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An Investigation of Mechanical Properties of Hybrid Polymer Composites

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Abstract—**Bamboo/Glass fiber reinforced polymer composites are replacing conventional metal alloys owing to their eco-friendly nature. Natural fibers as reinforcement offer number of advantages than traditional synthetic fibers. This paper aims to determine the mechanical properties namely, Tensile strength(TS), Impact strength (IS), Flexural strength (FS) and Hardness of hybrid composites reinforced with Bamboo/Glass fiber. The Treated bamboo fibers are mixed with the glass fiber in the proportion of 1:1, in order to reinforce in epoxy resin with different fiber lengths(5,10,15 mm) and fiber weight fractions of (20%,30%,40%). Experiments are planned according L_9 orthogonal array in Taguchi's design of experiments. The control parameters considered were fiber length (F_l) and percentage Fiber weight fraction (W_f). In this work 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 quadratic models are suitable for the prediction of mechanical properties of the Bamboo/glass fiber reinforced epoxy composites. The experiment result reveals that tensile strength, flexural strength and hardness were decreased with increase of fiber length but impact strength increased with increase of fiber length.**

Keywords: **Bamboo fiber, Chemical resistance, Glass fiber, Hybrid composites, Mechanical properties.**

I. Introduction

A composite is usually made up of at least two materials out of which one is the binding material, also called matrix and the other is the reinforcement material (fiber, Kevlar and whiskers). The advantage of composite materials over conventional materials are largely from their higher specific strength, stiffness and fatigue characteristics, which enables structural design to be more versatile. By definition, composite materials consist of two or more constituents with physically separable phases. However, only when the composite phase materials have notably different physical properties it is recognized as being a composite material. Composites are materials that comprise strong load carrying material (known as reinforcement) imbedded in weaker material (known as matrix).Reinforcement provides strength and rigidity, helping to support structural load. The matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. Significantly, constituents of the composites retain their individual, physical and chemical properties; yet together they produce a combination of qualities which individual constituents would be in capable of producing alone. The reinforcement may be platelets, particles or fibers and are usually added to improve mechanical properties such as stiffness, strength and toughness of the matrix material. Thermoplastics occupy only a small percentage of the advanced composite market, while other and epoxy thermoset materials contribute to more than 70 per cent. Epoxy resins the most important matrix polymer when it comes to high performance. Natural fibers such as bamboo, coir, jute, flux, sisal etc., are low density fibers available at low cost. Natural fibers are renewable and also easily biodegradable. In spite of having several merits, natural fibers show lower modulus, lower strength and poor resistance when compared with the composites reinforced with synthetic fibers such as glass, carbon and aramid. To overcome these limitations and to obtain great diversity of material properties, hybrid composites have been conceived where in two or more fibers are reinforced in a single matrix. Its combination with glass fibers gives an advanced composite with properties like low weight, good mechanical properties and tribological properties. These materials make very attractive for use in aerospace applications. A rough estimate has it that for every unit of weight reduction in aircraft, there is a considerable less considerable fuel consumption or higher load capacity and hence material offers material saving. Due to low density around 1.3g/cm^3, good adhesive and mechanical properties, epoxy resins become a promising material for in the transportation industry, usually in the form of composite materials. The performance of these composites not only depends on the selection of its components, but also on the interface between fiber and resin. Sometimes it is necessary to modify the matrix and reinforcement for specific properties. Due to low density natural fibers are widely used as reinforcing agent as it is high biodegradability. Natural fibers are largely divided into two categories depending on their origin: plant based and animal based. Therefore, natural fiber can serve as reinforcements by improving the strength and stiffness and also reducing the weight of resulting Biocomposites materials, although the properties of natural fibers vary with their source and treatments.

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Syed Altaf Hussain, V. Pandurangadu.[1] studied on Mechanical properties of green coconut fiber reinforced HDPE polymer composite (2011). Raghavendra Rao et al. [2] studied on effect of frictional and impact properties, dielectric strength, chemical resistance and SEM analysis of reinforced Bamboo/ Glass fiber Epoxy based Hybrid Composites Ashok Kumar et al. [3] studied on epoxy hybrid composites reinforced with sisal/glass fiber on frictional co-efficient, impact, hardness and chemical resistance as function of fiber length. Hence proved that, mechanical properties were optimized at 2cm fiber length. G.Venkata Reddy et al. [3] studied on epoxy hybrid composites reinforced with Kapok/glass polyester hybrid composites: tensile and hardness properties, J. Rein. Plast. Comp. 27(2008) 1775-1787.

