Corrosion Resistance of Arc Welds with E-coat
—Effect of Shielding Gas Composition on the Corrosion Resistance—

by
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Synopsis

The corrosion resistance of gas shielded metal arc welds with E-coat (electro-coating) is inferior to base metal. The corrosion behavior was investigated and the corrosion resistance was improved by appropriate compositions of shielding gas in this study.

The corrosion of welds was caused by two reasons. (1) *Coating defects were formed by slag on welding bead.* (2) *Inadequate phosphating and poor coating adhesion are caused by oxidation and fume deposition on the surface of HAZ. The corrosion resistance was improved by the decrease of CO_2 and O_2 content in Ar based shielding gas, because the amount of slag decreases. Since at least 1% CO_2 or O_2 is necessary to uniform the width of welding bead, appropriate shielding gas composition ranges were determined Ar+1%-5%CO_2 and Ar+1%-3% O_2.*

1. Introduction

Gas metal arc welding (GMAW) is one of the major welding method to assemble automotive components, because it can be applied to the various shape and size of parts. Most automotive steel components are coated by E-coat (electro-coating) to prevent from corrosion. Arc welds however are apt to corrode despite covered with E-coat. Authors investigated the effect of shielding gas composition on corrosion resistance of welds with E-coat, in order to clarify the corrosion behavior and to obtain appropriate shielding gas composition ranges.

2. Experimental Procedures

2.1 Materials and Welding

Base metal used in this study was 2.6mm thick hot rolled steel sheets which have tensile strength of 440MPa. The chemical compositions of the base metal and the welding wire are shown in **Table 1**. Bead on plate welding was carried out with pulsed current GMAW process in the condition as shown in **Table 2**. Ar-CO_2 mixture and Ar-O_2 mixture shielding gas were used in this study.

Table 1 Chemical compositions

(mass%)

	C	Si	Mn	P	S
Base metal	0.07	0.05	1.11	0.014	0.001
Welding wire	0.06	0.58	1.18	0.014	0.015

Table 2 Welding condition

Welding current	140A
Peak current	410A
Pulse duration	1.5msec
Welding speed	100cm/min
Arc voltage	22V

2.2 Surface Treatment and Corrosion Test

Welded specimens were coated with 20μm thickness E-coat after phosphating. The E-coating and phosphating process were conventional methods used in automotive production. The corrosion performance was examined by cyclic corrosion test (CCT). In the CCT, salt water splay, dry, humid environment were cycled once for 8 hours, and the test was continued to 180 cycles. After the CCT, appearance of welds was observed and maximum corrosion depth in heat affected zone (HAZ) was measured.

3. Result and Discussion

3.1 Appearance of Welds

Photo 1 shows the appearance of welds. In case of using Ar-20%CO_2 shielding gas (conventional composition), welding slag, which generated by deoxidation reaction in molten pool, was fixed on the side of welding bead. Fume, fine metal oxide particle generated by evaporation, lay on the base metal neighbor welding bead. In addition, surface color changed by oxidation. After E-coating the slag was not coated. It is considered the slag, which consists of Si and Mn oxide, has too high electric resistance to be coated with E-coat.

In case of using Ar-3%CO_2 and 100%Ar, the amount of slag and non-coated portion (coating defects) decreased. **Figure 1** shows the length of coating defects at the side of welding bead in welding direction. Obviously the decrease of CO_2 and O_2 content in Ar based shielding gas reduced coating defects. It was due to the amount of oxygen absorbed in molten metal from shielding gas decreased using Ar rich shielding gas.

Otherwise the welds by Ar-3%CO_2 and 100%Ar shielding gas had a bright zone on HAZ neighbor welding bead. It was reported that the bright zone which appeared using Ar rich shielding gas was the trace of cathode spot of arc[1]. (The bright zone is described "cleaning zone" in present paper.) Bead uniformity was poor only using 100%Ar shielding gas. The bead uniformity will be discussed later.

