A MATHEMATICAL MODEL TO PREDICT AND OPTIMISE THE GAS METAL ARC HARDFACED STELITE 6 WELDBEAD ON LOW CARBON STEEL

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ABSTRACT

This paper comprises an experimental investigation to predict and optimize the parameters of gas metal arc hard facing using Design of Experimental technique. In this investigation a stellite 6 (cobalt chromium alloy) was deposited on the low carbon steel by gas metal arc welding process, weld bead geometry is highly influenced by the process parameters so, it should be optimized to attain a defect free weld. Minitab version 10.0 software was used to develop the mathematical model and to find the optimized gas metal arc welding (GMAW) parameters. The adequacy of the developed models was checked by using Anova technique. Finally, main and interaction effect of process parameters on responses were presented in the graphical form.

Keywords: Gas Metal arc welding, Hardfacing, Design of Experiments, Anova technique.

Introduction

Wear and corrosion are the two major problems in all metallic components. To solve these problems; hardfacing technique was grown considerably in recent years. Hardfacing, one of the surfacing techniques, is the process of applying a layer of wear resistant metal onto the required metal

Wu et all [6] reviewed various cobalt and nickel alloys, their available product forms and the corresponding hardfacing methods. Foroulis [7] , compared the wear and corrosion properties of three classes of alloys; Cobalt base alloys, Nickel base alloys and Trib alloys. He presented that alloys T – 400 and ST – 6 exhibits excellent galling resistance in addition to good wear resistance and very good corrosion resistance in a variety of environments. Nickel base alloys generally have inferior galling resistance. Jong-Ning Aoh et al [8] assert that the stellite 6 with approximate composition of Co-28Cr-4.3W1.1 (wt. %) was the most used widely because of its good wear and corrosion resistance and especially its good weldability to different steels. He predicted that carbon had the greatest influence on the microstructure of stellite 6. It combines with chromium to form very hard carbides, which are responsible for the high room temperature hardness.

Tungsten is indispensable to ensure that the alloys retain high hardness at elevated temperatures. The tungsten addition must be higher in high carbon alloys than in low carbon ones, since any carbon that does not combine with the chromium will combine with some of the tungsten and cobalt in the solid solution to form carbides of the η̃-Co_3 W_3C type and it is the tungsten that remains in solid solution, which appears to be responsible for the high temperature properties of the alloys.

Grainger [1] presented the history, composition and properties, deposition of hardfacing, hardfacing applications and problems in hardfacing of cobalt based alloys. He also reported that the stellite 6 alloys, in addition of being in stainless steel, are non-toxic and are safely used for food processing industries in the human body. Nadkarni [9] stated alloy rods can be deposited easily by oxyacetylene or gas metal arc welding. For small jobs of low carbon metals upto 0.40% carbon preheating is not required. Although there is no pickup of carbon the hardness of the deposit is affected, as the base metal dilution is higher. DC current with reverse polarity is preferable, as it is more stable. Cobalt base alloys contain carbon, chromium, tungsten, silicon, nickel, molybdenum and iron.

Welding is one the major hardfacing technique and it has been widely used in fabrication industry. Various welding processes can be employed for hardfacing; among those, gas metal arc welding and plasma transferred arc welding processes are widely used in industries. When compare to plasma transferred arc welding the gas metal arc welding process has many advantages like superior quality of weld, high accuracy and low equipment cost and ease control [2] because heat input in the plasma transferred arc welding is considerably more so it may lead to the recrystallization of the base metal and promotes the service failure of the component. For this reason, most of the industries have been using gas metal arc welding process for hardfacing. Defect free deposit can be made without preheating by gas metal arc welding process [3] and argon gas can be used as shielding gas for gas metal arc welding process [4]. In this weld bead geometry is highly influenced by the gas metal arc welding process parameters so, it should be optimized to attain a defect free weld

Plan of investigation

This research work was planned to carry out in the following steps:

1. Identifying the important process parameters and their working range
2. Developing the design matrix
3. Conducting the experiments according to the design matrix and Recording the responses
4. Developing the mathematical models and calculating the model coefficient
5. Testing the adequacy of models
6. Presenting the main and interaction effects of process parameters in graphical form.
7. Optimization and conclusion.

