ISSUES OF FLUX COMPOSITION ON ELEMENT TRANSFER DURING SUBMERGED ARC WELDING

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Annotation: *In this article, flux data are used in submerged arc welding (SAW) to improve the stability of the arc, refining the weld metal and adding alloying elements, in order to correlate properties with the composition of the weld, it is necessary to understand the interaction between metal and flux, since it determines the degree of element transfer in weld seam.*

Key words: *Flux, welding, arc stability, metal, SAW.*

Аннотация: *В данной статье проведены данные флюсов используемые при дуговой сварке под флюсом (SAW) для повышения стабильности дуги, рафинирования металла шва и добавления легирующих элементов, для корреляции свойств с составом сварного шва необходимо понимать взаимодействие между металлом и флюсом, поскольку оно определяет степень переноса элемента в сварной шов.*

Ключевые слова: *Флюс, сварка, стабильность дуги, металл.*

Fluxes are used in submerged arc welding (SAW) to improve arc stability, to refine the weld metal and to add the alloying elements [1, 2]. Different ingredients in the flux provide different weld metal properties. The transfer of alloying elements during SAW depends on the physical and chemical properties of the fluxes. For correlating the properties with the composition of the weld it is necessary to understand the interaction between metal and flux because it will decide the extent of element transfer to the weld. To understand the mechanism of elements transfer during SAW is very difficult because the reactions involved in the weld pool and arc column are of very complex nature. The final weld metal composition in SAW depends upon the slag metal reactions, dilution, base plate composition and wire used [3]. As slag metal reactions play a major role in deciding final weld metal composition during SAW, much work is required to understand the transfer of elements from the flux [4]. As the reactions during SAW are very fast and the temperature involved is very high, it is uncertain that the equilibrium has been achieved [5]. Hence, to determine the final weld metal composition, the kinetic and chemical factors that are responsible for elements transfer must be clearly understood. When a slag is placed in contact with an iron alloy, an instantaneous equilibrium is established at the interface and FeO is formed [6, 7]. The chemical potential of the FeO is governed by the slag, metal compositions, equilibrium constant and diffusion coefficients. This chemical potential has a strong influence on weld pool chemistry. The electrochemical reactions can be more influential in metallic additions to the weld from the slag than thermochemical reactions [8, 9]. Frost et al [10] demonstrated electrochemical effect through chemical analysis of the electrode tip, detached droplets and the weld metal as a function of travel speed of the weld pool. Besides these, the concentrations of elements such as carbon, sulphur and phosphorus are higher in molten state than in the solid so that there is a tendency for these elements at the solid–liquid boundary [6]. Basicity index (BI), which is defined as the ratio of basic oxides to the acidic oxides, is commonly used as a measure of expected weld oxygen content. This BI also affects the elements transfer, as the various elements like carbon and manganese react with the available oxygen in the weld. Eagar [11] found that weld metal oxygen is reduced by increasing BI of the flux. The role of inclusions in the weld or slag is also decided by the flux constituents [12, 13]. In SAW, a molten drop after detaching from the electrode passes through high-temperature plasma and during this travel it reacts with various ions present in the plasma. The reactivity of ions with the droplet depends upon the flux composition, wire and base plate composition. After the arc has passed the high-temperature, stirring in the weld pool keeps the molten metal in intimate contact with the slag [14]. These weld pool reactions depend upon the kinetic considerations. In this study, CaF_2, FeMn and NiO additions were made to the base fluxes $CaO–SiO_2–Al_2O_3$ and their effects on the transfer of carbon, manganese, sulphur, phosphorus, nickel and silicon have been investigated. CaF_2 tends to reduce the weld metal oxygen content but this effect is supposed to be due to dilution of metal oxide rather than a direct chemical reaction [15]. CaF_2 improves de-sulphurizing and de-phosphorizing, and lowers the weld oxygen content [16]. FeMn and NiO additions increase Mn and Ni to the weld metal, which are supposed to improve the strength of the weld. The Mn and Ni promote formation of acicular ferrite, which is supposed to be good for mechanical properties [17]. Mild steel has good weldability with moderate strength, and it is the most widely used steel in fabrication and structural applications. Hence, the aim should be to improve the strength of welded structure and it should be safe against brittle fracture. In high-carbon steels the strength may be high but the chances of brittle fracture are also high. Hence, because of general, critical and versatile applications, mild steel was selected for this study. 2. Experimental procedure To investigate the effects systematically, 20 fluxes were designed using response surface methodology (RSM). The design matrix in coded form is given in table 1. The fluxes were prepared by agglomeration technique. The base constituents CaO, SiO_2 and Al_2O_3 were mixed in the ratio 7:10:2 based on ternary phase diagrams. These base fluxes were selected as these are the most widely used commercial fluxes for low-carbon steel. The role of various ingredients in the flux is given as follows. a. CaO: it is a stable oxide and it helps in removal of sulphur and phosphorus from the weld metal. It also improves impact strength of the weld metal [18]. b. SiO_2: improves viscosity of the flux in molten state. It also improves current carrying capacity of flux in molten state. The bead appearance and slag detachability are also improved by the addition of SiO_2. However, large amount of silica may result in poor mechanical properties. The additives CaF_2, FeMn and NiO were selected as control parameters and were added in varying range (2–8%). These additives were added to the base constituents to know their effects on elements C, Mn, Ni, Si, S, P and O transferred to the welds. The percentage of the additives was based on the fact that the flux constituents melt 50–70 C prior to the melting of base plate. The three levels of the aforesaid additives are shown in table 2. The composition of base plate and wire is given in table 3 and the welding parameters such as voltage, current and travel speed, which were made constant during the welding process, are given in table 4. All the components, base constituents and additives were mixed in a container and potassium silicate was used as a binder for making these fluxes. The powder of $CaCO_3$ was used in place of CaO because of its hygroscopic nature. A photograph for preparation of the fluxes has been shown in figure 1a. After preparation, the fluxes were heated in a furnace up to 400 C for more than 6 h to remove any traces of moisture. Before making the weld the fluxes were again heated up to 100 C.