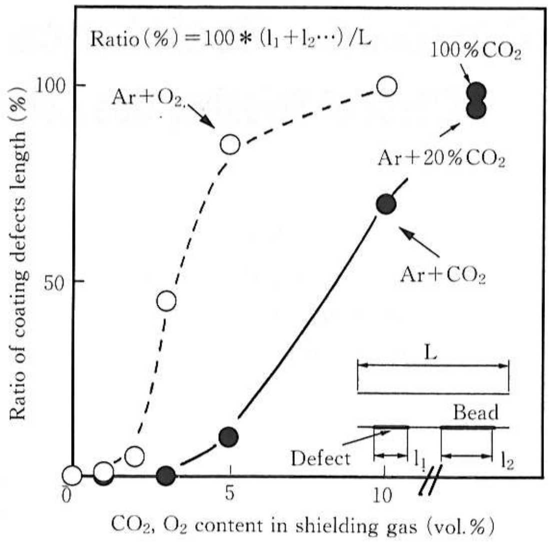

Fig. 1 Effect of shielding gas composition on coating defect

3.2 Phosphatability and Adherence of Coating

Phosphatability, which effects on coating adhesion and corrosion resistance, was investigated by SEM. **Photo 2** shows feature of surface in HAZ after phosphating. At base metal portion (10mm far from welding bead), lump shape phosphate crystals were formed. In case of using conventional Ar-20% CO_2 gas, however, only welding fume deposition was observed, phosphate crystals were hardly observed in HAZ (1mm from bead). It is considered that fume and oxidation are harmful for phosphating

While in case of using Ar-3%CO_2 gas, planer phosphate crystals were observed in cleaning zone. Fume was eliminated by cathode spot heating in cleaning zone, so that the phosphatability was improved by using lower oxidizing shielding gas such as Ar-3%CO_2. However the phosphatability was not improved as the same level as base metal, because of surface oxidation.

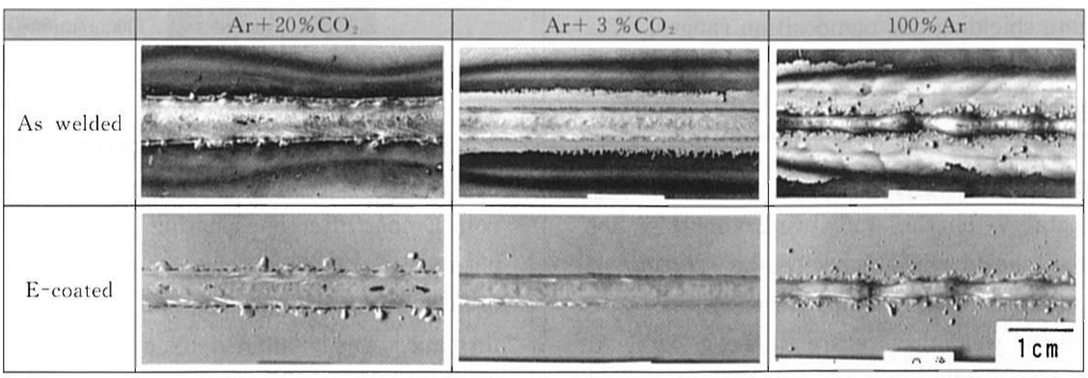

Photo 1 Appearance of welds by various composition of shielding gas

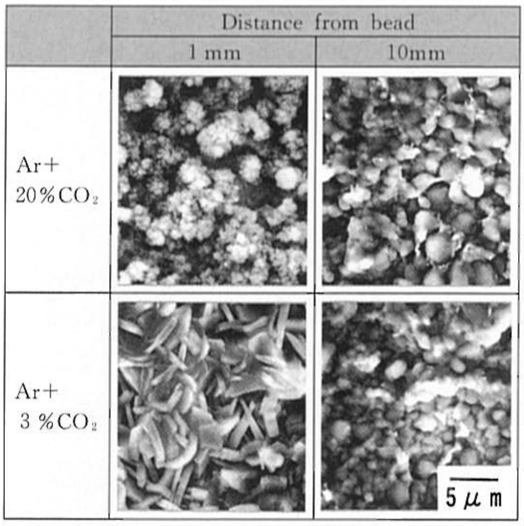

Photo 2 Surface feature in HAZ after phosphating

Figure 2 shows coating adherence examined by delamination test with adhesive tape. The adherence of coating at bead and HAZ was inferior to base metal portion. The adherence of coating at HAZ by Ar-3%CO_2 shielding gas was superior to that by Ar-20%CO_2 gas. It is considered due to the improvement of phosphatability.