Identifying the of important and independent process parameter and their working ranges

Based on the impact on weld bead geometry, ease of control and capability of being maintained at the desired level, three independently controllable GMAW process parameters were identified namely, welding current (I), the filler rod feed rate (F), and the welding speed (S). The experiment was conducted to deposit a single layer of stellite 6 (cobalt chromium alloy) on low carbon steel keeping electrode negative. Trail runs were conducted by varying one of the process parameters at a time while keeping the rest of them at constant values [7, 10]. The working range was fixed by inspecting the bead for a smooth appearance and the absence of visible defects. The upper and lower limits were coded as 1 and 5 respectively and shown in Table.1 the coded values for intermediate values are calculated by the following equation:

Xi = 2{2 X – (X max – X min)}/ (X max –X min)

Where,

Xi = required code value of a variable X

X = any value of the variable from X max to X min

X min = the lowest level of the variable

X max = the upper level of the variable

Table.1 Ranges and Levels of Control Parameters.

Parameter	Units	Notation	Factor level				
			1	2	3	4	5
Welding current	Amps	I	225	217.7	210	202.2	195
Welding speed	Cm/ min	S	28	27.04	26	24.96	24
Filler roe feed rate	Cm/ min	F	15	14.51	14	13.48	13

Developing the design matrix

Factorial designs are most frequently employed in engineering and manufacturing experiments. Factorial design is appropriate when several factors are to be investigated at two or more levels and interaction effects are important. Several factors are investigated at several levels by running all combinations of factors and levels. The direct and interaction effects were estimated independently; Minitab version 10.0 was used to develop the design matrix; selected matrix is three factors five level factorial designs consist of 25 experimental runs as detailed below [9, 11]:

1. Complete 2k factorial design, k is number of factors which are called as the factorial portion of the design.

2. For three factors the factorial portion is 23 = 8.

3. Center points (no ≥ 1) = 11.

4. Two axial points on the axis of each design variable i.e. Minimum and maximum, for three factors (3x2) = 6.

5. The total number of design points is thus, 2k + 2k + no = 25.

The responses are dilution (D), Penetration (P), reinforcement (R) and bead width (W). Five levels of each parameter were used in the experimental design. The coded forms are used to represent the actual values of the process parameters or factors. Tabel.2 shows the developed design matrix.

Conducting the experiments according to the design matrix and Recording the responses

stellite 6 filler rod of 2.15 mm diameter and 500 mm in length was used for depositing stellite 6 on valve seat rings having 50 mm outer diameter, 36 mm inner diameter and 30 mm thickness. The experiments were conducted as per design matrix at random, to avoid the possibility of systematic errors infiltrating into the system. The welded specimens were obtained by cutting hardfaced seat rings radially by

Electro Discharge Machining (EDM) process. The weld bead profiles were traced using a reflective type profile projector and the bead dimensions were measured with the assistance of optical profile projector, digital planimeter. The observed values of P, R, W and the calculated values of dilution percentage are shown in Table.2 along with the design matrix.

