

Prediction of Chemical Composition of Pure Weld Metal in SAW

Y. Kim, D. H. Ryu, J. S. Kim, and B. Y. Lee

Abstract

An element of Pure Weld Metal(PWM) is important factor to understand the Flux's conduct in Submerged Arc Welding(SAW). To get the element of PWM, pile-up welding over than 10 layers have been used in the past. But, it took a long time to analyze the elements of PWM in this method. Therefore, in this study, instead of pile-up welding over than 10 layers, one pass bead welding is used to predict an element of PWM using mathematical formula which got to be derived. As a results that applied the formula, there was no differences between theoretical and experimental value except the element Mn and Si.

Key Words : Submerged Arc Welding(SAW), Flux, Slag, Dilution ration, Pile-up welding, Pure Weld Metal(PWM) .

1. Introduction

Submerged arc welding(SAW) is a process that melts and joins metals by heating them with arc established between a consumable wire electrode and the metals, with the arc being shielded by a molten slag and granular flux^{1,2}. Since the arc is literally buried (or submerged) in the flux, it is not visible. As a result, the process is relatively free of the intense radiation of heat and light typical of most open arc welding process, and the protecting and refining action of the slag helps produce clean welds in SAW. Both alloying elements and metal powders can be added to the granular flux to control the weld metal composition and increase the deposition rate, respectively.

Flux used in SAW process is divided by fused type and baked type according to making way. Also, it is divided to neutral flux, activated flux, compound

flux according to change of Mn and Si contented to pure weld metal (PWM) by change of arc length while welding³.

It is difficult to manufacture a flux because mechanical characteristic and weld bead shape are showed differently depend on flux type. Therefore, various study findings is need for development of superior flux and effective selection, but has been not established the flux behavior yet. IWE reference⁴ is presented that pile-up welding over than 10 layers need to obtain PWM. However, it took a long time in order to get the PWM composition through pile-up welding over 10 layers. Therefore, instead of the method, mathematical formula were derived. It became to calculate PWM composition using composition of weld metal (WM), base metal (BM) and dilution ratio in one pass bead welding.

Main purpose of this study is to compare pile-up welding with bead welding for the PWM composition. The comparison of experimental method with mathematical formula shows the accuracy and validity of the proposed method. These results are graphed for chemical composition.

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2. Theoretical background

2.1 Metallurgical welding process of SAW

Chemical composition of PWM during welding is decided by base metal (BM), wire and flux. as shown in Fig. 1. At SAW process, metallurgical reaction between droplet and flux, droplet and BM, BM and slag are sequentially happened^{5,6)}. After the metallurgical reaction is gone, WM and slag is remained finally. Slag is removed after welding ends.

Though chemical reaction of slag is existed at SAW process, but suppose that reaction of slag is slight, so that slag reaction was not considered in this study.

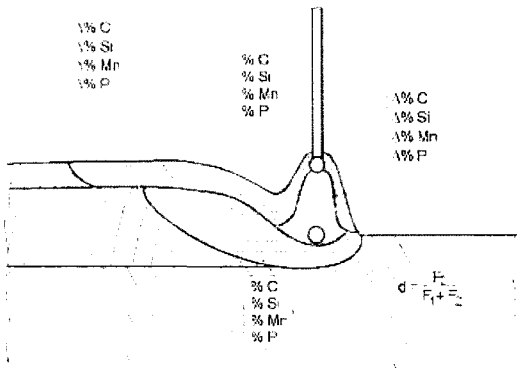


Fig. 1 Metallurgical model of SAW

2.2 Mathematical derivation of PWM

PWM means a state that is no effect from base metal in terms of metallurgical. In the past, pile-up welding was carried out to get the chemical composition of PWM at the SAW process, as shown in Fig. 2. Usually, pile-up welding more than 10 layers has to be carried out to obtain the chemical composition of PWM. A reason that it carry out the pile-up welding over than 10 layers in order to get PWM is can be explained by definition of dilution ratio. In general, dilution ratio D, expressed as a percentage, is defined as^{1,7)}

$$D = \frac{\text{Weight of parent metals melted}}{\text{Total weight of fused metal}} \times 100$$

The possible value of the dilution are between 0 and 1 i.e. 0% and 100%. Therefore the more far from base metal, the less influence of base metal composition. When expressed Fig. 2 with Fig 3 briefly, metallurgical reaction of between layer was expressed from the following equation (1).

$$\begin{aligned} X_{WM1} &= X_{BM} \cdot D + (X_{wire} + \Delta R)(1 - D) \\ X_{WM2} &= X_{BM} \cdot D^2 + (X_{wire} + \Delta R)(1 - D^2) \\ &\vdots \\ X_{WMn} &= X_{BM} \cdot D^n + (X_{wire} + \Delta R)(1 - D^n) \end{aligned} \quad (1)$$

Where, D is the mean dilution ratio for the base metal, X_{WMx} ($1 \leq x \leq n$) is chemical composition of PWM, X_{BM} is chemical composition of BM, and $X_{wire} + \Delta R$ is the mean the reaction between wire and slag during welding process. This equation can be proved by the mathematical method complete induction. For this propose, the equation is assumed to be correct for n runs and it is proved to be correct also for $n+1$. The pure weld metal is scientifically reached by welding an infinite number of runs. The term D_n is zero for an infinite number of n .

