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Optimization and Prediction of Preheat Temperature; A Tig Process Parameter needed to Eliminate Crack Formation and Stabilize Heat Input in Mild Steel Weldment using RSM and ANN

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ABSTRACT
Welding failures are mostly influenced by improper combination of the welding process factors such as; current, voltage, welding speed and gas flow rate. To improve the quality of welded joints, it is imperative that input parameters that affect the welding process be monitored and optimally determined. The target of this study is to optimize and predict the optimal combination of current, voltage and welding speed needed to minimize preheat temperature in order to eliminate crack formation and stabilize heat input in mild steel weldment using response surface methodology (RSM) and artificial neural network (ANN).
The key input parameters considered in this work are welding current, welding voltage and welding speed while the response or measured parameter is preheat temperature (PT). Using the range and levels of the independent variables, statistical design of experiment (DOE) using central composite design (CCD) method was employed to randomize the input variables. Hundred (100) pieces of mild steel coupons measuring 60 x 40 x10 were used for the experiments. The experiment was performed 20 times, using 5 specimens for each run. The plate samples were 60 mm long with a wall thickness of 10mm. The samples were cut longitudinally with a Single-V joint preparation. The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined. The welding process uses a shielding gas to protect the weld specimen from atmospheric interaction. For this study, 100% pure Argon gas was used. The weld samples were made from 10mm thickness of mild steel plate; the plate was cut to size with the power hacksaw. The edges grinded and surfaces polished with emery paper and the joints welded and thereafter, the response (preheat temperature) was measured and recorded. To optimize the welding process, numerical optimization based on response surface methodology was employed while the prediction of preheat temperature using input variables not captured by the design of experiment was done using artificial neural network.
From the result, it was observed that; for a current of 190.00amp, voltage of 21.95volts and welding speed of 5.00mm/s the minimized preheat temperature was computed to be 150.677^{0}C. In addition, the reliability plot of observed preheat temperature versus ANN predicted preheat temperature yielded a coefficient of determination (R^2) value of 0.9978.

Keyword: Preheat temperature, Design of experiment, Central composite design, Response surface methodology and artificial neural network

I. INTRODUCTION

Welding failures are mostly influenced by improper combination of the welding process factors such as; current, voltage, welding speed and gas flow rate (Sreeraj et al., 2013). Choosing the most suitable combinations of input process

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parameters in order to achieve the required optimum weld bead quality is one of the fundamental issues facing Engineers in the manufacturing sector presently (Sharma et al., 2020, Srirangan and Paulraj, 2016). Since the quality and strength of a weld is characterized by the reduction and elimination of weld defects such as cracks, undercut, deformation and porosity, it is important to employ standard methods for the selection of input variables and also for the optimization and prediction of the response variables using the selected input variables that can influence the quality and strength of the welded material (Panagiotidou and Tagaras, 2007). Numerous supervised machine learning algorithm are available for achieving these task. Popular among them is response surface methodology (RSM), support vector machine (SVM), random forest algorithm and artificial neural network (ANN) (Ghosh et al., 2016). Response surface methodology is an advance statistical technique which involves the incorporation of the second order effects of non-linear relationships (Cerino-Cordova et al., 2011). It is a popular optimization technique employed in most process industries to determine the best possible combination of variables needed to optimize a specific response while artificial neural network is a predictive technique that employs different training algorithm and neurons to learn on a particular task. Numerous literatures on the application of machine learning algorithm were reviewed in the course of this study. Notable among the literatures includes;

Murugan and Gunaraj, 2018 who employed RSM to correlate the angular distortion in GMAW of structural steel plate (IS: 2062) to the process parameters, namely: time gap between successive passes and wire feed rate. The main and interaction effects of the process parameters were analyzed and presented. It was found that the number of passes had a strong effect on the response, therefore, to control the angular distortion in practice the number of passes has to be monitored carefully. Moreover, it was demonstrated that all the process parameters have a negative effect on the angular distortion.

Kim et al., (2002) have used genetic algorithm (GA) and RSM to determine the optimal welding conditions in GMAW process, the base metal was mild steel with a thickness of 5.8 mm. First, the near-optimal conditions were determined through GA, and then the optimal conditions were determined over a relatively small region by using RSM. The desirability function approach was used to find the optimal conditions. They correlated the following parameters; wire-feed rate, welding voltage and welding speed to some responses, namely, bead width, Penetration and height. They concluded that by combining these two techniques, a good result for finding the optimal welding conditions can be obtained.

Benyounis and Olabi (2008) have developed a mathematical model using RSM to relate the failure load to the laser welding parameters namely: laser power, welding speed and focal position. The effect of the process parameters on the failure load and the tensile-shear strength of the lap joint made of AIS13O4 with I mm thickness have been investigated. It was found that the main factor affecting the joint strength is the welding speed and the other two factors are slightly affecting the joint strength.

Turan et al., (2014) have applied the ANN models to predict the mechanical properties of steels in various applications, namely: impact strength of quenched and tempered pressure vessel steel exposed to multiple post weld heat treatment cycles. In addition, the hardness of the simulated HAZ in pipeline and lap fitting steel after in-service welding and the hot ductility and hot strength of various micro-alloyed steel over the temperature range for stand or slab straightening in continuous casting process were also predicted. It was found that the three ANN models successfully predicted the mechanical properties. It was also shown that ANNs could successfully predict multiple mechanical properties and the result of the sensitivity analysis were in agreement with both findings of the experimental investigation and reported results in the literature, Furthermore, it was mentioned that the use of ANNs resulted in large economic benefits for organizations through minimizing the need for expensive experimental investigation and/or inspection of steels used in various applications.

