

Investigation of the Kinetic Process of Metal-Oxygen Reaction during Shielded Metal Arc Welding

Experiments suggest a link between kinetics and the control of oxygen levels in the weld metal

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ABSTRACT. An investigation of the kinetic process of metal-oxygen reaction and its affecting factors throughout the stages of heating the covering, drop growth, and weld pool formation was carried out in manual arc welding. The results obtained indicate various kinetic links for controlling the oxygen content in the weld metal.

Introduction

Metal-oxygen reaction during welding had been one of most popularly investigated subjects by welding metallurgists before the 1950's. In recent years, with increasing demands for greater weld metal toughness, the control of nonmetallic inclusions and oxygen content (hereafter, the oxygen content is symbolized as [O]) has once again drawn attention. However, most of the work done placed emphasis on thermodynamics (Refs. 1-3). There have been relatively few papers that emphasize the kinetic process (Refs. 4-7). The authors designed a series of experiments simulating production welding, and thus investigated the kinetic pro-

cesses of metal-oxygen reaction throughout the stages of heating the covering, drop growth, and weld pool formation. The experiments were conducted with electrodes that use marble and fluorspar as the main components in their coverings. The results obtained indicate various kinetic links for controlling the [O] in the weld metal.

Experimental Procedure

Materials

The composition of the test pieces and core wire and the formulas of the coverings of the test electrodes are shown in Tables 1 and 2.

Experiments in Heating the Covering

The specimen, having the same composition as the electrode covering, was extruded to form a hollow cylinder 4 mm (0.16 in.) in diameter. The specimen was put in a small crucible of alumina, which

was then placed in a niobium crucible and heated in argon by a heavy current. The thermal cycle simulated that of the covering near the handle end of a production electrode—Fig. 1. Marble in the specimen was heated and decomposed giving off CO₂, part of which was deoxidized to CO by the metal powders. The mixed gas, including both CO₂ and CO, was carried by the argon to the Coulomb oxygen analyzer through the two different tube systems shown in Fig. 2. Before being analyzed, one of the tube systems carried the mixed gas into the hot copper oxide furnace. Here the CO in the mixed gas was reoxidized. Thus, the quantity of analyzed CO₂ represented the total amount of CO₂ evolved from the decomposed marble. The mixed gas traveling through the other tube system was analyzed directly, and the quantity of analyzed CO₂ represented the remaining amount after deoxidization. The difference after subtracting the remaining CO₂ from the total CO₂ represented the quantity of CO₂ that was deoxidized by the metal powder while heating and covering. It is termed the quantity of predeoxidation.

The quantities of total and remaining CO₂ evolved from the specimens heated for various times along the simulated thermal cycle were measured. And the quantities of predeoxidation were calculated.

KEY WORDS

Shielded Metal Arc
SMA Welding
Kinetic Process
Metal-O₂ Reaction
Electrode Coverings
Marble/Fluorspar
Kinetic Analyses
Arc Atmosphere
Predeoxidation
Cover O₂ Potential

Table 1—Composition of the Test Pieces and Core Wire

Composition	C%	Si%	Mn%	O%
Test piece	0.19	0.14	0.46	0.027
Core wire	0.085	0.027	0.39	0.061

Table 2—Formulas of the Covering for the Test Electrodes (%)

Series	Marble	Fluor-spar	Mica	Na ₂ CO ₃	Titanium Dioxide	Fe-Si ^(a)	Fe-Mn ^(a)	Fe-Ti ^(a)	Fe Powder
Mn	44	20	—	1	5	—	0-3	—	30-0
Si1	44	20	—	1	5	0-24	—	—	30-6
Si2	44	46-26	—	1	5	0-24	—	—	—
Ti	44	20	—	1	5	—	—	0-30	30-0
J ^(b)	44	20	—	1	5	9X	10X	21X	30-0
C1	0-70	70-0	2	1	4.0	5.5	5.5	13	—
C2	0-80	80-0	2.3	1	4.6	2.8	2.8	6.8	—

(a) Fe-Si with 48% Si; Fe-Mn with 78% Mn; Fe-Ti with 38% Ti.
(b) Σx = 0-30.

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deoxidized by the unit content of the deoxidizers, *i.e.*, in the order Fe-Si, combined (J-series in Table 2), Fe-Ti and Fe-Mn.

Figure 16 shows the effect that iron powder added to the covering has on the [O] of the deposited metal. Even though the iron powder acted as a deoxidizer during the heating of the covering as mentioned before, the [O] increased when iron powder in the covering increased and only 10% Fe-Mn was present as a deoxidizer. But in the case of the covering with 20% Fe-Mn, the iron powder had only a slight effect on the [O].

Composition of Gases Evolved during Welding

Using the apparatus shown in Fig. 5, the quantities of total CO₂ and remaining CO₂ were measured—Fig. 17. The difference between the two quantities represented the decrease of oxygen potential in the gases during welding. It took about 80% of the total CO₂ evolved from the covering.

Discussion

Kinetics of the Oxygen-Metal Reaction

Because this investigation focused on the theoretical aspect of the kinetic process in the oxygen-metal reaction, the formulas were devised appropriately to reveal this process. The content of oxygen in some weld metal was higher than that produced by commercial electrodes. These results do not indicate that the covering should have 20–25% deoxidants. For example, with only 12% deoxidizer (Fig. 14), oxygen content decreased to 300 ppm, while the marble content decreased to less than 20%.

