MECHANICAL PROPERTIES OF GREEN COCONUT FIBER REINFORCED HDPE POLYMER COMPOSITE

Syed Altaf Hussain*
Associate Professor, Department of Mechanical Engineering,
RGM College of Engineering & Technology, Nandyal-518501, A. P., India.
s_a_hussain1@rediffmail.com

Dr.V. Pandurangadu
Professor, Department of Mechanical Engineering,
JNTUniversity-Anantapur, Anantapur-515002, A.P, India.
pandurangaduv@yahoo.com

Dr. K. Palanikuamr
Professor, Department of Mechanical Engineering,
Sri Sai Ram Institute of Technology, Chennai-44, T.N, India.
kumarlatha@gmail.com

ABSTRACT:

During the last few years, natural fibers have received much more attention than ever before from the research community all over the world. These natural fibers offer a number of advantages over traditional synthetic fibers. The present study aims to determine the mechanical properties namely, Tensile strength (TS), Flexural strength (FS), and Impact strength (IS) of green coconut fiber reinforced HDPE polymer composite material. Experiments are planned to produce the test specimens according Taguchi's L_9 orthogonal arry concept. The control parameters considered were fiber volume fraction (V_f) and fiber length (f_l). An attempt has been made to model the mechanical properties through response surface methodology (RSM). Analysis of variance (ANOVA) is used to check the validity of the model. The results indicated that the developed models are suitable for prediction of mechanical properties of green coconut fiber reinforced HDPE composite.

Keywords: Response surface methodology, Green coconut fiber, HDPE resin, ANOVA

INTRODUCTION

Many of our technologies require materials with unusual combination of properties that cannot be met by the conventional metal alloys. They are being extensively used in variety of engineering applications in many different fields such as aerospace, oil, gas and process industries as per the strategic engineers piping manual [1]. Besides superior corrosion resistance, composite materials exhibit good resistant to temperature extremes and wear, especially in industrial settings. The tailorability of composites for a specific purpose has been one of their greater advantages and also one of the more perplexing challenges to adopting them as alternative materials to metallic ones. FRP composite use polymers either thermoplastics or thermosets, as matrix and fibers of various types as reinforcement. The fibers of FRP composites give them their mechanical characteristics. The purpose of the matrix material is to bind the fibers together. Since the 1990s, natural fiber composite are emerging as realistic alternatives to replacement the glass-reinforced composite in many applications. Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP) and china reed fiber-PP are attractive material in automotive application particularly because of lower cost and lower density. Natural fiber composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emission, and enhanced energy recovery and of life biodegradability of components [2]. Natural fibers such as banana, cotton, coir, sisal and jute have attracted the attention of scientists and technologists for application in consumer goods, low cost

housing and other civil structures. It has been found that these natural fiber composites possess better electrical resistance, good thermal and acoustic insulating properties and higher resistance to fracture. Natural fibers have many advantages compared to synthetic fibers, for example low weight, low density, low cost, acceptable specific properties and they are recyclable and biodegradable. They are also renewable and have relatively high strength and stiffness and cause no skin irritations. On the other hand, there are also some disadvantages, for example moisture uptake, quality variations and low thermal stability. Many investigations have been made on the potential of the natural fibers as reinforcements for composites and in several cases the result have shown that the natural fiber composites own good stiffness, but the composites do not reach the same level of strength as the glass fiber composite [3]. Coconut fiber has been used as reinforcement in low-density polyethylene. The effect of natural waxy surface layer of the fiber on fiber/matrix interfacial bonding and composite properties has been studied by single fiber pullout test and evaluating the tensile properties of oriented discontinuous fiber composites [4]. Tensile and flexural behaviors of pineapple leaf fiber–polypropylene composites as a function of volume fraction were investigated. The tensile modulus and tensile strength of the composites were found to be increasing with fiber content in accordance with the rule of mixtures [5]. Rice straw polyester composites having volume fraction of 40% resulted in mean tensile strength 104 MPa [6]. Moreover, tensile and flexural strength and elastic moduli of the kenaf fiber-reinforced composites increased linearly up to a fiber content of 50% [7].
In the present work a thermoplastic polymer (High Density Polyethylene (HDPE) was used as a matrix material and green coconut fibers used as reinforcing material to produce a composite material to evaluate the various mechanical properties like Tensile strength (TS), Flexural strength (FS), and Impact strength (IS) respectively.

2. MATERIALS AND METHODS

The selected raw material of the fiber for this project work was Green Coconut fiber and the matrix material was HDPE (High Density Poly-ethylene).