II. RESEARCH METHODOLOGY

The key input parameters considered in the study includes; welding current, welding voltage and welding speed while the response or measured variable is pre-heat temperature (CR). The range and level of the experimental variables used for statistical design of experiment are presented in Table 1

Table 1: Range and Levels of independent variables

Independent Variables	Range and Levels of Input Variables	
	Lower Range (-1)	Upper Range (+1)
Welding Current (Amp) X_1	170	190
Welding Voltage (Volt) X_2	21	25
Welding Speed (mm/s) X_2	2	5

Using the range and levels of the independent variables presented in Table 1, statistical design of experiment (DOE) using central composite design (CCD) method was done. The total number of experimental runs that can be generated using the CCD is defined as;

$$N= 2^n + n_o + 2n \quad (1)$$

Where;

N; is the number of experimental runs based on CCD design
2^n; is the number of factorial points
n_0; is the number of center points
2n; is the number of axial points
n; is the number of variables
Using Equation 1, twenty (20) experimental runs were generated based on the central composite design method and presented in Table 2

Table 2: Design of experiment (DOE)

Std	Run	Type	Current (A)	Voltage (V)	Welding Speed (mm/s)
15	1	Center	180	23	3.5
16	2	Center	180	23	3.5
17	3	Center	180	23	3.5
18	4	Center	180	23	3.5
19	5	Center	180	23	3.5
20	6	Center	180	23	3.5
9	7	Axial	163.1820717	23	3.5
10	8	Axial	196.8179283	23	3.5
11	9	Axial	180	19.63641434	3.5
12	10	Axial	180	26.36358566	3.5
13	11	Axial	180	23	0.977310754
14	12	Axial	180	23	6.022689246
1	13	Fact	170	21	2
2	14	Fact	190	21	2
3	15	Fact	170	25	2
4	16	Fact	190	25	2
5	17	Fact	170	21	5
6	18	Fact	190	21	5
7	19	Fact	170	25	5
8	20	Fact	190	25	5

Applying the design of experiment presented in Table 2, 100 pieces of mild steel coupons measuring 60 x 40 x10 were used for the experiments. The experiment was performed 20 times, using 5 specimens for each run. The plate samples were 60 mm long with a wall thickness of 10mm. The samples were cut longitudinally with a Single-V joint preparation.

The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined. The welding process uses a shielding gas to protect the weld specimen from atmospheric interaction. For this study, 100% pure Argon gas was used. The weld samples were made from 10mm thickness of mild steel plate; the plate was cut to size with the power hacksaw. The edges grinded and surfaces polished with emery paper and the joints welded and thereafter, the responses were measured and recorded. The measured response corresponding to the input variable is presented in Table 3

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Table 3: Design of experiment (DOE)

Run	Type	Current (A)	Voltage (V)	Welding Speed (mm/s)	Preheat Temp. (^{0}C)
1	Center	180	23	3.5	162
2	Center	180	23	3.5	160
3	Center	180	23	3.5	159
4	Center	180	23	3.5	158
5	Center	180	23	3.5	162
6	Center	180	23	3.5	161
7	Axial	163.1820717	23	3.5	150
8	Axial	196.8179283	23	3.5	182
9	Axial	180	19.63641434	3.5	140
10	Axial	180	26.36358566	3.5	170
11	Axial	180	23	0.977310754	160
12	Axial	180	23	6.022689246	150
13	Fact	170	21	2	190
14	Fact	190	21	2	180
15	Fact	170	25	2	155
16	Fact	190	25	2	180
17	Fact	170	21	5	180
18	Fact	190	21	5	195
19	Fact	170	25	5	130
20	Fact	190	25	5	145

For analysis of design data, Design Expert Statistical Software, Version 7.01, was employed in order to obtain the effects, coefficients, standard deviations of coefficients, and other statistical parameters of the fitted models. The behaviour of the system which was used to evaluate the relationship between the response variables (Y_1, Y_2, Y_3, Y_4 and Y_5) and the independent variables (X_1, X_2, and X_3) was explained using the empirical second-order polynomial equation proposed by Nuran, (2007)

$$Y = \beta_0 + \sum_{i=1}^{q} \beta_i x_i + \sum_{i=1}^{q} \beta_{ii} x_i^2 + \sum_{i=1, i<j}^{q-1} \sum_{j=2}^{q} \beta_{ij} x_i x_j + \varepsilon \tag{2}$$

Where;
X_1, X_2, X_3… X_k = input variables
Y, β_0, β_i, β_{ii}, and β_{ij} = the known parameters and ε = the random error.

To predict the preheat temperature beyond the scope of experimentation; artificial neural network (ANN) was employed. The step by step methodology of applying neural network is discussed as follows;

2.1 Generation of input data

Input data employed in the training, validation and testing were obtained from series of batch experiments based on the central composite design of experiment under varied welding current, welding voltage and welding speed. A full factorial central composite design of an experiment with 6 center points and 3 replicates resulted in a total of 60 experimental runs was used as the input data. The data were randomly divided into three subsets to represent the training (60%), validation (25%) and testing (15%). The validation data were employed to assess the performance and the generalization potential of the trained network while the testing data were used to test the quality of the network. To avoid the problem of weight variation which can subsequently affect the efficiency of the training process, the input and output data were first normalized between 0.1 and 1.0 using the normalization equation proposed by Sinan et al., 2011 presented in Equation 2.3

$$x_i = \frac{x - x_{min}}{x_{max} - x_{min}} + 0.1 \tag{2.2}$$

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Where;
x_i; is the normalized value of the input and output data
x_{min}; and x_{max} are the minimum and maximum value of the input and output data
x is the input and output data.

