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CO_2-gas-shielded One-side Welding Process Two-electrode "NS-Oneside MAG®"

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Abstract

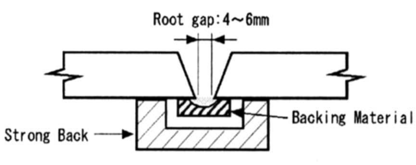
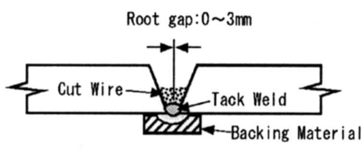
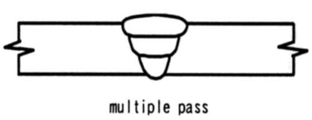
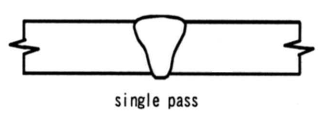
The one-side submerged arc welding (SAW) process has been a principal method for butt welding of large steel plates in the field of shipbuilding for many years. A simple automatic, one-side welding process using backing materials and flux-cored wires was newly developed to substitute the SAW process. The developed process enables one-side welding of heavy plates by a single pass, not adversely affected by tack-weld beads in the groove. Because of its lower heat input, the process causes significantly reduced rotational distortion, and hence, is capable of preventing cracking caused by the distortion.

1. Introduction

One-side, submerged arc welding has been a common practice for butt welding of large steel plates in the shipbuilding and other industries as a labor-saving and highly efficient method. At work fields, one-side, semi-automatic CO_2 welding using flux-cored wire and a backing material has also been widely employed for the purpose. However, as shown in **Table 1**, the efficiency of the conventional CO_2 welding method is low, because the method requires restricting fittings on the back side of the plates to secure a gap between the beveled edges and the joining work requires two or more weld passes.

Nippon Steel Welding Products & Engineering Co. Ltd. studied automation of the one-side, semi-automatic CO_2 welding to signifi-

Table 1 Comparison between conventional MAG process and welding NS-Oneside MAG process

	Conventional	NS-Oneside MAG
Preparation for welding		
Welding process	CO_2 gas shielded welding process	CO_2 gas shielded one-side welding process two electrodes
Example of pass sequence		

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cantly enhance its work efficiency, and as a result, has established a high-efficiency, automatic CO_2 welding process (trade name: NS-Oneside MAG) capable of forming a good penetration bead in a single pass with two electrodes; the developed process does not require a root gap, and allows there to be tack-weld beads inside the groove.

2. Outline of NS-Oneside MAG Process

Fig. 1 schematically illustrates the welding process by NS-Oneside MAG, **Photo 1** shows the equipment for the process, and **Fig. 2** the configuration of the equipment. As seen in Fig. 1, the NS-Oneside MAG process follows the following procedures: plates are set with beveled edges contacting each other; tack weld is applied at several points in the groove; a backing material for common CO_2 welding is attached on the back side; cut wires are put in the groove; and the plates are welded in a single pass using two electrodes.

During the welding pass, two large-current CO_2 electrodes arranged in tandem in the welding direction, approximately 300 mm apart from each other, form two molten pools, while being oscillated laterally: a solid wire is used for the leading electrode (L electrode), and a flux-cored wire for the trailing electrode (T electrode); a solid wire can also be used for the T electrode.

The L electrode using a solid wire, getting a deep-penetration.

