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Effect of Various Flux Compositions Mixed With Slag on Mechanical Properties of Structural Steel Weld Using Submerged ARC Welding

Amit Gupta[1]*, Pawan Kumar Sapra[2], Naveen Singla[1] and Gora Ram[3]

[1]*ME Department, GZS PTU Campus, Bathinda, Punjab - 151 001, India*

[2]*ME Department, AIT, Gharuan, SAS Nagar, Punjab - 140 413, India*

[3]*ME Department, BMSCE, Sri Muktsar Sahib, Punjab - 152 026, India*

Email: amit4u1984@gmail.com

Abstract **– Submerged arc welding (SAW) is a process in which welding joint is obtained by heating the metal with an arc set between bare electrode and work piece. Intense heat produced during the process fuses the metal and filler metal. Flux is used as a shielding agent which is placed over the welding area to protect the molten pool from atmospheric contamination. It also shields the spatter of arc. This flux gets converted into slag after solidification at the surface of welding metal. The wastage of flux in the form of slag increases the cost of process. In the present study different flux and slag compositions are used to analyse the effect of slag/flux mixture on mechanical properties of submerged arc welded joint performed on mild steel plates. Present work is an attempt to utilize this slag as flux and reduce the cost of SAW welding process. For the investigation three agglomerated flux compositions are prepared and slag is mixed in these compositions in percentage of 10, 20, and 30 respectively. The various tests such as tensile test, impact test, microhardness test, microstructure test were performed on the welded specimens, to study the mechanical behaviour of structural steel. It is found that the mechanical properties of the welded joint by mixing slag in all three flux compositions are significant according to AWS requirement.**

Keywords: **Submerged arc welding, Flux composition, Slag**

I. Introduction

Submerged arc welding (SAW) is a process in which welding joint is obtained by heating the metal with an arc set between bare electrode and work piece. Intense heat produced during the process fuses the metal and filler metal [1].

Flux is used as a shielding agent which is placed over the welding area to protect the molten pool from atmospheric contamination. It also shields the spatter of arc. The molten slag also provides favourable conditions for very high current densities, which together with the insulating properties of the flux; concentrate intense heat into a relatively small welding zone. This result in a deeply penetrating arc, which makes narrower and shallower welding grooves practicable, thus reducing the amount of weld metal, required to complete the joint. It also results in higher welding speeds. The properties of the flux enable submerged arc weld-to be made over a wide range of welding currents, voltage and speeds, each of which can be controlled independently of the other. Thus one can obtain welded joints of desired shape, chemistry and mechanical and metallurgical properties by using an appropriate welding procedure [2].

Flux is mainly of two types depending upon the method of manufacturing i.e. fused flux and agglomerated flux. Agglomerated fluxes produce weld deposits of better ductility, alloy transfer efficiency and impact strength as compared with fused fluxes. These fluxes are hygroscopic in nature, therefore baking is essential for good weld metal integrity [3].

This flux gets converted into slag after solidification at the surface of welding metal. It is removed with the help of hammer and treated as a waste material. Large quantity of flux that becomes slag after welding & it has to be disposed-off. Land-fill space is required to dump the slag waste. It is non bio-degradable and will not decay with time. Disposal cost will increase apart from environment pollution. Non renewable resources may get exhausted due to continuous mining. It is not possible to stop the generation of slag because it is a by-product of the process but slag can be reused as a flux in the same submerged arc process again [4-6].

Datta *et al.* [7] have performed optimization to determine the amount of waste slag and flux mixture that can be used without sacrificing any negative effect on bead geometry, compared to conventional SAW process, which consumes fresh flux only.

The motive of this work is to check the application feasibility of recycled slag in the form of a mixture consisting fresh flux and fused slag. The influence of using slag mix on weld has been investigated. Fused slag was crushed and sieved to grain size of original fresh flux and mixed mechanically with fresh flux in different proportions and mechanical properties like tensile strength, impact strength, microhardness and microstructure are analyzed.

