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Empirical Modeling Relating Weld Current, Mass Flow Rate of Hot Air and Welding Speed to Stiffness of Hot Air Welded PVC Plastic

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ABSTRACT

In the field of plastic welding few research works is done in last few decades but now a days repairing of plastic become very important and its finding surprising use in manufacturing of plastic goods. So in this sequence we have done some work in the same field. The present work is done to observe the effect of mass flow rate of hot air, welding speed and welding current on stiffness of the welded PVC joint. For design of experiment full factorial technique has been used. The effect of input parameter been evaluated on the output response stiffness of weld bead. The analysis and empirical modeling is done by ANOVA i.e. analysis of variance. MINITAB 15 is being used to determine the best fit relation between response and input parameter. In statistical analysis 95% level of confidence is used.

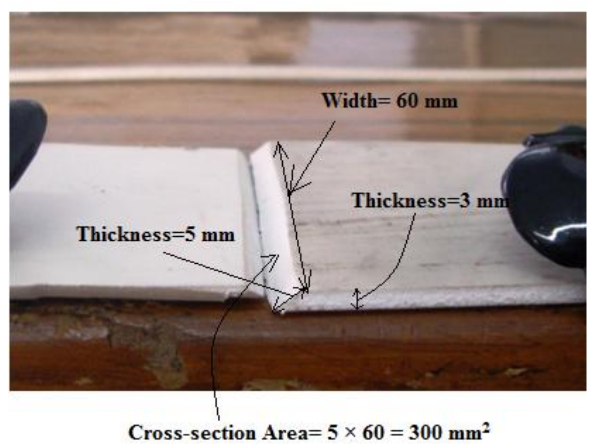
Keywords:- ANOVA, MINITAB, PVC

I. INTRODUCTION

As the plastics becoming important material to manufacture the components for various category of load carrying application. In this regard repairing of the plastics specially thermoplastics s very important. Hot air technique is used in which weld groove and welding rod is simultaneously heated by hot air stream until it get soften[2] and welding rod is then pressed in to groove to complete the weld process. This technique first introduced by R.C. Reinhardt [1] in 1940. It is an external heating method [3, 5, 6, and 7] in which work piece and welding rod should not be melted but it is in pliable condition [4].

II. EXPERIMENTAL WORK AND DESIGN OF EXPERIMENT

First of all sheet were cut to make 60^0 V- groove on desired work piece and then specimen is fixed in a suitable fixture as shown in figure 1, fixture will help to prevent thermal distortion in weld zone [9].Now hot air supplied to the groove and welding rod which is heated up to required temperature up to 365^0 C [2] and get fused as shown in figure 1. The experiment has been done by using full factorial technique i.e. 2^n Technique where n is the number of variable [8]. Table 1 is shown below which matrix is prepared for various observations taken in our experiment



(a)

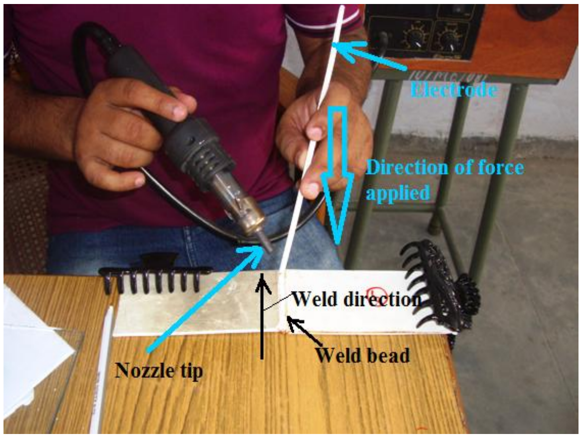


Figure 1 (a) Geometry of weld specimen (b) Diagram showing weld action along with fixture used

III. INPUT PARAMETER FOR EXPERIMENT

We have take three input parameter for our experiment (a) Current (I) (b) mass flow rate of hot air (ṁ) (c) welding speed (V)

Current range $I_{maximum}$ =1.7 amp and $I_{minimum}$ = 1.3 amp, Mass flow rate of hot air $\dot{M}_{maximum}$= 17648 mm^3/sec, $\dot{M}_{minimum}$= 4412 mm^3/sec Welding speed $V_{maximum}$ = 2.068 mm/sec $V_{minimum}$ = 1.304 mm/sec

After selecting input parameter, design matrix is generated according to full factorial method [8] and the design matrix given below in table 1. Total eight experiments were conducted by selecting different combination of input parameters according to the table 1.

