DEVELOPMENT OF INCOMPLETE PENETRATION PREDICTIVE MODELS USING RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL NETWORK

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Abstract. This paper seeks for forecasting partial penetration inside tungsten inert gas welding utilizing reaction surface technique plus artificial neural network. It handles the statistical approach of main composite design, Analysis of Variance (ANOVA), surface plots as well as cooks distance and also the quasi newton neural network to examine along with forecast the reaction aim. The outcome extracted from the all model suggests that the design predicts the partial penetration adequately. Even so the artificial neural network is a greater predictive model with least mean square error. The statistical method for prediction used have discovered boosting applications in an assortment of areas of sciences and engineering, the techniques outlined in this paper for incomplete penetration prediction is able to eradicate the requirement for performing experiments on the groundwork of the conventional technique which happens to be time consuming and economically not justifiable.
Keywords: *incomplete penetration, prediction, tungsten inert gas welding, artificial neural network, mild steel*

Introduction

The choices that are generated by fabrication specialist are based not merely all over their expertise and experience but additionally on conventions with regards to the phenomena which usually occur throughout processing. During welding, a lot of such phenomena are extremely sophisticated plus interact with numerous factors, therefore avoiding high operation performance right from becoming attained. The information of the way welding procedure parameters greatly influence weld bead geometry is essential since it may be utilized in semiautomatic and automatic control of arc welding operations exactly where optimum choice of input variables is necessary for top cost and productivity effectiveness. Research scientific studies disclosed that the majority of the failures noticed in fabricated steel components is associated with Insufficient fusion, Lack of penetration, Porosity, Slag inclusions and Crack initiation. Among the most considerable factors impacting on the fatigue life of the weld is insufficient weld penetration Research studies happened to be carried out to expand mathematical models to foresee the penetration sizing ratio (PSR) (the ratio of bead width for the position of the reinforcement and penetration) form factor (RFF) the ratio of bead width on the level of reinforcement (Gunaraj and Murugan, 1999) prediction scientific studies of weld penetration of Flux Core Arc Welding operation parameters of welding current, nozzle-to-plate distance, arc voltage, electrode-to-work angle as well as welding speed was done (Mostafa and Khajavi, 2006).

The weld bead geometry plays a crucial part in determining the hardware components of the weld. Thus the input welding procedure variables that affect the bead geometry needs to as a result be effectively selected to acquire a suitable top quality

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joint. Various approaches have actually been reported developing mathematical models to foresee bead geometry inside welding towards the option in addition to being control of the progression variables. A number of scientists have resorted to significantly less comprehensive regression methods based upon big experimental databases. Mathematical relationships have been completely discovered for penetration, reinforcement height, and bead width (Chan et al., 1999).Weld bead geometry is generally managed by numerous welding process input parameters including welding speed, power, voltage, arc performance, preheating heat, thermal conductivity, thermal diffusivity, as well as plate thickness (Azar et al., 2012). The bead cross-section area typically defines the whole shrinkage as well as consequently the inner residual pressure plus distortion (Shumovsky, 1952). Weld bead geometry even offers a tremendous impact in the determination of the mechanical components of the welded structure (Dey et al., 2009). Numerous scientific studies had been conducted to create mathematical models which correlate the input parameters with the bead geometry dimensions. For instance, mathematical models have been proven to anticipate the geometry of the weld bead within the deposition of 316L stainless steel right onto structural steel will be 2062 using GMAW (Murugan and Parmar, 1987). It's claimed that the strength associated with a welded joint is mainly based on the dimensions along with condition of its bead. The fractional factorial approach was used to forecast the weld-bead shape and geometry relations penetration, width, reinforcement height, width to penetration ratio and percentage dilution.

The foundation metal was a 13 mm thick minimal carbon structural metal plate. The variables with the FCAW operation viewed as part of this particular work happen to be arc voltage, welding speed, welding current, gun angle as well as nozzle to plate distance. They've formulated models that can be employed whether in order to predict the bead geometry or perhaps to be able to establish a range or a combination of parameters to acquire the desired bead geometry dimensions within the aspects domain. In addition, these models may also be applied in a generation platform for automatic control of welding conditions (Raveendra and Parmar, 1987). Studies to exhibit the inter connection among robotic CO2 arc welding variables along with bead penetration was created by producing mathematical models to forecast the desired bead penetration (Kim et al., 2003a). An investigation on robotic gasoline steel arc welding utilized factorial pattern to do a correlation involving its key in system variables (welding voltage, welding speed and arc current) to three responses (bead width, bead height and penetration) employing AS 1204 mild metal plates (Kim et al., 2003b).