2.1 Response Surface Methodology

RSM is a collection of mathematical and statistical techniques that are useful for modeling, analysis and optimizing the process in which response of interest is influenced by several variables and the objective. R.S.M uses quantitative data from appropriate experiments to determine and simultaneously solve multi variant equations. The response surface methodology comprises regression surface fitting to obtain approximate responses, design of experiments to obtain minimum variances of the responses and optimizations using the approximated responses.

In many engineering fields, there is a relationship between an output variable of interest ‘y’ and a set of controllable variables $\{x_1,x_2\ldots\ldots x_n\}$. in some systems, the nature of relationship between y and x values might be known. Then, a model can be written in the form

$$Y= f(x_1, x_2, \text{-----} x_n) + \varepsilon \quad (1)$$

Where ε represents noise or error observed in the response ‘y’

If we denote the expected response be $E(Y) = f(x_1, x_2, \text{-----} x_n) = \widehat{Y}$ is called response surface. The first step is to find suitable approximation for the true functional relation ship between y and set of independent variables employed usually a second order model is used in RSM.

$$\widehat{Y} = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^{\,2} + \sum_{i} \sum_{j} \beta_{ij} X_j + \varepsilon \quad (2)$$

2.1 Chemical treatment of Coconut fibers:

The green coconut fibers are chemically treated with two different types of chemicals namely H_2O_2 and NaoH at varies concentration levels. The purpose of chemical treatment is to remove the moisture content of green coconut fiber and to increase the tensile strength of green coconut fiber.
The green coconut fibers(100g) were pre-treated with 1L alkaline solution which is prepared in different concentrations as 2, 3 and 4% of NaoH ,for an hour under constant stirring and for 24hrs at room temperature and then dried in open air for 6 to 7 days. Thereafter fibers are tested for its tensile strength. From the experimental results it is found that, green coconut fiber treated with NaoH 2% concentration has the highest tensile strength of 42.09Mpa

2.2 Composite fabrication

The composites were produced using green coconut fiber as a reinforcement and HDPE (High Density Ply-Ethylene) as a matrix material. Exhaustive literature review on mechanical behavior of polymer composites reveals that parameters viz., fiber length and fiber volume fraction etc., largely influence the mechanical behavior of polymer composites. Composite materials were fabricated using Taguchi's L9 orthogonal array in the design of experiments (DoE) [8], which needs 9 runs and has 8 degrees of freedom. The control parameters used and their levels chosen are given in Table 1.

Table 1: Control Parameters and Their Levels

	Level 1	Level 2	Level 3
Fiber volume fraction (V_f) %	30	40	50
Fiber length (f_l) in mm	3	6	9

The treated fibers were chopped of length 3, 6 and 9mm length. The proper proportion of fiber (30%, 40% and 50% by weight for each of 3, 6 and 9mm) and HDPE were then properly blended to have homogeneous mixture. The mixture is then placed in the barrel of a hand injection molding machine. The machine was maintained at the constant temperature of 80^0C. At this temperature the resin melts and the pressure is applied to inject the molten material in to the die. Then after pressure is released and the specimen is taken out from the die and dipped in water for curing. The inner cavity of the dimensions of the mould is 163x12.5x6mm.

2.3 Tensile test

The tensile test is performed on specimens according to ASTM test standard D638-03 on a universal testing machine Instron 3369.The cross head speed was maintained 2mm/min, at a temperature 22^oC and humidity 50%. In each case three samples are taken and average value are recorded. In each case three samples were tested and average value is recorded.

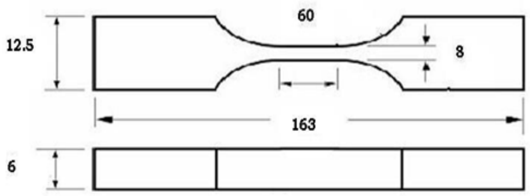

Fig:1 Specifications of Tension test specimen


Fig:2 Specimen for tension test

2.4 Flexural test

Flexural test were performed using 3-point bending method according to ASTM D790-03 procedure. The specimens were tested at a crosshead speed of 2 mm/min, at a temperature 22˚C and humidity 50%. In each case three samples were taken and average value is recorded.

