Optimization and Prediction of MIG Welding Process Parameters using ANN

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Abstract
MIG Welding is widely used by engineers and production personnel as a quick and effective welding process for joining metals. Process parameters of MIG welding are considered as the utmost significant influences that affects the quality, productivity and cost of welding process. The work presents effect of such welding parameters like welding current, welding voltage, gas flow rate, wire feed rate, etc. on weld strength, ultimate tensile strength and hardness of weld joint using design of experiments method. The above-mentioned parameters were optimized using Genetic Algorithm and suitable combination of parameters were proposed for target quality using ANOVA. A prediction model is also developed using Artificial Neural Network. The analysis provides significance of said process parameters and its effect on the quality and strength of joint.

Keywords: *Optimization, MIG Welding, ANN, GA, UTS, hardness*

INTRODUCTION

MIG is an arc welding process where in a coalescence is obtained by heating the job with an electric arc produced between work piece and metal electrode feed continuously. The arc and the molten puddle are protected from contamination by the atmosphere (i.e. oxygen and nitrogen) with an externally supplied gaseous shield of inert gas such as argon, helium or an argon-helium mixture. Since the metallic electrode provides the arc as well as the filler metal, no external filler metal is necessary. It is often referred to in abbreviated form as MIG welding. The weld bead geometry, depth of penetration and overall weld quality depends on the following operating variables:

- Electrode size, Welding current, Arc voltage
- Arc travel speed, welding position
- Gas Flow rate, Shielding Gas composition
- Electrode extension

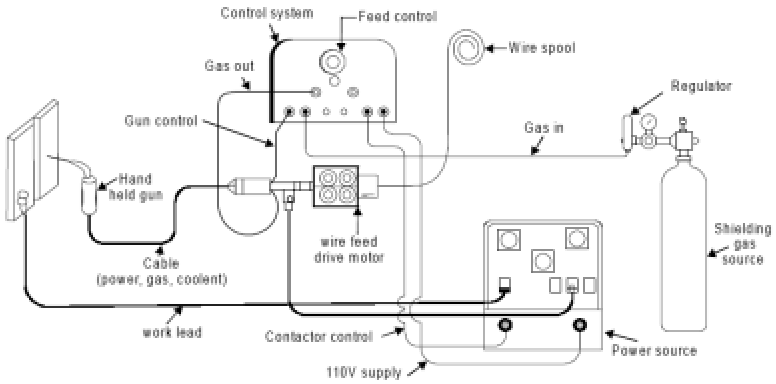

Fig. 1: MIG welding Process Setup

EXPERIMENTATION

In experimentation, the following process parameters were nominated with three different levels:

Table 1: *Set of process variables*

Process Designation	Parameters	Level 1	Level 2	Level 3
A	Welding speed (mm/s)	4.5	5.5	6.5
B	Welding current (A)	150	170	190
C	Gas pressure (psi)	12	15	18

After nomination of process parameters, design of experiments is applied to get various combinations of the designated process parameters and for each combination values of hardness and UTS of the weld joint were obtained as shown in the following table:

Table 2: *DOE for MIG welding*

Exp. No.	Run Order	Welding Speed	Welding Current	Gas Pressure	Hardness	UTS
1	1	4.5	150	12	228	563
2	2	5.5	150	12	222	562
3	3	6.5	150	12	220	557
4	4	4.5	170	12	228	572
5	5	5.5	170	12	225	573
6	6	6.5	170	12	223	566
7	7	4.5	190	12	235	599
8	8	5.5	190	12	229	587
9	9	6.5	190	12	235	579
10	10	4.5	150	15	235	573
11	11	5.5	150	15	232	566
12	12	6.5	150	15	230	562
13	13	4.5	170	15	238	591
14	14	5.5	170	15	235	588
15	15	6.5	170	15	237	581
16	16	4.5	190	15	242	611
17	17	5.5	190	15	239	593
18	18	6.5	190	15	237	586
19	19	4.5	150	18	241	582
20	20	5.5	150	18	238	577
21	21	6.5	150	18	236	572
22	22	4.5	170	18	244	593
23	23	5.5	170	18	241	591
24	24	6.5	170	18	239	585
25	25	4.5	190	18	248	619
26	26	5.5	190	18	245	602
27	27	6.5	190	18	243	596

It is clearly observed form the experimental results that the ultimate tensile strength remains constant up to 15 psi gas pressure and then it increases with the increase in the gas pressure. It is also observed that the ultimate tensile strength increases an increase in the value of current from 150 Amp to 190 Amp.

