NIPPON STEEL TECHNICAL REPORT No. 95 January 2007

UDC 621 . 791 . 763 . 3 : 620 . 197 . 6 : 669 . 14 . 018 . 8 : 627

Welding Technology for Metallic Sheathing of Offshore Steel Structures Using Seawater-resistant Stainless Steel Sheet

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Abstract

Welding technology for metallic sheathing of offshore steel structures in seawater tidal and splash zones was described. Seawater-resistance stainless steel SUS 312L sheets of 0.4-0.6mm in thickness were lap-welded on carbon steel pipes with the indirect seam welding process. Compared to conventional metallic sheathing methods, this method enabled to reduce material and fabrication costs. A combined welding method - indirect seam welding and plasma welding with Inconel 625 filler wire were preformed simultaneously - was developed to prevent crevice corrosion at severer environments. In case the metallic sheathes get damaged, a repair welding procedure was established.

1. Introduction

Offshore steel structures are welded structures made of homogeneous steel materials whose qualities remain stable on a lasting basis. They have a number of advantages over structures made of other materials, such as plenty of leeway in design and short construction period. On the other hand, they require suitable measures to prevent corrosion of the steel members. In particular, it is necessary to apply highly reliable corrosion-preventive treatment to offshore steel structures used in extremely corrosive marine environments such as splash zone and tidal zone. To prevent corrosion of offshore steel structures constructed in such a corrosive environment, it has been common practice to apply corrosion-preventive organic material to them[1). However, since offshore steel structures are subject to damage caused by some driftage, age-related deterioration of their members, etc., their corrosion-preventive coating must be repaired or renewed as required to maintain their long-term durability. Because of this, offshore steel structures are hugely expensive to maintain. There are cases where corrosion-preventive metallic sheathing is applied to an offshore steel structure which is required to withstand use for an extremely prolonged periods, for example from 50 to 100 years[2). When this method is used, the steel structure seldom needs repair and hence, the cost of maintenance can be cut significantly. Nevertheless, the application of metallic sheathing has been limited because the cost of the material and fabrication are higher than those of the conventional corrosion-preventive methods.

From the standpoint of minimizing the lifecycle cost of an offshore structure used in a highly corrosive environment, Nippon Steel Engineering Co., Ltd. has developed and put into practical use metallic sheathing technology using a highly reliable and economic seawater-resistant austenitic stainless steel sheet[3). This paper describes in detail the welding technology for metallic sheathing that is mentioned in Reference 3), which outlines the metallic sheathing method.

2. Problems in Conventional Welding Methods for Metallic Sheathing

Metallic sheathing is a corrosion-preventive method in which the steel members of a structure are sheathed with a metallic sheet having high strength and excellent corrosion resistance (hereinafter referred to as “covering material”) to protect their surfaces from a corrosive environment. As shown in **Fig. 1**, metallic sheathing is mainly applied to those members in offshore steel structures which are exposed to splash zone and tidal zone. The conventional metallic sheathing method uses a sheet of stainless steel, Monel, cupronickel or some other metal as the covering material, which is applied to car-

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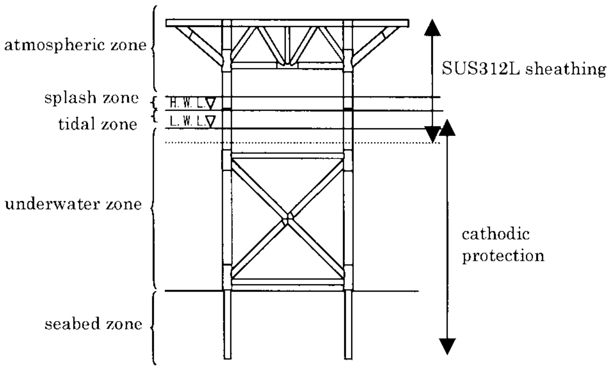
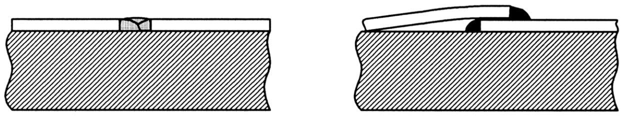