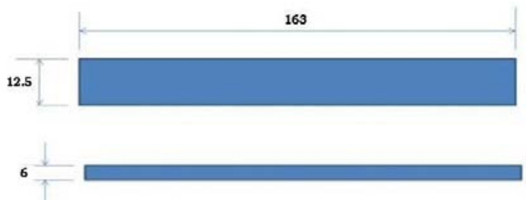

Fig:3 Specifications of Flexural test specimen

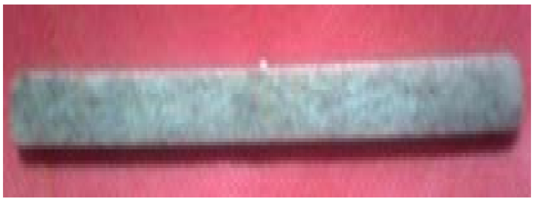
Fig:4 Specimen for flexural test

2.5 Impact test

The impact strength of notched specimen was determined by using an impact tester according to ASTM D256-05 standards. In each case three specimens were tested to obtain average value.

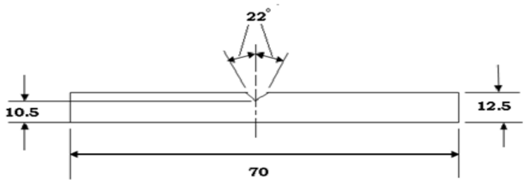

Fig:5 Specifications of Impact test specimen

Fig:5 Specimen for Impact test

3. Results and Discussion

In this work composite material is fabricated using hand injection molding method. Then test specimens were prepared as per ASTM standards and were tested to evaluate mechanical properties like tensile strength, flexural strength and impact strength.

The experimental results are modeled using RSM and empirical model has been developed. Table 2 shows the summary of models for the three responses.

Table.2. Model Summary Results

Measure of performance	Model expression	R^2	Adi R^2
Tensile strength	$8.93+0.474*V_f$ $-0.284*$ f_l- $0.00587*(V_f)^2+$ $0.012(f_l)^2$ $+0.0058*V_f*f_l$.	95.1	87.0
Flexural strength	$21.741-0.276*V_f - 0.795*f_l+0.00238*(V_f)^2+0.0243(f_l)^2$ $+0.0107*V_f*f_l$.	94	84.1
Impact strength	$257.767-9.358*V_f+26.705*f_l+0.115*(V_f)^2- 2.328(f_l)^2$ - $0.0166*V_f*f_l$.	95	86.7

The statistical testing of the developed mathematical models was done by Fisher's statistical test for the analysis of variance (ANOVA). As per ANOVA, if the calculated value of F-ratio of the regression model is more than the standard tabulated value of the F-table for a given confidence interval, then the model is adequate within the confidence limit. The results of ANOVA at 95% confidence interval are presented in Table 3 and it is found that the developed mathematical models are highly significant at 95% confidence interval as F-ratio of all three models is greater than 9.01 ($F\text{-}table_{(5, 3, 0.05)}$).

The coefficient of determination (R^2) is also determined to test the goodness-of fit of the mathematical model, which provides a measure of variability in the observed values of response and can be explained by the controlled process parameters and their interactions. The R^2 values of the developed models are given in Table 2, which clearly indicate the excellent correlation between the experimental and the predicted values of the responses. Adding a variable to the model will always increase R^2, regardless of whether the additional variable is statistically significant or not. In this discussion including unnecessary terms R^2 can be artificially high. Unlike R^2, adjusted R^2 will often decrease, when unnecessary terms are added to the model.

Adjusted R^2 will be taken into consideration, when the number of independent variables included in the model in the model. Hence, adjusted R^2 is more appropriate than R^2 for comparing models with different number of independent variables. When R^2 and adjusted R^2 differ dramatically, there is a good chance that non-significant terms have been included in the model.

From the models, it was revealed that the co-efficient of determination (R^2) is more than 95% in all the cases, which shows high correlation exists between the model and experimental values.

Table 3. ANOVA results for Mechanical properties of composite material, viz., Tensile strength, Flexural strength and Impact strength.

Response	Sum of squares		Degree of freedom		Mean square		F-ratio
	Regression	Residual	Regression	Residual	Regression	Residual	
Tensile Strength	1.47634	0.07555	5	3	0.29527	0.02518	11.72
Flexural Strength	1.18860	0.07529	5	3	0.23772	0.02510	9.47
Impact Strength	1388.21	72.75	5	3	277.64	24.25	11.45

3.1 Tensile strength

The tensile strength is a predominant property in processing of composite materials. The influence of constituent phases on the tensile strength (TS) of coconut fiber reinforced HDPE composite can be studied by using response graph and response table. Figure 6 shows the effect plot for tensile strength. From the graph it is inferred that, the observed tensile is higher at the fiber volume fraction of 40% than at 30% and 50%. It is also observed that tensile strength slightly decreases with increase in fiber length. From the response table 4 shows the effect of constituent phases on tensile strength. From the response table, it can be asserted that the fiber length is the main parameter which affects the tensile strength of the composite material.

