Study and Experimental Modelling of Welding Parameters on Hardness of Hot Air Welded Poly Vinyl Chloride (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 Poly Vinyl Chloride (PVC) plastic welding by hot air technique. The effect of hot air temperature, welding speed and air flow rate has been evaluated on the Hardness of the welded joints. 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.

Key words: Poly Vinyl Chloride (PVC), Welding of PVC plastic, Hot air welding, ANOVA technique, Experimental Modeling, and Hardness of PVC plastic

I. 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 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.

II. DESIGN OF EXPERIMENT

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 2^3 design matrix is shown in Table 1.

Exp.	Temperature (°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Hardness Shore D
Run	T	AF	WS	H
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	

Table 1: Matrix Prepared for Input Variables and Corresponding Response.

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:

III. INPUT PARAMETERS

A. *Welding Temperature(T):*

Maximum Temperature(Tmax) = 275 °C

Minimum Temperature(Tmin) = 225 °C

B. *Air flow rate (AF):*

Maximum Air flow rate (AFmax) = 17.679 cm^3/sec

Minimum Air flow rate (AFmin) = 5.893 cm^3/sec

C. *Welding Speed (WS):*

Maximum welding speed

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

And minimum welding speed

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

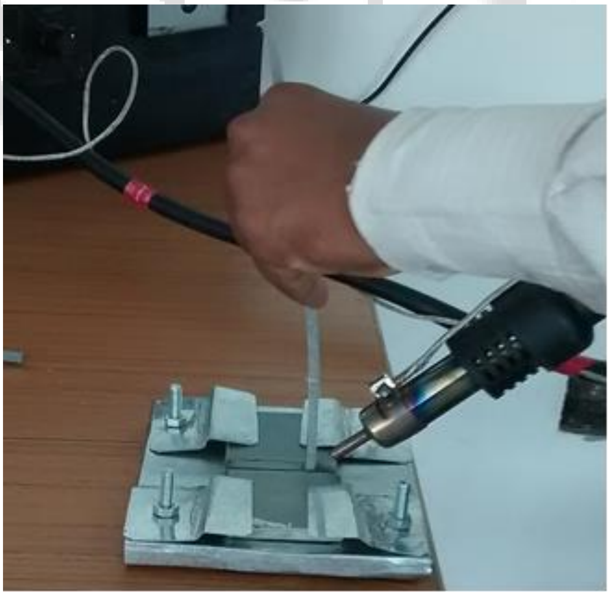


Fig. 1: Hot Air Welding Operation Performing in Lab

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

Fig. 2: Weld Bead Obtained using Different Combination of Input Parameter

IV. TESTING OF WELDED WORK PIECE

Tests have been being conducted on Shore-D Hardness Durometer. Range of the Durometer is upto 100 Shore-D.

Exp.	Temp(°C)	Air flow Rate cm^3/s	Welding Speed mm/s	Response Hardness Shore D
Run	T	AF	WS	H
1	225	5.893	0.25	70.75
2	225	5.893	0.35	69.25
3	225	17.679	0.25	74.25
4	225	17.679	0.35	69.00
5	275	17.679	0.25	77.75
6	275	17.679	0.35	76.75
7	275	5.893	0.25	75.00
8	275	5.893	0.35	74.25

V. EXPERIMENTAL MODELING

A. Regression analysis for hardness of the obtained welded joint:

Equation (1) is the regression equation obtained from the regression analysis. ANOVA for the regression has been given in table 4. Table 4 indicates that p value of the regression equation is significant

$$H = 52.00 + 0.1025\,T + 0.1803\,AF - 21.25\,WS \text{------(1)}$$

Where,
T = Temperature
WS = Welding speed, and
AF =Hot air flow rate
H= Hardness

Source	DF	SS	MS	F-Value	P-Value
Regression	3	70.594	23.531	13.15	0.015
Error	4	7.156	1.789		
Total	7	77.75			

Table 3: ANOVA Table for Hardness of Welded Joint

S=1.3356; R-sq=90.80%; R-sq(adj)= 83.89%

Term	Coef	SE Coef	T-Value	P-Value
Constant	52.0000	5.6200	9.2600	0.0010
T	0.1025	0.0189	5.4200	0.0060
AF	0.1803	0.0802	2.2500	0.0880
WS	-21.2500	9.4600	-2.2500	0.0880

Table 4: Regression Table for Hardness of Welded Joint

B. Effect analysis of input parameters for hardness of the obtained welded joint:

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 3, 4 and 5. Main effect plots show that when airflow (AF) and temperature (T) increases hardness also increases. When welding speed (WS) increases hardness decreased. Therefore hardness of welded joint is directly proportional to the airflow and temperature and indirectly proportional to welding speed.

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

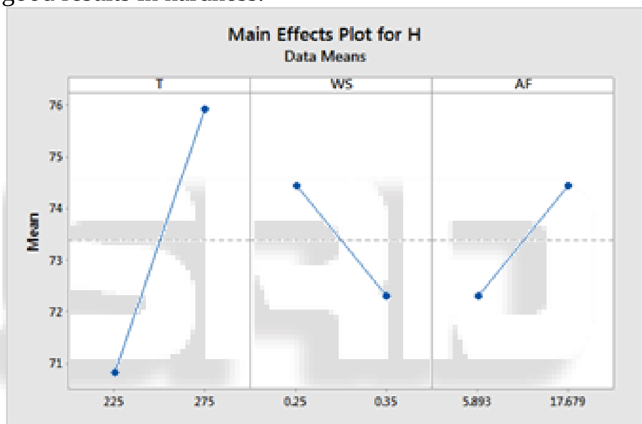


Fig. 3: Main Effect Plots for Hardness

The interaction plots are shown in figue-4. First is interaction between temperature and welding speed. It shows that at both temperature lower welding speed give positive results. Minimum hardness was obtained at maximum welding speed and and minimum temperature combination. And maximum hardness was obtained at minimum welding speed and maximum temperature combination.