Table 1 Design matrix to perform experiment

	Y_1	Y_2	Y_3	Response
S.N0.	I Ampere	V mm/sec	$\dot{M}$ mm^3/sec	S stiffness (N/mm^2)
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 and +1 indicates minimum and maximum value of input parameter.

EXPERIMENT NO.1

First experiment conducted by taking the all parameter at low level i.e. -1 that mean value of current is minimum level (1.3 ampere), minimum weld speed is 1.304 mm/sec and minimum mass flow rate of hot air through the nozzle tip is 4412 mm^3/sec. At these parameter the weld bead is obtained shown in figure 2

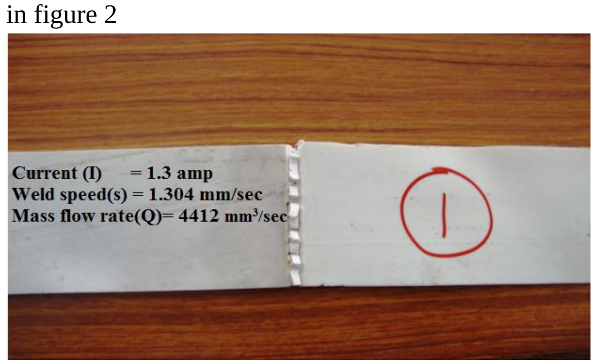


Figure 2 Weld bead formed in first experiment

EXPERIMENT 2

Second experiment was conducted by taking two variable minimum and other is maximum. In this experiment welding current and welding speed is taken as minimum level i.e. 1.3 ampere current and 1.304 mm/sec weld speed and mass flow rate is at maximum level i.e. 17648 mm^3/sec

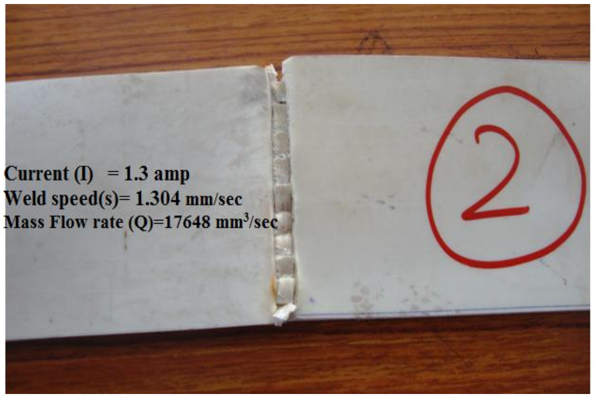


Figure 3 Weld bead formed in 2nd experiment

Similarly Experiment no 3, 4,5,6,7 and 8 was conducted by taking different values of input parameter as shown in table 1 and the weld bead can be seen in figure given below

