INFLUENCE OF FLUX COMPOSITION ON RECOVERY OF CARBON SILICON AND MANGANESE DURING SUBMERGED ARC WELDING

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ABSTRACT

CaO-Al_2O3 based flux system along with other constituents like MGO, TiO_2, MnO and CaF have been designed with the help of binary and ternary phase diagrams. The flux constituents selection has been made according to the flux liquidus temperature. Fluxes were prepared by agglomeration technique and basicity index (B.I.) varied between 1.20 and 3.8.

The influence of flux basicity on the transfer of carbon and distribution of silicon and manganese between weld metal and slag system has been determined. With the help of above data, a relationship has been developed between the flux composition and the gain or loss of these elements during welding. The results show that the flux composition which affects the physico-chemical and metallurgical characteristics of the slag, plays significant role in the transfer of C, Si and Mn to the weld metal.

INTRODUCTION

Flux perform many key roles during submerged are welding such as arc stability, bead shape, slag detachability, welding speed capabilities and weld metal chemistry. Fluxes are formulated to meet specific objectives because one flux formulation cannot perform optimally for all applications. The welding behaviour of fluxes and weldmetal chemistry depend upon the physico-chemical and metallurgical properties of fluxes. The reactions between molten flux and metal are primarily of oxidation/reduction type, which depend upon the relative stability of flux constituents. It is therefore, necessary to know the oxidising power of the flux along with its basicity.

Transfer of carbon and distribution of silicon and manganese between molten flux and metal and also the dissolved oxygen have been studied by various research workers [1-10]. The investigations carried out by them involve the use of mostly the commercial fluxes, however, few have used experimental fluxes formulated in the laboratory. The results reported by these investigators are essentially emperical in nature and the conclusions drawn are purely qualitative. It has also been reported that irrespective of the type of flux carbon is lost during welding. The amount of carbon lost, however, varied depending upon the type of consumables used as well as the setting of the welding parameters. The distribution of silicon and manganese has been found to depend upon silica and Mno content of the fluxes and with the change in flux basicity for the same amount of these oxides, the transfer of these elements have been found to vary.

The effect of flux composition on weld metal oxygen content has also been reported [11-14]. The oxygen content of weld metal increases with silica content of the flux. Further, the weld metal oxygen content depends upon the flux basically and it decreases with the increase in basicity upto 1.25 and then attains a constant value with further rise in basicity. The above observation is again empirical in nature and applicable only to those flux systems which have been studied by them. Also this does not take into account the change in the activity of FeO for the same basicity of flux when FeO content of flux changes. Oxygen content of weldmetal in case of $CaO-Al_2O_3$ based fluxes is much less as compared to silica based fluxes [12].

There is, however, a lack of comprehensive study on various flux systems because of which no correlation could be made between the flux composition, its behaviour and weld metal chemistry which is necessary for building a scientific basis to formulate the submerged are welding fluxes for specific use.

Experimental Procedure

Flux constituents based on $CaO-Al_2O_3$ system have been selected with the help of existing phase diagrams. To keep the liquidus temperature of the fluxes close to 1300°C so as to make them suitable for welding, additions of MnO, MgO and CaF_2 were made to the $CaO-Al_2O_3$ base. The TiO_2 and MnO contents of all the fluxes have been kept constant whereas MgO and CaF_2 have been varied from 5 to 10% and 4 to 22% respectively. With the above constituents agglomerated fluxes were manufactured and their actual melting temperatures were determined. Only those fluxes have been used for investigations which has melting temperatures below 1300°C.

Six high pad bead-on-plate welding was carried out using various experimental fluxes with 4 mm electrode under similar welding conditions to minimise/eliminate the dilution effect. The composition of base metal and the electrode wire are given in Table. 1. The selected voltage, current and speed were 30 V. 500 A and 59 cm min^{-1} respectively.

After multibead welding was completed, the weld metal and slag samples were collected from the top most bead for chemical analysis.

The carbon, sulphur, silicon and manganese contents of weldmetal were determined. Analysis of slag constituents was carried out by fusion method using sodium peroxide as fusion reagent to obtain a clear solution. The solution was analysed for silicon, manganese etc. by atomic absorption spectrometer.

