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Study And Empirical Modeling Relating Welding Parameters And Stiffness of Hot Air Welded Polypropylene Plastic

Sandeep Kumar Gupta, AnuragShrivastava, MahmoodAlam, Shailendra Kumar

P.G Student,Department of Mechanical Engineering, SRIMT, Lucknow, India
Assistant Professor, Department of Mechanical EngineeringSRIMT, Lucknow, India
Assistant Professor,Department of Mechanical Engineering, Intigral University, Lucknow, India
Assistant Professor, Department of Mechanical Engineering, BBDEC, Lucknow, India

ABSTRACT: The goal of the work is to investigate the effect of some input parameters on the desired responses in the Polypropylene plastic welding by hot air welding technique. The effect of welding current, welding speed and mass flow rate of hot air 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 Polypropylene (PP) plastic, Hot air welding, Empirical Modeling, and tensile strength of Polyproylen 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 thermoplastics 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 (air)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 air stream until they soften sufficiently to fuse, then the welding rod is pressed into the groove. During welding, weld strength isreduced 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

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 air. 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 air (Q)
Cross-section area of the nozzle= 22.06 mm^2
Minimum velocity of hot air (V_{min}) = 0.2 m/sec= 200 mm/sec
Maximum velocity of hot air (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

$$Q_{max}= 17648 \quad mm^3/sec$$

Similarly, Minimum mass flow rate (Q_{min}) = A * V_{min}= 22.06 * 200= 4412 mm^3/sec

$$Q_{min}= 4412 \quad mm^3/sec$$

Welding Speed (S)

$$\text{Maximum welding speed } (S_{max}) = \frac{Distancetravel}{timetakentocovert \quad hedistance}$$

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})

$$= \frac{Distancetravel}{Minimumtimetaken \quad totravelt \ hedistance}$$

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

$$S_{max}= 2.068 \text{ mm/sec}$$

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

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

$$S_{min}= 1.304 \text{ mm/sec}$$

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 kgf or4905 Newton. When gradual load (tensile) is applied to the work piece, work piece suffered a little deflection before fracture

Table 2 Stiffness 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 kgf	Ultimate load(W) in Newton	Stiffness= $\frac{Load}{Deflection}$ (N/mm)
1.	1.3	1.30	4412	2.3	97.85	97.85×9.81=959.90	959.90/2.3 =417.34
2.	1.3	1.30	17648	1.4	105.5	105.5×9.81=1034.9	1034.95/1.4=739.25
3.	1.3	2.07	4412	1.2	100	100×9.81= 981	981/1.2=817.5
4.	1.3	2.07	17648	1.7	79.51	79.51×9.81= 779.99	779.99/1.7=458.81
5.	1.7	1.30	4412	1.1	115.4	115.4×9.81= 1132.04	1132.07/1.1=1029.15
6.	1.7	1.30	17648	0.9	110.11	110.11×9.81= 1373.4	1080.08/0.9=1200
7.	1.7	2.07	4412	1.5	140	140×9.81= 1373.4	1373.4/1.5=915.6
8.	1.7	2.07	17648	0.8	80.4	788.72×9.81=788.72	788.724/0.8=985.90

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

$$Y= B_0 + B_1 X_1+€ \qquad .1$$

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.

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A REGRESSION ANALYSIS FOR STIFFNESS 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 –
Stiffness (P) = - 700 + 1061 I - 68 S + 0.0039 Q………… (2)
Where I = Current
S = Welding speed
Q = Mass flow rate of hot air

TABLE.3 REGRESSION TABLE FOR STIFNESS OF WELD BEAD

Predictor	Coef	SE Coef	T	P
Constant	-700.0	615.3	-1.14	0.319
I	1061.1	345.7	3.07	0.037
S	-67.5	179.6	-038	0.726
Q	0.00386	0.01045	0.37	0.731

S = 195.579 R-Sq = 70.8% R-Sq(adj) = 48.9%

TABLE. 4 ANALYSIS OF VARIANCE TABLE FOR STIFNESS OF WELD BEAD

Source	DF	SS	MS	F	P
Regression	3	370920	123640	3.23	0.143
Residual Error	4	153005	38251		
Total	7	523924			

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 Vspercent variation in Stiffness)
(b) Residual Vs frequency histogram.
(c) Residual Vs fitted value.
(d) Residual Vs observation order. (see figure 2, 3, 4, and 5)