2.2 Selection of training algorithm and hidden neurons

Input and output data training resulting in the design of network architecture is of paramount importance in the application of neural network to data modelling and prediction. To obtain the optimal network architecture that possess the most accurate understanding of the input and output data, two factors were considered. First was the selection of the most accurate training algorithm and secondly, the number of hidden neurons. Based on this consideration, different training algorithm and hidden neurons were selected and tested to determine the best training algorithm and accurate number of hidden neurons that will produce the most accurate network architecture. Selectivity was based on (r^2 and MSE).

2.3 Network Training/Performance of MNN

To train the network, 3 runs of 1000 epochs, each were used. In addition, cross validation data representing about 15% of the total input data were introduced to monitor the progress of training and prevent the network from memorizing the input data instead of leaning which was a common problem associated with overtraining. The progress of the training was checked using the mean square error of regression (MSE) graph for training and cross validation

2.4 Network Testing/Validation

To test the efficiency of the trained network, 25% of the input data was introduced to the network.

III. RESULTS AND DISCUSSION

The target of the optimization model was to minimize preheat temperature by optimizing the input variables. Using the method of numerical optimization based on response surface methodology, a second order polynomial equation was generated using the quadratic model. To validate the suitability of the quadratic model in analyzing the experimental data, the sequential model sum of squares were calculated and presented in Table 4

Table 4: Sequential model sum of square for preheat temperature (PT)

Notes for PUNDI
Design (Actual) — Summary, Graph Columns, Evaluation
Analysis — BHN (Analyzed), HI (Analyzed), HIW (Analyzed), CR (Analyzed), PT (Analyzed)
Optimization — Numerical, Graphical, Point Prediction

Transform | Fit Summary | f(x) Model | ANOVA | Diagnostics | Model Graphs

Response 5 PT Transform: None

*** WARNING: The Cubic Model is Aliased! ***

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	5.343E+005	1	5.343E+005			
Linear vs Mean	1102.66	3	367.55	1.36	0.2914	
2FI vs Linear	1681.50	3	560.50	2.75	0.0853	
Quadratic vs 2FI	2618.30	3	872.77	268.63	< 0.0001	Suggested
Cubic vs Quadra	16.84	4	4.21	1.61	0.2853	Aliased
Residual	15.65	6	2.61			
Total	5.398E+005	20	26987.65			

"Sequential Model Sum of Squares [Type I]": Select the highest order polynomial where the additional terms are significant and the model is not aliased.

The sequential model sum of squares table shows the accumulating improvement in the model fit as terms are added. Based on the calculated sequential model sum of square, the highest order polynomial where the additional terms are significant and the model is not aliased was selected as the best fit. From the results of Tables 4, it was observed that the cubic polynomial was aliased hence cannot be employed to fit the final model. In addition, the quadratic and 2FI model with p-value <0.0001, F-value of 268.63, mean

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square value of 872.77 and sum of square value of 2618.30 were suggesed as the best fit.

To test how well the quadratic model can explain the underlying variation associated with the experimental data, the lack of fit test was estimated for preheat temperature. Model with significant lack of fit cannot be employed for prediction. Results of the computed lack of fit for preheat temperature is presented in Table 5.

Table 5: Lack of fit test for preheat temperature (PT)

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	4318.96	11	392.63	147.24	< 0.0001	
2FI	2637.46	8	329.68	123.63	< 0.0001	
Quadratic	19.16	5	3.83	1.44	0.3503	Suggested
Cubic	2.31	1	2.31	0.87	0.3945	Aliased
Pure Error	13.33	5	2.67			

"Lack of Fit Tests": Want the selected model to have insignificant lack-of-fit.

From the results of Tables 5, it was observed that the quadratic polynomial with p-value of 0.3503, F-value of 1.44, mean square value of 3.83 and sum of square value of 19.16 had a non-significant lack of fit and was suggested for model analysis while the cubic polynomial with p-value of 0.3945, F-value of 0.87, men square value of 2.31 and sum of square value of 2.31 had a significand lack of fit hence aliased to model analysis. The model summary statistics computed for preheat temperature based on the different model sources is presented in Table 6

Table 6: Model summary statistics for preheat temperature (PT)

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	16.46	0.2029	0.0534	-0.4549	7907.32	
2FI	14.28	0.5123	0.2872	0.0882	4955.44	
Quadratic	1.80	0.9940	0.9886	0.9696	165.38	Suggested
Cubic	1.61	0.9971	0.9909	0.9027	528.79	Aliased

"Model Summary Statistics": Focus on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared".

With R-squared value of 0.9940, Adjusted R-squared value of 0.9886, predicted R-squared value of 0.9696 and the predicted error sum of square (PRESS) value of 165.38, the quadratic model was acclaimed the best fit model. Low standard deviation, R-Squared near one and relatively low PRESS is the optimum criteria for defining the best model source. Based on the results of Tables 6, the quadratic polynomial model was suggested

In assessing the strength of the quadratic model towards minimizing preheat temperature (PT), one-way analysis of variance (ANOVA) was generated for and presented in Table 7.