Fig. 1 Application of SUS 312L sheet sheathing to offshore steel structure



(a) plug welding (b) strip welding

Fig. 2 Conventional welding methods for lining

bon steel or low-alloy steel structural members by TIG (Tungsten Inert Gas) welding or covered arc welding. The typical covering material is 1.5 to 2.0 mm thick. Plug welding, strip welding or a combination thereof is used to produce welded joints as shown in **Fig. 2**[4].

From the standpoint of minimizing the cost of covering material and facilitating the application of covering material to structural members, it is desirable that the covering material should be as thin as possible. With the conventional method, however, an excessively thin covering material cannot be used because it imposes certain welding problems. Namely, when the covering material thickness is 1.0 mm or less, deformation of the covering material caused by the welding heat increases to such an extent that a crevice is produced between the covering materials or between the covering material and the structural member. The crevice can cause the covering material to melt down or be perforated during the welding operation. In order to prevent that, it is necessary to decrease the pitch of tack welding or adjust the welding speed or wire rod feeding speed in accordance with the crevice produced during welding. Because of this, welding speed and efficiency are not very good. Thus, if the conventional welding methods are applied to metallic sheathing, any reduction in the covering material thickness, improved welding efficiency and the cutting of covering material costs could hardly be hoped for.

3. Development of Efficient, Low-Cost Sheathing Method

3.1 Sheathing using indirect seam welding

The aim of the present development project, intended for steel pipe members that occupy the greater part of the lining area of steel structures, was to establish a new welding technique which permits using much thinner covering materials and welding them more efficiently than conventional welding techniques. Specifically, the ability to weld a covering material 0.4 to 0.6 mm in thickness at a speed of about 1.0 m/min on a stable basis was set as the development target.

First, from several candidate welding techniques, including resistance seam welding, laser welding and plasma welding, we selected resistance seam welding. In this welding method, as a large current is passed directly to the parts to be joined, the temperatures of the parts are raised by the resistance heat generated by the current so that the parts can be welded together. With this method, it is possible to weld thin covering materials at high speed. In particular, the adverse influence of material deformation caused by the welding heat can be avoided since a proper pressure is constantly applied by the electrode during welding. Thus, it is a rational welding method for metallic sheets that are thin and have a large thermal expansion coefficient. Since our new welding technique should be applicable to metallic sheathing of relatively large structures, such as offshore steel structures, we adopted not the commonly-used direct conduction seam welding method in which the welding current is passed from two electrodes to the joint sandwiched between them, but the indirect conduction seam welding method (hereinafter referred to as the “indirect seam welding method”) in which a couple of electrodes are applied to the covering material side as shown in **Fig. 3**.

In the indirect seam welding method, it is common practice to provide a back bar of copper, etc. at the back of the sheet to be welded in order to secure a stable current path which runs through the sheet in the thickness direction. In our method, a current path through the steel structural member at the back of the covering material can be obtained. Therefore, it is possible to weld stainless steel sheet of about 0.5 mm in thickness directly to the steel structural member. **Fig. 4** shows an example of sheathing of a tubular steel member with stainless steel sheet. In Fig. 4, both ends of the indirect seam welded joint in the axial direction are sealed by TIG welding in order to ensure sufficient watertightness. After the sheathing, a leak test in

