International Journal of Manufacturing and Materials Processing
Vol. 4: Issue 1
www.journalspub.com

Investigation of Optimal Process Parameters of Extrusion Blow Molding Process Using Grey Taguchi Analysis

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ABSTRACT

Optimization of machining processes is essential for achieving higher productivity and high-quality products in order to remain competitive. The objective of this study is to optimize the process parameter of extrusion blow molding process for making a plastic container of high density polyethylene (HDPE) grade B52A003 produced by the extrusion blow molding process at CIPET Gwalior. Quality of plastic container of HDPE B52A003 material depends on various parameters. In this paper three process parameters namely Barrel temp. (°C), Cooling/cycle time (sec.) and extruder speed (rpm) and three responses haze and clarity, hardness and compressive strength were selected as a quality target. Taguchi Method is a statistical method to improve the process parameters and improve the quality of components that are manufactured. Nine experimental runs based on Taguchi's L9 (3^3) orthogonal array were performed followed by the Grey relational analysis to solve the three response optimization problem. Based on the Grey relational grade value and signal to noise ratio based on the higher is better criterion, optimum levels of parameters have been identified. The significance of parameters on overall quality characteristics of the extrusion blow molding process has been evaluated by the analysis of variance (ANOVA). The optimal parameter values obtained during the study have been validated by confirmation experiment.

Keywords: ANOVA, grey relational analysis, HDPE B52A00, orthogonal array, signal-to-noise ratio

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INTRODUTION

Extrusion blow molding is a low-cost manufacturing process for complex hollow parts. The process involves complex procedures such as parison extrusion, clamping, blow up, and cooling. First, the parison extrusion produces a molten thermoplastic tube coming out from the die. Once extrusion is finished, the parison is clamped and high-pressure air is blown into it to get the final part. To control the parison thickness over time, there is a mandrel that can move in and out to the die. Obviously, the parison thickness determines the thickness of the inflated part. The function of the parison programming is manipulating the die gap openings to obtain the desired thickness distribution of blown parts