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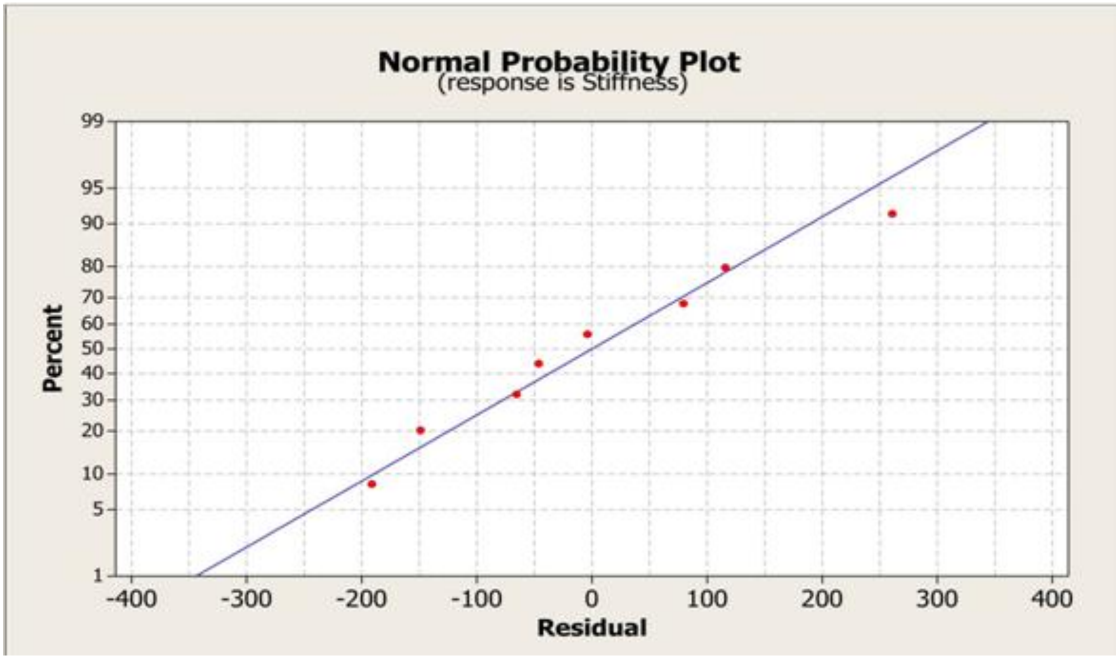