II. Material And Methods

High performance epoxy resin LY 556 and the curing agent hardener HY 951 system were used as the matrix. Bamboo fibers were procured from Tripura state of India in the dried form. Some of these fibers were soaked in 3moles of NaOH solution for 30 min. to remove any greasy material and hemi cellulose, washed thoroughly in distilled water and dried under the sun for one week. The glass chopped strand mat was used in making the hybrid composite percentage.

Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response, Montgomery (1991). Palanikumar and Karthikeyan (2007) have developed a second order mathematical model using RSM to predict surface roughness on machining of Al/Sic particulate composite material. . In the present work, second order RSM based mathematical model of mechanical properties have been developed. 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(x1, x2, -----Xn) + ε (2)

Where ε represents noise or error observed in the response 'Y'

If we denote the expected response be E(Y) = f(x1, x2, -----Xn) $=\hat{Y}$) is called response surface. The first step is to find suitable approximation for the true functional relationship between y and set of independent variables employed usually a second order model is used in RSM.

$$\hat{Y} = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ij} x^2 + \sum_{i=1}^{n} \beta_{ij} x_i x_j + \varepsilon \qquad (3)$$

Where β_0, β_i and β_{ij} are the regression coefficients and n is the number of model parameters (i.e., process parameters). The β coefficients, used in the above model can be calculated by means of using least square method. The second-order model is normally used when the response function is not known or nonlinear.

III. Experimental Details

Composite Manufacturing

Hybrid laminates of Bamboo and glass fiber were prepared by simple hand layup technique in a wooden mold at room temperature. For making the composite, a molding box was prepared with wood as per the ASTM standards with 200 mm X 100 mm X 5 mm mould cavity. The impregnated layers were stacked one over the other in the mold and pressed up to the removal, uniform thickness was achieved by using spacers of desired thickness between the mold plates. Figure-1 shows the stacking sequence used in the laminate preparation. 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 L_9 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.

EPOXY
GLASS FIBER
EPOXY
BAMBOO FIBER
EPOXY

Figure 1 Stacking sequence in laminate

Table 1 Control Parameters and Their Levels

Fiber weight fraction(W_f) ,%	Level 1	Level 2	Level 3
	20	30	40
Fiber length(F_l), mm	5	10	15

2.3 PREPARATION OF TEST SPECIMENS

Tensile testing samples were prepared like dumbbell shapes as per the ASTM D 638-02a (165mm x 20 mm x 5mm). The specimens were tested by universal testing machine (UTM). The tension test is generally performed on flat or round specimens [3]. A uniaxial load is applied through the ends. Ultimate tensile strength is the force required to fracture a material. The tensile strength can be experimentally determined by the given formula.

$$\text{Tensile strength} = \frac{\text{Maximum tensile load applied}}{\text{Original cross section area}}$$

$$= \frac{P_{MAX}}{A}$$

The ultimate tensile strength P_{max} can be determined by the stress strain graph. The unit used for tensile strength is N/m^2.In each case 3 samples were tested and average value is recorded.

FLEXURAL TEST

Flexural strength was determined using universal testing machine equipment. The specimen are prepared as per ASTM D790-03, the test speed was maintained at 5mm/min, at a temperature 22˚C and humidity 50%. According to ASTMD 790-03 the flexural test specimen dimensions are 150mm X 20mm X 5mm. In each case 3 samples were tested and average value is recorded.

IMPACT TEST

The Impact strength of notched specimens was determined by using an impact tester according to ASTM D 256- 04(65mm x10 mm x5 mm). In each case 3 samples were tested and average value is recorded.

HARDNESS

According to ASTM D 785, the Rockwell hardness tester is used for testing hardness of the composites.

The type of indenter used is Ball indenter.

Diameter of the ball indenter=0.25inches =0.635 cm.

Maximum Load applied is 60 kgs and L-scale is used.

