Reclaiming of Submerged Arc Welding Slag: Comparison between SAW processes with and without slag-mix

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ABSTRACT

Slag formed during SAW process has been collected and processed for using further in subsequent runs of Submerged Arc Welding of mild steel material. The mixture of fused flux (slag) and fresh flux has been used as an alternative of fresh flux. The percentage (by volume) of slag in the mixture of fused flux and fresh flux has been termed as slag-mix%. The aim is to observe whether any noticeable adverse effect on the features of the weldment including bead geometry, hardness of the weld metal and HAZ, tensile strength of the welded joint etc. occurs while consuming increasing percentage of slag-mix in SAW process. The present investigation leads to the idea that reconsumption of slag in SAW process does not impose any alarming adverse effect on parameters of the desired weld quality. Therefore, this technique could be recommended in practical applications to yield 'Waste to Wealth'.

Keywords: SAW, slag-mix, HAZ

INTRODUCTION:

Slag produced due to fusion of the portion of the granular flux used during Submerged Arc Welding, is not reused. It is discarded. The possibility of reuse of slag and the results thereof is a new field of research. Rare or only very few investigations have been carried out in this encouraging field of Submerged Arc Welding.

Eagar, T. W. (1980) investigated on reprocessing and reuse of the fused slag as means of reducing costs of Submerged Arc Welding of titanium. In general it was found that the cost of titanium Submerged Arc Welding did not compare favorably with the costs of alternate process such as gas metal arc welding of titanium. The author also outlined the advantages and disadvantages of flux shielded welding of titanium.

Beck, H. P. and Jackson, A. R. (1996) concluded that according to code requirement, the properly processed slag could be reliable and could be used as an alternative for new flux. They further claimed a saving of 50% of the procured flux by recycled flux. Research related to slag reconsumption in conventional SAW process has been carried out by Moi, S. C. et al. (2001), and Pal, P. K. et al. (2001) Their study introduced the concept of using slag-mix% as a process variable. The percentage of slag, in the mixture of fused flux and fresh flux, has been denoted as slag-mix%. The main effects of using slag-mix and interactive effects of process parameters (including slag-mix%) on features of bead geometry and HAZ, in terms of bead height, depth of penetration, bead width and HAZ width have been evaluated through Analysis of Variance (ANOVA) method. But their work did not provide the optimal factor combination to yield acceptable weldment and the maximum slag-mix% that can be used during SAW process without adversely affecting bead geometry as well as HAZ dimensions. They, however, carried out Microstrutural studies for comparing the results of conventional SAW and SAW with a mixture of fresh flux and fused slag. Motivated by their concept, Sing, K. et al. (2005) investigated to see the effect of recycled slag on bead geometry in Submerged Arc Welding. The slag was processed by replenishing with suitable alloying elements/deoxidizers and then converted into new flux called as recycled flux. Recycled flux was used to study the effect of welding parameters on bead geometry and shape relationships. Mathematical models were developed using a two level half factorial technique to predict weld bead geometry and shape relationships.

As a continuation of the study, Sing, K. et al. (2006) recycled fused slag by replenishing it with suitable alloying elements and deoxidizers and by agglomeration. They carried out experiments with this modified recycled flux. The performances of the weldment were checked by chemical analysis, radiography, mechanical and metallurgical tests. They observed favorable results.

Research related to slag recycling and subsequently reuse in Submerged Arc Welding is not rich. Very few weld researchers have been so far attracted in this field. But the scope of work is vast and bright. It is significantly important as well. If it can be experimentally proved that use of slag (mixed with fresh flux) can be consumed instead of fresh flux only, without producing any harmful adverse effects on various quality aspects of the weldment, then this technique can be adopted in practical field, on commercial basis in the fitted applications. Additionally, it is always important and useful to reduce waste and to move towards 'Waste to Wealth', or finally approaching towards 'Zero Waste Concept'.

Thus in the present work, experiments have been carried out by doing Submerged Arc Welding on mild steel plates, using fused slag, mixed with fresh flux, in various proportions. The objective is to analyze the effect of slag-mix percentage on bead width, penetration depth, HAZ width and other relevant bead geometry parameters under constant settings of voltage (OCV), wire feed rate, traverse speed and electrode stick out.

Table 1. Experimental runs for bead-on-plate welding

Observation No.	Sample No.	Slag-mix%
1	O	0 (Fresh flux)
2	A	10
3	B	20
4	C	40
5	D	60
6	E	80
7	F	100

Besides experimenting with bead-on-plate welding, butt joints have been made using both conventional and non-conventional Submerged Arc Welding. The objective is to study the weld quality- i.e. tensile strength of the welded joint; in terms of maximum load carrying capacity. The feasibility of the use of fused slag, mixed with fresh flux, can thus be determined and assessed from the results and analysis of the experimental data.

To comply with the objective of the present work, consideration has also been made to study mechanical characteristics of the weldment- both in conventional SAW and SAW with a mixture of fresh flux and fused slag. The purpose is to evaluate the new process (i.e. SAW using slag-mix) in connection with application feasibility of the process. One of the motives in the present work is to move towards the idea of 'Zero Waste Concept', such that fused slag be reused instead of being discarded and disposed off as waste.

EXPERIMENTATION

Bead-on-plate welding

In this set of experiments, fused slag has been mixed with fresh flux at different proportions, and this mixture of fused flux and fresh flux has been used to do bead-on-plate welding of mild steel plates. The percentage (by volume) of fused slag in the mixture of fresh flux and fused slag is referred to here as slag-mix%. The slag-mix% has been varied from 0 to 100 with a total of seven levels (Table 1).

The parameters voltage (OCV) (36 V), wire feed rate (0.79 cm/s), traverse speed (0.24 cm/s), electrode stick-out (20 mm), flux basicity index (1.6) and electrode diameter (3.14 mm) have been kept invariable in all the above experimental runs.

