

Touch-up-Less Welding Wire for High Corrosion Resistance Galvanized Steel Plates

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Abstract

High corrosion resistance galvanized steel sheets are widely used in the building members to provide structural members. When galvanized sheets are welded, zinc near a weld portion evaporates. As a result, the corrosion resistance is deteriorated and repair coating treatment is required after welding. The use of stainless steel welding wires with high corrosion resistance appears to be beneficial. However, the conventional welding wires have such problems that zinc embrittlement cracks likely to occur in their weld metals. To solve this problem, a stainless steel welding wire was developed. Susceptibility to zinc embrittlement crack was improved by increasing the ferrite content in the weld metal through the adjustment of Ni and Cr contents. The joints welded by the newly developed welding wire exhibited suitable mechanical properties and satisfactory corrosion resistance evaluated by salt spray testing.

1. Introduction

Galvanized steel sheets are widely used in architectural and automotive industrial fields from the perspective of enhancing corrosion resistance. Furthermore, recently, galvanized steel sheets with higher corrosion resistance (alloy-galvanized steel sheets of Zn-11%Al-3%Mg-0.2%Si system)¹⁾ have been developed, expanding application mainly as building materials.

However, even if highly corrosion-resistant galvanized steel sheets are used, there has been a problem of deterioration of the corrosion resistance at the weld part due to the evaporation of coating elements on the surface of a steel sheet when welding. Therefore, when a galvanized steel sheet was welded, a touch-up treatment of brush coating or spray coating of rust-preventing paint after welding was applied, and deterioration in productivity due to the coating has also been a problem. Furthermore, the rust-preventing paint coated on the welded surface sometime came off the weld part after long service, resulting in a corrosion resistance problem. As a mean for prevention, a touch-up-less welding technology that secures corrosion resistance of the weld part has been fervently sought.

2. Development of Stainless Steel Welding Wire for Galvanized Steel Sheet

2.1 Zinc embrittlement crack of stainless steel welding metal

As a mean to secure corrosion resistance of a weld part, the use of

a stainless steel welding wire is considered. However, when the stainless steel welding wire is applied to galvanized steel sheets, a zinc embrittlement crack occurred in the weld metal; therefore, the application thereof has been considered as impossible. A zinc embrittlement crack is a kind of embrittlement caused by liquidized zinc that intrudes into the grain boundaries of the heat affected zone of the base and weld metals, triggering cracks during the cooling process of the weld part. Particularly, zinc embrittlement in austenitic stainless steel has been well known, and an example of studies²⁾ on the use of stainless steel welding wire reports the necessity of removing zinc coating by a grinder or the like before welding.

Figure 1 shows the result of welding of a bead on a galvanized steel sheet using a stainless steel welding wire (JIS Z 3323 YF309LC). The upper surface of the welded bead was ground, and the ground surface was checked for weld metal cracks after corroding the surface with aqua regia. Cracks in the direction perpendicular to the direction of welding occurred and propagated into the weld metal, starting at the toe of the weld. Through the observation conducted with Electron Probe Microanalysis (EPMA), the resulting intrusion of zinc into the crack and zinc embrittlement was confirmed. Furthermore, since zinc remaining on the surface of the base metal also exists in the neighborhood of the toe of the weld, it is considered that zinc propagated into the grain boundaries of the stainless steel weld metal from the toe of the weld.

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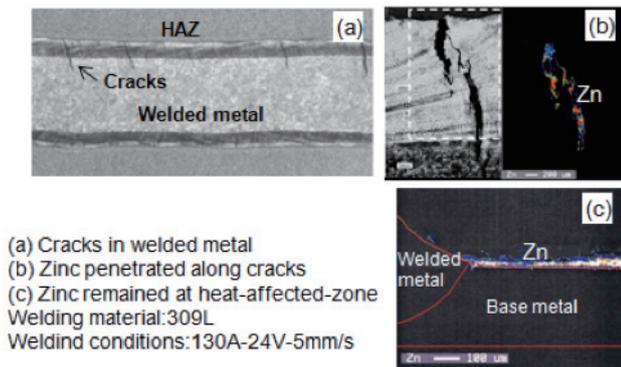


Fig. 1 Liquid zinc embrittlement in weld metal of stainless steel

2.2 Suppression of zinc embrittlement crack in weld metal

Aiming at the suppression of cracks by increasing the amount of ferrite in weld metal, stainless steel welding wire applicable to galvanized steel sheets has been developed.³⁾ Table 1 shows the chemical compositions of welding wires for trial production. Yet for the welding wire, flux cored wire (FCW) that allows easy adjustment of alloying metal compositions was employed; the welding wires were designed in such a way as to increase the amount of ferrite of the weld metal in order from A to D by varying the concentration of Ni and Cr.

