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Empirical Modelling Relating Welding Parameters and Tensile Strength of Hot Nitrogen Gas Welded PVC Plastic

Vijay Kumar Gupta, Anurag Shrivastava, Manoj Kumar Gupta, Shailendra Kumar

P.G Student, Department of Mechanical Engineering, SRIMT, Lucknow, India
Assistant Professor, Department of Mechanical Engineering, SRIMT, Lucknow, India
Lecturer, Government Polytechnic Gonda, India
PhD Scholar, KNIT Sultanpur, India

ABSTRACT: The goal of the work is to investigate the effect of some input parameters on the desired responses in the PVC plastic welding by Hot Nitrogen gas welding technique. The effect of welding current, welding speed and mass flow rate of Nitrogen gas has been evaluated on the Tensile Strength, of the butt weld bead deposited. These responses have been analyzed using the analysis of variance (ANOVA) and empirical modeling. Plots of significant factors and empirical modeling have been used to determine the best fit relationship between the responses and the model parameters using MINITAB 15. This has been used to determine which is the most influencing factor or parameter. A confidence level of 95%has been used for the analysis. The weld tensile strength has been found to increase with increase of welding current and welding speed

KEYWORDS: Welding of Poly Vinyl Chloride (PVC) plastic, Hot Nitrogen gas welding, Empirical Modelling, and tensile strength of PVC plastic, ANOVA technique.

I. INTRODUCTION

Plastics have excellent strength to weight ratio, good corrosion resistance and ability to take good surface finish. Plastics can be categorized as thermosets and thermoplastics. Among these two only the thermoplasticis wieldable. In case of thermosets resins, a chemical reaction occurs during processing and curing, that is, as a result of irreversible cross-linking reaction in the mold [2]. There are many ways to weld plastic such as hot plate, friction, vibration, hot gas and ultrasonic. Hot gas (Nitrogen)welding is one of the external heating methods [1, 3, 5, 6] and it was patented by Reinhardt in 1940 [4].He reported that weld groove and weld rod were heated with hot Nitrogen stream until they soften sufficiently to fuse, then the welding rod is pressed into the groove. During welding, weld strength is reduced by high consumption of antioxidant and thermo oxidative decomposition of the polymer molecules [7]

II. DESIGN OF EXPERIMENT AND EXPERIMENTAL WORK

The design of experiment is based on 2^n factorial design which is known as full factorial technique. Here n is number of variables taken during the experiment[8]. In my experiment n= 3.A full factorial design contains all possible combinations of a set of factors. This is the most fool proof design approach, but it is also the most costly in experimental resources. The full factorial designer supports both continuous factors and categorical factors with up to nine levels. In full factorial designs, an experimental run at every combination of the factor levels.
If there are **n** factors that we need to evaluate in a process we need to run the experiment 2^ntimes. Each factor will have two levels, a "high" and "low" level. Table 1 shows the factorial design in a standard order matrix.
The 2^3 factorial design has two levels of each of the three variables requires 2×2×2= 8 run. The 2^3 design matrix is shown in Table 1design matrix is shown in Table

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TABLE 1 MATRIX PREPARED FOR INPUT VARIABLES AND CORRESPONDING RESPONSES

	X_1	X_2	X_3	Responses
S.N0.	I Ampere	S mm/sec	Q mm^3/sec	T Strength (N/mm^2)
1	low	low	low	
2	low	low	high	
3	low	high	low	
4	low	high	high	
5	high	low	low	
6	high	low	high	
7	high	high	low	
8	high	high	high	

"High" indicates the maximum value of input parameter
"Low" indicates the minimum value of input parameter
Where X_1= Input current in ampere
X_2= Welding speed in mm/second
X_3= Mass flow rate of hot air in mm^3/sec

A total of 8 experiments have been conducted using 3 different parameter. The combination of input parameter is taken on the basis of full factorial technique. Three parameter have been taken as current, weld speed and mass flow rate of the hot Nitrogen. Detail description of input parameter is given below:

A. INPUT PARAMETERS TAKEN IN EXPERIMENT

Welding Current (I)

Maximum Current (I_{max}) = 1.7 ampere
Minimum Current (I_{min}) = 1.3 ampere

Mass flow rate of hot Nitrogen (Q)