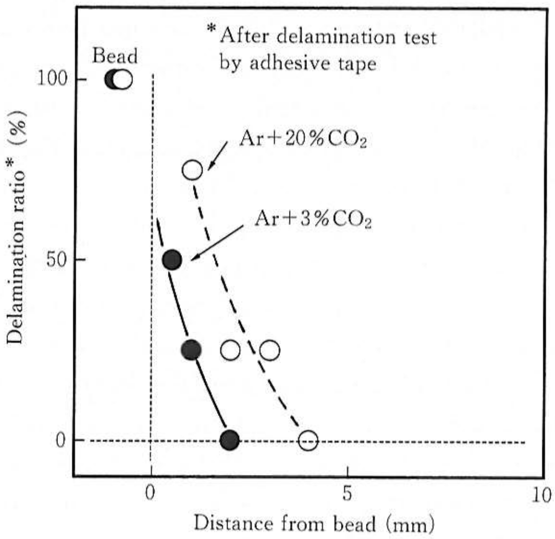

Fig. 2 Adherence of coatings at HAZ

3.3 Corrosion Behavior

Photo 3 shows the appearance of specimens at early stage (30 cycles) in corrosion test. In case of conventional Ar-20%CO_2 gas, corrosion initiated at coating defects formed on welding bead, after that, the corrosion spread to HAZ. On the other hand, the welds by Ar-3%CO_2 gas did not corrode at all. **Figure** 3 shows rust occupation ratio in welding direction after corrosion test at 90 cycles. The red rust area was smaller as CO_2 or O_2 gas content decreased. **Figure** 4 shows maximum corrosion

