Reuse of Slag as Flux in Submerged arc Welding & its Effect on Chemical Composition, Bead Geometry & Microstructure of the Weld Metal

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Abstract—*Slag generated during submerged arc welding (SAW) is normally thrown away as a waste. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaust of non-renewable resources. Reusing of slag will not only solve these problems but also be economical. In the present work an attempt has been made to use the submerged arc welding slag as flux in the same submerged arc welding process. Fused slag was crushed to the desired particle size as that of the original flux. The properties of weld metal deposited using reused slag & fresh flux were evaluated & compared. It was found that the weld metal obtained using reused slag showed negligible changes in terms of physical appearance, bead geometry & microstructure. However significant change was observed in the chemistry of weld metal obtained using reused flux. It can be concluded that although recycled slag can not be used for critical applications and the applications where AWS code requirement is important, however it can be used for general non critical applications where strict compliance of AWS code is not a critical issue.*

Keywords: *SAW slag, recycling of slag, reuse of slag*

Introduction

Submerged arc welding is a versatile welding process in which coalescence is produced by heating the metal with an arc maintained between a bare metal electrode and the workpiece. The arc is shielded by a blanket of granular fusible material known as flux placed over the welding area. Filler metal is obtained from the electrode and sometimes a supplementary welding rod or metallic addition. Flux contributes a major part towards welding cost in submerged arc welding. The Flux is converted into slag during welding which is treated as waste and discarded.

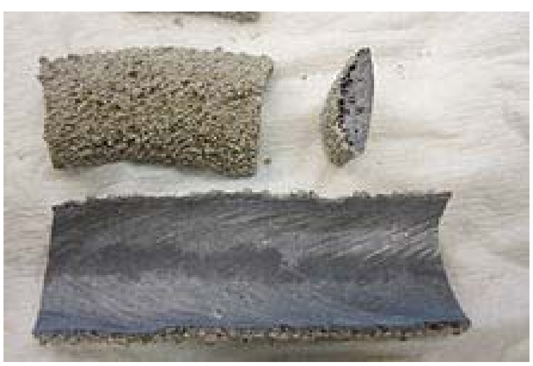


Fig. 1: Submerged Arc Welding Slag

About 2500 tonnes of flux was consumed in India alone in year of 1982 [1] which has risen to 10000 tonnes in the year of 2006 [2]. Such a 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. The first attempt of recycling the slag was made by Alfred Beck in 1959 [3]. He used closed loop recycling process and started practicing this in 1963. After that the Paton electric welding institute of the national academy of science in Ukraine also reported the development of a technology for recycling of slag [4].Reuse of slag can not only minimize the above problems, but can also save non-renewable mineral resources.

The slag is normally reused after its processing & recycling so as to reclaim its original characteristics. However this requires a considerable amount of effort and money to be spent on it. However if this slag is reused as flux again only after crushing it to the normal particle size of the original slag without any new additions/processing, the cost of reuse of this slag will be quite low. However the quality of weld/clad metal obtained using this reused slag needs to be analyzed before recommending its reuse. The preset study aims at exploring the possibility of reused of the crushed slag as flux & effects of use this flux on the chemical composition and weld bead characteristics of the welds/clads obtained using this flux.

Experimental Procedure

For carrying out this study, experimental procedure consisting of the following steps was followed:

- Collection of slag from industry.
- Crushing and sieving of slag.
- Welding with crushed slag.

- Welding with fresh flux.
- Comparison of weld metal composition, bead geometry and microstructure of the weld metal obtained using fresh flux & crushed slag.

Collection

The slag was collected from the dump yard of Mukat Pipes Ltd. Rajpura, Punjab, an industry engaged in production of large diameter cross country pipes using SAW process. This slag was generated during the SAW welding process using F7AZ flux & EL8 filler wire. This slag was collected free of cost.

Crushing and Sieving

The above slag was crushed using a crusher to convert it into reusable granular flux. Crushed mass was then sieved so that the grains of the reusable flux(slag) should confirm to the particle size of the original flux (10 mesh sieves).

Welding with Crushed Slag

The crushed & sieved slag obtained above is then used to produce a bead on mild steel plate as shown in Fig. 2. The size of the base plates was kept to be 12×75×250 mm. The weld bead was deposited using a 3.2mm diameter EL-8 wire electrode in combination with crushed slag. A constant potential transformer-rectifier type power source with a current capacity of 600 amperes at 60% duty cycle and an open circuit voltage of 12-48 volts was used. Reverse polarity with electrode positive was used during welding. The welding parameters of the SAW machine were kept as shown in Table 1. These welding parameters were selected after extensive trial runs, so that a defect free weld bead is obtained. The chemical composition of electrode and base plate used is as shown in Table 2.