IV. Result and Discussion

In this work composite material is fabricated using hand layup method. The experiments were conducted as per the Taguchi's orthogonal array L_9 design of experiments. The four mechanical properties selected for this investigation is tensile strength, Impact strength, Flexural strength and hardness. The experiment results are molded using RSM and empirical model has been developed. Table 2 shows the summary of models for the three responses.

Table 2 Model summary of Mechanical properties

Measure of performance	Model expression	R^2	Adj (R^2)
Tensile strength(MPa)	145 - 2.42 W_f - 17.8 F_l + 0.100 W_f*W_f + 1.13 F_l*F_l - 0.278 W_f*F_l	98.5%	96.1%
Impact strength (KJ/m)	13.3 - 0.235 W_f - 1.57 F_l + 0.00013 W_f*W_f + 0.0473 F_l*F_l + 0.0220 W_f*F_l	94.7%	85.9%
Flexural strength(Mpa)	876 - 24.2 W_f - 74.3 F_l + 0.225 W_f*W_f + 2.40 F_l*F_l + 0.700 W_f*F_l	98.0%	94.7%
Hardness	55.8 + 1.99 W_f - 4.34 F_l - 0.0295 W_f*W_f + 0.262 F_l*F_l - 0.0315 W_f*F_l	95.2%	87.1%

Where W_f is fiber volume fraction (%) and Fl is fiber length

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-table$_{(5,3)}$).

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 3, 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 materials, viz., Tensile strength, Impact strength, Flexural strength and hardness

	Sum of squares		Degree of freedom		Mean square		
Response	Regression	Residual	Regression	Residual	Regression	Residual	F-ratio
Tensile strength	4894.99	73.13	5	3	979.00	24.38	40.16
Impact strength	7.8268	0.4376	5	3	1.5654	0.1459	10.73
Flexural strength	25519.3	518.7	5	3	5103.9	172.9	29.52
Hardnes	118.82	6.05	5	3	23.766	2.017	11.78

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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 hybrid composite can be studied by using Response graph and response table. Figure 2 shows the effect plot for tensile strength. From the graph it is inferred that, the observed tensile strength is higher at the fiber length of 5 mm than at 15 mm and 10 mm. It is also observed that tensile strength slightly increases with increase in fiber weight fraction. 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 volume fraction is the main parameter which affects the tensile strength of the composite material.

Table 4 Response table for Tensile strength

Level	Fiber weight fraction(W_f)%	Fiber length(F_l), mm
1	33.89	65.96
2	31.85	19.72
3	49.80	29085
Delta	17.95	46.23
Rank	2	1

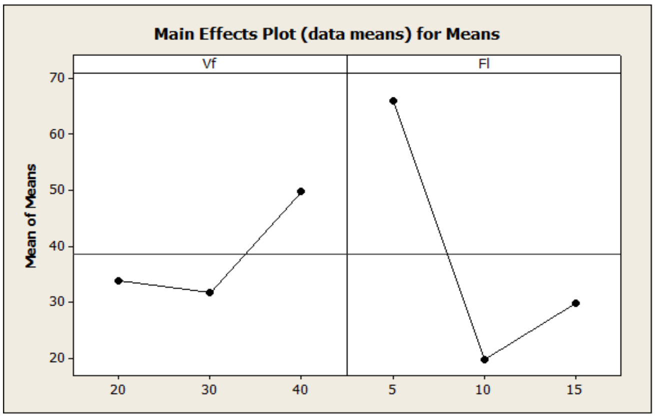

Figure: 2 Main effect plots for Tensile strength

Flexural strength

The flexural strength is a predominant property in processing of composite materials. It is more influenced by fiber length (fl) and fiber weight fraction (Wf). The influence of the amount of constituent phases on flexural strength of the bamboo/glass fiber reinforced Hybrid composites can be studied by using response Table 5 and response graph 3. From the graph it is inferred that, the observed flexural strength of the composite material is high at low fiber weight 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 weight fraction is the main parameter which affect the flexural strength of the bamboo/glass fiber reinforced Hybrid composites.

