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An Experimental Analysis to Determine the Effects of Welding Parameters on Tensile Strength of Hot Air Welded Poly Vinyl Chloride (PVC) Plastic

Md Shakibul Haque[1], Inayat Hussain[2], Athar Hussain[3] and Mohd Anees Siddiqui[4]

ABSTRACT

The present work has been carried out to study the effect of some input parameters on the desired response in the Poly Vinyl Chloride (PVC) plastic, welded by hot air technique. The effect of hot air temperature, welding speed and air flow rate has been evaluated on the Tensile Strength, of the weld bead deposited. These responses have been analysed using the analysis of variance (ANOVA) and experimental modeling. Plots of significant factors and experimental modeling have been used to determine the best fit relationship between the responses and the model parameters using MINITAB 17. This has been used to determine the most influencing parameter.

Keywords : *Poly Vinyl Chloride (PVC), Welding of PVC plastic, Hot air welding, ANOVA technique, Experimental Modeling, and tensile strength of PVC plastic.*

1. INTRODUCTION

Plastics have the ability to take good surface finish, good corrosion resistance and excellent strength to weight ratio. Plastics can be categorized as thermosets and thermoplastics. Only 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 air welding is one of the external heating methods [3, 5, 6] and it was patented by Reinhardt in year 1940 [4]. He reported that weld groove and weld rod were heated with hot air stream until they soften sufficient to fuse, then the welding rod is pressed into the groove.

To evaluate welding strength, weld factor, (*f*w), which is also called as comparative weld strength, is expressed as

$$f_w = \frac{\sigma_{weld}}{\sigma_{base}} \text{............} \qquad (1)$$

where σ_{weld} and σ_{base} are strengths of a weld and its base material, respectively.[1]

O. Balkan et. al. find the weld factor is 0.45 for PVC[1] and it is compared in this work. Mahmood Alam et. al reported the highest strength of 3.92MPa in their work[9] which is also compared and better result was obtained.

2. DESIGN OF EXPERIMENT AND EXPERIMENTAL WORK

The experiment has been designed using 2^n factorial method. 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 2×2×2= 8 runs[9]. The 2design matrix is shown in Table 1.σe

1. Md Shakibul Haque, Department of Mechanical Engineering, Invertis University, Bareilly.
2. Inayat Hussain, Department of Mechanical Engineering, Invertis University, Bareilly.
3. Athar Hussain, Department of Mechanical Engineering, Integral University, Lucknow.

Table-1: Matrix prepared for input variables and corresponding response

Exp.	Temperature (°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Tensile Strength MPa
Run	T	AF	WS	TS
1	225	5.893	0.25	
2	225	5.893	0.35	
3	225	17.679	0.25	
4	225	17.679	0.35	
5	275	17.679	0.25	
6	275	17.679	0.35	
7	275	5.893	0.25	
8	275	5.893	0.35	

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

3. INPUT PARAMETERS

3.1 Welding Temperature(T)

Maximum Temperature(T_{max}) = 275 **°C**

Minimum Temperature(T_{min}) = 225 **°C**

3.2 Air flow rate (AF)

Nozzle dia=5mm

Cross-section area of the nozzle= 19.64mm²

Minimum velocity of hot air (V_{min}) = 0.3 m/sec= 300 mm/sec

Maximum velocity of hot air (V_{max}) = 0.9 m/sec= 900 mm/sec

Therefore,

Maximum Air flow rate (AF_{max}) = A× V_{max}= 19.64× 900= 17679 mm^3/sec=17.679 cm^3/sec

Similarly, Minimum Air flow rate (AFmin) = A×V_{min}= 19.64× 300= 5893mm^3/sec = 5.893 cm^3/sec

3.3 Welding Speed (WS)

Maximum welding speed (WS_{max})

$$= \frac{\text{Distance travel}}{\text{Time taken to cover the distance}}$$

Distance travel = width of the workpiece= 5 cm= 50 mm

Maximum time taken to travel the distance= 200 seconds

Minimum time taken to travel the distance= 143 seconds

Therefore, maximum welding speed

$$(WSmax) = \frac{\text{Distance travel}}{\text{Minimum time taken to cover the distance}} = \frac{50}{143} = 0.35\,mm\ /\ s$$

