

Application of Narrow Gap Welding Process with “J-STAR™ Welding” to Shipbuilding and Construction†

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Abstract:

The “J-STAR™ Welding” is performed with an electrode negative polarity in CO₂ gas shielded arc welding using rare earth metal added wire. In the “J-STAR™ Welding,” a conical arc plasma is formed from the wire tip and the droplets that transfer to molten pool become fine and continuous, which called “spray transfer.” As a result, reduction of spatter and deep penetration can be obtained. In the narrow gap welding of thick steel plate, it is necessary that spatter doesn’t accumulate on the welding nozzle and the groove sidewall, and the bottom corner and sidewall of the groove are melted stably. Therefore, narrow gap welding utilizing the benefits of the “J-STAR™ Welding” was examined, and a new narrow gap welding process by 2-pass one-layer technique using an electrode with curved tip was developed. It was confirmed that the good joint of 100 mm plate in thickness for which the developed narrow gap welding process is applied can be produced with a very few welding processes of 31 passes and 16 layers.

1. Introduction

Accompanying the trends toward larger scale and heavier plates in steel structures, more time is required in assembly welding, and increased welding cost is a concern. Narrow gap welding has attracted attention as a countermeasure for shortening welding time, as this technique makes it possible to reduce the amount of weld metal¹⁻⁴⁾. In conventional narrow gap welding, the general practice was to apply gas shielded metal arc

welding (GMAW) using a mixed gas such as Ar-20% CO₂ as the shield gas. A mixed gas was used due to the large amount of spatter generated in CO₂ gas shielded welding using 100% CO₂ shield gas. Spatter is particularly a problem in narrow gap welding, since deposition and accumulation of spatter on the welding nozzle and groove sidewall cause welding to become unstable and welding defects tend to occur easily.

JFE Steel developed “J-STAR™ Welding,” which is a CO₂ gas shielded welding method using a welding wire containing a trace amount of added rare earth metal (REM) as an arc stabilizer in direct current electrode negative welding (DCEN welding) using a negative polarity welding wire⁵⁻⁸⁾. “J-STAR™ Welding” makes it possible to obtain deep penetration and a large reduction in spatter generation by forming a stable conical arc and realizing fine and continuous spray transfer of droplets to the molten pool. To date, application to 25°-single bevel grooves and square grooves for welds in steel structures has been studied, and approval of newly developed building technology has been received from General Building Research Corporation of Japan⁹⁻¹³⁾.

Recently, JFE Steel developed a new narrow gap welding technology with “J-STAR™ Welding” by a 2-pass one-layer technique using an electrode with a curved tip with the aim of further expanding the applicable plate thickness and improving quality. This paper introduces the new method, and also presents examples of study of the application of “J-STAR™ Welding” to the shipbuilding and construction fields.

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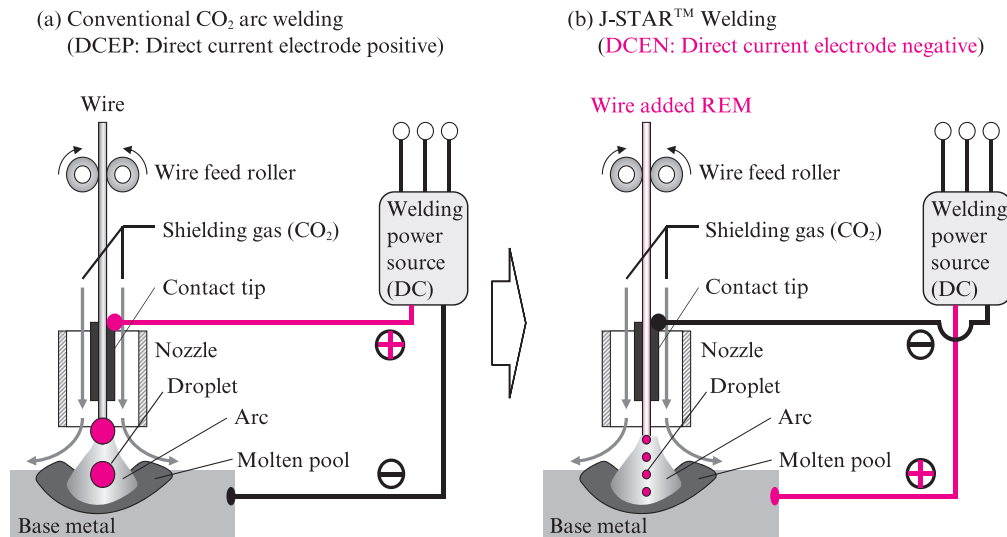
Fig. 1 Comparison between conventional CO₂ arc welding and “J-STAR™ Welding”

