Kobelco Group's Welding Technologies for Architectural Steel Frames

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Abstract

Joining is the most important production technology in the manufacturing and assembly of architectural steel frames. The Kobelco Group has long contributed to advancement of the construction industry through its high-tension bolts and arc welding technologies. Recent labor shortages have increased the need for automation by robotization. This has led to a notable trend toward the expansion of large-scale arc welding robot systems in steel frame manufacturing factories, as well as the adoption of portable arc welding robots on-site. In addition, efforts are being made to lower the barriers to training for welders, who are becoming increasingly rare, by combining practical and virtual training methods.

Introduction

As an earthquake-prone country, Japan's history includes numerous major earthquakes that have caused significant casualties and damage. As such, the country has put great effort into the technological development of materials, structures, and joining methods to improve the seismic resistance of all of types of structures, from tall historical wooden buildings such as five-story pagodas to modern steel-framed skyscrapers.

The KOBELCO Group has contributed to these efforts by developing numerous technologies for constructing resilient building structures to strengthen Japan's infrastructure. One area in which we possess exceptional strength is that of technologies and products related to the arc welding of steel, which has steadily gained importance in recent years.

This paper broadly introduces the KOBELCO Group's standout solutions for quality improvement, optimization, and automation, focusing on the various types of steel structures and the associated joining methods.

1. Materials used in building construction[1)]

The main materials used for the structural elements of buildings are wood, concrete, and steel. Common construction methods using these materials include (1) reinforced concrete (RC) construction, (2) steel-reinforced concrete (SRC) construction, and (3) steel frame (S) construction.

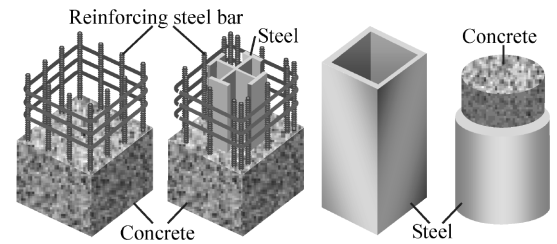

Fig. 1 Column styles in large buildings

There are many other structures, including hybrid structures combining wood and steel, as well as (4) concrete-filled steel tube (CFT) construction, in which steel columns are filled with concrete (**Fig. 1**).

Selection of the optimal construction depends on a building's intended use and is influenced by the recent trend of structures becoming increasingly larger and taller. Multistory apartments and condominiums often use RC construction because livability is prioritized. Conversely, high-rise offices, hotels, and production facilities often use S or CFT construction. Particularly with these two construction types, the steel must have high strength and toughness to ensure maximum seismic performance of the building, and the joints must likewise exhibit high stress transmission capabilities.

2. Column and beam connection types in S construction

S constructions often employ rigid-frame structures, in which columns and beams are rigidly connected (**Fig. 2**). Such structures are generally one of two main configurations: (a) continuous beam, where column segments are attached to the beam, or (b) continuous column, where beam segments are attached to the column (**Fig. 3**).

Configuration (a) is also known as the "continuous diaphragm" type and has seen expanding use particularly in Japan. While relatively uncommon from a global perspective, its widespread adoption is owed to high compatibility with arc welding robots and significant advantages in terms of safeguarding quality and reducing labor needs. Configuration (b) uses inner diaphragms and is commonly used in Japan for welded box columns in skyscrapers.