Agrawal et al. [1] investigated that optimization parameters of extrusion blow molding process for making plastic container of high density polyethylene grade B6401 (HDPE). A plastic container made by using L9 orthogonal array. Nine experimental runs based on an orthogonal array of Taguchi method were performed. The process parameters were screw temperature, blowing time and exhaust/cooling time and the responses were the compressive strength and volume accuracy were selected as the quality target. Subramanian et al. [2] proposed the temperature control of plastic extruder using the fuzzy genetic algorithm. The aim of the article is to review the research for the determination of process parameters and the design for plastic extrusion. Research is based on various logic, genetic algorithm (GA) and he also find that plastic extrusion process is the well-known process for the plastic industries but is also well accepted by the pharmaceutical industries. With the use of plastic extrusion process, we can increase solubility and bioavailability. This research develops a system that may help users to determine the membership function of FLC using the GA optimization for the fastest processing in completing the problems. Barot et al. [3] have measured the strength of the sheet by using destructive test. And then change the design of the sheet that have more strength by using FEA method and optimize the window sheet(extrude) by using taghchi method, therefore to understand the plastic extrusion process, to understand its process parameter researcher study various research paper related to extrusion process. Roman Denysiuk et al. [4] found that there is a growing interest to optimize the use of raw material in blow molded products. Commonly, the material in blow molded containers is optimized by dividing the container into different sections and minimizing the wall thickness of each section. The definition of discrete sections is limited by the shape of the container and can lead to suboptimal solutions. This study suggests determining the optimal thickness distribution for blow molded containers as a function of geometry. The proposed methodology relies on the use of neural networks and finite element analysis. Jyh-Cheng Yu et al. [5] presented the application of soft computing technology to determine the optimum die gap programming of the extrusion blow molding process. A simple case study reveals that the Taguchi’s method is cost effective to obtain an improved design in a few experiments. Sharma et al. [6] presented that High-density polyethylene (HDPE) pipes find versatile applicability for transportation of water, sewage and slurry from one place to another. Hence, these pipes undergo tremendous pressure by the fluid carried. The present work entails the optimization of the withstanding pressure of the HDPE pipes using Taguchi technique. The traditional heuristic methodology focus on a trial and error approach and depends upon the gathered experience of the process engineers for analyzing the optimal process control parameters. This results in setting up of less-than-optimal values. Hence, there arouse a necessity to determine optimal process control parameters for the pipe extrusion process, which can ensure robust pipe quality and process reliability. In the proposed optimization strategy. PVC window profile is most widely used in now days in home appliances because of its light weight, low cost and corrosion resistance properties. Window profile (hollow sheet) is made from polycarbonate material through extrusion process. The above mentioned window sheet has low strength. So in this paper researcher has measure the strength of the sheet by using destructive test From this review, it has been concluded that, a finite element analysis of extrude product is very useful to study the effects of various parameters like Melting temperature, Screw speed, Extrusion pressure, Extrusion ratio, Die angle which are difficult to measure during process and all these features have significant effects on microstructure, extrude quality, material flow behavior and strength of the extrude. So, these parameters need to be analyzed and according to this modeled the extrude product. Dutta et al. [7] an analysis of parison inflation (in extrusion blow molding) for inelastic polymer melts has been presented. The primary objective of the theoretical development is to illuminate some of the effects produced by changes in material properties and process conditions on the growth dynamics and to identify the critical parameters controlling the inflation behavior. Pawar et al. [8]. The feed drum temperature: 1300, the die temperature: 1700, the extrusion pressure 100 MPa, and extrusion speed: 50 rpm gives the maximum optimize the thickness of the PVC pipe for minimizing the pipe defects. The die temperature is most significant process parameter in PVC pipe extrusion process and the second most significant factor is extrusion pressure which affects the PVC pipe wall thickness. Bordival et al. [9] presents an optimization strategy developed for the stretch-blow molding process and also proposed in this work a modeling of the full SBM process. The IR heating step was simulated using a finite-volume software, whereas the deformation process was simulated using ABAQUS. All the boundary conditions needed for the simulations were wisely measured or calculated numerically. A major contribution of this work remains the modeling of the fluid-structure interaction existing between the preform and the air flow applied inside the preform. Qun Huang et al. [10] used, a hybrid method consisting of finite element method (FEM), artificial neural network (ANN), and genetic algorithm (GA) was developed to find the optimal parison thickness distribution for a blow molded part with required thickness distribution. In Xiong Huang et al. [11], a new strategy was proposed to apply the finite element simulation to the varying die gap parison formation in extrusion blow molding. The parison formation from two different die gap profiles was simulated. In Shahrul Kamaruddin et al. [12], growing demands of plastics deriving environmental and social concern on the plastics contained in municipal waste. Realizing to this fact, this study emphasizes on minimization of plastic wastes during extrusion blow molding process by controlling the processing parameters including parison thickness, chiller temperature, melting temperature and extruder speed.

SCHEME OF INVESTIGATION

In order to maximize the quality characteristics, the present investigation has been made in the following sequence.

- Selection of material.
- Identify the importance extrusion blow molding process parameters.
- Find the upper and lower limits (i.e. range) of the identified process parameters.
- Select the orthogonal array (design of matrix).
- Conduct the experiments as per the selected orthogonal array.
- Record the quality characteristics (i.e. material properties).
- Find the optimum condition for maximizing the compressive strength, haze and clarity and hardness.
- Identify the significant factors.
- Conduct the confirmation test.
- Check the adequacy of the developed models.

GREY RELATIONAL ANALYSIS

Data Preprocessing

Grey data processing must be performed before Grey correlation coefficients can be calculated. A series of various units must be transformed to be dimensionless. Usually, each series is normalized by dividing the data in the original series by their average. Let the original reference sequence and sequence for comparison be represented as $x_0(k)$ and $x_i(k)$, *i*=1, 2. . . *m*; *k*=1, 2, . . ., *n*, respectively, where *m* is the total number of experiment to be considered, and *n* is the total number of observation data. Data preprocessing modify the original sequence to a comparable sequence. Several methodologies of preprocessing data can be applied in Grey relation analysis, depending on the characteristics of the original sequence. If the target value of the original sequence is "the-larger-the-better", then the original sequence is normalized as follows [2].