Figure 2 Normal probability plots for Stiffness of weld bead

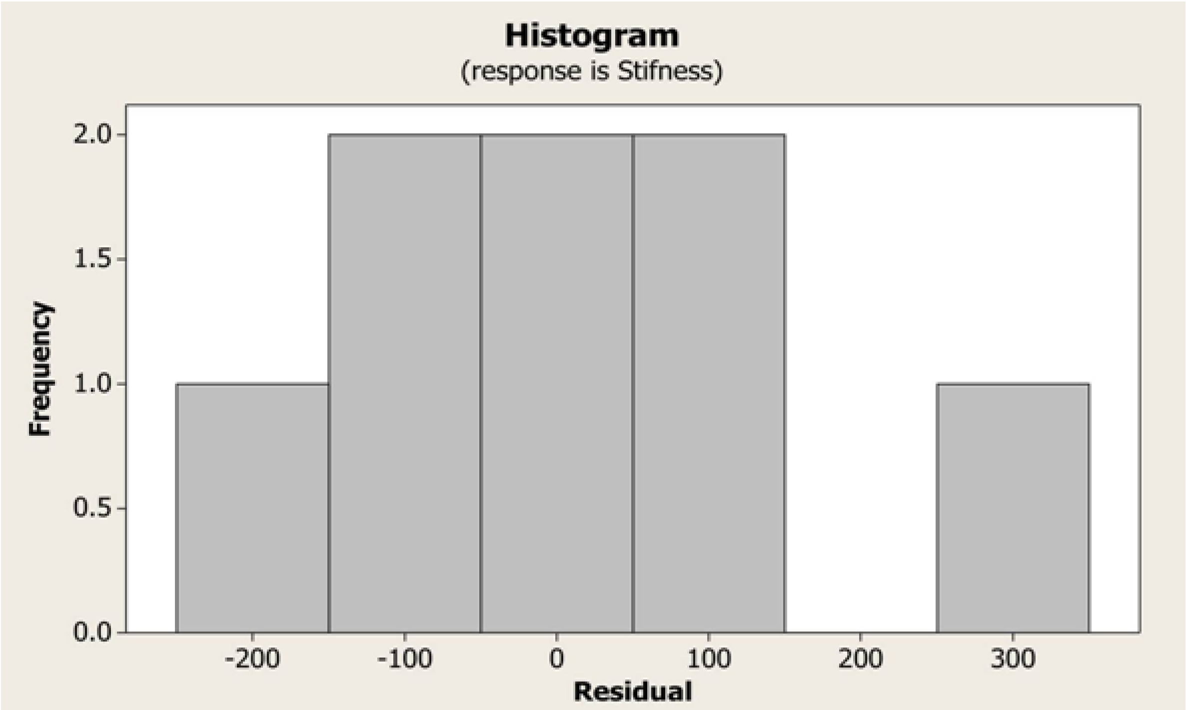

Figure 3 Histogram for Stiffness of weld bead

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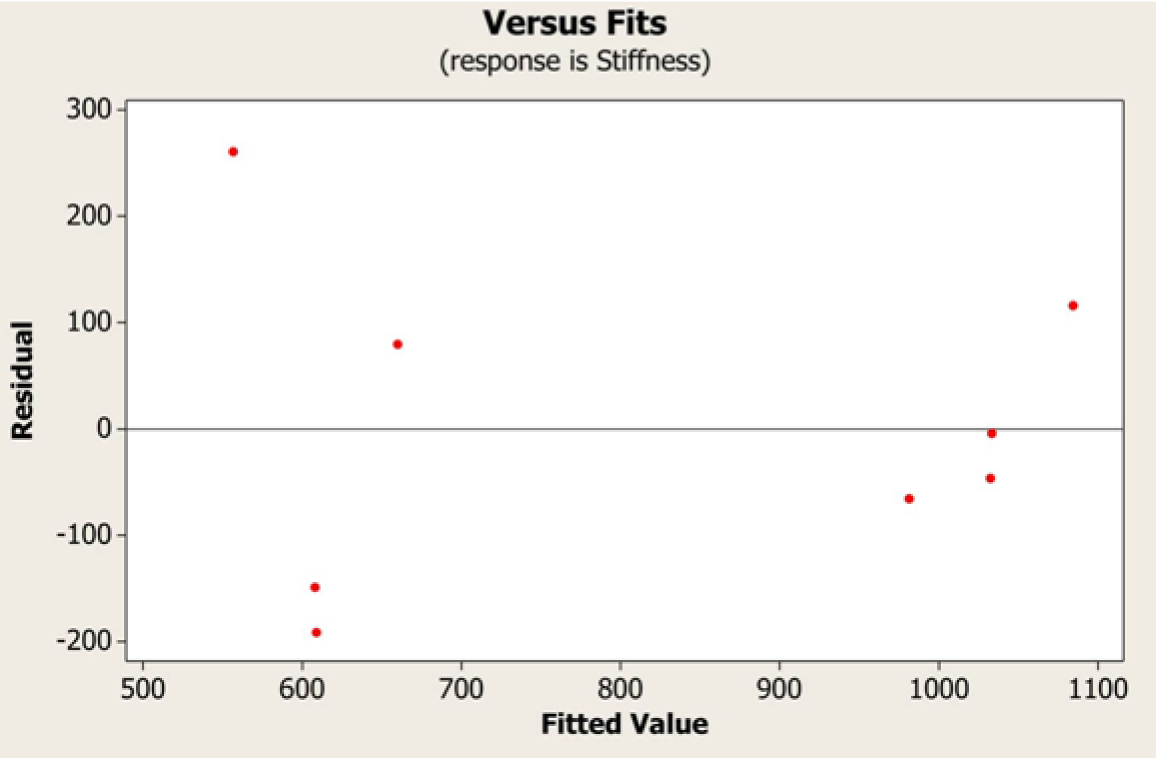