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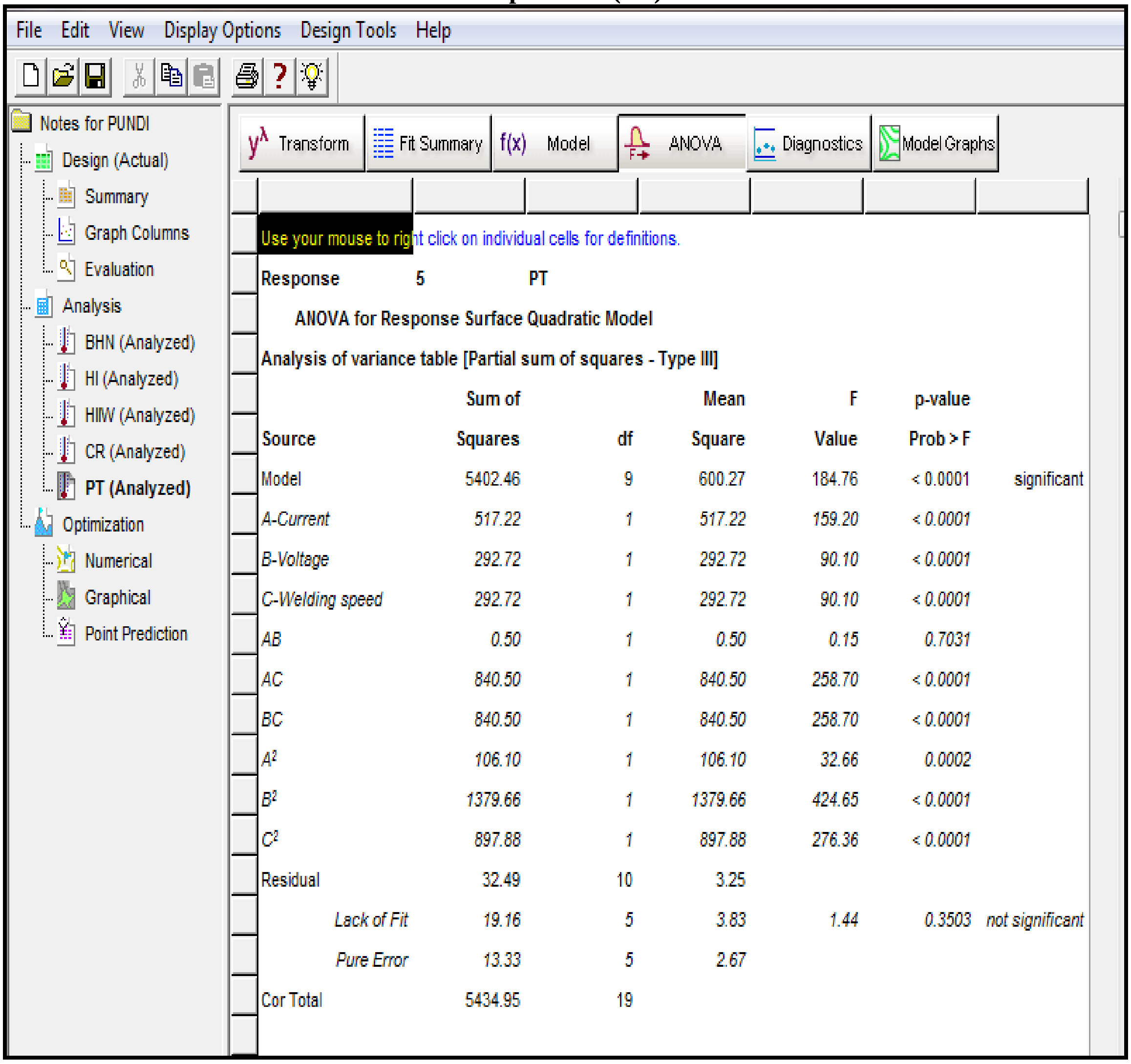
Table 7: ANOVA table for validating the model significance towards minimizing preheat temperature (PT)



Response 5 PT

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5402.46	9	600.27	184.76	< 0.0001	significant
A-Current	517.22	1	517.22	159.20	< 0.0001	
B-Voltage	292.72	1	292.72	90.10	< 0.0001	
C-Welding speed	292.72	1	292.72	90.10	< 0.0001	
AB	0.50	1	0.50	0.15	0.7031	
AC	840.50	1	840.50	258.70	< 0.0001	
BC	840.50	1	840.50	258.70	< 0.0001	
A^2	106.10	1	106.10	32.66	0.0002	
B^2	1379.66	1	1379.66	424.65	< 0.0001	
C^2	897.88	1	897.88	276.36	< 0.0001	
Residual	32.49	10	3.25			
Lack of Fit	19.16	5	3.83	1.44	0.3503	not significant
Pure Error	13.33	5	2.67			
Cor Total	5434.95	19				

Analysis of variance (ANOVA) was needed to check whether or not the model is significant and also to evaluate the significant contributions of each individual variable, the combined and quadratic effects towards each response. From the result of Table 7, the Model F-value of 184.76 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, B, C, AC, BC, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 1.44 implies the Lack of Fit is not significant relative to the pure error. There is a 35.03% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good as it indicates a model that is significant.

To validate the adequacy of the quadratic model based on its ability to minimizing preheat temperature (PT), the goodness of fit statistics presented in Tables 8 was employed;

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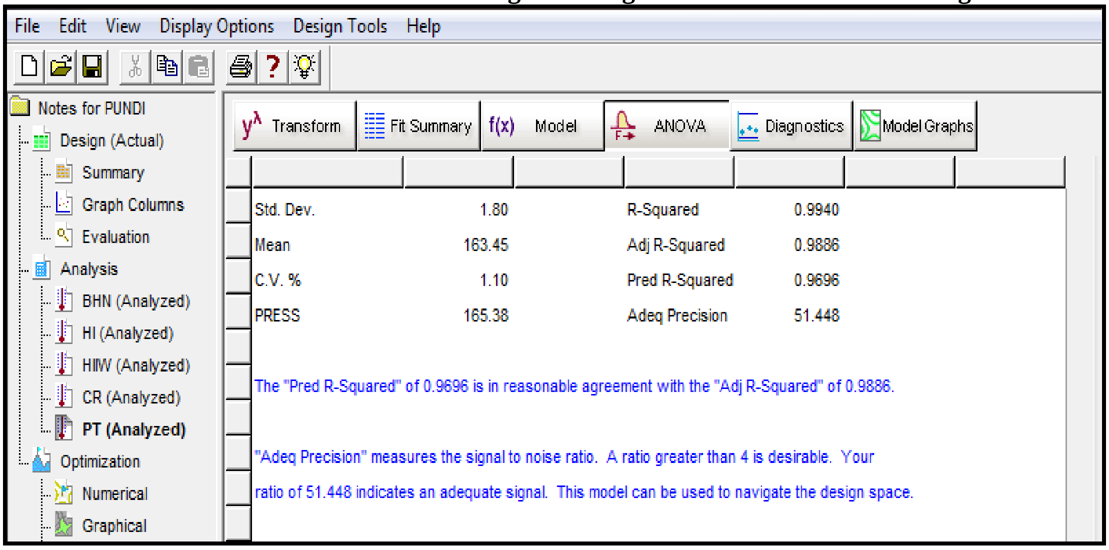
Table 8: GOF statistics for validating model significance towards minimizing PT



