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BEAD GEOMETRY WITH CRUSHED SLAG IN SUBMERGED ARC WELDING

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ABSTRACT

Slag generated during submerged arc welding is generally thrown away as a waste and poses storage and disposal problem, needs landfill space and environment pollution apart from exhaust of non-renewable resources. Reuse of fused slag will not only solve these problems but also be economical. An attempt has been made to reuse slag as a flux in submerged arc welding. Slag was crushed and sieved to grain size of original flux. This crushed slag was used as a flux in submerged arc welding. Beads on plates were deposited. A specimen about 20 mm wide was removed from the centre of plate, polished and etched with Nital. Bead profile i.e. penetration, bead width and reinforcement was measured. Mathematical models were developed from the data generated which are useful for prediction of bead geometry. The adequacy of developed models and significance of the coefficients was tested by the 'F' test and Student's 't' test respectively. Acceptable bead geometry was achieved using crushed slag.

Keywords: *Reuse, Slag, Flux, Submerged Arc Welding and Bead Geometry.*

1. Introduction

Flux contributes a major part towards welding cost. During welding flux is converted into slag, which is a waste and has to be disposed off. About 2500 tonnes of flux was consumed in India alone in the year of 1982 [1] which has risen to 10000 tonnes in the year of 2006 as estimated by Honavar [2]. Beck and Jackson [3] found that if processed properly and according to code requirements, recycled slag could be reliable and could be used as an alternative for new flux. They further claimed a saving of 50% of the purchased flux by recycling the slag. Simultaneously some researchers also explored the possibility of using mixture of fused slag and fresh flux.

Experiments carried out by Livshits et al. [4] have shown the possibilities of using pulverized slag crust mixed with iron fillings for hard facing applications. They further claimed that this process is more efficient and economical. Pal et al. [5] found that the use of mixture containing up to 20% fused slag in fresh flux has a negligible change in weld metal chemistry. Singh et al. [6] claimed that acceptable mechanical properties of weld metal deposited with recycled slag can be achieved. Above researchers attempted to achieve chemical and mechanical propertied of weld metal using recycled slag or mixture of slag and fresh flux but no consideration was given to use pure slag. As the literature regarding use of pure crushed slag is not available, so an attempt was made to use pure crushed slag and to investigate its effect on bead geometry in submerged arc welding. This will lead "zero waste technology" which is the need of hour.

2. Experimentation

2.1 Collecting and crushing of slag

The slag generated by Mukat Pipes Ltd. Rajpura, Punjab. It is available in abundance at their dump yard, free of cost. The slag was crushed and sieved to obtain required grain size. This crushed and sieved slag was used as a flux and bead on plates were deposited. The weld bead geometry obtained was studied. To study the effects of welding parameters on weld bead, following steps were followed.

i. Identification of process parameters and finding their working range
ii. Development of design matrix using two level factorial technique
iii. Conducting experiments as per design matrix
iv. Recording of responses
v. Selection of mathematical model
vi. Evaluation of coefficients of the model
vii. Development of models
viii. Adequacy test of developed models
ix. Presentation the effects of welding parameters on bead geometry in graphical form

2.2 Identification of the process variables and finding their working range

Welding current (I), open circuit voltage (V), travel speed (S) and nozzle-to-plate distance (N), were

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selected as direct welding parameters affecting bead geometry. The upper limit of a factor was coded as (+1) and lower limit as (-1) or simply (+) and (-) for the ease of recording and processing the data. Selected parameters are given in Table 1.

Table 1: Welding Parameters and their Limits

Parameter	Unit	Symbol	Limits Low (-1)	High (+)
Welding current	Amp.	I	300	500
Arc voltage	Volt	V	26	32
Travel speed	m/min	S	0.3	0.5
Nozzle to work distance	mm	N	18	25

2.3 Development of design matrix

The design matrix as shown in Table-2 was developed to conduct eight trial runs (2^{4-1}) = 8 of two level half factorial design. The first three columns were generated by standard 2^3 two level full factorial and the forth column was generated by confounding the effect of parameter 4 with the three parameters inter action effects. The procedures of designing such a design matrix are dealt with Adler et al. [7].

Table 2: Design Matrix

Trial No.	I 1	V 2	S 3	N 4=123
1	+	+	+	+
2	-	+	+	-
3	+	-	+	-
4	-	-	+	+
5	+	+	-	-
6	-	+	-	+
7	+	-	-	+
8	-	-	-	-

2.4 Conducting experiments

Beads on plates having size 10×50×150 mm were deposited as per design matrix using 3.2mm diameter EL-8 wire in combination with pure 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. Electrode positive polarity was used. The experiments were performed in a random manner to avoid any systematic error. The complete set of eight trials was repeated thrice for the sake of determining the variance of parameters and variance of adequacy for the model. The weld samples of appropriate length were removed from the middle of weld plates and polished using standard metallographic procedures and subsequently etched with 2% Nital. Fig. 1 indicates the elements of weld bead geometry.