$$x_i^*(k) = \frac{x_i^{(O)}(k) - \min.\ x_i^{(O)}(k)}{\max.x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \quad (1)$$

If the purpose is "the-smaller-the-better", then the original sequence is normalized as follows

$$x_i^*(k) = \frac{\max.x_i^{(O)}(k) - x_i^{(O)}(k)}{\max.\ x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \quad (2)$$

However, if there is "a specific target value" then the original sequence is normalized using.

$$x_i^*(k) = 1 - \frac{\left|x_i^{(O)}(k) - OB\right|}{\max.\ \left\{\max.x_i^{(O)}(k) - OB, OB - \min.\ x_i^{(O)}(k)\right\}} \quad (3)$$

Where OB is the target value.

Alternatively, the original sequence can be normalized the simplest methodology that is the values of the original sequence can be divided by the first value of the sequence, $x_i^{(O)}(1)$.

$$x_i^*(k) = \frac{x_i^{(O)}(k)}{x_i^{(O)}(1)} \quad (4)$$

Where $x_i^{(O)}(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, max. $x_i^{(O)}(k)$ The largest value of $x_i^{(O)}(k)$, min . $x_i^{(O)}(k)$ the smallest value of $x_i^{(O)}(k)$.

Calculation of Grey Relational Coefficient and Grey Relational Grades

Following the data preprocessing, a Grey relational coefficient can be calculated using the preprocessed sequences. The Grey relational coefficient is defined as follows.

$$\gamma\left(x_0^*(k), x_i^*(k)\right) = \frac{\Delta_{\min.} + \zeta\,\Delta_{\max.}}{\Delta_{0i}(k) + \zeta\,\Delta_{\max.}}$$

$$0 < \gamma\left(x_0^*(k), x_i^*(k)\right) \leqq 1 \quad (5)$$

Where $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$, namely?

$$\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|, \qquad \Delta_{\max.} = \max_{\forall j \in i}.\ \max_{\forall k}.\ \left|x_0^*(k) - x_j^*(k)\right|,$$

$$\Delta_{\min.} = \min_{\forall j \in i}.\ \min_{\forall k}.\ \left|x_0^*(k) - x_j^*(k)\right|,$$

ζ is the distinguishing coefficient, $\zeta \in [0,1]$

A Grey relational grade is a weighted sum of the Grey relational coefficients and is defined as follows.

$$\gamma\left(x_0^*, x_i^*\right) = \sum_{k=1}^{n} \beta_k \gamma\left(x_0^*(k), x_i^*(k)\right)$$

$$\sum_{k=1}^{n} \beta_k = 1 \quad (6)$$

Here, the Grey relational grade $\gamma\left(x_0^*, x_i^*\right)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are same, then the value of the Grey relational grade equals to one. The Grey relational grade also specifies the degree of influence exerted by the comparability sequence on the reference sequence.

Accordingly, if a particular comparability sequence is more significant to the reference sequence than other comparability sequences, the Grey relational grade for that comparability sequence and the reference sequence will exceed that for other Grey relational grades. The Grey relational analysis is truly a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences

Signal to Noise Ratio Calculation

Signal-to-noise ratio (S/N ratio) was introduced by Sir Michael A Choma. The purpose of the signal-to-noise ratio (S/N ratio) is to investigate which design parameters significantly affect the quality characteristic.

Quality Characteristics

S/N characteristics formulated for three different categories are as follows.

Larger Is Best Characteristic

Data sequence for compressive strength, hardness and haze and clarity which are higher-the-better performance characteristic are pre-processed as per Eq. 6.

$$S/N = -10 \log ((1/n) ((1/y^2)) \quad (7)$$

Nominal and Smaller are Best Characteristics

$$S/N = -10 \log (y/s^2 y) \quad (8)$$

$$S/N = -10 \log ((1/n) (\sum(y^2)) \quad (9)$$

Where $y^{\wedge}$ is average of observed data y, sy^2 is variance of y, and n is number of observations.

Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows.