Collected slag has been crushed manually and passed through proper sieves to control its grain size approximately equal to that of fresh flux. Copper coated electrode wire of diameter 3.14 mm (AWS A/S 5.17:EH14) has been used during the experiments. Bead-on-plate welding has

Table 2 : Data related to bead geometry

Observation No.	Sample No.	Bead width (mm)	Reinforcement (mm)	Penetration (mm)	Area of reinforcement (mm^2)	Area of penetration (mm^2)	% Dilution
1	O	19.643	4.103	2.011	50.135	25.013	33.28
2	A	18.574	3.660	1.475	45.343	17.930	28.34
3	B	17.708	3.684	1.830	42.274	22.295	34.53
4	C	17.443	3.575	1.680	42.816	19.486	31.28
5	D	18.384	4.934	2.027	42.349	20.690	32.82
6	E	17.132	3.237	1.928	37.731	18.919	33.40
7	F	17.467	3.594	1.612	42.517	18.332	30.13

been performed on mild steel plates with flux (AWS A5.17/SFA 5.17) with grain size 0.2 to 1.6 mm with basicity index 1.6 (Al_2O_3+MnO_2 35%, CaO+MgO 25% and SiO_2+TiO_2 20% and CaF_2 15%). The experiments have been performed on Submerged Arc Welding Machine- INDARC AUTOWELD MAJOR (Maker: IOL Ltd., India). The specimens have been prepared for metallographic test. Macrostructures have been investigated in Optical Trinocular Metallurgical Microscope (Make: Leica, GERMANY, Model No. DMLM, S6D & DFC320 and Q win Software). Data related to bead geometry and HAZ are furnished in Table 2. Weld and HAZ hardness have been measured by Eseway Hardness Tester (Table 3).

Butt-welding

Apart from bead-on-plate welding, few samples of double pass square butt weld have been made in order to investigate the effect of use of slag-mix in Submerged Arc Welding on tensile strength of the welded joint. Using same experimental set-up, as mentioned earlier in section 2.1 and following the same procedure, submerged arc double pass (primary pass or backing pass and secondary pass) square butt weld has been done on mild steel plates of thickness 12 mm with a gap of 1 mm between the plates. After welding, tensile test specimens have been prepared from the joint samples with dimensions as per BIS. Tensile strength of the welded joint (in terms of maximum load carrying capacity before fracture) has been measured by tensile testing machine: ERAX at National Test House, Kolkata. The data (Table 4) have subsequently been used to compare the conventional and non-conventional SAW processes in regard to maximum load carrying capacity of the joint.

Table 3 : Results of Hardness Test

Observation No.	Sample No. No.	Weld hardness (VHN)	HAZ hardness (VHN)
1	O	248	238
2	A	184	230
3	B	238	243
4	C	248	310
5	D	248	279
6	E	213	226
7	F	208	200

RESULTS AND DISCUSSION

Bead-on-plate welding

The effects of slag-mix% on various geometric parameters of the weld bead are shown in Figures 3.1 to 3.6, graphically. In all these figures, observation nos. 1, 2, 3, 4, 5, 6 and 7 represent the conditions of constant process parameters (voltage, traverse speed, wire feed rate and electrode stick out) but varied slag-mix% (0%, 10%, 20%, 40%, 60%, 80% and 100% respectively).

Bead width obtained with varied slag-mix% is shown through the bar charts in the Figure 3.1. These charts also bring about the comparison between conventional SAW and SAW with slag-mix, in so far as bead geometry is concerned. With 0% slag-mix, bead width obtained is maximum. While in SAW, using slag-mix, it is found that in each case (10%, 20%, 40%, 60%, 80% and 100% slag-mix), bead width is less than the bead width found in conventional SAW i.e., with 0% slag-mix. At 80% slag-mix (observation no. 6) it is found that bead width is maximum. A good economic weldment should ensure minimum bead width, while satisfying the functional requirements. From this point of view use of 80% slag-mix may be used, as per the observations of the present study. However, if larger deposition rate is of prime importance, the conventional SAW is a probability of choice, because both wide weld bead and deep penetration may be required.

Table 4: Results of tensile test

Sample No.	Process parameters used: Voltage (OCV)	Wire feed cms^{-1}	Traverse speed cms^{-1}	Slag-mix%	Maximum load carrying (KN) capacity
T1	34	2.73	0.24	20	48.64
T2	34	2.73	0.24	60	48.79
T3	36	1.46	0.23	40	37.36
T4	36	1.46	0.40	0	39.24
T5	36	1.46	0.40	80	37.96

