

# Study And Empirical Modeling Relating Welding Parameters And Tensile Strength of Hot Air Welded PVC Plastic

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## Abstract:

The present work has been carried out to study the effect of some input parameters on the desired responses in the PVC plastic welding by hot air technique. The effect of welding current, welding speed and mass flow rate of hot air has been evaluated on the Tensile Strength, of the 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 PVC plastic, Hot air welding, Empirical Modeling, and tensile strength of PVC plastic, ANOVA technique.

## 1. 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 thermoplastic is weldable. 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]. Hot gas welding is one of the external heating methods [3, 5, 6] and it was patented by Reinhardt in 1940 [4]. He reported that weld groove and weld rod were heated with hot air 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]

## 2. Design of experiment and experimental work

The experiment has been designed using  $2^n$  factorial method (also known as full factorial technique). Here  $n$  is the number of variables taken during the experiment [8]. In the present case,  $n = 3$ . A full factorial design contains all possible combinations of a set of factors. The  $2^3$  factorial design has two levels of each of the three variables requiring  $2 \times 2 \times 2 = 8$  runs. The  $2^3$  design matrix is shown in Table 1

**Table 1** Matrix prepared for input variables and corresponding responses

	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Response
S.NO.	I Ampere	S mm/sec	Q mm <sup>3</sup> /sec	T Strength (N/mm <sup>2</sup> )
1	-1	-1	-1	
2	-1	-1	+1	
3	-1	+1	-1	
4	-1	+1	+1	
5	+1	-1	-1	
6	+1	-1	+1	
7	+1	+1	-1	
8	+1	+1	+1	

+1 indicates the maximum value of input parameter

-1 indicates the minimum value of input parameter

Where X<sub>1</sub>= Input current in ampere, X<sub>2</sub>= Welding speed in mm/second, X<sub>3</sub>= Mass flow rate of hot air in mm<sup>3</sup>/sec. A total of 8 experiments have been conducted using 3 different parameters. The combination of input parameters is taken on the basis of full factorial technique. Three parameters have been taken as current, weld speed and mass flow rate of the hot air. Detail description of input parameters is given below:

### 3. Input parameters taken in experiment

#### 3.1 Welding Current (I)

Maximum Current (I<sub>max</sub>) = 1.7 ampere

Minimum Current (I<sub>min</sub>) = 1.3 ampere

#### 3.2 Mass flow rate of hot air (Q)

Cross-section area of the nozzle = 22.06 mm<sup>2</sup>, **Minimum** velocity of hot air (V<sub>min</sub>) = 0.2 m/sec = 200 mm/sec, Maximum velocity of hot air (V<sub>max</sub>) = 0.8 m/sec = 800 mm/sec

Therefore, Maximum mass flow rate (Q<sub>max</sub>) = A \* V<sub>max</sub> = 22.06 \* 800 = 17648 mm<sup>3</sup>/sec, Similarly, Minimum mass flow rate (Q<sub>min</sub>) = A \* V<sub>min</sub> = 22.06 \* 200 = 4412 mm<sup>3</sup>/sec

#### 3.3 Welding Speed (S)

Maximum welding speed

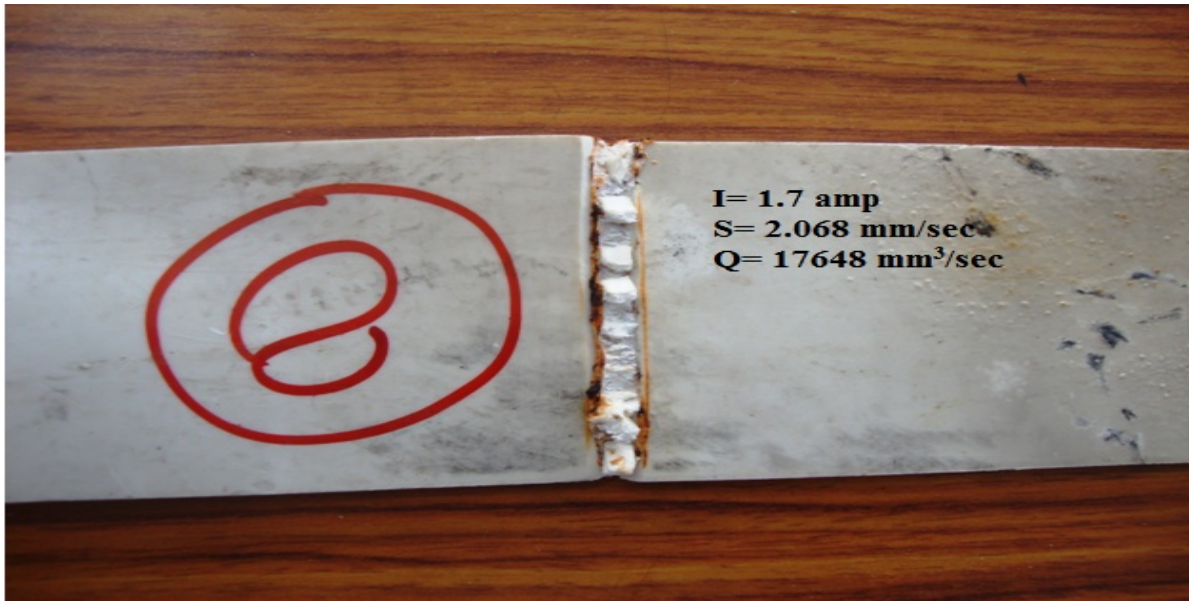
$$(S_{\max}) = \frac{\text{Distance travel}}{\text{time taken to cover the distance}}$$