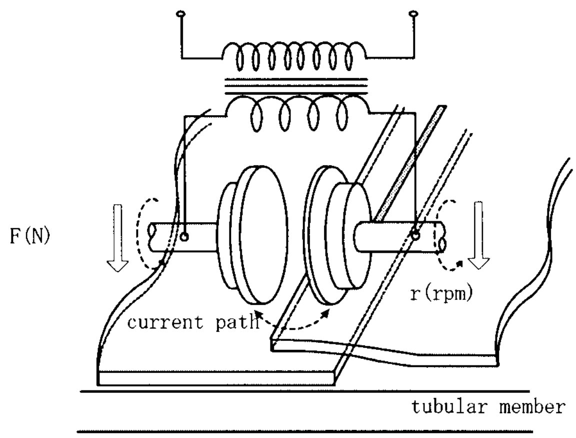


Fig. 3 Schematic illustration of indirect seam welding

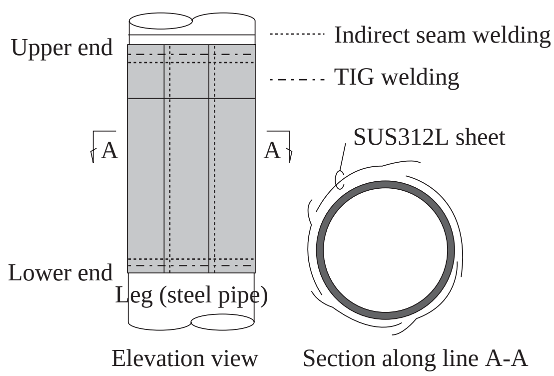


Fig. 4 Example of sheathing of tubular member with SUS 312L sheets

Fig. 5 Appearance of the indirect seam welding equipment

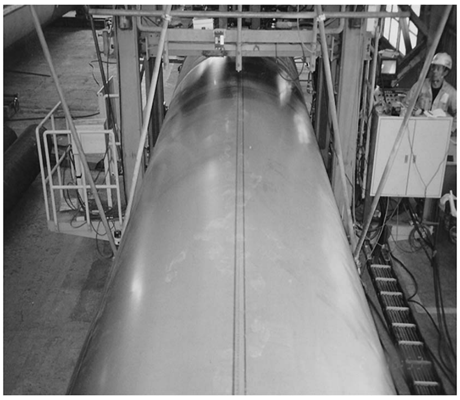


Fig. 6 Appearance of a weld seam

which air is passed between the tubular member and covering material is carried out to confirm the soundness of the joint. **Fig. 5** shows the appearance of the indirect seam welding equipment developed for practical use.

3.2 Characteristics of parts sheathed with seawater-resistant stainless steel sheet

Concerning the sheathing method using seawater-resistant stainless steel SUS 312L[5] as the covering material, we studied the applicability of indirect seam welding and the fatigue characteristics of welded joints.

Table 1 shows the mechanical properties of SUS 312L (JIS standard values and typical values). SUS 312L is a high-strength stainless steel having a proof stress about 1.5 times that of SUS 304 or SUS 316. Since SUS 312L is hard, it also has excellent resistance to shock and wear.

Table 2 shows examples of welding conditions when the indirect seam welding method was used for sheathing. High welding speeds up to 1.5 m/min could be attained. Due to limitations set by the force and current distributions, the indirect seam welding method is somewhat inferior in weldability to the direct conduction seam welding method as indicated by a little surface fusion. **Fig. 6** shows the appearance of an indirect seam weld, and **Fig. 7** shows the cross section of an indirect seam weld.

Since the seam welds are subject to repeated stresses caused by wind and waves, a fatigue test was carried out using specimens (covering material thickness: 0.5 mm). The appearance of a specimen is shown in **Fig. 8** (a). The fatigue test conditions were partial pulsation (stress ratio: 0.1), frequency 10 Hz, stress amplitude control. Fig. 8 (b) shows the S-N diagram based on the fatigue test results. The fatigue characteristic of the seam weld is nearly the same as that of the Class A joint indicated by the fatigue design curve (for joints subject to shear stress) in the Guidelines for Fatigue Design[6]. The fatigue characteristics of Class A joints are comparable to that of hoops with machined surfaces and edges. Thus, the seam weld demonstrates good fatigue characteristics.

