Application of Response Surface Methodology for predicting Weld Distortion and % of Dilution in Gas Metal Arc Welding of SS409M

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Abstract-- **Response surface methodology (RSM) is a mathematical tool used to find and represent the cause and effect relationship between responses and input variables. An experimental regression equation was developed by using RSM. In the present work, the effect of wire feed (f), welding speed (s) and torch angle (θ) on weld distortion and % of dilution were investigated in 4mm SS409M steel plates by Gas Metal Arc Welding process (GMAW). The main objective of the study is to find the minimum bowing distortion and finding the range % of dilution to obtain quality weld. It is observed that GMAW process parameters have considerable influence on welding distortion and % of dilution. Design Expert software is used as optimizing tool.**

Index Term-- **SS409M, Gas Metal Arc Welding process, RSM, Mathematical models, Central composite design, Wire feed, Welding speed, Torch angle, Distortion and % of dilution.**

1. INTRODUCTION

Ferritic Stainless steel is used instead of Austenitic stainless steel because of low production cost, high ductility, good corrosion resistance and high temperature oxidation. Ferritic Stainless steels (FSS) belongs to the stainless steel which is having face centered cubic structure, [1]. FSS is noted for stress corrosion cracking and pitting corrosion when it is used in chemical environment [2]. SS 409M is a modified version of SS 409 of Ferritic grade with 0.03% carbon content. SS409 M replaces carbon steels and low alloy steels where higher strength, abrasion resistance, weld-ability and slide-ability are required. It posses very good scaling & oxidation at elevated temperature including sulphur bearing atmospheres. The material is mainly used in transport wagons, petrochemical, agriculture, fishing, mining, quarrying & sewage plants [3].Welding is one of the permanent joint type fabrication process which is highly economical, faster and reduction in weight when compared with temporary fabrication process. GMAW welding process is that melts and join metals by heating them with an arc established between a continuously fed filler wire electrode and the metals. The process is used with externally supplied shielding gas without applying pressure [4]. Type of shielding gas and its flow rate also have effect on heat input [5]. It is a versatile welding process used in variety of metals and alloys. In this process the electrode used is consumable wire of 1.2 mm diameter wounded on a spool, which is fed through the weld through the welding torch nozzle. The shielding gas used is argon to protect the weld pool from the contaminants present in the air. If oxygen, nitrogen gases enter into the welding atmosphere it may cause porosity in the weld. This process is suitable for producing high quality welds even in high speed welding condition, and also this process reduce spattering and minimize the porosities in the weld [6].

Welded components undergo various types of distortions like longitudinal shrinkage, transverse shrinkage, angular and bowing etc [7]. These distortions are affected by different factors such as heat input, shape of penetration, joint type and plate thickness, etc [8]. % of dilution is the major factor deciding strength of the weld in parent metal, heat affected zone and weldment.

2. EXPERIMENTAL PROCEDURES

Fig .1 shows the experimental set up of Semi-automatic Gas Metal Arc Welding equipment with digital linear manipulator.

Fig. 1. Experimental setup of GMAW machine

Fig .2 shows the welded specimen in the fixture. The pulsed arc transfer is selected because it is suitable for all position welding and it is suitable process for 4 mm thickness plate [9]. 308L and 316L electrode are suitable for welding FSS grade steels [10-11]. 308L type filler shows better performance than 316L type of filler wire because the strength is 30% higher than the base plate. 2mm root gap is maintained while welding between plates. The experiment was designed based on five level factorial central composite design [12].

Fig. 2.Welded specimen in the fixture.

Table I shows the composition of SS 409M base plate and SS 308L electrode. Table II. shows the base plate dimension and welding conditions.

Table I
Chemical composition of SS 409M base plate and ASS 308L electrode.

Material	C	Mn	P	S	Si	Cr	Ni	Ti	Mo	Cu	Fe
AISI 409M	0.080	1.10	0.030	0.010	0.40	10.90	0.39	0.004	-	-	Bal
AISI 308L	0.035	0.82	0.018	0.015	0.67	19.0	11.0	-	0.01	0.1	Bal

Table II
Base plate dimension and welding conditions.

