cannot detach may gradually grow and enlarge over time. These enlarged droplets can transform into large-sized spatter due to their contact with the molten pool and the repulsive force of the arc, among other factors [4)].

To tackle this mechanism, enhancements have been made to improve the stability of droplet transfer and mitigate spatter generation while restraining arc length fluctuations in the globule transfer region, as depicted in **Fig. 3**.

In the conventional control method, only the base period for droplet formation has been modulated. However, in the new approach, both the base period and the pulse's peak current are modulated simultaneously to ensure sufficient energy for melting the wire and forming droplets. Furthermore, by ensuring a sufficient duration of the pulse's base period during the droplet formation phase,

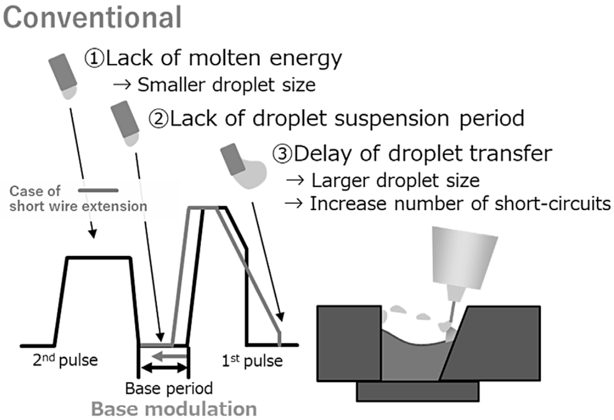

Fig.2 Spatter generation mechanism

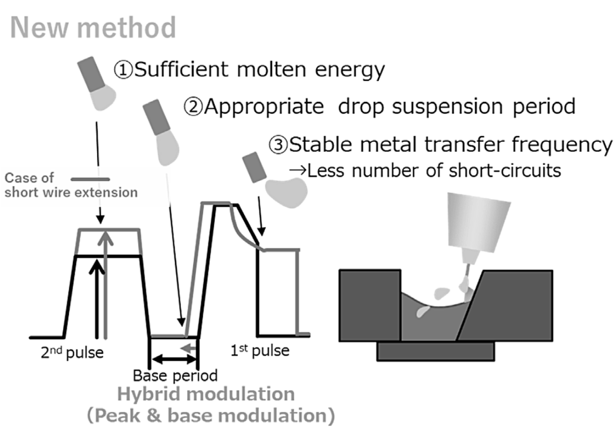

Fig.3 Method for reducing spatter generation

more stable droplet formation has been achieved. Additionally, by introducing a fixed current section during the pulse's descent period in the droplet detachment phase, the success rate of droplet detachment within the specified droplet transfer period has been increased. As a result, excessive droplet growth has been restrained, leading to a reduction in the generation of large-sized spatter. In the new REGARC™ process using the welding power source RA500, the basic waveform of the conventional REGARC™ has been retained, but waveform control has been further optimized to enhance the stability of the droplet transfer mode in the globule region and reduce spatter. **Fig. 4** shows a comparison of droplet transfer phenomena inside a groove.

3.1.2 Expansion of welding current region

As a result of enhancing droplet transfer stability, the wire feed speed in REGARC™ has been increased to 18.0 m/min from the conventional 16.4 m/min, and the maximum welding current has been expanded from 320 A to 340 A. This, as will be described in section 3.3, has contributed to realizing high-efficiency welding.

Figs. 5 and **6** compare the droplet transfer modes of the conventional REGARC™ process and the new REGARC™ process at a wire feed speed of 18 m/min and a set welding current of 340 A. In Fig. 5, the conventional method exhibits large spatter resulting from droplets growing and short-circuiting with the molten pool. However, in Fig. 6, the improved control method demonstrates regular droplet formation and stable droplet detachment.

3.1.3 Regarding the occurrence of spatter in the groove of steel frame structure

The new REGARC™ process also enhances stability in the droplet transfer mode within the conventional welding current range. Column specimens with a thickness of 22 mm, simulating the structure of an architectural steel frame, were welded using both the conventional REGARC™ process and the new REGARC™ process. **Figs. 7** and **8** show the results of comparing the amount of spatter generated when the gap is 4 mm and 10 mm. Under the welding conditions of a set current of 280 A and a wire feed speed of 13.8 m/min, the amount of spatter generated is reduced for both gap conditions of 4 mm and 10 mm. This suggests that even with gap variations due to assembly errors, compared to the reference gap of 7 mm, a reduction in spatter is still observed.

