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Establishing Relationship between ASAW Parameters and Welding Voltage during Surfacing

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Abstract

Submerged arc welding (SAW) has been used for surfacing applications for last many decades in nuclear and thermal power industries. Desirable conditions for good quality weld surfacing/cladding are high deposition rates and least dilution of base metal. Submerged arc welding often does not fulfill the condition of low dilution since it works on high current densities. Advanced submerged arc welding (ASAW) process, which was developed in welding research laboratory at IIT Delhi in the year 2004, is a process which satisfies both the desirable surfacing requirements. Control of welding current and welding voltage is very much essential during surfacing applications. The present work is an attempt to establish a relationship of welding voltage with open circuit voltage and other ASAW parameters during surfacing.

***Key words*:** Advanced submerged arc welding, weld cladding, welding voltage, central composite design.

Introduction

Cladding is one of the essential processes used commonly in various chemical, fertilizer, food, petrochemical, nuclear and steam power plants [1]. A number of arc welding processes e.g. gas metal arc welding (GMAW), shielded metal arc welding (SMAW), flux cored arc welding (FCAW), gas tungsten arc welding (GTAW) and submerged arc welding (SAW) have been used for cladding [2-5]. Some non-conventional processes such as laser cladding , electron beam cladding , explosion welding, strip roll welding, solar cladding etc. have also been used for surfacing [6-10].

In continuous electrode welding processes such as GMAW, SAW and ASAW, welding voltage and arc voltage are different terms, but can be used interchangeably if one neglects the loss of voltage in the remaining welding circuit, especially in the electrode stick-out region. Arc voltage or welding voltage is, in general, considered to be one of the process parameters for most of the welding processes as it decides the heat input and nature of arc. Due to dynamic nature of the welding arc in above mentioned processes, it is difficult to precisely preset the welding voltage. These processes normally use constant potential welding power sources and the operator has the option to preset open circuit voltage instead of welding voltage. In the present work, the purpose of considering welding voltage as one of the responses was to explore the extent of influence of open circuit voltage and other ASAW process parameters on it. In the past, no study has been done for modeling of welding voltage with respect to other process parameters as it has been considered an independent parameter which bears a fixed relationship with open circuit voltage *Vo*.