Std. Dev.	1.80	R-Squared	0.9940
Mean	163.45	Adj R-Squared	0.9886
C.V. %	1.10	Pred R-Squared	0.9696
PRESS	165.38	Adeq Precision	51.448

The "Pred R-Squared" of 0.9696 is in reasonable agreement with the "Adj R-Squared" of 0.9886.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 51.448 indicates an adequate signal. This model can be used to navigate the design space.

From the result of Table 8, it was observed that the "Predicted R-Squared" value of 0.9696 is in reasonable agreement with the "Adj R-Squared" value of 0.9886. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The computaed ratio of 51.448 as observed in Table 8 indicates an adequate signal. This model can be used to navigate the design space and adequately minimize preheat temperature (PT). Based on the goodness of Fit statistics, the optimized mathematical model which shows the relationship between current, voltage, welding speed and the preheat temperature was generated and presented as follows;

$$PT = 1908.41615-6.47345X_1-119.91417X_2+72.05994X_3-0.012500X_1X_2-0.68333X_1X_3+3.41667X_2X_3+0.027133X_1^2+2.44610X_2^2-3.50812X_3^2 \quad \text{---} \quad (1)$$

Using the optimal equations, the response variables; preheat temperature was predicted and a reliability plot of observed versus predicted values of preheat temperature was obtained and presented in Figure 2

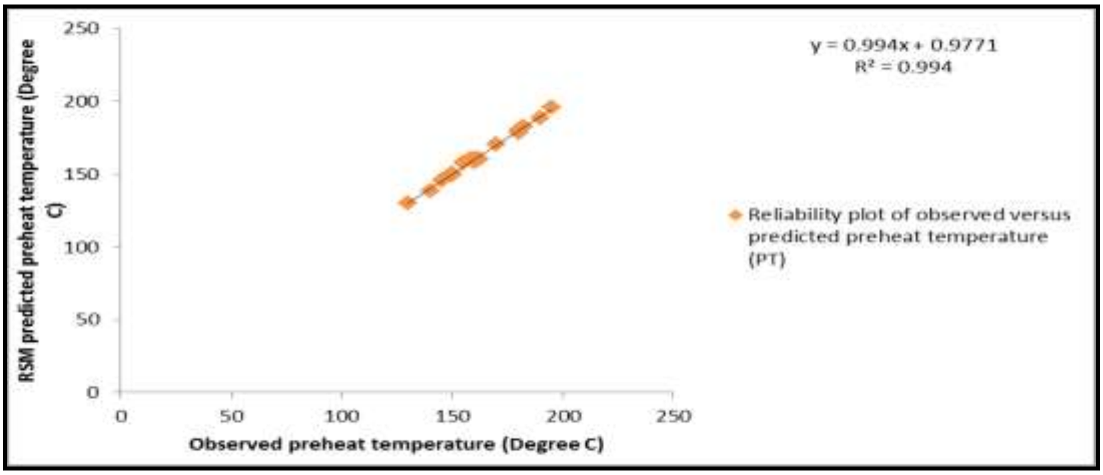


Figure 2: Reliability plot of observed versus predicted preheat temperature (PT)

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The high coefficient of determination ($R^2 = 0.9940$) as observed in Figure 2 was used to established the suitability of response surface methodology in minimizing preheat temperature (PT). Finally, numerical optimization was performed to ascertain the desirability of the overall model. The optimization objective was to minimize preheat temperature (PT). The relative importance was set at the optimum value of 5.0 and the lower and upper boundary conditions were set at 1.0 and 0.1 for minimization. Lower boundary of 1.0 constrains the optimization tool to minimize the response variable. The final solution of numerical optimization is presented in Table 9