Results and Discussion

For analysis of data it has been assumed that dilution effect is almost negligible and slag-metal reaction attained equilibrium during welding and the temperature of reaction being 2000°C.

From the analysis of the weld metal it has been seen that all the three elements i.e. C, Si and Mn have suffered a significant loss. The loss of these elements may be attributed to the oxidising gaseous atmosphere which is developed due to dissociation of carbonates. This oxidising atmosphere comes in contact with the molten metal droplet at the tip of the electrode. Since the product of oxidation of carbon is gaseous in nature it escapes to the atmosphere alongwith gases where-as oxides of silicon and manganese enter in the molten flux. Beyond this stage when metal droplet

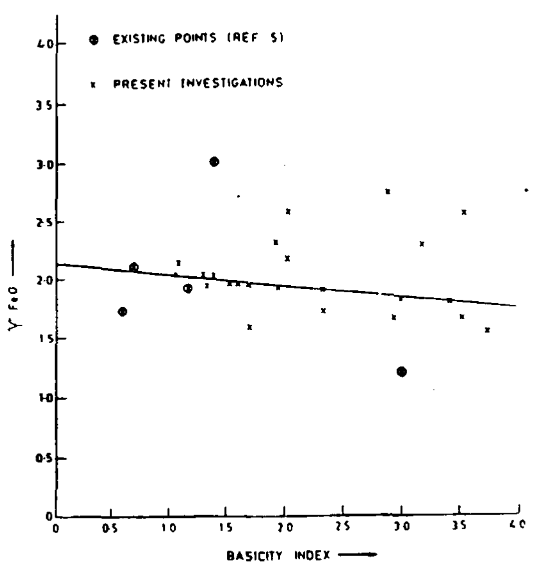

FIG. 1 : VARIATION IN FeO ACTIVITY COEFFICIENT WITH BASICITY INDEX OF SLAG

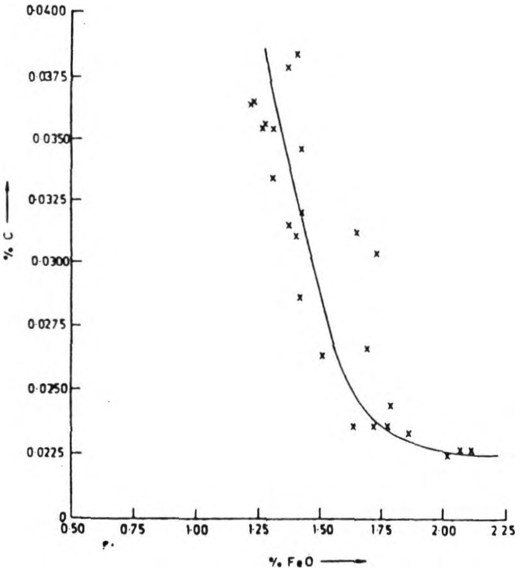

FIG. 2 : CHANGE IN WELD METAL CARBON CONTENT WITH FeO IN SLAG

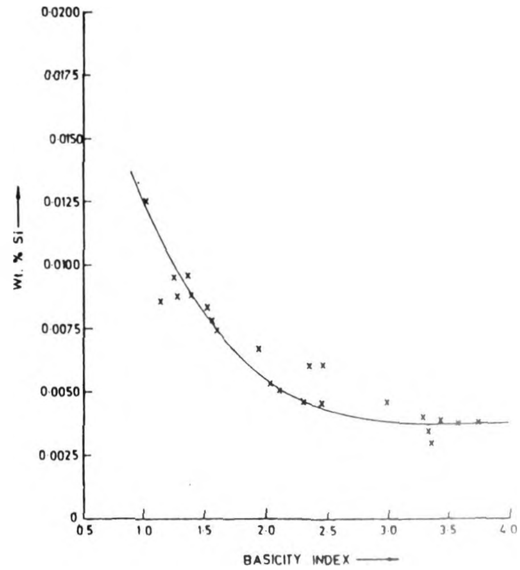

FIG. 3 : RELATIONSHIP BETWEEN WELD METAL SILICON CONTENT AND SLAG BASICITY INDEX

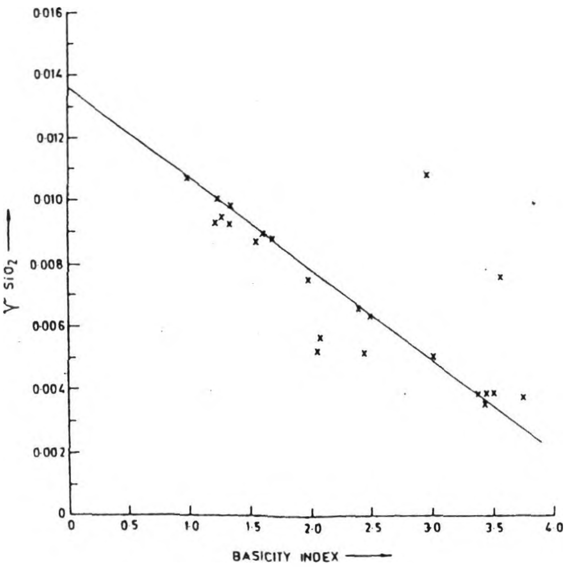

FIG. 4 : VAIRATION IN SiO_2 ACTIVITY COEFFICIENT WITH BASICITY INDEX OF SLAG

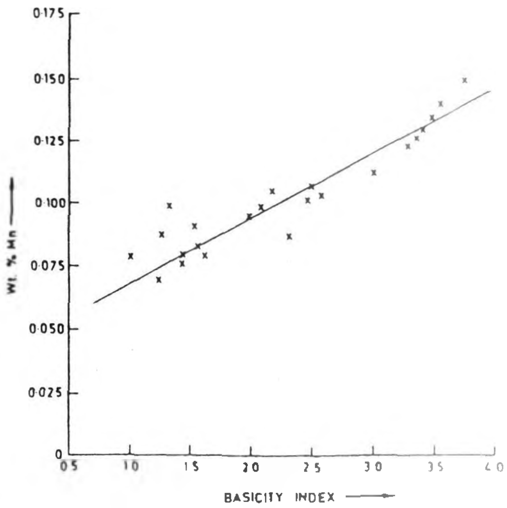

FIG. 5 : VAIRATION IN WELD METAL Mn CONTENT WITH SLAG BASICITY INDEX

detaches itself from the electrode and enters in the molten pool it is essentially in contact with the slag. At this stage the weld metal composition is controlled by oxidising power of the slag.

It is seen that effect of CaF_2 on loss of carbon is not appreciable. This observation in fact suggests that loss of carbon is taking place primarily due to gas-metal reaction and slag composition does not have any bearing as far as reaction involving carbon is concerned. This is