Distance travel = width of the work piece = 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

$$(S_{\max}) = \frac{\text{Distance travel}}{\text{Minimum time taken to travel the distance}} = \frac{60}{29} = 2.068 \text{ mm/sec}$$

Weld beads obtained at different combinations of welding parameters are shown below:



**Figure1:** Weld bead form using different combination of input parameter

#### 4. Testing of welded work piece

Tests have been being conducted on tensile testing machine. Range of the load is up to 500 kgf or 4905 Newton. When gradual load (tensile) is applied to the work piece, work piece suffered a little deflection before fracture

**Table 2** Strength at different values of input parameters

S.No	Current(I) ampere	Weld speed (S) mm/sec	Mass flow rate(Q) mm <sup>3</sup> /sec	Deflection (Δl) mm	Ultimate load(W) kgf	Ultimate load(W) Newton	Responses Strength= $\frac{\text{Ultimate load}}{\text{Cross-section area}}$ (N/mm <sup>2</sup> )
1	1.3	1.30	4412	0.3	9	88.29	88.29/300= 0.29
2	1.3	1.30	17648	0.6	39	382.59	382.59/300=1.27
3	1.3	2.07	4412	0.4	20	196.20	196.20/300= 0.65
4	1.3	2.07	17648	0.5	6	58.86	58.86/300= 0.19
5	1.7	1.30	4412	0.5	22	215.82	215.82/300= 0.71
6	1.7	1.30	17648	0.5	62	608.22	608.22/300= 2.03
7	1.7	2.07	4412	0.3	5	49.05	49.05/300= 0.16
8	1.7	2.07	17648	0.7	120	1177.20	1177.20/300= 3.92

#### 5. Empirical modeling

##### 5.1 Regression analysis

Regression analysis has been used to establish relationship between the response variable y (independent variable or variable of interest) and the predictor variable x is (the dependent variable). The objective of

regression analysis has been to develop a regression model, relating y to x that can be used to predict the values of the response variable. As in case of simple linear regression model relating y to x is

$$Y = B_0 + B_1 X_1 + \epsilon \tag{1}$$

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  $\epsilon$  is the random error,

*5.2 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 the most significant factor. Table 3 indicates that p value for regression equation is significant

$$\text{Tensile strength (T)} = - 4.50 + 2.76 I + 0.20 S + 0.000106 Q \tag{2}$$

Where I = Current  
 S = Welding speed, and  
 Q = Mass flow rate of hot air

**Table 3:** Regression table for Tensile Strength of weld bead

Predictor	Coef	SE Coef	T	P
Constant	-4.497	3.565	-1.26	0.276
I	2.763	2.003	1.38	0.240
S	0.201	1.041	0.19	0.856
Q	0.00010577	0.00006054	1.75	0.156