Table.2 Design Matrix and Bead Dimensions

Trail No.	Process variables			Bead parameters			
	I	F	S	P	R	W	D %
01	1	1	1	0.352	2.721	12.482	11.455
02	1	2	2	0.313	2.845	12.356	9.911
03	1	3	3	0.194	2.631	12.459	6.867
04	1	4	4	0.333	2.542	11.521	11.583
05	1	5	5	0.252	2.754	10.892	8.383
06	2	1	2	0.283	2.831	10.561	9.088
07	2	2	3	0.323	2.92	11.321	9.96
08	2	3	4	0.232	2.785	10.254	7.69
09	2	4	5	0.218	2.765	11.265	7.308
10	2	5	1	0.345	2.542	12.369	11.95
11	3	1	3	0.271	2.426	11.358	10.048
12	3	2	4	0.325	2.345	12.357	12.172
13	3	3	5	0.251	2.159	10.354	10.415
14	3	4	1	0.268	2.357	12.359	10.21
15	3	5	2	0.371	2.526	12.658	12.806
16	4	1	4	0.384	2.42	10.956	13.695
17	4	2	5	0.421	2.338	10.865	15.259
18	4	3	1	0.182	2.625	10.859	6.484
19	4	4	2	0.376	2.715	10.367	12.164
20	4	5	3	0.282	2.78	12.356	9.21
21	5	1	5	0.261	2.891	11.956	8.28
22	5	2	1	0.242	2.562	10.268	8.631
23	5	3	2	0.325	2.653	11.659	10.93
24	5	4	3	0.321	2.569	12.356	11.107
25	5	5	4	0.333	2.346	12.834	12.43

Developing the mathematical models and model coefficients

The response function representing any weld bead dimension can be expressed as,

Y = f (I, S, F)

Where, Y = Response function.

b_0, b_i = Regression co-efficient.

X_i = Parameters or variables

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i$$

For three factors the selected polynomial (regression) equation could be expressed as:

$Y = b_0 + b_1 I + b_2 S + b_3 F$

The values of the regression co-efficient give an idea to what extent the control variables affect the responses quantitatively. The values of the co-efficient of the polynomial were calculated by regression method using Minitab version 10.0 software packages. The regression co-efficient are presented in Table.3

Table.3 Regression Coefficients

Coefficient	Value			
	P	R	W	%D
b_0	0.139793	4.475622	10.72647	-2.38238
b_1	0.000843	-0.00478	-0.00404	-0.044377
b_2	-0.00026	-0.01436	0.172388	0.035175
b_3	-0.00078	-0.0345	-0.19329	0.172377

The final mathematical models as determined by the above analysis are presented below:

Penetration (P) mm = 0.139793 + 0.000843 x I - 0.00026 x S - 0.00078 x F

Reinforcement (R) mm= 4.475622 - 0.00478 x I - 0.01436 x S - 0.0345 x F

Bead width (W) mm =10.72647- 0.00404 x I + 0.172388 x S - 0.19329 x F

Dilution (D) % = - 2.38238 - 0.044377 x I +0.035175 x S + 0.172377 x F

Testing the adequacy of models

The adequacies of the models were tested using the analysis of variance technique (ANOVA). According to this technique, if the calculated F value exceeds the standard tabulated value of the F for a desired level of confidence (say 95%), then the model can be considered as adequate. The results of Anova technique are presented in Table.4

Table.4 Anova Results

Bead Parameter	Sum of Square		Degree of freedom		Calculated F-value	Tabulated F-value	Remarks
	Regression	Residual	Regression	Residual			
P	0.002	0.088	3	21	0.922	0.159	Significant
R	0.096	0.882	3	21	0.780	0.765	Significant
W	0.738	0.737	3	21	0.411	0.380	Significant
%D	2.050	5.245	3	21	0.760	0.590	Significant

Direct Effects of Process Parameter on Bead Geometry

The direct effects of process parameters on bead geometry were presented in Fig.1-3 It is clear from Fig.1 that penetration and percentage of dilution increases with increases of welding current, keeping the other variables constant. This is due to the fact that the increase in welding current resulting in enhanced heat input, causing large volume of the base metal to melt and hence deeper penetration and more dilution. Reinforcement and bead width are not significantly affected by welding current.