Figure 4 Versus fits for Stiffness of weld bead

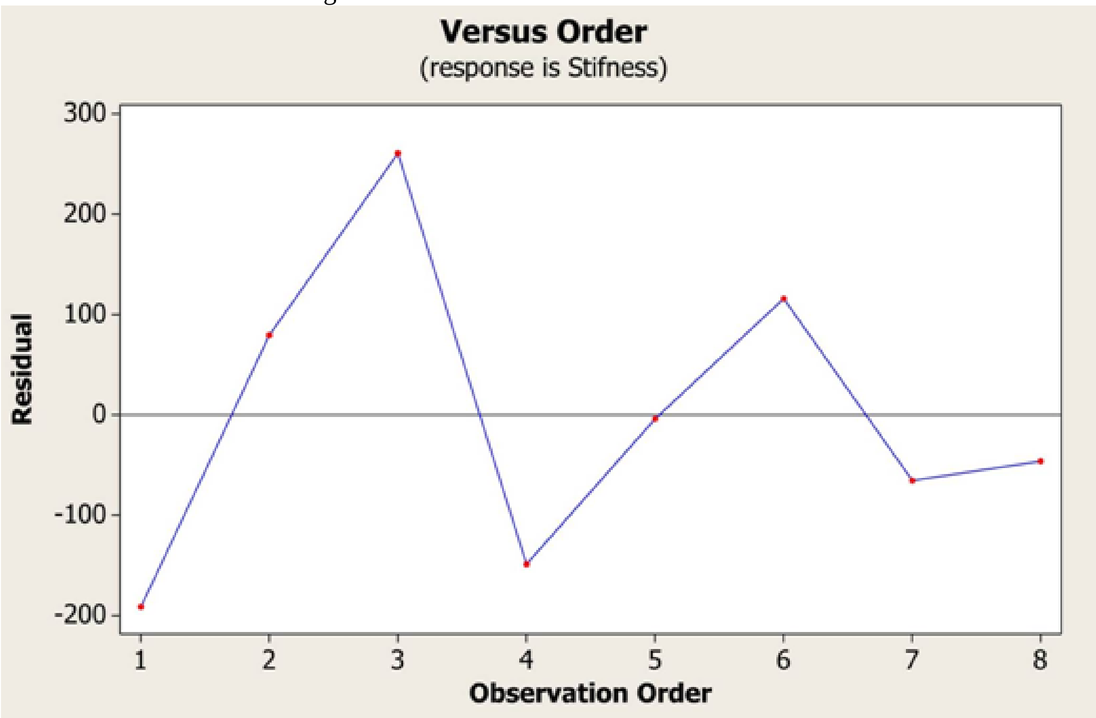

Figure 5 Versus order for Stiffness of weld bead

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

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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.

V.RESULTS AND DISCUSSION

The effect of input parameter was studied on stiffness of the butt weld bead by using Regression analysis and full factorial design. Stiffness 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 STIFFNESSOBSERVED AND PREDICTED.

S.N0.	I Ampere	S mm/sec	Q mm^3/sec	P (Observed) Stiffness (N/mm)	P (Predicted) Stiffness (N/mm)
1	1.3	1.30	4412	417.33	608.10
2	1.3	1.30	17648	739.25	659.72
3	1.3	2.07	4412	817.5	555.74
4	1.3	2.07	17648	458.81	607.37
5	1.7	1.30	4412	1029.15	1032.15
6	1.7	1.30	17648	1200	1084.12
7	1.7	2.07	4412	915.6	980.14
8	1.7	2.07	17648	985.90	1031.76

A.RESULTS

1. Weld current has been found to be a significant factor in regard to stiffness with p value of **0.037**(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 **0.726**(table 3). Mass flow rate shows a little significant impact on the tensile strength of the weld bead.
2. Maximum value of stiffness can be calculated by the model developed as
Stiffness (P) = - 700 + 1061 I - 68 S + 0.0039 Q
The maximum value of stiffness predicted by above formula is **1084.12 N/mm** which is shown in given Table 5 and obtained at higher level of weld current.

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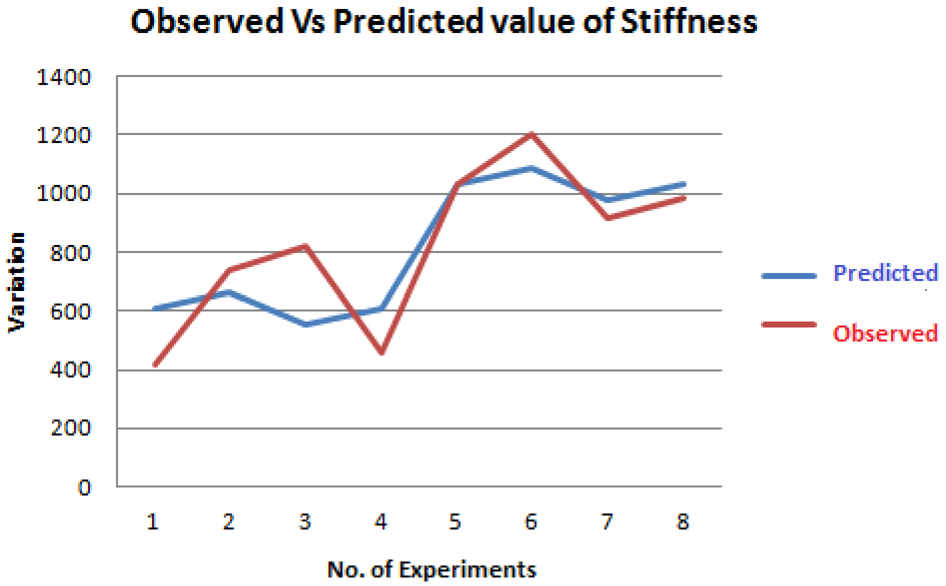

Figure 7: Graph showing Comparison between predicted and observed value of stiffness

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

VI. CONCLUSION

The present work has been carried out to study the effect of input parameters on Stiffness of butt welds, made of Polypropylene 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 Stiffness of the weld bead is mainly affected by the weld current and welding speed. Higher stiffness can be achieved at higher current.

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