Table 4 : Response table for Tensile strength

Level	Fiber volume fraction(V_f)%	Fiber length (f_l) in mm
1	16.76	17.18
2	17.20	16.97
3	16.92	16.73
Delta	0.43	0.46
Rank	2	1

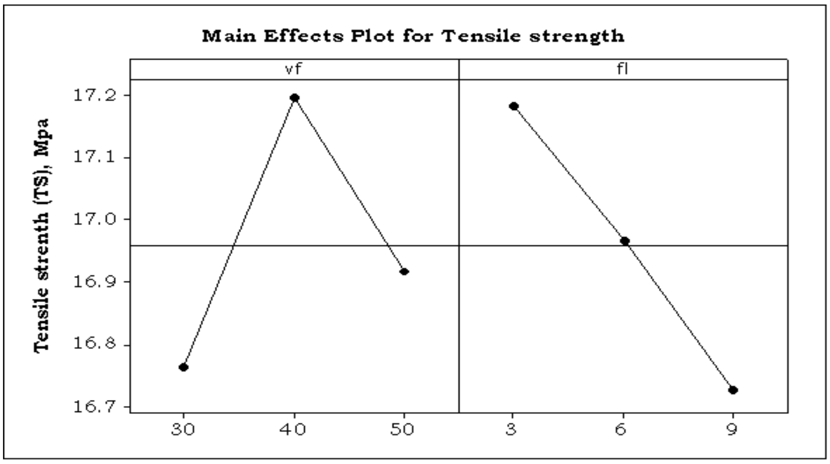

Figure: 6 Main effect plots for Tensile strength

3.2 Flexural strength

The flexural strength is a predominant property in processing of composite materials. It is more influenced by fiber length (f_l) and fiber volume fraction (V_f). The influence of the amount of constituent phases on flexural strength of the green coconut fiber reinforced HDPE composites can be studied by using response table 5 and response graph 7. From the graph it is inferred that, the observed flexural strength of the composite material is high at low fiber volume fraction as compared to high fiber volume fraction. The experimental results indicated that the flexural strength of the composite material is higher at lower fiber length. From the response table is asserted that the fiber volume fraction is the main parameter which affect the flexural strength of the coconut fiber reinforced HDPE composite material.

Table 5 : Response table for Flexural strength

Level	Fiber volume fraction(V_f)	Fiber length (f_l) in mm
1	13.78	13.78
2	13.33	13.34
3	13.36	13.34
Delta	0.45	0.44
Rank	1	2

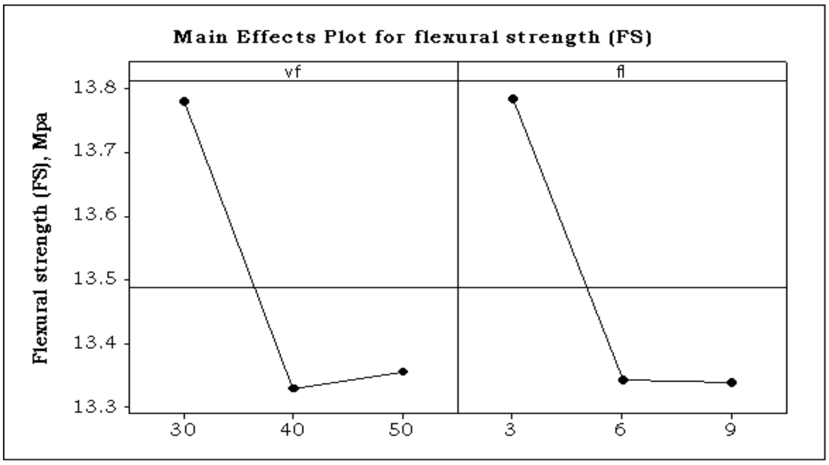

Figure: 7 Main effect plot for Flexural strength

3.3 Impact strength

The impact strength is a predominant property in processing of composite materials. It is more influenced by fiber length (f_l) and fiber volume fraction (V_f). The influence of the amount of constituent phases on impact strength of the green coconut fiber reinforced HDPE composites can be studied by using response table 6 and response graph 8. From the graph it is inferred that, the observed impact strength of the composite material is high at low fiber volume fraction as compared to high fiber volume fraction. The experimental results indicated that the flexural strength of the composite material is higher at lower fiber length than at higher fiber length. From the response table is asserted that the fiber length is the main parameter which affect the impact strength of the coconut fiber reinforced HDPE composite material.

