

# Application of Narrow Gap Welding Process with High Speed Rotating Arc to Box Column Joints of Heavy Thick Plates<sup>†</sup>

IWATA Shinji\*<sup>1</sup> MURAYAMA Masatoshi\*<sup>2</sup> KOJIMA Yuji\*<sup>3</sup>

## Abstract:

Recently, heavy thick plates of high strength steel have been applied to the columns of high-rise buildings in Japan. The maximum thickness of the plates reaches 100 mm and the application of SA440 steel, having yield strength of 590 N/mm<sup>2</sup>, has now become common. In addition, unprecedented high welding performance, such as higher than 70 J CV at 0°C for the welded metal, is now required to fabricate these plates. The authors have developed a new welding system to combine the narrow gap welding process with high speed rotating arc (Patented by JFE Engineering) and the submerged arc welding to keep the required quality for the corner welding of plates with the thickness more than 70 mm. The paper introduces the outline of the new system.

## 1. Introduction

Submerged arc welding is generally used in the corner joints of box columns for building structures. Although materials with plate thicknesses up to 70 mm are welded by one-side welding with one run and one pass, for those with thicknesses exceeding 70 mm, welding is performed by gas shielded metal arc welding, multi-pass welding by submerged arc welding, or a combined welding procedure employing these two methods.

The conventional welding procedures for heavy thick plates and high performance steel plates had a number of problems, including heat input, power supply capacity, weldability, cost, deformation, and others. Therefore, as a result of a study of various welding procedures

and their combinations, these problems were solved by adopting a combined welding procedure in which welding is performed by a high speed rotating arc welding process using a square-shaped narrow gap groove as the root of the groove in corner joints, which is followed by submerged arc welding with a single V groove at the surface of the groove. This paper presents an outline of the new system.

## 2. Welding Sequence and Features of Box Columns

Figure 1 shows the welding sequence used with box columns. The main structure of a box column comprises

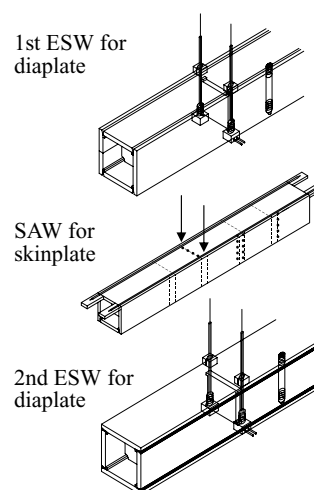


Fig. 1 Welding sequence of box column

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\*<sup>1</sup> Group Manager, Welding Technic Group,  
Shimizu Works Production Sec.,  
Building Structure Engineering West Dept.,  
Steel Structure Engineering Sector,  
JFE Engineering



\*<sup>2</sup> Chief Researcher,  
Production Engineering Research Dept.,  
Technical Research Center,  
JFE Engineering



\*<sup>3</sup> Group Manager,  
Sales Dept.,  
Japan Techno-Mate

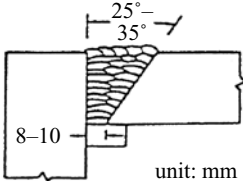
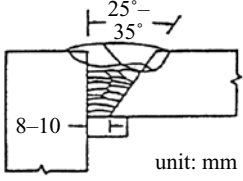
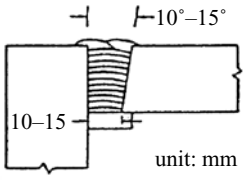
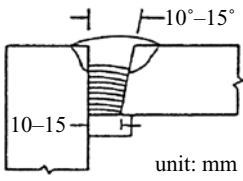
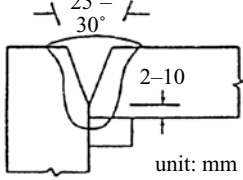
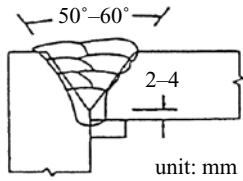
skin plates on the four outer sides and diaphragms as inner stiffener plates. The corner joints of the skin plates are welded by submerged arc welding (SAW), and the joints between the skin plates and the diaphragms are welded by electroslag welding (ESW). The specification requires full penetration. In skin plates for high-rise buildings, use of high strength, heavy thick plates with a maximum thickness of 100 mm and tensile strength of 590 N/mm<sup>2</sup> class has become common. Unprecedented high welding performance is also required, as exemplified by Charpy impact values of more than 70 J at 0°C for HAZ toughness.