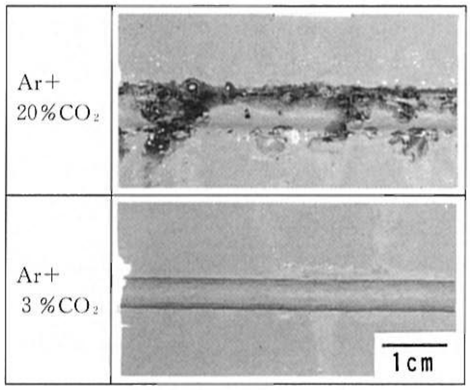

Photo 3 Appearance of welds after CCT 30 cycles

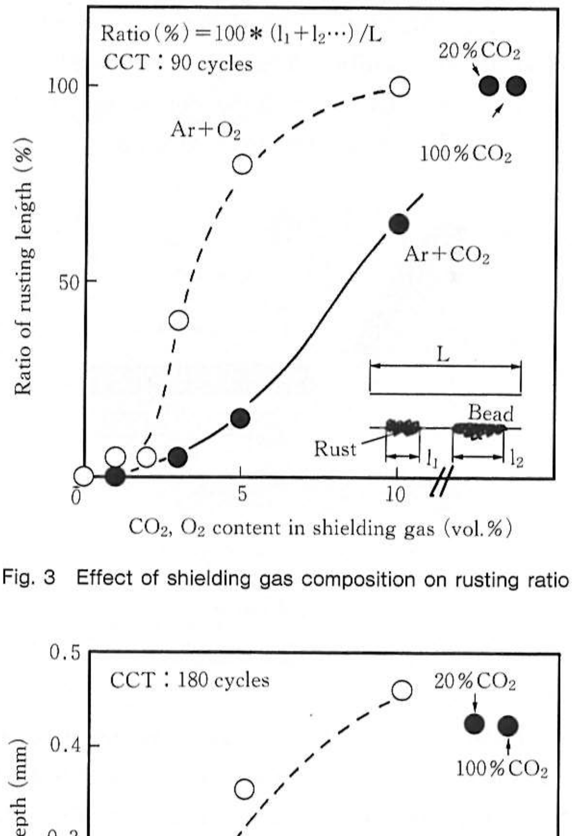

Fig. 3 Effect of shielding gas composition on rusting ratio

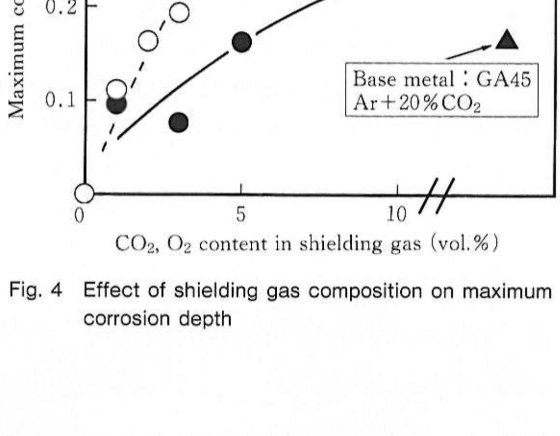

Fig. 4 Effect of shielding gas composition on maximum corrosion depth

depth in HAZ after corrosion test at 180 cycles. The corrosion depth was significantly improved by Ar rich shielding gas containing less than 5% CO_2 or less than 3% O_2. The corrosion depth of welds by using such shielding gas composition was smaller than that of welds in galvannealed steel sheet having $45g/m^2$ zinc coating in each side by conventional Ar-20%CO_2 gas.

3.4 Corrosion Mechanism

The causes of the corrosion are summarized as follows. **Figure 5** illustrates the causes schematically. (1) Since welding slag acts as an insulator during E-coating, non-coated portions are formed on welding bead. they becomes a site of corrosion when the welds is exposed to corrosive environment. (2) Degradation of coating adhesion and the formation of insufficient phosphate crystals are caused by oxidation and fume deposition on the surface in HAZ. It accelerates corrosion.

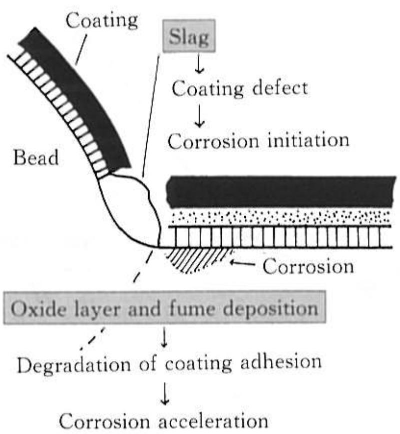

Fig. 5 Corrosion mechanism

In order to clarify the corrosion mechanism, an additional corrosion test was carried out. **Photo 4** shows the appearance of specimens after CCT. It was obvious that the removal of slag significantly improved the corrosion resistance. However the polishing on HAZ improved corrosion resistance slightly. This result shows the principal cause of corrosion is the coating defects formed by slag. It is concluded that in order to improve the corrosion resistance of welds, control of the amount of slag is the most effective.

In present study, the corrosion resistance of GMAW was focused. However in the another type of welds, for example, laser welding, seam welding and spot welding, surface oxidation seems to possibly be one of the causes of corrosion. The effect of surface oxidation on corrosion resistance was investigated in another report[2].

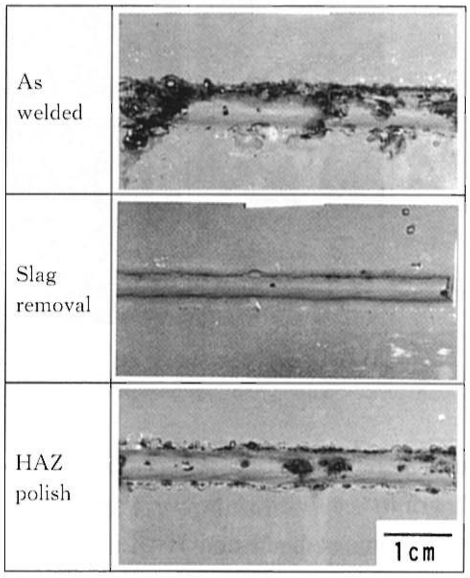

Photo 4 Effect of removal of slag and polish on HAZ on corrosion resistance (CCT : 30 cycles)