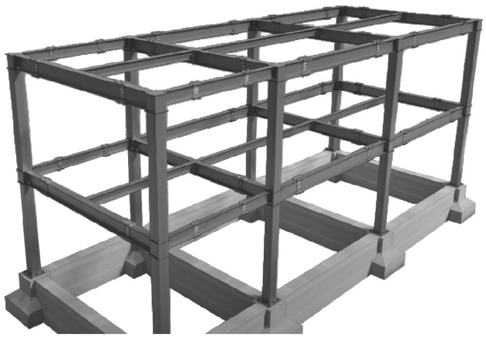

Fig. 2 Image of steel rigid-frame structure

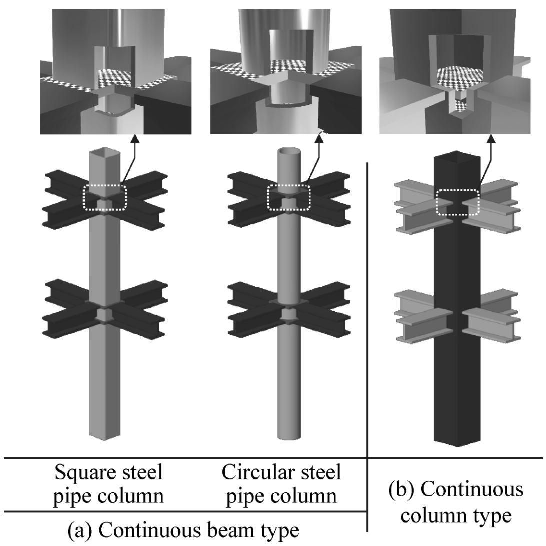

Fig. 3 Types of column and beam connections

3. Main types of joining methods and Kobe Steel's approach

Metal joining methods can be broken down into the categories of (1) mechanical joining, (2) metallurgical joining, and (3) chemical joining. (1) includes nut/bolt fastenings, rivets, nails, etc.; (2) includes arc welding, resistance welding, laser welding, pressure welding, gas welding, etc.; (3) primarily consists of adhesives. The most common methods used in the construction of architectural steel frames are nut/bolt fastenings and arc welding (examples of (1) and (2)). These methods have the advantages of high joint strength, long-term reliability, fire resistance, efficiency, and versatility (**Fig. 4**).

Further benefits of nut/bolt fastenings include the following: (a) high tolerance for gaps (joint can be tightened to close gaps), (b) process does not degrade the material, (c) low skill requirement, (d) low defect rate, (e) ease of defect detection, and (f) safe execution. Disadvantages of nut/bolt fastenings include the following: (a) can loosen over time, (b) limitations in scope of use based on joint geometry and plate thickness, (c) unsuitable for automation, (d) cross-sectional decreasing in steel plates, and (e) being a partial joint.

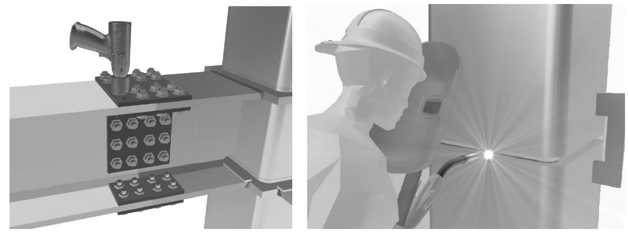

Fig. 4 Images of joining via nut/bolt and arc welding

The advantages of arc welding include the following: (a) ability to join any geometry, (b) high reliability owing to high strength and toughness, (c) ease of automation, (d) high efficiency, and (e) low cost. Disadvantages of arc welding include the following: (a) process can degrade the material, including the surrounding base metal, (b) high skill requirement, (c) susceptible to internal defects, which are difficult to detect, and (d) health and safety concerns such as sparks and spatter, light, smoke, and intense heat.

Joining methods are selected based on their characteristics because each comes with its own advantages and disadvantages. Within the KOBELCO Group, Kobelco Bolt, Ltd. provides nut and bolt products, and a wide range of arc welding solutions are provided by companies including our Welding Business, KOBELCO WELDING TechnoSolutions Co., Ltd., and Kobelco ROBOTiX Co., Ltd. Additionally, Kobe Steel's Steel & Aluminum Business provides high-performance wire rod for nuts and bolts, as well as thick steel plate with excellent weldability.

4. Arc welding

Arc welding is used in a broad spectrum of applications, ranging from the in-plant assembly of steel pipes and structural steel members into architectural steel frames, to field welding when erecting frames at construction sites. The types of arc welding, in chronological order of technological maturity, are (1) shielded metal arc welding (SMAW), (2) submerged arc welding (SAW), (3) electroslag welding (ESW) (not arc welding per se, but included here as a related process), (4) self-shielded tubular cored arc welding, (5) gas metal arc welding (GMAW), and (6) electrogas arc welding (EGW). Kobe Steel's Welding Business provides all the welding consumables needed for these processes and has been advancing the field of building infrastructure since its founding in 1940.

Furthermore, to promote the widespread adoption of arc welding, which requires great technical proficiency, we established a training center in the early 1960s and launched a welding training program. As a result of this initiative, we have helped cultivate outstanding welders who accomplish high-quality welding throughout Japan.