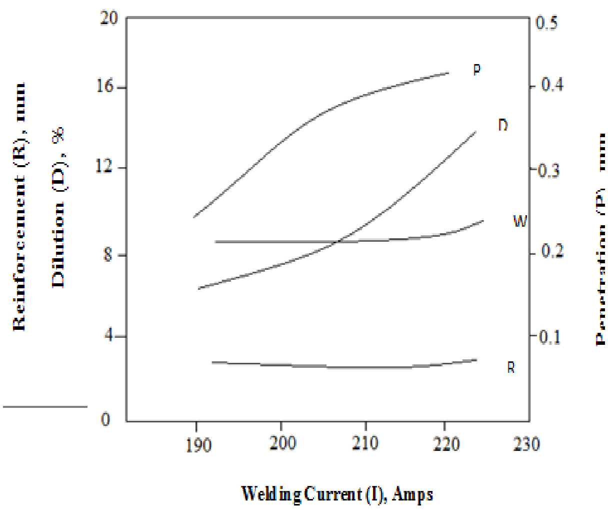


Fig.1 Direct effect of Welding current on bead parameters

Fig.2 depicts dilution decrease with increases of feed rate at the same time bead width increases. This is due to the fact that maximum heat input is utilized for melting the filler rod and less melting of base metal.

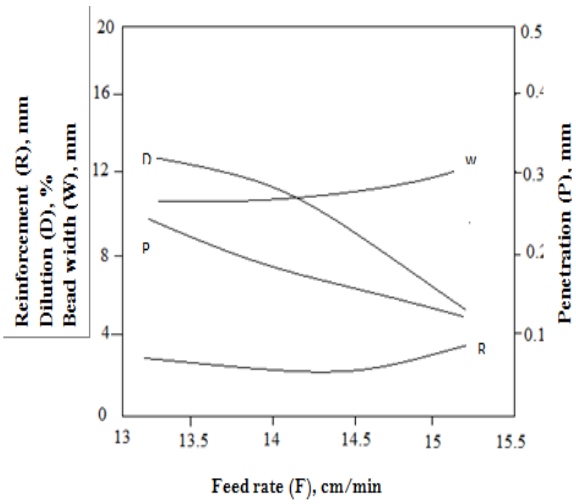


Fig.2 Direct effects of Feed rate on bead parameters

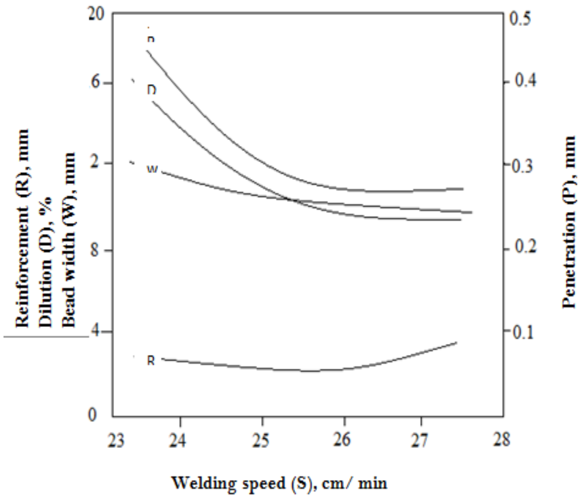


Fig 7.3 Direct effect of welding speed on bead parameters

From Fig.3 reinforcement decreases slightly with the increases of welding speed, also penetration, dilution and bead width initially with the increase in welding speed. Less melting of base metal and filer rod is taking place while increasing welding current.