Table 1 Mechanical properties of SUS 312L

	0.2%proof stress (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Hardness (Hv)
JIS	≧ 350	≧ 650	≧ 35	
Example	461	843	39	192

Table 2 Indirect seam welding condition

Current I (A)	Force F (N)	Travel speed v (m/min)
7,000-10,000	1,000-3,000	0.6-1.5

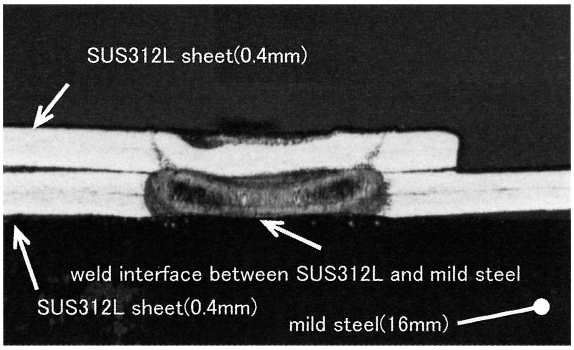
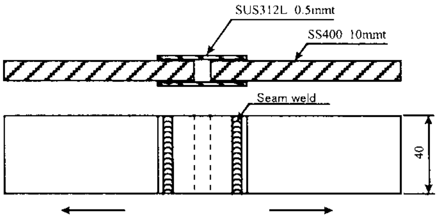
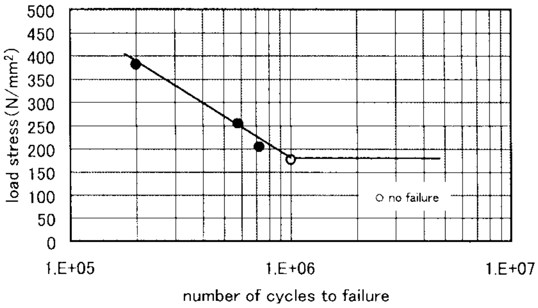


Fig. 7 Cross section of weld seam



(a) specimen for fatigue testing (SS400:10t,SUS312L:0.5t)



(b) S-N diagram

Fig. 8 Results of fatigue testing

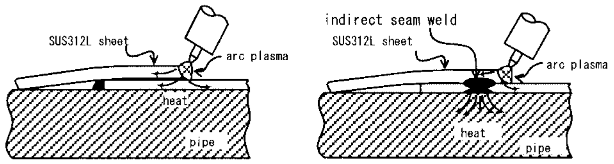
4. Development of Sheathing Method Offering Good Corrosion Resistance

With the sheathing method applying indirect seam welding, it is possible to use a thinner covering material and improve the welding efficiency. However, since the welded structure obtained has crevices, it was considered that the crevice-corrosion resistance of those joints may become a problem depending on the ambient conditions. With the aim of further improving the corrosion resistance of the welded structure, therefore, we attempted to find a welding method for sheathing which would not produce crevices and which would still permit using a thinner covering material and offer high welding efficiency. As a result, we came up with a new welding method—the combination of indirect seam welding and arc welding—for sheathing with thin covering material.

4.1 Indirect seam-plasma arc welding method

With the strip sheathing method using conventional arc welding, the transfer of arc heat to the mild steel at the back of the covering material cannot be expected (**Fig. 9** (a)). In particular, since stainless steel used as the covering material has less heat conductivity than carbon steel, the heat transfer through the covering material is slow. Therefore, the thinner the covering material, the higher the possibility of a burn-through or perforation.

On the other hand, with the heat transfer strip sheathing method in which indirect seam welding is followed by arc welding (Fig. 9 (b)), it is possible to transfer the arc heat to the carbon steel member at the back of the covering material via the indirect seam weld, thereby preventing the burn-through and perforation even when the covering material is thin. **Table 3** shows typical plasma arc welding conditions.

