Springer

KSME

Journal of Mechanical Science and Technology 27 (8) (2013) 2457~2465
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-013-0631-8

Genetic algorithm based optimization of the process parameters for gas metal arc welding of AISI 904 L stainless steel †

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(Manuscript Received August 14, 2012; Revised January 22, 2013; Accepted February 19, 2013)

Abstract

The present study is focused on welding of super austenitic stainless steel sheet using gas metal arc welding process with AISI 904 L super austenitic stainless steel with solid wire of 1.2 mm diameter. Based on the Box - Behnken design technique, the experiments are carried out. The input parameters (gas flow rate, voltage, travel speed and wire feed rate) ranges are selected based on the filler wire thickness and base material thickness and the corresponding output variables such as bead width (BW), bead height (BH) and depth of penetration (DP) are measured using optical microscopy. Based on the experimental data, the mathematical models are developed as per regression analysis using Design Expert 7.1 software. An attempt is made to minimize the bead width and bead height and maximize the depth of penetration using genetic algorithm.

Keywords: Gas metal arc welding; Box - Behnken design; Bead geometry; Optimization; Genetic algorithm

1. Introduction

Super austenitic stainless steel 904 L is a highly-alloyed austenitic low carbon stainless steel with a fully austenitic structure. Due to its high molybdenum content and specially designed welding consumables with low impurity level, hot crack formation during welding can be avoided despite the fully austenitic filler metal. This type of steels cannot be hardened by heat treatment as they are normally supplied in quench annealed condition. Major industrial applications of 904L super austenitic stainless steel are in production and in pipe work required for general paper and allied industries, sea water cooling equipment's, oil and refinery components and in transport of sulfuric acid, sea water, condensers and heat exchangers. The quality of the weld may be dependent on a number of input process parameters namely welding speed, voltage, gas flow rate and wire feed rate. Several methods have been developed by various investigators to predict bead geometry in welding. These methods include theoretical studies, statistical analysis and others, some of which are stated below. Rosenthal studied the temperature distributions on an infinite sheet due to a moving point heat source by considering the conduction mode of heat transfer [1]. It could be related to arc welding process with a number of assumptions. However, it is not focused on theoretical studies for the weld bead-geometry predictions. Super austenitic stainless steels are particularly interesting because they bridge between relatively cheap austenitic stainless steel and expensive Nickel base super alloys, when high corrosion properties are required at moderately high temperatures Wallen et al. [2], Heino et al. [3], investigated the welding of the super austenitic stainless steel Avesta 654 SMO wires, Ames et al. [4] compared the austenitic (316 L), super austenitic (254 SMO) and super duplex (SAF 2507) weld properties produced using GTAW filler wire. The microstructure, mechanical properties and corrosion resistance of such welds are compared to autogenous welds produced in the current industry. In all cases, the welds produced with GTAW filler wire exhibited equivalent or improved microstructure and properties when compared to the autogenous non-flux welds. Depending on the amount of cold work present, the strength and hardness in the HAZ and FZ softened due to the weld thermal cycle. Microhardeness transverse across welds also examined. Kim et al. [5] have employed factorial design to correlate the robotic GMAW process parameters (welding voltage, welding speed and arc current) to three responses (bead width, bead height and penetration) for optimization purposes. The material was used as a plates of AS 1204 mild steel adopting the bead-on-plate technique. Electrode wire with a diameter of 1.2 mm with the

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same mechanical and physical properties of the base metal was used. Their results showed that all process parameters influenced the responses and the models developed are able to predict the responses with 0-25% accuracy.