S = 1.13319 R-Sq = 55.5% R-Sq(adj) = 22.2%

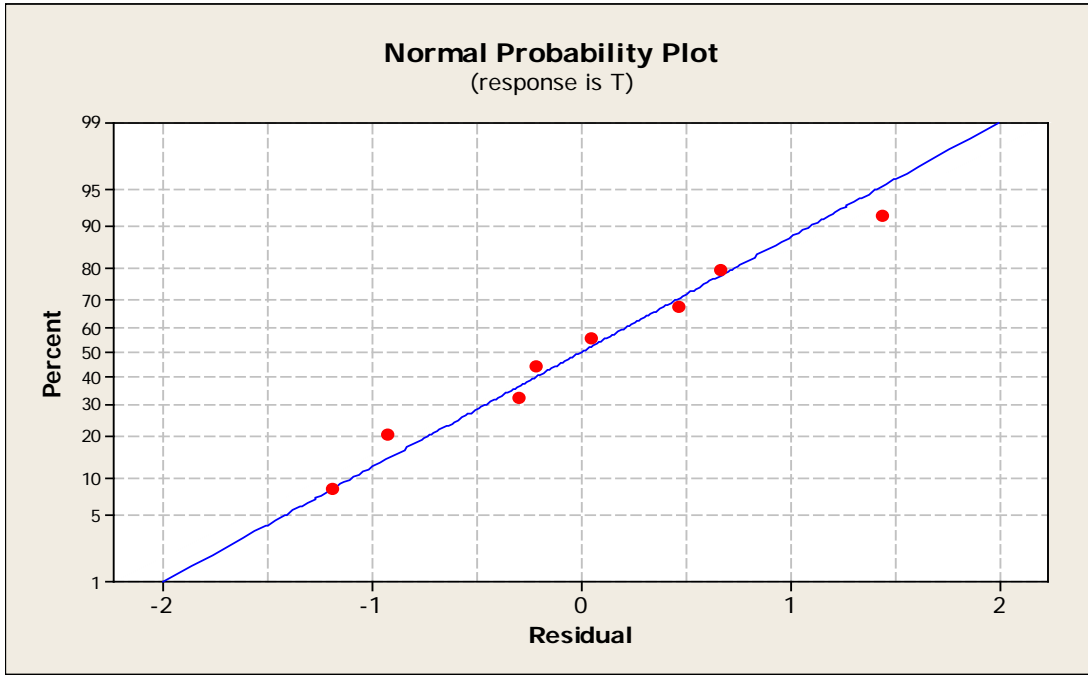
**Table 4:** Analysis of variance table for Tensile Strength of weld bead

Analysis of Variance	DF	SS	MS	F	P
Regression	3	6.410	2.137	1.66	0.310
Residual Error	4	5.136	1.284		
Total	7	11.547			

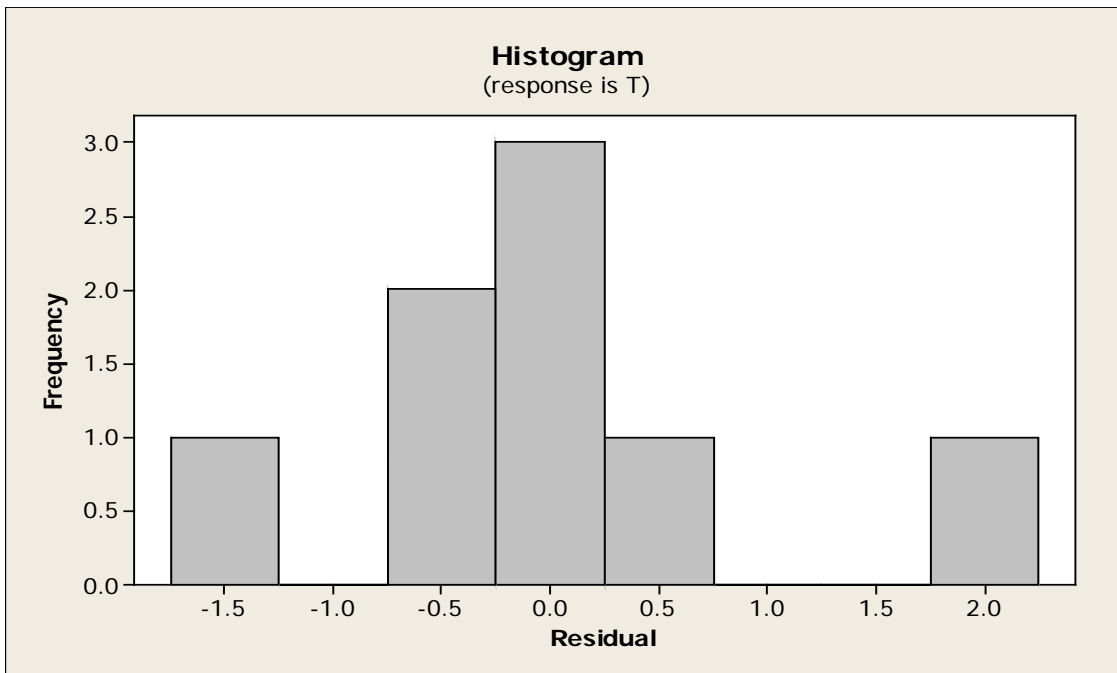
*5.3 Residual analysis for tensile strength*