Base plate material	SS409M
Base plate size	150mm x 150mm x 4mm
Electrode material	ASS308L
Electrode diameter	1.2 mm
Shielding gas	Argon
Flow of shielding gas	14 lit/min
Joint type	Single V-Butt joint
Polarity	DCRP
NPD	12 mm
V-Groove	60°

3 Response Surface Methodology

In this paper application of RSM in developing mathematical models and plotting contour graphs relating input variables namely wire feed (f), welding speed (s), welding torch angle(θ) the measured output variables are weld distortion (d) and percentage of dilution (p) are discussed. The equations is represented in first order polynomial equation and second order polynomial equation, represented in eqn.(1)

Y = (s, f, θ). Where Y is the response.

In order to evaluate the weld distortion and % of dilution of the welded specimen, a regression equation is developed to correlate the process parameters.

$$Y = a_0 + a_1 f + a_2 s + a_3 \theta + a_{11} f^2 + a_2 s^2 + a_{33} \theta^2 + a_{12} fs + a_{23} s\theta + a_{31} f\theta \quad \text{.....eqn(1)}$$

Where a_0 the free term of the regression equation; the coefficients a_1, a_2, a_3 the linear terms; the coefficients a_{11}, a_{22}, a_{33} are the quadratic terms and the coefficients a_{12}, a_{23}, a_{31} are the interaction terms.

Most of the literature works concentrate on microstructure, micro hardness, tensile strength, impact strength and corrossion studies of the welded specimens. But the published information about GMAW welding process parameters on distortion and % of dilution in SS 409M plate is very much minimum.

4. Selecting Input Process Parameter, Developing the Design Matrix and Its Response

In this work, the input process parameters taken is wire feed (f) welding speed (s) and welding torch angle (θ). After conducting a number of trials by varying one of the process parameters and remaining is kept constant. The limits of the each process parameter is evaluated based on inspecting the bead smooth appearance. Table III briefs the limits of GMAW process parameters and their levels. Fig. 3 shows all the welded specimens. After welding the specimens were cut into to the required dimension with the use of power hacksaw.

Fig. 3. All the welded specimens

Table III
Input process parameters and their levels

S.no	Process Parameters	Units	Factor Levels				
			-1.682	-1	0	1	1.682
1	Wire Feed (f)	(mm/sec)	6.528	7.03	7.765	8.5	9.001
2	Welding speed (s)	(mm/sec)	2.659	3	3.5	4	4.340
3	Torch angle (θ)	(°)	69.886	75	82.5	90	95.113

After cutting, the weld bead surface is roughly polished in hand and by emery sheets. The etchant 5% Nital solution (1/20 of Nitric acid in ethanol)is applied on the surface of the weld bead. Distortion measurement is essentail part in prediction and control of distortion. Distortion in welded componets is measured by using photogrammetry [13]. By using vernier height gauge bowing distortion is mesured [14]. In this investigation the weld distortion and percentage dilution is measured by using Rapid – I Vision Measuring System (V 2015J LX) Model as given in fig. 4

Fig. 4. Rapid – I Vision Measuring System (V 2015J LX) Model

Table IV
Input process parameters and output response

Exp no	Wire Feed, f (mm/sec)	Welding Speed, s (mm/sec)	Welding torch angle, θ (degree)	Distortion, d (mm)	% of dilution , (p)
1	7.765	3.5	82.5	10.658	47.685
2	7.03	4	90	8.169	52.005
3	8.5	4	75	11.575	47.079
4	7.765	3.5	69.886	10.27	43.490
5	7.765	2.659	82.5	11.482	53.541
6	7.765	3.5	82.5	10.228	46.819
7	7.03	3	90	10.619	50.267
8	7.765	3.5	82.5	10.883	52.829
9	7.03	4	75	10.619	48.420
10	8.5	4	90	9.635	42.427
11	7.765	3.5	82.5	10.987	48.487
12	7.765	4.34	82.5	7.555	44.281
13	7.765	3.5	95.113	8.739	49.082
14	9.001	3.5	82.5	13.459	55.256
15	8.5	3	90	13.36	54.536
16	6.528	3.5	82.5	9.891	49.681
17	7.03	3	75	8.682	44.631
18	7.765	3.5	82.5	10.012	50.155
19	7.765	3.5	82.5	10.575	51.233
20	8.5	3	75	11.25	53.583

5. Results and Discussions

The analysis of variance for the factor d and p is made with the aim of analyzing the influence on f, s and θ. The analysis is for 5% significance level and 95% confidence level.