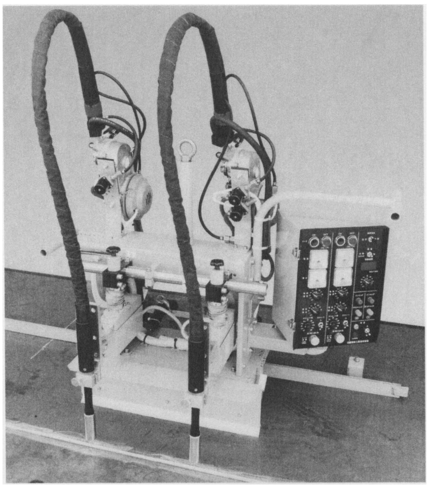


Photo 1 Welding equipment of NS-Oneside MAG welding process

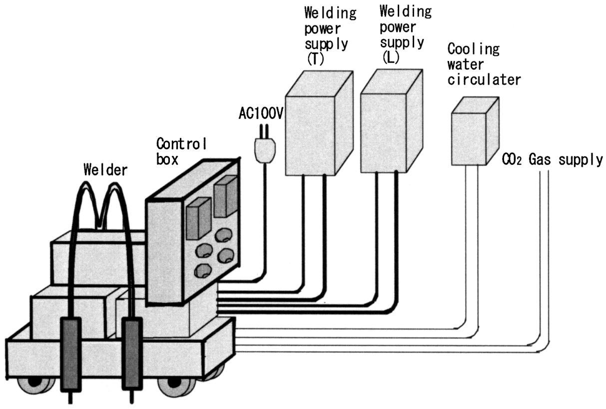


Fig. 2 Schematic illustration of equipment components of NS-Oneside MAG

melts the tack-weld beads completely and forms a back side bead. It also serves for making the width of the back side bead sufficiently large, uniform mixing the molten pool and applying optimum welding conditions coping with the fluctuation of the gap between the plate edges. The T electrode, on the other hand, forms a face-side bead of an adequate width; the use of a flux-cored wire makes the slag easily removable and forms a bead of good appearance. The shielding gas is CO_2 gas for welding use under JIS K 1106-1990.

3. Characteristics of NS-Oneside MAG Process

The principal characteristics of the NS-Oneside MAG process are as follows:

1) Welding of steel plates 12 to 22 mm in thickness is possible by one-pass operation from one side without having to secure a gap and allowing there to be tack-weld beads at several positions inside the groove.
2) Use of cut wires realizes good melting and uniform beads on both the sides without being significantly affected by gap fluctuation and tack-weld beads.
3) Angular distortion is minimized.
4) Simple and portable equipment allows easy change of work positions.
5) Upward welding up to approximately 10° is possible.
6) For ease of work, the backing material can be attached with ad-

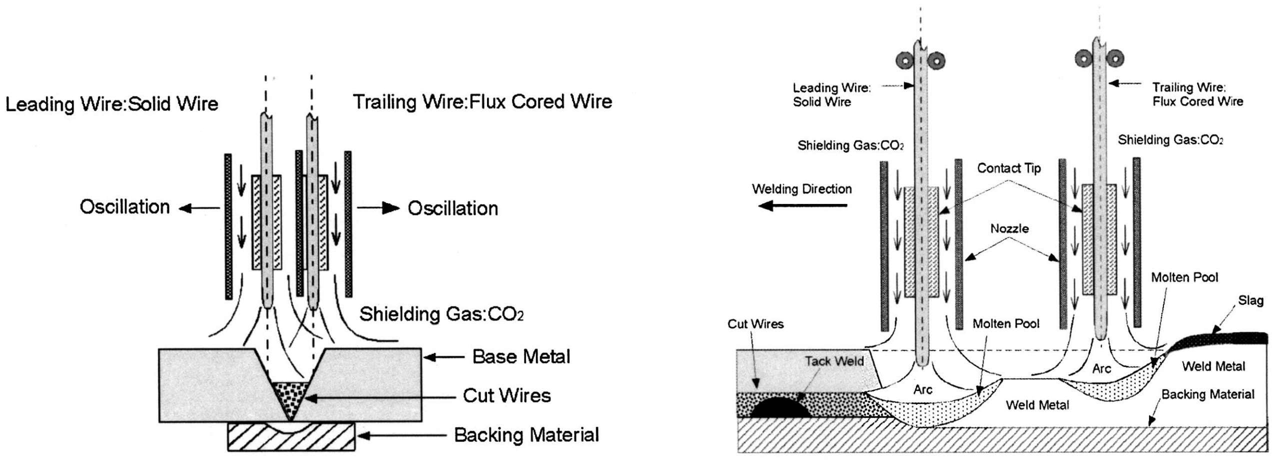


Fig. 1 Schematic diagram of NS-Oneside MAG welding process

hesive tapes.