Materials and Methods

In this study an optimum experimentation to maximize penetration area was conducted. Gas tungsten arc welding process was used to join the weld specimen made of low carbon steel. The first step taken was to cut the mild steel coupons, sand paper and bevel the edges. Using the optimal experimental matrix as a guide, five set of welded sample was made for each experimental run which amounted to a total of one hundred weld samples.

Material selection

Minimal carbon metal can be selected beyond different substances due to its unique components, more affordable price tag plus the availability of its in market. Moderate metal content consumed inside pressure vessel as well as dairy packaging. This quality has top corrosion resistance as well as may be operated at temperature which is elevated. The task plot has the subsequent Dimensions of specimen: 60mm x 40mm x 10 mm.

Welding process parameters

The welding process parameters consists of current, voltage, gas flow rate, their range of values are shown in *Table 1*.

Table 1. *Process parameters.*

Factors	Unit	Symbol	Low (-1)	High (+1)
Welding current	Ampere	I	130	170
Welding voltage	Volts	V	20	24
Gas flow rate	Lit/min	GFR	13	17

Conducting the experiments using the design matrix

In the current job, moderate iron plates of 10 mm thickness along with 60 mm lengths were butt joined utilizing the preferred filler rod at different levels of existing gas and voltage flow speed *t* by manual TIG welding process. These three variables happened to be considered as variable for current research plus their three levels have been selected that reactions ended up being assessed, for which main composite design was selected as experimental design technique. These variables because of their levels have been proven in *Table 2*. Prior to welding throughout the splats had been washed chemically by acetone as a way to get rid of some origin of contaminants as rust, dust, oil etc. Individual pass welding was conducted within the samples underneath the circumstances described below. Welding frequent parameters: Electrode type: 98% tungsten, 2% thoriated Shielded gasoline type: clean argon Electrode dia.: 2.4 mm Current type: DCEN.

Table 2. *Experimental data.*

Run	I	V	GFR	α_R (Mpa) residual stress	P_1 (mm) incomplete penetration	T_L (◦C) liquidus temperature	*n* (kg/m.s.) viscosity
1	130.00	21.50	12.50	407.8	7.63	1650	0.007564
2	130.00	21.50	12.50	388.3	7.48	1655	0.007495
3	110.00	20.00	11.00	340.42	5.34	1632	0.007875
4	110.00	23.00	11.00	307	4.2	1645	0.007634
5	130.00	21.50	12.50	405.47	7.63	1650	0.007564
6	130.00	24.02	12.50	472.54	6.78	1680	0.007167
7	163.64	21.50	12.50	385.73	9.65	1736	0.006514
8	130.00	21.50	12.50	388.3	7.48	1655	0.007495
9	110.00	23.00	14.00	289	6.74	1624	0.007938
10	96.36	21.50	12.50	234.8	4.89	1645	0.007634
11	150.00	20.00	14.00	410.28	8.84	17.00	0.006921
12	130.00	21.50	15.02	405.47	7.63	1650	0.00756
13	150.00	20.00	11.00	380	8.84	1660	0.00767
14	130.00	21.50	12.50	388.3	7.49	1655	0.007495
15	130.00	18.98	12.50	405.47	7.63	1650	0.007564
16	110.00	20.00	14.00	318	6.74	1624	0.007638

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17	150.00	23.00	11.00	445.88	8	1706	0.006645
18	130.00	21.50	9.98	364.32	6.12	1632	0.00782
19	130.00	21.50	12.50	405.47	7.63	1650	0.007564
20	150.00	23.00	14.00	445.88	8.82	1724	0.006645

Results and Discussion

To test for the integrity of the second order quadratic model the analysis of variance is required which is shown in *Table 3*.