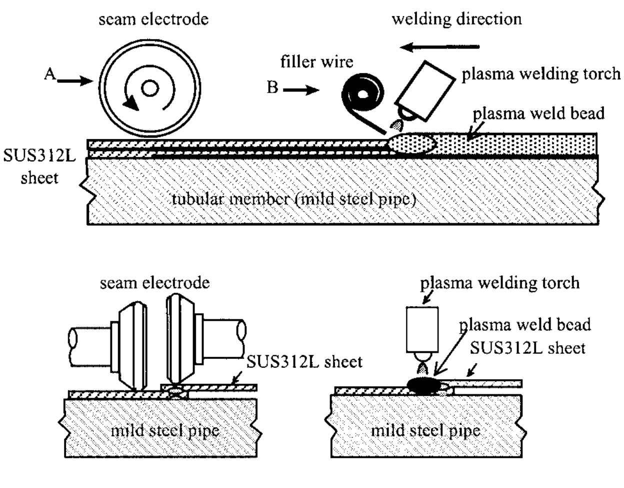


(a) normal lap joint (b) lap joint in combined welding

Fig. 9 Heat transfer from arc plasma to base material

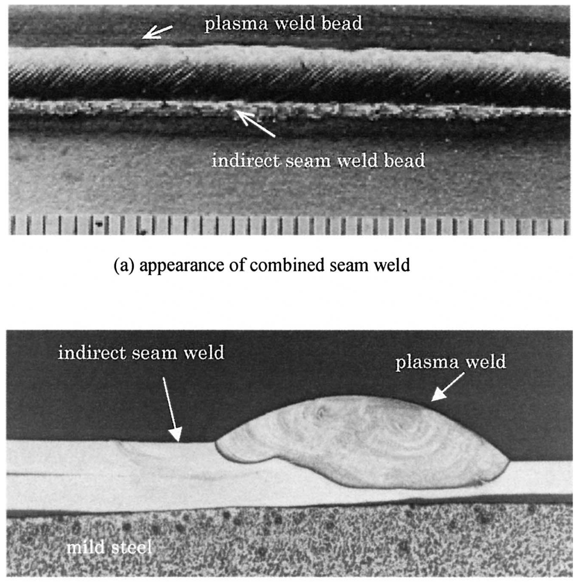
Table 3 Plasma welding condition (filler wire: Inconel 625, 0.8mmϕ)

Current (A)	Voltage (V)	Travel speed (m/min)	Wire feed rate (m/min)
80-120	26-30	0.6-1.2	4.0-7.0



(a) A-view (b) B-view

Fig. 10 Schematic illustration of combined welding



(a) appearance of combined seam weld

(b) cross section of combined seam weld

Fig. 11 Appearance of weld bead (top) and cross section (bottom)

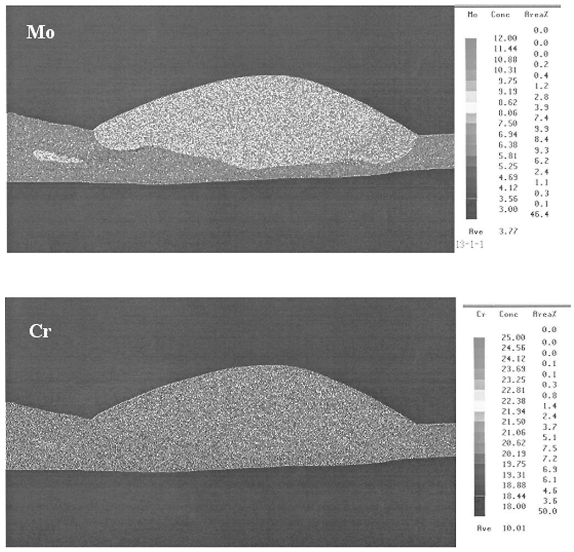


Fig. 12 Surface element analysis of a plasma arc weld by EPMA

Fig. 10 schematically shows the combination indirect seam-plasma arc welding method. By performing indirect seam welding and plasma arc welding at the same time, it is possible to complete the sheathing without causing the welding efficiency to decline. Typical plasma arc welding conditions are shown in Table 3. It should be noted that this combination welding method can also be applied to the TIG weld mentioned in 3.1.