Cross-section area of the nozzle= 22.06 mm^2
Minimum velocity of hot Nitrogen (V_{min}) = 0.2 m/sec= 200 mm/sec
Maximum velocity of hot Nitrogen (V_{max}) = 0.8 m/sec= 800 mm/sec
Therefore, Maximum mass flow rate (Q_{max}) = A* V_{max}= 22.06* 800= 17648 mm^3/sec
Q_{max}= 17648 mm^3/sec
Similarly, Minimum mass flow rate (Q_{min}) = A * V_{min}= 22.06 * 200= 4412 mm^3/sec
Q_{min}= 4412 mm^3/sec

Welding Speed (S)

Maximum welding speed (S_{max}) = $\frac{Distance\ \ travel}{time\ taken\ to\ cover\ the\ distance}$
Distance travel = width of the workpiece= 6 cm= 60 mm
Maximum time taken to travel the distance= 46 seconds
Minimum time taken to travel the distance= 29 seconds
Therefore, maximum welding speed (S_{max}) = $\frac{Distance\ \ travel}{Minimum\ \ time\ taken\ to\ travel\ \ the\ distance}$

$$= \frac{60}{29} = 2.068 \text{ mm/sec}$$

S_{max}= 2.068 mm/sec

Similarly, minimum welding speed (S_{min}) = $\frac{Distancetravel}{Maximumtimetakentotravelt\quad hedistance}$

$$= \frac{60}{46} = 1.304 \text{ mm/sec}$$

S_{min}= 1.304 mm/sec

Weld beads obtained at different combination of welding parameter are shown below:

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Figure 1 Weld bead formed in 1 to 8th experiment

III.TESTING OF WELDED WORK PIECE

Tests have been being conducted on tensile testing machine. Range of the load is up to 500 kef or4905 Newton. When gradual load (tensile) is applied to the work piece, work piece suffered a little deflection before fracture.

TABLE 2STRENGTH AT DIFFERENT VALUES OF INPUT PARAMETERS

S.No	Current(I) In ampere	Weld speed (S)in mm/sec	Mass flow rate(Q) in mm^3/sec	Deflection (Δl)in mm	Ultimate load(W) in kef	Ultimate load(W) in Newton	Strength= $\frac{\text{Ultimateload}}{\text{Cross-sectionarea}}$ (N/mm^2)
1.	1.3	1.30	4412	2.3	93.92	93.92×9.81=921.355	921.355/300= 3.071
2.	1.3	1.30	17648	1.4	95.27	95.27×9.81=934.599	934.599/300= 3.115
3.	1.3	2.07	4412	1.2	92.81	92.81×9.81= 910.50	910.5/300= 3.035
4.	1.3	2.07	17648	1.7	89.76	89.76×9.81= 880.546	880.546/300= 2.935
5.	1.7	1.30	4412	1.1	104.01	104.01×9.81= 1020.338	1020.338/300= 3.401
6.	1.7	1.30	17648	0.9	107.07	107.07×9.81= 1050.357	1050.357/300= 3.501
7.	1.7	2.07	4412	1.5	130.06	130.06×9.81= 1275.889	1275.889/300= 4.253
8.	1.7	2.07	17648	0.8	117.28	117.28×9.81= 1150.517	1150.517/300= 3.835

IV. EMPIRICAL MODELING

Regression analysis is used to establish relationship between two variables. The response variable y is independent variable or variable of interest, and the predictor variable x is the dependent variable. An objective of regression analysis is to develop a regression model, relation y to x that can be used to predict values of the response variable. As in case of simple linear regression model relation y to x is

$$Y= B_0 + B_1 X_1+€ \quad (1)$$

Where, B_0= y-intercept, and B_1= slope of the line. B_0 is the mean value of y when x is zero. B_1 is the change in the mean value of y for one unit change in x and€ is the random error.

A. REGRESSION ANALYSIS FOR TENSILE STRENGTH OF THE OBTAINED WELD BEAD

Equation 2 is the regression equation obtained from regression analysis. ANOVA for the regression has been given in table 3. Regression table also suggests that welding speed is most significant factor. Table 3 indicates that p value for regression equation is significant. The regression equation is –

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Tensile strength (T) = T = 0.284 + 1.771 I + 0.315 S – 0.000007Q (2)
Where I = Current
S = Welding speed
Q = Mass flow rate of hot air

TABLE.3 REGRESSION TABLE FOR TENSILE STRENGTH OF WELD BEAD

Predictor	Coef	SE Coef	T	P
Constant	0.284	0.899	0.32	0.768
I	1.771	0.505	3.51	0.025
S	0.315	0.262	1.20	0.296
Q	-0.00000.7	0.000015	-0.46	0.668

