

Predicted Modeling for Reinforcement for AISI4140 steel during MIG Welding

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Abstract

This paper presents the influence of welding parameters like Wire Feed Rate, arc voltage, welding speed and distance to nozzle on welding reinforcement of AISI 4140 steel material during welding. A plan of experiments based on RSM technique has been used. A central composite design and analysis of variance (ANOVA) are employed to study the welding characteristics of material & Modeled the welding parameters. The result computed is in form of contribution from each parameter, through which parameters are identified for reinforcement. From this study, it is observed that welding speed is only major parameter which influence the reinforcement of the welded joint.

Keywords: RSM; CCD; MIG; steel

1. Introduction

The problem that has faced the manufacturer is the control of the process input parameters to obtain a good welded joint with the required weld quality. Traditionally, it has been necessary to study the weld input parameters for welded product to obtain a welded joint with the required quality. To do so, requires a time-consuming trial and error development method. Then welds are examined whether they meet the requirement or not. In really the weld parameters can be chosen to produce a welded joint that closely meets the joint qualities. Also, what is not achieved or often considered is an predicted value of parameters, since welds can often be formed with very different parameters. In other words, there is often a more ideal welding input parameters combination, which can be used. In order to overcome this problem, various DOE methods can be useful to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. Response surface methodology techniques has been applied to carry out such experimentation.

2. Literature Review

Kocabekir et al. (2008) [1] investigated the effect of weld time, different weld atmospheres and weld cooling conditions on the resistance spot weld quality of 316L stainless steel. Therefore, the

microstructure of welded samples was evaluated and the hardness and tensile shear load bearing capacity of weldment was also determined. It was found that the final mechanical properties of welded samples are directly related to the parameters of the process used, knowing the weld time and weld atmosphere. Tensile shear load bearing capacity of welded samples increased with increasing heat input related with weld time due to the enlargement of nugget size. In addition, the tensile shear load bearing capacity of welded samples obtained in nitrogen atmosphere was found slightly higher compared to the normal atmosphere for all weld time.

Shanmugam et al. (2008) [2] explained the effect of filler metals such as austenitic stainless steel, ferrite stainless steel and duplex stainless steel on fatigue crack growth behavior of the gas tungsten arc welded ferrite stainless steel joints was investigated. Rolled plates of 4 mm thickness were used as the base material for preparing single 'V' butt welded joints. Centre cracked tensile (CCT) specimens were prepared to evaluate fatigue crack growth behavior. Servo hydraulic controlled fatigue testing machine was used to evaluate the fatigue crack growth behavior of the welded joints. From showed superior fatigue crack growth resistance compared to the joints fabricated by austenitic and ferrite stainless steel filler metals. Higher yield strength, hardness and relatively toughness may be the reasons for superior fatigue performance of the joints fabricated by duplex stainless steel filler metal.

Kolukisa (2009) [3] explained the effect of welding temperature on the weld ability in diffusion welding of martensitic (AISI 420), stainless steel with ductile (spherical graphite-nodular) cast iron was investigated experimentally under protective atmosphere at various temperatures and constant prescribed pressure blow those which would cause macro detonation. Microstructure examinations were carried out by SEM and EDS

Kishore et al. (2010) [4] analyzed the effect of process parameters in qualitative manner for welding of AISI 1040 steel using processes of Shielded Metal Gas Welding (MIG and TIG). Taguchi method is used to formulate the experimental layout. Exhaustive survey suggest that 5-7 control factors viz., a voltage, arc current, welding speed, nozzle to work distance and gas pressure predominant) influence weld quality, even plate thickness and backing plate too have their own effect Design of experiments based on orthogonal array is employed to develop the weldments. The weldments are subjected to testing to find the qualitative properties. The data obtained checked for adequacy based on ANOVA. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for minimum defect The data in the present work is collected using ultrasound testing (UT), in which angle beam technique is adopted for the testing of weldments and results are quantified accordingly. The testing of specimens indicated, the presence of defects like LOP, LOF, Blowhole, and Crack