The bead geometry that characterizes the quality of the weld is dependent on a number of input process parameters. These parameters are closely coupled in such a way that it is difficult to identify the extent of contribution of these factors toward the desired output. An expert welder from his experience of trial and error selects a set of parameters that may yield good results. However, the obtained results may not be the optimal one. The trial and error of the welder can be avoided, if a suitable mathematical model is developed, which can forecast the output from a set of desired parameters or vice versa. A mathematical model can be made to solve the above problem using differential equations depicting the actual physical phenomena. Welding is a process comprising of a number of complicated natural phenomena, none of which may be fully understood. Thus, it may not be always possible to develop an appropriate differential equation of the said process. In such situations, models are made from the outcomes of experiments performed as per some statistical designs and then analyzed by regression methods to predict the required output. The regression equations can be either linear or non-linear. Yang and Chandel [6], performed both linear as well as non-linear regression analysis to model submerged arc welding process. Yang et al. [7] observed that non-linear regression equations are generally used to model welding phenomena but it, during modeling of submerged arc welding process that linear regression equations were found equally suitable. The above statistical regression analysis yielded more or less satisfactory results, while predicting the response from the process parameters. It is to be mentioned that the statistical methods are mainly global in nature, that is, the usual practice is to establish a single working relationship between the input and the output for the entire domain of interest, as a result of which, it might be possible to predict the results accurately at the anchor points only (that is, the points used to carry out the regression analysis). If the search space is large and the objective functions become highly complicated, then the computational time of a GA increases drastically and it is difficult to get solution in real time. To overcome this difficulty, Kumar and Debroy [8] showed that multiple sets of welding variables capable of producing the target weld geometry could be determined in a realistic time frame by coupling a real-coded GA with a neural network model for gas metal arc fillet welding. Kim et al. [9] exploited the above mentioned benefit of regression analysis. They used genetic algorithm and response surface methodology simultaneously, in order to find a set of welding process variables that could produce the desired weld-bead geometry in GMAW. A genetic algorithm does not require the objective function to be differentiable. It means that even if there are some bad data in the search space, the model does not get affected. However, this algorithm could not produce a mathematical model between the input and output variables. To overcome this problem, the response surface methodology uses the near-optimal values as a reference point to obtain a model of the welding process and determine optimal values of the process variables. Vidut Dey et al. [10] conducted the bead -on-plate welds on austenitic stainless steel plates using GMA welding machine. Experimental data were collected as per Box - Behnken design and regression analysis was conducted to establish input-output relationships of the process. An attempt was made to minimize the weldment area, after satisfying the condition of maximum bead penetration. Thus, it was posed as a constrained optimization problem and it was solved by utilizing a genetic algorithm with a penalty function approach. The genetic algorithm is able to determine optimal weld-bead geometry and recommend the necessary process parameters for the same.

Considering the above available literature, it seems only a very limited literature is available on welding and its parameter optimization of super austenitic stainless steel. In the present investigation, the bead on plate welding trials are carried out using a gas metal arc welding process and the bead profiles i.e., output variables BW, BH and DP of the welds are measured using optical microscopy. These output variables are determined according to the variables, which are the voltage, gas flow rate, travel speed and wire feed rate. Based on the input and output parameters the welding parameters are optimized using genetic algorithms.

2. Genetic algorithm

Genetic algorithm, introduced by Holland (1975), is a population-based search and optimization tool. The GA works equally well both in continuous or discrete search space. It is a heuristic technique inspired by the natural biological evolutionary process comprising of selection, crossover, mutation, etc. The evolution starts with a population of randomly generated individuals in first generation. In each generation, the fitness of every individual in the population is evaluated, compared with the best value, and modified (recombined and possibly randomly mutated), if required, to form a new population.

The new population is then used in the next iteration of the algorithm. The algorithm terminates, when either a maximum number of generations has been produced or a satisfactory fitness level has been reached for the population. The fitness function of a GA is defined first. Thereafter, the GA proceeds to initialize a population of solutions randomly and then improves it through repetitive application of selection, crossover and mutation operators. This generational process is repeated until a termination condition is reached.

The major aim of this study is to develop a genetic algorithm model for predicting optimum bead profiles: to minimize the bead height, minimize the bead width and maximize the depth of penetration. Based on the constrained conditions the parameters are optimized by genetic algorithm.