Similarly, minimum welding speed

$$=(WSmin) = \frac{\text{Distance travel}}{\text{Maximum time taken to cover the distance}} = \frac{50}{200} = 0.25\,mm\ /\ s$$

Cross section area of welding sample = 6×50 = 300 mm²

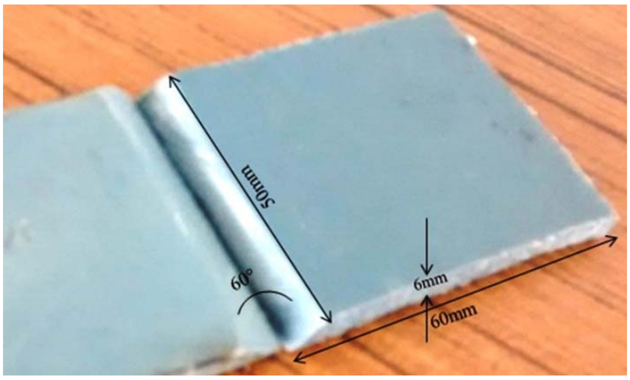
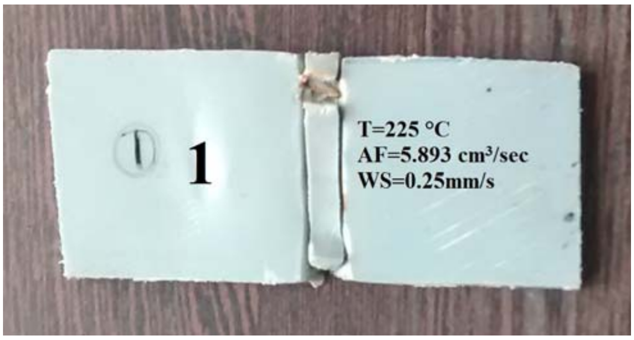
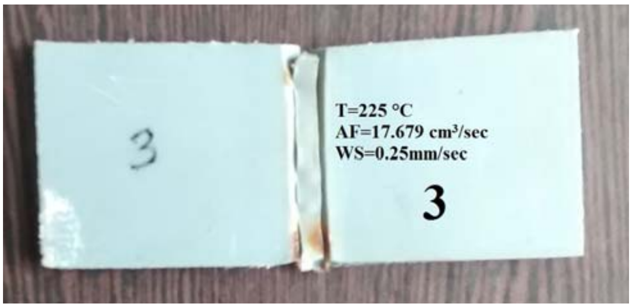


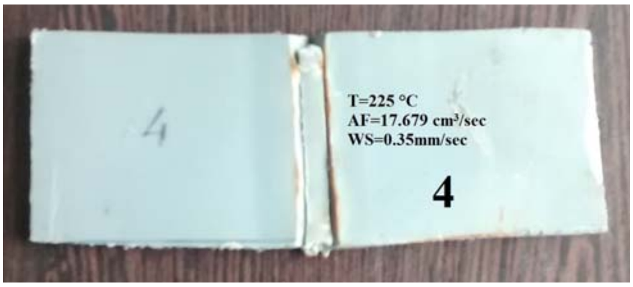
Fig.1: Sample Size details

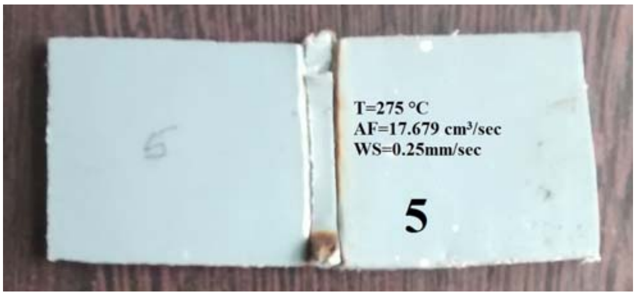
Fig.2: Hot air welding operation performing in Lab