***Table 3**. ANOVA for incomplete penetration.*

Model	Average		Mean	F	p-value	Significant
A-current	27.80	1	27.80	1864.33	<0.0001	
B-voltage	0.86	1	0.86	57.75	<0.0001	
C-gas flow rate	3.90	1	3.90	261.63	<0.0001	
AB	9.800E-0.03	1	9.800E-0.03	0.66	0.4364	
AC	1.22	1	1.22	81.60	<0.0001	Significant
BC	0.48	1	0.48	32.20	0.0002	
A^2	0.093	1	0.093	6.22	0.0317	
B^2	0.15	1	0.15	10.30	0.0093	
C^2	0.70	1	0.70	46.73	<0.0001	
Total	35.10	9	3.90	261.55	<0.0001	
Residual	0.15	10	0.015	-	-	-
Lack of fit	0.12	5	0.023	3.61	0.0925	Not significant
Pure error	0.032	5	6.467E-003	-	-	-
Cor total	35.25	19	-	-	-	-
Model	35.10	9	3.90	261.55	<0.0001	Significant

Table 3 shows the Anova table for incomplete penetration, a p-value of 0.0001 shows that the model is significant and the process parameters are also significant with p-values <0.05. The diagnostic case statistics for the incomplete penetration which checks for data and model compatibility and integrity is shown in *Table 4*.

***Table 4**. Diagnostics case statistics report of incomplete penetration.*

Standard	Actual	Predicted	Residual	Leverage	Studentized		Influence on fitted value	Cooks	Run
					Internally	Externally			
1	5.34	5.33	0.010	0.670	0.144	0.136	0.194	0.004	3
2	8.84	8.89	-0.053	0.670	-0.762	-0.745	-1.061	0.118	13
3	4.20	4.27	-0.068	0.670	-0.964	-0.961	-1.368	0.189	4
4	8.00	7.97	0.029	0.670	0.410	0.392	0.559	0.034	17
5	6.74	6.69	0.051	0.670	0.728	0.710	1.011	0.108	16
6	8.84	8.69	0.15	0.670	2.102	2.670	1.80	0.896	11
7	6.74	6.61	0.13	0.670	1.900	2.255	1.21	0.732	9
8	8.82	8.75	0.070	0.670	0.994	0.994	1.415	0.201	20
9	4.89	4.93	-0.037	0.607	-0.482	-0.463	-0.576	0.036	10
10	9.65	9.73	-0.076	0.607	-0.993	-0.993	-1.234	0.153	7
11	7.63	7.68	-0.054	0.607	-0.703	-0.684	-0.851	0.076	15
12	6.78	6.84	-0.059	0.607	-0.773	-0.756	-0.940	0.092	6
13	6.12	6.03	0.087	0.607	1.143	1.163	1.446	0.202	18
14	7.63	7.83	-0.20	0.607	-2.619	1.43	-1.51	0.106	12
15	7.63	7.55	0.077	0.166	0.687	0.667	0.298	0.009	1
16	7.63	7.55	0.077	0.166	0.687	0.667	0.298	0.009	19
17	7.49	7.55	-0.063	0.166	-0.569	-0.549	-0.245	0.006	14

18	7.63	7.55	0.077	0.166	0.687	0.667	0.298	0.009	5
19	7.48	7.55	-0.073	0.166	-0.659	-0.639	-0.285	0.009	2
20	7.48	7.55	-0.073	0.166	-0.659	-0.639	-0.285	0.009	8

Table 4 shows the various statistics employed to measure the integrity of the data and model, the cooks distance should be between o and 1. To study the effects of current and voltage on the incomplete penetration, 3D surface plots presented in *Figure 1* was generated.

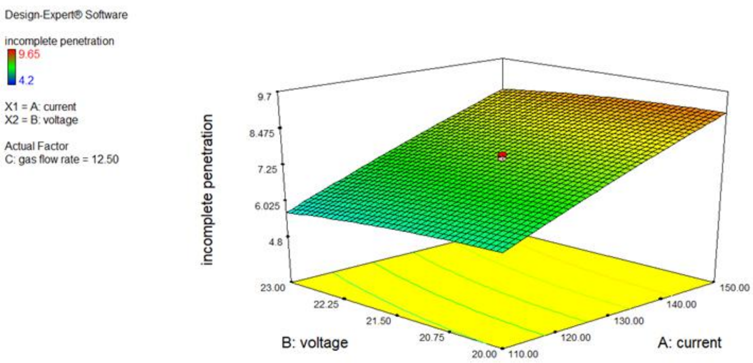

Figure 1. *Effect of voltage and current on incomplete penetration.*

Figure 1 shows the combined interaction between current, voltages on incomplete penetration, the figure shows that voltage does not have significant effect on the incomplete penetration but the current has a very significant effect. The artificial neural network method was also used to make predictions of the incomplete penetration as the performance plot is produced as shown in *Figure 2*.