The genetic algorithm is able to determine optimal weld-

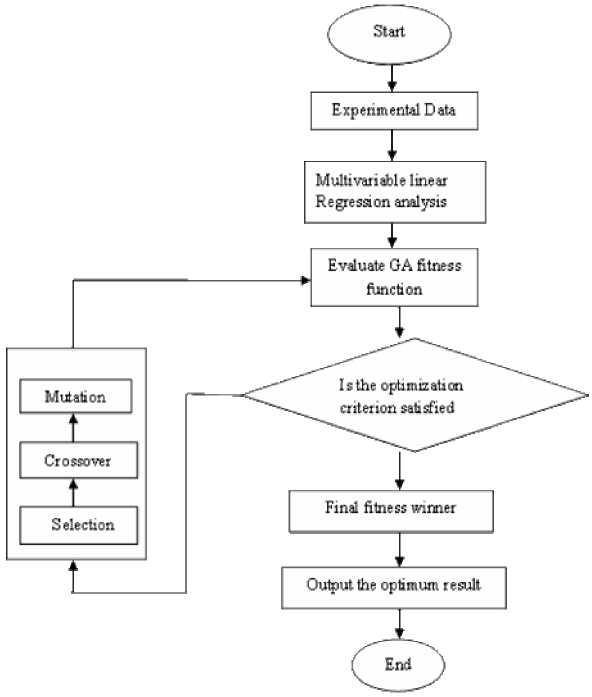


Fig. 1. Flow chart for GA.

bead geometry and recommend the necessary process parameters for the same. The flow chart of the genetic algorithm is presented in Fig. 1. The aim of this experimental work was to investigate the effects of welding parameters, and to establish a correlation between input and output parameters. In order to this, gas flow rate, voltage, travel speed and wire feed rate were chosen as process input parameters. The experimental results were analyzed with analysis of variance (ANOVA), which is used for identifying the significant factor analysis for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%.

3. Experimentation and data collection

The experiments are carried out on 904L super austenitic stainless steel of size 100x40x5 mm^3. The experiments are performed with a GMAW process. The working ranges of the welding parameters like gas flow rate (GF), voltage (V), travel speed (S) and wire feed rate (WF) are kept fixed to (12-16 lpm), (28-32 V), (90-110 mm/min) and (1.5-2 m/min) respectively. The direct current electrode positive polarity and argon gas is used as a shielding media. In this study Box Benken design method is used and presented in Table 1. After the welding is done the specimens are sectioned and polished with suitable abrasive and diamond paste. After polishing, the specimens are etched with electrolytic with oxalic acid to clearly reveal the fused metal zone. The etched samples are measured for bead width (BW), height (BH) and depth of penetration (DP) using optical microscopy. The measured bead profiles values are presented in Table 2.

Table 1. Four factors Box-Behnken design.

Exp. Nos	Factor 1	Factor 2	Factor 3	Factor 4
1	2	2	3	3
2	2	3	3	2
3	2	2	1	1
4	3	2	3	2
5	2	3	1	2
6	3	2	2	1
7	1	3	2	2
8	2	2	1	3
9	1	1	2	2
10	1	2	2	3
11	1	2	1	2
12	2	2	2	2
13	2	3	2	1
14	3	2	2	3
15	2	1	2	3
16	3	1	2	2
17	1	2	3	2
18	2	1	3	2
19	1	2	2	1
20	2	2	2	2
21	3	3	2	2
22	2	2	3	1
23	2	2	2	2
24	2	1	2	1
25	3	2	1	2
26	2	1	1	2
27	2	3	2	3

4. Mathematical formulation of the problem

The main aim of the present study is to determine the set of optimal parameters of a GMA welding process to ensure minimum bead width and height after satisfying the condition of maximum depth of penetration. Based on the given constrained conditions the mathematical statement is formulated as below:

$$\text{Minimize weldment area} = 2/3(BH+DP)\,BW. \quad (1)$$

Subject to the condition that BP takes the maximum value and

$$GFmin \leq GF \leq GFmax \quad (2)$$
$$Vmin \leq V \leq Vmax \quad (3)$$
$$WFmin \leq WF \leq WFmax \quad (4)$$
$$Smin \leq S \leq Smax. \quad (5)$$

Table 2. Bead profile measurements.