Table 5 Response table for Flexural strength

Level	Fiber weight fraction(W_f)%	Fiber length(F_l), mm
1	178.33	170.00
2	95.33	43.67
3	48.33	108.33
Delta	130.00	126.33
Rank	1	2

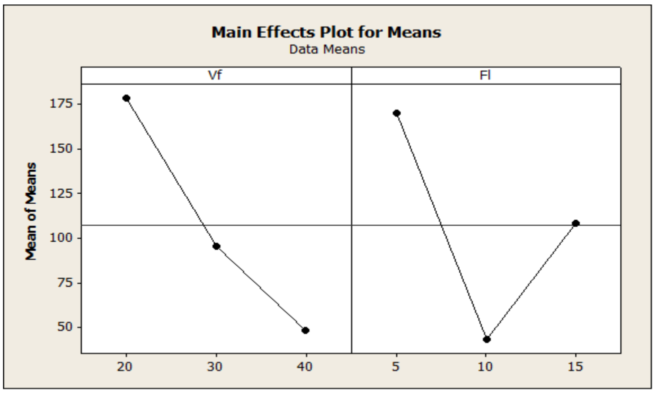

Figure 3 Main effect plot for Flexural strength

3.3 Impact strength

The impact strength is a predominant property in processing of composite materials. It is more influenced by fiber length (Fl) and fiber weight fraction (Wf). The influence of the amount of constituent phases on impact strength of the bamboo/glass fiber reinforced Hybrid composites can be studied by using response Table 6 and response Graph 4. 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 weight fraction. The experimental results indicated that the Impact strength of the composite material is higher 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 bamboo/glass fiber reinforced Hybrid composites.

Table 6 Response table for Impact strength (IS)

Level	Fiber volume fraction(W_f)%	Fiber length(F_l), mm
1	2.813	2.970
2	2.724	1.947
3	2.667	3.290
Delta	0.147	1.343

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Rank	2	1

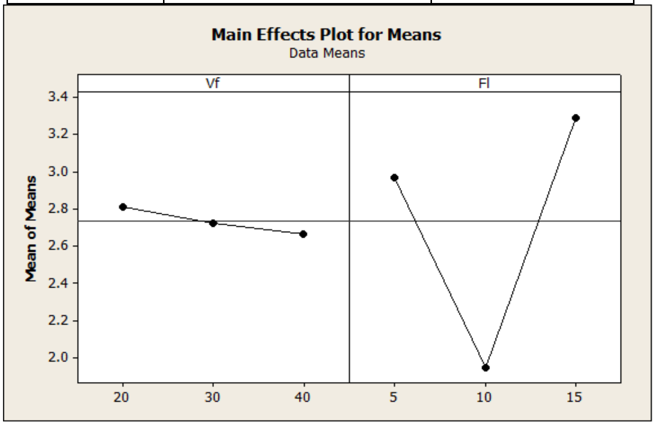

Figure 4 Main effect plots for Impact strength

Hardness

The Hardness is a predominant property in processing of composite materials. It is more influenced by fiber length (F_l) and fiber weight fraction (W_f). The influence of the amount of constituent phases on hardness of the bamboo/glass fiber reinforced Hybrid composites can be studied by using response Table 7 and response graph 5. From the graph it is inferred that, the observed hardness of the composite material is high at low fiber length as compared to high fiber length. The experimental results indicated that the hardness of the composite material is higher at lower fiber length. From the response table is asserted that the fiber length is the main parameter which affect the hardness of the bamboo/glass fiber reinforced Hybrid composites.

Table 7 Response table for Hardness (Hn)

Level	Fiber weight fraction(W_f)%	Fiber length(F_l), mm
1	2.813	2.970
2	2.724	1.947
3	2.667	3.290
Delta	0.147	1.343
Rank	2	1