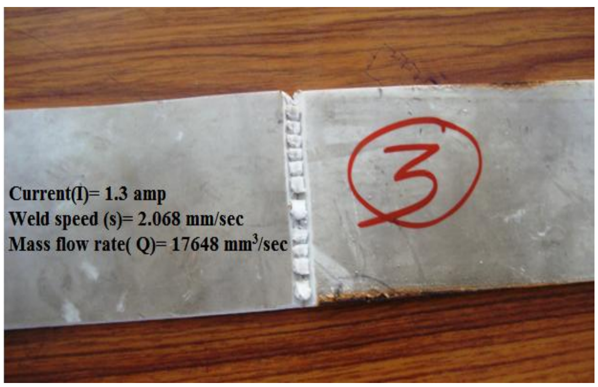


Figure 4 Weld bead formed in 3rd experiment

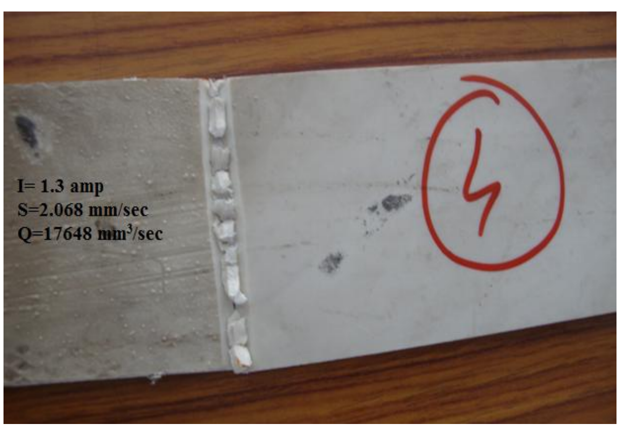


Figure 5 Weld bead formed in 4th experiment

Figure 6 Weld bead formed in 5th experiment

Figure 7 Weld bead formed in 6th experiment

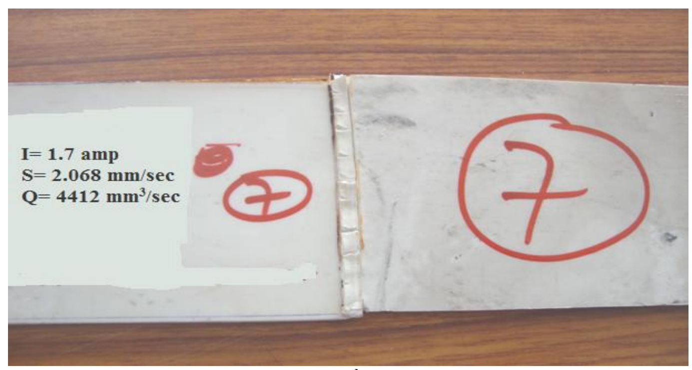


Figure 8 Weld bead formed in 7th experiment

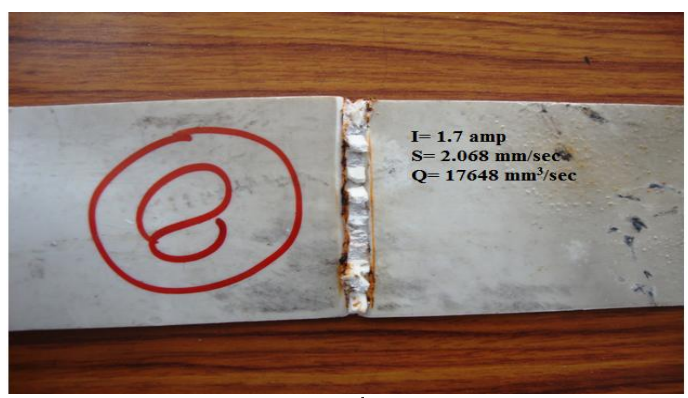


Figure 9 Weld bead formed in 8th experiment

During testing of the workpiece, before the fracture ultimate load (W) and maximum deflection (Δl) were observed which is shown in observation table 2

Table 2 Observation during testing of the workpiece on tensile testing machine

S.No	Current(I) In ampere	Weld speed (V)in mm/sec	Mass flow rate(M) in mm^3/sec	Deflection	Ultimate load(W) in	Ultimate load(W) in Newton
1	1.3	1.30	4412	0.3	9	9×9.81= 88.29
2	1.3	1.30	17648	0.6	39	39×9.81 =382.59
3	1.3	2.07	4412	0.4	20	20×9.81 = 196.20
4	1.3	2.07	17648	0.5	6	6×9.81= 58.86
5	1.7	1.30	4412	0.5	22	22×9.81 = 215.82
6	1.7	1.30	17648	0.5	62	62×9.81 = 608.22
7	1.7	2.07	4412	0.3	5	5×9.81= 49.05
8	1.7	2.07	17648	0.7	120	120×9.81=1177.20

On the basis of above data response (stiffness) for all workpiece is were calculated as shown in given table 3