Runs	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3
	Travel speed	Voltage	Wire feed rate	Gas flow rate	Bead height	Bead width	Depth of penetration
	(mm/min)	(Volts)	(m/min)	(lpm)	(mm)	(mm)	(mm)
1	110	30	2	14	3.412	12.19	3.502
2	110	32	1.75	14	3.19	12.03	3.415
3	90	30	1.5	14	3.475	12.05	3.505
4	110	30	1.75	16	3.042	12.29	3.507
5	90	32	1.75	14	3.21	11.85	3.214
6	100	30	1.5	16	3.23	12.1	3.512
7	100	32	1.75	12	3.12	12	3.08
8	90	30	2	14	3.12	11.82	3.3
9	100	28	1.75	12	3.06	12.09	3.2
10	100	30	2	12	3.132	12.14	3.134
11	90	30	1.75	12	3.108	12.16	3.17
12	100	30	1.75	14	3.09	11.99	3.345
13	100	32	1.5	14	3.1	12.01	3.211
14	100	30	2	16	3.201	12.11	3.503
15	100	28	2	14	3.22	11.29	3.289
16	100	28	1.75	16	3.275	12.19	3.527
17	110	30	1.75	12	3.107	12.26	3.124
18	110	28	1.75	14	3.402	11.95	3.49
19	100	30	1.5	12	3.15	12.02	3.155
20	100	30	1.75	14	3.12	11.97	3.34
21	100	32	1.75	16	3.085	11.95	3.245
22	110	30	1.5	14	3.14	11.89	3.32
23	100	30	1.75	14	3.12	11.99	3.34
24	100	28	1.5	14	3.251	11.46	3.294
25	90	30	1.75	16	3.588	12.18	3.715
26	90	28	1.75	14	3.13	11.9	3.306
27	100	32	2	14	3.3	12.23	3.342

5. Results and discussion

5.1 Mathematical modeling

Regression analysis was carried out using Design Expert 7.1 software on the experimental data collected as per the 27 welding conditions given by Box - Behnken design (Table 1). The experimental bead height (BH) was expressed in a coded form as a non-linear function of (V), travel speed (S) and wire feed rate (WF), represented by A, B, C and D respectively.

Regression model for bead height

$$BH=-226.93812-4.49660A+17.15963B-0.015625AB+0.018763AC-0.11428BC-3.39450BD+0.062700CD-0.00338208C^2+1.21667D^2-0.00315000A^2C+0.00184375B^2C+0.058500B^2D. \quad (6)$$

ANOVA results for the response surface quadratic model are given in Table 3. The results were obtained using Design Expert 7.1 software.

The model F-value of 135.29 implies the model is significant. There is only a 0.01% chance that a "model F-value" of this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, D, AB, AC, BC, BD, CD, B^2, C^2, D^2, A^2C, AC^2, B^2C, B^2D are significant model terms. Values greater than 0.05000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.The "lack of fit F-value" of 0.59 implies the lack of fit is not significant relative to the pure error. There is a 75.07% chance that a "lack of fit F-value" this large could occur due to noise. Non-significant lack of fit is good, we want the model to fit. The model summary statistics of bead height is given in Table 4.

From Table 4, the "Pred. R-squared" of 0.9451 is in reasonable agreement with the "Adj R-squared" of 0.9887. "Adeq precision" measures the signal to noise ratio. A ratio

Table 3. ANOVA table of Bead height.

Source	Sum of squares	Df	Mean square	F value	p-value Prob > F	
Model	0.46802062	17	0.027530624	135.2887017	< 0.0001	Significant
A-gas flow rate	0.01353013	1	0.013530125	66.48861335	< 0.0001	
B-voltage	0.00924075	1	0.00924075	45.41012399	< 0.0001	
C-travel speed	0.00046225	1	0.00046225	2.271550449	0.1660	
D-wire feed rate	0.0021125	1	0.0021125	10.38107155	0.0105	
AB	0.015625	1	0.015625	76.7830736	< 0.0001	
AC	0.07425625	1	0.07425625	364.903879	< 0.0001	
BC	0.021316	1	0.021316	104.7493118	< 0.0001	
BD	0.01334025	1	0.01334025	65.55554544	< 0.0001	
CD	0.09828225	1	0.09828225	482.970447	< 0.0001	
A^2	5.0704E-05	1	5.07037E-05	0.249163918	0.6296	
B^2	0.00404556	1	0.004045565	19.88037766	0.0016	
C^2	0.05351126	1	0.053511259	262.9605733	< 0.0001	
A^2C	0.031752	1	0.031752	156.0330338	< 0.0001	
AC^2	0.01045838	1	0.010458375	51.39367535	< 0.0001	
B^2C	0.01087813	1	0.010878125	53.45637584	< 0.0001	
B^2D	0.009126	1	0.009126	44.8462291	< 0.0001	
Residual	0.00183146	9	0.000203495			
Lack of fit	0.00123146	7	0.000175923	0.58640873	0.7507	Not significant
Pure error	0.0006	2	0.0003			
Cor total	0.46985207	26				