primarily due to the fact that CaO in the agglomerated flux is present in the form of $CaCO_3$, it undergoes dissociation and raises the oxygen potential of gaseous atmosphere by releasing significant quantities of CO_2. On the other hand the weld metal carbon content should also depend upon the oxygen potential of the slag with which the molten metal is in intimate contact both during its flight as well as in the molten pool. If one takes into consideration the established experimental data [5,11], the oxygen potential of the molten flux may be represented in terms of activity of FeO. The temperature dependence of equilibrium constant for equilibrium attained between FeO in slag and oxygen in weld metal, has been derived by Eager (13) and expressed as :

$$\text{Log } K = (6272/T) - 2.73$$

K = Equilibrium constant

T = Temperature in degree K

With the help of above expression, assuming iron activity in metallic phase to be unity and oxygen content being 0.025 wt%, the activity coefficient of Feo has been determined for different fused fluxes in the molten state at 2000°C.

Table - 1

Chemical composition of electrode wire and base plare (Wt%).

	C	Si	Mn
Electrode Wire	0.08	0.05	0.50
Base Plate	0.15	0.25	0.63

Fig. 1 shows that activity coefficient of FeO decreases with the increase in basicity of slag. In this figure data given by chai and Eagar [5], have also been plotted and it is seen that behaviour of Feo is almost identical as observed in the present investigation. At steel making temperature as reported by Mcgannon [15], the FeO activity coefficient increases upto a B.I. of about 2.0 and then decreases with increase in B.I.. Such behaviour is not observed under welding conditions. This may be attributed to the prevailing high temperature as well as the presence of electrical potential existing between the two poles.