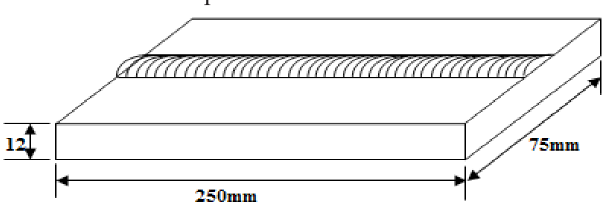


Fig. 2: Mild Steel Used to Carry out Welding

Table 1: Welding Parameter Used for Experimentation

Parameter	Units	Symbol	Value
Open circuit voltage	volts	V	30
Current	ampere	I	315
Travel speed	m/min	S	0.667
Nozel to plate distance	mm	N	24

Table 2: Chemical Composition of the Electrode Wire and Base Metal

% age	C	Mn	Si	S	P
Electrode	0.069	0.48	0.02	0.02	0.018
Base-plate	0.165	0.4	0.17	0.05	0.046

Welding With Fresh Flux

A weld bead on a similar plate as shown in Fig. 2 was prepared with original fresh flux (F7AZ) in combination with EL-8 filler wire maintaining the same welding parameters as were used in case of preparing the weld using crushed slag. This wire-flux combination was selected as the slag collected from the industry for reuse, had been generated using the same wire-flux combination

Comparison of Weld Metal Composition

Weld samples of appropriate length were removed from the middle of weld plates as shown in Fig. 3.

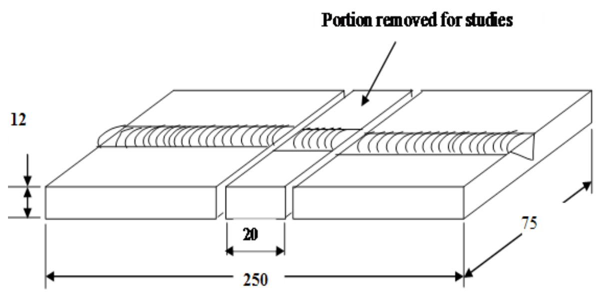


Fig. 3: Removal of Samples for from the Work-Piece

The samples thus removed from the work-pieces were subjected to the following tests/studies:

- Physical appearance
- Spectroscopic analysis to find out the chemistry of the weld metal.
- Study of weld bead profile.
- Study of the microstructure of the weld metal.
- The results of these tests/studies have been presented in the next section.

Results and Discussion

Physical Appearance

It was observed that the arc stability & slag detachability were acceptable while working with reused slag.

The surface appearance of the weld obtained using reused slag was good with no visual defects as can be seen on weld beads.

Chemistry of Weld Metal

Chemical composition of weld beads on plates with original flux and slag is shown in Table 3. & a graphical analysis of the same is given in Fig. 5.

It can be seen that there is significant decrease in the %age of Carbon (C), Silicon (Si), Sulphur (S) and Phosphorus (P) in the weld metal for the work piece prepared using reused slag, as compared to the %age of same elements in the weld metal deposited using fresh flux under the similar welding conditions. However there is an increase in the %age of Mn in case of reused slag than that in case of fresh flux.

It can be interpreted that since there were no deoxidizers available in the reused slag, which have already been exhausted during its first use, excessive oxygen might be present in the weld pool as a result of which the elements like C, Si, P & S might have been lost by oxidation. However the weld metal chemistry obtained is acceptable for general purpose applications.

Table 3: Comparison of Chemistry of the Weld Metal

%age	C	Mn	Si	S	P
With fresh flux	0.357	0.325	0.188	0.0485	0.0489
With reused slag	0.180	0.431	0.107	0.0274	0.0288

Bead Geometry

Bead geometry of both specimens were inspected to detect bead width (W), penetration(P) and reinforcement(R). The cross section of both the specimens after grinding is shown in Fig. 4 (a) & (b). The values of W, P & R obtained for the two pieces have been shown in the table 4 given below & its graphical comparison is presented in Fig. 6.

Fig. 4(a): Weld with Crushed Slag

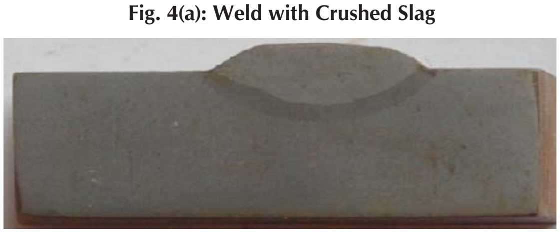


Fig. 4(b): Weld with Fresh Flux

Table 4: Geometry of the Weld Bead of the Specimens

in mm	W	R	P
Weld with crushed slag	11.78	3.18	2.58
Weld with fresh flux	12.5	2.78	2.98

It can be seen that there is negligible variation in weld bead parameters for the two specimens. It shows that the reuse of slag as flux do not affect the bead geometry to a significant extent.