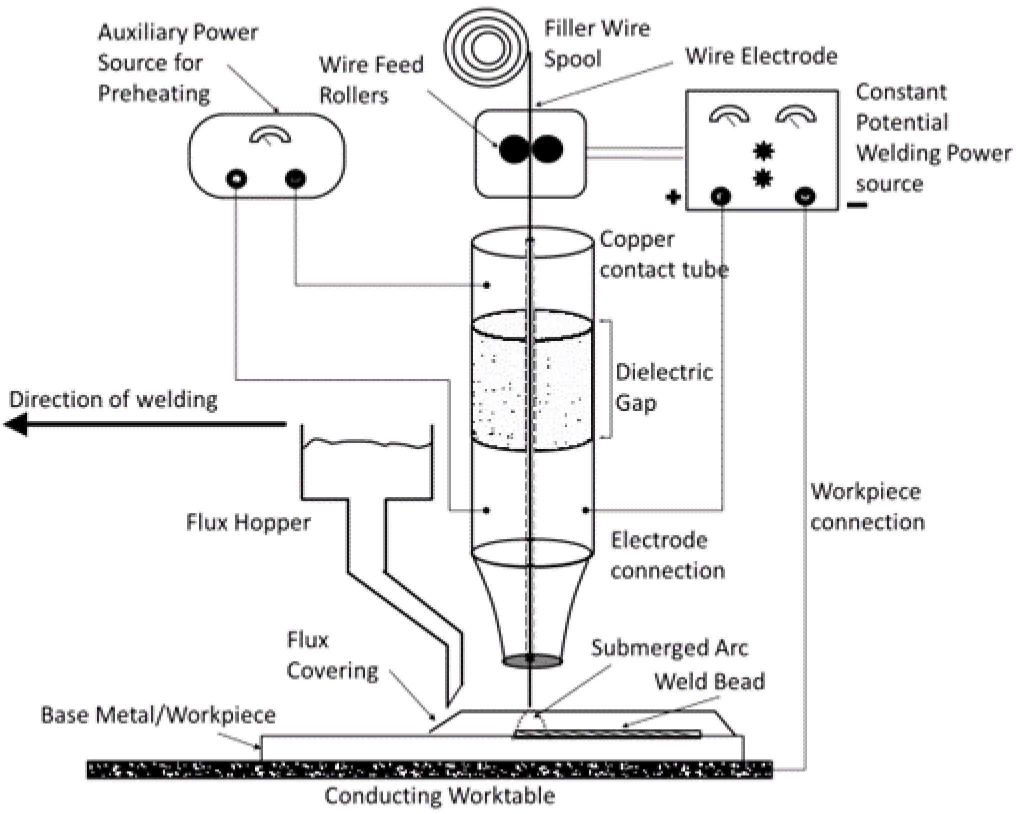

Figure 1: Schematic diagram for Advance Submerged Arc Welding (ASAW) setup

What is Advanced Submerged Arc Welding?

Advanced Submerged Arc Welding (ASAW) is a modified submerged arc welding process and was developed in Welding Research Laboratory of Indian Institute of Technology Delhi (Sunil Pandey, 2004, Patent application number: 2533 / DEL / 2008 Dated: November 07, 2008). Its works differently from the usual submerged arc welding (SAW) in that the continuous wire electrode is preheated by supplying a current from a separate auxiliary power source before being fed to arc region. In the ASAW process, a fraction of the energy required to bring the electrode wire in molten state is mined through preheating by resistance heating when the auxiliary current is passed through the first part of the contact tube length and rest of the energy for melting is provided by main welding current through main power source. A noteworthy decrease in welding current due to preheating of wire electrode is detected during welding which in turn reduces arc force. This leads to lower penetration depth and thus reduced weld dilution [11].

Experimentation

Experimental setup

The experiments were carried out using Advanced Submerged Arc Welding process. A constant potential direct current (DC) power source with mechanized submerged arc welding head connected with two contact tubes in series with a dielectric gap in between. First part of the contact tube was connected to an auxiliary constant current power source for providing preheat current to the electrode wire passing through it. Welding current for producing arc was supplied across second part of contact tube.

Material selection and identification of process parameters limits

A ‘single bead on plate’ technique was adopted to deposit beads of SFA/AWS 5.9 class ER308L stainless steel single bare wire electrode of 3.15 mm diameter on 300 mm x 75 mm x 12 mm mild steel plates. A compatible agglomerated flux of class AWS SFA A-5.23 was used to shield the weld metal from atmosphere.

Five major independent variables i.e. wire feed rate F, travel speed S, open circuit voltage Vo and nozzle to plate distance D and preheating current I_P were chosen for the present work. An additional sixth variable, electrode polarity Po as a two level categorical variable, along with the above five variables was also selected for the study. The working limits of selected variables were decided on the basis of trial runs. Minimum and maximum levels of each variable were finalized by examining the resulting bead on plate carefully for any possible defects during trial experiments and are shown in table 1.

Table 1: Parameters and their values at various levels

Process parameter/ variable	Units	Notation	Parameter type	Parameter levels				
				-2	-1	0	+1	+2
Wire Feed Rate	mm/sec	*F*	Numeric	20	24	28	32	36
Travel Speed	mm/sec	*S*	Numeric	2.5	4	5.5	7	8.5
Open Circuit Voltage	Volts	*Vo*	Numeric	30	33	36	39	42
Nozzle to plate distance	mm	*D*	Numeric	18	21	24	27	30
Preheat current	A	*IP*	Numeric	0	42	84	126	168
Electrode Polarity		*Po*	Categorical	Electrode Negative *EN*			Electrode Positive *EP*	

Development of mathematical model
Response surface methodology

Response surface methodology (RSM) is useful for modelling and analysis of problems with several variables and where objective is to optimize the multiple responses. Response function Y can be written in terms of process variables as $Y = f\ (F, S, V_O, D, I_P)$.The model includes the main effects and interaction effects of all the factors. Second order polynomial, which was adopted for the present study, is represented by following general expression.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum_{i<j} \beta_{ij} x_i x_j + \epsilon \quad (1)$$

Where β_0, β_{ii} and β_{ij} are the constants and x_i, is the process variable and ϵ is the error term of the model [12].

