Introducing New Automation System and CAD-Linked Software for Architectural Steel Frame Beam Welding

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Abstract

Steel frame fabricators are facing challenges such as shortages of skilled workers and the need to improve productivity, driving demand for automation solutions. Kobe Steel has developed beam welding software that integrates with steel frame design CAD data and has also created a system that automates the assembly process, which is the process before beam welding. The developed software automatically generates operating programs for the system directly from the CAD data of the frame design. The automated assembly system supports a wide variety of beam and column shapes, enabling automated assembly and welding. This facilitates deskilling and improved assembly precision, while also achieving high-quality welding, which helps resolve the challenges faced by steel frame fabricators.

Introduction

Based on the statistics on building starts published by the Ministry of Land, Infrastructure, Transport and Tourism, the demand for steel frames in fiscal year 2024 was about 3.65 million tons. This marks the second consecutive year that demand was below 4 million tons.[1)] Although there are large-scale projects such as redevelopment in the Tokyo metropolitan area, the demand for steel frames remains low, owing to factors including sharp increases in material costs and construction plan pivots made necessary by labor shortages.[2)]

Amidst this environment, steel frame fabricators are feeling the pressure to automate every stage of their operations – not just welding – both to improve productivity and quality and to counteract the labor shortages that have intensified over the last few years. Structural steel beams have lagged behind structural steel columns in terms of automated fabrication, revealing the former as the next challenge to tackle.

This paper introduces our SMART TEACHING™ software [Note 1)], which automatically generates welding information based on CAD data. It also introduces our structural steel beam automatic assembly and welding system, which automates the assembly process that precedes main welding.

Note 1) SMART TEACHING is a trademark of Kobe Steel, Ltd.

1. Background of development

Efforts toward automating the fabrication of architectural steel frames have traditionally centered around box columns, and more specifically on structural steel columns. The pertinent processes are characterized by long welding times and high arc generation frequencies. These factors are particularly concerning because the average age of the workforce is increasing and because the steel fabrication sector is susceptible to the impacts of labor shortages. Furthermore, Japan's work hour limits mandated in 2024 have made it increasingly difficult to maintain throughput.[3)]

Against this backdrop, steel frame fabricators are likely to automate processes that have traditionally relied on manual labor. Welding robots can handle an ever-growing range of workpieces, making consistent, high-quality welding possible and simultaneously helping to alleviate labor shortages impacting welding operations. The welding process for structural steel beams has a shorter welding time than that of structural steel columns. However, there has been relatively little progress toward automating the former. This is due in part to the wide variety of workpiece dimensions, which does not lend itself well to automation. Consequently, increasing attention has centered around automated welding systems for structural steel beams.

Furthermore, the construction industry is promoting digital transformation (DX) and BIM (building information modeling), which uses 3D models of buildings to improve productivity. Integrating CAD data for steel frame design using the concept of BIM enables continuous data management from design to construction, which will reduce errors in every process and improve efficiency.

Labor shortages are afflicting societies all over the world. In North America in particular, the severe shortage of welders and increasing labor costs are driving momentum in the automation of assembly and welding. A related issue is that because Japan experiences frequent earthquakes, building columns are usually box columns and circular steel tube columns, or SRC (steel-reinforced concrete) structures. Many regions outside Japan, including North America, have relatively low seismic activity.

As such, the columns in high-rise buildings in these areas usually use H-beams (similar to building beams). These markets can make use of automated systems designed for H-beams.

This situation led us to develop SMART TEACHING™, which links to CAD data for steel frame design, as well as our structural steel beam automatic assembly and welding system. These developments will improve construction efficiency and quality, thus enhancing productivity and competitiveness for steel frame fabricators that adopt these innovations.

2. Challenges in assembly process and overview of the system and software developed

In steel frame structures, various parts are attached to the main members, such as H-beams and box columns. These parts are positioned so as to reinforce the main members and connect them to each other or to structural elements such as floors. **Fig. 1** shows an outline of the conventional assembly process. In the part assembly process, technicians first read drawings to determine the attachment positions of each part. They then align parts in the specified positions and finally perform tack welding. There are multiple issues associated with this process. First, reading drawing dimensions properly and aligning parts in the specified positions takes great skill – it is challenging to secure competent personnel. Next, even a skilled technician takes quite some time to execute this process, leaving room for optimization. Additionally, weld quality and thus product quality may vary because the process is dependent upon the technician's skill level. Furthermore, errors in reading drawing dimensions or low accuracy during alignment could lead to rework during main welding or during assembly at the construction site.

