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Development of Welding Robot Technology for Civil Engineering and Construction

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Abstract:

Amid the revival of the shipbuilding industry and the expansion of domestic demand in Japan, greater emphasis in recent years has been placed on welding automation and robotization to meet an increasing number of welding operations and as a counter measure for the aging of skilled welders. As key technologies to promote steel sales and to increase business opportunities in the civil engineering and construction fields, the NS stud welding process and stud and MAG welding method for stud welding of reinforcing rods, the NS-ROBO 21 system for field welding of building steel frames, and a column splice welding robot have been developed, tested on-site, and put to practical use. Coupled with the articulated steel frame welding robot system SF Robo system, these technologies have become features of the welding equipment business in the Nippon Steel group. More recently, the Nippon Steel group has also worked on the development of robotic welding by incorporating the latest in mechatronics and image processing techniques, such as on-line and off-line groove profiling, groove shape measuring, automatically welding condition setting, and automatic welding status monitoring.

1. Introduction

Nippon Steel's welding research group developed OSCON, PAW, LOOPNAP, VERTNAP, VEGA, CIRCWELL, and LW8-MK II as automatic welding machines for ships, storage tanks, piles, and pipelines. Some of which are still on the market today. These automatic welding machines were novel welding processes, but had no judgment functions and were operator dependent. The slump of the shipbuilding industry in the late 1970s left the development of automatic welding processes dormant for nearly 10 years. The subsequent revival of the shipbuilding industry and expansion of domestic demand have increased the number of welding work projects. Coupled with the aging of skilled welders, these trends have highlighted welding automation and robotization as issues of utmost importance. Welding work must be carried out at the project site when building steel frames in the construction industry, and reinforcing bars, shapes, rails and pipes in the civil engineering industry. The delay in the automation of field welding may adversely affect the sale of steel products for these applications. Steelmakers are being required to develop automatic field welding techniques for reinforcing bars, steel frames, rails, and pipes. In addition, these techniques can become powerful tools when steelmakers enter the civil engineering business.

Automatic reinforcement stud welding techniques, automatic building steel frame welding systems, and articulated welding robot techniques developed against the above-mentioned background are introduced here. Also described is the development of robotic welding technology incorporating the latest in mechatronic and image processing techniques for off-line and on-line

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groove profiling and groove shape measurement, automatic welding condition settings and automatic welding status monitoring.

2. Development of Reinforcing Bar Welding Techniques

2.1 NS stud welding process[1)]

The stud welding process, designated "NS stud welding process", was developed for horizontally welding large and long deformed rods to steel pipe sheet piles and other steel members in civil engineering projects. As an improvement on the NS stud welding process, a multiple-stud welding machine was developed that can be applied to composite structures such as the concrete connections for highway bridge pier footings. A welding status monitor was also developed to maintain quality control for on-site work. The development history of these techniques are reported here, together with weld joint properties and on-site work applications.

2.1.1 Features of the NS stud welding process

The NS stud welding process has the following features:

(1) High reliability joints

Deformed bars of good weldability are stud welded to steel pipe sheet piles with a recently designed stud gun to produce highly reliable stud weld joints.

(2) Stud welding of thick and long horizontal deformed rods

The conventional hand gun was capable of stud welding deformed rods up to 16mm in diameter and 500mm in length. The new end-grip-type stud gun (see **Fig.** 1) was developed to enable the stud welding of deformed rods of any desired length and shape up to 22mm in diameter.

(3) Automatic multiple-stud welding machine

Four to ten studs can be continuously welded in the horizontal or vertical direction by using an automatic multiple-stud welding machine, providing efficient, safe, and accurate welding operations.

(4) Quality control of all studs by monitor

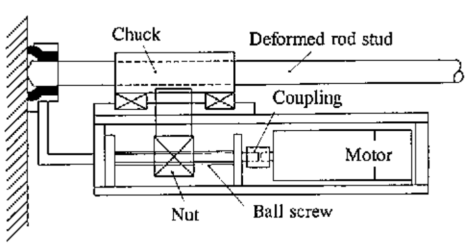


Fig. 1 Stud gun of servomotor type

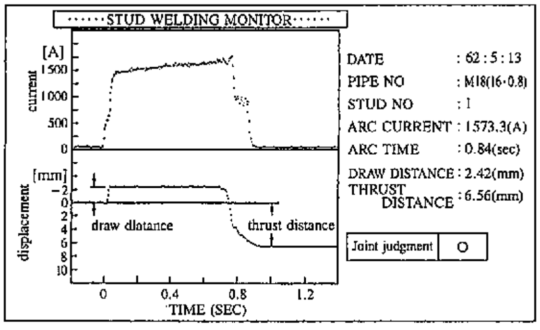


Fig. 2 Monitoring display

Deformed rod stud welding conditions can be monitored and recorded (see **Fig.** 2) to enable quality control of all stud welds.