### 3. Study of Applicable Welding Procedures

#### 3.1 Comparison and Selection of Welding Procedure

**Table 1** shows a comparison of the various welding procedures and their combinations used as welding procedures for box corner joints when using heavy thick plates and high performance steel plates as skin plates for box columns. Procedures ① through ⑥ all have advantages and defects. For example, ① and ② are advantageous from the viewpoints of heat input and workability, but welding efficiency is a problem; conversely, ⑤ and ⑥ offer good efficiency, but have problems related to heat input, workability, etc. Therefore, the authors focused on fact that ③ has a small heat input but comparatively high welding efficiency, and ④ offers

Table 1 Comparison of corner welding procedures

Welding procedure	Groove shape and pass scheme	Advantage	Defect
① CO <sub>2</sub> gas metal arc welding		<ul style="list-style-type: none"> <li>· Few restrictions for application</li> <li>· Small heat input</li> </ul>	<ul style="list-style-type: none"> <li>· Low efficiency</li> </ul>
② CO <sub>2</sub> gas metal arc welding ISAW		<ul style="list-style-type: none"> <li>· Few restrictions for application</li> </ul>	<ul style="list-style-type: none"> <li>· Low efficiency</li> <li>· Large heat input</li> </ul>
③ Narrow gap SAW or Narrow gap MIG welding		<ul style="list-style-type: none"> <li>· Higher efficiency than q or w</li> <li>· Small consumable consumption</li> <li>· Small heat input</li> </ul>	<ul style="list-style-type: none"> <li>· Sensitive to accuracy and cleanliness of groove</li> </ul>
④ Narrow gap SAW (or Narrow gap MIG welding) ISAW with large heat input		<ul style="list-style-type: none"> <li>· Higher efficiency than e</li> <li>· Small consumable consumption</li> </ul>	<ul style="list-style-type: none"> <li>· Sensitive to accuracy and cleanliness of groove</li> <li>· Large heat input</li> </ul>
⑤ One-run SAW with three electrodes		<ul style="list-style-type: none"> <li>· Excellent efficiency</li> </ul>	<ul style="list-style-type: none"> <li>· Inapplicable to heavy thick plate (Maximum plate thickness is 60 to 70 mm.)</li> <li>· Huge heat input</li> <li>· Specialized equipment required</li> </ul>
⑥ Multi-run SAW with large heat input		<ul style="list-style-type: none"> <li>· Good efficiency</li> </ul>	<ul style="list-style-type: none"> <li>· Strict procedure control required</li> <li>· Large heat input</li> </ul>

good workability and high efficiency, even assuming use within the heat input limit of this method. Based on the results of a comparative study and simple pretests of these methods using sample test pieces, a combined welding procedure consisting of a combination of ③ narrow gap MIG (narrow gap welding with high speed rotating arc) and ④ final pass SAW was selected for further study.

### 3.2 Outline of Narrow Gap Welding Process with High Speed Rotating Arc

The principle of the narrow gap welding process with a high speed rotating arc is shown in Fig. 2<sup>1)</sup>. This welding process is an original technology developed by JFE Engineering. In this method, the contact tip, which is offset in the hole for passing the wire, is attached to the electrode and inserted into a narrow gap joint, and welding is performed by rotating this at high speed, which causes rotated weaving of the arc at the wire tip. The arc rotating speed is 50–100 Hz, the diameter of rotation is approximately 8 mm, and the width of the face of the groove of the narrow gap joint is 12–16 mm.

**Photo 1** shows the effect of arc rotation on the shape of the weld bead. In welding with no arc rotation, penetration concentrates at the center of the groove, and

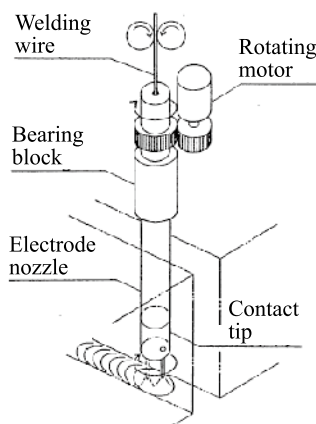


Fig. 2 High speed rotating arc welding process

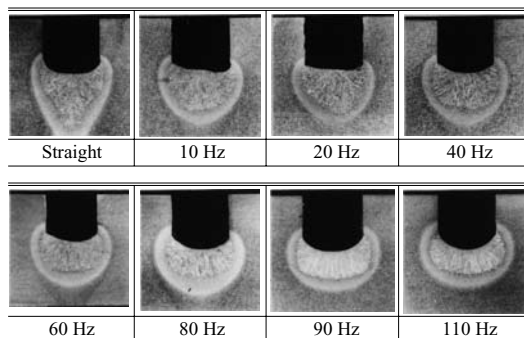


Photo 1 Effect of the rotating speed to the shape of weld bead in narrow grooves

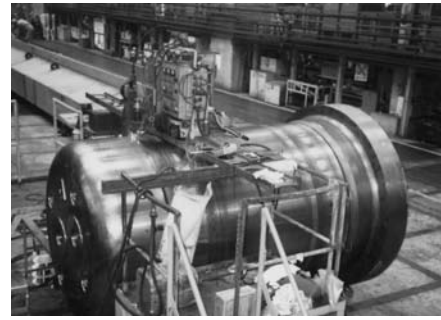


Photo 2 Application to cylindrical structure



Photo 3 Weld bead section of rotating arc welding

as a result, lack of penetration can easily occur in the side fusion zone. However, as the arc rotating speed increases, penetration into the side fusion zone also expands, and the surface shape of the bead becomes concave with curvature. Because the system is equipped with an automatic groove tracing function using an arc sensor, torch positioning work during welding is not necessary.