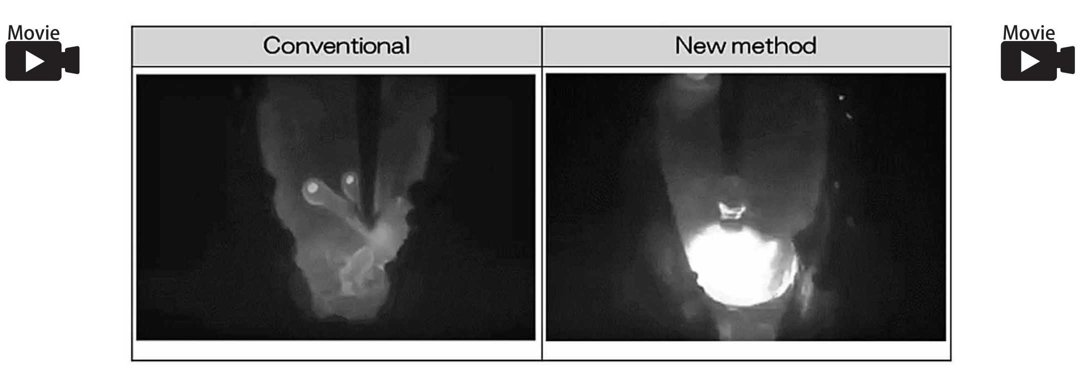

Fig.4 Observation of Metal droplet transfer in welding groove

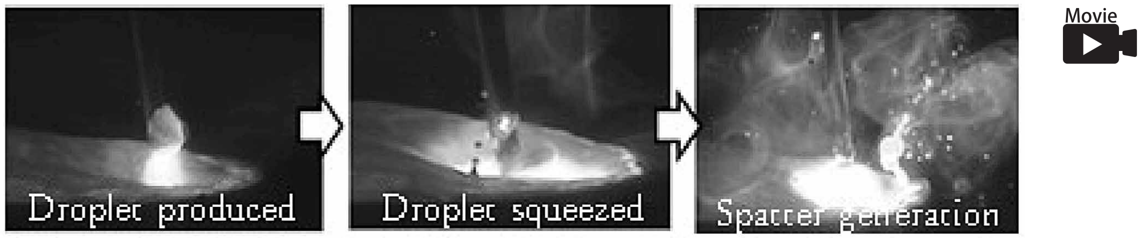

Fig.5 Metal droplet transfer by conventional process

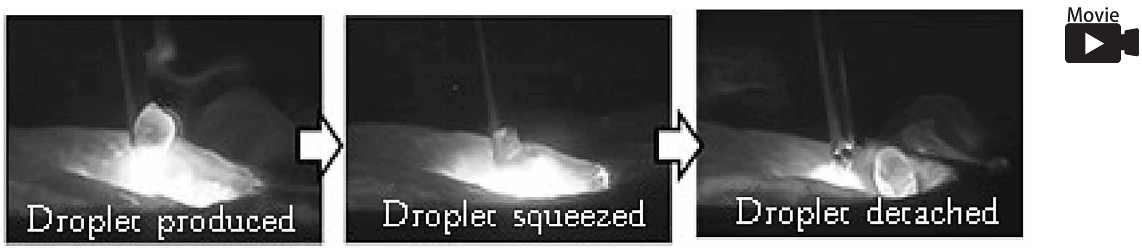

Fig.6 Metal droplet transfer by new process

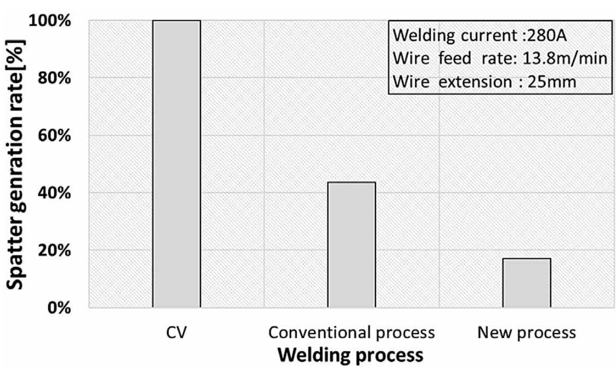

Fig.7 Comparison of spatter generation rate between conventional process and new process (column t: 22mm, gap: 4 mm)