Kolahan & Heidari (2010) [1] used the regression modeling in order establish the relationships between input and output parameters for Gas Metal Arc Welding (GMAW) process. To gather the required data for modeling, actual tests were carried out based on the proposed Taguchi experimental matrix design. The process variables considered include voltage (V); wire feed rate (F); torch Angle (A); welding speed (S) and nozzle - to-plate distance (D). The process output characteristics include weld bead height, width and penetration. To develop mathematical models, various regression functions have been fitted on the experimental data. The adequacies of the models are then evaluated using analysis of variance (ANOVA) technique. The best and most fitted model is then selected based on the ANOVA results and other statistical analysis. The ANOVA results recommend that the curvilinear model is the best fit in this case. In the next stage, the selected model is implanted into a Simulated Annealing (SA) optimization algorithm. This optimization procedure has been developed in order to determine the best set of process variables levels for any desired weld bead geometry characteristics. Computational results show very good compatibility with experimental data and demonstrate the effectiveness of the proposed modeling and optimization approach.

Pekkarinena & Kujanpaaa (2010) [5] determined empirically, which micro structural changes occur in ferrite and duplex stainless steels when heat input is controlled by welding parameters. Test welds were done autogenously bead-on-plate without shielding gas using 5 kW fiber laser. For comparison, some gas tungsten arc welds were made. Used test materials were .4016 (AISI 430) and 1.4003 (low-carbon ferrite) type steels in ferrite steels group and 1.4162 (low-alloyed duplex, LDX2101) and 1.4462 (AISI 2205) type steels in duplex steels group. Micro structural changes in welds were identified and examined using optical metallographic methods.

Haragopal et al. (2011) [6] used Taguchi method to design process parameters that optimize mechanical properties of weld specimen for aluminum alloy (A1-65032), used for construction of aerospace wings. Process parameters of MIG welding setup considered and ANOVA analyse gas pressure, current, groove angle and pre-heat. Assigning process parameter to L-9 orthogonal array, experiments were conducted and optimization condition was obtained along with the identification of most influencing parameters using S/N analysis, mean response analysis and ANOVA.

Patel & Patel (2013) [7] explained that the welding parameter and effect of these parameter can be predict so if want to varies input the parameter can directly predict the effect of output by using the Artificial Neural Network. Welding is a manufacturing process, which is carried out for joining of metals. Metal Active Gas (MAG) this is a variation of MIG welding, in which identical equipment is used but the inert gas is replaced by carbon dioxide, which is chemically active. Shielding gas CO₂ is used and consumable electrode is used which also plays role of conductor. MAG-002 welding is versatile, gives very little loss of alloying elements and can be operated as semi as well as fully automated. Artificial Neural Network (ANN) is a powerful empirical modeling tool, suitable for problems which are not amenable to exact analytical solutions, or, where interrelationships between variables are not fully understood but which provide an abundance of data from which ANN can learn and predict. All welds will be prepared by MAG-002 welding and TIG welding techniques. They studied Design of Experiments for this work and by use of the experimental data have performed ANN (Artificial Neural Network) prediction and make comparison with experimental data. Where inputs parameters for MAG-002 welding are welding current, wire diameter and wire feed rate and for TIG welding are welding current, wire diameter output parameter is weld strength for both MAG-002 welding and TIG welding techniques.

3 Experimental Details

3.1 Experimental Conditions and Planning of Experiment

The experiments are performed, on the basis of central composite design (CCD) with three process parameters namely welding speed, wire feed rate, arc voltage, distance to nozzle for reinforcement. The experimental setup of MIG welding is shown in figure 1.

The experimental conditions on which the experiments are performed are given below:

Table 1: Experimental Conditions

Machine tool	Manufactured by Mark Industries, Gujrat, India
Work material	8 mm thickness , 10 cm length
(Work material	M4 steel
Electrode size (mm)	Diameter = 1.2



Figure 1 MIG welding set up

3.2 Work material

Alloy steels are designated by AISI four-digit numbers. They comprise different kinds of steels having composition exceeding the limitations of B, C, Mn, Mo, Ni, Si, Cr, and Va set for carbon steels.

AISI 4140 alloy steel is chromium, molybdenum, manganese containing low alloy steel. It has high fatigue strength, abrasion and impact resistance, toughness, and torsional strength. The following datasheet gives an overview of AISI 4140 alloy steel.

Chemical Composition

The following table shows the chemical composition of AISI 4140 alloy steel.