ANOVA

After getting the values for hardness and UTS of the weld joint, ANOVA was applied to analyze contribution of designated process parameters in the MIG welding process. The confidence level (CL) used for investigation is taken 95% for this investigation.

Table 3: *ANOVA Table For Tensile strength*

Source	DF	Adj SS	Adj MS	F	P
WELDING SPEED (mm/s)	2	1418.00	709.00	12.69	0.418
CURRENT (A)	2	3698.67	1849.33	33.10	0.005
VOLTAGE (V)	2	40.67	20.33	0.36	0.000
ERROR	20	1117.33	55.87		
TOTAL	26	6274.67			

Comparing the p-value to a commonly used α-level = 0.05, it is interpreted from the above table, that the values of probability are less than 0.05, which indicates that the factors are significant to the response parameters. From the above table, it is observed that the gas pressure and current are most influencing parameters for tensile strength compared to other parameters. The amount of variation observed in output parameters by the input factors was observed as 94.31 % which indicates that the model is able to predict the response with high accuracy.

The parametric study indicates that the percentage contribution of gas pressure is of 22.5%, current is of 58.9% and speed is of 12.50% for ultimate tensile strength, which denotes that the welding current is most significant parameter for the tensile strength of welding of SS316 and it is followed by gas pressure and welding speed.

Table 4: *ANOVA Table For Hardness*

Source	DF	Adj SS	Adj MS	F	P
WELDING SPEED (mm/s)	2	1246.52	623.259	50.43	0.256
CURRENT (A)	2	173.41	86.704	7.02	0.000
VOLTAGE (V)	2	9.19	4.593	0.37	0.000
ERROR	20	247.19	12.359		
TOTAL	26	1676.30			

It is interpreted from the above table, that the values of probability are less than 0.05, which indicates that the factors are significant to the response parameters. It is observed that the gas pressure and current are the most influencing parameters for hardness compared to others parameters.

The parametric study indicates that the percentage contribution of gas pressure is of 68.00 %, current is of 20.3 % and speed is of 7% for hardness, which denotes that the gas pressure is the most significant parameter for hardness of welding of SS316, followed by welding current and welding speed.

MAIN EFFECTS PLOT

The main effects plot for UTS and hardness with respect to gas pressure, welding current and welding speed is shown in figure below. It is clearly observed that at 18 psi of gas pressure, 190 A of welding current and 4.5 m/min of welding speed, maximum tensile strength can be achieved.