This welding procedure is applied to butt welding of heavy thick plates, for example, in heavy machinery, long-span bridges, and various types of plants. **Photo 2** shows a view of application to a heavy cylindrical structure. An example of the weld bead section with a plate thickness of 235 mm is shown in **Photo 3**. It can be understood that satisfactory, uniform penetration to the side fusion zone has been obtained. The development of a small rotating torch has also made it possible to apply this method to fillet welding in shipbuilding, bridges, etc.

### 4. Problems for Application to Box Columns and Related Countermeasures

In applying the narrow gap welding process with a high speed rotating arc to the corner joints of box columns, the following countermeasures were studied and implemented. In this process, the test results of the pretests with sample test pieces were used as reference.

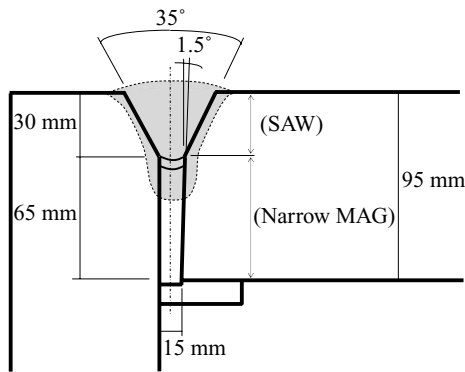


Fig. 3 Groove detail

#### 4.1 Groove Shape and Welding Methods Applied

The standard groove shape for box corner joints is shown in Fig. 3. From the root of the groove to a groove depth of approximately 30 mm, a square groove with a groove face width of approximately 15 mm was used, and one layer and one pass multi-layer welding was performed by the high speed rotating arc welding process. Next, using a V groove from a groove depth of approximately 30 mm at the surface of the groove, final pass welding was performed by one layer and one pass one-layer SAW welding.

In performing full thickness welding of heavy thick plates by narrow gap welding with a high speed rotating arc, there are problems related to the progress of the shop line, maintaining the width of the groove, etc. Therefore, a combined welding procedure was adopted, in which SAW welding within the heat limits of the plates is performed at the surface of the groove (final pass).

#### 4.2 Maintaining Groove Width by Shrinkage by Welding

In the groove shape in Fig. 3, an approximate 1.5° reverse trapezoid shape was adopted considering heat shrinkage by multi-layer welding, thereby maintaining a constant groove width as welding progressed.

#### 4.3 Securing Groove Accuracy

The shape of the groove in corner joints is formed by gas-cutting the edges of the skin plates. Therefore, the possibility of applying this welding process with the existing level of dimensional accuracy and cut surface roughness was studied. From the results of pretests, it was concluded that the condition of the groove is within the tolerance of this method and application is possible if accuracy control can be performed at the existing upper limit (target value:  $\pm 2$  mm).

#### 4.4 Securing Penetration of First Layer

When small heat input welding is applied to heavy thick plates in corner joint welding, weld defects can easily occur, particularly in the first layer. As a countermeasure against this, a recess is formed by machining the backing metal so that any defects which might occur are limited to the outside of the plate thickness.

#### 4.5 Training Welding Operators

Because the narrow gap welding process with a high speed rotating arc is performed with automatic tracking of the groove by an arc sensor, correction of the target of the torch during welding is not necessary. However, manual fine tuning of the welding speed in response to changes in the groove width is necessary. Accordingly, in practical application, operators were given training in the operation of the welding system by assigning two personnel on a full-time basis from the start of introduction of the system, thereby ensuring that the operators mastered the work manual, including accuracy checks in the related processes from steel plate cutting to corner welding, points related to the use of the welding system, and procedures for responding to non-conformance.

### 5. Welding Procedure Test

#### 5.1 Pretests Using Sample Test Pieces

In order to confirm the characteristics of the narrow gap welding process with a high speed rotating arc, a welding procedure test for butt welding (plate thickness: 50 mm, joint length: 800 mm) was performed. In this test, welding characteristics such as weldability and the amount of shrinkage due to welding were assessed using a square groove with a width of 15 mm. A view of the test is shown in Photo 4.