Interaction Effects of Process Parameters on Bead Geometry

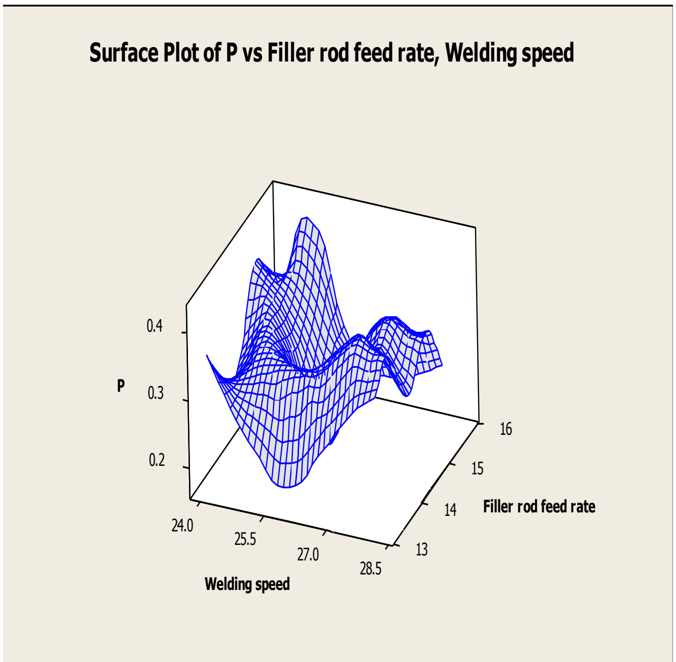


Fig.4 Interaction Effect of F and S on Penetration

It is clear from Fig.4 that penetration (P) increases in its surface plot for an increases in filler rod feed rate (F) with decreases in welding speed (S) however when the welding speed increases the penetration (P) reaches its minimum

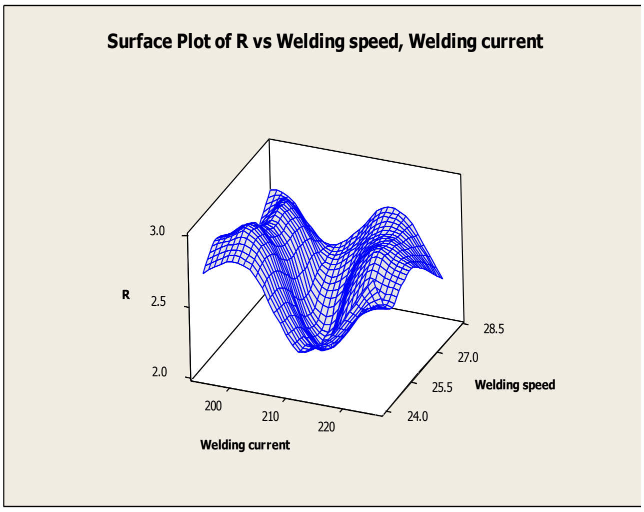
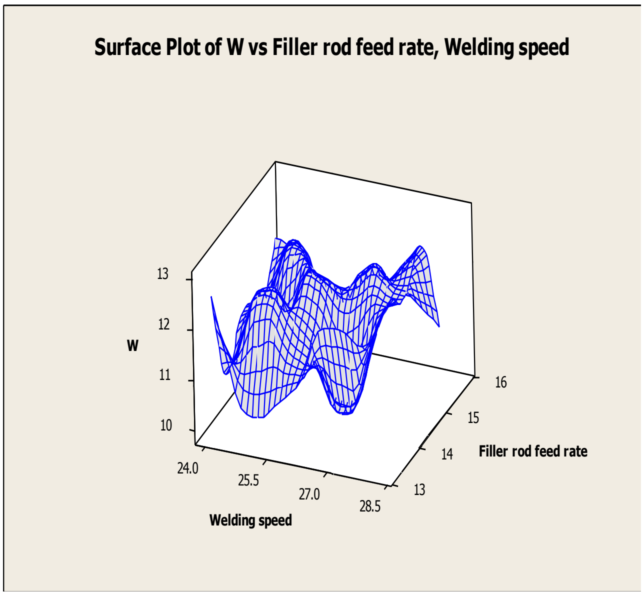


Fig.5 Interaction Effect of I and S on Reinforcement

It is evident from Fig.5 reinforcement (R) reaches maximum when the welding current (I) and welding speed (S) is at minimum condition. However while increase in welding current (I) the reinforcement (R) decreases suddenly and increases slightly upto some extend.



With reference of Fig.6 the bead width,W decreases to its minimum when the Filler rod feed rate, F is at maximum and reaches to its maximum when the filler rod feed rate is maximum.