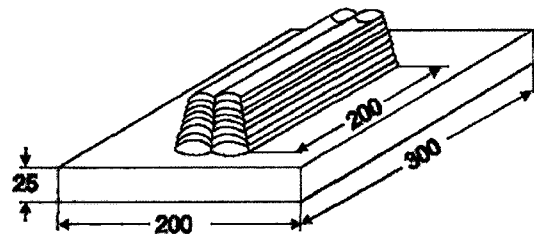


Fig. 2 Schematics of the PWM test piece

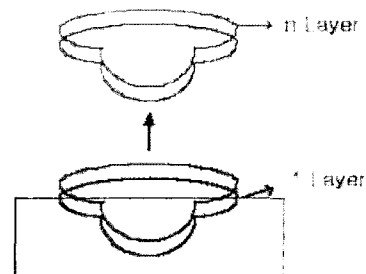


Fig. 3 Theoretical process about pile-up welding

$$X_{PWM} = \lim_{n \rightarrow \infty} (X_{WMn}) = (X_{wire} + \Delta R) \quad (2)$$

Therefore, substituting equation (2) into equation (1), the following equation (3) is obtained.

$$X_{WMn} = X_{BM} \cdot D + X_{PWM} \cdot (1 - D) \quad (3)$$

Rearranging equation (3) in terms of X_{PWM} , we can obtain the following equation (4).

$$X_{PWM} = \frac{X_{WMn} - X_{BM} \cdot D}{1 - D} \quad (4)$$

Now, instead of pile-up welding over than 10 layers to get the PWM, it is possible to obtain the composition of PWM theoretically just one pass welding using equation (4).

Table 1 Chemical Composition of Base Metal

C	Si	Mn	P	S	Cu	Mo
0.156	0.387	1.365	0.010	0.011	0.024	0.024

Table 2 Chemical Composition of Wire

C	Si	Mn	P	S	Cu	Mo
0.075	0.005	1.850	0.011	0.007	0.010	0.054

Table 3 Chemical Composition of Flux A

FeO	MnO	TiO ₂	CaO	SiO ₂
4.5	4.0	7.5	0.0	15.0
Al ₂ O ₃	MgO	CaF ₂	BI	
40.5	9.0	11.0	0.62	

Table 4 Chemical Composition of Flux B

FeO	MnO	TiO ₂	CaO	SiO ₂
3.5	1.0	26.0	7.5	26.5
Al ₂ O ₃	MgO	CaF ₂	BI	
23.0	4.0	0.0	0.27	

3. Material and experimental procedure

SM 490 steel was used for the present study of SAW. Thickness of base metal was 20mm, and wire diameter was 4mm. Chemical composition of the base metal and wire are shown in Table 1 and Table 2, respectively. Because any change of the flux probably will affect also the metallurgical reactions of different elements, two kinds of fluxes are used in this study and chemical composition of the each kind of flux are shown in Table 3. and Table 4., respectively. In order to pile-up welding, carried out under welding conditions of 650A current, 34V voltage, 45cm/min speed and 29.5J/cm heat input.



Fig. 4 Box type weld (12 layers 72 passes)



Fig. 5 Stair type welding (12 layers)

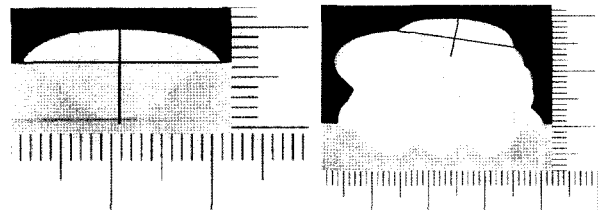


Fig. 6 Location of Chemical analysis

To get accurate result, two kinds of pile-up welding method were applied. At first according to reference, box type welded 12 layers 72 passes were carried out as shown in Fig 4. Secondly, to confirm the chemical composition under 10 layers, stair type welding is carried out as shown in Fig 5.

After welding, specimen were macro etched with 10% of Nital solution and chemical composition were analyzed using energy dispersive spectroscopy (EDS) and electron probe micro analyzer (EPMA) on the position of '+' mark as shown in Fig 6. In bead welding, dilution ratio was also calculated with Image Analyzer.