#### 5.2 Box Column Test

In order to confirm applicability to the box column structure and the mechanical properties in this case, a welding test was performed with a full-scale box col-

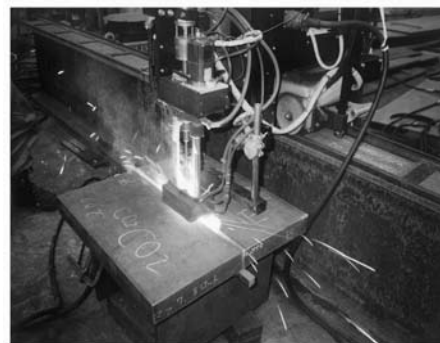


Photo 4 Procedure test for butt welding

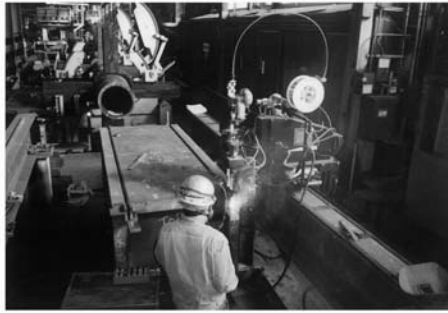


Photo 5 Procedure test for box column corner welding



Photo 6 Macroetch test specimen for corner welding

umn specimen (plate thickness: 100 mm, dimensions of box column: 1 000 mm $\square$ , joint length: 3 000 m). Narrow gap welding with a high speed rotating arc (welding conditions: 14–15 passes at 340A-36V-25 cm/min) was performed using the standard groove shape shown in Fig. 4. This test confirmed the establishment of the work manual (each stage) and characteristics of the mechanical properties of the weld when this welding process is applied to box column corner joints. A view of the test and a macroetch test specimen of the weld are shown in **Photos 5** and **6**, respectively.

### 5.3 Welding Procedure Test

In application of the narrow gap welding process with a high speed rotating arc to an actual project, a welding procedure test (plate thickness: 95 mm, material used: SA440 steel plate with high HAZ toughness) was performed with inspection by the client's engineers prior to the start of actual work, and weldability, workability, and the integrity of the weld were confirmed. As a result, all items in the acceptance criteria for weld performance required in the actual project were satisfied. Examples of the results of the mechanical property tests are shown in **Tables 2** and **3**.

## 6. Application to Actual Projects

Since the introduction of narrow gap welding with a high speed rotating arc + submerged arc welding at JFE Engineering's Shimizu Works, this process has been applied to more than 10 projects. Examples of applica-

Table 2 Tensile test results of all deposited metal

Position of specimens	Number	YS (N/mm <sup>2</sup> )	TS (N/mm <sup>2</sup> )	EI (%)
Deposited metal (SAW)	1	552	647	24
	2	563	648	25
Deposited metal (Boundary)	1	533	617	26
	2	558	627	24
Deposited metal (NGW)	1	657	690	24
	2	674	686	24
Acceptance criteria	—	—	≥590	—

\*NGW: Narrow gap welding

Table 3 Impact test results

Position of specimens	Impact test: vE <sub>0C</sub> (J)			Aver.
	Each			
	①	②	③	
Deposited metal (SAW)	132	110	123	122
Deposited metal (Boundary)	148	117	160	141
Deposited metal (NGW)	79	87	89	85
Weld junction (SAW)	115	121	94	110
Weld junction (Boundary)	99	156	162	139
Weld junction (NGW)	203	205	187	198
Acceptance criteria	—	—	—	≥70

\*NGW: Narrow gap welding

Projects	Size of box column	Plate materials (Thickness)	Groove shape and pass scheme
A	1 000 $\square$	SA440C-E(95)	unit: mm
	800 $\square$	SA440C-U(90)	unit: mm
B	800 $\square$	TMCP355C(80)	unit: mm
C	1 000 $\square$	TMCP385C(52)	unit: mm

Fig. 4 Example groove details in actual projects

tion to the corner joints of box columns for high-rise buildings are shown in **Fig. 4**. Application to heavy thick plates and high strength/high quality plates is remarkable, as seen in application example A (thickness: 95 mm, material: SA440C-E), B (thickness: 80 mm,

material: TMCP355C), C (thickness: 52 mm, material: TMCP385C), etc.

## 7. Conclusion

The application of a new welding procedure (high speed rotating arc + submerged arc welding) for corner joints, responding to the use of heavy thick plates and high strength, high quality steel plates in box columns for building structures, was introduced.

In the future, the authors intend to expand the range of applicable shapes and joints with this welding procedure as a welding technology responding to higher strength and higher quality requirements.

## Reference

- 1) Nomura, Hirokazu; Sugitani, Yuji; Kobayashi, Yukio. "Narrow Gap MIG Welding Process with High Speed Rotating Arc." *Journal of High Pressure Institute of Japan*. 1984, vol. 22, no. 4, p. 186–193.