MATHEMATICAL MODELS FOR PREDICTION OF DILUTION AND BEAD GEOMETRY IN SINGLE WIRE SUBMERGED ARC SURFACING

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INTRODUCTION

Metal surfacing is a process in which a metal is deposited on the surface of a base metal (substrate) either to build it up to the dimensions required or to impart special surface properties such as resistance to wear, abrasion, impact of corrosion. It can be used in maintenance and repair applications to reclaim worm parts, or it can be used as a part of the production process in the manufacture of new articles (1). The practice of surfacing has been commonly used for the past sixty years or so first with manual metal arc welding electrodes, then with semi-automatic and automatic processes, using continuous wires, such as gas-shielded arc or submerged arc welding. As success of weld overlays especially stainless steel overlays was demonstrated, the use was expanded to larger and larger areas with the development of new techniques and processes such as addition of cold or hot filler wires, multiple wires, oscillating welding heads, single or multiple strips, addition of metal powders, etc. The internal surfaces of paper digesters, urea reactors, atomic reactor containment vessels and pressurisers, hydrocrackers, to name some of the more spectacular examples, are often overlaid by welding to produce such a corrosion resistant surface(2).

Submerged arc strip cladding is one of the popular methods employed for surfacing the inside surface of thick walled pressure vessels (3). However, the process cannot be used for cladding all sizes and shapes and for positional surfacing because of the width of the strip electrode and the size of the molten pool. Offen single wire submerged arc cladding is considered as a cost effective technique to overlay smaller areas.

In cladding by a welding process, the most important aspect is the dilution of the filler metal with the base metal due to the arc penetration. Dilution reduces the alloying elements and increases the carbon content in clad layer which leads to decrease in the corrosion resistant properties, percentages of delta ferrite content and other metallurgical problems (4,5). Also, control of dilution plays an important role in the economics of the weld cladding processes because the economics of stainless steel cladding are dependent on achieving the specific chemistry at the practical deposition rate in minimum number of layers. Although each process has an expected dilution factor, it is essential to establish a cladding procedure which will minimize its effects, consistent with good bonding and a sound deposit.

Also, with the increase in mechanization and automation in arc welding and cladding, the selection of welding procedures must be more specific to ensure that adequate weld bead quality is obtained (6). Further, for the effective utilization of automated welding processes it is essential that a high degree of confidence be achieved in predicting the weld bead geometry (7,8) to attain the desired mechanical and corrosion reisstant properties because the bead profile determines the amount of dillution involved. These requirements necessitate the development of mathematical models or equations relating the weld bead dimensions to the important controllable process parameters affecting the bead dimensions for establishing a cladding procedure. The equations can as well be fed to the computer which controls the automated caldding system and also could be utilized for the development of expert systems.

To develop mathematical models, a 31 point central composite rotatable design matrix was employed to carry out a set of experiments. The experimental data so obtained was used to develop methematical models for predicting weld bead geometry and to select welding parameters for depositing 316L stainless steel onto structural steel IS : 2062

This paper deals with the response surface analysis of the developed mathematical models capable of accurate prediction of weld bead dimensions viz., depth of penetration, weld width, height of reinforcement and dilution for the input process parameters of arc voltage, wire feed rate, welding speed and nozzle-to-plate distance. All these bead dimensions are depicted in Figure 1. The interaction effects of the control parameters on dilution and bead geometry have been presented in graphical form, which is more useful in selecting cladding procedural parameters to achieve the optimum dilution in overlay.

AREA A IS ADDED METAL
AREA B IS BASE METAL MELTED

$$DILUTION = \frac{B}{A+B}$$

$$\% \ DILUTION = \frac{B}{A+B} \times 100$$

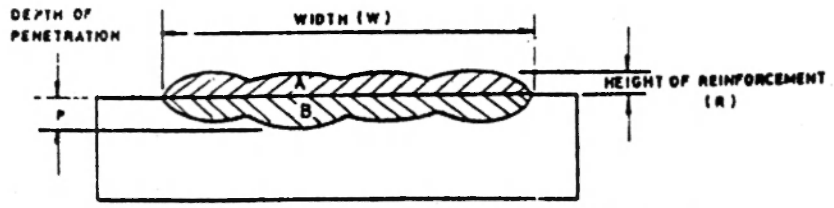

Fig 1 : Weld bead geometry

Development of Mathematical models

The procedure for the development of methematical models to predict the bead dimensions based on response surface mechodology is :

* Identifying important process control variables.
* Finding upper and lower limits of control variables viz., open circuit voltage (V), wire feed rate (F), welding speed(s) and nozzle-to-plate distance (N)
* Developing design matrix.
* Conducting experiments as per design matrix.
* Recording responses, viz., penetration (P), weld width (W), reinforcement(R), and dilution (D).
* Development of mathematical models
* Calculating coefficients of polynominals
* Checking adequancy of developed models.
* Testing significance of regression coefficients and arriving at final mathematical models.