Table 1 Chemical composition of welding wire

(mass%)							
Type	C	Si	Mn	P	S	Ti	Others
KC-550 (JIS Z 3312, YGW18)	0.05	0.7	1.9	0.01	0.01	0.2	Mo, B, REM*

*Rare earth metal

Table 2 Chemical composition and mechanical properties of deposited metal

Chemical composition (mass%)					Mechanical properties			
C	Si	Mn	P	S	0.2% proof stress (N/mm ²)	Tensile strength (N/mm ²)	Elongation (%)	Absorbed energy at -5°C (J)
0.06	0.5	1.4	0.01	0.01	571	621	30	146

2. Features of “J-STAR™ Welding”

As shown in **Fig. 1**, conventional CO₂ gas shielded arc welding is a direct current electrode positive (DCEP) technique, in which the welding wire has positive polarity. In contrast, “J-STAR™ Welding” is a CO₂ gas shielded welding method using a welding wire with a trace amount of added REM and a welding wire with negative polarity, which is the opposite of the conventional method. The features of “J-STAR™ Welding” including the following:

- (1) Remarkably small generation of welding spatter
 - (2) Possible to obtain deep penetration due to easy concentration of the welding arc
 - (3) Good detachability of oxides (slag) on weld surface
- Thus, “J-STAR™ Welding” has features which are suitable for narrow gap welding.

Table 1 shows an example of the chemical composition of the “J-STAR™ Welding” welding wire “KC-550.” “KC-550” is a welding wire which is equivalent to YGW18 in JIS Z 3312 (JIS: Japanese Industrial Stan-

dards) and contains a trace amount of added REM. **Table 2** shows the results of an all-deposited metal test of CO₂ gas shielded welding using “KC-550.” The results show satisfactory strength and toughness as a welding wire for use with 550 N/mm² class steel. The fact that the weld properties in “J-STAR™ Welding” can be obtained regardless of the strength level by adding a trace amount of REM to the welding wire has been confirmed, and this wire is easily expanded to welding wires for high strength steels such as 590 N/mm² class.

3. Narrow Gap Welding Technology for Extra Thick Plates

3.1 Two-Pass One-Layer Technique Using Curved Electrode Tip

JFE Steel has developed a narrow gap welding technology for 25°-single bevel grooves and other groove configurations as a high efficiency welding technology

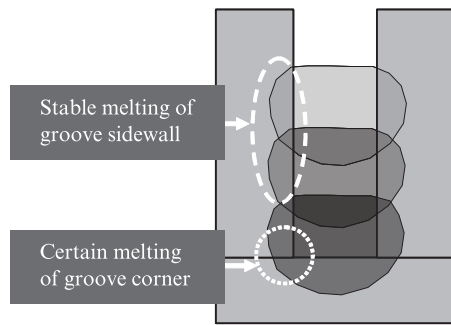


Fig. 2 Issues required in narrow gap welding

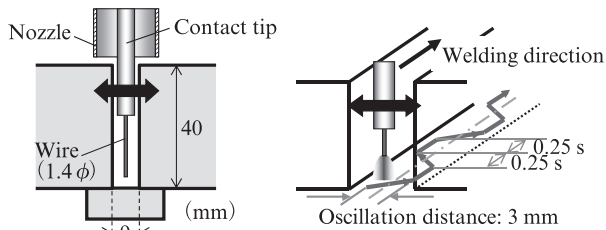
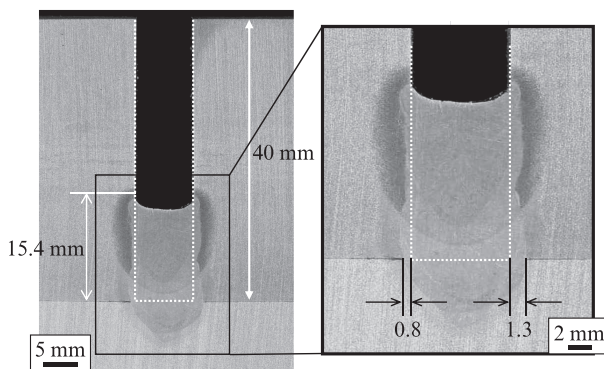