II. Experimental Procedure

The experimental procedure consists of following steps:

1. Development of flux compositions.
2. Collection of slag.
3. Mixing of slag in flux
4. Welding with fresh flux
5. Welding with slag/flux mixture
6. Comparison of mechanical properties of weld obtained using fresh flux and mixture of slag/flux.

A. Development of Flux

Three flux compositions as shown in Table I are developed by mixing various ingredients on the basis of basic index. Basic index is the ratio of basic oxides in the composition to the acidic oxides in the composition by weight. For the preparation of flux, different compounds viz., CaF_2, CaO, Na_2O, MnO, SiO_2, Al_2O_3, MgO, TiO_2, FeO are used [8]. The compounds received in powder form and mixed together (manually) with binder (Sodium Silicate) in different weight percentages to prepare the required type of flux. The flux ingredients are weighed and wet mixed for 10 minutes and then passed through a 10 mesh screen to form small pallets. Sodium silicate is added as binder because of better arc stability. The pellets of the flux are dried in air for 24 hours and then bakes in the muffle furnace between 650-700˚C for nearly three hours. After cooling, these pallets are crushed and subsequently sieved. After sieving, fluxes are kept in air tight bags and baked again at 300˚C before welding [9-10].

Table 1 Flux Compositions

S.No.	Ingredients	A	B	C
1	CaF2	8	11	14
2	CaO	10	12	14
3	SiO2	5	10	15
4	MnO	5	5	5
5	TiO2	20	15	10
6	FeO	5	6	7
7	Al2O3	20	15	10
8	MgO	7	6	5
9	Sodium Silicate	20	20	20
10	Total	100	100	100
	basic index	1.2	1.3	1.5

B. Collection of Slag

For experimental work slag has been collected from Mukat pipes limited Rajpura, Punjab. It is one of the leading manufacturers of large cross-section pipes in Punjab. Slag was collected from their dump yard. Slag is being thrown away as wastage there.

C. Mixing of Slag

Slag collected is crushed and sieved in the required size. It is then properly mixed with each flux in percentage of 10, 20, and 30 respectively. The different samples are prepared as shown in sample matrix Table II.

Table II Sample Matrix

Sample no	Flux	Slag %age (by weight)
C1	A	0
C2	A	10
C3	A	20
C4	A	30
C5	B	0
C6	B	10
C7	B	20
C8	B	30
C9	C	0
C10	C	10
C11	C	20
C12	C	30

D. Welding With Fresh Flux

Three samples are prepared by using fresh flux compositions. The welding is done on mild steel plates of size 14x75x250 mm. The weld bead was deposited using a 3.2 mm diameter EL-8 wire. The welding parameters of the SAW machine were kept as shown in Table III. The chemical composition of electrode and base plate used is as shown in Table IV.

Table III Process Parameters

Current (A)	Voltage (V)	Travelling Speed (m/h)
250	25	28

Table IV Chemical Composition of Base Plate and Electrode Wire

%age	C	Si	Mn	S	P
Base plate	0.17	0.19	0.51	0.02	0.04
Electrode	0.5	0.1	0.02	0.01	0.09

E. Welding With Slag/Flux Mixture

With similar size of base plate 9 more samples are prepared using flux composition mixed with slag. Slag is mixed in 10, 20, and 30% by weight in flux composition. Submerged arc welding is done firstly with fresh flux compositions A, B and C and after that slag is mixed in these compositions as per design conditions.

III. Results and Discussion

A. Microstructure

It is observed from the micrographs that specimen welded using flux C has the finest structure whereas specimen with flux A has coarse structure. It can be seen that the addition of slag in a given flux makes the structure coarse. Moreover as the percentage of slag in a given flux increases, more coarse structure is obtained.