For present study, welding parameters were selected to study their effects on bead geometry. The levels of process parameters were decided from trial runs conducted by inspecting for smooth bead appearance and absence of any visible defects viz., surface porosity, undercut, etc. and the same with their units and notations are given in Table 1. An automatic submerged arc welding system was employed for surfacing low carbon structural steel with 316L stainless steel of 3.15 mm dia, using stainless steel flux grade 1. Surfacing was done by laying four beads each of

Table 1
CONTROL PARAMETERS AND THEIR LEVELS OF SA SURFACING (316l WIRE, 3.15 mm DIA)

Parameter	Units	Notation	Factor Levels -2	-1	0	1	2
Open Circuit Voltage	Volt	V	36	38	40	42	44
Wire Feed Rate	m/min	f	1.26	1.52	1.78	2.04	2.3
Weldding Speed	m/min	S	0.04	0.56	0.72	0.88	1.04
No/le-to-plate Distance	mm	N	30	34	38	42	46

150 mm length with an overlap of 2 to 3 mm using positive polarity. All necessary details for conducting the experiments as per the evolved design matrix of central composite rotatable design and developing the final mathematical models including checking the adequency of those models have been well detailed (9).

The final models relating the various process parameters to the weld bead geometry are presented below :

$$P = 2.763 + 0.0454\ F - 0.296S - 0.131\ N - 0.124FS \quad (1)$$

$$R = 2.681 - 0.138V + 0.242\ F - 0.319\ S + 0.097\ VS + 0.147S^2 \quad (2)$$

$$W = 37.863 + 1.933\ v + 0.775\ F - 4.542\ S - 0.827\ F^2 \quad (3)$$

$$D = 42.552 + 0.667\ V + 2.358\ F + 0.197\ S - 1.062\ N - 1.83\ VS \quad (4)$$

Response Surface Analysis

Based on the mathematical models developed for predicting the weld bead dimensions, the effect of individual welding parameters and their significant interaction on penetration depth, reinforcement height, weld width and dilution were calculated. The interaction effects of welding parameters on various response parameters have been presented graphically for spontanelty analyses. Contour plots and perspective response surfaces were drawn to visualize their nature, Graphs constructed with help of such models gave satisfactory explanation about the effect of various welding variables on weld bead geometry.

Direct effects of welding variables

From equations (1) to (4), it is apparent that penetration (P) decreases with increases in NPD, and open circuit voltage(V) has no influence on P. Reinforcement (R) increases with incerases in wire feed rate (F) but R is not influenced by NPD. Weld width (W) increases with increase in (V) but decreases with welding speed (S). W increases to a maximum value with increase in F, then it decreases with further increase in F. Dilution increases with increase in F but decreases with increase in NPD. These direct effects of process parameters on bead geometry have been published (9).

Interaction Effect of Welding variables

Interaction of wire feed rate and welding speed on penetration

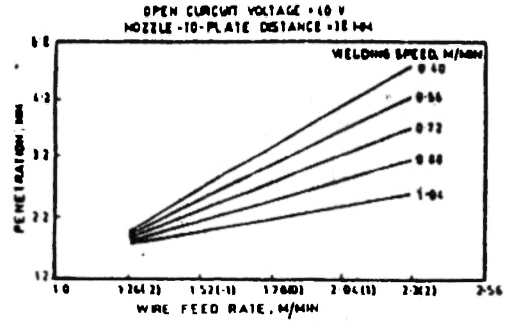

Fig 2 : Interaction effect of wire feed rate and welding speed on penetration in submerged arc surfacing (316 L wire, 3:15 mm dia)

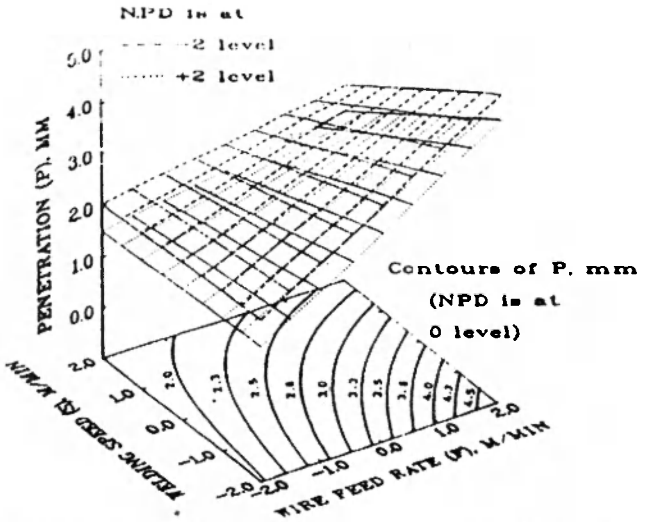

Fig 3 : Interaction effect of wire feed rate and welding speed on penetration in SA surfacing (316 L wire, 3:15 mm dia)