Fig. 3 Schematic illustration of developed narrow gap welding process

(a) Schematic illustration of conventional narrow gap welding



(b) Macrostructure of cross section

Photo 1 Macrostructure of welded joint by conventional narrow gap welding process

for plates by using “J-STAR™ Welding.” As shown in **Fig. 2**, in order to prevent welding defects such as lack of penetration, lack of fusion, etc. in narrow gap welding of plates (particularly in the case of square grooves), certain melting of the groove corner and stable melting of the groove sidewall are necessary. However, as shown in **Photo 1**, in 1pass one-layer welding (with oscillation) of a square groove, melting of the sidewall is limited to approximately 1 mm. This also includes “J-STAR™ Welding,” in which the directivity of the welding arc is strong, and was a problem for practical application.

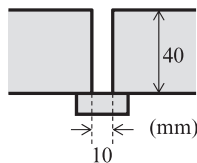
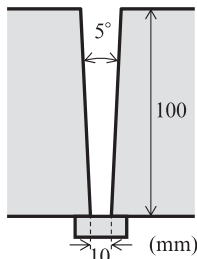
In order to expand melting of the groove sidewall, it is considered necessary that the arc strikes the groove corner and sidewall directly, as illustrated in **Fig. 3**. Therefore, a welding technique in which a welding tip with a slightly curved tip is inserted in a narrow groove was studied. The results of a preliminary study revealed that melting of the groove corner and sidewall can be

increased easily by skillfully utilizing the effect of the strong arc directivity of “J-STAR™ Welding.” Following that study, other issues such as optimization of the electrode tip curvature angle were carried out, and a narrow gap (square groove) welding technology applying “J-STAR™ Welding” by 2-pass one-layer welding using an electrode with a curved tip was developed¹⁴⁾.

3.2 Welding Conditions

Using the welding wire “KC-550” (equivalent to YGW18 in JIS Z 3312) with trace addition of the REM shown in Table 1, narrow gap welding was performed by 2-pass one-layer welding using an electrode with a curved tip. **Table 3** shows the groove geometries and welding conditions. A square groove with a gap of 10 mm was used in narrow gap welding with the plate

Table 3 Groove geometries and welding conditions

Groove configuration	Welding conditions	
	Current (A)	330–353
	Voltage (V)	35.3
	Welding speed (mm/min)	600
	Heat input (kJ/mm)	1.3
	Layer number	7
	Pass number	13
	Current (A)	324–371
	Voltage (V)	34.9–38.4
	Welding speed (mm/min)	200–600
	Heat input (kJ/mm)	1.2–2.5
	Layer number	16
	Pass number	31

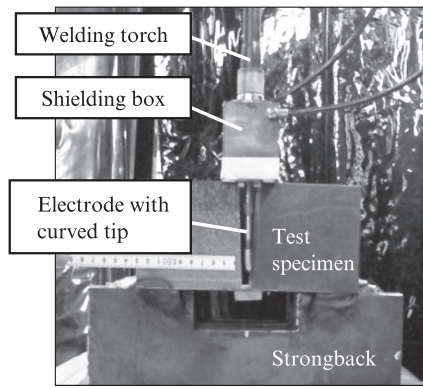


Photo 2 Welding technique in butt joint of 100 mm thickness

thickness of 40 mm, and a single V groove (groove angle: 5°) with a gap of 10 mm was used with the plate thickness of 100 mm. In both cases, 490 MPa class steel plates were used. In narrow gap welding with the plate thickness of 100 mm, welding was performed with a shielding box mounted on the base metal surface, as shown in **Photo 2**, to prevent entrainment of air.

3.3 Evaluation of Performance of Narrow Gap Welded Joint

Photo 3 shows cross-sectional macrostructures of a narrow gap welding joint with the plate thickness of 40 mm, which was produced by the 2-pass one-layer technique using the electrode with the curved tip developed in this research. As can be understood from the photograph after completion of welding of three layers (i.e., after partial welding), no spatter can be observed adhering to the groove sidewall, confirming the effect of low spatter which is a distinctive feature of “J-STAR™ Welding.” Penetration of the groove bottom and sidewall was also satisfactory, as melting of 2 mm or more could be secured; this is a large increase in comparison with the 1-pass one-layer joint described above (Photo 1). This improved penetration is considered to be possible because the arc can be directed toward the groove corner by using the electrode with the curved tip, resulting in more effective action of the distinctive high penetration force directly under the arc in “J-STAR™ Welding.”