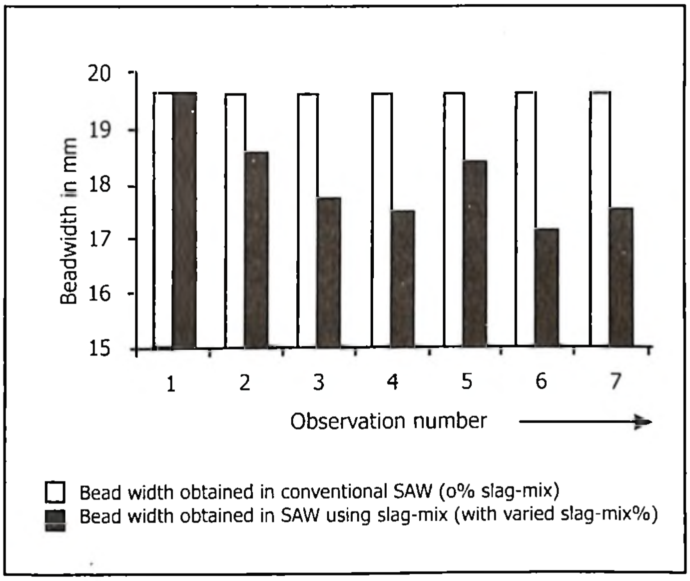

Figure 3.1: Effect of slag-mix on bead width

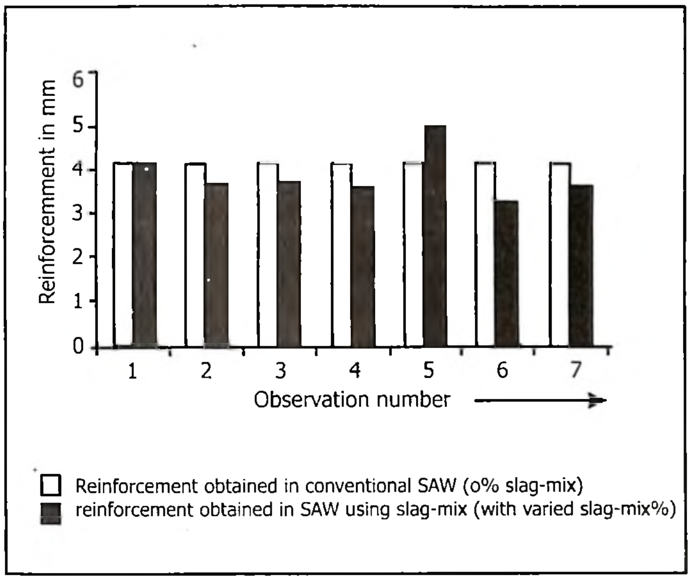

Figure 3.2: Effect of slag-mix on reinforcement

Bead height i.e. reinforcement obtained in the experimental runs is shown in the Figure 3.2. Comparison of conventional SAW and SAW using slag-mix can be made through the charts shown in this figure, in respect of the bead height. It is found that, while each of the other process parameters are kept at the respective constant value, use of 80% slag-mix produces lowest reinforcement. It is better that reinforcement is less; it is economic as well.

Figure 3.3 compares the values of depth of penetration obtained in conventional SAW process, and SAW using increasing percentages of slag-mix. It is found that depth of penetration at 60% slag-mix is maximum and it is more than that obtained in conventional SAW. Also at 80% slag-mix, depth of penetration is almost same as that for conventional SAW. For other slag-mix% values, depth of penetration is distinctly less as compared to the depth of penetration obtained with conventional SAW. It is desired that a good weld be produced with large depth of penetration. This will cause proper fusion during welding and desired characteristics. From this point of view 60% slag-mix is preferred, as observed in the present work.

Figure 3.4 reveals comparison of area of reinforcement obtained in two processes: SAW with slag-mix and SAW without slag-mix. A proper weld should ensure high percentage of dilution; it depends on area of reinforcement and area of penetration. High percentage

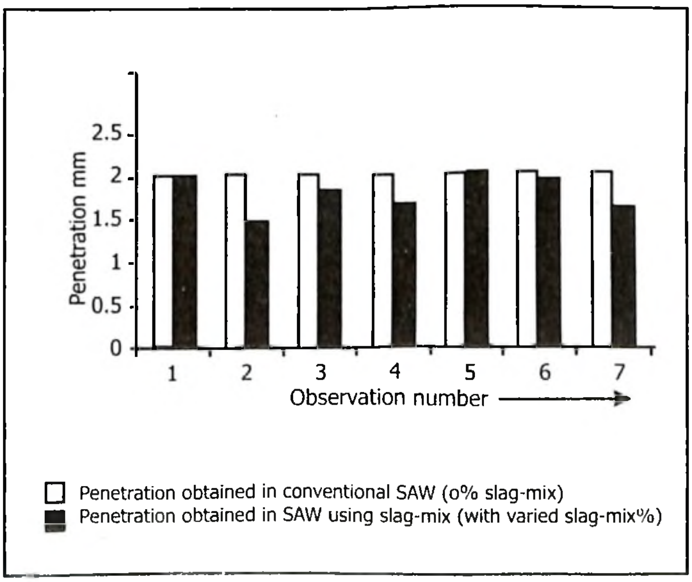

Figure 3.3 : Effect of slag-mix on penetration

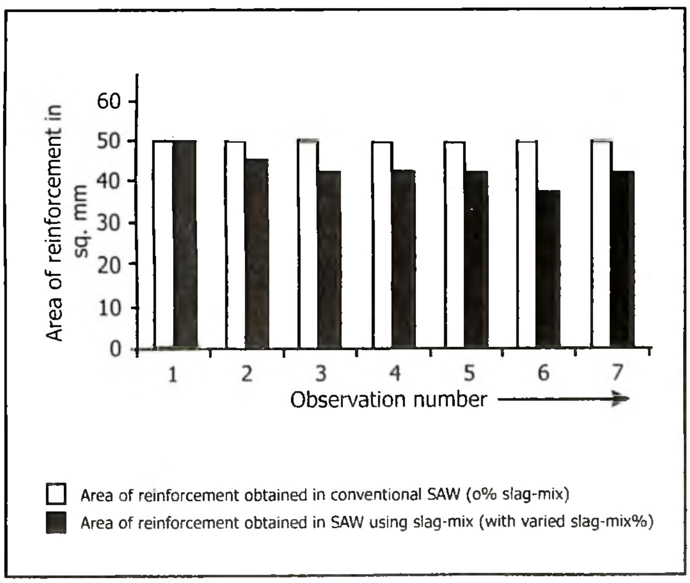

Figure 3.4 : Effect of slag-mix on area on reinforcement

dilution is to be obtained with lesser area of reinforcement. Figure 3.5.a shows a typical weld bead, which may be considered as actual geometry of the weld bead. For the purpose of calculation, the simplified weld bead geometry as shown in Figure 3.5.b has been considered. From this point of view, 80% slag-mix could be used because it provides minimum area of reinforcement among those obtained in conventional SAW and SAW with various percentages of slag-mix.