Table 9: Optimal solutions of numerical optimization

Number	Current	Voltage	Welding speec	BHN	HI	HIW	CR	PT	Desirability	
1	190.00	21.95	5.00	200.959	1.69076	12.3562	72.0727	150.677	0.964	Selected
2	189.99	21.93	5.00	201.01	1.68603	12.3393	72.1133	150.636	0.964	
3	190.00	21.98	5.00	200.885	1.69761	12.3822	72.0463	150.759	0.964	
4	190.00	22.05	5.00	200.684	1.71503	12.4468	71.9447	150.906	0.964	
5	190.00	21.78	5.00	201.42	1.64389	12.1757	72.3076	150.375	0.964	
6	190.00	21.89	4.99	201.146	1.67386	12.2933	72.2494	150.776	0.964	
7	189.79	22.04	5.00	200.707	1.71709	12.4963	72.5994	150.864	0.964	
8	189.72	22.14	5.00	200.394	1.74348	12.6062	72.704	151.153	0.963	
9	190.00	22.78	5.00	198.042	1.86833	12.9467	70.9786	154.175	0.963	
10	190.00	22.15	4.88	200.645	1.72186	12.4971	72.7981	153.308	0.963	
11	188.89	22.42	5.00	199.435	1.81586	13.0105	74.9173	152.134	0.960	
12	190.00	22.48	4.66	200.005	1.74949	12.6864	74.0488	157.624	0.959	
13	170.00	23.03	2.00	193.099	1.33013	12.7828	70.7123	134.014	0.956	
14	170.00	23.00	2.00	193.104	1.33181	12.8047	70.6133	134.093	0.956	
15	170.00	23.05	2.00	193.097	1.32927	12.7716	70.7665	133.989	0.956	
16	170.00	23.09	2.00	193.09	1.32681	12.7404	70.9074	133.885	0.956	
17	170.00	23.16	2.00	193.065	1.32138	12.6757	71.1856	133.718	0.956	
18	170.05	22.96	2.00	193.155	1.336	12.8437	70.6588	134.269	0.956	
19	170.00	23.10	2.01	193.087	1.32589	12.7277	71.0106	134.083	0.956	
20	170.00	22.77	2.02	193.088	1.34154	12.9622	69.8452	135.224	0.956	
21	170.00	22.60	2.00	193.005	1.34457	13.0446	69.222	135.546	0.956	

From the results of Table 9, it was observed that a current of 190.00amp, voltage of 21.95volts and welding speed of 5.00mm/s will produce a weld material with cooling rate (CR); of 72.0727^0C/s. The optimal solution was selected by design expert with a desirability value of 96.40%. To study the effects of combine input variables on cooling rate (CR), 3D surface plots was generated and presented in Figure 3

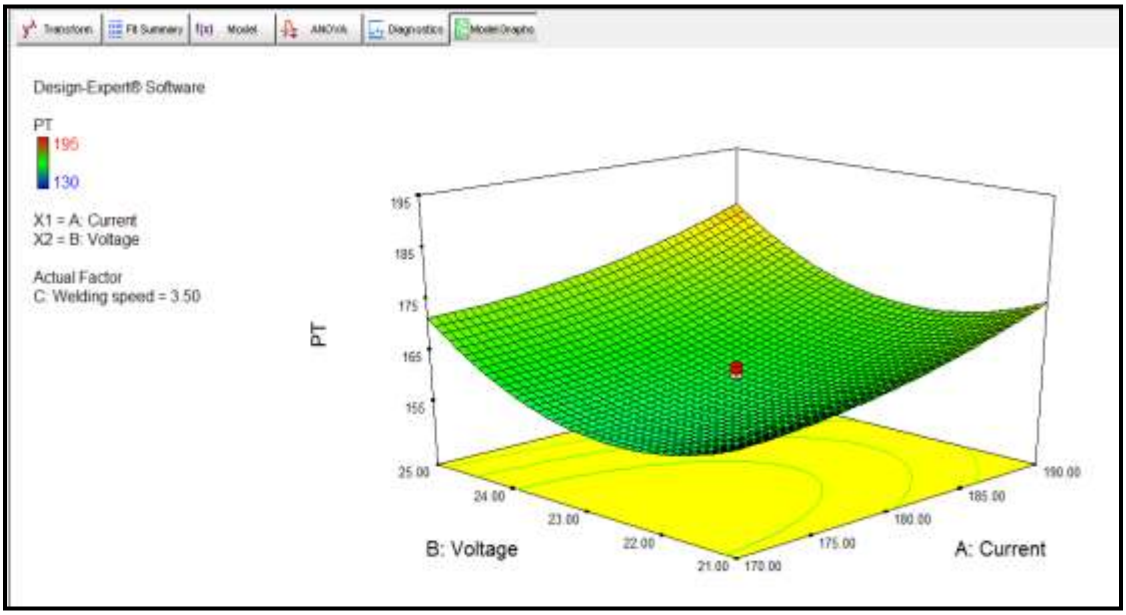

Figure 3: Effect of current and voltage on preheat temperature (PT)

The 3D surface plots presented in Figures 3 shows the relationship between the input variables (current and voltage) and the response variable (preheat temperature (PT)). It is a 3 dimensional surface plot which was employed to give a clearer concept of the response surface. Although not as useful as the contour plot for establishing responses values and coordinates, the view can provide a clearer picture of the interactions between the input and the response variables. The convex nature of Figure 3 implies that the selected input variables (current and voltage) has a critical influence on the response (preheat temperature). In which case an increase in the input variables will result to a corresponding increase in the response variable.

To apply ANN for the prediction of preheat temperature, two important factors were considered and they include; selection of the most accurate training algorithm and determination of the exact number of hidden neurons. Table 10 shows the different training algorithm that were tested and their performance.

Table 10: Selection of optimum training algorithm for ANN

S/No	Training Algorithm (Learning Rule)	Training MSE	Cross Validation MSE	R-Square (r^2)
1	Gradient information (Step)	0.05489	0.04905	0.74
2	Gradient and weight change (Momentum)	0.05339	0.08097	0.78
3	Gradient and rate of change of gradient (Quick prop)	0.06894	0.04467	0.68
4	Adaptive step sizes for gradient plus momentum (Delta Bar Delta)	0.07602	0.00335	0.82
5	Second order method for gradient (Conjugate gradient)	0.03367	0.06703	0.79
6	Improved second order method for gradient (Levenberg Marquardt)	0.00028*	0.00012*	0.98*

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Based on the result of Table 10, improved second order method of gradient also known as Levenberg Marquardt Back Propagation training algorithm (LMBPTA) was selected as the best since it has the highest coefficient of determination (R^2) and the lowest mean square error of regression (MSE). To determine the exact numbers of hidden neuron, different numbers of hidden neurons were tested to create a trained network using Levenberg Marquardt Back Propagation training algorithm. The number of hidden neuron corresponding to the lowest MSE and the highest R^2 as presented in Table 11 was selected to design the network architecture.