Because the experiment described above demonstrated that it is possible to apply 2-pass one-layer welding by “J-STAR™ Welding” using the electrode with the curved tip to narrow gap welding of heavy plates, application to a butt-welded joint of plates with the thickness of 100 mm was attempted. The cross-sectional macrostructure of the joint is shown in **Photo 4**. Satisfactory penetration of both the groove bottom and sidewall can be confirmed, and production of the joint was possible with very few welding processes (31 passes and 16 layers). As can be understood from the results of the hard-

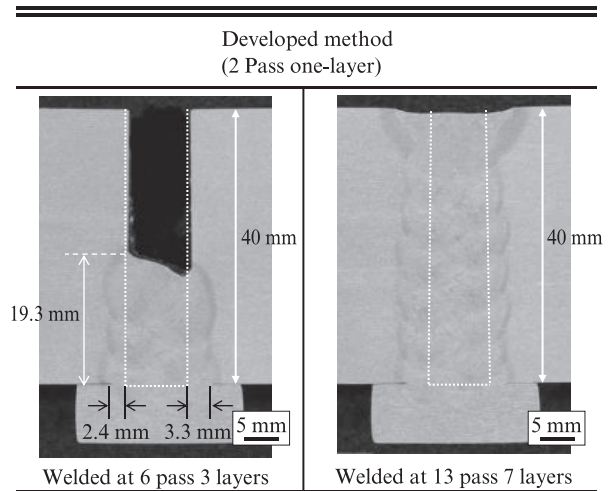


Photo 3 Macrostructure of welded joint of 40 mm thickness by developed narrow gap welding process

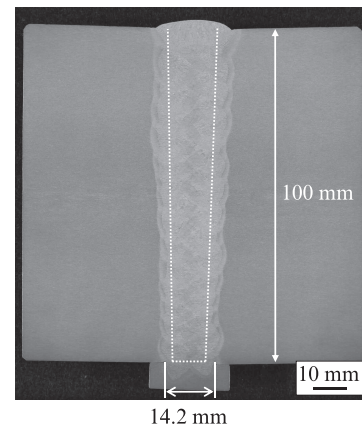


Photo 4 Macrostructure of welded joint of 100 mm thickness by developed narrow gap welding process

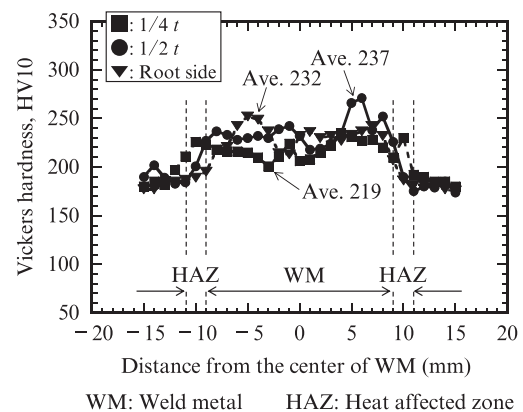
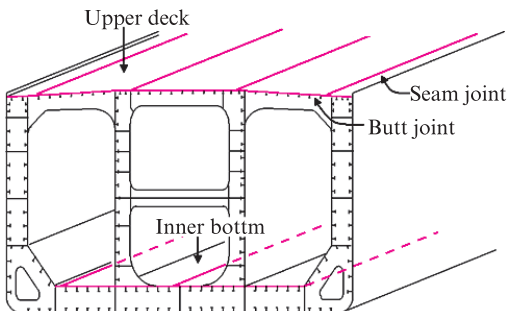


Fig. 4 Hardness distributions of welded joint of 100 mm thickness by developed narrow gap welding process

ness test of the joint in **Fig. 4**, the hardness of the weld metal was on the order of HV230 regardless of the measurement position, and variations due to build-up were slight.