Our efforts in the welding equipment business have ensured a high degree of automation as well as high efficiency and quality in welding. The welding robot system we developed in the mid-1980s for steel frame construction is still widely used in steel frame fabrication plants and on construction sites today.

4.1 Welding technology for RC and SRC constructions

The joining of reinforcing bar is an integral part of the RC and SRC construction methods. This need drove Kobe Steel to develop and promote the KEN (Kobe Steel's Enclose Narrow-gap) process in the 1960s.[2)] This method involved placing a copper backing plate over the joint and filling the joint with weld metal. The welding consumable used was a covered arc welding electrode. Then, in 1989, we developed an advanced version that uses CO_2 shielded arc welding: the KEN-SH (Kobe Steel's Enclose Narrow-gap Welding-Semiautomatic High-Performance) Process (**Fig. 5**).[3)]

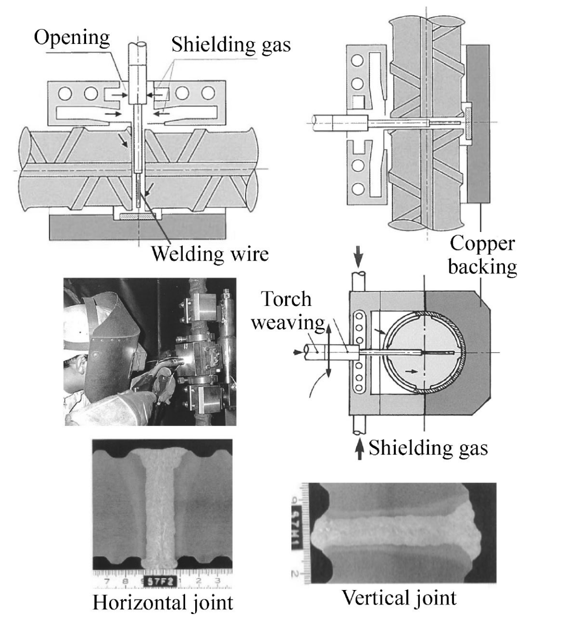

Fig. 5 Reinforcing steel bar welding process "KEN-SH"

These methods were originally implemented by Shinko Welding Service Co., Ltd., the predecessor of KOBELCO WELDING TechnoSolutions Co., Ltd. However, in 2010, the business was transferred to the Japan Reinforcing Bar Joints Institute, and the method was renamed the "JCe method." It is currently implemented in the reinforcing bar industry as an association-certified method.[4)]

4.2 Welding technology for continuous-column S construction

The members used for the columns in continuous-column construction include H-beams, H-beams combined to form cruciform columns, and welded box columns. As the main member used, we will focus on the welded box column, also known as a "built-up box column."

This fully welded structure consists of four steel plates, called "skin plates," and numerous inner diaphragms for reinforcement. Excluding position changes, the process mainly involves two steps, each of which requires a different welding method (**Fig. 6**).

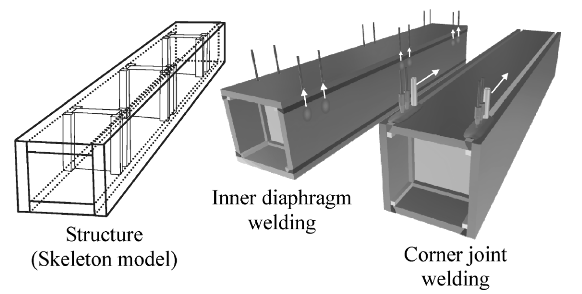

Fig. 6 Structure and assembly welding methods of built-up box section column

Where the plates meet along the longitudinal axis of the column are called the "corner joints." These are usually welded by high-current SAW in a single pass (**Fig. 7**) using a tandem configuration with two electrodes arranged in series. Single-pass welding is challenging with a plate thickness greater than about 60 mm. In such cases, the common method applied is to use CO_2 shielded arc welding to build up the weld metal and then perform SAW, requiring at least two passes in total (**Fig. 8**). We are now starting to see steel plate thicknesses of up to 100 mm in today's skyscrapers. Since building up weld metal is a low-efficiency process, research is being pursued intensively to increase the maximum single-pass thickness for SAW and to develop multi-pass SAW techniques.