These investigations show that activity coefficient of FeO in slag has a linear relationship with flux B.I. and decreases as B.I. increases. This type of behaviour explains more effectively the decrease in the amount of oxygen dissolved in weld metal as the basicity of flux increases. The experimental data was subjected to linear regression analysis and mathematically the FeO activity coefficient and B.I. of flux may be represented by the following expression;

$$\gamma FeO = 2.117 - 0.08 * (B.I.)$$

The effect of FeO content of slag on weld metal carbon content has been plotted in **Fig. 2**. which shows that with the increase in FeO content has been plotted in Figure 2, which shows that with the increase in FeO content from 1.25 to 1.75 there is significant decrease in weld carbon content but beyond 1.75% FeO, the decrease in carbon content is nominal. This observation gives a positive indication that slag FeO content plays an important role in carbon-oxygen reaction taking place at slag-metal interface.

The fluxes employed in this study do not contain any silica and also the silicon content of the electrode wire is quite low. However, even the low weld metal silicon content, corresponds to appropriate silica activity in the slag. The overall behaviour of silicon distribution for different fluxes employed is shown in **Fig. 3** which shows that the silicon content of the weld metal decreases with the increase of basically index upto 2.5 at an appreciable rate but beyond this value the silicon

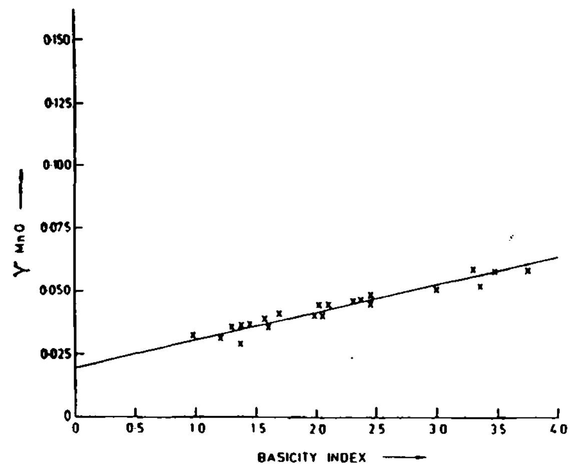

FIG. 6 : VAIRATION IN MnO ACTIVITY COEFFICIENT WITH BASICITY INDEX OF SLAG.

content of weld metal does not change noticeably. Such experimental observation suggests that the silica activity in molten flux decreases with increasing B.I. and this decrease is quite appreciable upto basicity ratio 2.0 but further increase in basicity ratio decreases silica activity at a slower rate which becomes significant beyond basicity ratio 2.5.

The relationship between equilibrium constant and temperature for silicon distribution between slag and metal under equilibrium conditions is given by Belton [1];

$$\text{Log } k = 28360/T + 10.61$$

The activity coefficient of silica has been calculated and plotted against B.I. in **Fig. 4**, where it can be seen that silica activity coefficient decreases with the increase in B.I. This relationship may be expressed mathematically as;

$$\gamma SiO_2 = 0.0136 - 0.00285 \cdot (B.I.)$$

The above relationship has, however, limited applicability with respect to the electrode wire and base plate composition and that of the flux. It is applicable to those welding runs which employ base plate and electrode wire having comparable Si content as the one employed in the present investigation. The fluxes used should be almost free of silica so that the silica activity in the molten flux is maintained in the same order as in the present case.

From the data obtained, it is found that there is a significant loss of Mn taking place during the process of welding. This loss may be attributed to two different reactions. Firstly it may be due to vaporisation at the excessively high temperature prevalent in the arc column and secondly due to oxidation of Mn by gas-metal reaction. The lower value of weld metal Mn content may also be due to low MnO activity in the slag. Effect of slag basicity index on weld metal Mn content is shown in **Fig. 5**. It is observed that the Mn content increases with the increasing basicity for almost fixed amount of MnO in the flux. The dependence of weld metal Mn content on basicity of slag may be expressed by following expression;

$$\text{wt\% } Mn = 0.056 + 0.0264 \cdot (B.I.)$$

The increase in Mn content with basicity is primarily due to the increase in the MnO activity which in turn is responsible for the increased Mn transfer to the weld metal.