Table 4. Model summary statistics of bead height.

Std. Dev.	0.01426518	R-squared	0.996102053
Mean	3.199185185	Adj. R-squared	0.988739265
C.V. %	0.445900425	Pred. R-squared	0.945134978
PRESS	0.025778444	Adeq. precision	46.87712903

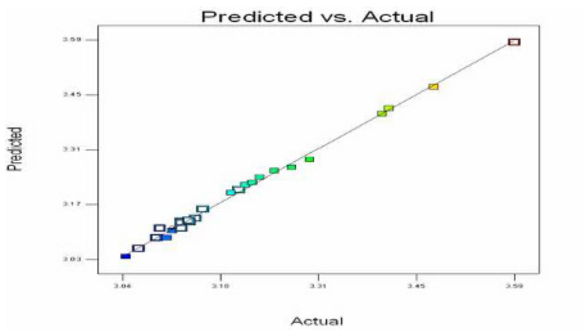


Fig. 2. Predicted bead height Vs Actual bead height.

greater than 4 is desirable. The value of Adeq precision is 46.877 that indicates an adequate signal. This model can be used to navigate the design space.

Regression model for bead width

$$BW= 889.84708-27.64000B-11.23192C+0.19500BD +0.053000CD+1.75323A^2-0.032396B^2+0.055479C^2 -1.35333D^2-0.056875A^2B-0.00182500BC^2. \quad (7)$$

The ANOVA results for bead width using response surface quadratic model are given in Table 5.

From Table 5, the model F-value of 127.26 implies the model is significant. There is only a 0.01% chance that a "model F-value" of this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, C, D, AB, BC, BD, CD, A^2, C^2, D^2, A^2B and BC^2 , BC2 are significant model terms.Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "lack of fit F-value" of 5.83 implies the lack of fit is not significant relative to the pure error. the "lack of fit F-value" of 5.83 implies the lack of fit is not significant relative to the pure error. There is a 15.50% chance that a "lack of fit F-value" of this large could occur due to noise. Non-significant lack of fit is good. The model summary statistics of bead width is given Table 6.

From Table 6, the "Pred R-squared" of 0.9461 is in reasonable agreement with the "Adj R-squared" of 0.9865. "Adeq precision" measures the signal to noise ratio. A ratio

Table 5. ANOVA table of bead width.

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Model	1.259593519	15	0.083972901	127.2608836	< 0.0001	Significant
A-gas flow rate	0.001875	1	0.001875	2.841561424	0.1200	
B-voltage	0.555025	1	0.555025	841.1400689	< 0.0001	
C-travel speed	0.035208333	1	0.035208333	53.35820896	< 0.0001	
D-wire feed rate	0.005208333	1	0.005208333	7.893226177	0.0170	
AB	0.005625	1	0.005625	8.524684271	0.0139	
AD	0.003025	1	0.003025	4.584385763	0.0555	
BC	0.004225	1	0.004225	6.402985075	0.0280	
BD	0.038025	1	0.038025	57.62686567	< 0.0001	
CD	0.070225	1	0.070225	106.4259472	< 0.0001	
A^2	0.188334259	1	0.188334259	285.4204618	< 0.0001	
B^2	0.089556481	1	0.089556481	135.7227963	< 0.0001	
C^2	0.028356481	1	0.028356481	42.97423141	< 0.0001	
D^2	0.038156481	1	0.038156481	57.82612578	< 0.0001	
A^2B	0.41405	1	0.41405	627.4925373	< 0.0001	
BC^2	0.26645	1	0.26645	403.804822	< 0.0001	
Residual	0.007258333	11	0.000659848			
Lack of fit	0.006991667	9	0.000776852	5.826388889	0.1550	Not significant
Pure error	0.000266667	2	0.000133333			
Cor total	1.266851852	26				

Table 6. Model summary statistics of bead width.