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









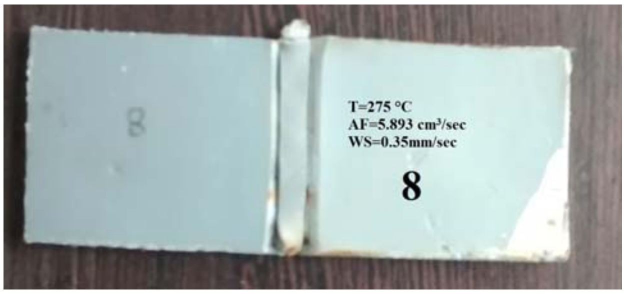


Fig.3. Weld bead obtained using different combination of input parameter

4. TESTING OF WELDED WORK PIECE

Tests have been being conducted on Universal Testing Machine(UTM). Range of the load is upto 500 kgf.

Fig.4: Testing of welded sample on UTM

Table-2: Strength at different values of input parameters

Exp.	Temp (°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Ultimate Load kg	Ultimate Load N	Response $Strength = \frac{UltimateLoad}{CrossSectionArea}$ Mpa	Weld factor *fw*
Run	**T**	**AF**	**WS**	**W**	**W**	**TS**	
Base	-	-	-	495	4855.95	4855.95/300 =16.19	-
1	225	5.893	0.25	278	2727.18	2727.18/300 = 9.09	0.56
2	225	5.893	0.35	276	2707.56	2707.56/300 =9.02	0.55
3	225	17.679	0.25	230	2256.3	2256.3/300=7.52	0.46
4	225	17.679	0.35	260	2550.6	2550.6/300=8.52	0.53
5	275	17.679	0.25	310	3041.1	3041.1/300 =10.14	0.63
6	275	17.679	0.35	316	3099.96	3099.96/300 =10.33	0.64
7	275	5.893	0.25	270	2648.7	2648.7/300=8.83	0.54
8	275	5.893	0.35	344	3374.64	3374.64/300 =11.25	0.69

Tensile test results of all eight PVC sheets are given in Table 2. Weld factors varied in the range of 0.46–0.69 for PVC. The minimum value of weld factor is 0.46 while O. Balkan et. al. reports 0.45 for hot air welded PVC sample

5. EXPERIMENTAL MODELING

5.1 Regression analysis for tensile strength of the obtained weld bead

Equation-2 is the regression equation obtained from the regression analysis. ANOVA for the regression has been given in table 3. Table 4 indicates that p value of the regression equation is significant.

The relation among tensile strength, welding speed, hot air temperature and airflow are written as following equation-2.

TS = - 0.90 + 0.0320T - 0.0356 AF + 8.85 WS...(2)

Where,

T = Temperature

WS = Welding speed, and

AF =Hot air flow rate

TS= Tensile strength

Table-3: ANOVA table for tensile strength of welded joint

Source	DF	SS	MS	F-Value	P-Value
Regression	3	7.0393	2.3464	3.56	0.126
Error	4	2.6387	0.6597		
Total	7	9.678			

S=0.812204; R-sq=72.73%; R-sq(adj)= 52.29%

Table-4: Regression table for Tensile Strength of welded joint

Term	Coef	SE Coef	T-Value	P-Value
Constant	-0.9	3.41	-0.26	0.805
T	0.032	0.0115	2.79	0.05
AF	-0.036	0.0487	-0.73	0.505
WS	8.85	5.74	1.54	0.198

5.2 Effect analysis of input parameters for tensile strength of the obtained weld bead

Three types of plots have drawn from the analysis. One is main effect plots, second is interaction plot and the third one is a contour plot. All the plots are shown in figure 4, 5 and 6.

Main effect plots show that when airflow (AF) increases tensile strength decreases. When welding speed (WS) and temperature (T) increases tensile strength is also increased. Therefore tensile strength of weld bead is directly proportional to the welding speed and temperature and indirectly proportional to airflow.

From these plots it is shown that higher temperature give good results in tensile strength.