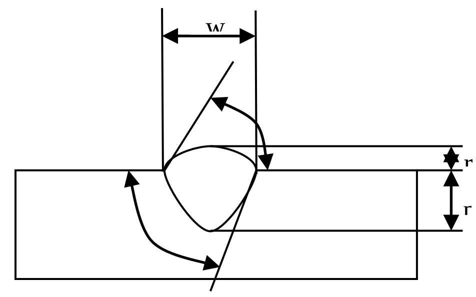

Fig. 1 Elements of Bead Geometry

2.5 Recording of responses

The plates were cross-sectioned at their mid points to obtain test specimens having 20 mm width as shown in Fig. 2. These specimens were polished and etched with 2% Nital The weld bead profiles were traced using an optical profile projector at 10 X magnification from where bead dimensions i.e. penetration, bead width and reinforcement were measured and recorded in Table-3.

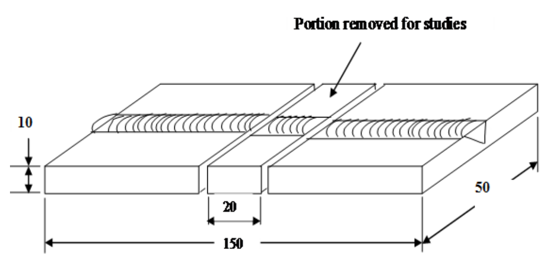

Fig. 2 Specimen Cutting Plan

2.6 Selection of mathematical model

The response function representing any of the weld bead dimensions could be expressed as:

Y= f (I, V, S, N)

Where Y is the response function i.e. weld penetration (p), weld width (w) and reinforcement height (r). I, V, S and N are welding current, arc voltage, travel speed and nozzle-to-plate distance respectively.

Assuming a linear relationship in the first instant and taking into account all the possible two factor interactions only, the above expression could be written as:

$$Y=b_0+b_1I+b_2V+b_3S+b_4N+b_5IV+b_6IS+b_7IN \qquad (1)$$

2.7 Evaluation of the coefficients

The regression coefficients of the selected model were calculated using Equation-2:

$$bj = \frac{\sum_{i=1}^{N} XjiYi}{N}, \; j = 0,1,2,......., k \qquad (2)$$

Where,
Xji= Value of a factor or interaction in coded form.
Yi = Average value of the response parameter
N = Number of observations.
k = Number of coefficients of the model.

The coefficients of the model and their significance were determined and recorded in Table-4.

2.8 Testing significance of the coefficients

The statistical significance of the coefficients was tested by student's "t" test. The value of 't' from the standard table for eight degree of freedom and 95% confidence level is 2.3. The calculated 't' values for the coefficients are given in Table-4. The coefficients having calculated 't' value less than 2.3 are considered to be insignificant and hence dropped in the final models.

Table 3: Observed Values of Bead Geometry

Trial No.	Penetration (mm)		Bead width,(mm)		Reinforcement (mm)		WPSF		WRFF	
	1st set	2nd set	1st set	2nd set	1st set	2nd set	1st set	2nd set	1st set	2nd set
1	4.1	3.7	18	18.6	2.4	1.8	4.4	5	9	8.5
2	2.5	2.7	12.5	11.4	1.3	1.9	5	4.2	8.5	9.9
3	3.2	3.9	13.1	13	2.6	2	4.1	3.3	5.5	5.9
4	3.6	4.4	12.3	12.5	2.1	2.1	3.5	3.1	8.2	7.3
5	5	5.8	20.2	20.7	3.5	3.7	4	3.6	5.8	5.6
6	3.7	3.1	16.6	16.8	2.6	2.7	5.5	5.1	7	6.4
7	4.5	5.4	17.5	17.5	2.8	2.4	3.5	3.4	5.8	6.2
8	4.1	4	18.2	18.2	2.4	2.5	4.4	4.2	6.2	6