Table 6. Response table for Impact strength (IS)

Level	Fiber volume fraction(V_f)	Fiber length (f_l) in mm
1	139.5	131.4
2	125.1	146.7
3	133.6	120.1
Delta	14.4	26.6
Rank	2	1

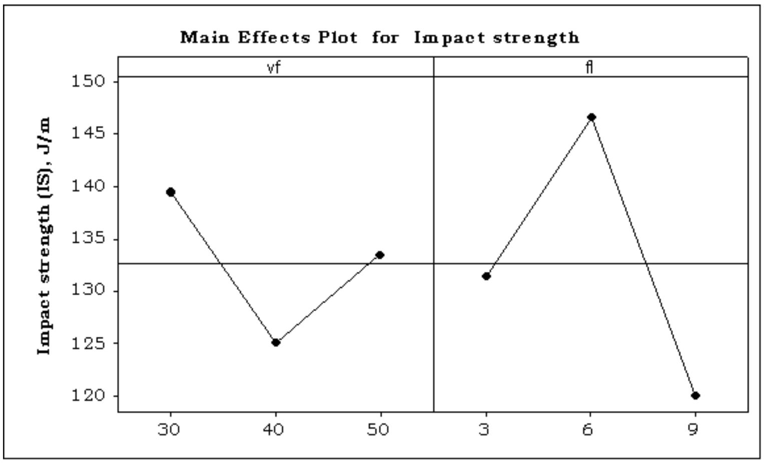

Figure: 8 Main effect plot for Impact strength

For analyzing the influence of process parameters on mechanical properties of green coconut fiber reinforced HDPE composite material, figure (9-14) shows the variation of mechanical properties like tensile strength (TS), flexural strength (FS) and impact strength (IS) with respect to the constituent phases were drawn using response surface model observed. In each graph one variable is variation and keeping the other variable constant at the middle level. From the graph 9, it is clearly seen that tensile strength of the composite material increases with increase in the fiber volume fraction up to 40% then after it decreases slightly. At lower fiber volume fraction (V_f) the density of the fiber is lower than the resign, at this stage load is not properly transmitted to the fiber. But at higher fiber volume fraction there should be increased bonding between the fiber and matrix. The load sharing is easily transmitted to the fibers. In the present investigation the maximum tensile strength of 17.37 Mpa was notice for the composite material of fiber volume fraction (V_f) of 40% and minimum tensile strength of 3.90 Mpa was noticed at fiber volume fraction (V_f) of 30%. Figure 10 is a plot between tensile strength verses fiber length. From the graph, it can be asserted that the tensile strength of the composite material slightly decreases with an increase in the fiber length (f_l). Maximum value of tensile strength of 17.82Mpa was noticed at a fiber length of 3mm, this is due the fact that the interfacial bond between the fiber and matrix increases. Minimum value of tensile strength of 17.12Mpa was noticed for a fiber length of 9mm. The percentage drop in the tensile strength is 3.9%. Hence, it is recommended to use short fibers, when injection molding is employed for making a composite, otherwise large fiber may cease the opening of the nozzle of the machine. For longer fibers (here 6mm to 9mm) tensile strength was decreased compared to 3mm fiber reinforced composite material. The probable reason is that a long fiber may not be compatible with the matrix properly. Thus improper bonding occurs between the fibers and the matrix. Moreover, fibers may be folded and there is no bonding between the folded and unfolded portion of fiber which resulted in a lower strength. %. Hence, it is recommended to use short fibers, when injection molding is employed for making a composite, otherwise large fiber may cease the opening of the nozzle of the machine.

Figure 11 is a plot of flexural strength verses and fiber volume fraction. From the graph it is asserted that the flexural strength of the composite material decreases with increase in fiber volume fraction. In the present investigation the maximum flexural strength of 9.35 Mpa was notice for the composite material at the fiber volume fraction (V_f) of 30% and minimum flexural strength of 1.31 Mpa was noticed at fiber volume fraction (V_f) of 50%.n Figure 12 the plot of variati0n of flexural strength with the fiber length (f_l). it is clearly seen form the graph the flexural strength of the composite material decreases with increase in fiber length to 6mm, then after it increases slightly.