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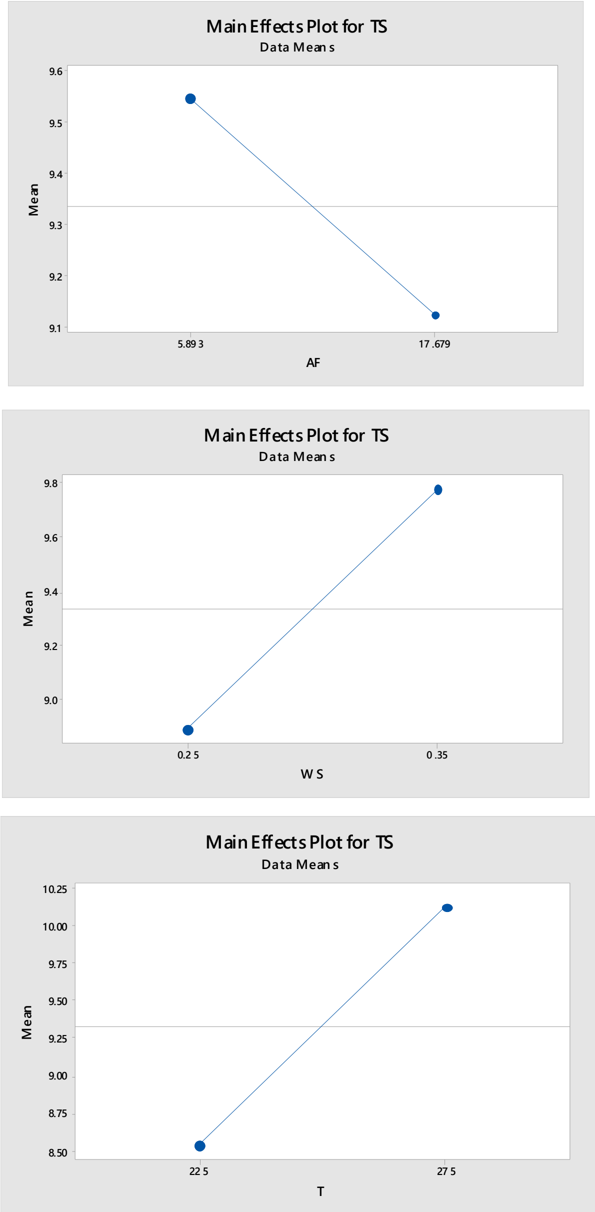


Fig.5: Main effect plots for Tensile Strength

Three interaction plots are shown here. First is interaction between temperature and welding speed. It shows that at both temperature higher welding speed give positive results. Minimum strength was obtained at minimum welding speed and minimum temperature combination with maximum strength was obtained at maximum welding speed and maximum temperature combination.

Second interaction is between airflow and welding speed. It shows that effect of airflow is negative while effect of welding speed is positive. At minimum airflow and maximum welding speed, higher strength value is obtained. At maximum airflow and minimum welding speed, minimum strength is obtained.

Third interaction is between airflow and temperature. It shows that minimum tensile strength is obtained at maximum airflow and minimum temperature while comparatively better results are obtained at minimum temperature and minimum airflow.

But always good results are obtained at higher temperature.