Table 3 calculated response

S.No	Stiffness= $\frac{Load}{Deflection}$ (N/mm)
1	88.29/0.3= 294.30
2	382.59/0.6= 147.15
3	196.20/0.4= 490.50
4	58.86/0.5= 117.72
5	215.82/0.5= 431.64
6	608.22/0.5= 1216.44
7	49.05/0.3= 163.50
8	1177.20/0.7= 1681.71

REGRESSION ANALYSIS OF EXPERIMENTAL OBSERVATION

Regression analysis is done to establish the relationship between two variables. Regression analysis indicates the relationship among the dependent variable and independent variable. Value of depend variable can be predicted only by putting the desired value of independent variable in the regression equation. Regression analysis has been done using statistical software MINITAB15.

IV. REGRESSION ANALYSIS FOR STIFFNESS OF THE WELD BEAD

Regression equation for stiffness of the weld bead is shown in equation number (1) Regression table 4 indicates the p value of significant factor. R-sq value given suggests the suitability of the model. In present study model is 50.4% suitable.

The regression equation is

Stiffness (P) = - 2294 + 1527 I + 118 V + 0.0337 Ṁ…………………….. (1)

Where I= Current, V= Welding speed, Ṁ = mass flow rate of hot air

Table 4 Regression table for Stiffness of weld bead

Predictor	Coef	SE Coef		P
Constant	-2294	1682	-1.36	0.244
I	1527.3	945.2	1.62	0.181
V	118.1	491.0	0.24	0.822
Ṁ	0.03368	0.02856	1.18	0.304

V = 534.658 R-Sq = 50.4% R-Sq (adj) = 13.1%

Table 5 Analysis of variance for regression of stiffness of weld bead

Analysis of Variance					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	3	1160385	386795	1.35	0.376
Residual Error	4	1143439	285860		
Total	7	2303823			

V. RESIDUAL ANALYSIS FOR STIFFNESS

The residual is the difference between the observed and fitted value of the response. There are four plots available as normal probability plot, histogram, versus fits and versus order as shown below