7) The two-pool welding and the use of high-toughness wires realize good mechanical properties of the weld metal.
8) The use of a flux-cored wire for the T electrode forms a face bead of good appearance and makes the slag easily removable.

4. Typical Applications

The NS-Oneside MAG process has been effectively applied to the ship block welding of portions such as a bottom hull, a double-hull tank top and an upper deck. It is also effective in butt welding of flat plates as a substitute for SAW. Other promising applications include one-side welding of steel plate deck of a bridge, flat position welding of a built-up H section for building frame use and multi-pass welding of heavy steel plates.

5. Welding Method

5.1 Welding consumables

Table 2 shows the materials used for the developed welding process. The solid wire NITTETSU YM-55H that realizes high toughness and deep penetration is used for the L electrode, and the flux-cored wire of a titania system SF-1 excellent in workability and capable of forming beads of good appearance is used for the T electrode; this combination is effective in obtaining excellent weld joints. NITTETSU YK-CM, a cut wire conventionally used for one-side SAW, is used as the filler wires. Since the use of the filler wires levels the height at portions with tack-weld beads with those without, a uniform bead is obtained without being affected by the tack-weld beads. The leveling enables welding operation under the same condition along a weld line, without having to change the current, voltage and other parameters.

5.2 Groove geometry

Fig. 3 shows the geometry of a groove. The included angle of a groove is basically 50°, and the root gap can be from zero (in contact) to 3 mm.

5.3 Welding conditions

Table 3 shows typical welding conditions for plate thicknesses of 12, 16 and 22 mm, and **Table 4** some examples of the mechanical properties of weld joints.

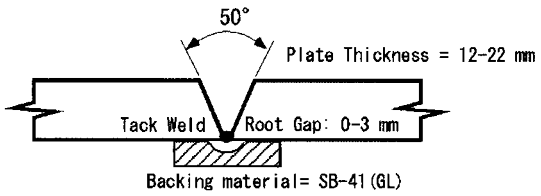


Fig. 3 Groove geometry

Table 2 Welding materials

Item	Brand name (size)
Welding consumables	L electrode NITTETSU YM-55H (1.6mmφ)
	T electrode NITTETSU SF-1 (1.6mmφ)
Cut wire	NITTETSU YK-CM (1.0×1.0mmφ)
Backing material	NITTETSU SB-41 (GL)
Shield gas	CO_2 (for both L and T wires: 25-30 l/min)

5.4 Bead appearance and macrostructure

Examples of bead appearance are given in **Photo 2**; as seen here, uniform beads of good appearance are obtained on both the sides. **Photo 3** shows sectional macrostructures of weld joints of plates 12, 16 and 22 mm in thickness.

6. Test of Resistance to Cracking at One-side Welding

High-temperature cracking constitutes a major problem of one-side welding. Attention was focused on rotational distortion as one of its principal causes, and the amount of rotational distortion was compared by the NS-Oneside MAG process with that by the conventional method through test using short specimen plates (1,000 mm long, 400 mm wide and 16 mm thick). Two specimen plates were set using jigs shown in **Fig. 4** so that one was restricted and the other was allowed to rotate on rollers, and the amount of deformation was measured before and after welding at the tail end of the weld line using a potentiometer. As shown in **Fig. 5**, tack weld was applied to the top end, center and tail end of the weld line, and a run-off tab was provided at the tail end without restriction.

Tables 5 and 6 show the welding materials used and welding conditions for the test, respectively. **Fig. 6** compares the rotational distortion by the NS-Oneside MAG process (CO_2 tandem) with those by one-side, single-electrode CO_2 welding (CO_2 single) and one-side, single-electrode SAW. The graph shows that the rotational distortion decreased remarkably as heat input decreased. The rotational distortion by the CO_2 single process (heat input: 3,200 J/mm) was approximately 1/10 that by the one-side, single-electrode SAW (heat input: 7800 J/mm); this corroborates the ability of NS-Oneside MAG to prevent cracking of the bead formed by the L electrode. Although the theoretical heat input of the developed process is 6500 J/mm, its rotational distortion was as small as 1/5 that by the one-side, single-electrode SAW; this also corroborates NS-Oneside MAG's ability to prevent weld cracks.