We developed our automatic assembly and welding system for structural steel beams precisely to address these issues. **Fig. 2** shows a 3D representation of the system. It comprises a parts identification device, a handling robot with slide, a turn-over positioner, and a welding robot with slide. It also has a PC with our SMART TEACHING™ software, which links to CAD data for steel frame design.

The purpose of each device and how it fits into the system are described next. First, the operator uses SMART TEACHING™ to generate the information needed for assembly and welding processes from CAD data and load it to each element. The operator then loads the beam onto the turn-over positioner, loads parts onto the parts identification device, and starts automatic operation. During automatic operation, the parts identification device determines the geometry of the parts, assesses whether the parts can be assembled, and locates the parts. A handling robot with a gripper retrieves a part from the parts identification device, moves to the attachment position for the part, and positions the part on the beam, which is on the turn-over positioner. The handling robot has a tool changer so it can handle parts with various geometries. After the handling robot positions the parts, an welding robot performs tack welding. Part assembly occurs through iterations of these steps of part identification, part positioning, and tack welding. When a part must be attached to a different face of the main member, such as the rear, the turn-over positioner changes the orientation of the beam. After part assembly is complete, the welding robot and turn-over positioner perform main welding.

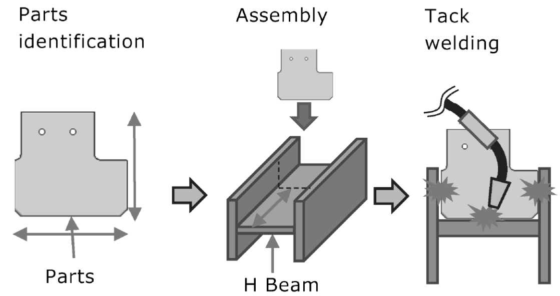


Fig. 1 Assembly process

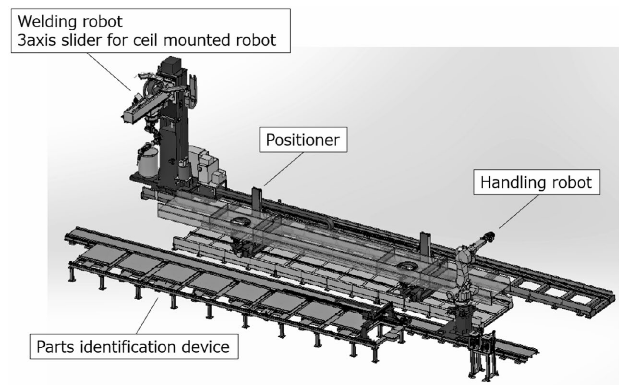


Fig. 2 Structural steel beam auto assembly welding system

This system automatically generates welding information and operating programs for assembly and main welding based on CAD data for steel frame design, yielding the core feature of automating both assembly and main welding in steel beam fabrication. The following sections describe SMART TEACHING™ and its components.

3. Features and operation of the CAD-linked software SMART TEACHING™

In conventional welding systems for steel frames, operators consult drawings for workpiece dimensions and welding variables, measure workpiece dimensions, and manually enter data into a program. By contrast, SMART TEACHING™ is linked to the CAD data for steel frame design so it can automatically extract the information necessary for assembly and welding from the CAD data. This eliminates input errors and time wasted on manual input. SMART TEACHING™ is operated from both the office and the shop floor.

Fig. 3 illustrates operation from the office, where the scope of automation is initially determined based on factors such as the parts to be attached and equipment operating time. If the system determines that assembly and welding will be performed, it processes an IFC file with CAD data on an entire building. SMART TEACHING™ then automatically generates an ST file for each main member to be welded. Kobe Steel's proprietary ST file format is an XML-based file with dimensional data on an individual main member and the parts to be welded to it. If an ST file cannot be prepared, the design data on an individual main member can be exported from the BIM software as an IFC file. The ST or IFC file generated is then transferred to the shop floor PC via USB or LAN, completing the preparatory work in the office.

Fig. 4 illustrates the subsequent process at the shop floor PC. Once the ST or IFC file for a main member has been loaded from the office and sent to SMART TEACHING™ on the shop floor PC, the main member viewer on the shop floor PC can be used to compare key specifications in the program with the actual main member and parts. These specifications include dimensions, geometry, the serial number of the main member, and welding information such as leg length and the length of parts that cannot be welded by the welding robot. Parts can be added, deleted, or edited as needed. Verifying the physical object against the data in the system on the shop floor prevents damage to equipment caused by errors and welding mistakes. After the operator confirms that all specifications are correct, the motion program is generated and sent to the welding robot, and automatic welding begins.