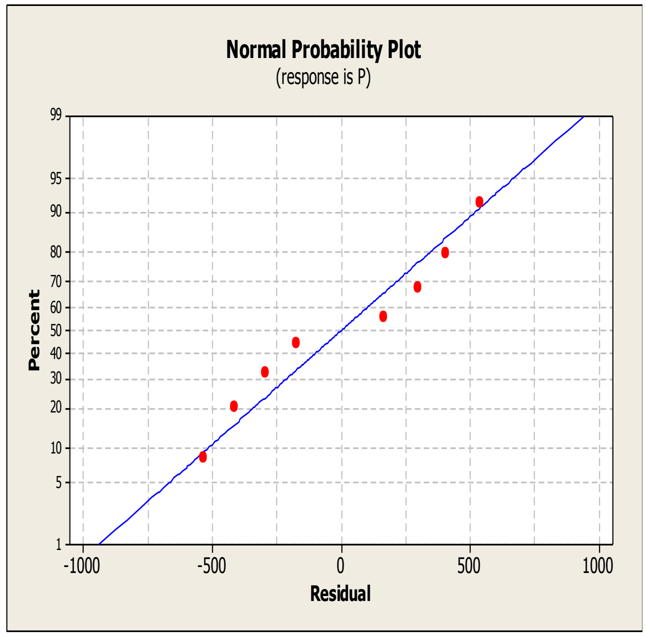


Figure 10 Normal probability plots for Stiffness of weld bead

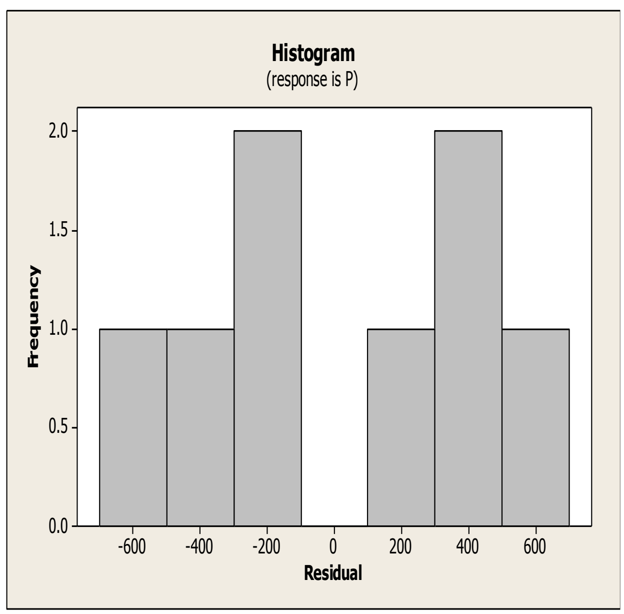


Figure 11 Histogram for Stiffness of weld bead

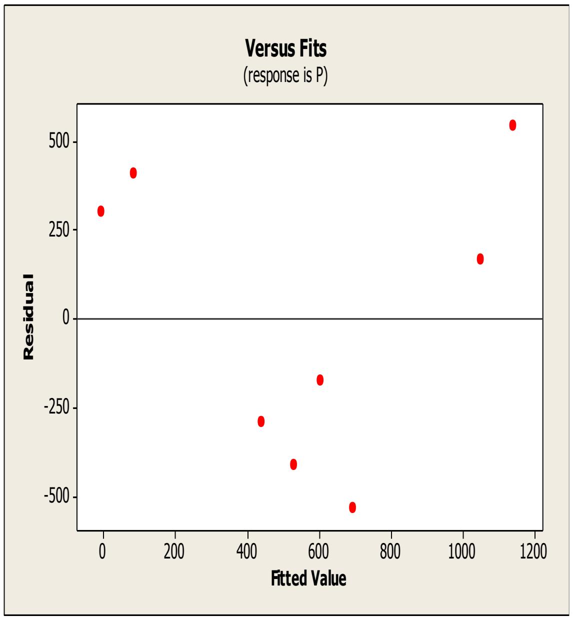


Figure 12 versus fits for Stiffness of weld bead

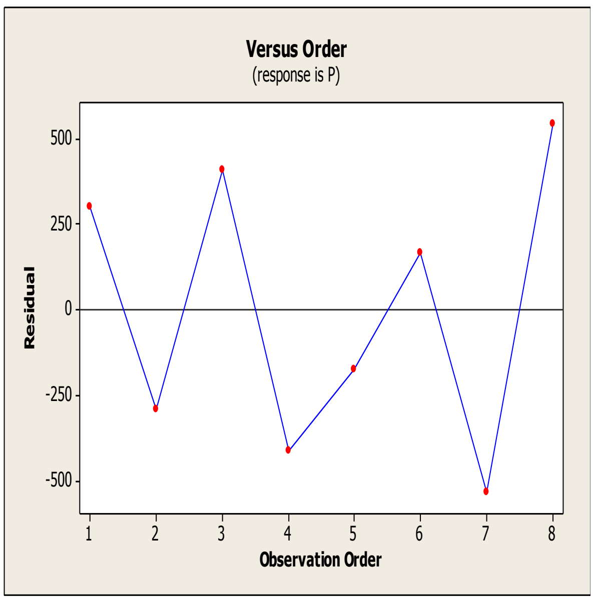


Figure 13 versus order for Stiffness of weld bead

The 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 stiffness response and y-axis the residuals. Straight horizontal line residual versus fits shows the zero residual or the fitted model line, which mean 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.

VI. RESULTS AND DISCUSSION

The effect of input parameter was studied on tensile strength, stiffness and resilience of the weld bead by using Regression analysis and full factorial design. Tensile strength, Stiffness and Resilience were 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 6 shows the values of responses measured

Table 6 Input variables and the corresponding Responses

S.No	Current I (Amp)	Weld speed (V) (mm/sec)	Mass flow rate $\dot{M}$ (mm^3/sec)	Stiffness S (N/mm)
1	1.3	1.30	4412	294.30
2	1.3	1.30	17648	147.15
3	1.3	2.07	4412	490.50
4	1.3	2.07	17648	117.72
5	1.7	1.30	4412	431.64
6	1.7	1.30	17648	1216.44
7	1.7	2.07	4412	163.50
8	1.7	2.07	17648	1681.71

a. For stiffness of the weld bead current and weld speed are most significant factor with p value of 0.181 and 0.822 respectively.

b. For optimal value of stiffness of weld bead, the current should be set at its higher level. Predicted values of Stiffness shown in Table 5.4 is calculated by

Stiffness (P) = - 2294 + 1527 I + 118 S + 0.0337 Q.