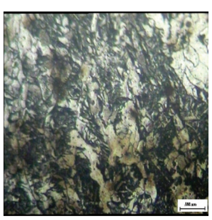

Fig 1(a) C1

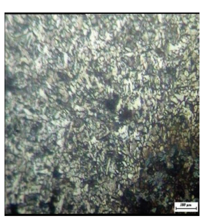

Fig 1(b) C2

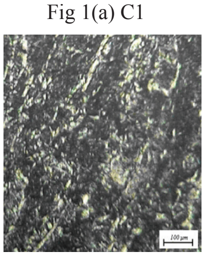

Fig 1(c) C3

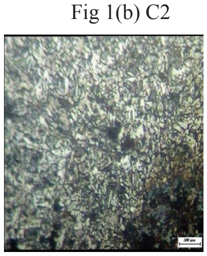

Fig 1(d) C4

B. Tensile Strength

The Table V and Fig.2, Fig.3, Fig.4 and Fig.5 show the variation in tensile strength of specimens prepared by using flux composition mixed with slag. As it is clear from the graph that tensile strength decreases with increase in basic index. As well tensile strength also decreases with addition of slag. Increase in the value of Rutile i.e. TiO_2 increases the ultimate tensile strength. As the value of TiO_2 is maximum in flux C thus tensile strength of Flux C is higher.

Table V Tensile Strength Observations

Slag% age \ Flux	A	B	C
0	479	511	585
10	447	456	541
20	394	418	511
30	372	368	490

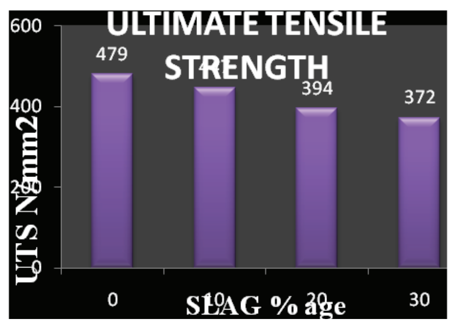

Fig. 2 effect of slag %age on tensile strength of weld prepared using flux A

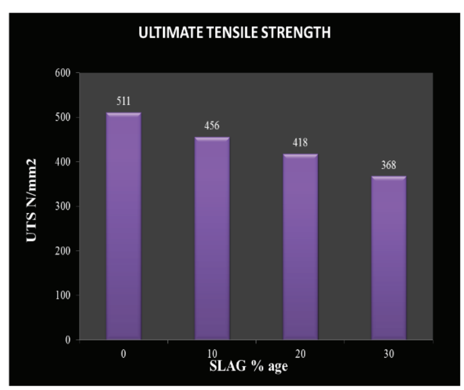

Fig.3 Effect of slag %age on tensile strength of weld prepared using flux B

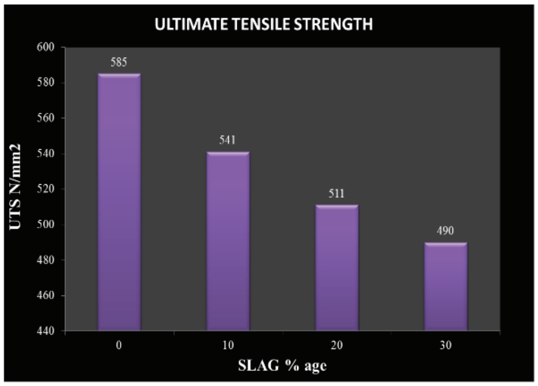

Fig.4 Effect of slag %age on tensile strength of weld prepared by using flux C

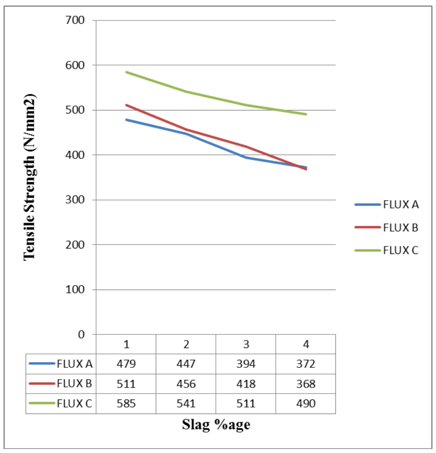

Fig. 5 Effect of slag %age on tensile strength of weld prepared using flux A, B and C