Fig. 7 shows the relationship between electrode spacing and the

Table 3 Typical welding conditions

Plate thickness (mm)	Electrodes	Current (A)	Voltage (V)	Speed (cm/min)	Oscillation width (mm)	Oscillation frequency (number/min)	Cut wire height (mm)	Heat input (J/mm)
12	L electrode	500	41	45	4	120	8	2730
	T electrode	400	38		5	100	-	2027
16	L electrode	500	41	35	4	100	8	3514
	T electrode	450	40		5	100	-	3086
22	L electrode	520	44	25	4	100	10	5491
	T electrode	450	40		5	100	-	4320

Table 4 Typical mechanical properties of welded joint

Plate thickness (mm)	Tensile test TS (N/mm^2)	Tensile test Location of fracture	Impact test (J at 0℃)	Bending tests Face bend	Bending tests Root bend	Radiographic inspection
12	560 545	Base metal Base metal	123 123 (121) 117	Good	Good	Grade1
16	563 558	Base metal Base metal	82 76 (80) 82	Good	Good	Grade1
22	563 558	Base metal Base metal	90 76 (83) 84	Good	Good	Grade1

Note Base metal: SM 490A
Tensile test: JIS Z 3121 Bending test: JIS Z 3122
Impact test: JIS Z 3128 Radiographic inspection: JIS Z 3104

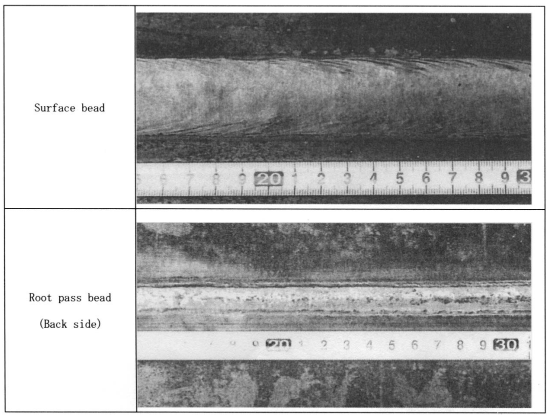


Photo 2 Examples of bead appearance (plate thickness: 22 mm)