Fig.6 Interaction Effect of F and S on Bead Width

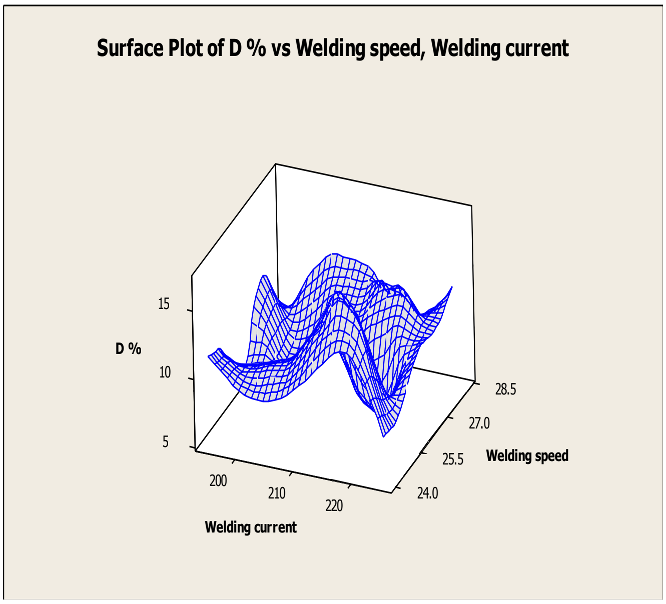


Fig.7 Interaction Effect of S and I on Dilution

It is evident from Fig.7 the Dilution value, D reaches its maximum with an increase in Welding current, I to the optimum value this is due to the fact that more heat energy is consumed by base metal and dilution decreases when welding speed is minimum.

Optimization and conclusion

Minimization of bead geometry was the main purpose of the present study while keeping in mind other important bead parameters within their constraints. This was done to retain the metallurgical properties of the deposited metal. The optimization model is a non-linear equation with constraints (the codes for minimizing the dilution was derived from the self-generated optimization module of Microsoft Word software package version 2007). The objective function selected for optimization was the percentage of dilution. The constraints of the equation were penetration, reinforcement, width and total area.

An optimization routine algorithm available from Microsoft Excel Software version 2007 was invoked. The lower boundary limits was set to variables as 5, 5, 5. The upper boundary limits was set to variables as 1, 1, 1. For these parameters values, the optimum values of the process parameters and their corresponding bead geometry obtained were:

Welding Current, (I) = 217 Amp

Welding Speed, (S) = 24.93 cm/min

Filler rod feed rate, (F) = 15.10 cm/min

Penetration (P) = 0.268 mm

Reinforcement (R) = 2.751 mm

Bead width (W) = 11.523 mm

Dilution % (D) = 9.413 mm

Reference:

1. Gregory E.N, (1980) 'Surfacing by Welding-Alloy Processes, Coatings and Material Selection, Metal Construction', pp. 685 – 690.

2. Jean Cornu, (1988) 'Advanced Welding Systems', IFS Publications Ltd., U.K., Vol. 2, pp. 56-59.

3. Albert S.K, Gowrisankar I, Seetharaman V, and Venkatesan S, ' Effect of Welding Parameters on the Microstructure of Stellite-6 Deposits', Proceedings of National Welding Seminar, IIW, Bangalore., Nov.26-28, pp. A1-A7.

4. Larry Jeffus, 'Welding Principles and Applications', 4th Edition, Delmar Publishers, New York, 1999.

5. Budinski K.G, (1986) 'Hardfacing, An Overview of the processes', Welding Design and Fabrication, pp. 51-57.

6. Wu J.B.C. and Redman J.E, (1994) 'Hardfacing with Cobalt and Nickel Alloys', Welding journal, pp.63 -68.

7. Foroulis Z.A, (1979) 'Guidelines for the selection of hardfacing alloys for Sliding Wear Resistance Application', TMS –AIME, New York, pp. 203 – 218.

8. Jong-Ning Aoh, (1999), 'On the wear behavior of surface clad layers under high temperature', wear 225-229, pp. 1114-1122.

9. Nadkarni S.V., (1996) 'Modern Arc Welding Technology', Oxford & IBH Publishing Company Pvt. Ltd.

10. Dennis Destefan, (1995) 'Basics to know when choosing a GMAW &GTAW power source', Welding Journal, pp. 67-72.

11. Stanley Merrick, (1994) 'Hardfacing extends the life of steel Mill Continuous Casters', Welding Journal, pp.63-70.