Std. Dev.	0.025687516	R-squared	0.994270574
Mean	12.00407407	Adj R-squared	0.986457721
C.V. %	0.213989983	Pred R-squared	0.946051725
Press	0.068344472	Adeq precision	50.10722913

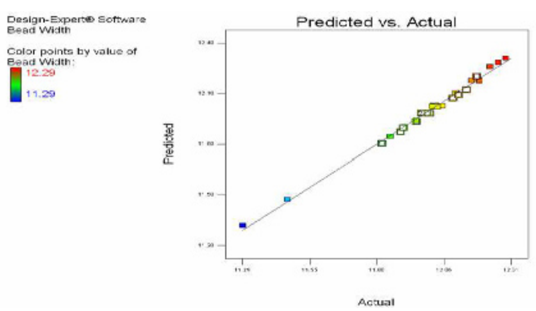


Fig. 3. Predicted bead width vs actual bead width.

greater than 4 is desirable. The value of Adeq Precision 50.107 indicates an adequate signal. This model can be used to Navigate the design space.

The predicted response vs. actual response graph, shown in Fig. 3 confirms the adequacy of the model to predict a very much close value at nearly all conditions.

Regression model for depth of penetration

$$DP = -58.52500-17.80410A+0.75412AB-0.00510000AC-0.10354BC-2.21950BD+0.038700CD-0.20825B^2+0.00224014C^2-0.011625A^2B-0.00169375A^2C-0.00731250AB^2+0.000252500AC^2+0.00230000B^2C. \quad (8)$$

The calculated ANOVA result for depth of penetration is presented in Table 7.

From Table 7, The model F-value of 508.50 implies the model is significant. There is only a 0.01% chance that a "model F-value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, AB, AC, BD, CD, A^2, B^2, C^2, A^2B, A^2C, AB^2, AC^2, B^2C, B^2D, BC^2 are significant model terms. Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "lack of fit F-value" of 10.54 implies there is a 8.89% chance that a "lack of fit F-value" of this large could occur due to noise. Lack of fit is bad -- we want the model to fit. This relatively low probablity (< 10%) is troubling. The model summary for depth of penetration is presented in Table 8.

From Table 8, the "Pred R-squared" of 0.9574 is in reasonable agreement with the "Adj R-squared" of 0.9973. "Adeq precision" measures the signal to noise ratio. A ratio

Table 7. ANOVA for depth of penetration.

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Model	0.629300801	19	0.033121095	508.5049736	< 0.0001	Significant
A-gas flow rate	0.131769	1	0.131769	2023.036747	< 0.0001	
B-voltage	0.000225	1	0.000225	3.454403298	0.1054	
C-travel speed	7.225E-05	1	7.225E-05	1.109247281	0.3272	
D-wire feed rate	0.000351125	1	0.000351125	5.390788258	0.0533	
AB	0.006561	1	0.006561	100.7304002	< 0.0001	
AC	0.006561	1	0.006561	100.7304002	< 0.0001	
BC	7.225E-05	1	7.225E-05	1.109247281	0.3272	
BD	0.004624	1	0.004624	70.991826	< 0.0001	
CD	0.03744225	1	0.03744225	574.8472528	< 0.0001	
A^2	0.003239501	1	0.003239501	49.73574881	0.0002	
B^2	0.018555574	1	0.018555574	284.881939	< 0.0001	
C^2	0.024395001	1	0.024395001	374.5340998	< 0.0001	
A^2B	0.017298	1	0.017298	265.5745256	< 0.0001	
A^2C	0.009180125	1	0.009180125	140.9415737	< 0.0001	
AB^2	0.0068445	1	0.0068445	105.0829483	< 0.0001	
AC^2	0.0051005	1	0.0051005	78.30748454	< 0.0001	
B^2C	0.016928	1	0.016928	259.8939512	< 0.0001	
B^2D	0.003876042	1	0.003876042	59.50849385	0.0001	
BC^2	0.002346125	1	0.002346125	36.01983083	0.0005	
Residual	0.00045594	7	6.51343E-05			
Lack of fit	0.000439273	5	8.78546E-05	10.54255556	0.0889	Not significant
Pure error	1.66667E-05	2	8.33333E-06			
Cor total	0.629756741	26				

Table 8. Model summary statistics for depth of penetration.