Kobe Steel has a long history in the development and marketing of multi-electrode SAW systems for high-efficiency welding of the corner joints of welded box columns.[5), 6)] **Fig. 9** shows a recent iteration of one of these welding systems.

Inner diaphragms, however, are welded via ESW. The structure, as shown in **Fig.10**, is a closed space formed by a side skin plate, the diaphragm,

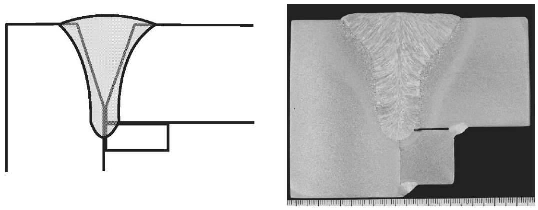

Fig. 7 Example of cross section of single pass corner welding joint by double electrode submerged arc welding method (Steel thickness: 50 mm)

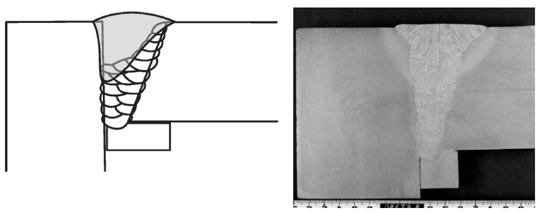

Fig. 8 Example of cross section of multi-pass corner welding joint by CO_2 arc welding and double electrode submerged arc welding mixed method (Steel thickness: 80 mm)

Fig. 9 Example of Kobe Steel's multi-electrode submerged arc welding system for corner joints of built-up box section column (Customer: OATEC corporation)

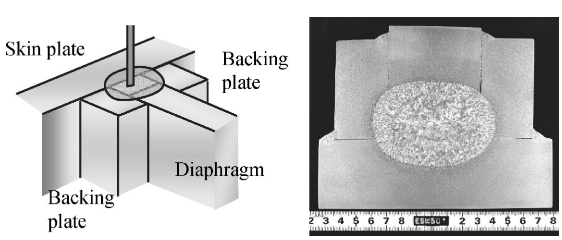

Fig.10 Example of cross-section and structure of electroslag-welded joint of diaphragm and skin plate

and two backing plates. A nozzle for introducing the welding wire is inserted into a hole in the top skin plate, and welding is performed while the nozzle is drawn upward. This process, which is more like casting than welding, is highly efficient. However, its heat input is extremely high, and the limited pathway for heat dissipation during welding slows the rate of cooling of the weld zone, potentially causing material degradation around the weld. As such, we are focusing on developing not only ESW consumables that achieve high strength and toughness, but also steel plates that are suitable for this method by having the capacity to withstand high heat input. Also called "high-HAZ toughness steel," such materials address the growing demand for large-section columns, which increase usable floor space by reducing the number of columns per floor. In response, Kobe Steel has developed high-strength steel plate capable of withstanding high-heat input welding. For more information, see p.66 of this issue, "Development of 780 N/mm^2-Class Structural Steel for Building Structures Suitable for High Heat Input Welding".

4.3 Welding technology for continuous-beam S construction

The joint construction that has seen the most significant development and become the mainstream approach in recent years is the continuous-beam type. This construction uses steel tube columns fabricated by cold-pressing thick plates into square or circular cross-sections and creating one or two welds along the length of the column. The welding method primarily used for steel tube fabrication is SAW, occasionally combined with CO_2 shielded arc welding. A specialized SAW fixture called a "boom welder" is used for welding the inside of these narrow spaces (**Fig.11**).[7)]

Improvements in steel pipe manufacturers' forming technologies and general capabilities have made it possible to produce high-strength steel pipe with greater wall thicknesses for continuous-beam constructions. Another reason this type of construction is gaining prevalence is because its manufacturing process is simpler than that of welded box columns, yielding greater economic efficiency.

Fig.12 shows how steel frame fabricators execute continuous-beam constructions. First, core parts (sometimes called "dice") are fabricated for the joints between the steel columns and the beams. Specifically, diaphragms are circumferentially welded to a short steel pipe.