Assuming the shape of bead cross-section to be a circular sector with radius , from simple geometry, total bead cross sectional area can be easily evaluated approximately. Actual and simplified bead geometry is shown in Figure 3.5.a and 3.5.b.

$A_t = (p + h)^2 \phi$, (ϕ in radian), the semi arc angle (3.1)

where, $\tan \phi = \frac{w}{2p}$, (ϕ in degree) (3.2)

$\%D = \frac{A_p}{A_t} \times 100$ (3.3)

$A_p = \frac{1}{2} wp$ (3.4)

where

w = Bead width

h = Bead height (reinforcement)

p = Depth of penetration

Ar = Area of reinforcement

Ap = Area of penetration

At = Total brad cross sectional area

D% = Percentage dilution

Figure 3.6 represents a comparison on the values of area of penetration obtained in both conventional SAW and SAW process with varying percentages of slag-mix. It is found that using 0% slag-mix, area of penetration obtained is maximum

Figure 3.7 draws a comparison on values of %dilution obtained in SAW process, with and without slag-mix. It is interesting to note that using 80% slag-mix, %dilution obtained is exactly equal to that obtained in conventional SAW process. It is also surprising that 20% slag-mix produced highest %dilution among the series of experiments, and this value is greater than that obtained in conventional SAW process.

The foregoing comparisons on the features of bead geometry obtained in SAW processes (with and without slag-mix) have been studied and critically examined, but no definite trends have been found to describe clearly how an increase in slag-mix% influences parameters of bead geometry. It is found that at a particular slag-mix%, some bead geometry parameters are satisfactory but at some other slag-mix%, some other feature(s) of bead geometry is (are) favorable. No specific slag-mix% has been observed which favorably satisfies all the features of the bead geometry: (maximum) depth of penetration, (maximum) dilution, (minimum) reinforcement, (minimum)

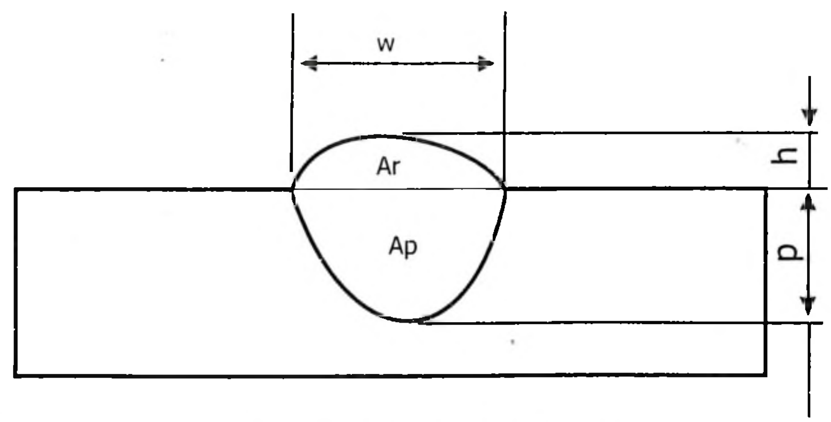

Fig 3.5 a Actual weld bead geometry

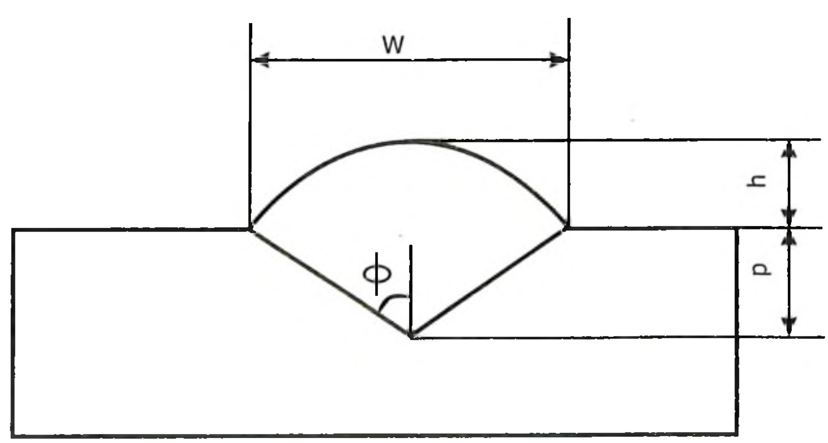

Fig 3.6 b Specified weld bead geometry

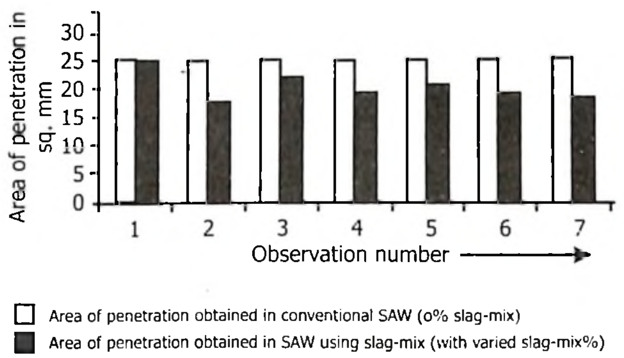

Figure 3.6: Effect of slag-mix on area of penetration

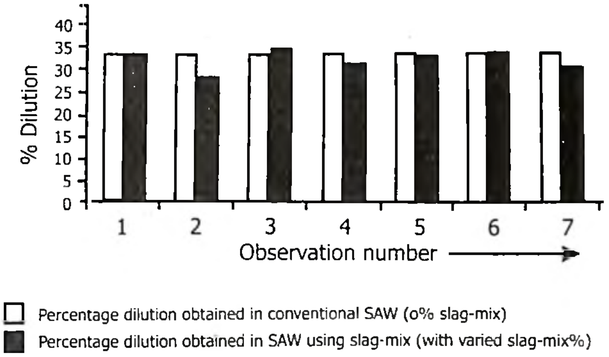

Figure 3.7: Effect of slag-mix on % dilution

bead width, (minimum) area of reinforcement and (maximum) area of penetration. So to obtain a desired weld with appropriate bead geometry parameters it requires trial and error experimentation. Parametric optimization may also prove meaningful in this context.