4.2 Characteristics of sheathing weld obtained by combination welding method

Fig. 11 shows the appearance of weld beads and the cross-section of a joint obtained by the combination welding method using the indirect seam welding conditions shown in Table 2 and the plasma arc welding conditions shown in Table 3.

A 0.4 mm thick stainless steel sheet used as the covering material was free from burn-through or perforation by the plasma arc welding and produced a good joint without crevices. **Fig. 12** shows the distributions of Cr and Mo concentrations in the cross-section of the combination weld, obtained by an X-ray micro-analyzer. It was confirmed that the Cr and Mo concentrations in the weld metal and heat-affected zone remained nearly the same as those in the base metal and hence, there were no problems in terms of corrosion resistance.

5. Repair Welding

Fig. 13 shows the patching repair procedure applicable to metallic sheathing damaged by some driftage, etc. As the patching material, use an SUS 312L sheet 1.0 to 1.5 mm thick. If seawater has entered the crevice between the covering material and structural member from the damaged part, drill a steam vent 5 mm in diameter in the center of the patching sheet to use the welding heat to expel the moisture inside. Such a steam vent is unnecessary when the part around the defect is dry. Apply lap fillet welding to the part surrounding the defect and block the steam vent by TIG welding. Use Inconel 625 as the welding material. After the repair welding, carry out a liquid penetration test to check for leaks.

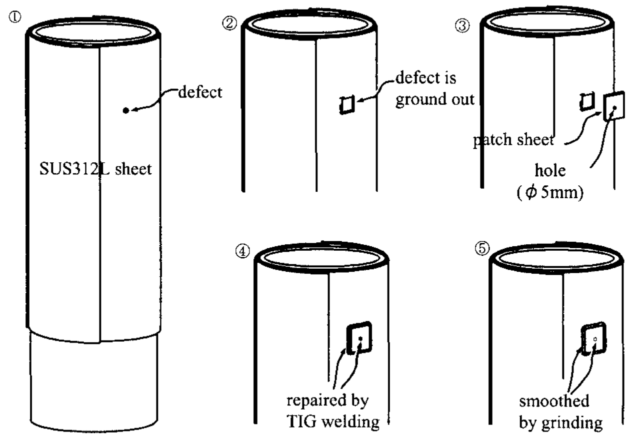


Fig. 13 Procedure of repair welding

6. Application of the New Welding Method to Offshore Steel Structures

Reference 3) posts a photograph of a structure to which our new welding method was applied. As illustrated by this application example, the sheathing with seawater-resisting stainless steel has achieved “low initial cost” and “low maintenance cost”. Thus, we have come up with a new corrosion-preventive method that makes it possible to minimize the lifecycle cost of offshore steel structures with prolonged life expectancies. In the construction project of the new runway D of Tokyo International Airport that will be started soon, some of the offshore steel structures are of steel jacket construction and sheathing with seawater-resisting stainless steel is planned to be applied to those parts of the steel structures which are exposed to splash zone and tidal zone.

7. Conclusions

(1) We developed a new metallic sheathing method using indirect seam welding. This has made it possible to reduce the covering material thickness to 0.4 to 0.6 mm and improve the welding efficiency.

(2) It has been confirmed that the weld of seawater-resisting stainless steel SUS 312L has sufficient fatigue strength.

(3) In addition to the above sheathing method, by using the combination indirect seam-plasma arc welding, we developed a new corrosion-resistant sheathing method that produces crevice-less joints.

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