Second interaction is between airflow and welding speed. It shows that effect of airflow is positive while effect of welding speed is negative. At minimum welding speed and maximum airflow higher hardness value is obtained. And at maximum welding speed and minimum airflow lower hardness is obtained.

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

But always good results are obtained at higher temperature.

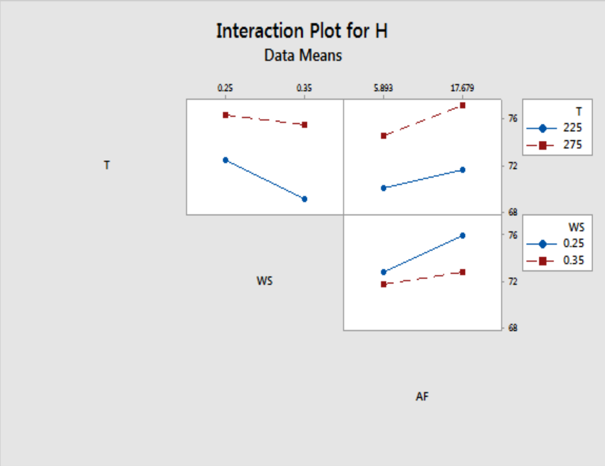
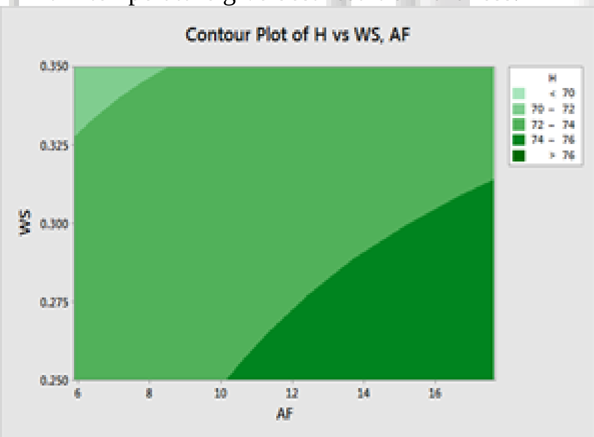


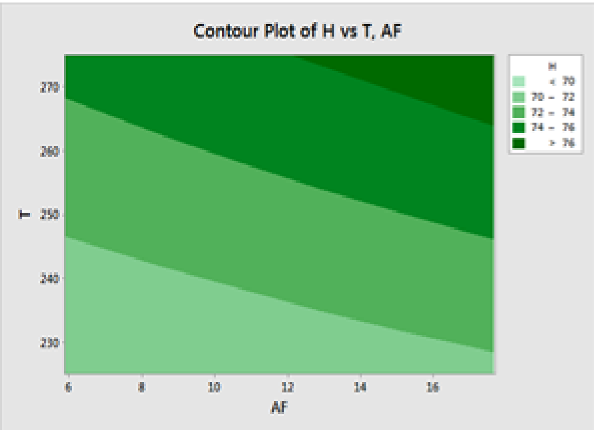
Fig. 4: Interaction Plots for Hardness

Three contour plots are shown in the figure 6. In first contour plot, it shows that the value of hardness is increased with increase in airflow and decrease in welding speed upto certain limit. And at minimum welding speed and maximum airflow the best hardness is obtained.

In second contour plot it shows that the value of hardness is increased as temperature increases. At minimum airflow and minimum temperature, the minimum hardness is obtained and vice versa.

In third contour plot, it shows that when welding speed decreases and temperature increases, better hardness is obtained. And at last, minimum welding speed and maximum temperature give best result of hardness.





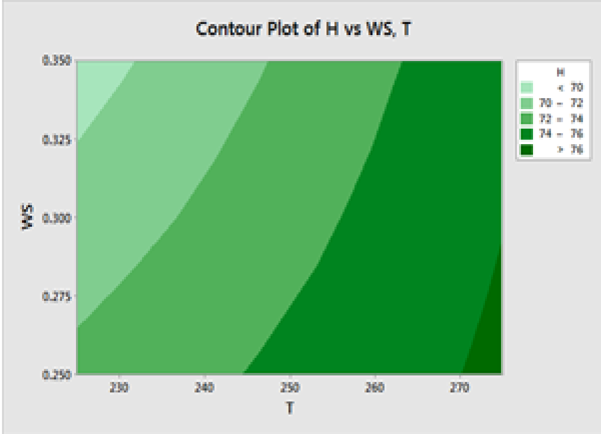


Fig. 5: Contour Plots for Hardness

VI. RESULTS AND DISCUSSION

The effect of input parameter has been studied on hardness of the welded joint by using full factorial design and hardness 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.

Exp.	**Temp(°C)**	**Air flow Rate cm^3/s**	**Welding Speed mm/s**	**Response Hardness Shore D**
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Table 5: Input Variables and the Corresponding Responses

A. Results:

1) Hot air temperature has been found to be very much significant factor for hardness of welded joint.
2) Welding speed give negative impact on the hardness of the welded joint.
3) Airflow gives positive impact on the hardness of welded joint.

VII. CONCLUSION

The present work has been carried out to study the effect of input parameters on hardness 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 the better hardness of the welded joint is obtained at higher level of temperature.

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