Notation

Following Notation are used for calculation of ANOVA method
C.F. = Correction factor
T = Total of all result
n = Total no. of experiments
= Total sum of squares to total ST variation.
= Value of results of each experiments Xi (i = 1 to 9)
SY = Sum of the squares of due to parameter Y (Y = A, B, C)
NY1, NY2, NY3 = Repeating number of each level (1, 2, 3) of parameter Y

XY1, XY2, XY3 = Values of result of each level (1, 2, 3) of parameter Y FY= Degree of freedom (D.O.F.) of parameter of Y

Ft = Total degree of freedom (D.O.F.)
Fe = Degree of freedom (D.O.F.) of error terms
VY = Variance of parameter Y
Se = Sum of square of error terms
Ve = Variance of error terms
FY = F-ratio of parameter of Y
SY' = Pure sum of square
CY= Percentage of contribution of parameter Y

Ce = Percentage of contribution of error terms
$CF = T^2/n$
$ST = \sum i=1 \text{ to } 9\ Xi^2 - CF$
$SY = (XY1^2/NY1 + XY2^2/NY2 + XY3^2/NY3) - CF$
fY = (number of levels of parameter Y) – 1
fT = (total number of results)-1
$fe = fT - \sum fY$
VY = SY/fY
$Se = ST - \sum SY$
Ve = Se/fe
FY = VY/Ve
SY = SY – (Ve*fz)
Pz = SY'/ST * 100%
$Pe = (1- \sum PY)*100\%$

EXPERIMENTAL PROCEDURES AND TEST RESULT

Material

High density polyethylene (HDPE) grade B52A003 is a blow molding grade material produced by the GAIL India Ltd.

This resin is particularly recommended for small size containers upto 5 liter for lubricant and foodstuffs (edible oils, ghee, etc.). B52A003 is offers an optimum combination of toughness, stress cracking resistance and process ability. HDPE is used in the production of plastic container, toys and automobile parts, etc. HDPE (High Density Polyethylene) is defined by a density of 0.954 g/cm^3, Melt flow index 0.35 g/10 min, Tensile strength at yield is 240 kg/sq.cm, hardness 62 shore D, flexural modulus 10000 kg/sq.cm, barrel temp.150-190 °C mold temperature 25–40 °C.

Schematic of Machining

In this study, the experiments were carried out on an Extrusion blow molding machine. Extrusion blow molding machine is based on the automatic microprocessor fully controlled by P LC (programmable logic control) with the help of hydraulic and pneumatic pump and valves. with a screw diameter 40 mm and diameter to length ratio is 1:20, extruder motor DC 7.5HP, hydraulic pump 5 HP with container capacity of 1000mL and Blowing air pressure is 3 kg/cm^2 Figures 1–6.

Fig. 1. *Machining setup.*

Fig. 2. *Work piece produced.*

Fig. 3. *Haze and clarity testing machine.*

Fig. 4. *Compressive strength testing machine.*

Fig. 5. *Hardness testing machine.*

Fig. 6. *Samples for hardness test.*

Selection of the Extrusion Blow Molding Parameters and Their Levels

In this study, the experimental plan set as three variables, namely, barrel temperature, cooling/cycle time and extruder speed. On the basis of preliminary experiment conducted by using one variable at a time approach, the feasible range for the extrusion parameters was defined by the barrel temperature (150–190 °C), cooling/cycle (20–40 sec) time and extruder speed (35–55 rpm). In the extrusion blow molding process, parameters were selected as shown in Tables 1–10.

Table 1. *Parameters and their levels.*

Notation	Process parameter	Level 1	Level 2	Level 3
A	Barrel temp. (°C)	150	170	190
B	Cooling/cycle time(sec.)	20	30	40
C	Extruder speed (rpm)	35	45	55

Table 2. *Experimental layout using L9 orthogonal array.*

Experiment no.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3. *Experimental result.*

Experiment no.	Haze and clarity on scale Larger is better	Hardness on scale Larger is better	Compressive strength (N/mm^2) Larger is better
1	11.70	33.3	0.348
2	14.20	11.9	0.189
3	15.15	22.75	0.236
4	16.35	34.84	0.471
5	14.10	41.36	0.511
6	13.00	17.7	0.198
7	13.15	11.36	0.178
8	15.25	25.4	0.258
9	12.95	20.6	0.219