Table 11: Selection of optimum number of hidden neurons for ANN

S/No	Number of Hidden Neurons	Training MSE	Cross Validation MSE	R-Square (R^2)
1	2	0.0345	0.00453	0.75
2	3	0.0269	0.03367	0.67
3	5	0.0306	0.04051	0.88
4	8	0.0178	0.02241	0.71
5	10	0.0009	0.00033	0.97

Based on the results of Tables 10 and 11, Levenberg Marquardt Back Propagation training algorithm having 10 hidden neurons in the input layer and output layer was used to train a network of 3 input processing elements, namely; current, voltage and welding speed and one response variable (preheat temperature)

The network training diagram generated for the prediction of preheats temperature (PT) using back propagation neural network is presented in Figure 4.

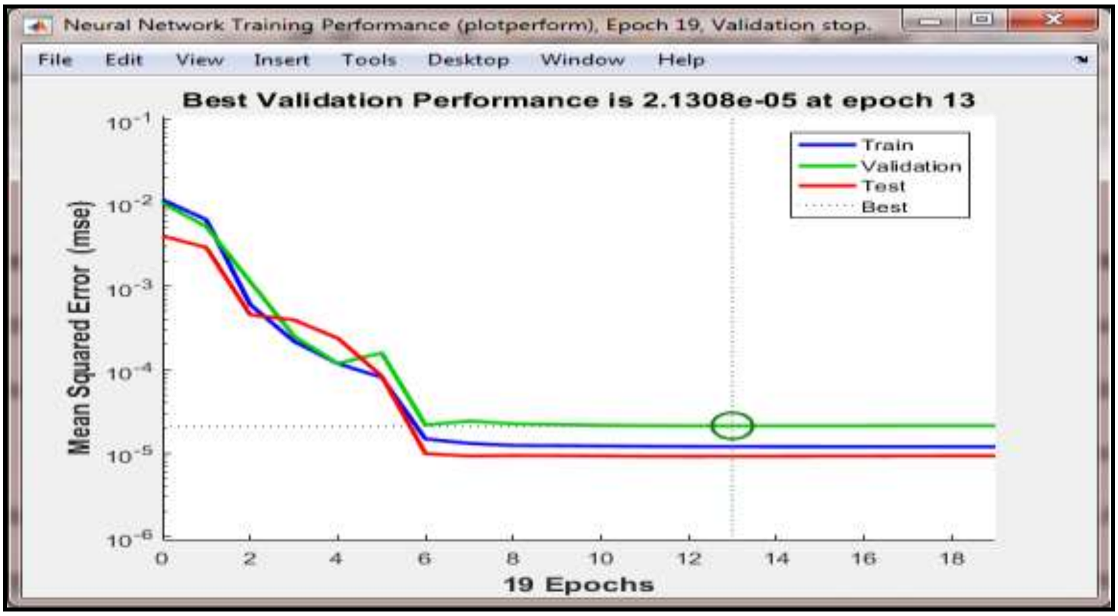

Figure 4: Performance curve of trained network for predicting preheat temperature

From the performance plot of Figure 4, no evidence of over fitting was observed. In addition similar trend was observed in the behaviour of the training, validation and testing curve which is expected since the raw data were normalized before use. Lower mean square error is a fundamental criteria used to determine the training accuracy of a network. An error value of 2.1308e-05 at epoch 13 is an evidence of a network with strong capacity to predict preheats temperature.

The regression plot which shows the correlation between the input variables (current, voltage and welding speed) and the target variable preheat temperature (PT) coupled with the progress of training, validation and testing is presented in Figure 5