After this preliminary investigation about feasibility of reuse of crushed slag as flux in submerged arc welding, a detailed investigation of the effect of welding parameters on the bead geometry, using crushed slag, was carried out using fractional factorial design approach.

Microstructure

Mechanical properties depend on the microstructure of weld metal. Representative weld bead microstructures produced using crushed slag, fresh flux are shown in Figures 7 & 8.

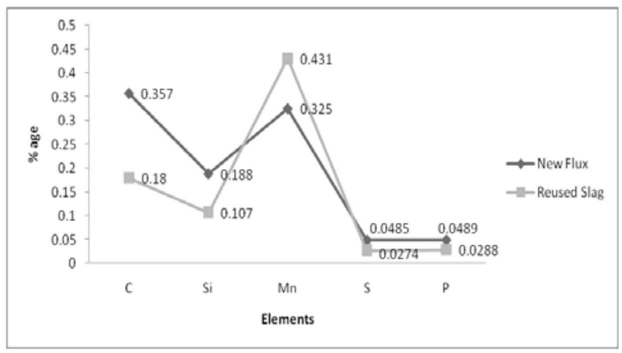


Fig. 5: Comparison of Chemistry of Weld Metal Deposited using New (Fresh) Flux and Reused (Crushed) Slag

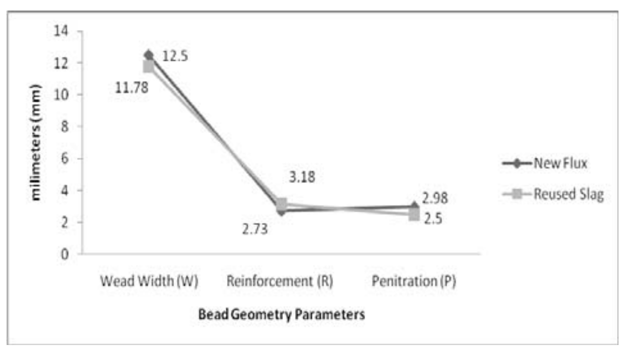
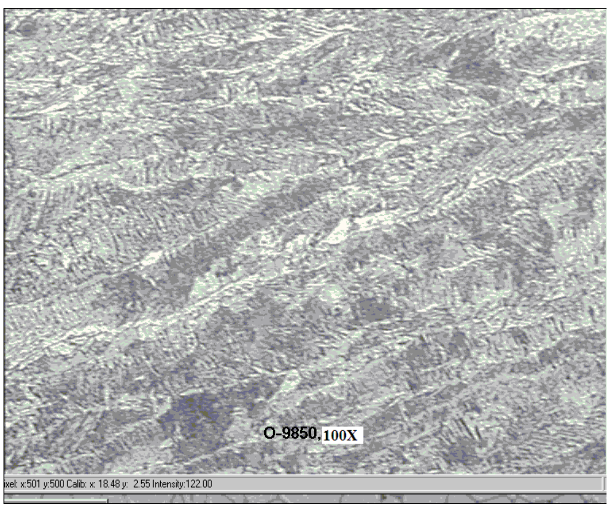


Fig. 6: Comparison of Geometry of the Weld Bead using New (Fresh) Flux and Reused (Crushed) Slag

Microstructure in both cases consists of ferrite and pearlier grains in the parent metal and towards weld bead columnar grains were evidenced. It shows that the use of reused slag do not produce any significant change in the microstructure of the weld metal.

AF- Acicular Ferrite, PF- Polygonal Ferrite, GBF- Grain Boundary Ferrite.

Fig. 7: Microstructure of Weld Metal Deposited with Crushed Slag (100X)



AF- Acicular Ferrite, PF- Polygonal Ferrite, GBF- Grain Boundary Ferrite

Fig. 8: Microstructure of Weld Metal Deposited with Fresh Flux

Cost Savings

The SAW slag is normally treated as waste & is hence discarded. It is available free of cost. Its reuse as flux only requires that it is proper collection, crushed & sieved to the desired particle size. The cost of this collection & processing is very nominal & that too can be offset by the cost that is otherwise incurred in handling & dumping of this slag as a waste product. So effectively reuse of slag in this manner can result in almost 100% savings in the cost of new flux.

Conclusion

From the above study the following conclusion may be drawn:

- Arc stability and slag detachability were acceptable, with the crushed slag.
- There is a loss of majority of alloying elements from the weld metal using reused slag. Which can attributed to the presence of insufficient amount deoxidizing agents in the reused flux/ slag.
- Reused slag does not produce significant changes in the weld bead geometry & microstructure of the weld metal.
- Submerged arc welding slag can be reused as welding flux after cursing & sieving to original particle size, for general purpose applications where the jobs are not much critical and AWS requirements are not mandatory and crucial.

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