Maximum predicted value of Stiffness is **1140.9 N/mm** and it is also shown in Figure 5.3, is obtained at higher level of current and weld speed

Table 7 Predicted values of Stiffness of weld bead for different input parameters

I (Amp)	V(mm/sec)	$\dot{M}$ (mm^3/sec)	S (N/mm)
1.3	1.3	4412	-6.8156
1.3	1.3	17648	439.238
1.3	2.07	4412	84.0444
1.3	2.07	17648	530.098
1.7	1.3	4412	603.984
1.7	1.3	17648	1050.04
1.7	2.07	4412	694.844
1.7	2.07	17648	1140.9

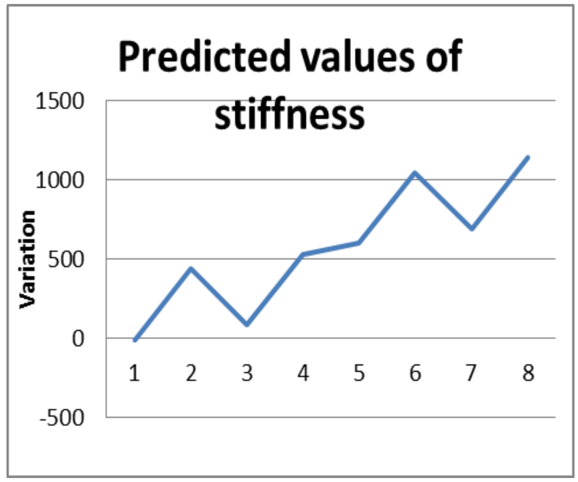


Figure 14 Graph showing different values of Stiffness

From the Table 7 indicates the maximum value of Stiffness is 1140.9 N/mm

c. Comparison between predicted value and observed value is given in Table 8

d. Since is very less difference between predicted values and observed values, small error shows that model is suitable and justified

Table 8 Comparison between predicted and observed value of Stiffness

Predicted value	Observed value	Error
-6.8156	294.3	-301.116
439.238	147.15	292.0876
84.0444	490.5	-406.456
530.098	117.72	412.3776
603.984	431.64	172.3444
1050.04	1216.44	-166.402
694.844	163.5	531.3444
1140.9	1681.71	-540.812

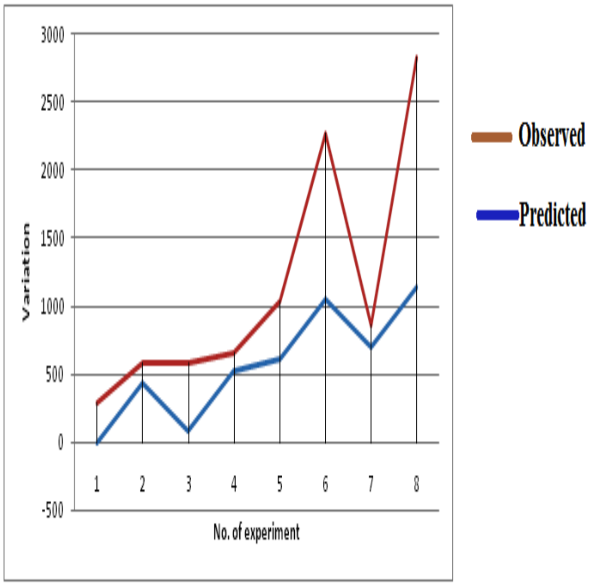


Figure 15 Graph showing comparisons between predicted and observed values of Stiffness

VII. CONCLUSION

The present work has been carried out to study the effect of input parameters on stiffness 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. Stiffness of the weld bead is mainly affected by welding current and weld speed

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