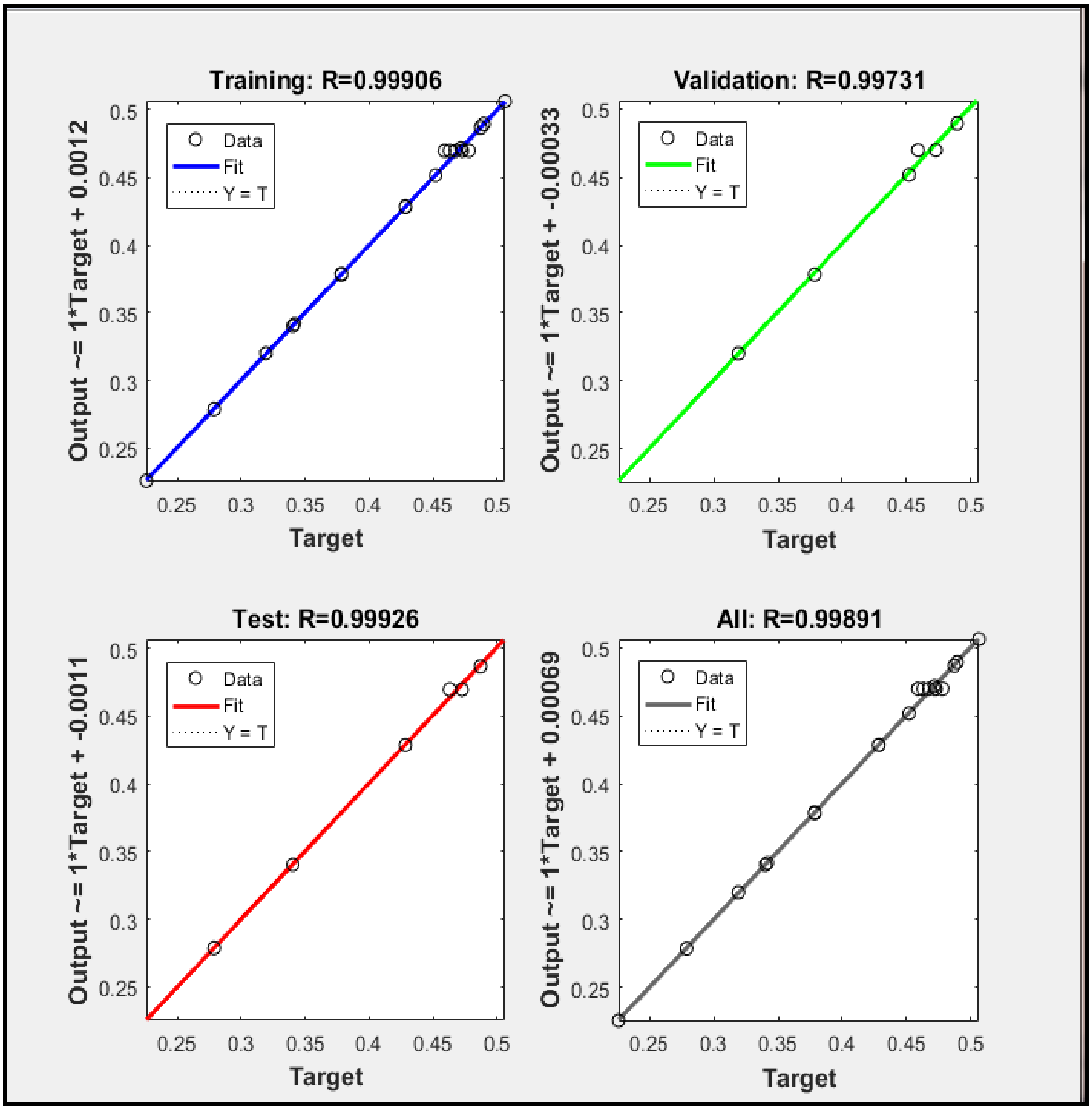

Figure 5: Regression plot showing the progress of training, validation and testing for minimizing preheat temperature (PT)

Based on the computed values of the correlation coefficient (R) as observed in Figure 5, it was concluded that the network has been adequately trained and can be employed to predict preheat temperature (PT). To test the reliability of the trained network, the network was thereafter employed to predict its own value of preheat temperature (PT) using the same set of input parameters (current, voltage and welding speed) generated from the central composite design. Based on the observed and the predicted values, a regression plot of outputs was thereafter generated and presented in Figure 6

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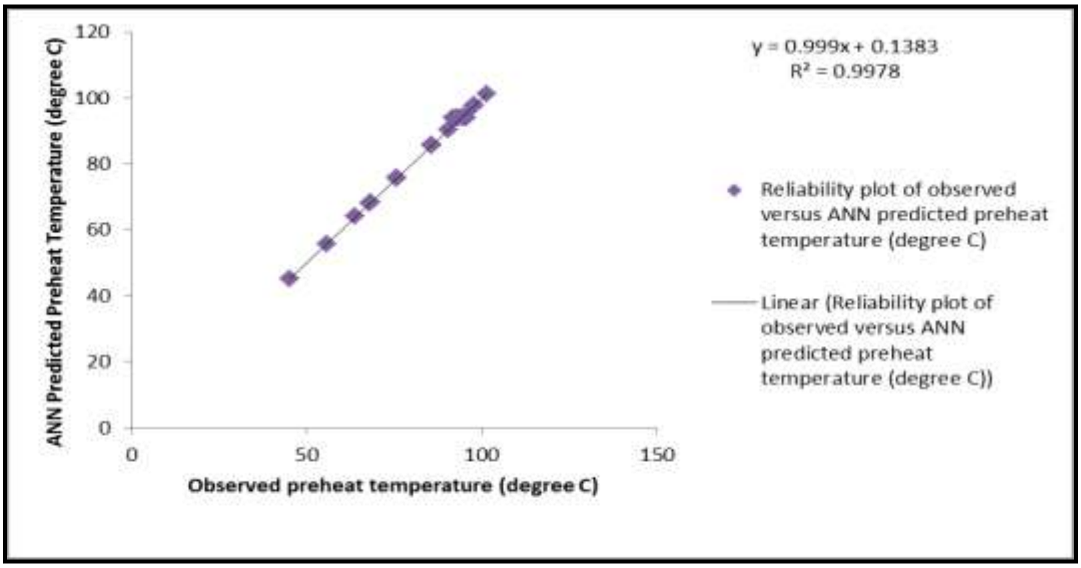

Figure 6: Regression plot of observed versus predicted preheat temperature

Coefficient of determination (r^2) values of 0.9978 as observed in Figure 6 was employed to draw a conclusion that the the trained network can be used to predict preheat temperature (PT) beyond the scope of experimentation.

IV. CONCLUSION

In this study, optimization and prediction of preheat temperature using response surface methodoloy (RSM) and artificial neural network have been implemented successfully. The study will not only provide additional information to the already existing literatures and optimization and prediction of welding process, it will also form the bases for future research in related field of study. It is interesting to note that determining the optimum conditions for any welding process is completely beyond the scope of the traditional methods of experimentation hence, the need to optimize all the controlling variables collectively using statistical design of experiment (DOE) which allows a large number of factors to be screened simultaneously. In this study, response surface methodology (RSM) has been successfully applied to optimize selected welding variables, namely; current, voltage and welding speed in order to minimize the preheat temperature and eliminate crack formation. More also, Artificial Neural Network (ANN) is gradually gaining general acceptability as one of the most versatile predictive tool of the 21st century. Its application and usefulness especially in the process industry cannot be over emphasized. In this study, the network has successfully been utilized to predict weld variables effectively.

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