Iron, Fe	96.785 - 97.77
Chromium, Cr	0.80 - 1.10
Manganese, Mn	0.75 - 1.0
Carbon, C	0.380 - 0.430
Silicon, Si	0.15 - 0.30
Molybdenum, Mo	0.15 - 0.25
Sulfur, S	0.040
Phosphorous, P	0.035

3.3 Response Surface Methodology

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristic of machined parts produced by turning process. In applying the response surface methodology, the dependent

variable is viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of turning process, the second order response surface has been assumed as:

$$y = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_i x_i^2 + \sum_{i < j=2}^2 b_i x_i x_j \pm e_r \quad (1)$$

This assumed surface Y contains linear, squared and cross product terms of variables x_i 's. In order to estimate the regression coefficients, a number of experimental design techniques are available. Box and Hunter (1957) have proposed that the scheme based on central composite rotatable design fits the second order response surfaces quite accurately.

3.4 Central composite design

Box and Hunter [38] proposed that the scheme based on central composite design (CCD) fits the second-order response surfaces quite accurately. Also, CCD[8] is the most popular among the various classes of RSM designs due to its flexibility, ability to run sequentially, and efficiency in providing the overall experimental error in a minimum number of runs. Therefore, it has been selected in the present work. In CCD, each factor is varied at five levels $(-\alpha, -1, 0, 1, \alpha)$ for developing a second-order model as given in Eq. (2). When the number of factors (k) is five or greater, it is not necessary to run all combinations of factors. The factorial part of the design can be run using a fraction of the total number of available combinations. The possible design options can either be regular fractional factorials.

4. Experimental Results

The MIG welding experiments were conducted, with the process parameter levels set as given in Table 2, to study the effect of process parameters over the output parameters. Experiments were conducted according to the test conditions specified by the second order central composite design (Table 2). Experimental results are given in Table 3 for reinforcement. Altogether 18 experiments were conducted using response surface methodology.

Table 2: No. of Process Parameters & Levels (CCD)

Coded Factors	Parameters	Levels		
		(-1)	(0)	(+1)
A	Wire Feed Rate	5	112	8
B	Arc voltage	32	45	36
C	Welding speed	25	35	45
D	Distance to nozzle	12	15	18

Table 3: Observed Values for Performance Characteristics

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	
Std	Run	A:Wire feed Rate	B:Arc Voltage	C:Welding Speed	D:distance to nozzle	Reinforcement
14	1	6.5	34	51.8	15	3.03
13	2	6.5	34	18.1	15	4.62
8	3	5	32	25	12	4.12
16	4	6.5	34	35	20.0	3.7
6	5	5	32	45	12	2.65
5	6	8	32	25	18	3.98
15	7	6.5	34	35	9.9	3.78
2	8	8	36	25	12	4.93
3	9	8	32	45	18	3.28
12	10	6.5	37.3	35	15	3.3
1	11	8	36	45	12	3.62
9	12	3.9	34	35	15	3.66
11	13	6.5	30.6	35	15	3.41
17	14	6.5	34	35	15	2.93
7	15	5	36	45	18	3.47
4	16	5	36	25	18	4.13
18	17	6.5	34	35	15	3.83
10	18	9.0	34	35	15	3.99

4.1 Analysis and Discussion of Results

The experiments were designed and conducted by employing response surface methodology (RSM). The regression equations for the selected model were obtained for the response characteristics, metal removal rate. These regression equations were developed using the experimental data (Table 4) and were plotted to investigate the effect of process variables on various response characteristics. The analysis of variance (ANOVA) was performed to statistically analyze the results.

4.1.1 Effect of Process Variables on reinforcement

The regression coefficients of the second order equation are obtained by using the experimental data (Table 3). The regression equation for the surface roughness as a function of four input process variables was developed using experimental data and is given below. The coefficients (unimportant identified from ANOVA) of some terms of the quadratic equation have been omitted.

$$\text{reinforcement} = +5.44361 - 0.049967 * \text{Welding Speed}$$

It is observed from Figs.2 that reinforcement decreases with the weld speed from 25 to 45 mm/sec and it is also found that reinforcement is only depends upon the welding speed. The other three parameters such as arc voltage, welding current distance to nozzle is non-significant for the model of penetration.

The residual analysis as a primary indicative tool is also done. It can be seen from Figure 2 that all the actual values are following the estimated values and thus confirming model assumptions are correct. Normal probability plot of residuals has been drawn (Figure 4). All the data points are following the straight line. Thus the data is normally distributed.