Design matrix and testing the significance of developed models

The five levels of six ASAW parameters based on half fraction rotatable central composite design (CCD) were selected and coded as -2, -1, 0, +1 and +2. A matrix consisting of 60 test runs was designed using Design Expert 8 statistical software. The adequacy of the model was established by using Analysis of Variance (ANOVA) technique. The results of ANOVA for the considered response i.e. *Vo* are presented in Table 2. This table shows details of sum of squares (SS), degrees of freedom (DF), mean square (MS), F- Ratio and Probability of larger F- value or simply P-value [13]. Any variable having P-value less than 0.05 is significant.

The statistical significance of the coefficients was confirmed by applying the t-test. Coefficients having t values less than or equal to the standard tabulated t value at 95% confidence level, are considered non-significant and can be ignored along with the responses with which they are related and affecting minutely the accuracy of the proposed model [14-17]. Table 3 shows also the P-values for individual parameters in the model. Underlined values, where P-values are more than 0.05, depict non-significant parameters and are consequently dropped from the model.

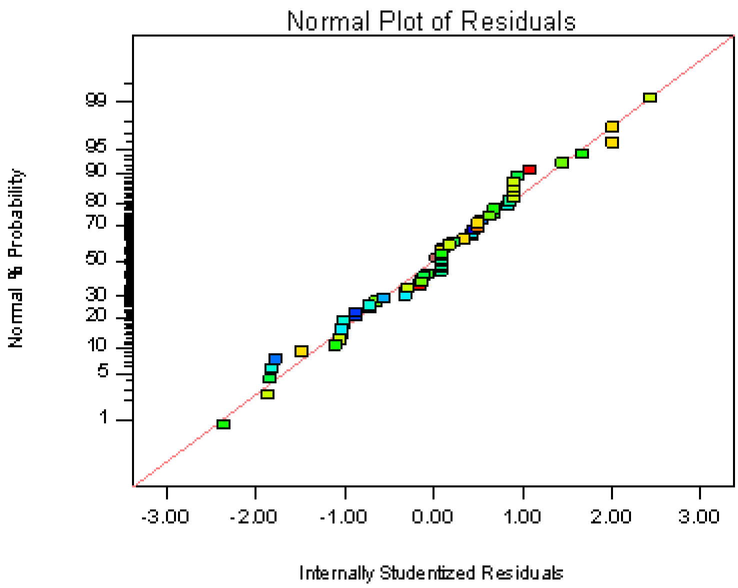

Figure 2: Normal probability vs. Studentized residuals for welding voltage

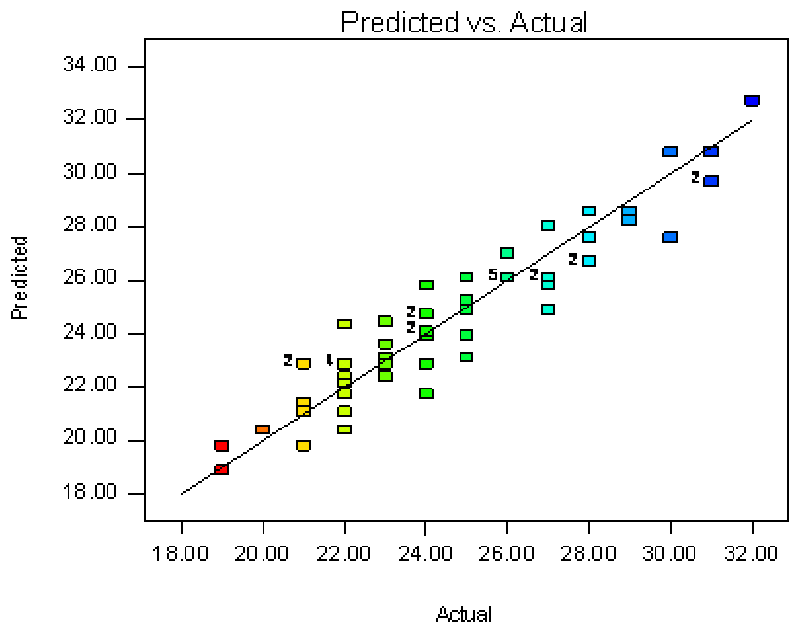

Figure 3: Actual vs. predicted plot for welding voltage

Results and analysis

Figure 2 represents the normal probability vs. Studentized residuals plot for all the observations of welding voltage V_w during each run. It can be resolved that the assumption of a normal distribution is reasonable since all the plotted points fall on a straight line. In figure 3 predicted vs. actual plot for welding voltage is shown.