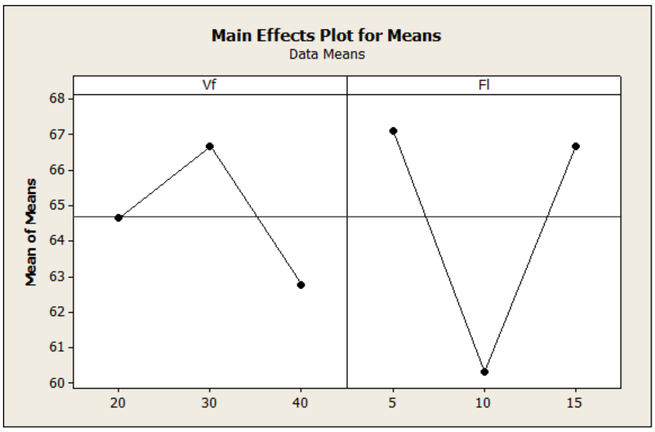

Figure: 5 Main effect plots for Hardness

For analyzing the influence of process parameters on mechanical properties of bamboo/glass fiber reinforced Hybrid composite material, Figure (6-14) shows the variation of mechanical properties like tensile strength (TS), flexural strength (FS) , impact strength (IS) and hardness with respect to the constituent phases were drawn using response surface model observed. In each graph one variable is in variation and keeping the other variable constant at the middle level. From the graph 6, it is clearly seen that tensile strength of the composite material decreases with increase in the fiber weight fraction. In the present investigation the maximum tensile strength of 78.9 Mpa was noticed for the composite material at the fiber weight fraction (Wf) of 20% and minimum tensile strength of 77.9 Mpa was noticed at fiber weight fraction of 40%. Figure 7 is a plot between tensile strength verses fiber length. From the graph it is asserted that the tensile strength of the composite material decreases with increase of fiber length (F_l) up to 10 mm. However further increase in fiber weight fraction (Wf) increases the Tensile strength value. Maximum values of tensile strength of 130.2 Mpa were noticed at a fiber length of 15 mm and minimum tensile strength of 78.4 Mpa was noticed at a fiber length of 10 mm. Figure 8 is a plot of flexural strength Vs. fiber weight fraction. From the graph it is asserted that the flexural strength of the composite material increases with increase of fiber weight fraction. In the present investigation the maximum flexural strength of 374.8 Mpa was notice for the composite material at the fiber weight fraction (Wf) of 40% and minimum flexural strength of 373.9 Mpa was noticed at fiber weight fraction (Wf) of 20%. Figure 9 the plot of variation of flexural strength with the fiber length (Fl). It is clearly seen form the graph the flexural strength of the composite material decreases with increase in fiber length. . In the present investigation the maximum flexural strength of 564.8 Mpa was notice for the composite material at the fiber length (F_l) of 5 mm and minimum flexural strength of 303.9 Mpa was noticed at fiber length (F_l) of 15 mm.

Figure 10 shows the variation of impact strength of the composite material with respect to fiber weight fraction.

From the graph it can be seen that the Impact strength is decreasing with the increase in fiber weight fraction

(Wf). In the present investigation the maximum impact strength of 2.327 K j/m was notice for fiber weight fraction (Wf) of 20% and minimum impact strength of 2.324 K j/m was noticed for fiber weight fraction (Wf) of 40%. Figure 11 shows the plot between impact strength of the composite material verses fiber length (fl). From the graph it is clearly seen that Impact strength of the composite material decreases with increase in the fiber length. In the present investigation the maximum impact strength of 6.65 K j/m was notice for fiber length (fl) of 5 mm and minimum impact strength of 0.42 K j/m was noticed for fiber length (fl) of 15 mm.

Figure 12 shows the plot between hardness of the composite material with respect to fiber weight fraction. From the graph it can be seen that the hardness of the composite material decreasing with the increase in fiber weight fraction (Wf) up to 30%. However further increase in fiber weight fraction (Wf) increases the hardness value. In the present investigation the maximum hardness value of 39.3 Mpa was notice for fiber weight fraction (Wf) of 20% and minimum hardness value of 39.1 Mpa was noticed for fiber weight fraction (Wf) of 30%. Figure 13 shows the plot between hardness of the composite material with respect to fiber length (F_l). From the graph it can be seen that the hardness of the composite material decreasing with the increase in fiber length (F_l) to 10mm. However further increase in fiber length (F_l) increases the hardness value. In the present investigation the maximum hardness value of 50.1 was notice for fiber length (fl) of 15 mm and minimum hardness value of 39.1 was noticed for fiber length (fl) of 10 mm.

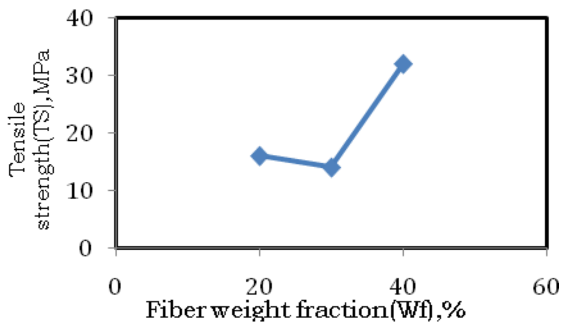

Fig: 6 Variation of tensile strength with respect to fiber weight fraction.