Figure 2 shows the state of cracks. After bead-on-plate welding, the existence of cracks was checked by the liquid penetrant test. Different from the case of FCW A (equivalent to FCW of 309L system), where a big transverse crack starting at the toe of the weld occurred and propagated into the weld metal, cracks became smaller in FCW B, where the Ni concentration was decreased, and cracks were not noticed in FCW C and D, where Cr concentration was further increased.

To observe the extent of propagation of the cracks, the microstructure was observed. Figure 3 shows the state of propagation of a crack. In FCW A where cracks occurred, the structure is primarily austenite, wherein Varmicular ferrite or Lacy ferrite is observed within the grains, and coarse cracks were observed at grain boundaries. On the other hand, FCW C, where cracks are not noticed, exhibits the dual-phase structure of ferrite-austenite and cracks were not noticed in the microstructure observation.

Incidentally, in the field of post hot-dipping in the molten zinc bath of the welded structures of general carbon steel, zinc embrittlement cracks caused by residual stress developed in welding are known. In particular, it is considered that in high-strength steel of 590 MPa class or above, cracks are prone to occur by the intrusion of liquidated zinc into the former austenitic grain boundaries of heat affected zone (HAZ). For this reason, to prevent the intrusion of zinc, lowering the quenchability of weld metal, forming ferrite at the former austenite grain boundaries, and making the grain boundaries blur are considered to be effective.⁴⁾ This phenomenon also takes place in stainless steel weld metal similarly. In FCW A and B, since clear austenitic grain boundaries formed during the solidification process remains even after the completion of solidification, it is considered that the cracks caused by the intrusion of zinc are more prone to occur. On the other hand, it is considered that in FCW C and D, though solidification is completed, yielding single phase of ferrite, blur grain boundaries are formed by the emergence of austenite crystal during transformation, and thereby, zinc crack resistance becomes exceptional.

Based on the above finding, touch-up-less welding wire for galvanized steel sheets has been developed. Stainless steel welding wire for galvanized steel sheets has been developed by increasing the Cr

Table 1 Chemical compositions of welding wires

Welding wire	Chemical composition (wt %)							Ferrite content (%)
	C	Si	Mn	P	S	Cr	Ni	
FCW A	0.02	0.32	1.25	0.02	0.004	24	12	16
FCW B	0.02	0.32	1.25	0.02	0.004	24	8.7	35
FCW C	0.02	0.32	1.25	0.02	0.004	27	8.6	65
FCW D	0.02	0.32	1.25	0.02	0.004	29	8.6	80