For a weld, it is expected that the hardness of the weld metal will be different from that of base metal and HAZ. Therefore, it is found that weld and HAZ are more prone to corrosion compared to the base metal. This gives an obvious indication that morphologies of the grains are different in these zones. The characteristics of HAZ depend on the cooling condition and composition of base metal, electrode wire and flux. So it cannot be stated directly that HAZ hardness will always be less than weld hardness, or the vice versa. This is the complexity of process behavior during welding.

Weld metal hardness also depends on the compositions of the base metal, electrode wire, slag metal reactions, cooling cycle etc. All these factors influence the hardness of the weld material.

Results of hardness test (Table 3) of bead-on-plate weld prepared under conditions of constant process parameters (voltage, wire feed rate, traverse speed etc.) but with varying slag-mix% have been furnished in bar chart in the Figures 3.8-3.9. Attempt has been made to compare the results of hardness test (weld as well as HAZ hardness) of the weldment prepared both in conventional (using fresh flux) as well as non-conventional (using slag-mix) SAW processes. From Table 3, it has been observed that compared to weld and HAZ, hardness of base metal is less

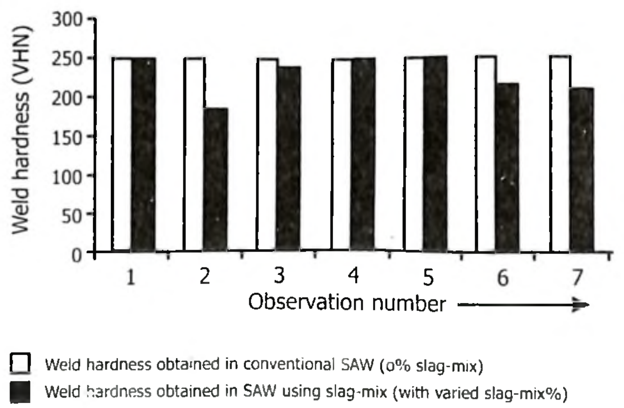

Figure 3.8: Effect of slag-mix % on weld hardness

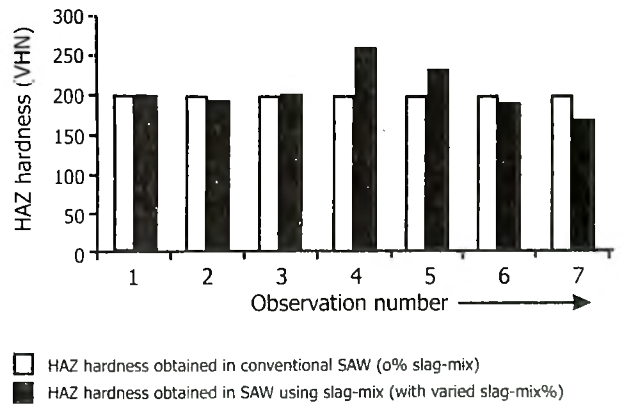

Figure 3.9: Effect of slag-mix % on HAZ hardness

for most of the welded samples. The fact is quite expected. During welding, due to fusion of base metal, electrode wire and flux ingredients carbon particles may get introduced to the weld zone, thereby increasing the hardness value of the weld metal as well as HAZ. However, this carbon entrapping is different at different locations, which is also influenced by cooling cycle, mode of cooling, phase change and solidification phenomena. Too high a hardness value indicates a weld to be brittle, which is prone to fracture, and corrosion. Too low a hardness value of a weld results low strength of the welded joint.

While comparing the hardness value of the welds obtained both in conventional and non-conventional SAW process; it is observed from Figure 3.8 that while using various percentages of slag-mix, weld hardness appears to be somewhat less than the hardness value obtained from the weld prepared using 0% slag-mix (fresh flux). But the deviation thus observed is not high.

From Table 3, it has been found that except for sample No. A (Observation No. 2, use of 10% slag-mix), for all other samples prepared using various percentages of slag-mix, hardness values are compatible to that obtained for the weld prepared using 0% slag-mix (Sample No. O, Observation No. 1).

Figure 3.9 represents bar charts comparing HAZ hardness of the welds prepared in conventional as well as non-conventional SAW processes. Except for sample Nos. C and D (Observation No. 5 and 6 respectively), HAZ hardness seems to be more or less consistent with that obtained in conventional SAW process (Sample O, Observation No. 1). The deviation is negligible. This deviation may be due to the variation in cooling phenomena, phase change, fusion of slag-flux with base metal and wire electrode at the weld zone. These may change weld microstructure and hence hardness value.

To this extent, from the aforesaid observations and overall analysis, the inference that can be drawn is that use of slag-mix does not impose any alarming effect on hardness of the weld metal and HAZ. The results of hardness test of the weld obtained in non-conventional SAW process are not found to be unsatisfactory as compared to the result obtained in conventional SAW.

BUTT WELDING

EFFECT OF SLAG-MIX% ON TENSILE STRENGTH OF THE WELDED JOINT

The location and nature of fractures in every sample have been analyzed critically. For all the samples, the fracture took place near or at the parent material. All the samples showed quasi-ductile manner of fracture.