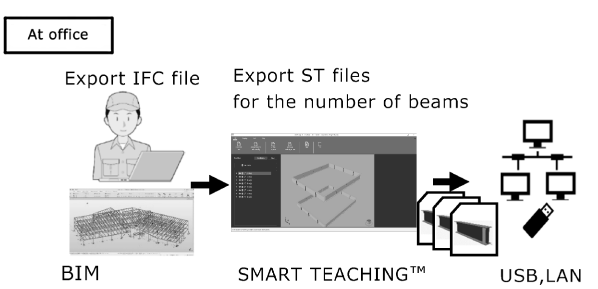


Fig. 3 Operation of SMART TEACHING™ software in the office

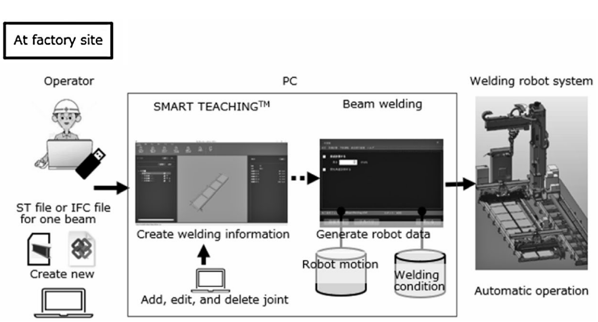


Fig. 4 Operation of SMART TEACHING™ software at factory site

4. Features of each component of the structural steel beam automatic assembly and welding system

Described next are products and technologies we developed to automate assembly and welding.

First, we have developed various handling tools for handling robots to accommodate parts with different geometries and attachment processes in the automated assembly of parts. One of these tools is a magnetic end effector for gripping stiffeners and gusset plates. Another tool uses linear motion devices, proximity sensors, and similar components to grip ring-shaped reinforcement members of various sizes for through-holes.

The parts identification device (**Fig. 5**) consists of a pallet section for arranging parts and a device that measures part geometries. The measuring device has a profile sensor that reads the three-dimensional measurements of a target object to a resolution of 0.1 mm. This sensor is on a carriage mounted on a gantry-type frame. As the sensor travels over the pallet in a precise manner, it reads the part geometries, including thickness. The system uses the precise measurements to determine whether a part can be assembled to the main member. It also calculates the positioning coordinates for the handling robot to grasp the parts, achieving positioning accuracy with a total error of ± 1.0 mm.

We also developed the welding robot's slide and the workpiece positioner for this system. The slide is designed for an overhead-mounted robot and is capable of 3-axis motion. By routing the torch cable through the robot's rotating parts, we reduced interference with equipment and workpieces, making this system usable in a wider spectrum of cases. Additionally, because the weaving accuracy of a welding robot is critical to welding quality, we ensured that the robot can operate with a very high level of accuracy.

The positioner we developed is a turn-over positioner (**Fig. 6**) capable of handling H-beam workpieces weighing up to 8 tons. This positioner has two pairs of hydraulic arms that operate in unison to turn the beam over. It accommodates beams with a depth of up to 1,200 mm. Thus, it has an expanded maximum dimensional capacity compared with our conventional rotary positioners, which have a workpiece width limit of 1,000 mm. The key feature of the turn-over positioner, however, is the scope of capabilities it makes possible. Conventional rotary positioners, which are primarily designed for box columns and circular steel tube columns, grip the workpiece using a ring-like chuck. The chuck can interfere with the welding robot at the gripping point, creating an area of up to 4,400 mm on the beam that is inaccessible for assembly or welding. The main member must be shifted and repositioned for the robot to access these remaining sections. By contrast, since the turn-over positioner supports the main member from below, no areas are made inaccessible due to interface points between a gripping mechanism and the beam. A further benefit of supporting the main member from below is that the labor to chuck the beam is eliminated, improving production efficiency and yielding savings in labor costs. However, it does take longer to turn the main member over compared with rotating on a conventional rotary positioner. Since the two pairs of hydraulic arms must operate in sync to turn the workpiece over while supporting its weight, the speed of this operation had to be limited to prevent the workpiece from falling. To address this issue, we developed a control method that increases the speed of the arms while supporting the full weight of the workpiece. Kobe Steel's turn-over positioner now incorporates load monitoring via oil pressure sensors and oil flow control to reduce turn-over time by about 20%.