4. Development of “J-STAR™ Welding” to Shipbuilding and Construction Fields

Figure 5 shows the applicable joints for the spray transfer CO₂ gas shielded welding method “J-STAR™ Welding” in a tanker^{15, 16}. The applicable parts are the inner bottom and upper deck seam welds and butt welds, which are long joints of 490 MPa class steel AH36 with



Welding part	Base metal		Single V groove	
	Grade	Thickness (mm)	Angle (°)	Gap (mm)
Upper deck	AH36	20	40	2–6
Inner bottom	AH36	20	40	0–4

Fig. 5 Application part and groove conditions of “J-STAR™ Welding”



(a) Conventional welding; DCEP (Direct current electrode positive), Welding current: 280 A

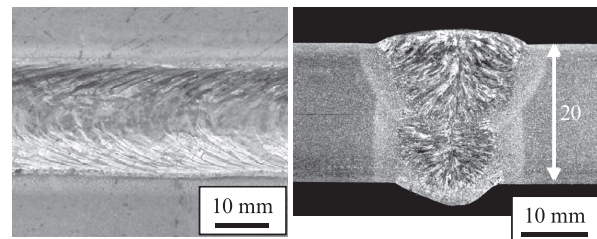


(b) “J-STAR™ Welding”; KC-550, DCEN (Direct current electrode negative), Welding current: 380 A

Photo 5 Comparison of welding phenomenon of internal bottom joint

a plate thickness of 20 mm, and one side welding using a ceramic backing material. The groove angles were narrowed from the conventional 50°V to 40°V. **Photo 5** shows the condition of scattering of spatter during inner bottom welding by the conventional method and the developed method using KC-550. With “J-STAR™ Welding,” the spatter particles are small and spatter generation is extremely slight in actual construction processes. In conventional welding of the inner bottom, spatter adhered and accumulated on the welding nozzle, causing sparks and poor gas shielding around the welding tip. To prevent this, it was necessary to stop the welder periodically and perform maintenance, and it was also necessary to perform repair welding of welded joints. Since repair welding is performed from the front or back side of the weld after gouging, mechanical cutting of the bead surface is necessary. With the developed method, continuous welding of a length of 15 m is possible, and the number of welding stops was reduced to less than half that with the conventional method. Moreover, welding time was also shortened to approximately two-thirds of the conventional time because the groove angle was narrowed from 50° to 40°, spatter was reduced and arc stability was improved, and welding could be performed in a higher current region than with the conventional welding method, making it possible to increase the welding speed and reduce the number of passes. Ultrasonic tests (UT) were performed at parts where “J-STAR™ Welding” was applied, but no welding defects were detected. Fume generation was also extremely slight in comparison with welding using the conventional solid welding wire.

Photo 6 shows the bead appearance and cross-sectional macrostructure when “J-STAR™ Welding” (KC-550, Direct current electrode negative (DCEN)) was applied. With the conventional method, slag adhesion to the bead surface is strong. Since about half of this slag remains on the bead surface even after using a chipper or other air tool following welding, and this slag becomes a painting defect, separate slag removal work had been performed as pretreatment for the painting pro-



One side welding of butt joint, Groove: V40°, Gap=0 mm, KC-550, DCEN (Direct current electrode negative), 2 Pass, 100% CO₂, Welding current: 380 A

Photo 6 Bead appearance and macrostructure of inner bottom

cess. In contrast to this, with the developed method, slag detachability was good, and this slag removal work was shortened to roughly half the conventional time. The appearance of the painting was also improved because dents on the bead surface caused by the chipper, etc. were reduced. In addition to the smoother welding bead, this improvement of slag detachability is also considered to be an effect of REM, which migrates to the slag as a result of the oxidation reaction during welding.

On the other hand, in order to expand the application of “J-STAR™ Welding” to the construction field, in June 2013, an additional approval of newly developed building technology was received from General Building Research Corporation of Japan for “Narrow gap welding with J-STAR Welding.” This approval expanded the strength class of the applicable materials to the 550 N/mm² class. The upper limit of the applicable plate thickness range for the single bevel groove shape was also expanded from the conventional 40 mm or less to 50 mm or less. In the future, progressive application of “J-STAR™ Welding” is also expected in the construction field as a result of this expansion of technical approval by a third-party organization.

5. Conclusion

A new narrow gap welding technology for heavy plates by 2-pass one-layer welding using an electrode with a curved tip was developed, utilizing the features of deep penetration and minimal spatter of JFE Steel’s “J-STAR™ Welding” method, which is a direct current electrode negative (DCEN) CO₂ gas shielded welding technology using an REM added welding wire. Application of the newly-developed welding technology makes it possible to secure stable penetration of the groove corner and sidewall in narrow gap joints. High efficiency and cost reduction in heavy plate welding are expected in shipbuilding, construction, and other fields.

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