S = 0.285721 R-Sq. = 77.72% R-Sq.(adj) = 61.01%

TABLE. 4 ANALYSIS OF VARIANCE TABLE FOR TENSILE STRENGTH OF WELD BEAD

Source	DF	SS	MS	F	P
Regression	3	1.13904	0.37968	4.65	0.086
Residual Error	4	0.32655	0.08164		
Total	7	1.46559			

B. RESIDUAL ANALYSIS FOR TENSILE STRENGTH

Residual is the difference between the observed and fitted value of the response. Four different plots have been drawn for residual analysis for tensile strength:
(a) Normal probability plot (residual Vs. present variation in tensile strength)
(b) Residual Vs frequency histogram.
(c) Residual Vs fitted value.
(d) Residual Vs observation order. (See figure 2)
The x-axis of histogram plot indicates the residuals and y-axis indicates the frequency of occurrence of that residuals. The normal probability plot and histogram suggests approximate normal distribution of residuals. In residual plot of fits x-axis represent the tensile strength response and y-axis the residuals. Straight horizontal line residual versus fits shows the zero residual or the fitted model line which means all the points would have been lying on that if there is zero residual or no residual which is nearly not possible. The scattered points in residual versus fits show the residuals lying away from the fitted value. Absence of any particular trend of residuals in versus fitted value plot shows the good fit of the model.

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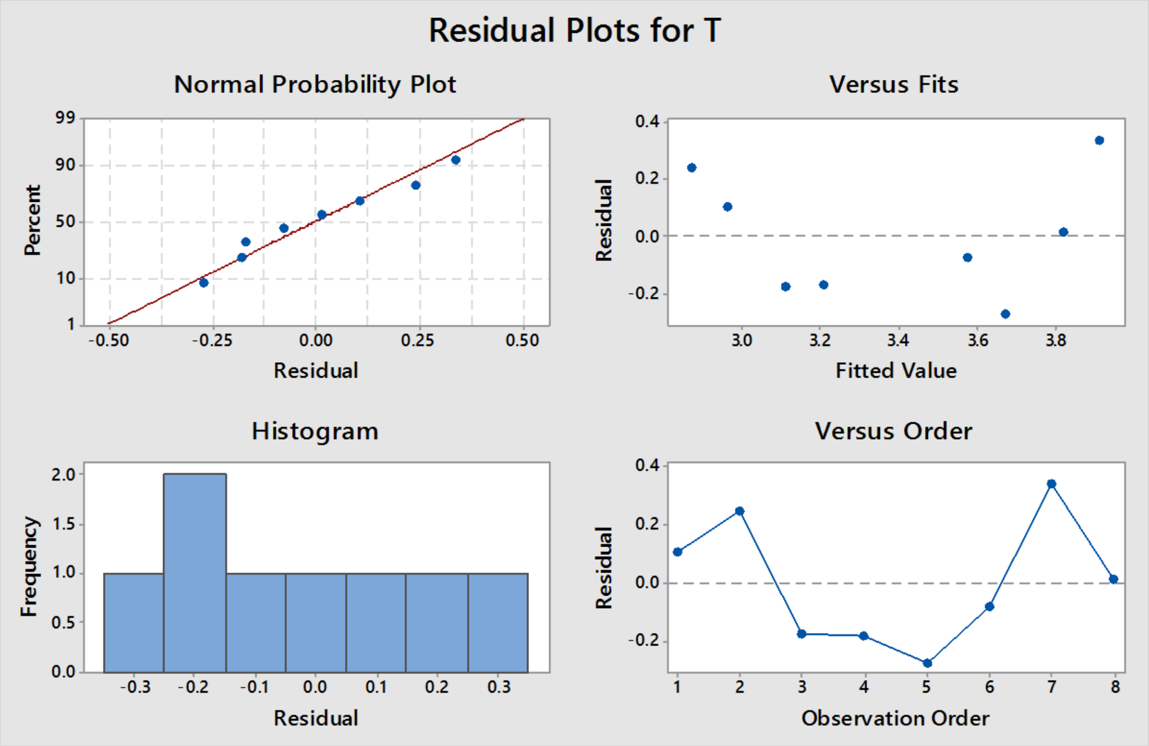

Figure 2

V.RESULTS AND DISCUSSION

The effect of input parameter was studied on tensile strength, of the butt weld bead by using Regression analysis and full factorial design. Tensile strength is measured as the response parameter. Regression analysis was completed for all the responses to analyze the significance of the input factors. Regression equation was developed to predict the relationship amongst the dependent and independent variables.