Short steel H-shaped sections (sometimes called "brackets") for nut/bolt fastenings during on-site construction are then welded to the diaphragms of the core parts. Multiple such sections are then welded to long steel pipes to form the final structure as it will depart from the factory. A potential exception is that if the beams will be joined on site via welding rather than nut/bolt fastening, the H-shaped brackets are omitted. The advantage

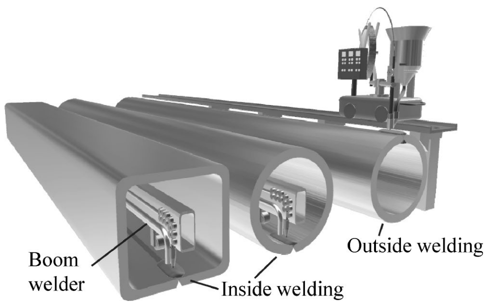

Fig.11 Seam welding of press-formed pipes

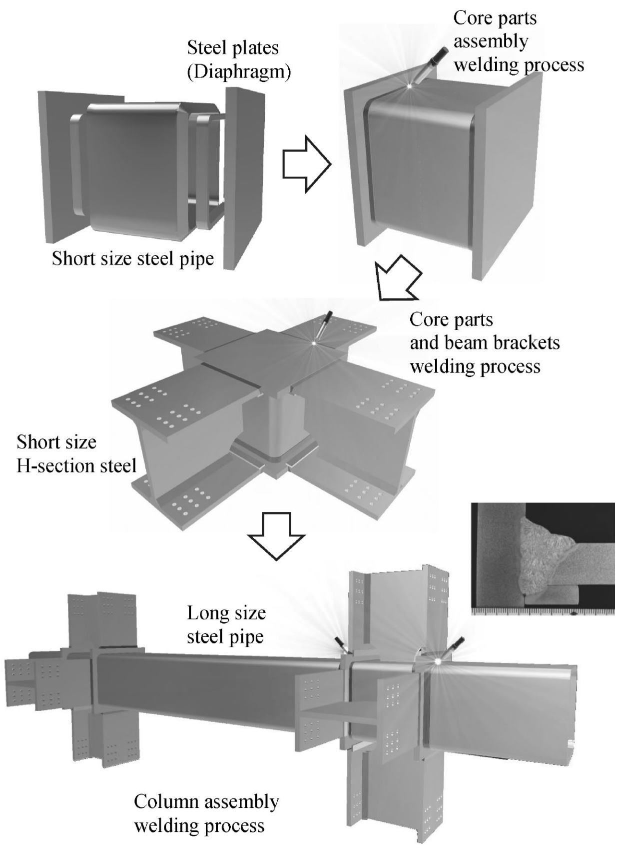

Fig.12 Typical welding assembly process of continuous-beam type column and an example cross-section of a weld joint

of the non-bracket method is that nothing is protruding from the beams, enabling more units to be loaded per truck for transport from the factory to the site, which in turn increases efficiency and reduces costs. However, unlike in the factory, on-site welding during erection of the structure is subject to constraints in terms of available welding positions. This leads to design changes to the details of the welding joints, which can reduce seismic performance. Research and practical testing are underway to resolve these challenges that are unique to on-site welding. Kobe Steel is developing on-site construction methods using arc welding that mitigate stress concentration and achieve excellent seismic performance in welding joints, although the details are beyond the scope of this paper.[8), 9), 10)]

The CO_2 shielded arc welding process shown in Fig.12 was traditionally a manual operation. However, it is now performed by welding robot systems comprising articulated robots, linear rails and guides for robot translation, workpiece positioners, and similar components. Such systems enable continuous, long-term operation around the clock, completely transforming the landscape of steel frame fabrication plants. The main elements of such systems are, as shown in **Fig.13**: (1) a space-saving, multi-purpose welding system for assembling steel frame core parts and brackets (primarily for welding the core part); (2) a steel frame core part welding system for continuously welding multiple core parts; (3) a steel frame bracket welding system for continuous welding of brackets; and (4) a large-column assembly welding system that accommodates long columns.

One technology that has improved weld quality is the REGARC™ process. It drastically reduces spatter – conventionally a drawback of CO_2 shielded arc welding – by using the welding power source to control current and voltage waveforms accordingly.[11), 12), 13), 14)] This unique technology, feasible only with Kobe Steel's SENSARC™ series arc welding power sources (**Fig.14**), yields significant cost savings. Specifically, reducing spatter adhesion on the workpiece significantly reduces the labor and time necessary for spatter removal before subsequent ultrasonic testing (**Fig.15**).