Figure 13 shows the variation of impact strength of the composite material with respect to fiber volume fraction. From the graph it can be seen that the Impact strength is decreasing with the increase in fiber volume fraction (V_f) up to 40%. However further increase in fiber volume fraction (V_f) increases the Impact strength value. In the present investigation the maximum impact strength of 153.96 j/m was notice for fiber volume fraction (V_f) of 30% and minimum impact strength of 139.89 j/m was noticed for fiber volume fraction (V_f) of 40%. Figure 14 shows the plot between impact strength of the composite material verses fiber length (f_l). From the graph it is clearly seen that Impact strength of the composite material increases with increase in the fiber length up to 6 mm then after it decreases slightly. In the present investigation the maximum impact strength of 139.07 j/m was notice for fiber length (f_l) of 6 mm and minimum impact strength of 112.45 j/m was noticed for fiber length (f_l) of 9 mm.

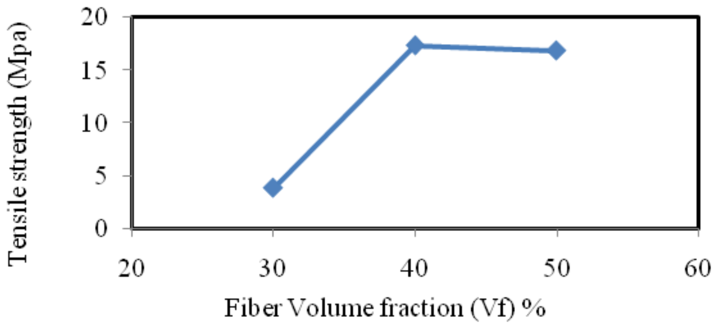

Fig: 9 Variation of Tensile strength with respect to fiber volume fraction

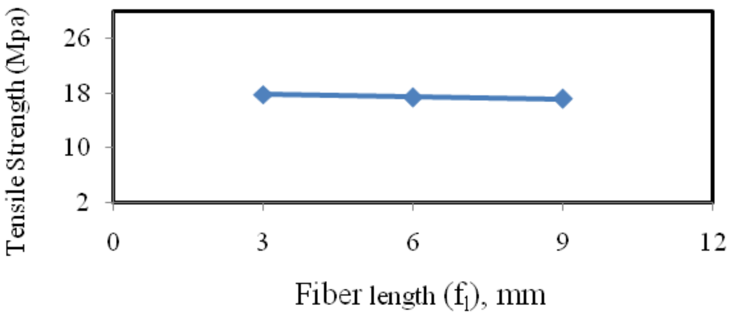

Fig: 10 Variation of Tensile strength with respect to fiber length.

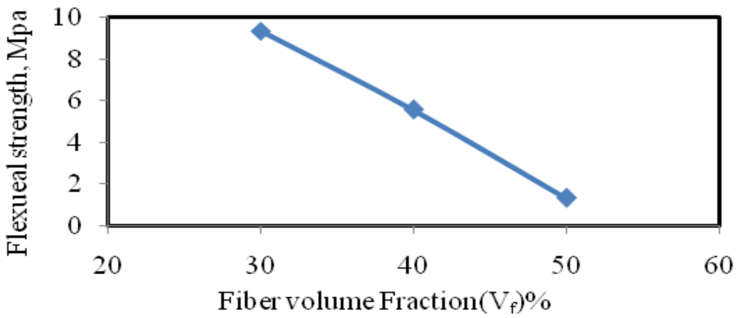

Fig: 11 Variation of flexural strength with respect to fiber volume fraction.

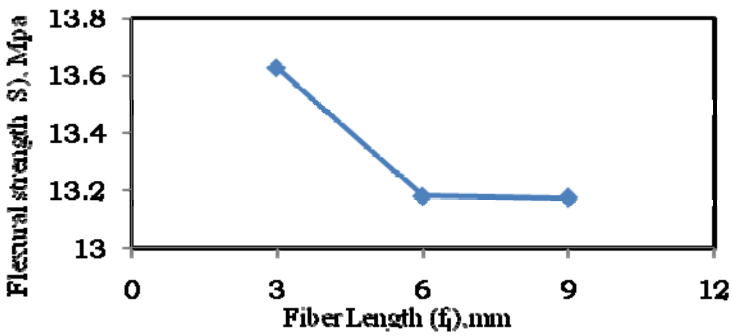

Fig:12 Variation of flexural strength with respect to fiber length.