C. Microhardness

Table VI Average Microhardness Observations

Slag% age \ Flux	A	B	C
0	173	220	232
10	159	186	192
20	142	162	174
30	126	143	153

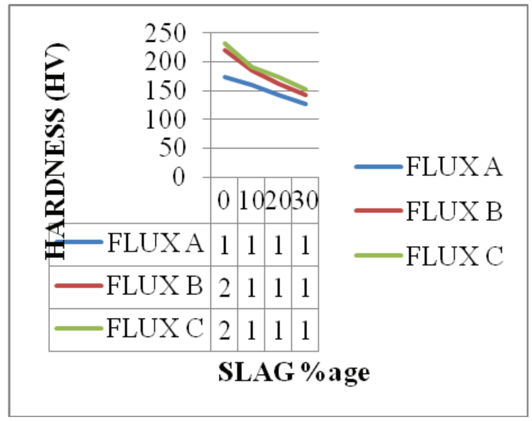

Fig. 5 Effect of slag %age on hardness of weld prepared by using flux A, B and C

It was observed that as flux basicity increases, the micro hardness of welded deposit decreases, probably due to the decrease of C and Si. Further addition of slag also decreases the hardness. It is seen that with addition of slag there is sharp decrease in hardness as compared to specimen with no slag. Moreover with increase in percentage of slag, the hardness decreases at slow rate. Hence it is concluded that presence of slag in flux, decreases the hardness of prepared specimens.

D. Impact Strength

It is clear from the graph that impact strength in case of flux A is greater than flux B and flux C with no addition of slag; it is due to high %age of fluorspar CaF_2 as it increases the toughness strength of joint. Also increase amount of ferromanganese reduces the amount of oxygen in weld pool. It is seen that with increase %age of slag impact strength decreases in all flux compositions but in flux B impact strength decreases more rapidly.

Table VII Average Impact Strength Observations

Slag% age \ Flux	A	B	C
0	69.7	58.8	49.4
10	60.2	47.4	38.4
20	49.4	32.9	27.3
30	38.4	21.6	15.8

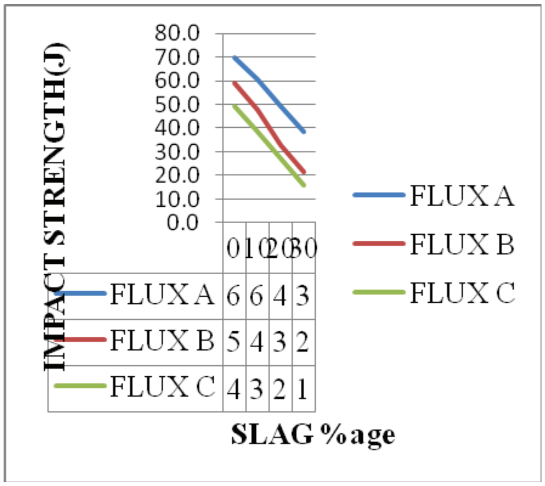

Fig. 6 Effect of slag %age on average impact strength of weld prepared by using flux A, B and C

IV. Conclusions

Ultimate tensile strength decreases with increase in basicity index. The value of Rutile i.e. TiO2 increases the ultimate tensile strength. Increases amount of CaF2 increases the impact strength of weld joint. Also increase amount of ferromanganese reduces the amount of oxygen in weld pool. Hardness of specimen decreases with increase in basicity index. The micro hardness of welded deposit decreases, probably due to the decrease of C and Si. Coarse micro structure is observed with addition of slag. Addition of slag decrease tensile strength, hardness and impact strength of welded joint made by submerged arc welding.

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