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:

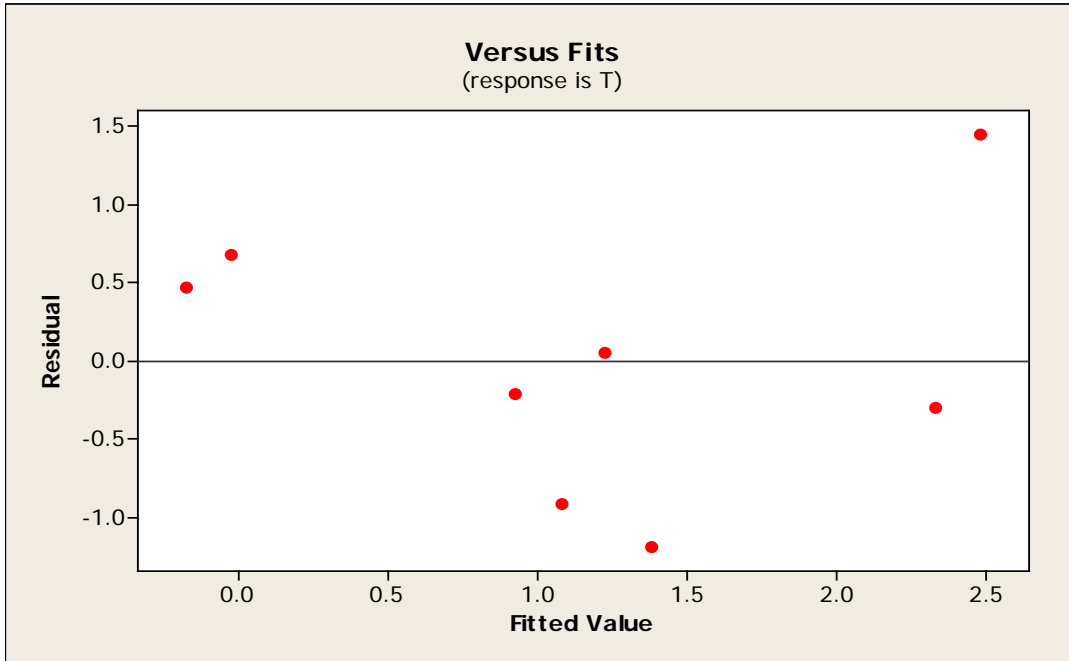
- (a) Normal probability plot( residual Vs percent variation in tensile strength)
- (b) Residual Vs frequency histogram.
- (c) Residual Vs fitted value.
- (d) Residual Vs observation order. (see figure 2, 3, 4, and 5)



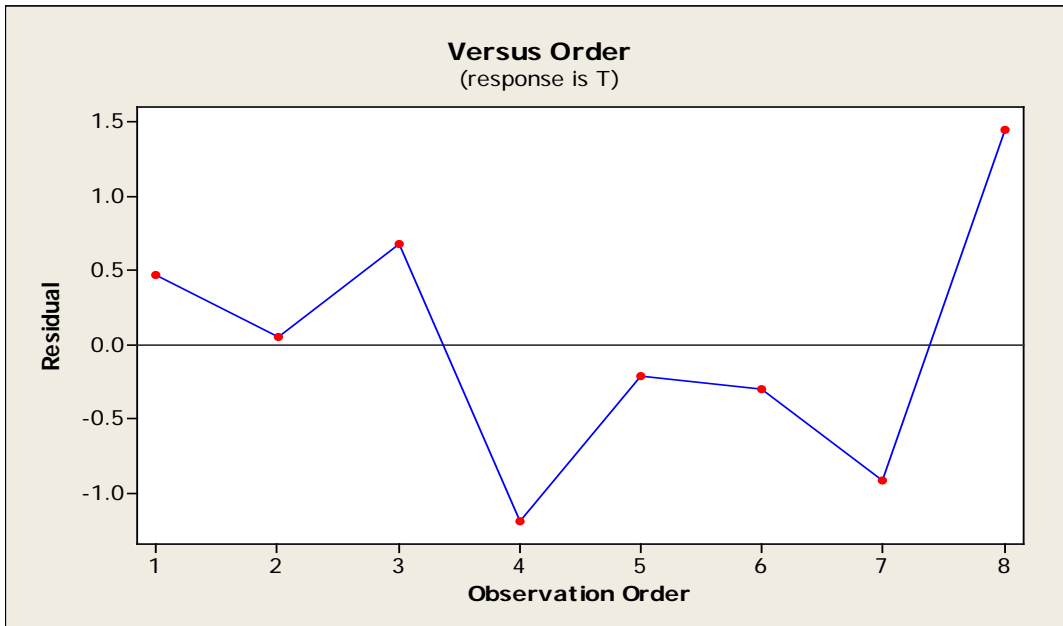
**Figure 2:** Normal probability plots for Tensile Strength