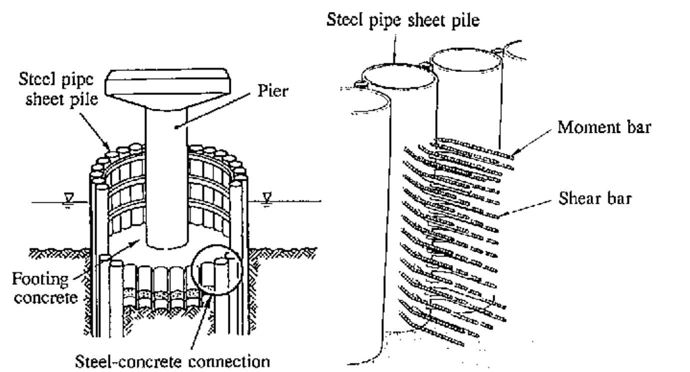
(5) Steel-concrete composite structures

When building concrete structures in the past, the same deformed rods could not be used as both concrete reinforcing rods and concrete-steel connectors. The long deformed rods welded by the NS stud welding process can serve as both the main reinforcement in the concrete structure and connectors between the steel pipe sheet piles and concrete.

2.1.2 Application to bridge pier footing concrete connection work[2)]

With the combination cofferdam and steel pipe sheet pile foundation construction method, deformed rods are directly stud welded to the steel pipe sheet piles, thereby connecting the pier footing concrete to the footing reinforcement (see **Fig.** 3).

Long reinforcing bar-footing concrete connection work calls for about 100 long reinforcing rods to be stud welded to each steel pipe sheet pile. To improve construction quality, reliability, and efficiency, an automatic multiple-stud welding machine was developed that can automatically stud weld the desired number of long reinforcing rods in the horizontal direction and can automatically move up and down the welding head. **Photos** 1 and 2 show long reinforcing rods being stud welded to steel pipe sheet piles with the automatic multiple-stud welding machine. This construction took place at the Takaishi section of the Hanshin Bay Expressway of the Hanshin Expressway Public Corporation. In



(a) Schematic showing combination cofferdam and steel pipe sheet pile foundation

(b) NS stud welding of deformed rods to steel pipe sheet pile for connection with footing concrete

Fig. 3 Bridge pier footing concrete-steel pipe sheet pile connection work

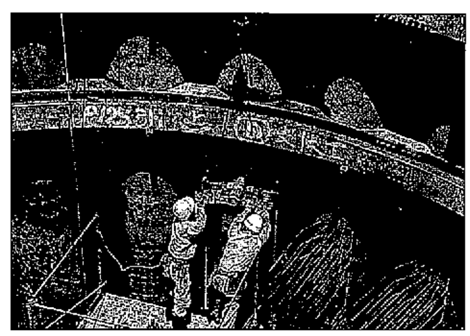


Photo 1 Installation of automatic multiple-stud welding machine to steel pipe sheet pile. Steel pipe sheet pile foundation in Takaishi section of Hanshin Bay Expressway (Owner: Hanshin Expressway Public Corporation)

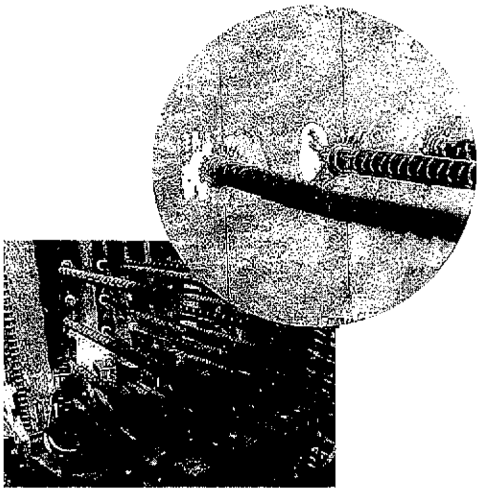


Photo 2 Studs being welded. Steel pipe sheet pile foundation in Takaishi section of Hanshin Bay Expressway (Owner: Hanshin Expressway Public Corporation)

pier footing concrete connection work carried out currently with a four-stud welding machine, 600 to 800 long reinforcing rods are stud welded per day by a crew of four workers.

2.1.3 Application to immersed tube elements of composite construction[3]

Under the immersed tube tunnel method, each tube element is prefabricated at a dry dock or other yard, floated on water, then towed to the construction site where it is sunk into place. The concrete tube elements are fitted with a steel skin that assures watertightness. To make effective use of the steel plate, it is connected to the concrete through headed studs and long deformed bar studs to form a composite tube element.

Studs are mainly welded in the flat position in the construction of composite tube elements. To weld an average of 4,000 studs per day, many improvements have been implemented, including the use of two or more multiple-stud welding machines and the raising of ease of handling and the addition of human skill into the welding machine system. **Photos 3** and **4** show stud welding by the NS stud welding process of a tube element for the Osaka Nanko immersed tube tunnel.