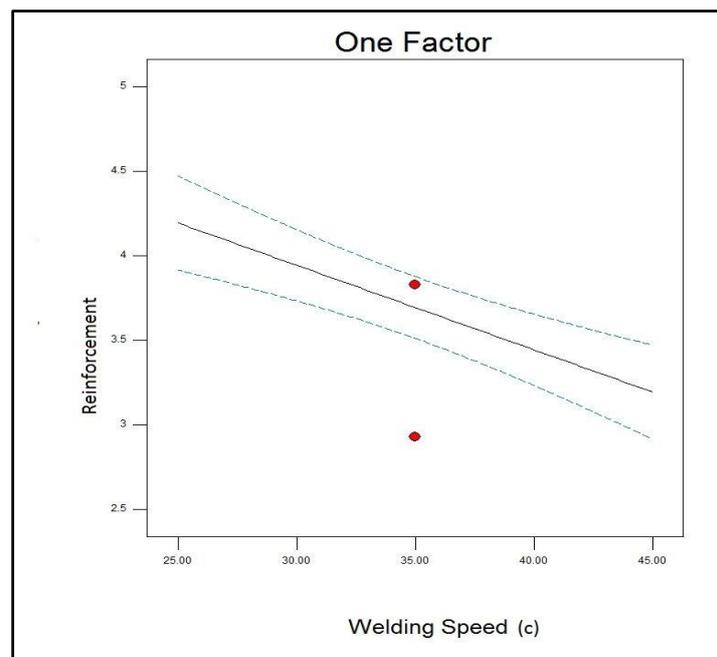


Figure 2: Overall performance of reinforcement

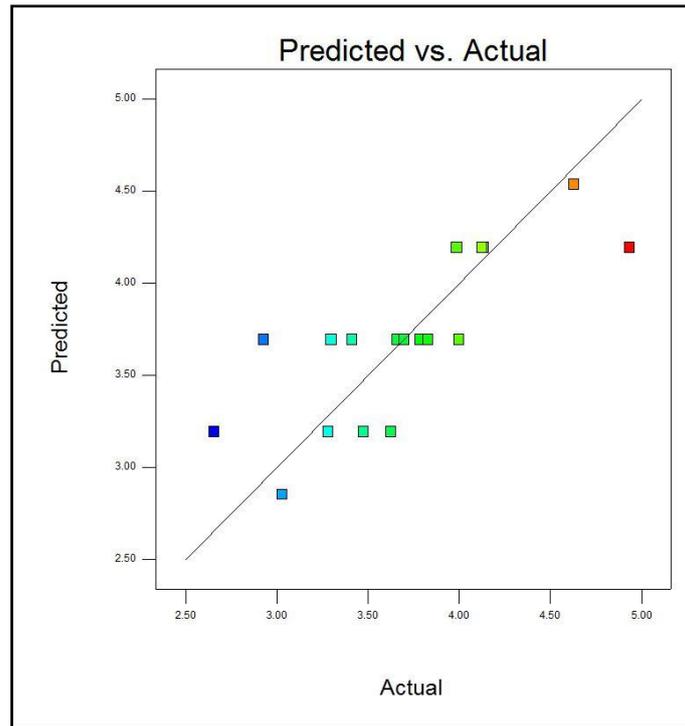


Figure 3: Predicted vs. Actual for reinforcement

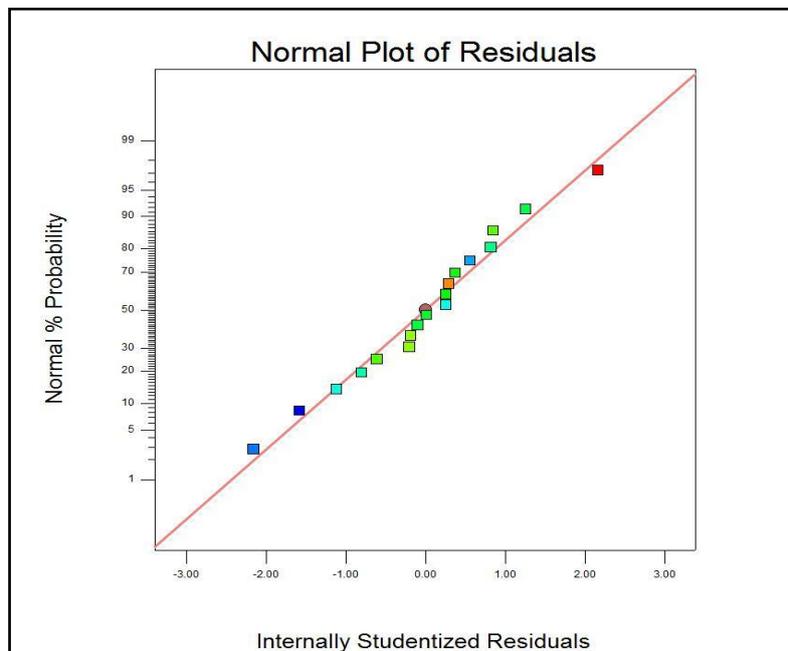


Figure 4: Normal Plot of Residuals for reinforcement

Table 4: Pooled ANOVA- reinforcement

Source	Sum of Squares	Df	Mean Square	F Value	p-value	
Model	3.409693703	1	3.409694	25.49780684	0.0001	Significant
C-Welding Speed	3.409693703	1	3.409694	25.49780684	0.0001	
Residual	2.139599675	16	0.133725			
Lack of Fit	1.734599675	15	0.11564	0.285530811	0.9191	not significant
Pure Error	0.405	1	0.405			
Cor Total	5.549293378	17				
Std. Dev.	0.365684262			R-Squared 0.614437455		
Mean	3.694769732			Adj R-Squared 0.590339796		
C.V. %	9.897349195			Pred R-Squared 0.521548836		
PRESS	2.655065877			Adeq Precision 13.78795392		

5. Conclusions

In the previous chapter, the effect of welding parameters on the response variables such as welding speed, wire feed rate, arc voltage and distance to nozzle has been discussed. Also the predicted modeling has been found for each of response variables using response surface methodology (RSM). The important conclusions drawn from the present study are summarized below:

1. For welding maximum reinforcement, minimum welding speed is desirable. Reinforcement decreases with the weld speed from 25 to 45 mm/sec and it is also found that reinforcement is only depends upon the welding speed. The other three parameters such as arc voltage, welding current distance to nozzle is non-significant for the model of penetration.
2. The experimental values are in good agreement with the predicted values.