The author agrees with the viewpoint that the arc length and arc force are important parameters that influence the dissolution of oxygen. So, in this investigation, arc lengths were kept as short as possible.

In this investigation, the oxygen content was not only the dissolved oxygen, but also that present in the oxide inclusions.

The Kinetic Process during Heating of the Covering

The results of the experiments identified the phenomenon of predeoxidation during the heating of the covering. As a result of this reaction, the oxygen potential was cut to about 40% of its original potential at a temperature near the melting point of covering that contained 24% Fe-Si. Compared with the results plotted in Fig. 17, it was shown that the predeoxidation conducted in this stage was responsible for about 75% of the total

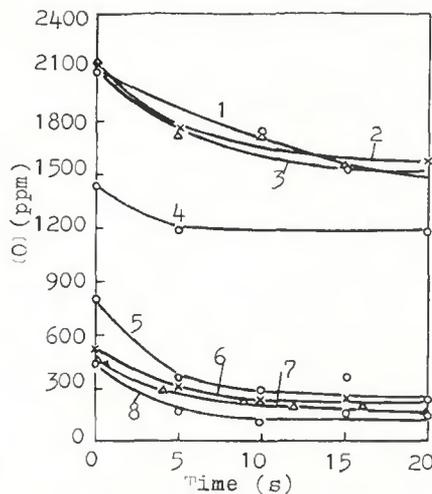


Fig. 13—Variations in the [O] of the deposited metal remelted for various times. Electrode types: 1—Si8; 2—Ti10; 3—J10; 4—Mn10; 5—Mn25; 6—Ti25; 7—J30; 8—Si20

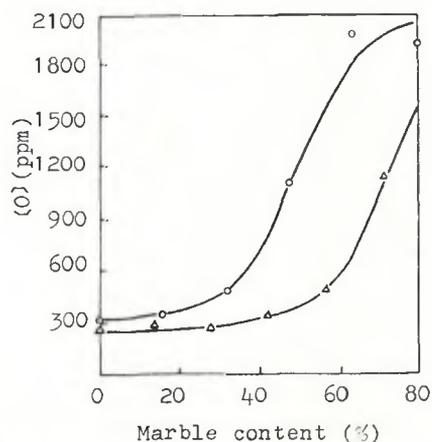


Fig. 14—Effect of marble content on the [O] of the deposited metal. o with 12% deoxidizer; Δ with 23% deoxidizer

decrease of oxygen potential for the gases during the whole welding process.

Because the duration of heating the covering was very short, the development of predeoxidation was controlled by kinetic factors, such as the temperature and contacting surface affecting the multiphase reaction. The fact that predeoxidation developed more perfectly in the covering with fine Fe-Si powder than the one with coarse powder was evidence of this. The affinity of metal to oxygen had less of an effect on this process. This was discovered from the results of the experiments of substituting Fe-Si for iron powder—Fig. 8. The oxygen potential of the gases evolved from the covering increased with the increasing content of marble and the decrease of Fe-Si in the covering. This was in keeping with the general concept of an oxygen-metal reaction. However, in spite of the decrease in oxygen potential for

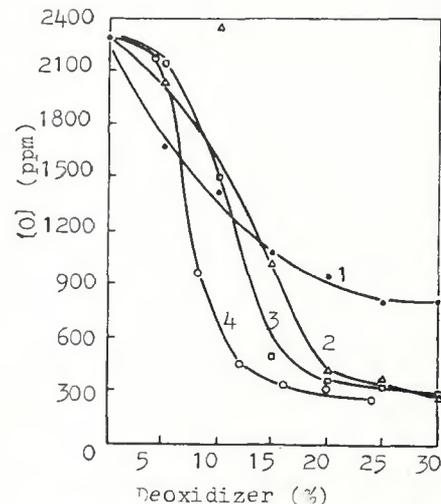


Fig. 15—Effect of the content of different deoxidizers on the [O] of the deposited metal. 1—Mn series; 2—Ti series; 3—combined series; 4—Si series

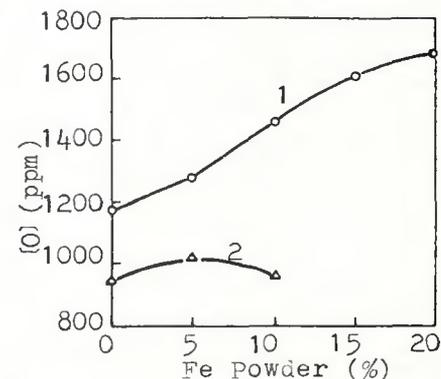


Fig. 16—Effect of the iron powder addition on the [O] of the deposited metal. 1—with 10% Fe-Mn; 2—with 20% Fe-Mn in the covering

the gases evolved from the covering, the [O] of the deposited metal increased as the iron powder content increased in a covering that contained insufficient deoxidizers, as shown in Figs. 8 and 16. It is reasonable to assume that the product of deoxidation, FeO, entered the slag and the melted metal. Because the fine iron powder in the covering increased the contact surface and, therefore, the time for oxygen-metal reaction, it is favorable to assume from the kinetics viewpoint an increase of [O] in the metal.

Kinetic Process during Drop Growth

As shown in Fig. 9, there were two different trends of [O] in the melted metal of the first drop after the ignition of the arc. In the first 50 ms of growth, as the covering had not yet taken part in the reaction, the arc burned between the core wire and the test piece in the air. In this case, because the oxygen potential in the air was higher than that in the normal arc atmosphere, and the deoxidizers