Compared with conventional methods, this systematized construction technology was confirmed to improve field construction

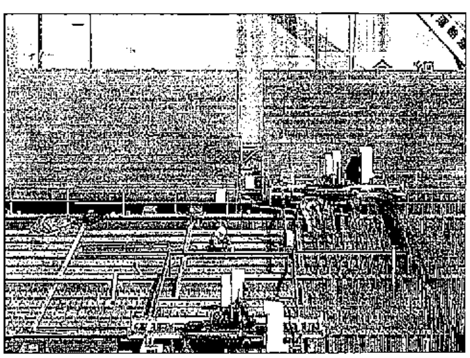


Photo 3 Arrangement of automatic multiple-stud welding machines on lower floor slab. Composite tube element for Osaka Nanko Tunnel (Owner: Third Port and Harbor Construction Division, Ministry of Transport)

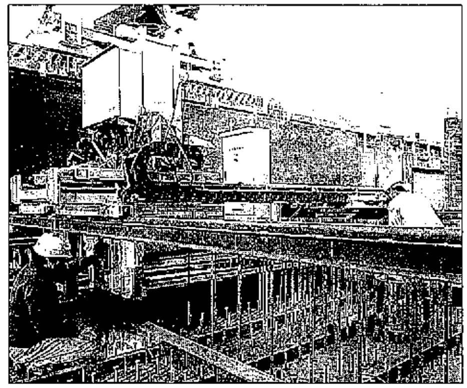


Photo 4 Deformed rods being stud welded. Composite tube element for Osaka Nanko Tunnel (Owner: Third Port and Harbor Construction Division, Ministry of Transport)

efficiency and connection stiffness in steel pipe sheet pile-footing concrete connection work—a method for building highway bridge foundations. The NS stud welding process was first employed in the construction of the Osaka Bay Expressway by the Hanshin Expressway Public Corporation in 1990. Local governments in Tokyo and the western part of Japan have since implemented this method. It was also adopted as the composite construction method for the Kisarazu Man-Made Island of the Trans-Tokyo Bay Highway, and for a composite immersed tube tunnel in the Osaka Nanko area. It has more than one million stud welds to its credit. In this way, the NS stud welding process meets the automation and robotization needs of civil engineering projects, helps to improve the reliability of structures and shortens the construction period.

2.2 Development of stud and MAG welding method

During the development of the NS stud welding process, the requirement for welding 25mm or thicker reinforcing bars to steel plates became apparent. There is a limit to the amount of the weld pool that can be supported by stud welding, and some other means must be used in combination for reinforcing bars larger than 25mm. A new method was developed whereby the lower and upper parts of the end of a reinforcing rod are welded by the stud welding process and the metal active gas (MAG) welding method, respectively, using a special windowed ferrule. The stud and MAG welding method have the following features:

(1) The conventional stud welding process is used together with the MAG welding method, so that reinforcing rods up to 51 mm can be welded.
(2) The ferrule is provided with an arc start metal piece, so that the end of the reinforcing bar need not be machined.
(3) Stable stud welds can be made by the MAG welding method, reducing the amount of repair welding required to correct weld defects.
(4) Welding conditions are recorded, so that the quality of all stud welds can be controlled.

2.2.1 Description of equipment

(1) Stud and MAG welding machine

The stud and MAG welding machine welds the first part of a stud by the conventional stud welding process and the last part by the MAG welding method. The MAG curved torch is rocked right and left by a rotating mechanism while being lifted, and the stud welding is automatically terminated when the welding current is detected. These operations are all automatically pro-

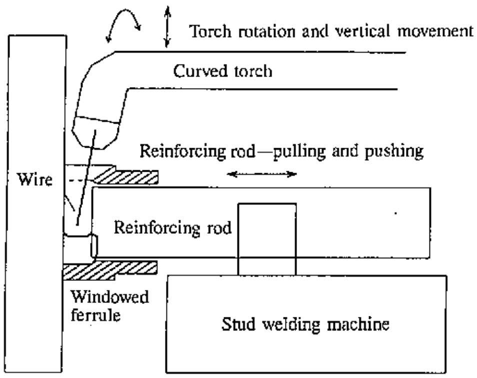


Fig. 4 Schematic showing stud and MAG welding machine

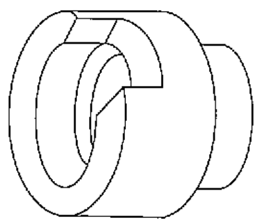


Fig. 5 Schematic showing windowed ferrule

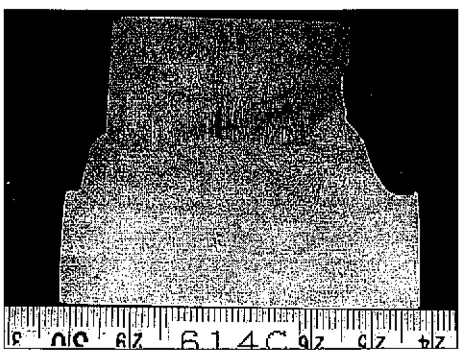


Photo 5 Macrograph of section through stud weld made by stud and MAG welding method. D41 reinforcing rod, stud welding: 2,500 A × 1.6 s, MAG welding: 300 A × 40 s

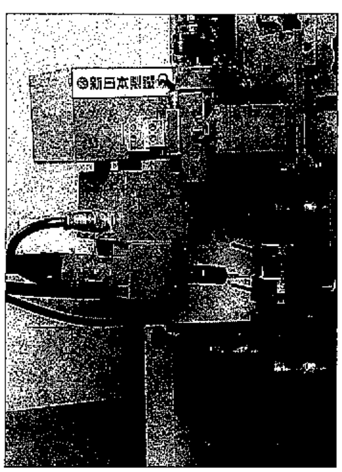


Photo 6 Reinforcing rod splice welding robot

grammed. The stud and MAG welding machine is schematically shown in **Fig. 4**.