It is obvious from the Figures 2 and 3 that high wire feed rate and low welding speed increased P but low wire feed rate and high welding speed reduced it. This is attributed to the fact that welding current increased with the raise in F resulting in enhanced heat input per unit length of the weld bead and higher current density causing larger volume of the base plate to melt and hence deeper penetration. P decreases with the increase in S due to the reduced heat input per unit length of weld bead as S increases. Due to the reduction in heat input melting of base metal was slowed down and occured near the surface of the base metal resulting in shallower penetration. As F and S had entirely opposite effects on P and they got added when S was low resulting deeper penetration and their effects got subtracted when S was increased causing shallower penetration.

The contour plot in Figure 3 shows that at any value of F increase in S reduces P and the rate of decrease in P and S increases in high when F is high.

Similarly, P increases with increases in F at all levels of S and the rate of increase in P as F increases is high when S is low. The penetration surfaces shown in the figure are twisted planes and represent that P decrease slightly when NPD is changed from lower level to upper level for all values of F and S. This is due to the direct effect of NPD on P.

Interaction of open circuit voltage and welding speed on reinforcement (R)

From Figures 4 and 5 with rise in V,R drops for the range of speed from 0.4 m/min to 0.88 m/min. and within this speed range R decreases as S increases at all levels of voltage which is more apparent from the contour plot. But at higher level of speed i.e. at 1.04 m./min., R increases slightly with rise in voltage. When S is high its effect on reducing width may be higher than the effects of increasing width by voltage and hence very little increase in R could be possible and this is also evident from the contour plot. R is maximum when V and S are at their low levels. Also from the response surfaces shown, R increases with rise in F and NPD at all levels of V and S.

Interation of open circuit voltage and welding speed on dilution (D)

It is apparent from Figures 6 and 7 that either high voltage and high speed or low voltage and low speed diminished D. Similarly, either high voltage and low speed

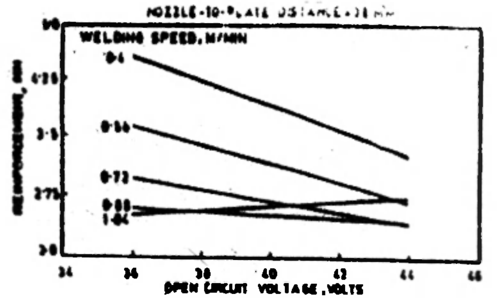

Fig 4 : Interaction effect of wire feed rate and welding speed on penetration in SA surfacing (316 L wire, 3.15 mm dia)

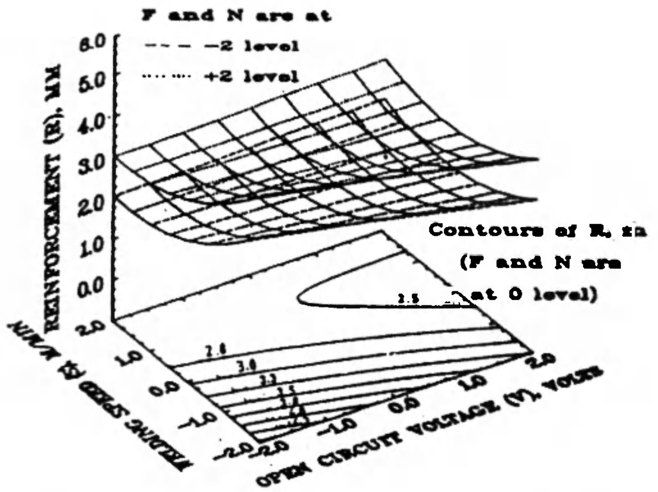

Fig 5 : Interaction effect of wire feed rate and welding speed on penetration in submerged surfacing (316 L wire, 3.15 mm dia) or low voltage and high speed raised D. But D is not altered when both are at their intermediate level. This is due to the opposing effects of voltage and speed on D and the heat input to the system increasing when S decreases, hence melting of more base metal resulting in more dilution. Also, when S increases metal deposited per unit length decreases even with the increase in voltage resulting lower dilution as area of metal deposited decreases. The effect of S on reducing P and R is more than that of increasing P and reducing R by V when S is high. This is more clear from the contour graph shown in Figure 7. It is seen from the response surfaces that rise in F and NPD raised D at all levels of voltage and speed and this was due to the net effect of F on D and NPD on D in which effect of F on D was more pronounced than that of NPD. Lower D is obtained when voltage, speed and wire feed rate are kept at their low levels(-2) and NPD at its high level (+2).