After releasing REGARC™ to market in 2008, we released an upgraded version, New REGARC™, in 2021 to achieve even lower spatter levels.

4.4 Welding technology for beam members

The base raw material for a beam member is a steel H-beam. There are two types of steel H-beams: rolled H-beams are formed by rolling, while welded H-beams are constructed by welding. Large beams and non-standard shapes are typically welded H-beams. For welded H-beams, the mating faces of the web plate and flange plates are fillet welded, usually by SAW (**Fig.16**).

Processes within beam member fabrication include drilling holes, welding on reinforcing elements called "stiffeners," and welding on reinforcing elements around the holes. Following their application to column fabrication, welding robot systems have recently entered the stage of full-scale welding of beam members (**Fig.17**).

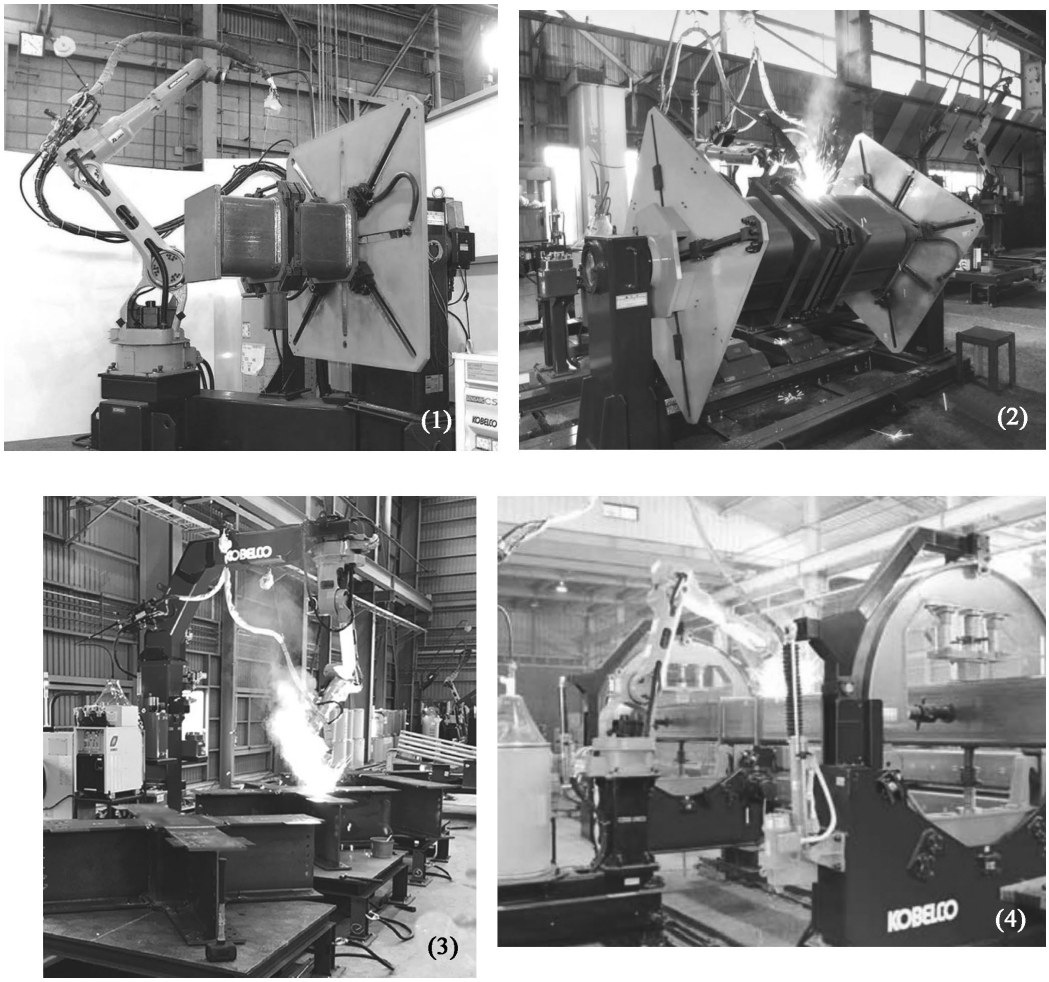

Fig.13 Steel frame welding systems using “ARCMAN™” robots for column assembly

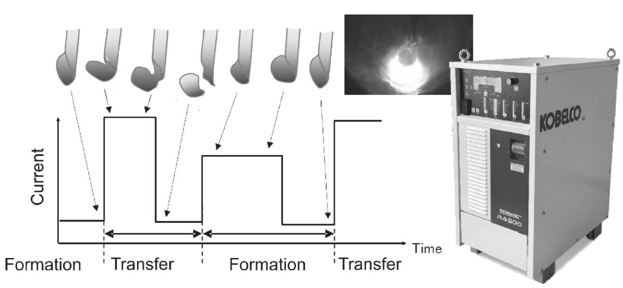

Fig.14 Basic current waveform of low-spatter CO_2 arc welding process REGARC™, and the latest model of SENSARC™ series that generates this function, RA500

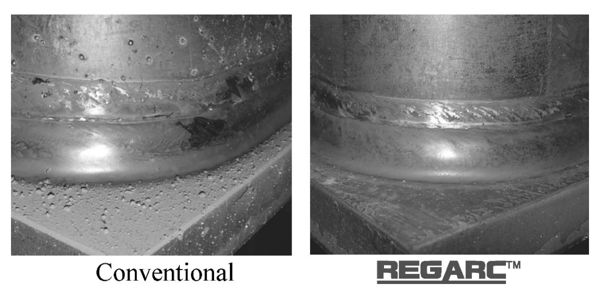

Fig.15 Comparison of spatter adhesion states with conventional CO_2 arc welding and REGARC™ process