(2) Windowed ferrule

A conventional ferrule with a window cut in the upper part is used to feed the electrode wire during MAG welding. The conventional NS stud welding process involved drilling a hole in the end of a reinforcing rod and pressing an arc-starting aluminum slug into the hole. To eliminate this procedure, the stud and MAG welding method has an arc-starting metal piece attached to the ferrule itself. The windowed ferrule is schematically shown in **Fig. 5**.

2.2.2 Weld joint characteristics

The cross-sectional micrograph of a D41 reinforcing rod stud welded by the stud and MAG welding method is shown in **Photo 5**.

The stud and MAG welding method was adopted in the construction of Kohrakuen Station on the No. 13 Subway Line, Teito Rapid Transit Authority. The stud and MAG welding method can perform MAG welding alone if required. Given the simplicity of equipment, reinforcing rod studs are expected to be stud welded by the MAG welding method alone in the future.

2.3 Development of a reinforcing rod splice welding robot

The NS stud welding process and the stud and MAG welding method were developed as techniques for welding reinforcing rods to plates or pipes. Far more reinforcing rods are joined to reinforcing rods compared with plates or pipes. With D32 and smaller reinforcing rods splices, 96% are made by pressure gas welding. Gas welding, mechanical coupling, and enclosed arc welding are employed on an even ratio for splicing of D35 and larger reinforcing rods. Reinforcing rod splices made by these welding processes have quality and cost problems, and call for robotic welding methods that do not depend on the skills of welders. To meet this demand, a three-axis controlled robot was developed that splices reinforcing rods, based on CO_2 enclosed arc welding. The robot has the following features:

(1) It can weld reinforcing rods up to D51 in nominal diameter.
(2) It can weld reinforcing rods placed in horizontal and vertical positions.
(3) It can weld D51 reinforcing rods in the short time of 3min.
(4) It can automatically weld reinforcing rods without assistance from skilled welders.
(5) It can be applied to preliminary reinforcing rod fabrication because there is no need to upset the reinforcing rods.
(6) It can automatically prepare reinforcing rod grooves for welding by using a gas cutting machine.

The general view of a prototype reinforcing rod splice welding robot is shown in **Photo 6**. The grooves of the reinforcing rods are enclosed with backing copper sheet and are welded by a CO_2-shielded torch that is lifted upward while being rotated and rocked. The macrograph of a reinforcing rod splice welded by the prototype robot is shown in **Photo 7**. Welded splices of horizontal and vertical reinforcing rods are shown in **Photo 8**.

3. Development of Automatic Building Steel Frame Field Welding Robot Systems

3.1 Development of column-beam joint welding robot "NS-ROBO 21"[4,5]

Brisk demand for steel frame buildings and an acute shortage of skilled labor have created strong needs for automation and labor savings in steel frame welding. To meet these needs,

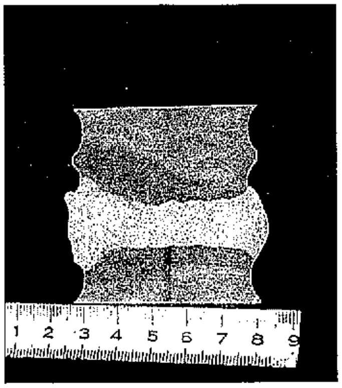


Photo 7 Macrograph of section through welded splice of reinforcing rods. Welded splice in D51 reinforcing rods placed in horizontal position

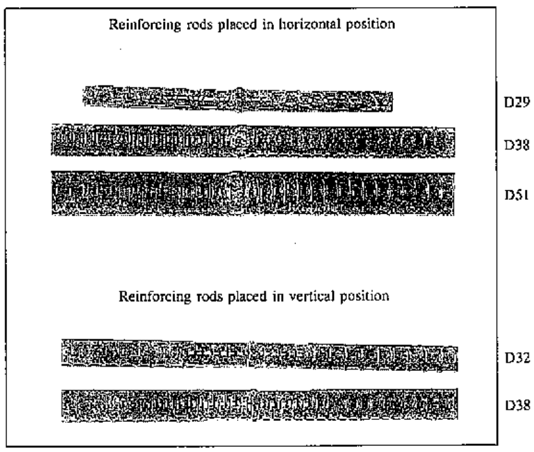


Photo 8 Reinforcing rod welded splices

Nippon Steel developed a Cartesian coordinate system welding robot, designated the NS-ROBO 21. The NS-ROBO 21 is compact, lightweight and portable. It is also maneuverable for the purpose of steel frame welding, adaptable to a variety of welding positions, and flexible enough to improve welding efficiency and follow groove shape variations. The general view of the NS-ROBO 21 is shown in **Fig. 6**.

The NS-ROBO 21 has the following features:

(1) Two robots alternately work under one controller set. This two-one system enhances work efficiency and assures proficient welding operations.