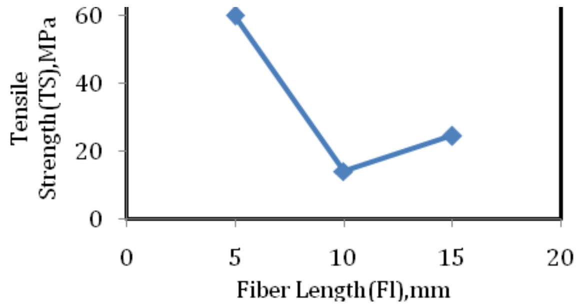

Fig: 7 Variation of tensile strength with respect to fiber length.

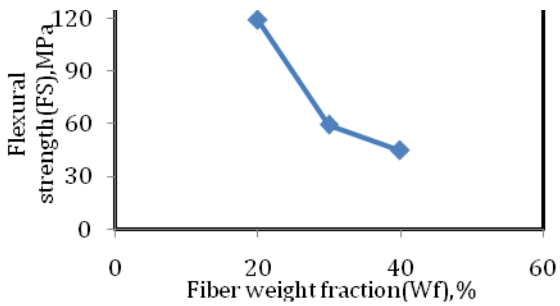

Fig: 8 Variation of flexural strength with respect to fiber weight fraction.

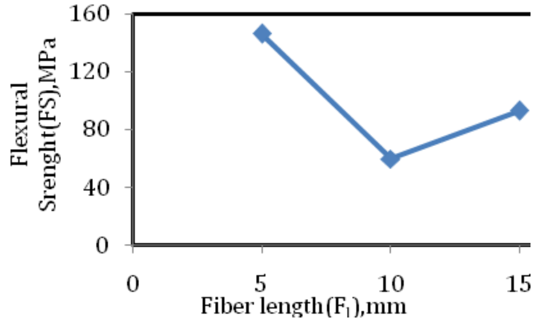

Fig:9 Variation of flexural strength with respect to fiber length.

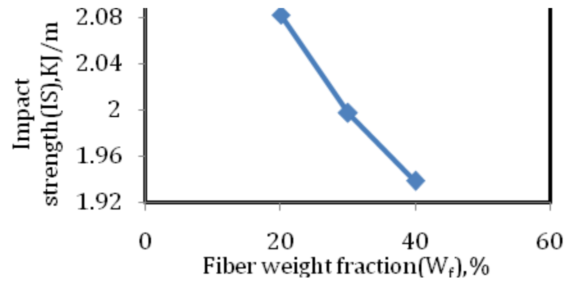

Fig: 10 Variation of impact strength with respect to fiber weight fraction.

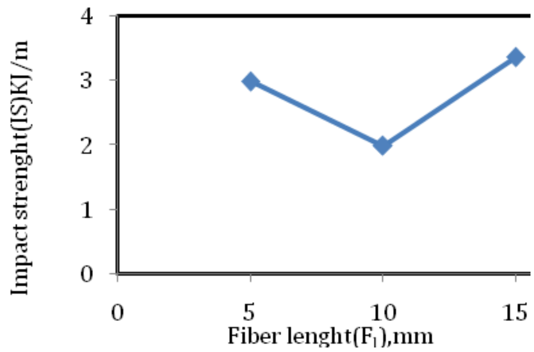

Fig: 11 Variation of impact strength with respect to fiber length.

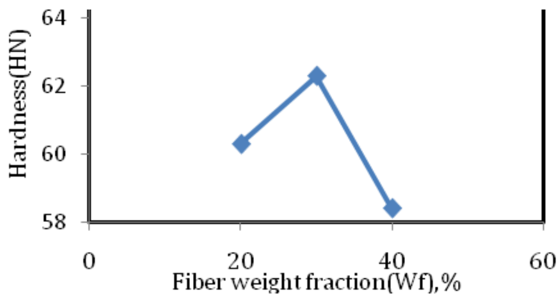

Fig: 12 Variation of hardness value with respect to fiber weight fraction.