5.1 Statistical analysis for weld distortion (d)

In Table V wire feed, welding speed, two level interaction effect of (s x θ) had the significant effect on weld distortion. The f contribution is 30.80%, which is the most significant factor. Welding speed is contributing 19.79%. Weld angle contribution is least amount. The two level interactions, (s x θ) are 20.93%. The s x f, s^2 and θ^2 not have much impact on weld distortion.

Table V
ANOVA for weld distortion (w)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	% of Contribution	Remarks
Model	0.927641	9	0.103071	12.25668	0.0003		Significant
A-Wire Feed	0.315004	1	0.315004	37.45859	0.0001	30.80209	Significant
B-Welding Speed	0.203605	1	0.203605	24.21157	0.0006	19.79136	Significant
C-Torch Angle	0.01856	1	0.01856	2.207006	0.1682	1.501482	Not significant
AB	0.021489	1	0.021489	2.555364	0.1410	1.791033	Not significant
AC	0.00104	1	0.00104	0.123723	0.7323	-0.23011	Not significant
BC	0.215135	1	0.215135	25.58266	0.0005	20.93099	Significant
A^2	0.062914	1	0.062914	7.481391	0.0210	5.885475	Significant
B^2	0.041275	1	0.041275	4.908171	0.0511	3.746652	Not significant
C^2	0.035061	1	0.035061	4.169234	0.0684	3.132458	Not significant
Residual	0.084094	10	0.008409			87.35143	
Lack of Fit	0.067251	5	0.01345	3.992873	0.0774	0	Not significant
Pure Error	0.016843	5	0.003369			12.64857	
Cor Total	1.011735	19				100	

5.2 Statistical analysis for % of dilution (p)

In Table VI the individual factors s and the combined factors (f x s) are the factors contributing for **%** of dilution. The factor s contributes 20.42 % and (f x s) contributes 25.34 %. Both are the higher level of contribution in % of dilution. The factor (f x θ) contributes 6.23% and θ^2 contribution is 5.60%. The factors f, (s x θ) and f^2 contribution is weak.

Table VI
ANOVA for % of dilution (p)

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	% of Contribution	Remarks
Model	0.011615	9	0.001291	6.136223	0.0045		Significant
A-feed	0.000453	1	0.000453	2.155981	0.1728	1.399772	Significant
B-speed	0.003063	1	0.003063	14.56272	0.0034	20.42092	Not significant
C-angle	0.00084	1	0.00084	3.992158	0.0736	4.214872	Significant
AB	0.003738	1	0.003738	17.77273	0.0018	25.3423	Significant
AC	0.001117	1	0.001117	5.311125	0.0439	6.237022	Not significant
BC	0.000405	1	0.000405	1.923615	0.1956	1.043526	Not Significant
A^2	0.000732	1	0.000732	3.480226	0.0917	3.430014	Not Significant
B^2	5.17E-05	1	5.17E-05	0.245951	0.6307	-1.52855	Not Significant
C^2	0.00103	1	0.00103	4.896334	0.0513	5.601093	Significant
Residual	0.002103	10	0.00021			66.16097	
Lack of Fit	0.000796	5	0.000159	0.609056	0.7002	0	Not Significant
Pure Error	0.001307	5	0.000261			33.83903	
Cor Total	0.013719	19				100	

6. Regression Equations

The relationship between the input parameters and the measured response is modeled by quadratic regression equation.