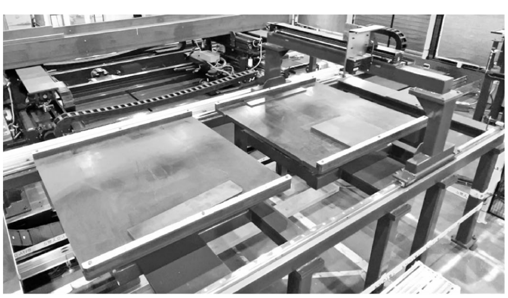


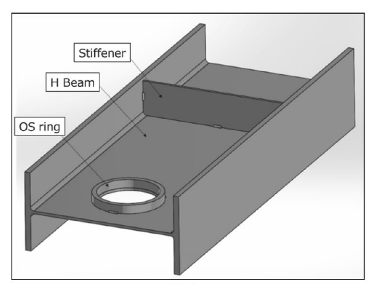
Fig. 5 Parts identification device

Fig. 6 Positioner

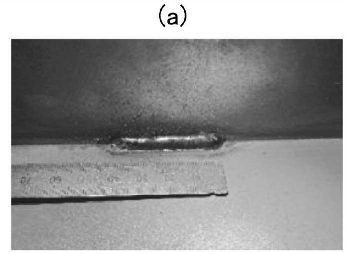
5. Expansion of scope through tack welding

Kobe Steel has extensive experience developing tack welding techniques that improve the efficiency and quality of main welding. In developing the system covered in this paper, we also developed techniques to support robotic tack welding, which involves different techniques from main welding.

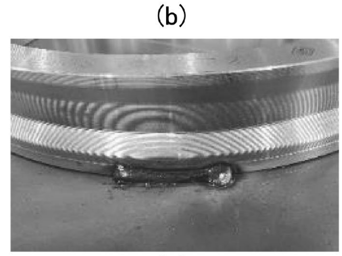
Many different types of parts get welded to beams, and they come in a variety of shapes and sizes. We have established various tack welding techniques to address this diversity of scenarios. We have achieved tack welding that meets the leg length and bead length specified by Japanese Architectural Standard Specification (JASS6) in not just the horizontal position, but also the vertical position (**Figs. 7**(a), 7(b)). Furthermore, by combining a turn-



(a)



(b)



(c)

Fig. 7 Appearance of welded assembly (a) Sample 3D model, (b) Web and stiffener tack welding, (c) OS ring and web tack welding over positioner with an overhead-mounted slide, this system can weld ring-shaped parts such as OS Rings (Note 2), which could not be handled by Kobe Steel's conventional products (Figs. 7(a), 7(c)).

6. Benefits of the system

This system achieves automation in a way that includes the structural steel beam assembly process, which has not yet been widely automated in Japan. As such, the system should solve multiple challenges faced by steel frame fabricators.

First, it addresses labor shortages and improves productivity. Automation using robots reduces the labor required for the assembly process, thereby counteracting labor shortages. Furthermore, because automation reduces the skill level required for assembly and welding, it counteracts shortages in skilled labor specifically. Additionally, since an automated system can operate 24 hours a day, it significantly improves productivity.

Automation also improves product quality. Robotization enables the production of high-quality products even without skilled workers who have advanced technical expertise in assembly or welding. Furthermore, linking to CAD data reduces manufacturing defects caused by operator input error and should increase yields.

FAMILIARC™ MX-Z200MP (Note 3), the recommended consumable for this system, yields favorable slag adhesion characteristics and a lustrous bead appearance. In this way, it is possible to achieve high-quality fillet weld joints (a common joint type in structural steel welding). In addition, the reduced spatter positively affects downstream processes. The associated time savings in cleaning and finishing processes is expected to reduce costs.

Finally, our system improves workplace safety. Specifically, craning is not required, even to attach parts to large components, ensuring a safe work environment by reducing the risk of accidents. Advancing automation through robots is helping to relieve physical strain on operators.

This system solves two key challenges faced by steel frame fabricators: labor shortages and the demand for increased productivity. Reduced labor and personnel costs, improved safety, shorter production lead times, lower technical skill requirements, and continuity through CAD integration together yield efficient, high-quality production. In this way, our system enhances competitiveness and enables sustained growth.

Conclusions

This paper introduces the technologies and key features of SMART TEACHING™ and our structural steel beam assembly and welding system. We are expanding the scope of parts to which these technologies can be applied and are fostering automation in the material handling of main members and parts. Our end goals in doing so are to increase the proportion of cases in which these technologies can be used and to automate the processes upstream of welding.

Moving forward, we will improve welding technology and develop automation technologies for the processes upstream and downstream of welding. In this way, we will continue developing products that meet users' automation needs.

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3) Y. Ikeda et al. Report of Obayashi Corporation Technology Research Institute. 2023, No.87.

Note 2) OS Ring is a trademark of OKABE Co., Ltd.
Note 3) FAMILIARC is a trademark of Kobe Steel, Ltd.