References

- [1] F. Kolahan and M. Heidari, "A New Approach for Predicting and Optimizing Weld Bead Geometry in GMAW," pp. 138–142, 2010.

- [2] V. Balasubramanian, K. Shanmugam, and A. K. Lakshminarayanan, "Effect of Autogenous Arc Welding Processes on Fatigue Crack Growth Behaviour of Ferritic Stainless Steel Joints," vol. 48, no. 4, pp. 489–495, 2008.
- [3] O. Article, "Optimization of quality characteristics parameters in a pulsed metal inert gas welding process using grey-based Taguchi method," pp. 1250–1260, 2009.
- [4] M. Aghakhani, E. Mehrdad, and E. Hayati, "Parametric Optimization of Gas Metal Arc Welding Process by Taguchi Method on Weld Dilution," vol. 1, no. 3, 2011.
- [5] J. Pekkarinen and V. Kujanpää, "The effects of laser welding parameters on the microstructure of ferritic and duplex stainless steels welds," *Phys. Procedia*, vol. 5, pp. 517–523, 2010.
- [6] D. O. E. Method, S. P. Chavda, J. V Desai, and T. M. Patel, "A Review on Optimization of MIG Welding Parameters using Taguchi ' s," no. 1, pp. 16–21, 2014.
- [7] P. D. Patel and P. S. P. Patel, "Prediction Of Weld Strength of Metal Active Gas (Mag) Welding Using Artificial Nueral Network Abstract ;," vol. 1, no. 1, pp. 36–44.
- [8] C. Tzeng, Y. Lin, Y. Yang, and M. Jeng, "Optimization of turning operations with multiple performance characteristics using the Taguchi method and Grey relational analysis," vol. 9, pp. 2753–2759, 2008.
- [9] Singh, R., S. Singhal, and P. Sharma. "Application of AHP in the Analysis of Flexible Manufacturing System." *Journal of industrial and intelligent information* 4.1 (2016): 15-20.