Table 2: ANOVA test for the fitted welding voltage V_w model

Source	SS	DF	MS	F-Value	P-value	Significance
Model	0.008663	4	0.002166	102.2586	< 0.0001	significant
A-F, mm/s	0.00057	1	0.00057	26.93098	< 0.0001	significant
C-V_o, Volts	0.005276	1	0.005276	249.1133	< 0.0001	significant
E-I_P, Amps	0.000132	1	0.000132	6.209702	0.0157	significant
F-Po	0.002685	1	0.002685	126.7805	< 0.0001	significant
Residual	0.001165	55	2.12E-05			
Lack of Fit	0.001043	49	2.13E-05	1.049536	0.5333	not significant
Pure Error	0.000122	6	2.03E-05			
Cor Total	0.009828	59				

R-Squared= 0.8815, Adj R-Squared= 0.8728 after backward elimination in order to reduce the model to significant factors

Mathematical Modelling

Welding voltage in terms of coded factors

$$1/\sqrt{(V_w)} = 0.20 + 3.447 \times 10^{-3} \times F - 0.010 \times V_O - 1.655 \times 10^{-3} \times I_P + 6.690 \times 10^{-3} \times P_O \quad (2)$$

Welding voltage in terms of actual factors for Electrode Negative polarity

$$1/\sqrt{(V_w)} = 0.301 + 8.618 \times 10^{-4} \times F - 3.495 \times 10^{-3} \times V_O - 3.941 \times 10^{-5} \times I_P \quad (3)$$

Welding voltage in terms of actual factors for Electrode Positive polarity

$$1/\sqrt{(V_w)} = 0.314 + 8.618 \times 10^{-4} \times F - 3.495 \times 10^{-3} \times V_O - 3.941 \times 10^{-5} \times I_P \quad (4)$$

Direct effect of ASAW process parameters on welding voltage V_w

Model presented by Equation 2 to 4 exhibits the effects of process parameters on the welding voltage. Model is presented in terms of coded factors in Equation 2 whereas Equations 3 and 4 are in terms of actual factors. Graphical representation of these direct effects is illustrated in Figure 4. It was observed that wire feed rate *F*, open circuit voltage *Vo* and preheating current I_P influence the welding voltage in a significant manner. Most influential parameter, which controls the welding voltage, is open circuit voltage *Vo* as expected. It shows a direct positive effect i.e. on increasing the open circuit voltage *Vo* welding voltage also increases. Next to the open circuit voltage *Vo*, wire feed rate *F* affects the welding voltage quite strongly, although it has a negative effect, which means that at higher level of wire feed rate *F*, the welding voltage decreases. This can be explained in terms of power source characteristics. Wire feed rate *F* directly controls the welding current in a constant current power source which, in general, shows almost flat characteristics with a slight drop in voltage with respect to welding current [18].

Preheating current I_P also has a positive direct effect on welding voltage. However, the preheating does not show such a promising impact on welding voltage as do the other parameters. It is observed that higher welding voltage is needed to maintain the arc at higher levels of preheating current I_P. This can be attributed to the fact that on passing the preheating current I_P, the electrode wire gets heated due to resistive (I^2R) heating, which obviously increases its resistivity and to maintain the main welding current higher value of voltage is required according to the Ohm's law. The nature of trends of the influence of wire feed rate *F*, open circuit voltage *Vo* and preheating current remains same for both the electrode polarities. Two variables of the ASAW process, Welding speed *S* and Nozzle to plate distance *D* were not found to have any significant effect on welding voltage V_w, so dropped out from the model.

Effect of electrode polarity on welding voltage V_w

Effect polarity on welding voltage is shown also in the Figure 4. The difference in the value of welding voltage is undoubtedly indicative that in case of electrode negative welding voltage requirement is higher than that of electrode positive polarity. The values of welding voltage shown in figure 4 at the two polarities correspond to the condition when all the other process parameters are kept constant at their middle levels. The requirement of high voltage at electrode negative polarity can be attributed to the fact that during the welding operation voltage drop at cathode (electrode with negative polarity) is considerably higher due to increased density of electrons around the electrode tip. Thus, to maintain the same welding current in the circuit and in turn to maintain the arc, welding voltage is to be increased. No interaction effects were observed between the process parameters for welding voltage. Simultaneous effects of process parameters on welding voltage (V_w) are shown with the help of response surface plots in Figure 5 to Figurer 7.