3.5 Appropriate Shielding Gas Composition

In order to determine appropriate gas composition for practical use, bead uniformity and penetration depth were investigated. Bead width uniformity (Wmin/Wmax) was investigated as shown in **Fig. 6**. The result showed at least 1% CO_2 or O_2 gas in Ar based shielding gas is necessary to obtain a sound bead. In addition, oxidizing gas was necessary to obtain deeper penetration depth as shown in **Fig. 7**. The poor bead uniformity and the small penetration by Ar rich shielding gas have been discussed by MATSUDA[1]. Our result was in agreement with their result. It is well known that cathode arc generates easily from oxide. In case of using lower oxidizing shielding gas, since enough oxides to stabilize the cathode spot on molten pool are not formed, so cathode spot deconcentration and instability occur. This phenomenon causes poor bead uniformity and small penetration.

The upper limit of oxidizing gas content was determined by corrosion resistance, and the lower limit was determined by bead uniformity. The appropriate shielding gas composition ranges to avoid the corrosion of welds with E-coat are concluded as Ar+1%-5%CO_2 and Ar+1%-3%O_2.

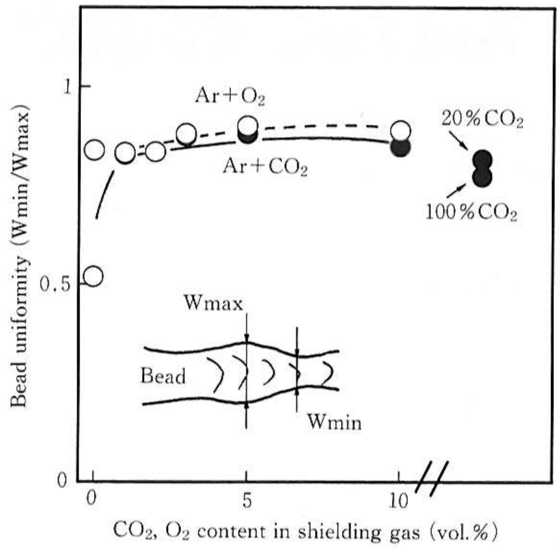

Fig. 6 Effect of shielding gas composition on bead uniformity

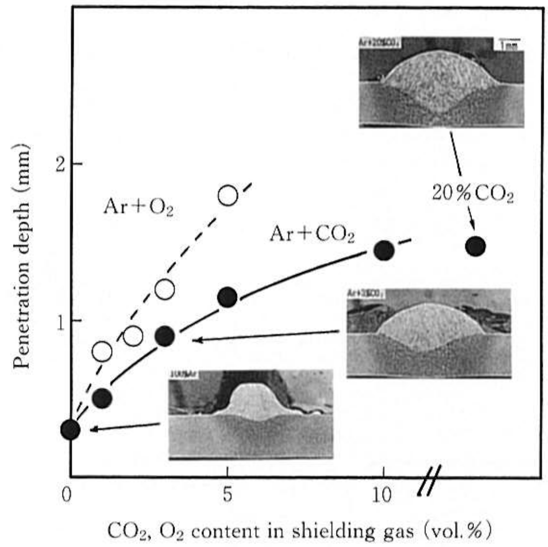

Fig. 7 Effect of shielding gas composition on penetration depth

4. Summary

(1) The corrosion of welds is caused by two reason. First, coating defects formed by slag on welding bead. Second, poor coating adhesion and phosphatability caused by oxidation and fume deposition at HAZ.

(2) The corrosion resistance is improved by the decrease of CO_2 and O_2 content in Ar based shielding gas, because the amount of slag decrease.

(3) From the viewpoint of productivity, more than 1% CO_2 or O_2 gas is necessary in shielding gas to obtain sound welding beads. The appropriate shielding gas composition ranges are determined to be Ar+1%-5%CO_2 or Ar+1%-3%O_2 in this study.

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