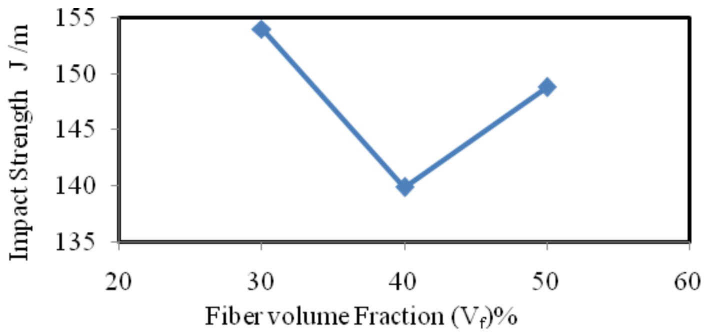

Fig: 13 Variation of impact strength with respect to fiber volume fraction.

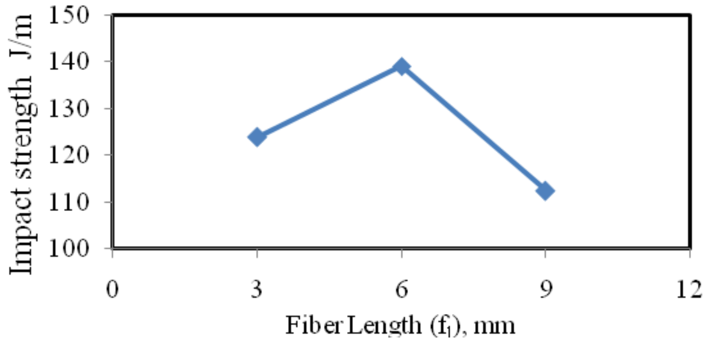

Fig: 14 Variation of impact strength with respect to fiber length.

The modeling of processing parameters for evaluating the mechanical properties of green coconut fiber reinforced HDPE composite material has been carried out by response surface methodology (RSM). The adequacy of the developed models has been varied through R^2 values. The quantity R^2 is called as coefficient of determination and is used to judge the adequacy of the model developed. The R^2 value is the variability in the data accounted by the model in percentage as

$$R^2 = 1 - \frac{SS\ Error}{SS\ total}$$

Where SSError is the sum of square error and SStotal is the sum of square total. The coefficient of determination is calculated using the above expression. In the present case, the coefficient of determination is 0.951 for tensile strength, 0.940 for flexural strength and 0.950 for impact strength, this shows high correlation exists between experimental and predicted values. Hence, RSM model can be used effectively for the prediction of mechanical properties of green coconut fiber reinforced HDPE composite material. Figures 15-17 shows comparison between experimental values and RSM predicted values of mechanical properties like Tensile strength, flexural strength and impact strength. From the graphs it is asserted that a close relationship exists between experimental values and predicted values.

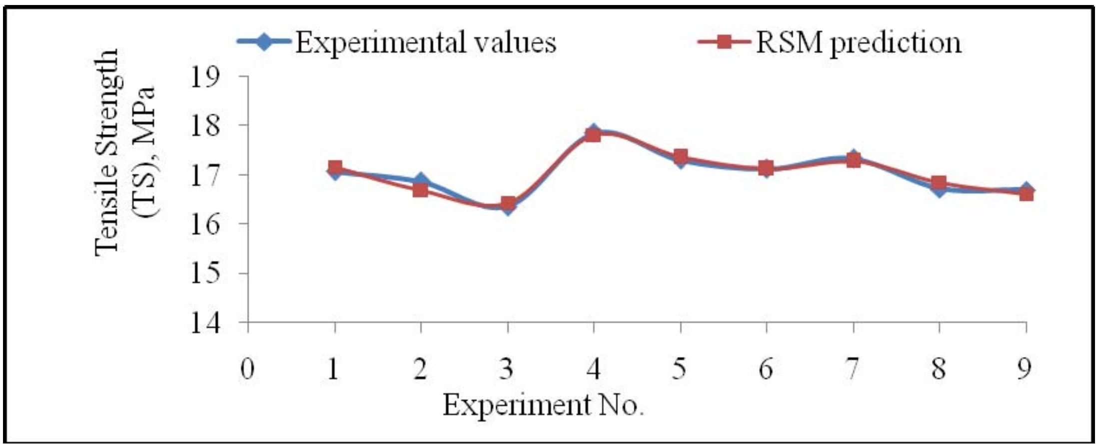

Fig: 15 Comparison of experimental values with RSM predicted values for Tensile strength (TS)