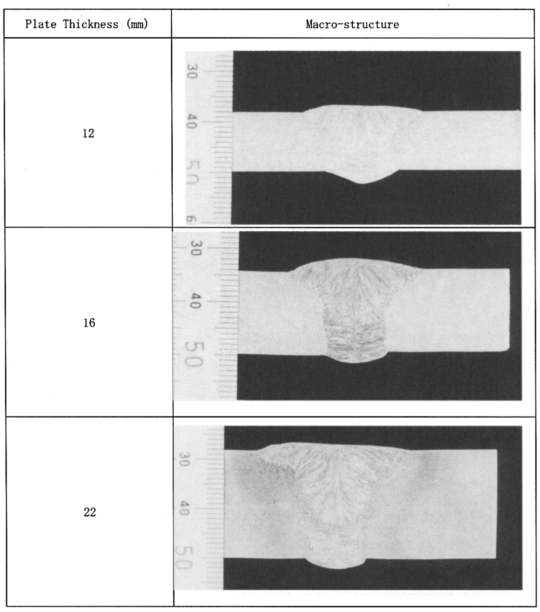


Photo 3 Cross sections of welded joints

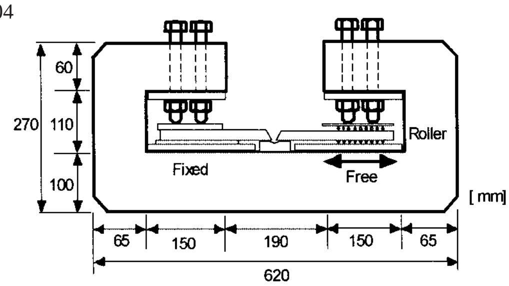


Fig. 4 Setting apparatus of test plate

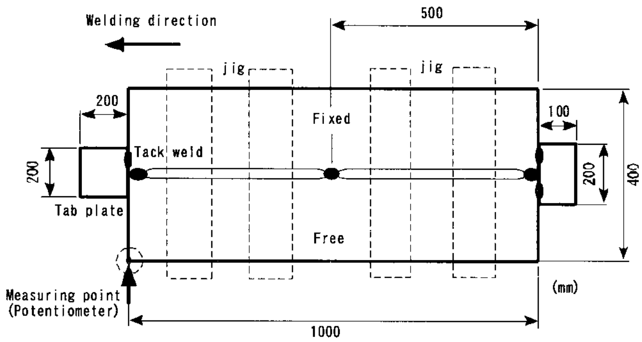


Fig. 5 Test plate and measuring point

amount of rotational distortion. The rotational distortion by the developed process tended to decrease as the distance between the electrodes increased, and became stable when the distance was approximately 300 mm or more. Based on this finding, the distance between electrodes was set at 300 mm for ordinary welding conditions.

Furthermore, to confirm that the NS-Oneside MAG process was free from cracking in a long welding length, we examined the effects of tack weld on crack resistance and rotational distortion through test using long specimen plates (3,000 mm long, 3,000 mm wide and 16 mm thick) shown in **Fig. 8**. **Table 7** and **Fig. 9** show the test results.

Here, a flux-cored wire was used for the tack weld, and a slit tab (200 mm long, 400 mm wide and 16 mm thick, with a slit 100 mm

Table 5 Welding materials

Test plate	SM 490A, 1 000L×400W×16 t (mm)	
Welding process	CO_2 welding	Submerged arc welding (SAW)
Test wire	NITTETSU YM-55H (1.6mmφ)	NITTETSU Y-D (4.8mmφ)
Test flux	-	NITTETSU YF-15A (12×150 mesh)
Cut wire	NITTETSU YK-CM (1.0×1.0mmφ)	NITTETSU YK-CM (1.0×1.0mmφ)
Backing material	NITTETSU SB-41 (GL)	NITTETSU SB-51

Table 6 Welding conditions

No.	Welding process	Heat input (J/mm)	Current (A)	Voltage (V)	Speed (cm/min)	Oscillation frequency (number/min)
1	CO_2 (GMAW)	3240	540	38	38	90
2	CO_2 (GMAW)	4100	540	38	30	90
3	CO_2 (GMAW)	4560	600	38	30	90
4	SAW	4950	850	34	35	-
5	SAW	7780	900	36	25	-
6	NS Oneside MAG	6500	L: 540 T: 480	38 43	38	90 74