4.5 Welding technology for on-site construction

Buildings are assembled floor by floor at the construction site. As cranes lift structural components such as prefabricated columns and beams into place, workers execute high-strength nut/bolt joints and perform arc welding. However, in recent years, the construction industry and related sectors have been facing the challenge of a growing shortage of skilled welders available for on-site erection work. Kobe Steel's ISHIMATSU™ compact portable welding robot is helping to overcome this issue. One key feature of the ISHIMATSU™ is its ultra-lightweight body, weighing around 6 kg. It requires no safety fencing and travels on a guide rail, which may be linear or contoured to fit a steel pipe. **Fig.18** shows this robot and its setup. The ISHIMATSU™ can operate in any position (flat, horizontal, overhead). **Fig.19** shows how this automatic welding robot operates in the challenging position of overhead welding, and a cross-section

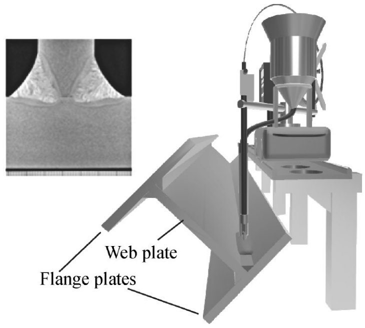

Fig.16 Fillet welding of welded H-beam assembly (submerged arc welding in a flat position) and an example cross-section of a weld joint

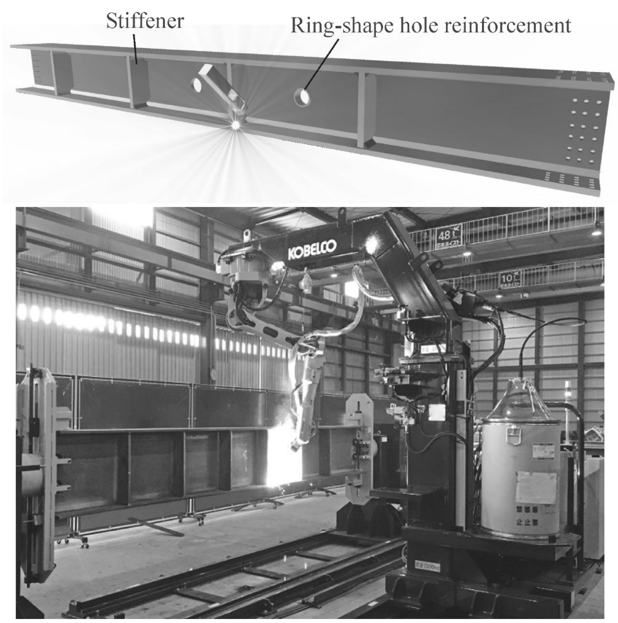

Fig.17 Welding of beam parts and "ARCMAN™" steel frame welding robot system for H-beam assembly