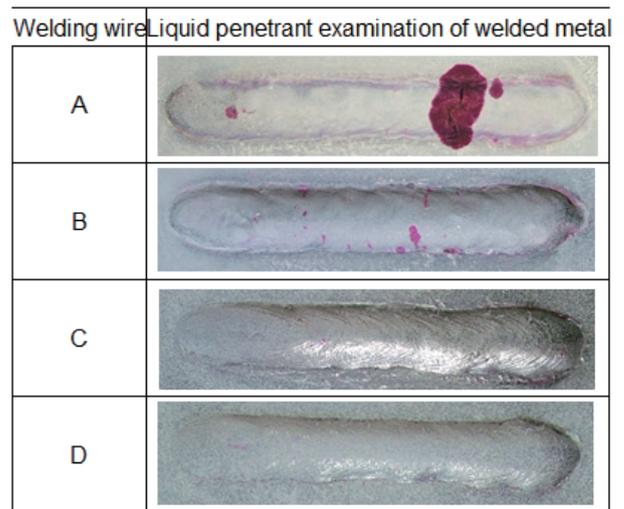


Fig. 2 Results of liquid penetrant examination

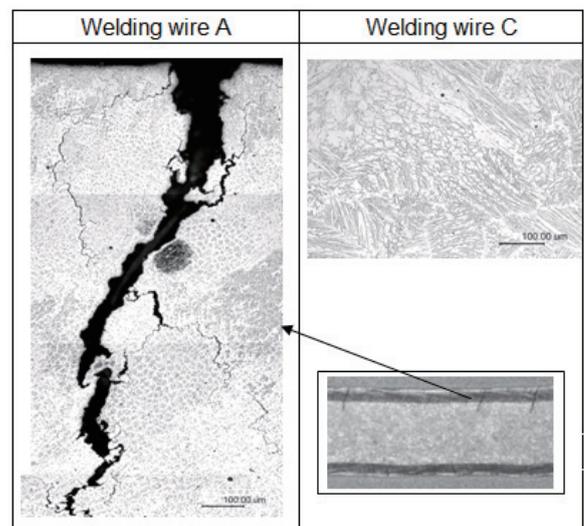


Fig. 3 Propagation of zinc embrittlement cracks

equivalent and reducing Ni equivalent, aiming at increasing the amount of ferrite in one way and suppressing in another way, deteriorating the ductility of the weld metal due to the excessive increase in amount of ferrite.

2.3 Weld joint performance of the newly developed welding wire

The weld joint performance of the newly developed welding wire for galvanized steel sheets was evaluated by applying it to alloy-galvanized steel plates of the Zn-11%Al-3%Mg-0.2%Si system. Tensile and Charpy tests' specimens were taken at the butt weld joint, and the

Table 2 Mechanical property of butt weld joints

Thickness of steel sheet (mm)	Welding conditions	Tensile test		Charpy test	
		Tensile strength (MPa)	Fracture position	Sample size	vE 0°C (J/cm ²)
3.2	170 A-25 V-6.7 mm/s-1 pass	469	Base metal	2.5 mm sub-size	12
5.4	180 A-26 V-6.7 mm/s-2 passes	422	Base metal	5 mm sub-size	19
8.2	200 A-30 V-6.7 mm/s-3 passes	451	Base metal	5 mm sub-size	20

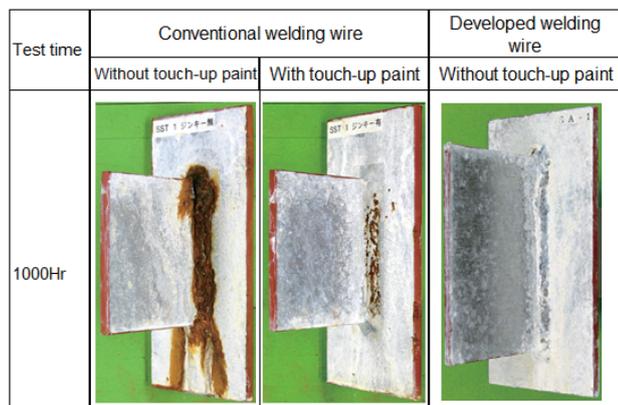


Fig. 4 Results of corrosion test

mechanical properties were evaluated. Table 2 shows the result. Plates of 3.2 mm, 5.8 mm and 8.2 mm in thickness were applied with welding of one pass, two passes, and three passes, respectively. Regardless of the plate thickness and welding condition, the tensile strength test specimen fractured at the base metal and exceptional values of impact energy absorption were exhibited.

Corrosion resistance performance was evaluated by the salt spray test applied to fillet-welded joints. Figure 4 shows the results of the corrosion test. Although red rust occurred regardless of the application of post-coating at the joints where a conventional welding wire was used, it has become possible to secure excellent corrosion resistance even without post-coating by using the developed wire.

3. Corrosion Resistance of Heat Affected Zone on Back Side

With the application of touch-up-less welding wire to highly corrosion-resistant galvanized steel sheets, excellent corrosion resistance of the weld metal was confirmed. However, when the application to welding thin steel sheets is assumed, rear corrosion resistance in weld heat affected zone must be secured. Namely, as compared with the welded surface protected by stainless steel weld metal; there are cases in which a wide range of damaged coating remains on the rear of the welded surface.