Table 4: Coefficients of the Model and their Significance

Parameter	Coeff.	b_0	$b_{1\,(I)}$	$b_{2\,(V)}$	$b_{3\,(S)}$	$b_{4\,(N)}$	$b_{5\,(IV)}$	$b_{6\,(IS)}$	$b_{7\,(IN)}$
	Value	3.99	0.49	-0.16	-0.46	0.09	0.34	-0.26	-0.11
	't' Value	24.05	2.94	0.98	2.7	0.52	2.1	1.5	0.68
Penetration	Significant	Yes	Yes	No	Yes	No	No	No	No
	Value	16.07	1.26	0.78	-2.14	0.16	1.27	0.49	0.42
	't' Value	131.71	10.3	6.4	17.57	1.28	10.4	4.05	3.43
Bead width	Significant	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
	Value	2.43	0.23	0.1	-0.4	-0.1	0.14	-0.1	-0.24
	't' Value	24.3	2.3	1	4	1	1.4	1	2.4
Reinforcement	Significant	Yes	Yes	No	Yes	No	No	No	Yes
	Value	4.143	-0.231	0.456	0.069	0.044	-0.119	0.356	0.119
	't' Value	31.82	1.7	3.5	0.53	0.34	0.91	2.7	0.91
Shape Factor	Significant	Yes	No	Yes	No	No	No	Yes	No
	Value	6.985	-0.446	0.598	0.865	0.31	0.09	-0.178	0.527
	't' Value	40.38	2.6	3.4	5	1.79	0.52	1.02	3
Form Factor	Significant	Yes	Yes	Yes	Yes	No	No	No	Yes

Table 5: Developed Models

S.No	Bead Geometry	Developed model
1	Penetration	*p=3.469+0.631I-0.4125S+0.2938IV-0.3438IS*
2	Bead Width	*w=15.644+1.81I+1.031V-1.719S+0.5313N+0.894IV*
3	Reinforcement	*r=2.34+0.41I-0.52S*
4	Shape Factor	*WPSF=4.143+0.456V+0.356IS*
5	Form Factor	*WRFF=6.985-0.4475I+0.5975V+0.865S+0.5275IN*

Table 6: Analysis of Variance

Optimn. Parameter	Degree of freedom S_y^2	Degree of freedom S_{ad}^2	Variance of optimn. parameter S_y^2	Std. devi. of coefficient S_{bj}	Vari. of adequacy S_{ad}^2	F-Ratio model $F_m = \frac{S_{ad}^2}{S_y^2}$	F-Ratio from table	Model whether adequate $F_m < F_t$
p	8	3	0.22	0.1658	0.898	4.08	4.12	Yes
w	8	3	0.119	0.122	0.083	0.69	4.12	Yes
r	8	3	0.08	0.1	0.023	0.29	4.12	Yes
WPSF	8	3	0.1356	0.1302	0.0608	0.45	4.12	Yes
WRFF	8	3	0.239	0.173	0.0708	0.30	4.12	Yes

2.9 Development of mathematical models

The mathematical models after dropping insignificant coefficients are presented in Table-5.

2.10 Assessing adequacy of developed models

The adequacies of the models were tested using the analysis of variance technique (ANOVA). According to this technique, if the calculated value of the 'F' ratio of the model exceeds the standard tabulated value of the 'F' ratio for a desired level of confidence (say 95%), the model may be considered adequate within the confidence limit. The results of ANOVA are presented in Table-6.

3. Results and Discussion

3.1 Direct effects of parameters

Relationship between p, w, r, WRFF and welding current have been shown in Fig. 3. It is clear from the figure that p, w and r increased with an increase in welding current. Increased current increases heat input which in turn increases the amount of molten base metal causing increase in penetration as well as bead width. Increase in welding current also causes an increase in metal deposition rate which in turn increases the reinforcement height. But at the same time, WRFF decreases with increase in welding current.

Fig. 4 indicates the effect of travel speed on weld penetration, bead width, reinforcement height and WRFF. It is clear from the figure that p, w and r decreases with increase in travel speed, but WRFF increases. The reason behind this is that the heat input per unit length decreases as the travel speed increases. Reduced heat input decreases the amount of molten base metal causing decrease in penetration and bead width. Reinforcement reduces with increase in travel speed. This is due to the fact that for given combination of voltage and current, the wire feed rate remains constant i.e. it does not change with change in travel speed. That means the melting rate of wire or in other words the deposition of filler metal per unit time does not change with increase in travel speed. With increase in travel speed same amount of metal is being spread over a larger length causing reduction in reinforcement height.