Table 4. *Normalized data.*

Experiment no.	Haze and clarity	Hardness	Compressive strength
1	0	0.7313	0.5105
2	0.5736	0.0180	0.0330
3	0.7419	0.3797	0.1742
4	1	0.7827	0.8799
5	0.5161	1	1
6	0.2796	0.2113	0.0601
7	0.3118	0	0
8	0.7634	0.4680	0.2402
9	0.2688	0.3080	0.1230

Table 5. *Deviation sequence.*

Experiment no.	Haze and clarity	Hardness	Compressive strength
1	1	0.2687	0.4895
2	0.4624	0.9820	0.9670
3	0.2581	0.6203	0.8258
4	0	0.2173	0.1201
5	0.4839	0	0
6	0.7204	0.7887	0.9399
7	0.6882	1	1
8	0.2366	0.5320	0.7598
9	0.7312	0.6920	0.8769

Table 6. *Grey relational coefficient.*

Experiment no.	Haze and clarity	Hardness	Compressive strength
1	0.3333	0.6504	0.5053
2	0.5195	0.9820	0.3408
3	0.6595	0.4463	0.3771
4	1	0.6971	0.8063
5	0.5082	1	1
6	0.4097	0.3880	0.3472
7	0.4208	0.3333	0.3333
8	0.6788	0.4845	0.3969
9	0.4061	0.4195	0.3631

Table 7. *Grey relational grade.*

Experiment no.	A	B	C	Grey relational grade
1	1	1	1	0.4963
2	1	2	2	0.6141
3	1	3	3	0.4943
4	2	1	2	0.8345
5	2	2	3	0.8361
6	2	3	1	0.3816
7	3	1	3	0.3625
8	3	2	1	0.5201
9	3	3	2	0.3962

Table 8. *Signal to noise ratio table for GRG.*

Experiment no.	A	B	C	Grey relational grade	S/N ratio
1	1	1	1	0.4963	-6.0851
2	1	2	2	0.6141	-4.2352
3	1	3	3	0.4943	-6.1202
4	2	1	2	0.8345	-1.5715
5	2	2	3	0.8361	-1.5548
6	2	3	1	0.3816	-8.3678
7	3	1	3	0.3625	-8.8138
8	3	2	1	0.5201	-5.6783
9	3	3	2	0.3962	-8.0417

Table 9. *Response for signal to noise ratio.*

Levels	A	B	C
1	-5.4802	-5.4901	-6.7104
2	-3.8314	-3.8228	-4.6161
3	-7.5113	-7.5099	-5.4963
Delta	**3.6799**	**3.6871**	**2.0904**