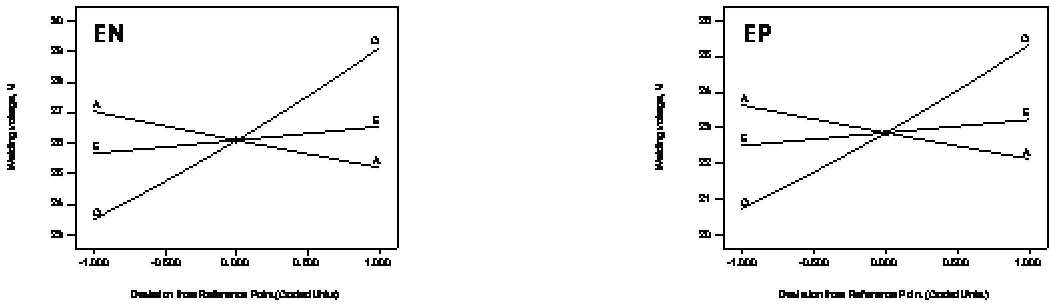

Figure 4: Effect of ASAW parameters on welding voltage (A: *F*, C: *Vo*, E: I_P)

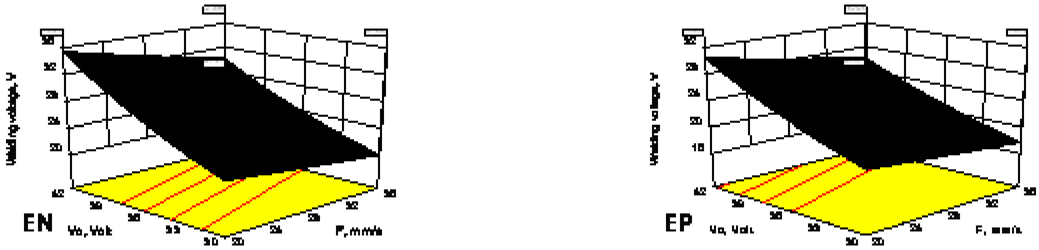

Figure 5: Surface graphs showing effect of open circuit voltage and wire feed rate on welding voltage

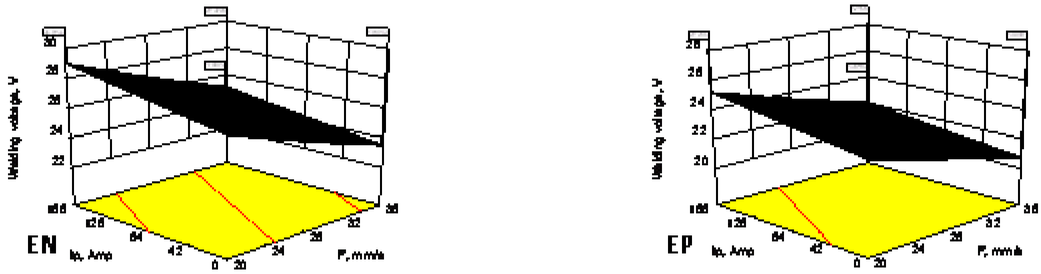

Figure 6: Surface graphs showing effect of preheating current and wire feed rate on welding voltage

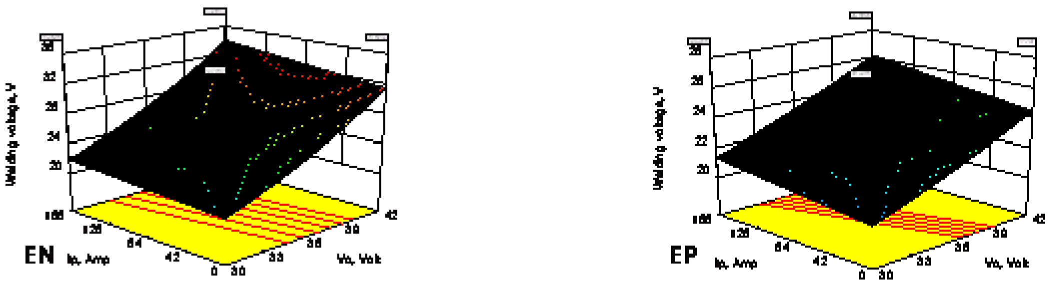

Figure 7: Surface graphs showing effect of preheating current and open circuit voltage on welding voltage

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