The weld distortion (d) model is given in eqn (2). The determination coefficient (R^2) is 92.66

Distortion=-12.44771-(1.36985*B2)+(5.95708*C2)+(0.27676*D2)(0.14103*B2*C2)+(0.00206878*B2*D2)-(0.04373*C2*D2)+(0.12231*B2*B2)-(0.21407*C2*C2)-(0.000088768734*D2*D2) …eqn (2)

The % of dilution (p) is shown in eqn (3). The coefficient of determination (R^2) is 84.67%.

% of Dilution= -3.37826+(0.18568*B2)+(0.63628*C2)+(0.049125*D2)-(0.058819*B2*C2)-(0.00214361*B2*D2)-(0.0018964*C2*D2)+(0.013192*B2*B2)-(0.00757843*C2*C2)-(0.000150282*D2*D2)

The predicted values of response weld distortion (d) and % of dilution (p) are given in regression equations (3) and (4).

The predicted values are compared with the corresponding experimental values are shown in fig.5 and fig.6 the diagram shows values are almost nearer.

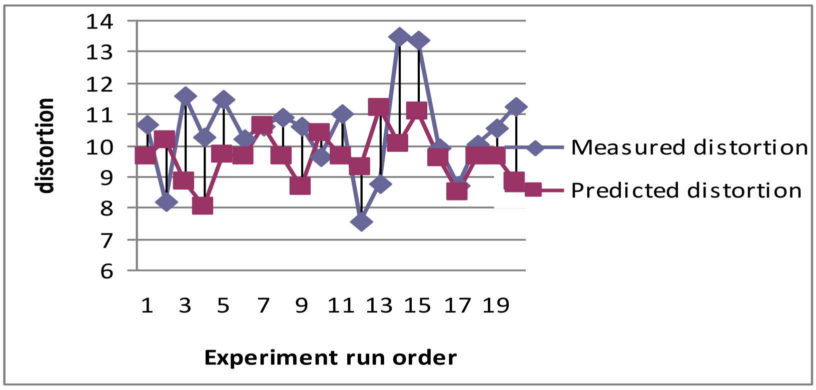

Fig. 5. Comparison between measured and predicted values for weld distortion

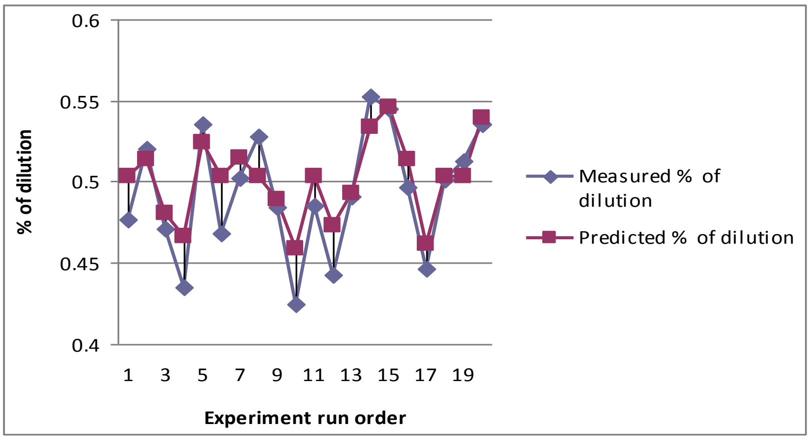

Fig. 6. Comparison between measured and predicted values for % of dilution

7. Effect of machining parameters on surface response factors

7.1 Distortion (d) Fig.7 shows the 3-d surface graph at wire feed at 7.77 mm/sec if welding speed s increases distortion value gradually reducing. The maximum distortion occurs at minimum welding speed and when the torch position is straight. Most significance interactions were found between wire feed f and welding speed s.ost