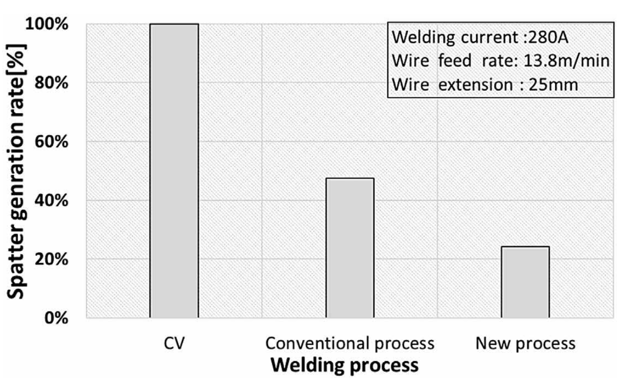

Fig.8 Comparison of spatter generation rate between conventional process and new process (column t: 22mm, gap: 10mm)

3.2 Development of dedicated welding wire

The welding wire used in the present process must be capable of responding to an increase in the wire melting rate, which corresponds to an increase in wire feed speed, compared with the conventional process. As the wire feed speed increases, the reaction force experienced by the wire from the feeding path's inner surface also rises, making it more challenging to maintain a stable wire feed speed. When assuming intermittent, long-duration continuous welding, it is essential for wire feedability to be of superior quality to suppress variations in the wire feed speed and achieve stable welding.

Factors that can influence variations in wire feed speed include the curvature of the feeding path and clogging due to solid matter within the feeding path. Regarding the curvature of the feeding path, the robot system is designed to avoid extremely small curvature radii. And here, the focus is placed on the details of clogging due to solid matter within the feeding path.

The packaged wire installed in the robot system, passes through the feeder from the flexible conduit, and then travels through the conduit liner within the torch cable and the inner tube inside the welding torch before being supplied to welding via the contact tip while receiving power. During this process, solid matter such as copper dust generated from the wire surface continues to deposit on components like the conduit liner, inner tube, and contact tip located downstream of the feeder. This deposition can negatively impact wire feedability and arc stability. In particular, the contact tip, located at the tip of the wire feeding path, has a small clearance with the wire, making it more prone to clogging due to solid matter. While regular cleaning of the feeding path can help mitigate the effects of the deposited solid matter, it may not be practical to clean the feeding path frequently, especially when considering the continuous operation capability of the robot system.

The New REGARC™ dedicated wire, as shown in **Table 1**, has the advantage of suppressing the amount of clogging in the feeding path compared with conventional wire, even under severe welding conditions with high welding current, as demonstrated in **Fig. 9**. This advantage is mainly achieved through a special treatment of the wire surfaces during the wire manufacturing process. The treatment reduces the sliding friction resistance between the wire surface and the conduit liner or inner tube, making it less likely for the copper plating on the wire surfaces to fall off within the feeding path. By applying the New REGARC™ dedicated wire, it is possible to achieve stable welding performance even during extended periods of continuous welding.

3.3 High efficiency welding conditions for columns

As described in section 3.1, the new REGARC™ process enables an increase in welding current and wire feed speed, as shown in **Fig.10**. Leveraging the expanded range of welding current and wire feed speed, new welding conditions have been developed for welding around columns and through diaphragms. These newly developed high-efficiency welding conditions maintain the heat input for each path below 30 kJ/cm, similar to the conventional process, while achieving cycle time reduction by increasing welding current and welding speed. This is accomplished while maintaining mechanical performance equal to that of the conventional REGARC™ process.

3.4 Joint performance

The welding conditions for the conventional REGARC™ and the newly developed welding conditions were used to evaluate a test piece resembling a joint between a 32 mm thick column and a through diaphragm. The inter-pass temperature between welds was maintained below 250℃, and FAMILIARC™ MG-56R(A) was used for the welding wire. **Table 2** presents a comparison of the mechanical performance of the welded joint, as determined by the results of tensile tests and Charpy impact tests for the weld metal. It should be noted that the Charpy impact test was conducted at a depth of 7 mm from the upper surface of the column in the direction of the plate thickness. Both the tensile strength and Charpy impact test values satisfactorily meet the standards required for architectural steel frame, similar to the conventional method. Moreover, as demonstrated by the cross-sectional macrophotographs in **Fig.11**, comparable results were obtained for the penetration depth achieved by the conventional method and by the newly developed conditions.