Results of tensile strength (in terms of maximum load carrying capacity of the joint) of butt-welds prepared under various combinations of process parameters (voltage (OCV), wire feed rate, traverse speed etc.) with varying slag-mix% have been shown earlier in Table 4, Sample T1 to T5). Figures 3.10 to 3.14 show load vs. extension curves for the samples.

While comparing the data between corresponding to the samples T4 and T1, it is found that with decrease in voltage and traverse speed maximum load carrying capacity of the welded joint increases from 39.24 KN to 48.64 KN. The same trend has been noticed due to increase in wire feed rate and slag-mix%. This is possibly due to the fact that for constant power source welding setup, decrease in voltage results an increase in welding current, which in turn increases heat input at the welded zone, producing deep penetration. An increase in wire feed rate provides increase in metal deposition rate enhancing the amount of liquid metal penetrating between the

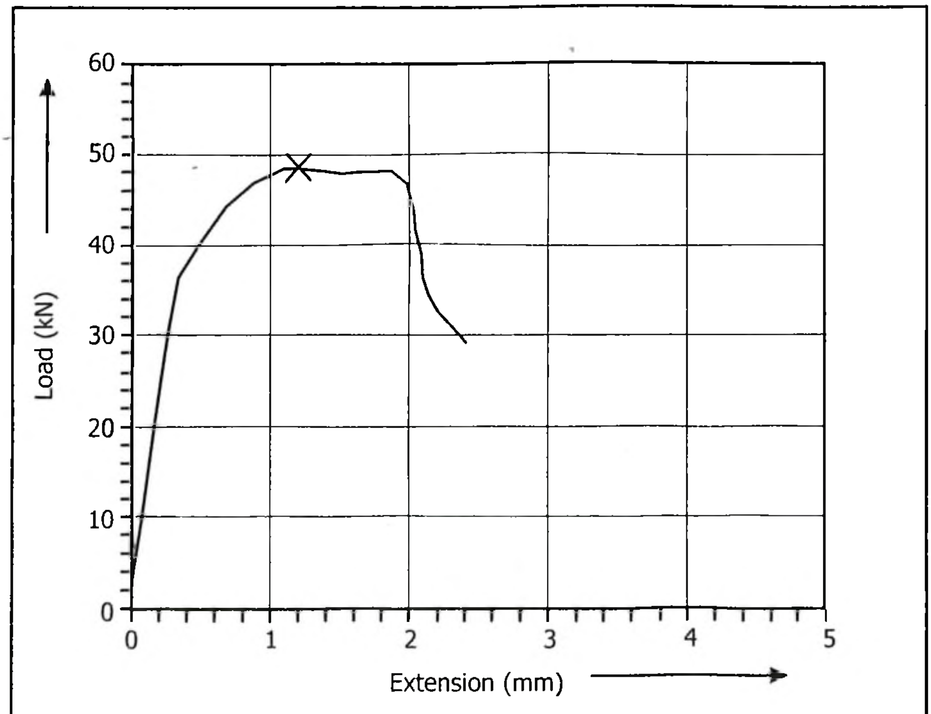

Fig 3.10 : Load vs. extension curve (Sample T1 of Table 4)

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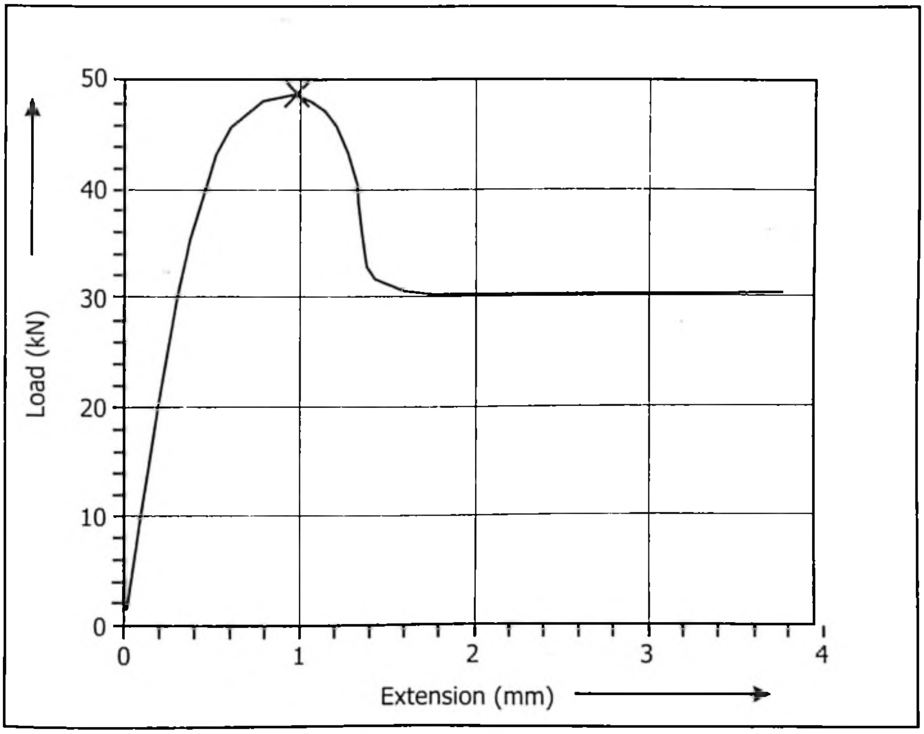

Fig 3.11 : Load vs. extension curve (Sample T2 of Table 4)