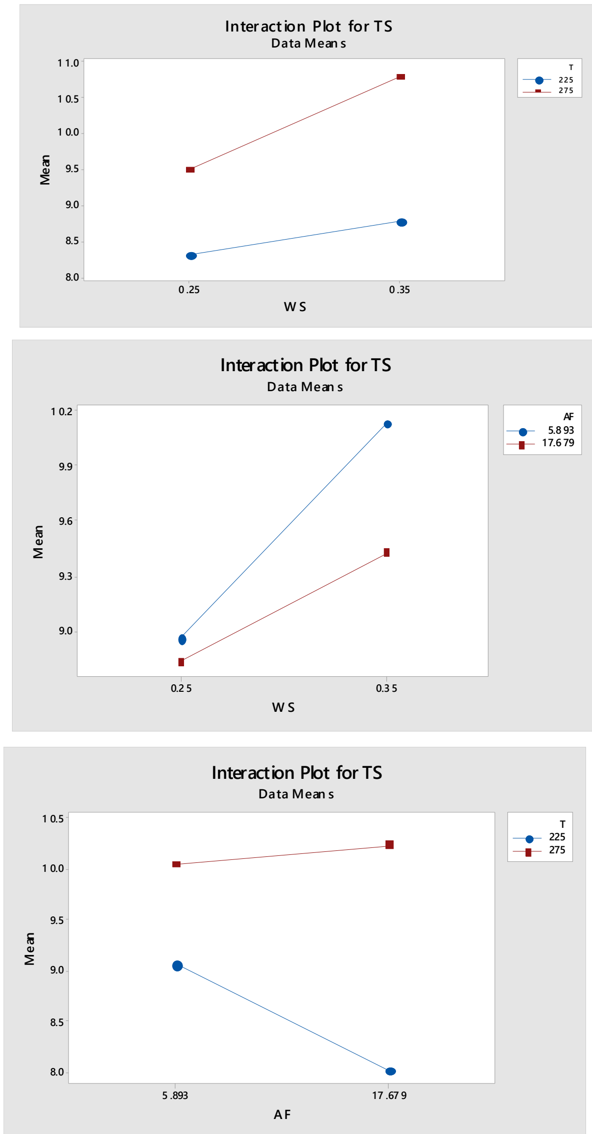


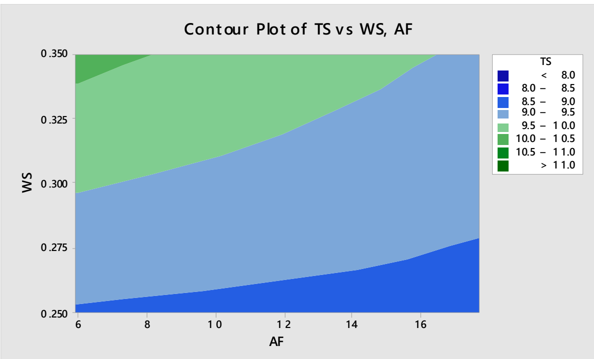
Fig.6 : Interaction plots for Tensile Strength

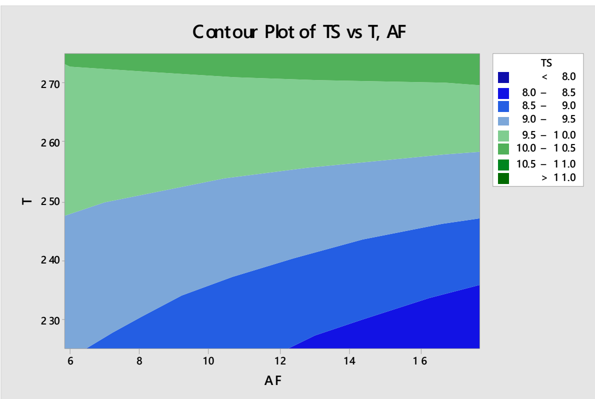
Three contour plots are shown in figure 6.

In first contour plot, it shows that the value of strength is increased with increase in welding speed and airflow upto certain limit. After that position welding speed give positive result but airflow gives negative result. At maximum welding speed and minimum airflow the best tensile strength is obtained.

In second contour plot it shows that the value of strength is increased as temperature increases. At maximum airflow and minimum temperature the minimum tensile strength is obtained.

In third contour plot, it shows that when welding speed decreases and temperature increases, better tensile strength is obtained. At last, maximum welding speed and maximum temperature give best result of tensile strength.





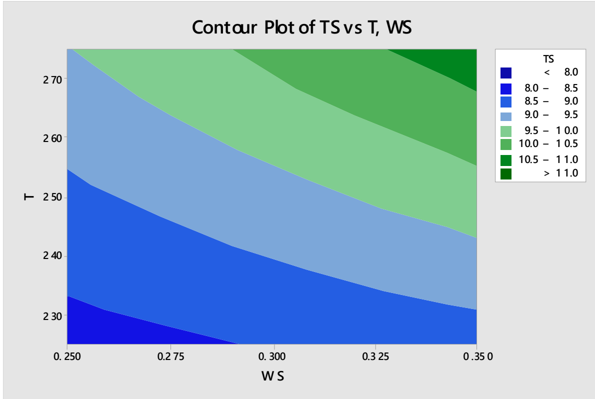


Fig.7 Contour plots for Tensile Strength

6. RESULTS AND DISCUSSION

The effect of input parameter has been studied on tensile strength of the welded joint 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