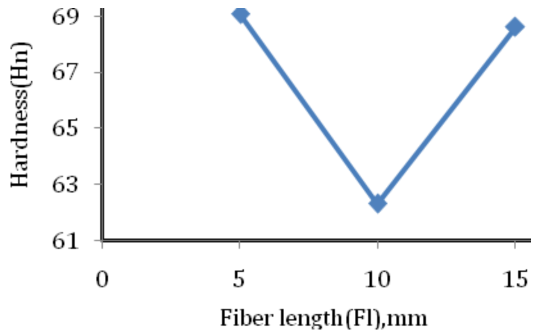

Fig: 13 Variation of hardness value with respect to fiber length

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 R2 values. The quantity R2 is called as coefficient of determination and is used to judge the adequacy of the model developed. The R2 value is the variability in the data accounted by the model in percentage as

$$R2 = 1 - \frac{SS\ Error}{SS\ total}$$

Where SS Error is the sum of square error and SS total 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

0.985 for tensile strength, 0.947 for flexural strength, 0.980 for impact strength and 0.952 for hardness, this shows high correlation exists between experimental and predicted values. Hence, RSM model can be used effectively for the prediction of mechanical properties of bamboo/glass fiber reinforced composite material. Figures 14-17 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.

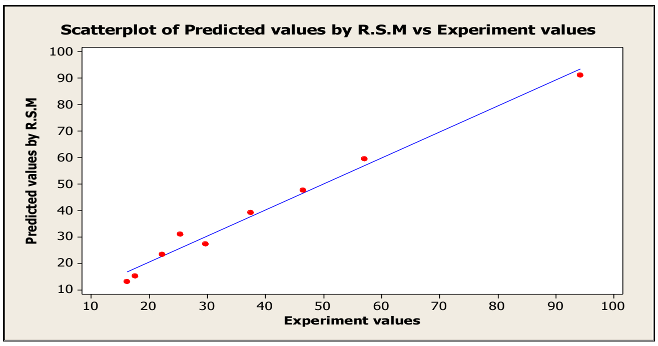

Fig: 14 Comparison between Experimental values and RSM predicted values of Tensile strength

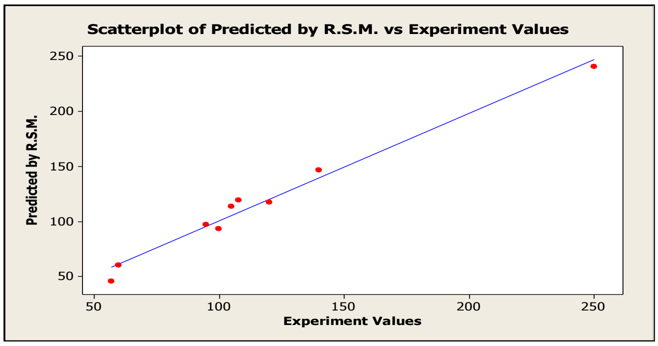

Fig: 15 Comparison between Experimental values and RSM predicted values of Impact strength

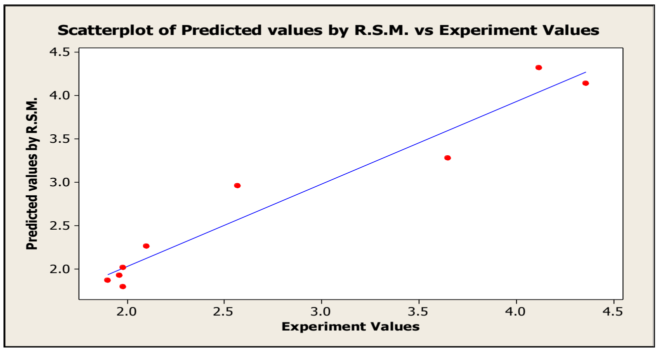

Fig: 16 Comparison between Experimental values and RSM predicted values of Flexural strength

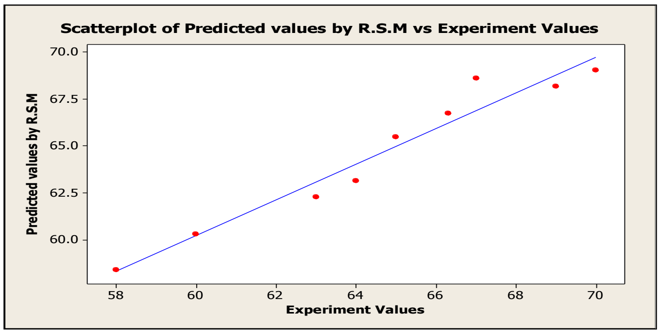

Fig: 17 Comparison between Experimental values and RSM predicted values of Hardness strength.