4. Results and discussion

It was compared the EDS analysis results about specimen welded 12 layers pile-upwelding using Flux A with the theoretical value of chemical composition

of PWM using equation (4), as shown in Fig 7. There was no difference between theoretical value and EDS analysis results except the element of Mn in Fig 7. Fig.8 show the analyzed results of EDS and EPMA for 6 layer, 9 layer and 12 layer, respectively. That is also fitted with the theoretical value of chemical composition of PWM using equation (4) except the value of Mn.

In order to confirm the affect of a flux, it is welded with Flux B under the same welding condition and the chemical composition of PWM were analyzed. Fig. 9 shows the result of theoretical and experimental value about chemical composition of PWM. In Fig. 9, there was no difference between theoretical and experimental value except the elements of Mn, Si and P same as Fig 7.

Fig 10. is a graph that indicated the comparison of theoretical PWM and EPMA analysis results of weld metal on 12 layer. In Fig. 10, element of P which showed

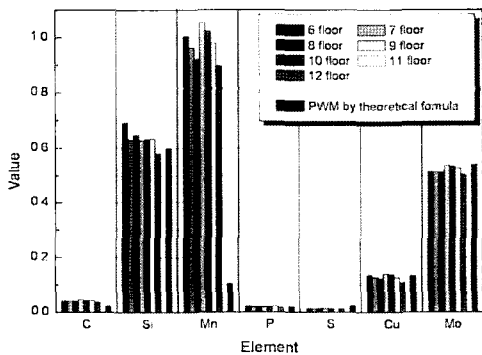


Fig. 7 Comparison of EDS & Theoretical Value about welded Flux A

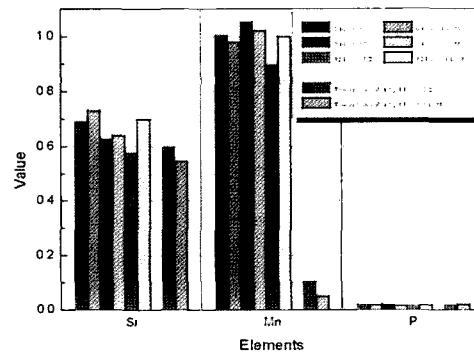


Fig. 8 Comparison of EDS & EPMA about welded Flux A

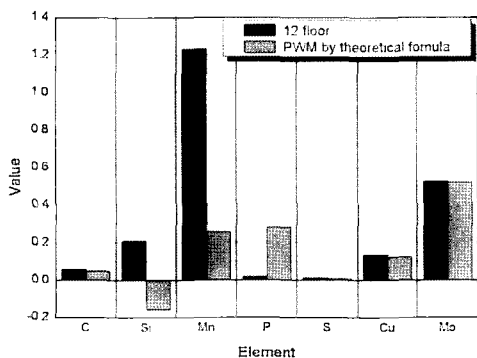


Fig. 9 Comparison of EDS & Theoretical Value about welded Flux B

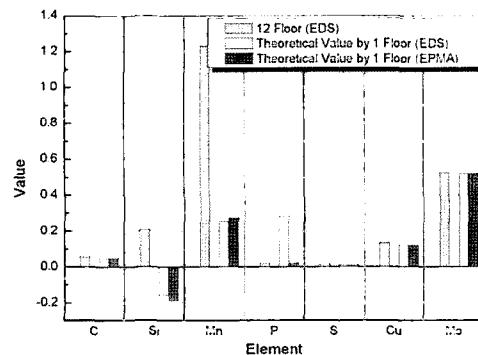


Fig. 10 Comparison of EDS & EPMA about welded Flux B

the difference in Fig 9. is fitted with the theoretical value. However, in case of Mn and Si, theoretical and experimental value were represented much differences same as the specimen welded by Flux A. The reason of the difference between theoretical and experimental value is that Metal-Slag reaction is existed while fused wire is solidifying with melted base metal into the weld metal. Therefore theoretical formula should be modified to predict a chemical composition of PWM.

5. Conclusion

To obtain the elements of pure weld metal, pile-up welding over 10 layers have used in the past, but it spent a long time to get the result if pile-up welding was carried out. In this study, instead of the conventional method, mathematical formula was derived as follows.

$$X_{PWM} = (X_{WM} - X_{BM}) / (1 - D)$$

As a results that applied the formula, there was no difference between theoretical and experimental value except the element Mn and Si. If using this formula, Chemical composition of the pure weld metal can be predicted by just one pass bead welding. But metal-slag reaction was not considered in the formula, so that it should be modified to get a data exactly in the future.

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