Std. Dev.	0.00807058	R-squared	0.999276006
Mean	3.336481481	Adj R-squared	0.997310881
C.V. %	0.241888945	Pred R-squared	0.957400664
Press	0.026827219	Adeq precision	91.90476224

greater than 4 is desirable. The value of Adeq precision is 91.905 indicates an adequate signal. This model can be used to Navigate the design space.

The predicted response vs. actual response graph, Fig. 4 confirms the adequacy of the model to predict a very much close value at nearly in all conditions.

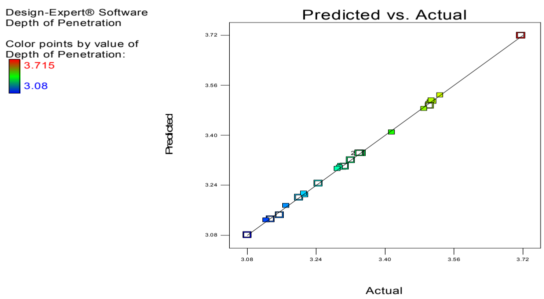


Fig. 4. Predicted depth of penetration vs actual depth of penetration.

5.2 Genetic algorithm (GA)

In this present study MATLAB tool box is used to obtain the GA results. The optimal GA parameters are obtained and the parameters are found to yield the best results: N = 20; G = 30 Tolerance limit or Termination = $1*10^{-25}$ and Mutation is Adaptive feasibility. A uniform crossover scheme is utilized for the said purpose. The convergence plot of genetical algorithm graph is presented in Fig. 5. From Fig. 5, the GA could find the minimum area of Weldment as 47.2046 mm^2. The GA obtained results and best individual parameters effects are presented in Fig. 6. From Fig. 6 shows that the number of variables Vs best individual variables, which respresents best individual parameters of GA major role in the welding parameters are wire feed rate and followed by the voltage, travel speed and gas flow rate. The relationship between the maximum constraint and generation is plotted in the graph and presented in Fig. 7.

Fig. 7 shows a straight-line graph and it means there is no

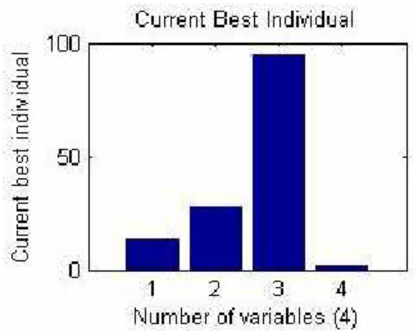


Fig. 5. Convergence plot of genetical algorithm.

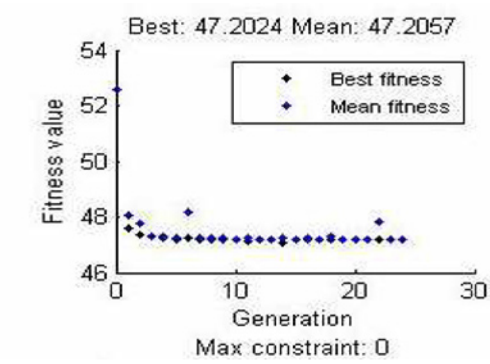


Fig. 6. Current best individual parameters of GA.

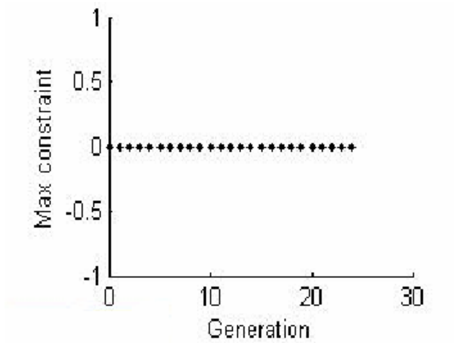


Fig. 7. Constraint vs generation.