V. Conclusion

The hybrid composites were prepared in order to characterize the four mechanical properties viz., Tensile strength, Impact strength, Flexural strength and hardness and also an attempt is made to check the affinity of the hybrid composite towards chemical resistance. Based on the experimental results, the following conclusions are drawn within the range of parameters selected.

- Response surface methodology is found to be successful for modeling and analysis of mechanical properties of hybrid composite materials with respect to various combinations of design variables (Fiber length and Fiber volume fraction).

- Tensile strength of the hybrid composite material decreases with the increase of fiber loading fraction.
- Tensile strength of the hybrid composite material decreases with the increase of fiber length upto 10mm there after rapidly increases with increase of fiber length.
- Flexural strength of hybrid composite materials linearly increases with increase in fiber weight fraction and its value goes on decreasing with increase of fiber length 5 to 15 mm.
- Impact strength of the hybrid composite material slightly decreases with increase in weight fraction and rapidly decreases with increase of the fiber length.
- Hardness of the hybrid composite material rapidly decreases with increase of fiber weight fraction upto 30% then after increases slightly with increase in fiber weight upto 40% and the hardness of the composite slightly decreases with increase in the fiber length up 10mm, then after it increases rapidly with increase in fiber length up to 15mm.
- The developed second order response surface model can be used to predict the mechanical properties of hybrid composites within the chosen range with 95% confidence intervals. Using such models, one can obtain remarkable saving in time and cost.

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REFERENCE

i. Syed Altaf Hussain, V. Pandurangadu,"Mechanical properties of green coconut fiber reinforced HDPE polymer composite",International journal of Engineering science & Technology, vol.3,No.11, (2011)pp.7942-7952.

ii. H. Raghavendra Rao, Ashok Kumar. M,G. Ramachandra Reddy, "Hybrid composites: Effects of fibers on Mechanical properties", International journal of Macromolecular science, (2011)pp.9-14.

iii. Ashok Kumar, M., Ramachandra Reddy, G., Siva Bharathi, Y., Venkata Naidu, S. and Naga Prasad Naidu, V. (2010). Frictional Co-efficient, Hardness, Impact Strength, and Chemical Resistance of Reinforced Sisal/Glass Fiber Epoxy Hybrid Composites, *Journal of Composite Materials*, (accepted).

iv. G.Venkata Reddy, S. Venkata Naidu, T. Shobha Rani, Kapok/glass polyester hybrid composites: tensile and hardness properties, J. Rein. Plast. Comp. 27(2008) 1775-1787.

v. P.Noorunnisa Khanam, M. Mohan Reddy, K. Raghu, K. John, S. Venkata Naidu, Tensile, flexural and compressive properties of sisal/silk hybrid composites, J. Rein. Plast. Comp. 26(2007) 1065-1075.

vi. K. Raghu, P. Noorunnisa Khanam, S. Venkata Naidu, Chemical resistance studies of silk/sisal fiber reinforced unsaturated polyester-based hybrid composites, J. Rein. Plast. Comp. 27 (2008) 1-3.

vii. P.Noorunnisa Khanam, G. Ramachandra Reddy, K. Raghu, S. Venkata Naidu, Tensile, flexural, and compressive properties of coir/silk fibre-reinforced hybrid composites, J. Rein. Plast. Comp. (xx) (2009) 1-4.

viii. H.Ismail, P. Freakley, I. K.Sutherland, E. Sheng, Effect of multifunctional additives on mechanical properties of silica filled natural rubber compound, Euro. Polym. J. 11(1995) 1109-1117.

ix. L.C. Sim, C.K. Lee, S.R. Raman, H. Ismail, Cure characteristics and mechanical and thermal properties of Al2O3 and ZnO reinforced silicon rubber, Polym. Plast. Technol. Eng. 45(2006) 17.