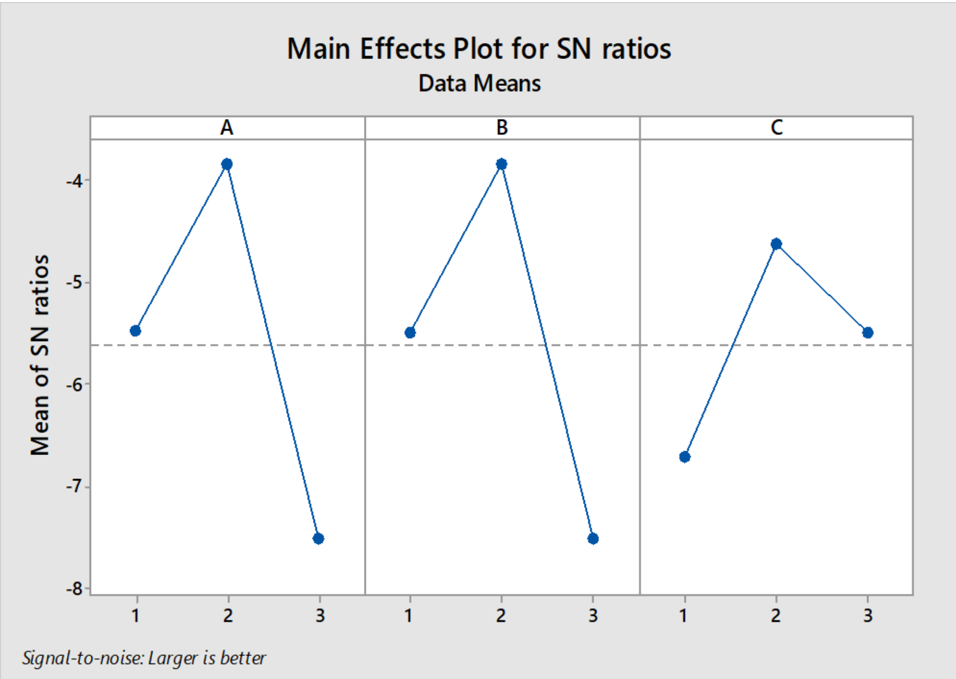

Table 10. *Analysis of variance (ANOVA) and F-test for HDPE B52A003.*

Main control factor	Symbol	DOF	Sum of squares	Mean of squares	F-ratio	Contribution (%)
Barrel temp.	A	2	0.1067	0.0534	2.8556	40.90
Cooling/cycle time	B	2	0.0824	0.0412	2.2032	31.58
Extruder speed	C	2	0.0344	0.0172	0.9198	13.19
Error	-	2	0.0374	0.0187	-	14.13
Total	-	8	0.2609	-	-	100

RESULTS AND DISCUSSION

Experimental work was performed on extrusion blow molding machine three responses haze & clarity, hardness and compressive strength responses were measured. Responses had in different units so we converted original sequence into comparable sequence and calculate grey relational coefficient by using Equation no. (1) and (5) respectively. Tables 4 and 7 show normalized data and grey relational grade respectively. After calculating the grey relational grade the next step of data analyzing the data is to calculate the signal to noise ratios of measured responses. Since haze & clarity, hardness and compressive strength should be maximum, thus we calculated the signal to noise ratio according for larger is better criterion using equation no. (7) and find the delta value of parameters A (3.6799), B(306871) and C(2.0904) with the help of S/N ratio response Table 9.

The purpose of the analysis of the variance (ANOVA) is to investigate which extrusion parameter significantly affects the quality characteristic. ANOVA is indicated for identifying the significant factors. In addition to degree of freedom (*DF*), mean of squares (*MS*), sum of squares (*SS*), *F*-ratio and contribution (*C*) associated with each factor was presented. The higher the percentage contribution was, the more important the factor for affecting the performance characteristics. The results of ANOVA for the Grey grade values are represented in Table 8. The results of the ANOVA indicate that the percentage contribution of barrel temp (A), cooling/cycle time (B) and the extruder speed (C) influencing the performance characteristics were 40.90%, 31.58 % and 13.19 %, respectively.

CONCLUSION

The Grey relational analysis based on an orthogonal array of the Taguchi method was a way of optimizing the parameter of blow molding process for manufacturing container of HDPE (B52A003). The analytical results are summarized as follows:

1.From S/N ratio, it is found that the optimal parametric combination for maximum performance is (A2B2C2) which is barrel temperature of 170ºC, Cooling/cycle time of 30 second and the extruder speed of 45 rpm. It is the recommended levels of the controllable parameters of the extrusion blow molding process as the maximization of the haze and clarity, hardness and compressive strength of container are considered.

Through ANOVA, the percentage of contribution to the extrusion blow molding process in sequence is the barrel temperature, cooling/cycle time and extruder speed.

Hence, the barrel temperature is the most noteworthy controlled factor for the extrusion blow molding process when the expansion of the compressive strength, haze and clarity and hardness.

CONFIRMATION TEST

Confirmation test is the final phase to verify the validity of optimization technique used. Conducting the confirmation experiments according to A2B2C2 which is an optimal parameter combination of the Blow molding process. If the optimal setting with a barrel temperature of 170ºC, cooling/cycle time of 30 second and extruder speed of 45 rpm is used. The extrusion blow molding machine operate on these parameter gives the Compressive strength of 0.539 N/mm^2, haze and clarity of 16.39 hardness of 42.36 on scale. In summary, the result of the confirmation test is better than the experiments in Table 3.

ACKNOWLEDGE

Authors would like to acknowledge CIPET, Gwalior, where experimental and testing work done.

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