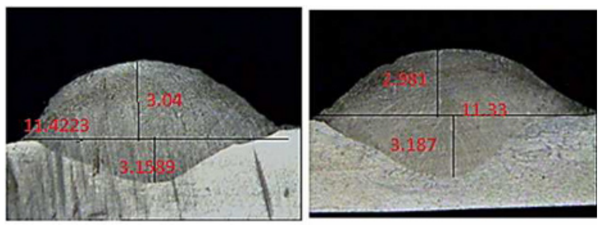
violation of the constrains in each generation. The optimal values of process parameters and bead geometry values obtained by the GA are presented in Table 9.

Table 9. Optimized working parameters and bead geometries.

Gas flow rate	13.3716 lpm
Voltage	28.0004 V
Travel speed	94.8679 mm/min
Wire feed rate	1.9999 m/min
Bead height	3.0400 mm
Bead width	11.4223 mm
Depth of penetration	3.1589 mm
Weldment area	47.2046 mm^2

Table 10. Comparative results of conformity test.

Sl. Nos	Parameters	Optimized welding parameters with predicted values	Experimentally observed values	% of Error
1	Gas flow rate (lpm)	13.3716	13	----
2	Voltage (V)	28.0004	28	----
3	Travel speed (mm/min)	94.8679	95	----
4	Wire feed rate (m/min)	1.9999	2	----
5	Bead height (mm)	3.0400	2.981	1.94
6	Bead width (mm)	11.4223	11.33	0.786
7	Depth of penetration (mm)	3.1589	3.187	-0.889
8	Weldment area (mm^2)	47.2046	47.00	0.433



(a) (b)

Fig. 8. Comparative bead profiles (a-predicted bead profile, b-experimental bead profiles).

5.3 Confirmation tests

The optimized parameter is validated by conducting confirmatory welding trials. For confirmatory trials, new welding process parameters, which have not been used for the preliminary welding set of trials are considered for welding. The welding trials are carried out and the bead profile is measured (Fig. 8) and area of the weld and the test results are compared to the predicted values as presented in Table 8.

The percentage of errors are calculated by using the Eq. (9) and the values are presented in the same. Table 10. It is observed that, percentage of error has less than 2% i.e., with in the acceptable range of percentage errors. So the optimized parameters has prone to give the good results i.e., to maximize the depth of penetration and minimize the bead width and dead height. This may be due to high wire feed and lower voltage, as welding current is directly proportional to the wire feed rate. So the more amount heat is placed on the weld pool area, which implies the high depth of penetraction and less bead width.

6. Conclusions

In this study, bead-on-plate weld runs are performed at a GMAW setup. Experiments are carried out as per Box-Behnken design and the data can be employed to develop mathematical models for predicting weld-bead geometry. The possibility of a GMAW welding optimization procedure using genetic algorithm is investigated in this work; more specifically, the determination of the near-optimal GMAW process parameters, welding voltage (V), wire feed speed (WF) travel speed (S) and gas flow rate (GF). The search for the optimum is based on the minimization of an objective function, which takes into account the geometric characteristics (depth penetration, bead width and bead height) of the bead. It is found that the GA can be a powerful tool in experimental welding optimization. The confirmation test is carried out and the predicted results are very closer to the experimental results (error < 2%).

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Nomenclature

GF : Gas flow rate lpm
V : Voltage volt
S : Travel speed mm/min
F : Wire feed rate m/min
FZ : Fusion zone
ANOVA : Analysis of variance
BH : Bead height
DP : Bead penetration
BW : Bead width
CCD : Central composite design
G : Number of generations
GA : Genetic algorithm
GMA : Gas metal arc
GMAW : Gas metal arc welding
MIG : Metal inert gas
N : Population size
S_{max} : Maximum travel speed of welding
S_{min} : Minimum travel speed of welding
TIG : Tungsten inert gas
V : Voltage
V_{max} : Maximum voltage
V_{min} : Minimum voltage
WF_{max} : Maximum wire feed rate
WF_{min} : Minimum wire feed rate
α : Probability
df : Degrees of freedom

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