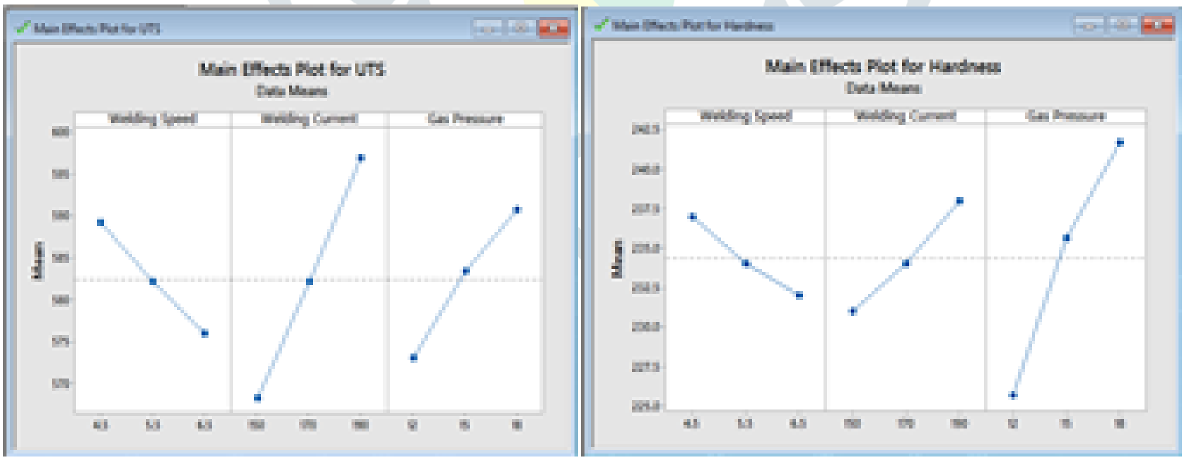

Fig. 2: Main effects plots for UTS and Harness

To get optimum hardness, the optimum value of gas pressure, welding current and welding speed should 18 psi, 190 A and 4.5 m/min respectively. It has been concluded from the results, that the optimum combination of each process parameter for higher Ultimate Tensile strength and hardness is achieved at high Gas Pressure [A3], high welding current [B3] and low Welding Speed [C1].

OPTIMIZATION USING GA

Three different initial population sizes were considered while running the GA. Test of 5 runs were conducted for each population size and the best results have been obtained. The values of control parameters and the response predicted using GA for maximum Ultimate Tensile Strength with population size 15, 20 and 25 respectively are shown in the table 5 & 6.

Table 5: *Optimized Table For Tensile Strength*

Ext No.	Population Size	Process Variables			Response
		Welding Speed	Welding Current	Gas Pressure	UTS
1	15	6.40134	176.012	14.9614	591.453
2	20	6.42410	176	15.0471	595.405
3	25	6.30012	176.004	14.658	594.532

Table 6: *Optimized Table For Hardness*

Ext No.	Population Size	Process Variables			Response
		Welding Speed	Welding Current	Gas Pressure	Hardness
1	15	6.15	152	12.02	222.177
2	20	6.49	150	12.3	221.529
3	25	6.14	153	12.15	223.897

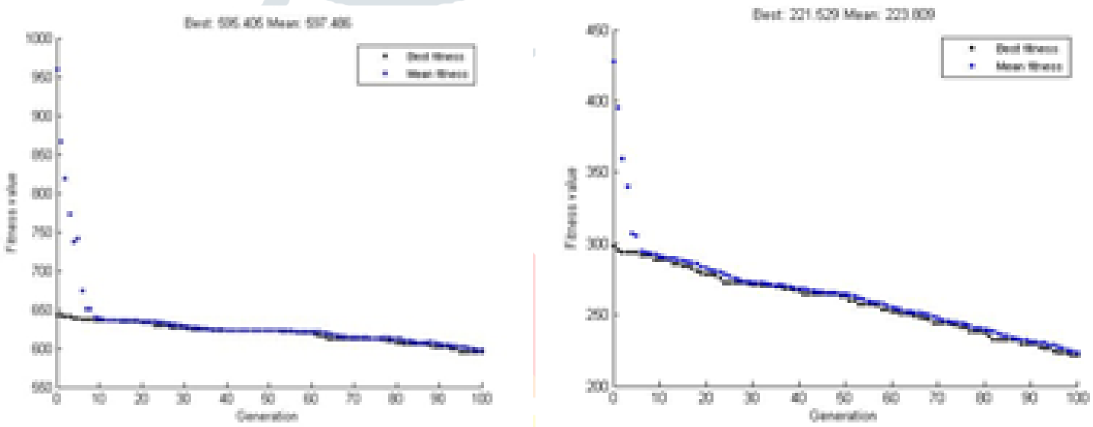

Fig. 3: Output of GA optimization

PREDICTIVE MODEL GENERATION USING ANN

Based on the experimental results, the ANN model is developed and trained for prediction of welding parameters. All 27 experimental data sets are divided for training, validation and testing. It is clear that more data sets in training reduces the processing time in ANN learning and improves the generalization capability of models, so large number of data sets were used to train the models. Hence 17 experimental data sets were trained by early stopping method which used for data sets for training, 5 data sets for validation and 5 models were used for testing. For the validation purpose, 3 experimental readings were nominated and the experiment results were validated through the model. Before applying inputs and outputs for ANN training, data have to be converted within a range of 0 to 1 or -1 to 1. i.e. data should be normalized for ANN training.