**Figure 3:** Histogram for Tensile Strength



**Figure 4:**versus fits for Tensile Strength



**Figure 5:**versus order plot for Tensile Strength

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.

## 6.Results and Discussion

The effect of input parameter has been studied on tensile strength of the weld bead by using full factorial design and tensile strength has been measured as the response parameter. Regression analysis has been carried out for all the responses to analyze the significance of the input parameters. Regression equation has been developed to predict the relationship amongst the dependent and independent variables. Table 5 shows the values of responses thus measured.

**Table 5** Input variables and the corresponding Responses

S.No	I	S	Q	Responses
	Current(A mp)	Weld speed (mm/sec)	Mass flow rate (mm <sup>3</sup> /sec)	Strength (N/mm <sup>2</sup> )
1	1.3	1.30	4412	0.29
2	1.3	1.30	17648	1.27
3	1.3	2.07	4412	0.65
4	1.3	2.07	17648	0.19
5	1.7	1.30	4412	0.71
6	1.7	1.30	17648	2.03
7	1.7	2.07	4412	0.16
8	1.7	2.07	17648	3.92

### 6.1 Results

1. Welding current has been found to be a significant factor in regard to tensile strength with p value of 0.240 (table 3). Apart from weld current other significant factor is weld speed but it is lesser significant than weld current. The p value of speed is 0.856( 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

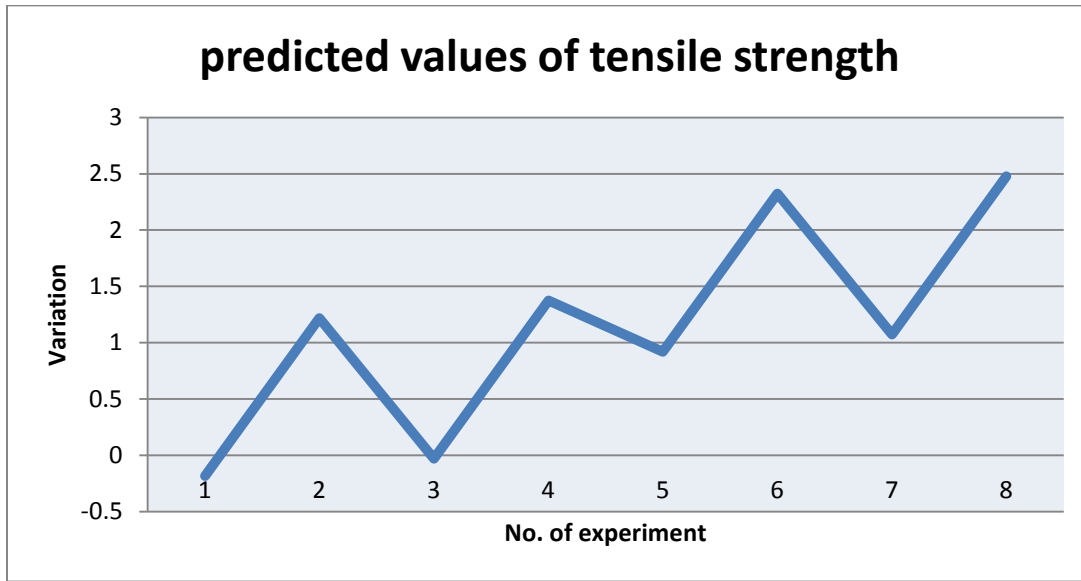
$$\text{Tensile strength (T)} = - 4.50 + 2.76 \text{ I} + 0.20 \text{ S} + 0.000106 \text{ Q}$$