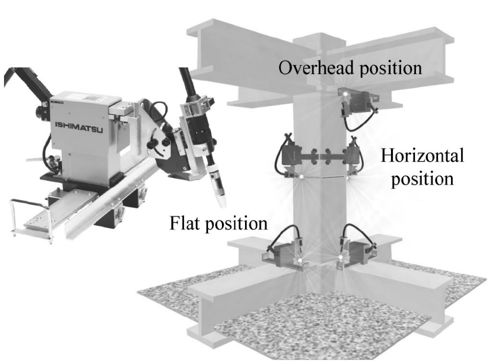

Fig.18 Portable welding robot "ISHIMATSU™" and image of on-site application

of the weld joint. This technology leverages not only robotic technology, but also the unique characteristics of Kobe Steel's specially designed flux-cored welding wire, Familiarc DW-1ST and -55ST.[15] While overhead welding is extremely labor intensive for human welders, who must also take

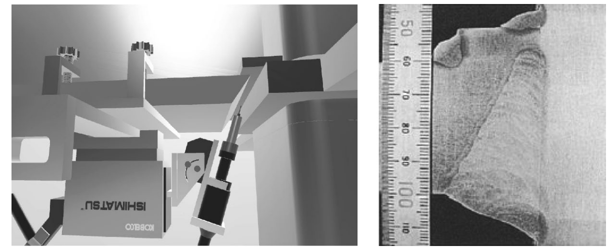

Fig.19 On-site welding of 40 mm-thick- beam-column joint using ISHIMATSU™ robot in overhead position[17)]

breaks, it presents no particular challenge to robots. The most frequently executed process in building construction is horizontal welding of the joints between columns. We are developing innovative control techniques to enhance the quality of such welds.[16]

There are only a few robots in the world like the ISHIMATSU™, and their high versatility has garnered favorable reviews from steel frame fabrication companies the world over. Outside of Japan, this robot is marketed under the name ARCMAN™ PORTABLE.

4.6 Further information

The Kobe Earthquake of 1995 spurred a wave of discussions, led primarily by the Architectural Institute of Japan, regarding the need to enhance seismic resistance, such as through high-performance welding consumables. For details on technologies related to welding consumables, see "Latest Trends and Lineup of Welding Consumables for Structural Steel" on p.86 of this issue. As a leading manufacturer of welding consumables, Kobe Steel spearheaded efforts within The Japan Welding Engineering Society to create JIS standards for high-strength, high-toughness welding consumables and thermal management indices.[17, 18]

To support the widespread use of welding robots, we worked with The Japan Welding Engineering Society and the Japan Robot Association to establish certification systems for robot models and for structural steel welding robot operators. These initiatives have since taken root as integral parts of the industry.

While automation represents the greatest need and prevailing trend in the welding of architectural steel frames today, fully robotizing the entire process is not realistic. Because manual welding will always be necessary, it remains important to continuously improve the competence of human welders. This is why, as stated in the introduction to Section 4, Kobe Steel also focuses on enhancing the skills of its welders (**Fig.20**).[19]

As part of our venture in practical welding skills training, we have recently commercialized a virtual welding training system, "NAP Welding Training,"[20,21] designed for those with little to no welding experience (**Fig.21**).

Our Welding Training Center at Kobe Steel Fujisawa Industrial Operations in Kanagawa Prefecture has provided hands-on training for over 60 years. We rebuilt the facility, opening the New Welding Training Center on October 7, 2025 (**Fig.22**). We will continue advancing the industry, including by fostering the development of welders and welding robot operators.

Fig.20 Skills training at the Welding Training Center in Fujisawa industrial operations

Fig.21 Virtual welding training system "NAP welding training"

Fig.22 New Welding Training Center in Fujisawa industrial operations

Conclusions

When buildings undergo significant deformation, the joints become the most likely failure points. With Japan being an earthquake-prone country, this means the welds and joints in steel structures must be of very high quality to protect the buildings themselves and human lives. The shortage of skilled personnel in the construction industry adds to the urgency of this issue. The practical application of the KOBELCO Group's various technological developments, particularly in welding, will help overcome both challenges.

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