(2) Using a special curved torch, the NS-ROBO 21 can weld in flat, vertical, horizontal, and horizontal fillet positions. It has a component system that allows the torch, robot, and carriage combination to be simply changed by an attachment method to suit the welding position concerned, and is controlled by sophisticated software that allows welding to be performed in a variety of positions.

(3) A control system is incorporated that automatically measures the groove shape, and calculates and controls the welding conditions in response to groove shape variations. Only the welding position, section thickness, and weld length need to be entered. Since the data necessary for welding are automati cally calculated, no operating skill is required, and even novices can easily perform welding.

(4) Welding can be made through a scallop or an fan-shaped notch made in structural steel to avoid a weld line intersection.

(5) Long welds can also be made.

3.1.1 Site applicability of robot

The newly developed NS-ROBO 21 performed on-site welding of columns and beams at a building construction site.

A five-story building with a total floor area of 23,000m^2 had all its column-beam joints directly welded on site to reduce the construction costs by minimizing the shop welding of steel frames. Approximately 1,800 column-beam joints had to be welded. Excluding column-beam joints not readily accessible by the robot carriage, a total of 1,354 column-beam joints were welded by the NS-ROBO 21.

(1) Mobile truck for NS-ROBO 21

Past experiences showed that the handling of cables and hoses poses a serious problem when carrying welding robots on each floor. For this reason, the NS-ROBO 21 was raised and lowered by an elevator mobile truck, as shown in **Photo 9**. First, column-beam joints on the second and third floors were welded by the NS-ROBO 21, and concrete was cast on the second and third floors. Then, column-beam joints were welded by the NS-ROBO 21 on the fourth and fifth floor and the roof. A work platform was installed on the top of the elevator mobile truck. The controller and two robots were suspended from the work platform. Arms that can rotate and expand were installed to lower the robots to the desired location by remote control. The welding power supply was mounted at the rear of the mobile truck. The cables and hoses were laid along and fixed to the side scissors as shown in **Photo 9**.

(2) Working efficiency of NS-ROBO 21

Two 2-1 systems (four robots) were brought into the con-

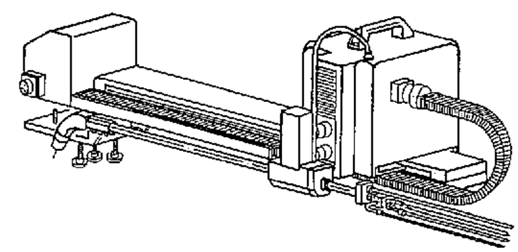


Fig. 6 General view of NS ROBO 21

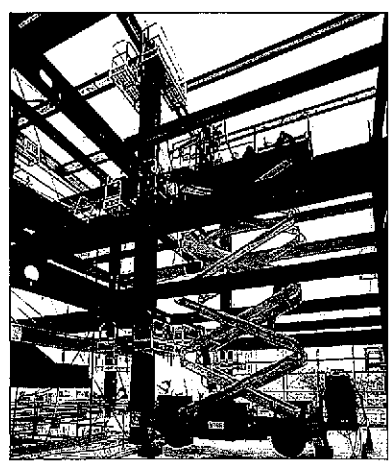


Photo 9 Elevator mobile truck for NS ROBO 21

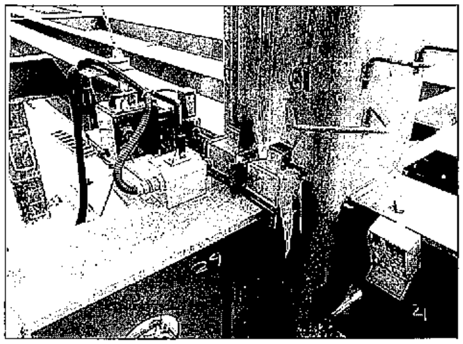


Photo 10 Column-beam joint being welded by NS ROBO 21

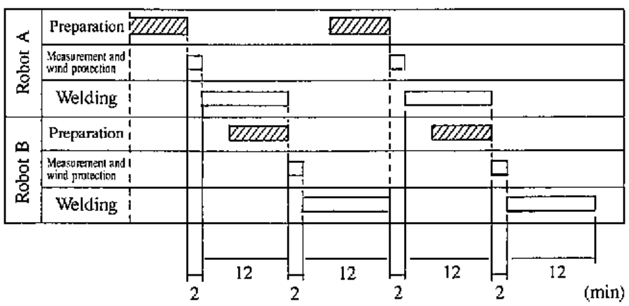


Fig. 7 Time schedule of 2-1 system

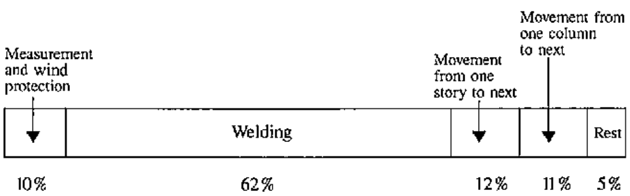


Fig. 8 Daily time schedule

struction site, and two young operators with little welding experience were assigned to them. At first, each of them was assisted by an adviser, but later they became competent enough to operate their 2-1 system independently.