Table 1 Products applied New REGARC™ process

Products' name	JIS Z 3312 classification	T.S. grade of deposited metal
FAMILIARC™ MG-50R(A)	YGW11	490MPa
FAMILIARC™ MG-56R(A)	YGW18	550MPa
TRUSTARC™ MG-60R(A)	G59JA1UC*	590MPa

*Index of chemical composition ; 3M1T

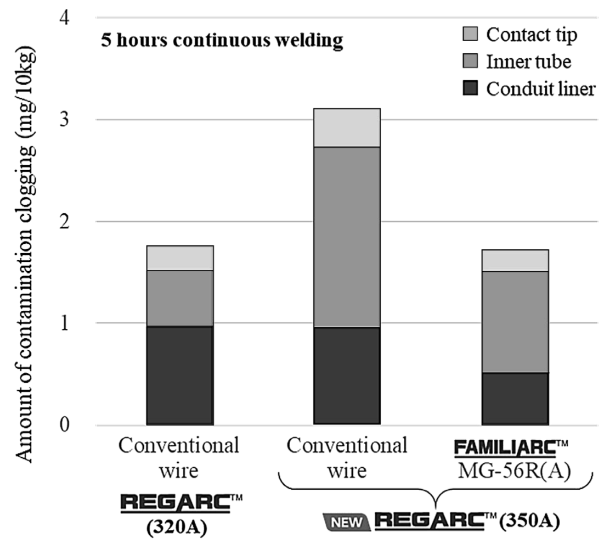

Fig.9 Example about amount of contamination clogging in wire feeding route parts

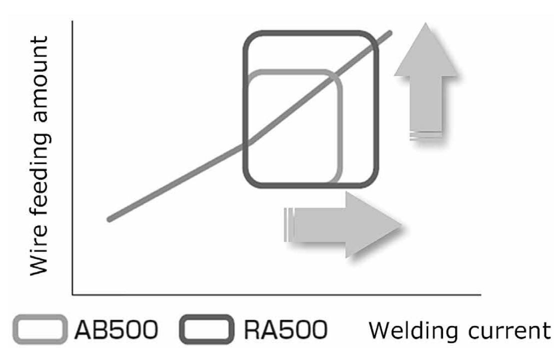

Fig.10 Expansion of welding current range of REGARC™

Table 2 Comparison of mechanical properties of weld metal between conventional process and developed process

Item	Location	Conventional	Developed
TS(MPa)	Straight	650	643
$_vE_{0℃}$(J)	Straight	111	108
	Corner	123	124

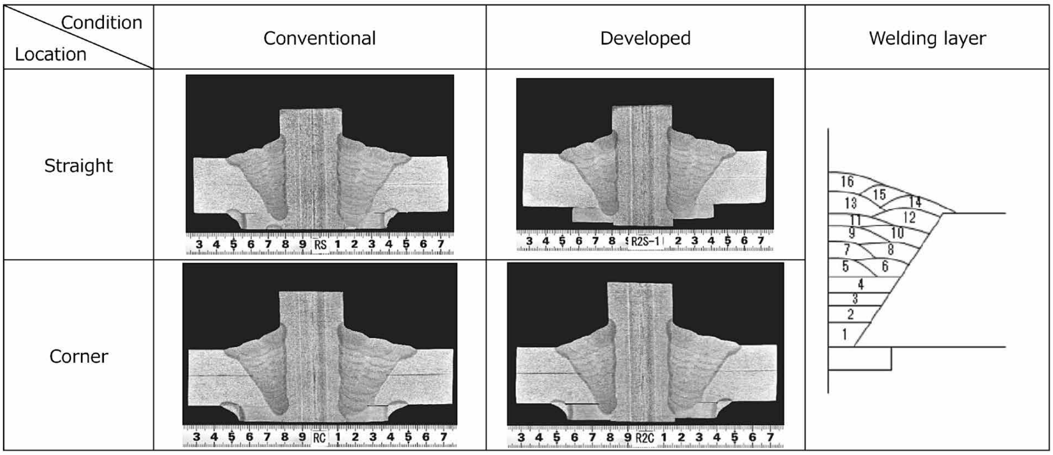

Fig.11 Cross-sectional macro comparison between conventional method and developed construction conditions

4. Configuration and advantages of new steel frame welding robot system [3)]

This section explains the system components mentioned in Chapter 2, specifically the arc welding robot ARCMAN™ A60, the nozzle autochanger (NAC-3), and other related equipment. **Fig.12** displays the appearance of the welding robot and the nozzle autochanger.