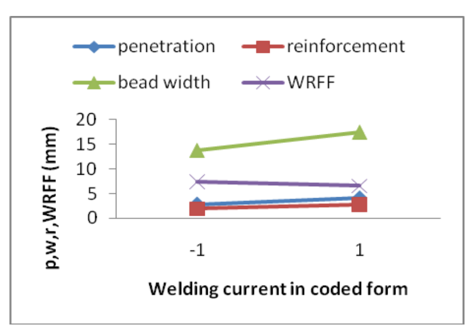

Fig. 3 Effect of Welding Current on Bead Geometry

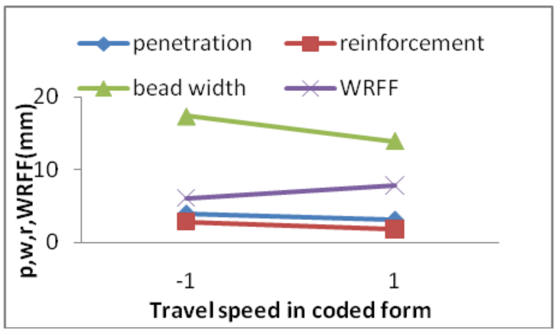

Fig. 4 Effect of Travel Speed on Bead Geometry

3.2 Interactive effects

Fig. 5 shows the interaction effect of welding current and travel speed on penetration. It is clear from the figure that penetration increases with increase in welding current at any rate of travel speed but the rate of increase is higher at low travel speed. Response surface for penetration due to interaction effect of welding current and travel speed is shown in Fig. 6.

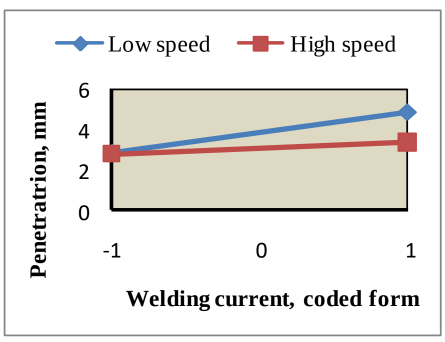

Fig. 5 Interactive Effect Welding Current and Travel Speed on Penetration

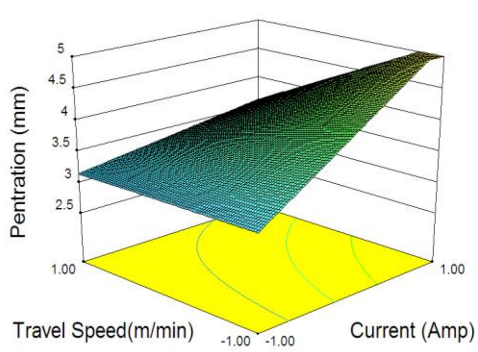

Fig. 6 Response Surface Due to Interactive Effect of Welding Current and Travel Speed on Penetration

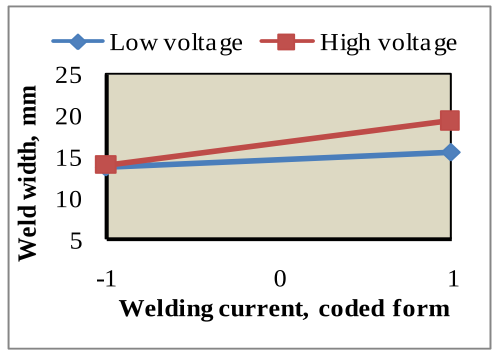

Fig. 7 Interactive Effect of Welding Current and Arc Voltage Weld Width

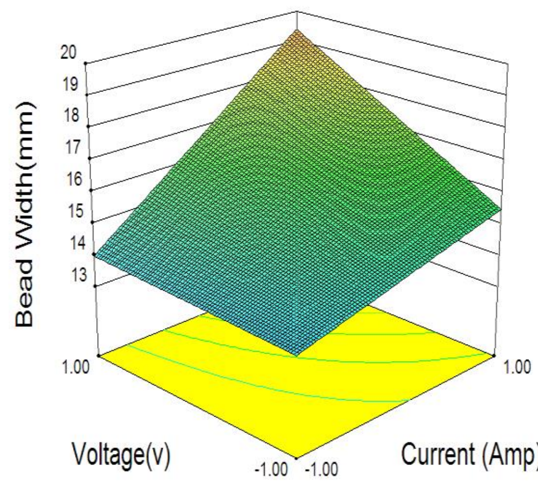

Fig. 8 Response Surface Due to Interactive Effect of Welding Current and Arc Voltage on Bead Width

Interactive effect of welding current and arc voltage on bead width has been displayed in Fig 7. It is observed from the figure that bead width increases with increase welding current at any level of arc voltage but rate of increase is high at higher voltage. It is further observed that rate of increase is high at higher voltage. It is due to the fact that arc length increases with increase in arc voltage as a result arc strikes on larger surface area resulting increase in bead width. Response surface due to interactive effect of welding current and arc voltage on bead width has been displayed in Fig 8.

4. Conclusions

Slag generated by conventional submerged arc welding process can be used as a flux after crushing. The crushed slag can produce weld having acceptable bead geometry.

References

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Nomenclature

Symbol	**Meaning**	**Unit**
p	Penetration	mm
w	Bead width	mm
r	Reinforcement	mm
WRFF	Weld reinforcement form factor	Dimension less
I	Welding current	ampere
V	Arc voltage	volts
S	Travel speed	m/min
N	Nozzle to work distance	mm