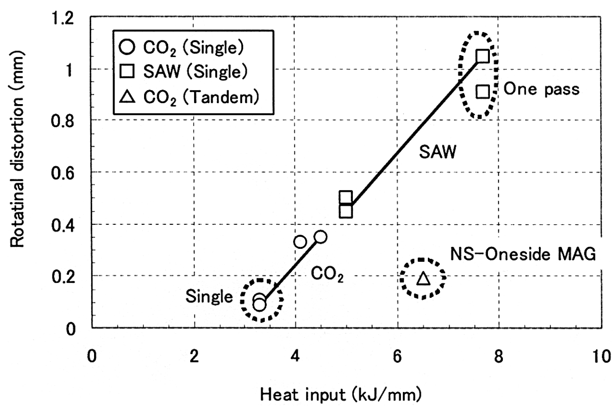


Fig. 6 Relationship between heat input and rotational distortion

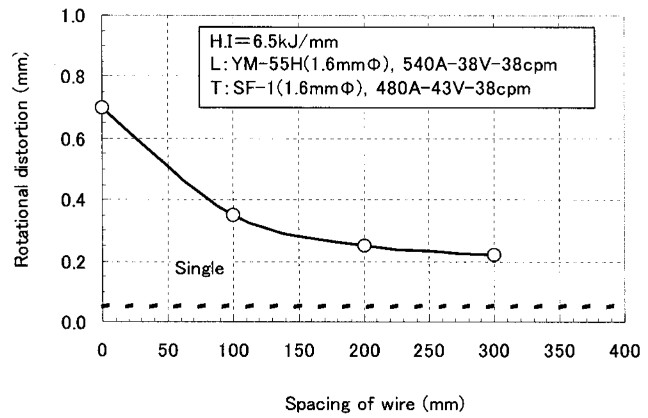
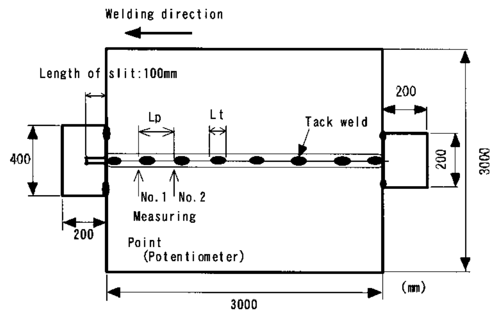


Fig. 7 Relationship between spacing of wires and rotational distortion

(a) Size of test plate and measuring points



(b) Measuring of rotational distortion

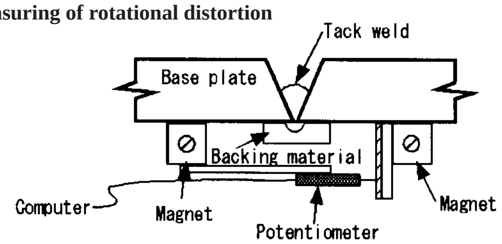


Fig. 8 Size of test plates and measurement method

Table 7 Test results

Heat input (J/mm)	Tack weld size (mm)	Tack weld pitch (mm)	Radiographic inspection
6500	100	300	Grade1
	200	300	Grade1
	50	300	Grade1
	100	600	Grade1
	200	600	Grade1

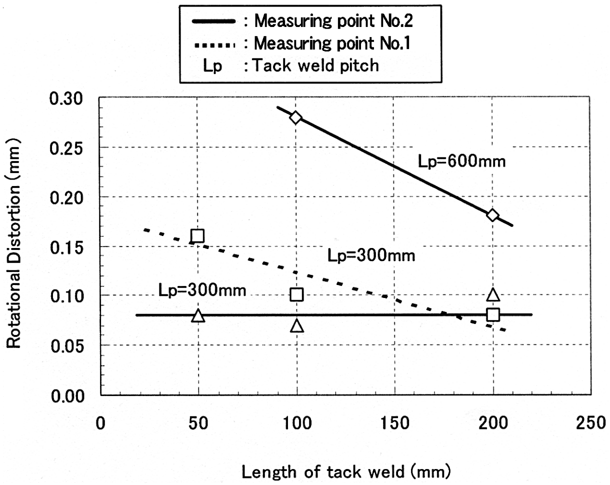


Fig. 9 Relationship between size of tack weld and rotational distortion

long) was provided at the tail end of the weld joint. Since the object of this test was to confirm the occurrence or otherwise of cracks in a weld joint, the distortion was measured at points 600 and 300 mm from the tail end of the weld line (No.1 and 2 measuring points, respectively), corresponding to the tail ends of two tack-weld beads.

The evaluation results shown in Table 7 were obtained in accordance with the X-ray test method under JIS Z 3104. Through the test using specimen plates 16 mm thick, we confirmed that the developed process was cable of preventing high-temperature cracking as far as tack weld was done in a groove as shown in Table 7 and a slit tab was provided at the tail end of a weld line. The measurement results of rotational distortion shown in Fig. 9 indicate that it is desirable to increase the length and decrease the pitch of tack-weld beads. The developed welding process is capable of preventing high-temperature cracking of a welded seam even in site welding work by adequately controlling the length and pitch of tack-weld beads and the fitting method of an end tab.

7. Closing

NS-Oneside MAG was developed as a long-awaited, high-efficiency, labor-saving, automatic welding method capable of replacing submerged arc welding in butt welding of steel plates in shipbuilding and other fields of industry. The authors are studying to extend the applicable thickness range of the developed process beyond the present limit to further expand its application.

References

Umadume et al.: Development of a One-side Welding Robot for Curved Outer Plates of Ship Hulls. 160th Meeting of Welding Method Research Committee, Japan Welding Society, 1997