The maximum value of tensile strength predicted by above formula is 2.476688 (table 6) which is shown in given Table6 and obtained at higher level of weld current

**Table 6** Predicted values of tensile strength of weld bead at different input parameters

I (amp)	S (mm/sec)	Q (mm <sup>3</sup> /sec)	T (N/mm <sup>2</sup> )
1.3	1.30	4412	-0.18433
1.3	1.30	17648	1.218688
1.3	2.07	4412	-0.03033
1.3	2.07	17648	1.372688
1.7	1.30	4412	0.919672
1.7	1.30	17648	2.322688
1.7	2.07	4412	1.073672
1.7	2.07	17648	2.476688

**Figure 6:** shows variation in tensile strength in different experiment at different input parameters



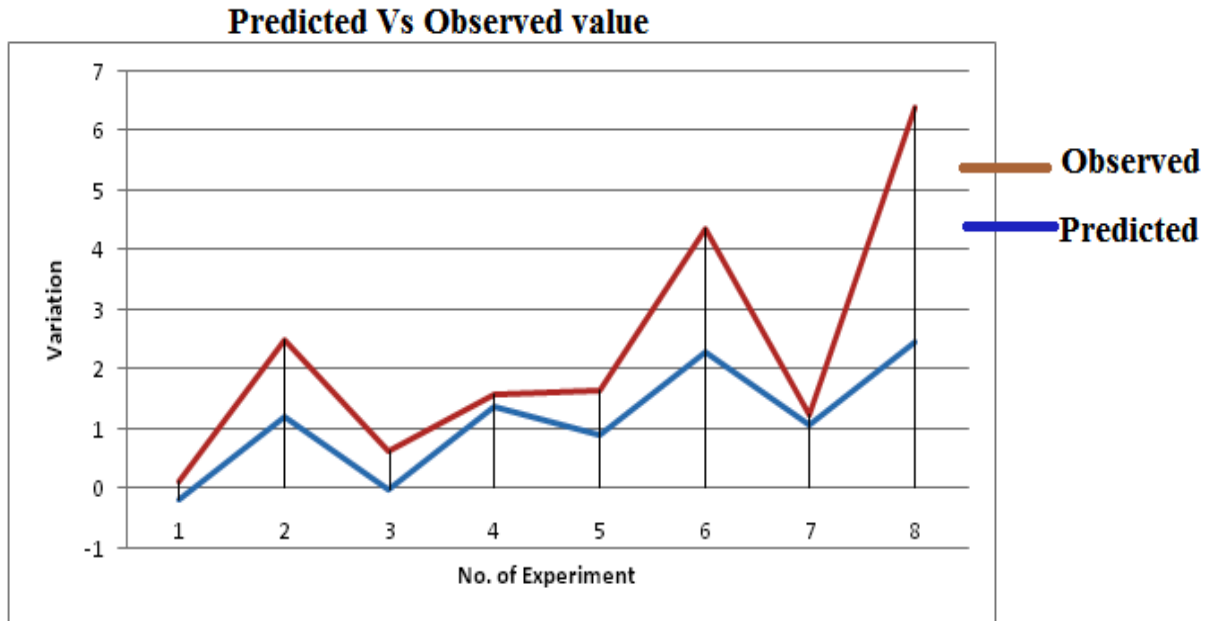
**Figure 6:** Graph showing the variations in tensile strength with observation order

3. Comparison between predicted value and observed value of tensile strength is given in table 7

**Table 7:** Comparison between predicted and observed values of Tensile Strength

Predicted values	Observed values	Error
-0.18433	0.29	-0.47433
1.218688	1.27	-0.05131
-0.03033	0.65	-0.68033
1.372688	0.19	1.182688
0.919672	0.71	0.209672
2.322688	2.03	0.292688
1.073672	0.16	0.913672
2.476688	3.92	-1.44331





**Figure 7:** 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.

## 7. Conclusion

The present work has been carried out to study the effect of input parameters on Tensile strength of butt welds, made on hard PVC plastic using hot air technique. These parameters (Current, weld speed and mass flow rate of hot air) 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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