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Citation	Transactions of JWRI. 1978, 7(2), p. 165-168
Version Type	VoR
URL	https://doi.org/10.18910/10933
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Inclusion Morphology in Submerged Arc Weld Metal Using the Fluxes of the System (CaO)-MnO-SiO_2 †

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Abstract

Inclusion morphology in SAW metal using the several fluxes of the system (CaO)-MnO-SiO_2 was investigated with SEM observation and X-ray microanalysis. Almost all inclusions were identified as manganosilicate and only a silicate containing sulphur was found out. It was suggested that these inclusions are originated in the redox equilibrium of manganese and silicon and manganese content in inclusion is not so changeable and richer than that of silicon. However, further investigations, especially on inclusion morphology in weld metal with fluxless welding process, are necessitated in order to certify these suggestions.

1. Introduction

Submerged arc welding (SAW) method as well as electroslag welding (ESW) occupies the great important position in welding technology. As described in the previous paper[1], however, the roles of slag in SAW are fairly diffrent from those in ESW though slag is the most essential material in both methods. Therefore, it is expected that the difference in the roles of slag produces the remarkable one in the morphology of inclusion. The increments of oxygen and nitrogen in weld metal by SAW process are very remarkable compared with those by ESW process[2] and, therefore, the information on the morphologies of inclusions such as oxide and nitride, especially the dependence upon flux composition, is necessitated in order to clarify the increments of these elements. In this study, the morphologies of oxide, sulphide and oxysulphide inclusions in SAW metal using the fluxes of the system (CaO)-MnO-SiO_2 were investigated by SEM observation and X-ray microanalysis.

2. Experimental Procedures

The specimens used in this study were the same ones which were used in the previous investigation[1]. The experimental conditions of SAW and the compositions of wire, fluxes and subtrate steel were also described in the previous paper[1]. Specimens for SEM observation were prepared by deeply etching with 5% nital after cutting off specimen pieces from weld metal and polishing them by SiC and ZrO_2 abrasives using water or ethylalchol as coolant. The conditions of SEM observation were as follows:

Voltage and Current : 20kV x 100~110μA,
Sensitivity in XMA : ·100 cps,
Type of microscope : Hitachi HSM-2B.

3. Results and Discussion

Typical oxide inclusions in weld metal are shown in **Photo. 1**. These inclusions were identified as mangano-

Table 1 The proportion of inclusions detected in SAW metal

Specimen No.	(Mn, Fe) (S, O)	Silicate Containing Sulphur	Silicate	Slag Trapping	Slag Composition		
					CaO	MnO	SiO_2
No. 1	0	0	18	1	0%	50%	50%
No.2	0	1	16	0	16.7%	33.3%	50%
No. 3	0	0	20	1	25%	25%	50%
No. 4	0	0	20	0	33.3%	16.7%	50%

† Received on October 14th, 1978

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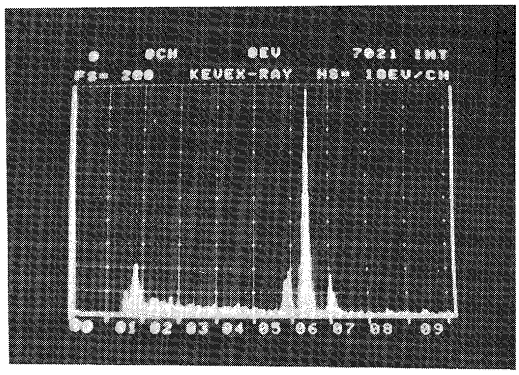


Photo. 1 Typical manganosilicate inclusions in SAW metal [from No. 1 sample] (x6000)

silicate and calcium was not detected in all of these inclusions except the inclusions attributed to slag-trapping. As shown in **Table 1**, inclusion morphology was almost independent on the change of slag composition in the system CaO-MnO-SiO_2 . Further, only a silicate with sulphur was found out in this study and, therefore, it is suggested that the formation of sulphide and even oxysulphide or oxide-sulphide duplex seems to require a fairly slow rate of solidification. A few inclusions which originate in slag-trapping were also detected and these inclusions are shown in **Photos.** 2 and 3. These slag-trapped inclusions are generally very large compared with common oxide inclusions and calcium was usually detected in these inclusions when CaO was contained in the flux used. Thus, as suggested in the previous paper[1)], the detection of calcium in a inclusion can be used as a measure to judge whether or not a inclusion is due to slag trapping. The noteworthy result in this study is that almost all inclusions were detected as manganosilicate without calcium and it is difficult to consider that these inclusions were simply formed by slag-trapping. In order to explain the formation of such small inclusions, at least, two following considerations are possible;

(1) these inclusions are originated in the incorporation of MnO and SiO_2 which were formed as the result of the redox equilibrium of Mn and Si,

(2) these inclusions are essentially due to slag-trapping and only calcium did not remain in the inclusions.