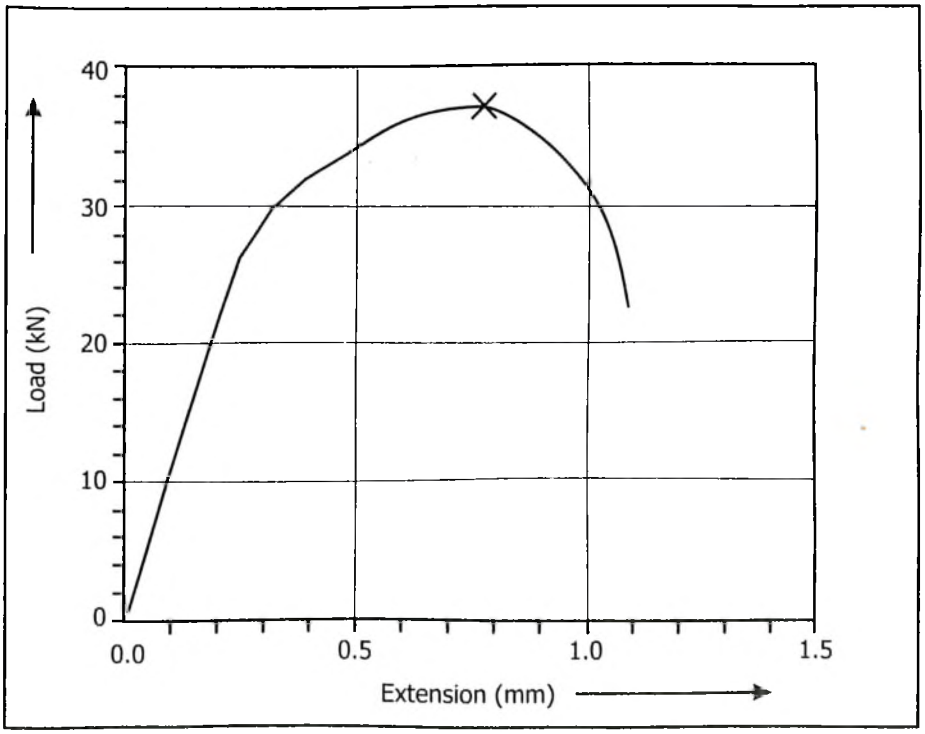

Fig 3.12 : Load vs. extension curve (Sample T3 of Table 4)

gaps of the plates. With decrease in traverse speed, time taken by the wire electrode to work at the welding zone is more. This causes increase in depth of penetration. More the penetration more will be the filling of the gap between the plates by the penetrating metal. As a result of high penetration tensile strength of the welded joint in terms of maximum load carrying capacity of the welded joint increases.

While comparing the samples T4 and T2 (Figures 3.13 and 3.11) the same trend is observed between process parameters and the tensile strength of the welded joint has been observed. It is to be noted that for sample T1 and T2 same process parameters (voltage, wire feed rate, traverse speed) have been used but with different percentages of slag-mix: 20% and 60% respectively. This clearly indicates that variation of slag-mix percentage does not significantly influence the tensile strength of the welded joints; almost same value of maximum load carrying capacity has been observed for samples T1 and T2 (48.64 KN and 48.79 KN respectively).

While comparing samples T4 with T3 (Figures 3.13 and 3.12), it is found that with constant voltage and wire feed rate, increase in slag-mix% and decrease in traverse speed, results decrease in load carrying capacity of the welded joint from 39.24 KN to 37.36 KN. This slight decrease in tensile strength is probably due to reduced penetration while reduction in traverse speed has occurred.

If comparison is made between the samples T4 and T5 (Figures 3.13 and 3.14), it is found that with constant voltage, wire feed rate and traverse speed, increase in slag-mix% (from 0 to 80%) results slight decrease in maximum load carrying capacity of the welded joint: from 39.24 KN to 37.96 KN.

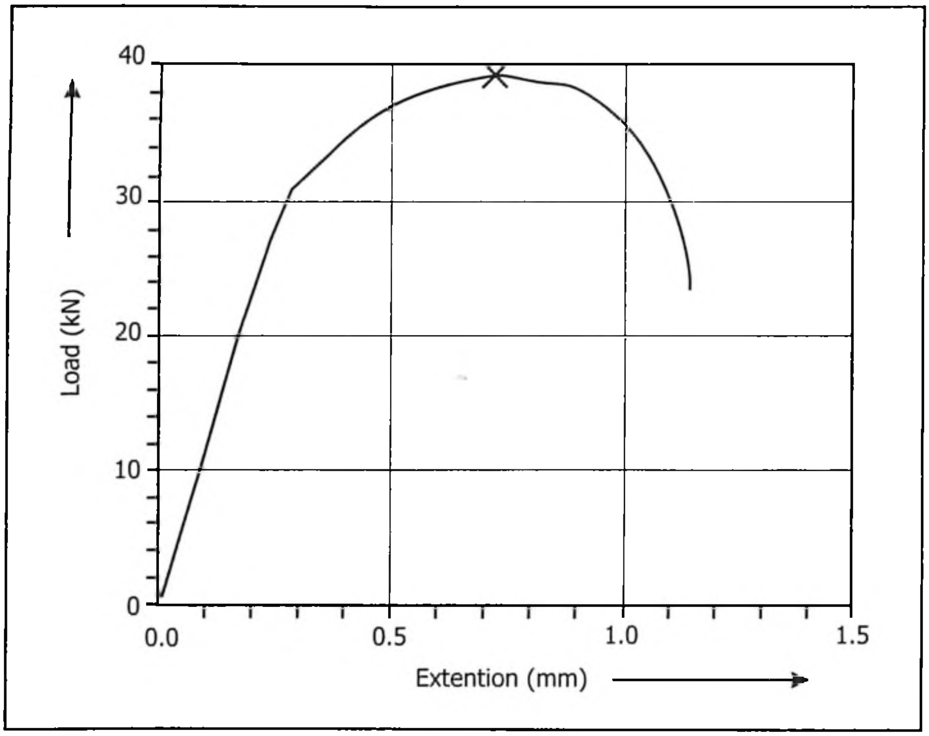

Fig 3.13 : Load vs. extension curve (Sample T4 of Table 4)