One of the advantages of ARCMAN™ A60 is that the center of the robot's one-axis drive section is hollow, allowing for the internal installation of cables within the one-axis part. In the steel frame welding robot system, a slag removal automation device is used, which allows for interchangeability with the welding torch. This setup involves wiring the necessary air hoses and signal lines up to the robot's wrist section. In the conventional system, these hoses and signal lines are run aerially behind the robot. However, in the new steel frame welding robot system, they are wired along the manipulator's lower arm through the one-axis part. This eliminates concerns about interference with the hoses and signal lines, which have previously been wired aerially at the rear, while the robot is in operation.

The nozzle auto changer/cleaner (NAC-3) is designed to prevent nozzle attachment/detachment errors and reduce the time required for replacement operations. Additionally, it features a function that checks if the set nozzle matches the specified position before the nozzle replacement operation, thereby avoiding system stoppages and equipment failures. In conjunction with the development of the NAC-3, the arrangement of related equipment mounted on the robot transfer device and the driving plan of the robot has been optimized. This has led to a reduction in non-welding time for activities such as nozzle cleaning, nozzle replacement, wire cutting, and more. **Fig.13** compares the operating times of the conventional ARCMAN™ MP system and the new ARCMAN™ A60 system.

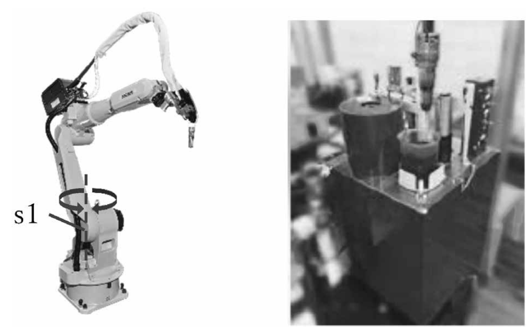

Fig.12 ARCMAN™A60, nozzle auto changer

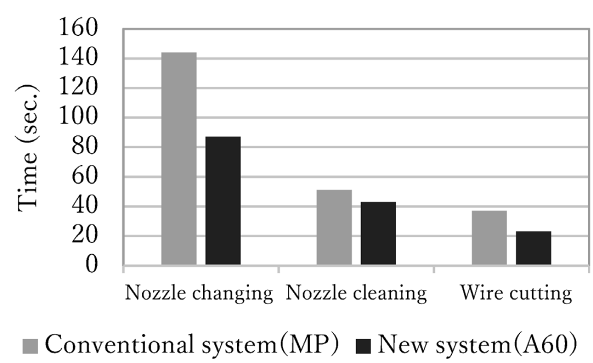

Fig.13 Comparison of related equipment time in structural steel assembly welding robot system

As described above, efforts have been made to optimize the ARCMAN™ A60 and related equipment mounted on the transfer device. The main body of the transfer device has also achieved the high rigidity required for thick plate welding through structural and component shape optimization.

5. Benefits

Through the changes in welding conditions, leading to a reduction in welding time, and the optimization of the arrangement of related equipment, which reduced non-welding time, the production time for robot-based column welding has been reduced by up to 10% or more [3).

As an example, the cycle time for a single joint with a column dimension of 800 mm square, a plate thickness of 32 mm, and a root gap of 7 mm was estimated and compared. The results are presented in **Table 3**. Approximately 15% of the overall cycle time and about 12% of the arc-on time have been shortened. Furthermore, the reduction in arc-on time has led to a decrease in the usage of shielding gas. It should be noted that this cycle time is calculated using actually measured values for the developed welding conditions and related equipment operating times, with the assistance of Kobe Steel's steel frame software. Therefore, it may differ from the cycle time observed on the actual machine. Additionally, this calculated cycle time includes the time required for removing slag from the intermediate layer.

Table 3 Comparison of estimate cycle time

	Conventional MP×AB500	New system A60×RA500
Cycle time (min)	201	171
Welding time (min)	148	129
Arc ratio (%)	73.4	75.5
Shielding gas consumption (L)	3,689	3,229
Pass count (pass)	16	16

Conclusions

This paper has introduced the latest technology and advantages related to Kobe Steel's steel frame welding robot system. The foundation for productivity enhancement enabled by these new technologies is stable and uninterrupted operation during continuous welding. While space constraints limited the extent of the description, it should be noted that Kobe Steel is not only focused on productivity enhancement but also on achieving stable operation and quality enhancement. Hopefully, the utilization of these new technologies and items in production settings can contribute to both productivity and quality enhancement in the field of welding.

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