The activity coefficients of MnO have been calculated for different fluxes under equilibrium conditions in the weld metal and plotted against flux basicity as shown in **Fig. 6**. The plot shows that there is a linear relationship between both the parameters and may be expressed in the following form.

$$\gamma MnO = 0.018 + 0.0113 \cdot (B.I.)$$

This relationship shows that the activity of MnO in the slag increases with the increase in basicity and thus would result in higher Mn content of the weld metal.

The loss or gain in Mn as well as Si content of the weld metal would depend upon the activity of these elements in the weld metal and the activity of their respective oxides in the slag.

CONCLUSION

From the analysis of weld metal and slag the following inferences may be drawn.

1. The oxidation/reduction reactions depend upon the chemical nature of slag systems and oxygen potential of the gaseous atmosphere in the arc region.
2. All the three elements such as C, Si and Mn have suffered significant loss during welding.
3. FeO content in the slag plays an important role in carbon-oxygen reaction at the slag-metal interface.

REFERENCES

1. Belton, G.R., et. al., "Slag Metal Reactions in Submerged Arc-Welding". Welding Journal, July 1963. pp 289-s to 297-s.
2. Davis, M.L.E. and Bailey, N.. "Properties of Submerged Arc Fluxes -A Fundamental Study". Metal Construction, April 1982, pp 202-209.
3. Davis, M.L.E. and Bailey, N., "How Submerged Arc Flux Composition Influences Elements Transfer". Proceedings of the Conference on Weldpool Chemistry and Metallurgy, the Welding Institute, London, April 1980, pp 289-310.
4. Their, H.. "Metallurgical Reactions in SAW", Proceedings of the conference on Weldpool Chemistry and Metallurgy. the Welding Institute, London. April 1980, pp 271-283.
5. Chai, C.S. and Eagar, T.W., "Slag Metal Equilibrium During Submerged Arc Welding" Metal trans., Vol. 12B, Sept. 1981, pp 539-547.
6. Tanaka, J., et. al., "Element Transfer Behaviour During SAW". Proceedings of the Conference on Weldpool Chemistry and Metallurgy, the Welding Institute, London, April 1980, pp 279-288.
7. Terashima, H. and Rsuboi, J.."Submerged Arc Flux for Low Oxygen and Hydrogen Weld Metal", Metal Construction, Dec. 1982, pp 648-654.
8. Potapov, N.N., et. al.. "Special Features of the Transfer of Alloying ELements into the Metal in Deposition Under a Fused Agglomerated Flux", Welding Production, No.3, 1974, pp 36-40.
9. Mitra, U. and Eagar, T.W., "Slag Metal Reactions During Transactions, Vol. 15A, Jan. 1984, pp 217-227.
10. Heuschkel, J., "Weld Metal Composition Control", Welding Journal, Research Supplement, Aug. 1969, pp 338-s to 347-s.
11. Tuliani, S.S., et. al., "Notch Toughness of Commercial Submerged Arc Weld Metal", Welding & Metal Fabrication, Aug. 1969. pp 327-339.
12. Lau, T., et. al., "The Sources of Oxygen and Nitrogen Contamination in Submerged Arc Welding Using CaO-Al2O3 Based Fluxes", Welding Journal, Dec. 1985, pp 343-s to 347-s.
13. Eager, T.W., "Sources of Weld Metal Oxygen Contamination During Submerged Arc Welding", Welding Journal, Marhc 1978, pp 76-s to 80-s.
14. Palm, J.H., "How Fluxes Determine The Metallurgical Properties of Submerged Arc Welds", Welding Journal, July 1972, pp358-s to 360-s.
15. Mcgannon, H.E., "The Making Shaping and Treating of Steel", U.S. Settl.