Beads on plate welds using SAW were made on 18-mmthick plates. Four beads were made for each sample. Some beads on plate welds are shown in figure 1b. For making beads on plate welds, an automatic SAW machine was used. A photograph of the machine is given in figure 2a. The specifications of the machine are CPRA 800(S) ESAB India Limited. Other specifications are as follows: a. primary voltage 415 V, 3 phase 50 Hertz, b. open circuit voltage 25–55 V, Table 3. Wire and plate composition. Composition Carbon (%) Silicon (%) Manganese (%) Sulphur (%) Phosphorus (%) Nickel (%) Base plate 0.03 0.07 0.34 0.017 0.022 – Wire 0.11 0.09 0.45 0.021 0.021 – Table 4. Welding parameters. Sl. no. Voltage Current Travel speed 1 30 V 475 A 20 cm/min Figure 1. (a) Preparation of fluxes. (b) Beads on plate welds. Figure 2. (a) Submerged arc welding machine. (b) Extracted powder for chemical analysis.

Conclusions

1. BI of the flux has a direct correlation with Mn and Ni content of the weld. The manganese and nickel contents in the welds increase with increasing BI of the flux, while weld Mn is reduced with increasing CaF_2. The weld Mn content also increases with increasing NiO.

2. BI of the flux only cannot be a true measure of oxidizing power of flux.

3. Weld Mn content not only depends on its concentration in the flux but also depends on CaO present in the flux, while SiO2 content seems to be responsible for weld oxygen content as DMn increases with SiO2 in the flux.
4. Weld Si increases slightly with increase in Al2O3 in the flux, but decreases with increase in BI of the flux.
5. Weld carbon content increases with increasing BI and FeMn.
6. Basicity of flux does not show much effect on desulphurization, but weld oxygen seems to be correlated with the desulphurization.
7. Less sulphur transfer is observed in those welds that have less negative DMn (low oxygen in the weld). This can be established from table 5. The weld sulphur is increased with increase of both FeMn and NiO additives, while it is reduced with increasing CaF2 and NiO.
8. Phosphorus content removal is increased from the weld if negative DMn is large. From this it can be interpreted that weld oxygen helps in removal of phosphorus.
9. The weld Mn content and weld carbon proportion increase with dilution, while weld Ni and silicon contents decrease with dilution.

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