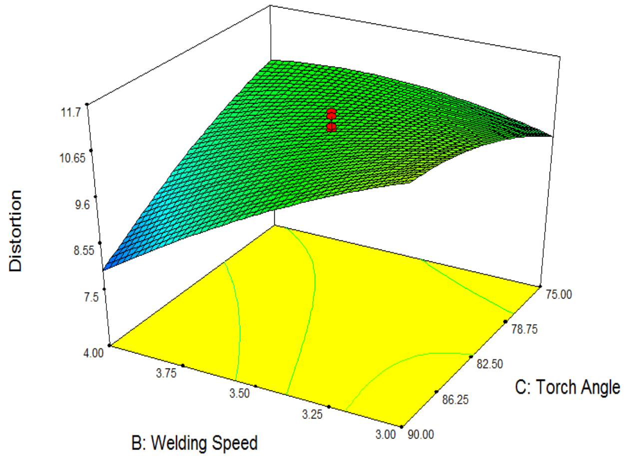

Fig. 7. Surface plots of weld distortion at Wire feed 7.77 mm/sec

7.2 % of dilution (p)

Fig.8 Shows graph of % of dilution. The p value is maximum when feed is at maximum level and speed is at minimum level. The objective of the study is to set the % of dilution level with in the range. The maximum % of dilution occurs when the wire feed is at maximum and the welding speed is at minimum. When the torch angle is at maximum position the dilution % is also at maximum level.

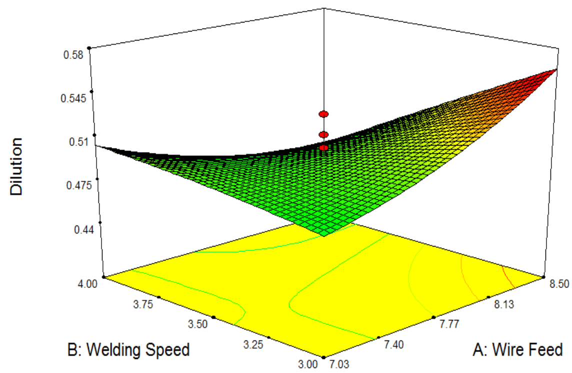

Fig. 8. Surface plots of % of dilution at Angle 82.5°

8. Optimization of Welding Conditions

The optimum welding condition for welding SS409M is achieved in the solution keeping the welding speed, feed in optimum level. Table VII. represents range of the input parameter and constraints of the response. Table VIII. represents the RSM optimization results in the order of decreasing desirability level. The optimized feed is 7.15 mm/sec, welding speed is 4 mm/sec and welding angle is 90°.

Table VII
Goal of constraints and its upper and lower limits

Name of the constraints	Goal	Lower limit	Upper limit
Feed (mm/sec)	Is in range	7.03	8.5
Speed (mm/sec)	Is in range	3	4
Angle (θ)	Is in range	75	90
Weld distortion (mm)	Minimize	7.555	13.459
% of dilution	Within range	42.4271	55.2567

Table VIII
Results of optimization

S.No	Feed (mm/sec)	Speed (mm/sec)	Angle (θ)	Weld distortion (mm)	% of dilution	Desirability
1	7.15	4	90	7.697287	0.500488	0.971998
2	7.13	4	90	7.697404	0.501527	0.971975
3	7.12	4	90	7.697661	0.502313	0.971924
4	7.19	4	90	7.698861	0.4969	0.971689
5	7.06	4	90	7.702448	0.507361	0.970987
6	7.04	4	90	7.705227	0.50905	0.970443
7	7.03	4	89.99	7.70789	0.509614	0.969922
8	7.3	4	90	7.71255	0.489556	0.969009
9	7.18	3.99	89.96	7.726832	0.49821	0.966216
10	7.38	4	90	7.734062	0.483906	0.964803

9. Conclusion

The investigation is done by using RSM, following conclusions are drawn

1. RSM approach investigate the influence of Wire Feed (f), Welding Speed (s) and Torch angle ( ) on weld distortion (d) and % of dilution (p).

2. Regression equation is formed for distortion (d) and % of dilution (p).

3. Comparison of experimental values with predicated values shows the values are almost nearer to each other.

4. It is observed that torch position also influencing distortion and % of dilution.

5. Increase in dilution is significant when the welding speed is minimum.

6. Wire feed has more predominant effect on weld distortion than that of the other parameters as at 7.15 to 7.13 mm/sec the feed remains constant, irrespective of value of welding speed and torch angle.

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