According to the consideration (1), it will be possible to detect simple inclusions such as MnO (or (Mn, Fe)O) and SiO_2 (or iron silicate). However, these simple oxide inclusions were not able to be detected in spite of the observation on thousands of fields.

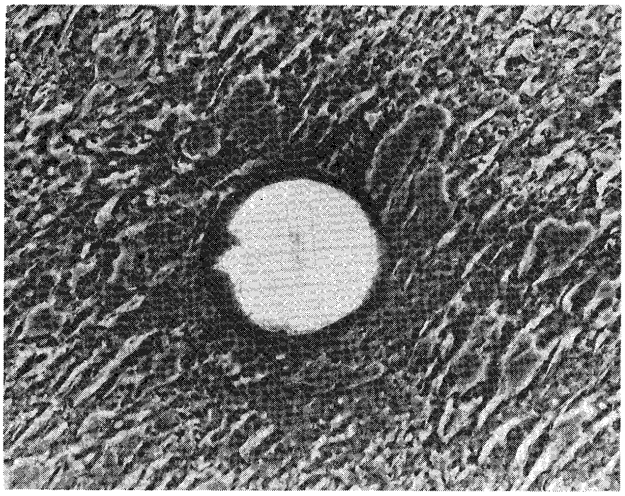
In the consideration (2), on the other hand, no detection of calcium in inclusions can not be explainable. In order to elucidate the contradiction, it is difficult to consider the reduction of CaO in inclusions by any reaction during welding and, therefore, it may be considered that no detection of calcium is not attributed to chemical reasons but to any physical mechanisms which depend upon CaO content. If such a consideration is reasonable, it is easily expected that the amount of inclusion, that is, oxygen content in weld metal decreases as the content of CaO in slag increases. However, the result in the previous paper showed that oxygen content in weld metal was nearly constant or slightly decreased with increasing the content of CaO in slag except flux CF-3. The result in flux CF-3 can not equally be discussed because the flux is high basic and commercial one. Thus, consideration (2) can not explain why manganosilicate inclusions were only detected in SAW metal.

Recently, Eager indicated that oxygen level of SAW metal is controlled by SiO_2 decomposition in most acidic fluxes[3)]. In other words, oxygen level of SAW metal is controlled by the following equilibrium among $\underline{Si}$, $\underline{O}$ and SiO_2:

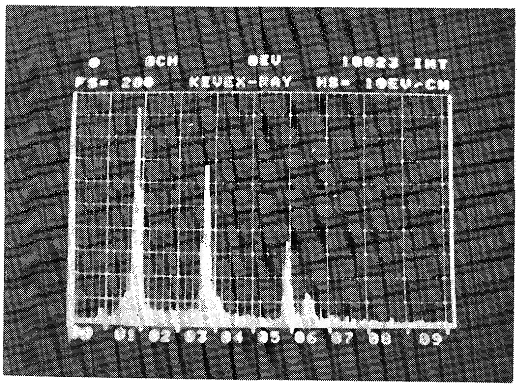
$$\underline{Si} + 2\underline{O} = SiO_2 \qquad (1).$$

The consideration apparently supports the result in the previous paper in which oxygen increment in SAW metal was almost independent upon CaO content in slag. Further, it is expected that the phenomenon is also supported by the nearly constant activity of SiO_2 in the slag of the system $xCaO{\cdot}(1-x)MnO{\cdot}SiO_2$. This would be reasonable expectation if activity of SiO_2 in the CaO-MnO-SiO_2 system is similar to that in the Fe_tO-CaO-SiO_2 system[4)].

Subsequently, redox equilibrium of Mn must be considered because MnO in slag can be fairly easily reduced. If the reduction of MnO is effective to increasing oxygen



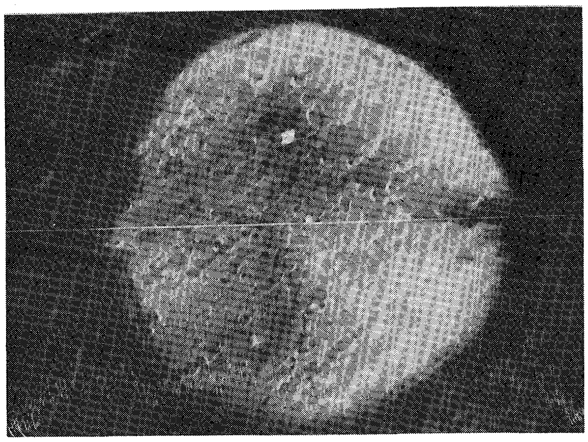
(a)



(b)