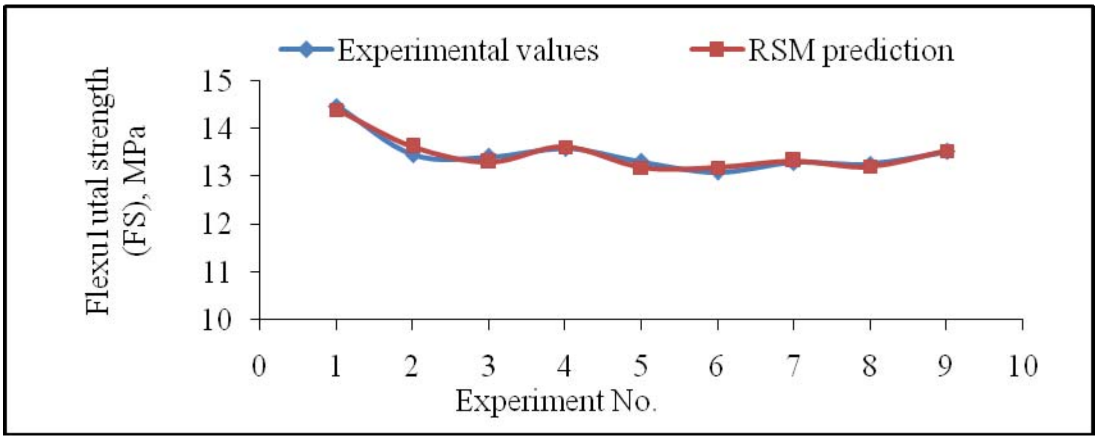

Fig: 16 Comparison of experimental values with RSM predicted values for Flexural strength (FS)

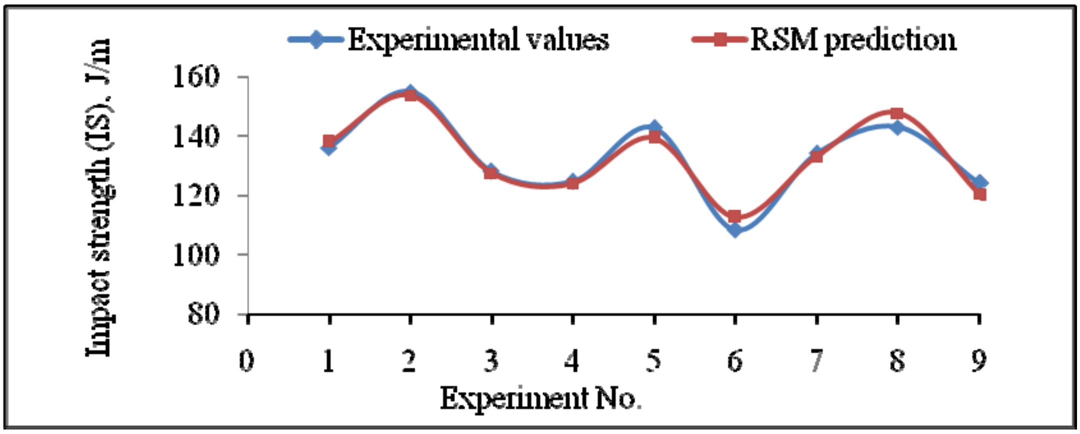

Fig: 17 Comparison of experimental values with RSM predicted values for Impact strength (IS)

CONCLUSIONS

The experimental investigation on mechanical behavior of green coconut fiber reinforced HDPE composites leads to the following conclusions:

1. Mechanical properties viz., Tensile strength (TS), Flexural strength (FS) and Impact strength (IS) of the green coconut fiber reinforced HDPE composite material is greatly influenced by fiber length as well as fiber volume fraction.
2. Tensile strength of the composite material increases with increase in fiber volume fraction (V_f) up to 40%, then after decreases slightly.
3. Tensile strength of the composite material decreases with increase in the fiber length (f_l).
4. Flexural strength of the composite material decreasing with increasing the fiber volume fraction (V_f).
5. Flexural strength of the composite material decreasing with increasing the fiber length (f_l) up to 6 mm, then after decreases slightly.
6. Impact strength of the composite material decreasing with increasing the fiber volume fraction (V_f) up to 40%. However further increase in fiber volume fraction (V_f) increases the Impact strength.
7. Impact strength of the composite material increasing with increasing the fiber length (f_l) up to 6 mm then after decreasing slightly.
8. The developed RSM models can be used to predict the mechanical properties of the green coconut fiber reinforced HDPE composite material at 95% confidence level. But the validity of the model is limited to the range of parameters considered for the investigation.
9. The accuracy of the developed model can be improved by including more number of parameters and levels.

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