CONCLUSIONS

The following conclusions were arrived at from the above investigations :-

(1) Response surface methodology can be easily employed to visualize the effects of process parameters on bead dimensions. The two-way interaction effects can be easily revealed with the help of plotting perspective surfaces and contour diagrams.

(2) High wire feed rate and low welding speed increased penetration while low wire feed rate and high welding speed reduced it.

(3) Reinforcement was maximum when both voltage and welding speed were at their low levels. But increase in voltage did not affect reinforcement significaltly when welding speed was above 0.88 m/min.

(4) Either high voltage and high welding speed or low voltage and low speed produced lower dillution. High dillution was produced when voltage was high and speed was low. But dilution was not significantly affected when any one factor was kept at its intermediate level and the other was altered.

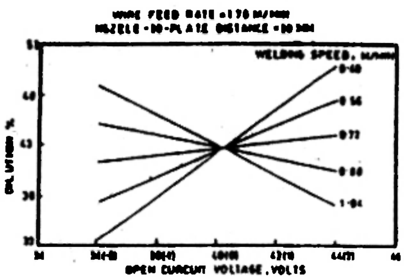

Fig 6 : Interaction effect of wire feed rate and welding speed on dilution in submerged arc surfacing (316 L wire, 3.15 mm dia)

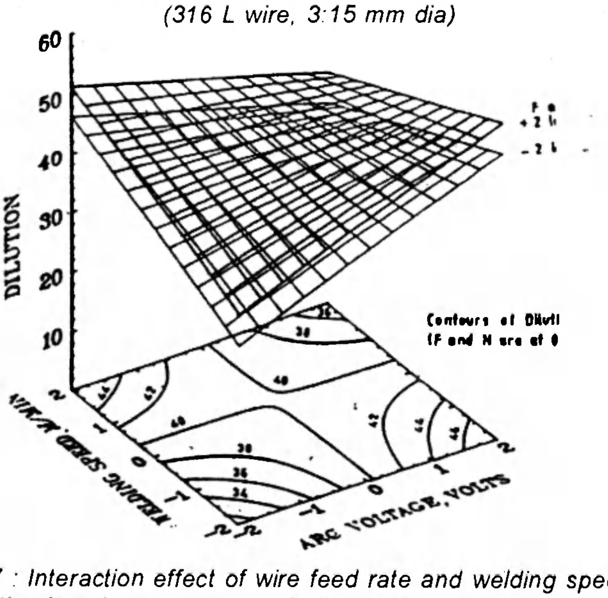

Fig 7 : Interaction effect of wire feed rate and welding speed on dilution in submerged arc surfacing (316 L wire, 3.15 mm dia)

REFERENCES

(1) Horsfield, A.M., Weld Surfacing and Hardfacing. The Welding Institute, Abington Hall, 1980. p 32-39.

(2) Stewart, J.P., The Welder's Handbook, Restor Pubi, Co., Inc, Virginia, 1981, p 163 - 219.

(3) Wyile, R.D. Mc. Donald,J., Jr., and Lowenberg, A.L., Weld deposited cladding of pressure vessels, British Weld, 12, 8 (1965), p 378 - 393.

(4) Prasad Rao, K. and Prasannakumar, Investigations into characteristics and corrosion behaviour of strip cladding. Proc. of National Welding seminar, IIW, India 1981, p 29-37.

(5) Gautam. D.K., and Breazu M., Some aspects of MIG stainless steel cladding. Inf. Cont. on Welding Tech., Sept. 1988, Uni. of Roorkee, India, pl-145 to 1-151.

(6) Mcglone, j.C., Weld bead geometry prediction - A review, Met, Constn., 14(1982), p 378 to 384.

(7) P Harris, P., and smith, B.L., Factorial techniques for weld quality prediction, Met., Constn., 15 (1983), p 661 to 666

(8) Reveendra J., and Parmar, R.S., Mathematical models to predict weld bead geometry for flux cored arc welding, Met. Constn., 19(1987), p 31R to 35R.

(9) Murugon, N, and R.S. Parmar, Effect of submerged arc process variables on dilution and bead geometry in single wire sirfacing, Jnl. of Materials Processing Technology, 37 (1993), p 767 - 780