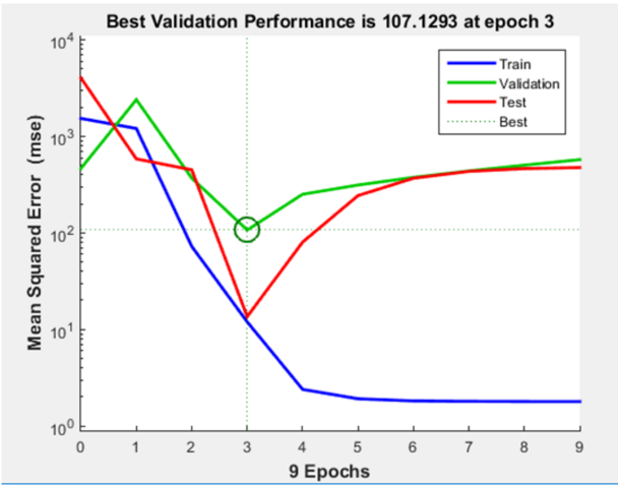

Figure 2. *Performance curve for trained network to predicting incomplete penetration.*

Figure 2 presents the performance curve for the trained network. In MATLAB software, an epoch can be thought of as a completed iteration of the training procedure of your artificial neural network. Which means, once all the vectors in your training set have been used or gone through your training algorithm, one epoch has been attained. Thus, the "real-time duration" of an epoch is dependent on the training method used. The best prediction for the Incomplete fusion was achieved at epoch 3, although, a total of 9 epochs where used in the iteration process.

To measure the correlation between the network output and the actual results a correlation plot is produced for the incomplete penetration is presented in *Figure 3*.

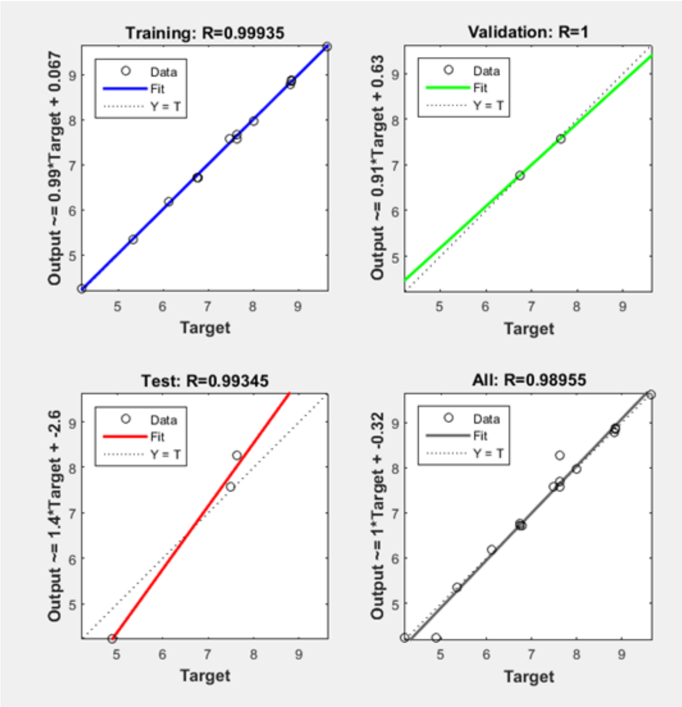

Figure 3. *Regression plot of training, validation and testing for incomplete penetration.*

Figure 3 present the training, validation and testing plot with correlation coefficient (R) of over 90% which signifies a robust prediction for the Incomplete fusion. The dotted diagonal line on each plot indicates the line of best fit which indicate a perfect prediction. A comparison between the experimental results and the predicted results of the incomplete penetration is presented in *Table 5*.