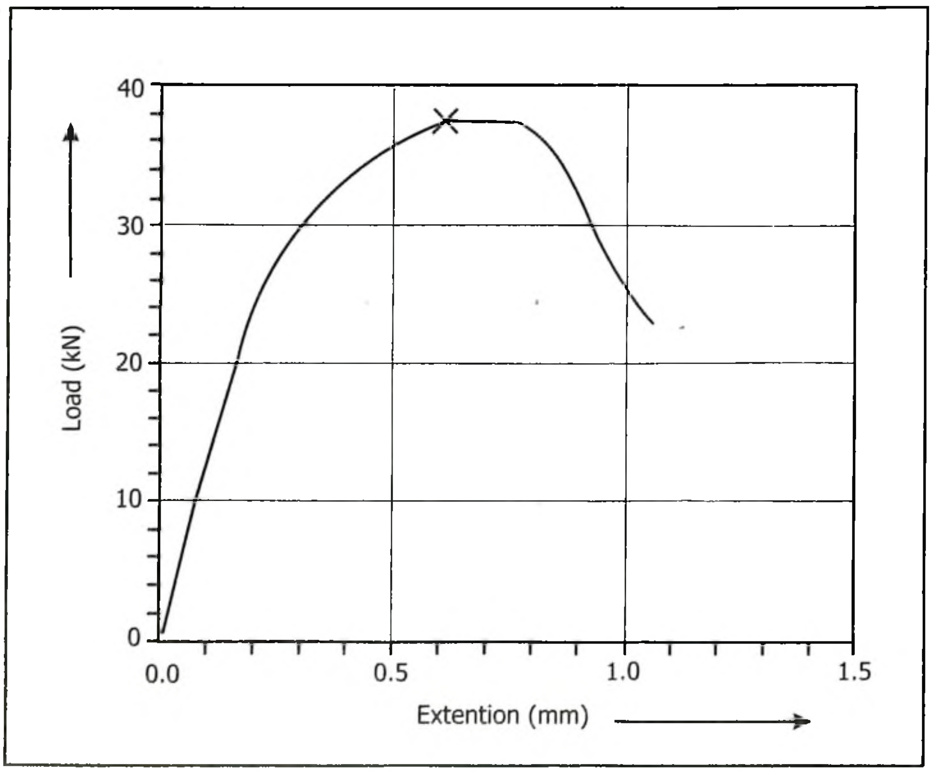

Fig 3.14 : Load vs. extension curve (Sample T5 of Table 4)

The results thus obtained for samples T1, T2, T3, T4 and T5 clearly indicate that no specific trend exists between slag-mix% and maximum load carrying capacity of the welded joint. The data are almost consistent with those obtained in conventional SAW process. Variation in tensile strength observed in different samples may be attributed to variation in the parameters namely voltage, wire feed rate and traverse speed. To this extent it can be concluded that use of slag-mix does not affect tensile strength of the welded joint adversely.

CONCLUSION

The present study deals with some aspects of the use of fused slag, mixed with fresh flux in Submerged Arc Welding of mild steel.

In one part of the study, bead-on-plate welding has been done to investigate the effect of slag-mix% on the features of bead geometry and HAZ. The effects on hardness of the weldment as well as HAZ have also been studied. In another part, A few square butt joints have also been made. The tensile properties of the joints have been tested. The following conclusions are drawn based on the scope and limitations of the above-mentioned part of the present work.

- ☐ Compared to SAW process, with 0% slag-mix, use of 80% slag-mix produces minimum bead width, minimum reinforcement, minimum area of reinforcement and maximum percentage dilution.
- ☐ Compared to conventional SAW process, use of 60% slag-mix yields maximum depth of penetration, where as use of 80% slag-mix produced lesser penetration compared to SAW process without slag-mix.
- ☐ Wile varying slag-mix% from 0 to 100, use of 40% slag-mix produces

maximum area of penetration.

- Use of 80% slag-mix produces most of the favorable and economic features of weld bead geometry (minimum bead width, minimum reinforcement, maximum depth of penetration and maximum %dilution).
- Use of slag-mix in SAW process does not affect adversely the hardness value of the weld metal as well as HAZ. The same inference can be drawn for tensile strength of the welded joint, in terms of its maximum load carrying capacity.

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ANNOUNCEMENT

DISPOSAL OF OLD ISSUES OF JOURNALS & PERIODICALS

To

All Readers of Indian Welding Journal

As an individual member of the some leading societies abroad over decades, I have a huge collection of journal, conference proceedings(of conferences attended abroad) and valuable books, which I would like to dispose.

The list includes the followings :

1. Journals

i. Journal of Iron & Steel Institute(UK), from 1960- 1972, plus the centenary issue-the most valuable publication in iron and steel covering the golden decade.

ii. Journal of Institute of Metals, UK

'Metals & Materials' from : 1962-1972, name changed to 'The Metallurgist' from 1973-1983 name changed to 'Materials World' (MW) from 1984 till date.

iii. American Welding Society, Welding Journal. 1981- 2008 (till date).

iv. Advanced Materials & Processes,journal of ASM International,1985-2008 (till date).

2. Conference proccedings (mostly abroad & includes my presentations on)

i. Welding(3rd Int.Conf. "The Trends in Welding Research', AWS & ASM Intl,Gatlingburg,TN, USA, in 1992.),

ii. Microstructural Sciences(IMS & ASM.,1985l, Calgary (Canada).1985 and another in Monterey, CA, USA , 992.

iii. Thermal Spraying Conferences - ITSCs (Montreal,London, Orlando, Kobe) & many others

iv. Wear of Material Conferences (ASME), San Farancisco,Cambridge

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If any member or reader is interested, please inform me in the following E mail: (drrammandira@yahoo.com)
Warm regards,
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