Table 7: *Normalized and randomized result table for ANN*

Exp. No.	Input Parameter			ANN Status	Output Parameter	
	Pressure	Current	Speed		Tensile Strength	Hardness
1	0	0	0	Validation	0	1
2	0	0	0.5	Testing	0.4	0.2
3	0	0	1	Training	0.8	0.4
4	0	0.5	0	Training	0.2	0.6
5	0	0.5	0.5	Training	0.4	0.8
6	0	0.5	1	Testing	0.8	1
7	0	1	0	Validation	0.4	0
8	0	1	0.5	Training	0.6	0.2

9	0	1	1	Testing	1	0.4
10	0.5	0	0	Testing	0	0.6
11	0.5	0	0.5	Training	0.2	0.8
12	0.5	0	1	Testing	0.6	0
13	0.5	0.5	0	Training	0.2	1
14	0.5	0.5	0.5	Training	0.6	0.2
15	0.5	0.5	1	Training	1	0.4
16	0.5	1	0	Training	0.2	0.6
17	0.5	1	0.5	Validation	0.8	0.8
18	0.5	1	1	Validation	1	0.4
19	1	0.5	0	Validation	0	0.6
20	1	0.5	0.5	Training	0.4	1
21	1	0.5	1	Training	0.8	0
22	1	1	0	Training	0.4	0.2
23	1	1	0.5	Training	0.6	0.8
24	1	1	1	Training	1	0.2
25	1	0	0	Training	0.4	0.4
26	1	0	0.5	Training	0.8	0.6
27	1	0	1	Training	1	0.8

POST PROCESSING

Table 8: *Weights In between Input Parameters and Neurons in Hidden Layers*

	N1	**N2**	**N3**	**N4**	**N5**	**N6**
P	16.7346	-16.8101	-16.7827	16.7727	-16.7987	16.7894
C	-16.6166	16.6011	-16.6962	16.6351	-16.7240	-16.6982
S	-17.8132	17.7856	16.7325	-16.6755	17.6960	16.6350
	N7	**N8**	**N9**	**N10**	**N11**	**N12**
P	-16.7981	16.7941	16.8106	-16.8527	-16.8101	-16.8100
C	16.6942	-16.7360	16.7425	16.8325	16.7646	-16.7988
S	-16.6786	-16.7762	17.6321	-17.6521	17.7521	16.9325

Table 9: *Weights in between neurons in hidden layers and output parameters*

	N1	**N2**	**N3**	**N4**	**N5**	**N6**
UTS	-0.4632	-0.1811	-0.3257	0.3193	0.2106	0.3644
	N7	**N8**	**N9**	**N10**	**N11**	**N12**
UTS	0.1846	0.5345	-0.1822	0.3420	0.1619	-0.5928
	N1	**N2**	**N3**	**N4**	**N5**	**N6**
Hardness	0.4559	-0.1721	-0.3456	0.4491	-0.3512	0.3745
	N7	**N8**	**N9**	**N10**	**N11**	**N12**
Hardness	0.1745	0.4535	-0.1721	0.2521	0.1521	-0.6821

PREDCTIVE MODEL FOR UTS AND HARDNESS

UTS = 452.8 - 6.611 Welding Speed + 0.7167 Welding Current + 2.944 Gas Pressure
Hardness = 177.28 - 2.167 Welding Speed + 0.1972 Welding Current + 2.407 Gas Pressure

In the comparison, it is observed that the 8.28% variation in predicted and actual results. So, it is interpreted the developed ANN model provides precise results and can be accepted for prediction.

CONCLUSIONS

From the experimental results it was found that the ultimate tensile strength increases initially and then decreases with the increase in the value of welding speed. The parametric study indicates that the gas pressure is the most significant parameter for hardness and is followed by welding current and welding speed. The parametric study also reveals that the welding current is the most significant parameter for tensile strength of welding and is followed by gas pressure and welding speed. Based on the experimental results, the ANN model is developed for prediction of ultimate tensile strength and hardness of welding. The comparison between predicted and actual values confirm minor variation in results. Therefore, the developed ANN model provides accurate results and can be used to predict the output parameters like ultimate tensile strength and hardness for given input parameters such as gas pressure, current and speed in MIG welding process.

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