Then, the corrosion resistance of the rear of the welded surface was evaluated.⁹⁾ Figure 5 shows the damage of the coating in the heat affected zone on the rear of the welded surface. In the photo that shows external appearance, followings were observed; exposed base metal surface, the domain of sticking oxidized zinc (domain where coating was evaporated), and the domain of residual coating compositions with trace of melting (damaged coating domain). However, the observation by EPMA of the residues of the coating showed the uneven existence of residues of Zn, Al, and Mg in the damaged coating domain together with the existence of the residue of Al in the domain where the coating had evaporated.

Figure 6 shows the results of the Cyclic Corrosion Test (CCT) for

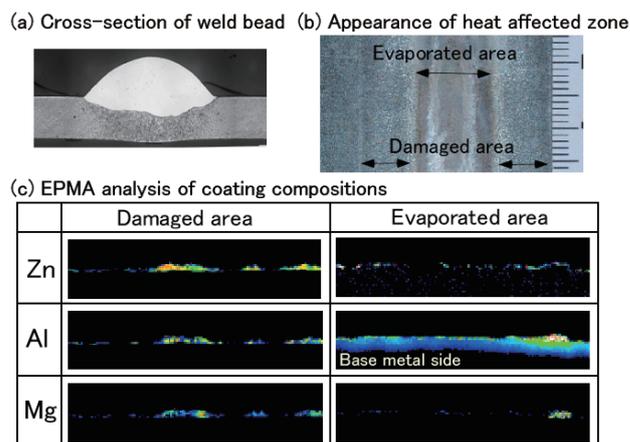


Fig. 5 Damage of the coating compositions in heat affected zone

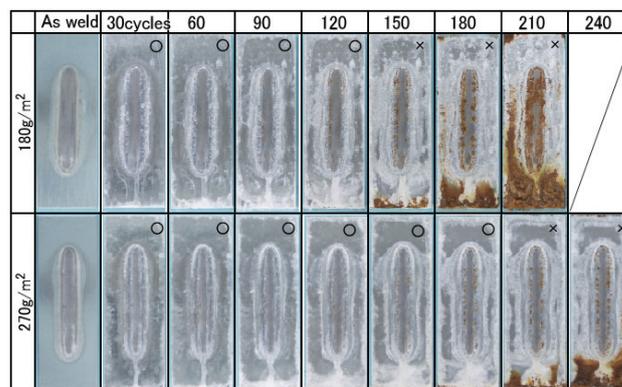


Fig. 6 Results of corrosion test of heat affected zone

testing corrosion resistance of heat affected zone on the rear. The following were catered for the test: alloy-galvanized steel sheets of Zn-11%Al-3%Mg-0.2%Si system having the coating weights of 180 g/m² and 270 g/m², and a stainless steel welding wire was used for welding.

As for the duration, red rust appeared at around 120th cycle in the sample of 180 g/m² and at around 180th cycle in the sample of 270 g/m², and excellent corrosion resistance was confirmed. It is considered that in addition to the effect of protective corrosion prevention rendered by high corrosion-resistant coating, apparent Al residue in the evaporated coating domain has contributed to the securing of corrosion resistance.

4. Summarization

Authors have developed a stainless steel welding wire applicable to galvanized steel sheets. By applying the subject welding wire to highly corrosion-resistant galvanized steel sheets, it has become possible to secure excellent weld part corrosion resistance and to simul-

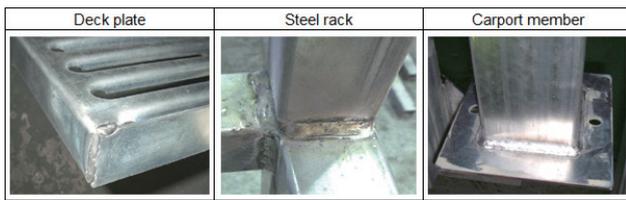


Fig. 7 Applications of developed welding wire

taneously obtain the weld metal that has the gloss equivalent to that of coated sheet, eliminating the touch-up process at galvanized steel sheet weld part.

The subject welding wire has obtained the special certification of the Minister of Land, Infrastructure, and Transport for application to building materials, and future expansion in application is expected. It

has already been applied to deck plates, steel racks for factory use, and the like (Fig. 7), and in addition to the effect of eliminating one process of touch-up for weld part, the subject welding wire has obtained favorable reception for reducing the work load for removing weld spatter, and enhanced weld part design produced by the good outlook of weld part.

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