Exp.	Temp (°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Response $Strength = \frac{Ultimate Load}{Cross Section Area}$ Mpa	Weld factor *fw*
Run	T	AF	WS	TS	
1	225	5.893	0.25	9.09	0.56
2	225	5.893	0.35	9.02	0.55
3	225	17.679	0.25	7.52	0.46
4	225	17.679	0.35	8.52	0.53
5	275	17.679	0.25	10.14	0.63
6	275	17.679	0.35	10.33	0.64
7	275	5.893	0.25	8.83	0.54
8	275	5.893	0.35	11.25	0.69

1. Hot air temperature has been found to be very much significant factor for tensile strength of welded joint with p value of 0.050 (table 4).
2. Welding speed give positive impact on the tensile strength of the welded joint.
3. Airflow gives negative impact on the tensile strength of welded joint.

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4. The values of tensile strength can be calculated by the model developed as

TS = -0.90 + 0.0320 T - 0.0356 AF + 8.85 WS--(1)

The maximum value of tensile strength predicted by above formula is 10.79MPa which is shown in Table 6 and obtained at higher level of Temperature and Welding speed.

Table-6: Predicted values of tensile strength of welded joint at different input parameters

Exp.	Temp(°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Predicted Value of Tensile Strength Mpa
Run	T	AF	WS	TS'
1	225	5.893	0.25	8.3
2	225	5.893	0.35	9.19
3	225	17.679	0.25	7.88
4	225	17.679	0.35	8.77
5	275	17.679	0.25	9.48
6	275	17.679	0.35	10.37
7	275	5.893	0.25	9.9
8	275	5.893	0.35	10.79

5. 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

Tensile Strength (PREDICTED) Mpa	Tensile Strength (Exp) Mpa	Error	Error %age
TS'	TS		
8.3	9.09	0.79	8.66
9.19	9.02	-0.17	-1.86
7.88	7.52	-0.36	-4.83
8.77	8.52	-0.25	-2.91
9.48	10.14	0.66	6.48
10.37	10.33	-0.04	-0.37
9.9	8.83	-1.07	-12.15
10.79	11.25	0.46	4.11

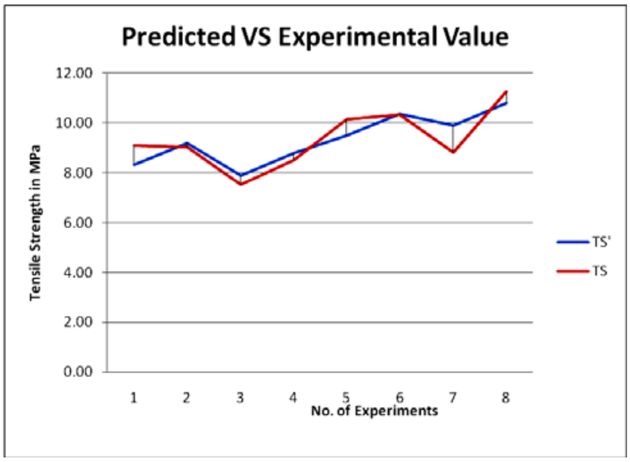

Fig.8: Graph showing Comparison between predicted and experimental value of tensile strength.

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

6. Weld factors varied in the range of 0.46–0.69 for welded PVC samples.

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 (Temperature, welding speed and airflow) are varied at two levels as higher level and lower level. From the above study conclusion is drawn that :

1. The better tensile strength of the welded joint is obtained at higher level of temperature.
2. Better weld factor was obtained as compared to O. Balkan et. al. report. They report 0.45 while here is is obtained from 0.46 to 0.69.
3. More than two times better result of tensile strength was obtained as compared to Mahmood Alam et.al. They report maximum of 3.92MPa while here it is obtained maximum of 11.25MPa.

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