Photo 10 shows a column-beam joint being welded by the NS-ROBO 21. Each weld is performed with practically no supervision. While one of the two robots in the 2-1 system, or robot B, is welding a joint, the operator sets the other robot or robot A, cleans the nozzle, and installs the wind shield. The time schedule of the 2-1 system is shown in **Fig. 7**. As evident from the figure, a welding arc is always produced from either robot A or B, except when groove data are being measured or when the wind shield is being installed.

In the construction project, beam section thicknesses ranged from 20 to 28mm. One robot set welded 22 joints per day, each measuring 300mm in length and 25mm in section thickness on average. An example of the daily time schedule is given in **Fig. 8**.

(3) Quality of weld joints

In the construction project, all of the 1,354 joints welded by the NS-ROBO 21 were inspected by ultrasound equipment for defects. All passed this test, except for some six or seven joints that had been abandoned because of robot failure or other troubles that occurred during the early stages of construction.

(4) Development of small carriage

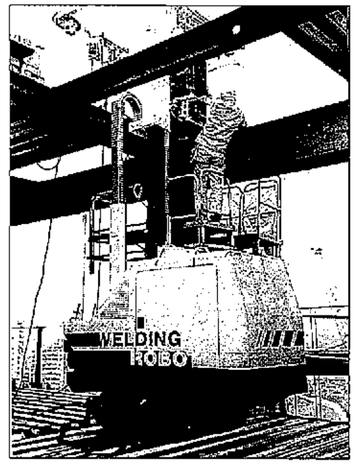


Photo 11 Small carriage for NS ROBO 21

The above-mentioned elevator mobile truck weighs more than five tons and cannot be used unless the floor is finished in concrete. It is also cumbersome, and cannot move quickly from one column to another. To solve these problems, the small carriage shown in **Photo 11** was developed. The carriage weighs 1.2 tons, can freely move on the deck plate, and can easily go from one column to next. It is expected to become a powerful tool for on-site welding.

3.2 Development of column-to-column joint welding robot system[6]

Column-to-column joints are building steel frame joints that must be always be welded on site. A column-to-column joint welding robot system was developed based on the NS-ROBO 21. The column-to-column joint welding robot system has the following features:

(1) Two robots can simultaneously weld a column-to-column joint, improving welding efficiency.
(2) Beads are connected on the straight portion, so that the weld quality of corners that are continuously welded is higher than with semiautomatic welding.
(3) The travel rails only need to be set once, and the necessary preparation time is short.
(4) The groove shape and weld line are automatically measured by a laser sensor, and the welding conditions are calculated and controlled to suit the groove shape. Skilled welders are not required to operate this system.
(5) A special handling car moves the welding robot from one column to the next.

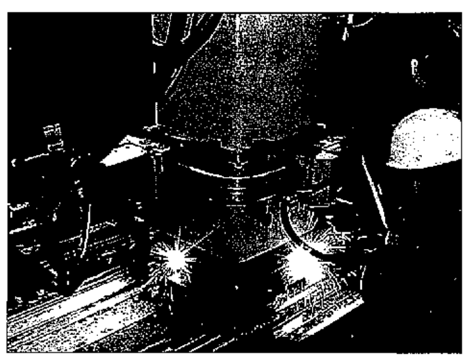


Photo 12 Column-to-column joint welding robots

Photo 12 shows the column-to-column joint welding robots at work. Each robot has three conventional axes plus one rotating axis (for section thicknesses of over 25mm), constituting one system. The groove measuring laser sensor is set on the same axis as the welding torch and can automatically measure the groove shape and weld line in the same condition as welding. A simple type of windproof sheet is used instead of the conventional type that completely covers a column-to-column joint to be welded.

The application of the column-to-column joint welding robot system to the on-site welding of the steel frames of a building is described here. The building has a total floor area of about 35,800m^2 with 12 stories above ground and 3 stories below ground, and is constructed with columns made of square pipes with rounded corners. The columns' external dimensions are 500, 600 or 650mm and 16mm thick. They are filled with concrete, are not given a fire-resistant coating. They are welded right above the beam level so that weld jigs and the like can be concealed below the floor level. The welding robot system welded 66 column-to-column joints, or 70% of the total, to which the robot handling car could be moved and the robots could gain access.

Photo 13 shows the column-to-column joint being welded by the robots. The welding procedure started with the laser sensor automatically measuring the joint position and cross-sectional groove shape and feeding back the welding conditions and other information in accordance with the root gap, and a fit-up misalignment range of ±4mm. The sensing time is short at about 3 min. The welding operation was started at the same time from the opposite sides of each 600-mm column-to-column joint, and the welding of each joint was completed in about 30min. Despite a localized fit-up misalignment of 7mm, the beam appearance was good, as shown in **Photo 14**. The column-to-column joints welded by the robot passed the ultrasound tests, and only one of them had a defect resulting from a groove shape measuring mistake.