Table 5*. ANOVA for incomplete penetration.*

S/N	Input parameters			Exp responses	ANN observed
	Current	Voltage	Welding speed	P_I (mm) incomplete penetration	P_I (mm) incomplete penetration
1	130.00	21.50	12.50	7.63	7.57902
2	130.00	21.50	12.50	7.48	7.57902
3	110.00	20.00	11.00	5.34	5.34621
4	110.00	23.00	11.00	4.20	4.23805
5	130.00	21.50	12.50	7.63	7.57902
6	130.00	24.02	12.50	6.78	6.71520
7	163.64	21.50	12.50	9.65	9.62225
8	130.00	21.50	12.50	7.48	7.57902
9	110.00	23.00	14.00	6.74	6.72510
10	96.36	21.50	12.50	4.89	4.23405
11	150.00	20.00	14.00	8.84	8.86060
12	130.00	21.50	15.02	7.63	8.26603
13	150.00	20.00	11.00	8.84	8.88413
14	130.00	21.50	12.50	7.49	7.57902

15	130.00	18.98	12.50	7.63	7.67991
16	110.00	20.00	14.00	6.74	6.76839
17	150.00	23.00	11.00	8.00	7.97233
18	130.00	21.50	9.98	6.12	6.19099
19	130.00	21.50	12.50	7.63	7.57902
20	150.00	23.00	14.00	8.82	8.77883

A graphical representation of the closeness between the ANN result and the actual values of the Incomplete penetration, a regression plot is produced which is shown in *Figure 4*.

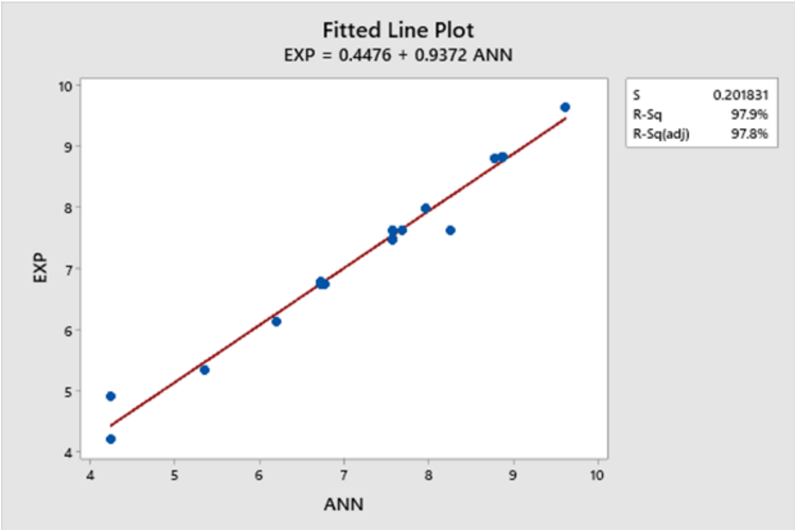

Figure 4. *Regression plot of experimental versus predicted incomplete penetration.*

Figure 4 presents the regression plot for the experimental observed results versus the predicted result. It was observed that a robust R2 value of 97.9% was obtained, with an adjusted R2 of 97.8% is presented in *Table 6*.

Table 6*. Model summary statistics for incomplete penetration.*

S	R-sq	R-sq(adj)
0.201831	97.92%	97.80%

The analysis of variance ANOVA for the network which measures the error probability of the incomplete penetration network is presented in *Table 7*. To measure the predictive accuracy of the incomplete fusion network a time series plot is produced as shown in *Figure 5*.

Table 7*. Analysis of variance for incomplete penetration.*

Source	DF	SS	MS	F	P
Regression	1	34.5183	34.5183	847.37	0.000
Error	18	0.7332	0.0407	-	-
Total	19	35.2515	-	-	-

Figure 5. *Time series plot showing the prediction accuracy of ANN with comparison to experimental for incomplete fusion.*

The RSM model developed in this study selected the second order quadratic model to accurately predict the incomplete penetration, the Anova results shows that the model selected is very significant with the p values of the input parameters and the model are < 0.0001 indicating minimum error probability, the RSM model produced reasonable predictions. Secondly the ANN model was also employed to predict the same response, the network showed very high correlation with the experimental results. The two models produced accurate prediction but the ANN model possesses a higher predictive adequacy.

Conclusion

This study reveals the successful use of ANN and RSM to predict incomplete penetration of TIG welded mild steel plates and the results reported are in good agreement with other researchers. ANN Predicted results show a mean squared error of 0.0407. The diagnostic case statistics and the Anova table showed the significance and strength of the RSM model, but the ANN model is observed to be a better predictive model.

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Conflict of interest

There is no conflict of interest with any party or organization in the course of this work.

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