Si

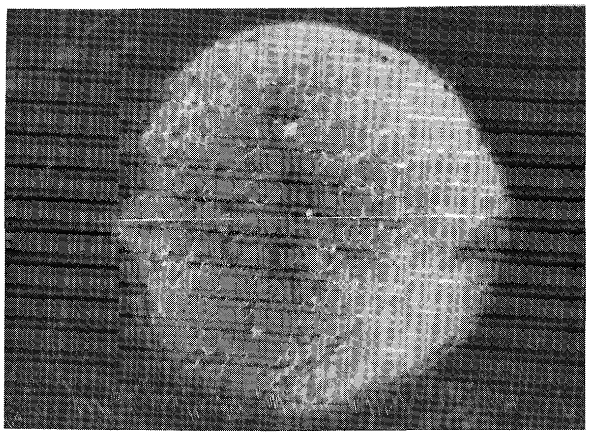
Mn



(c)

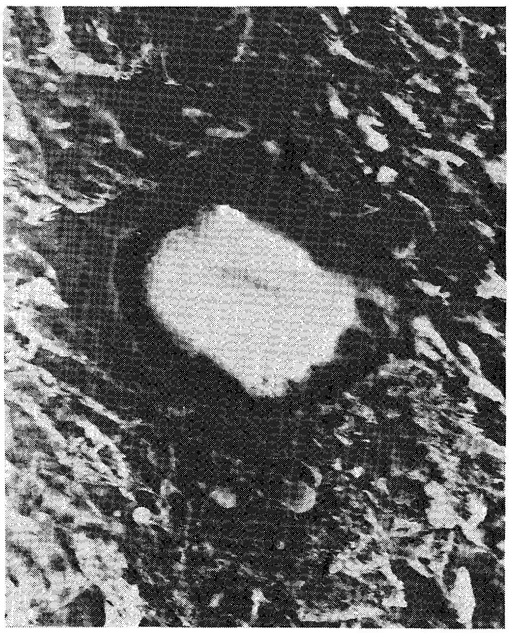
Fe

Ca



(d)

Photo. 2 Typical inclusion originated in slag trapping in SAW metal [from No. 3 sample]
(a) appearance (x1500)
(b) characteristic X-ray spectrum profile
(c) , (d) X-ray line analyses



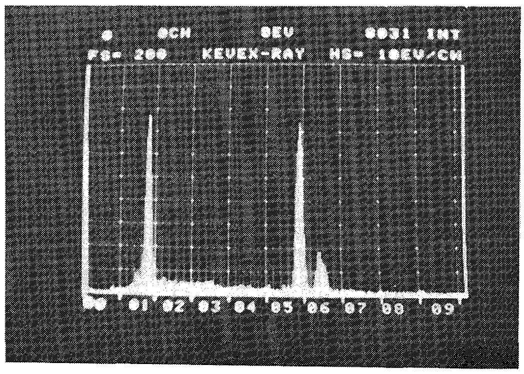


Photo. 3 Another typical inclusions originated in slag trapping in SAW metal [from No. 1 specimen] (x3000)

level in SAW metal, oxygen increment in weld metal must remarkably increase with increasing MnO content in slag. As shown in the previous paper[1], however, the increase of MnO in slag produced only the slight increase in oxygen content in weld metal. Therefore, it is suggested that reduction of MnO does not remarkably contribute to the oxygen increment in weld metal and that manganese content in inclusion is richer than that of silicon. In this suggestion, no remarkable contribution of reduction of MnO can be explained from thermodynamical consideration. According to Abraham et al.[5], activity of MnO does not remarkably change in the system $xCaO\cdot(1\text{-}X)MnO\cdot SiO_2$ and Bodsworth and Bell indicated that activity coefficient of MnO in the same system scarcely varies with the ratio CaO/SiO_2 until the ratio reaches unity[6]. Therefore, it is expected that the quantity of MnO redistributed is not so changeable in the system $xCaO\cdot(1-x)MnO\cdot SiO_2$. Further, taking thermodynamical data into account[6], it is indicated that the quantity of manganese oxide reduced is smaller than that of silica. Thus, the reduction of MnO would not so remarkably contribute to the oxygen increment in weld metal and the content of MnO in inclusions would also be not so changeable. However, structural investigations and quantitative analysis on inclusions must be performed in order to support the discussion described above.

4. Summary

Inclusion morphology in SAW metal using several (lime)–manganosilicate fluxes was investigated with SEM observation and X-ray microanalysis. Almost all inclusions were identified as manganosilicate and only a silicate containing sulphur was found out. On the basis of thermodynamical date, the origin of these manganosilicate was discussed and it was suggested that these inclusions is attributable to the redox equilibrium of Si and Mn. Further, it was indicated that manganese content in inclusions is not so changeable and richer than that of silicon. However, further investigations on structure of inclusion, qualitative analysis of components and inclusion morphology in weld metal with fluxless welding process are desired in order to certify the suggestion described above.

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