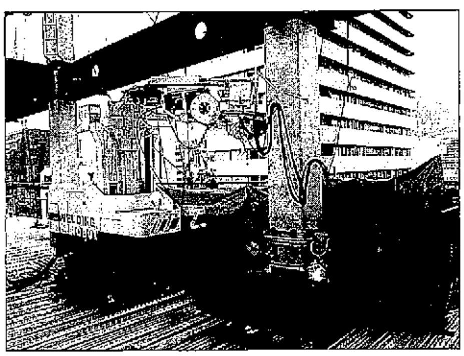


Photo 13 Column-to-column joint welding robots working at construction site

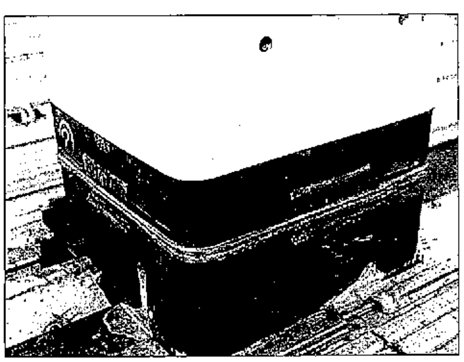


Photo 14 Appearance of weld beads deposited by column-to-column joint welding robots

The development of the welding robot system is continuing for round and box column applications, and is expected to lead to the increasing number of steel frame buildings constructed and orders received for construction projects.

4. Development of Articulated Welding Robot System for Building Steel Frames[7,8]

In automating welding operations in the construction sector, the development of welding robots for shop fabrication of building steel frames is as important as that of welding robots for on-site erection of steel building frames. Cores are fabricated at the shop, joined with short beams, and welded to columns. In this application, stationary articulated welding robots are used to an advanced degree, and many automatic welding robot systems are being developed. The conventional robots, however, failed to meet the needs of steel frame fabricators in terms of field weld quality and personal computer display operability. Nippon Steel succeeded in the development and commercialization of an articulated steel frame welding robot system, known as the SF Robo system. Joint research with Yaskawa Electric Mfg., Yaskawa Shoji, and Nippon Steel Welding Products & Engineering has succeeded in making this system capable of making high-quality welds despite groove fit-up misalignment and work displacement. The SF Robo system can automatically weld various types and sizes of cores and joints by merely entering work shape through the input display (**Photo 15**), using the mouse on the personal computer (see **Fig. 9**). High-quality multiple-layer welds can be made by automatically setting optimum welding speed and weaving width in response to groove root gap variations.

The SF Robo system is available in three types: a single-core system that welds a single core or joint, a connected-core system (see **Photo 16**) that continuously welds up to eight cores, and a joint system that continuously welds up to six joints.

The SF Robo system has the following features: (1) detection and compensation of work displacement and groove dimensions; (2) automatic setup of multiple-layer welding conditions with a welding condition calculation algorithm; and (3) elimination of the need for the human operator to teach the robot.

Research and development will continue toward full automation and robotization of welding operations by taking advantage

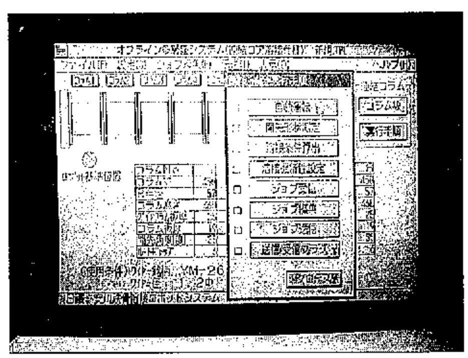


Photo 15 Entry display of SF Robo system

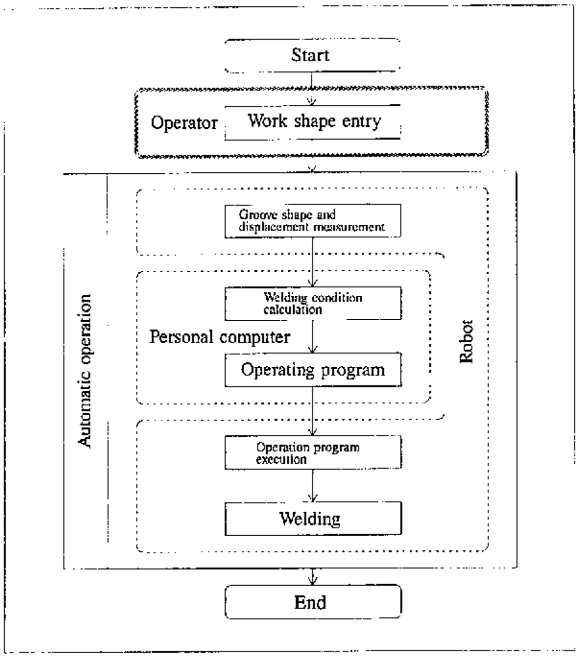


Fig. 9 Operation flow of SF Robo system

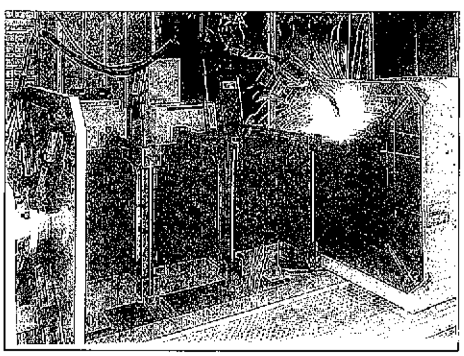


Photo 16 SF Robo connected-core system

of the articulated robot.