TABLE 5 SHOWS THE VALUES OF TENSILE STRENGTH OBSERVED AND PREDICTED.

S.N0.	I Ampere	S mm/sec	Q mm^3/sec	T (Observed) Strength (N/mm^2)	T (predicted) Strength (N/mm^2)
1	1.3	1.30	4412	3.071	2.965
2	1.3	1.30	17648	3.115	2.872
3	1.3	2.07	4412	3.035	3.207
4	1.3	2.07	17648	2.935	3.115
5	1.7	1.30	4412	3.401	3.673
6	1.7	1.30	17648	3.501	3.580
7	1.7	2.07	4412	4.253	3.916
8	1.7	2.07	17648	3.835	3.823

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A.RESULTS

1. Weld current has been found to be a significant factor in regard to tensile strength with p value of0.025(table3).Apart from weld current other significant factor is weld speed but it is lesser significant than weld current. The p value of speed is 0.296(table 3). Mass flow rate did not show any significant impact on the tensile strength of the weld bead.
2. Maximum value of tensile strength can be calculated by the model developed as Tensile strength
T = 0.284 + 1.771 I + 0.315 S - 0.000007 Q
The maximum value of tensile strength predicted by above formula is **3.916 MPa** which is shown in given Table 5 and obtained at higher level of weld current.

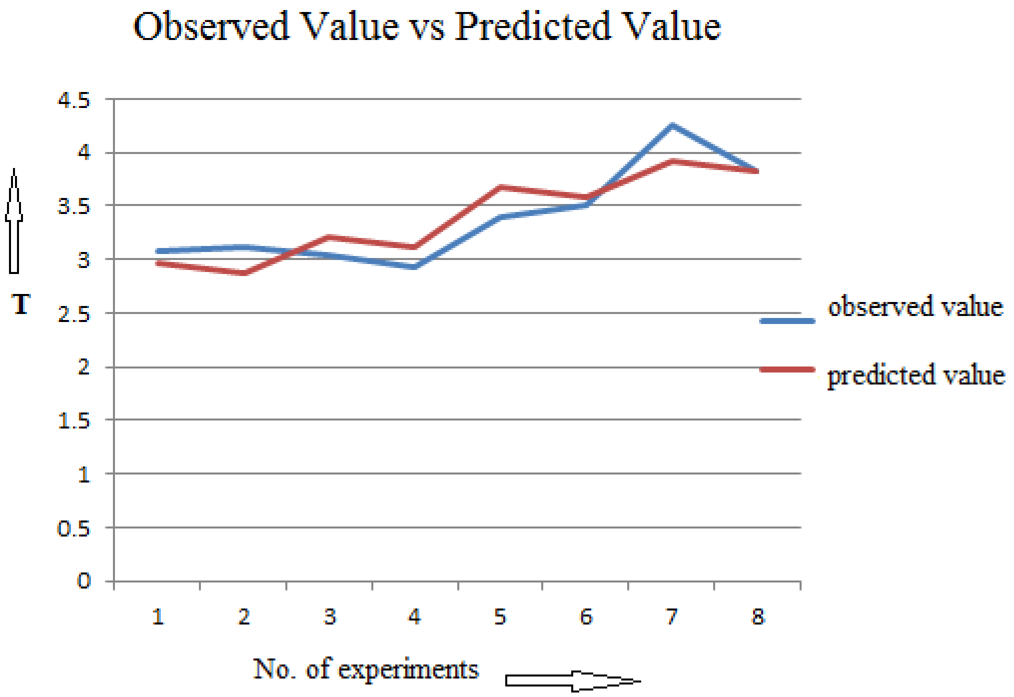

Figure 3: Graph showing Comparison between predicted and observed value of tensile strength

There is very small variation between predicted value and observed value of tensile strength, hence developed model is justified and suitable.

VI. CONCLUSIONS

The present work has been carried out to study the effect of input parameters on Tensile strength of butt welds, made of PVC plastic using hot Nitrogen gas technique. These parameters (Current, weld speed and mass flow rate of hot Nitrogen) are varied at two levels as higher level and lower level. From the above study conclusion is drawn that tensile strength of the weld bead is mainly affected by the weld current. Higher tensile strength can be achieved at higher current.

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