5. Development of Welding Robot Technology for Fluctuating Groove Dimension for Heavy Steel Joints

Double-bevel grooves are generally used for horizontal weld joints in heavy-section steel structures and are likely to produce root gap variations of less than 8mm and maximum fit-up misalignment of about 10mm. In addition, groove deformation during welding cannot be ignored and is not uniform either. When a skilled welder manually or automatically welds such a groove, she/he can select the welding conditions or buildup pattern to suit the actual condition of the groove. In the case of automatic welding, however, buildup design must be completed before the start of the welding operation, and the tolerances of fit-up accuracy and deformation are limited. For this reason, an on-line groove copying and groove shape measuring technique, a welding method amenable to robotization, and an automatic welding condition setup method are under development.

5.1 Development of the latest groove copying and groove shape measuring techniques

This development is concerned with irradiation of a groove with a laser slit beam, pickup of a resultant two-dimensional image (light-sectioned image) with a CCD camera, and on-line measurement of three-dimensional information, such as groove position, shape and size, from the two-dimensional image. The arc light image is received with another CCD camera, the center of gravity of the image is extracted and converted into three-dimensional coordinate values. These values are compared with the groove position data, and the torch position controlled by feedback accordingly (see Fig. 10).

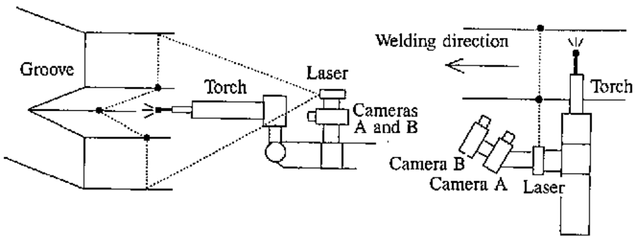


Fig. 10 Groove sensing and image processing system

The welding arc light is so intense that it masks the laser light. The following measures are implemented to counter this situation:

(1) An interference filter is adopted to improve the relative intensity of the illuminated image.

(2) The arc light at the instant when the arc is short circuited during short-arc welding is imaged with a random shutter camera. This ensures that a clear laser light-sectioned image can be obtained during the welding operation.

The other CCD camera fully reduces the intensity of the arc light with a neutral density (ND) filter and captures the groove shape as a spot image.

Consequently, the groove shape can be measured on-line, and the thermal deformation of the base metal and the bending of the welding wire during the welding operation can be accommodated.

5.2 Development of welding methods amenable to robotization and automatic welding condition setup methods in response to groove shape variations

In 1985, the R & D Dept. of the Plant & Machinery Division at Nippon Steel devised a one-pass one-layer welding process and verified its validity as a welding process that had large tolerances and was amenable to robotization. Fig. 11 shows the new welding process of depositing one wide bead per pass in comparison with the conventional welding process of depositing one or more narrow beads per pass. The new welding process deposits the

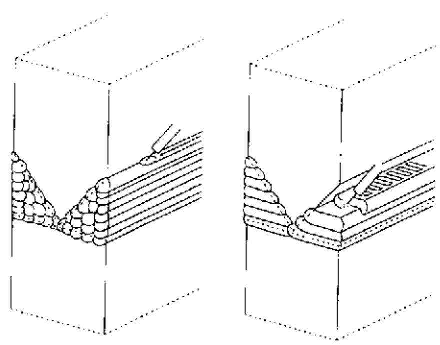


Fig. 11 New welding method amenable to robotization

weld metal at a constant pitch in the longitudinal direction while moving the torch across the entire width in the groove depth direction. It can tolerate the groove depth variations that occur along the weld line due to fit-up misalignment. The new welding method can also reduce the number of passes in heavy-section plates to a fraction of that required with the conventional welding process, and can sharply cut down the reciprocating motion of the torch along the weld line. The resulting welding efficiency enhancement and bead shape improvement meant that a practical one-pass one-layer welding process had been successfully developed.

The one-pass one-layer welding process organizes welding conditions into patterns according to the groove and the movement of the welding torch. The variations in the groove depth can be accommodated by changing the travel distance, and the variations in the groove angle can be countered by changing the laser deposit height by adjusting the torch weave motion pitch. These measures were combined to develop a welding condition calculation algorithm to suit misfit grooves in heavy-section plates. The technique of automatically setting up welding conditions that accommodate the groove variations on a real-time basis was developed by combining the algorithm with the groove copying and groove shape measuring technology described above.

6. Conclusions

Only some of the welding robot developments accomplished at the Welding & Joining Research Center have been presented above. Each technology is targeted to aid in marketing of steel products and acquisition of orders for engineering projects. Most of the development topics have been commissioned by other divisions within Nippon Steel.

To promote the full application of these research results, it is important not only to expand the use of the welding robots in engineering projects, but also to establish a manufacturing and marketing network for welding robots. We also think it necessary to upgrade the welding robots as required.

New techniques, such as on-line monitoring, will be incorporated into robots to be developed, and great efforts will be made to support the steel marketing and engineering personnel in their activities.

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