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Effect Of Reinforcement Of Chopped Agave Sisalana Variegata/Banana Hybrid Fibers On The Mechanical Properties Of Vinyl Ester Resin

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Abstract— **Natural cellulose fibers are one of the important resources in the field of composite materials in the recent years. This paper describes the mechanical properties of chopped agave sisalana variegata/banana hybrid fiber-reinforced vinyl ester composites. Since the mechanical properties of chopped fiber composites mainly depend upon the amount of fiber content, this study deals with the determination of the optimum fiber content at which the maximum properties could be obtained. Composites were prepared for various fiber contents of 10-55wt%. The ratio of fibers in each composite specimen is 1:1. Specimens were cut from the plates as per ASTM standards and subjected to different loading. The optimum fiber content (40 wt%) required to get maximum mechanical properties was reported. The experimental results are compared with theoretical and statistical results and found to be in good agreement.**

Keywords: Polymer –matrix composite, Natural cellulose fibers, Mechanical properties.

I. Introduction

Nowadays, the use of natural cellulose fibers as reinforcing fillers for commodity polymer (thermoset and thermoplastic) matrices has received much attention because of a number of advantages such as good specific strength, high toughness, and good thermal insulation, less abrasion, minimal dermal and respiratory irritation, biodegradability, and natural abundance [1, 2]. Several investigations have been conducted on natural cellulose fibers to study the effect of these fibers on the mechanical properties of composite materials [3, 4]. In case of fiber reinforced polymer composites, the hybrid refers to use of various combinations of fibers or particulate in polymer matrices. It can be used to meet the diverse and competing design requirements in a more cost effective way than conventional composites [5] is natural fibers or man-made based synthetic fibers, incorporated. There are many reported studies on hybridization of natural fiber-natural fiber, natural fiber-synthetic fiber and synthetic fiber-synthetic fiber in a single matrix [6-10]. Sisal fibers find traditional, age-old applications in India. Sisal fibers used to fix together the coconut leaf and wooden stem while preparing the roof of a house. Sisal fibers are also used for ornamental purposes.

The main objective of our study will to be combining two or more natural cellulose fibers in such a way that a synergism between the composite materials results in a new composite material that is much better than the individual natural fiber composite material. The reasons for selection of banana and sisal fibers (Hybridization) for vinyl ester matrices are: sisal fibers are superior for impact strength [11]; banana fibers are superior for tensile and flexural strength and natural fibers can give the best results with vinyl ester resin [12, 13]. In the present study, the effect of fiber contents on the mechanical properties of agave sisalana variegata/banana hybrid fiber-reinforced vinyl ester composites. Fiber contents vary from 10-55wt% with constant fiber length of 1mm. theoretical and statistical models were used to compare the exmerimental results.

II. Experimental procedure

2.1. Materials

Agave sisalana varigata and banana fibers were used as reinforcement fillers. The matrix material used for the investigation was commercially available Vinyl ester, Trade name Satyen Polymer supplied by GVR Enterprises, Madurai, Tamilnadu and India. It was tested at Saint-Gobain Vetrotex India Ltd. Methyl ethyl ketone peroxide (MEKP) and cobalt naphthanate were used as an accelerator and catalyst.

2.2. Processing

Composites were prepared by the hand lay-up method. The fiber material was spread uniformly by manual process, and compressed by applying a load of 30 tons in a hydraulic compression machine to get a single mat of thickness about 3mm. This mat was placed in a mold of 150 x 150 x 3 mm. Vinyl ester was mixed with accelerator, catalyst and promoter were mixed and stirred at low speed until it becomes uniform and poured into the mould slowly in order to avoid air trapping and then the mould was closed. Composite with mould was cured at room temperature until it was dry. No macrovoids and macrocracks were observed in all the samples. The composites were fabricated in the form of flat sheets of thickness 3mm. The length, width and the thickness of each specimen were approximately 150 mm × 20 mm × 3 mm, respectively.

2.3 Material testing

The tensile strength of the composites was measured with a computerized FIE universal testing machine in accordance with the ASTM D638 procedure at a crosshead speed of 5 mm/min. Standard specimens were cut from the plate and tested in three point bending with a crosshead speed of 5 mm/min as per ASTM D790. Impact strength or energy observed by composites due to the impact loading for various fiber weights was studied by Izod impact testing machine according to ISO 180 standard.

III. Results and Discussion

3.1. Effect of fiber content on tensile properties

The strength of the chopped fiber composites depends on the type of fiber, matrix, fiber concentration and bonding between the fiber and matrix. Tensile strength and modulus of cured unreinforced resin was 29 MPa and 1107.89MPa. The effect of fiber content on tensile strength and modulus is shown in Fig.1.

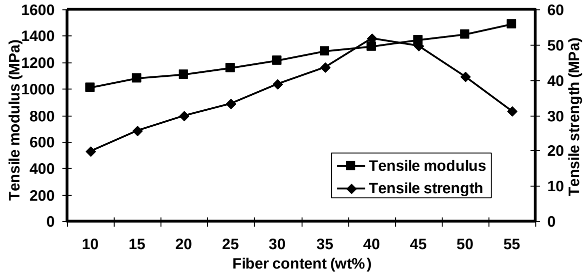


Fig.1. Effect of fiber content on tensile strength and modulus

From Fig.1 it is observed that for composites with fiber weight percentage less than critical fiber content the tensile strength and modulus is less than matrix strength and it increases as the fiber weight % in the composite increases. Critical fiber content is a fiber content below which the mechanical strength of the composite material is lower than that of the matrix itself. Composites reached the tensile strength and modulus of the cured un-reinforced resin at 20 wt% and 20wt%. The tensile strength of the vinyl ester resin increases with fiber content. The 40wt% composite exhibited the maximum tensile strength of 51.7Mpa. On a low weight percentage of fiber content, the matrix controls the strength of the composites and is less than the matrix strength. It could be attributed to the fact that the increase of the fiber content above a certain limit leads to the poor wetting of the fiber by resin and hence the mechanical properties decrease. At high levels of fiber content, the increased population of fibers leads to agglomeration, and stress transfer gets blocked which leads to decrease in mechanical properties. According to Carlo Santulli [13], the mechanical properties of composites are decreased while a larger volume of plant fibers is introduced. The tensile modulus increased linearly from 10 wt% to 50 wt%. The 55wt% composite exhibited a maximum tensile modulus 1488.4Mpa. Fig.2 shows the fractured surface of the composites specimens.

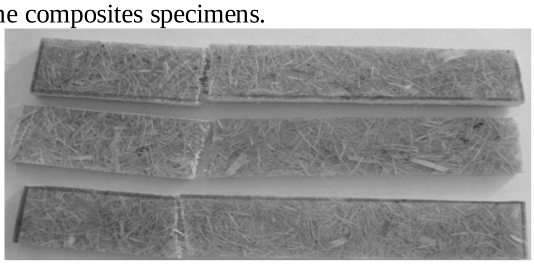


Fig. 2. Digital image of fractured composite specimens after the tensile test

3.2. Effect of fiber content on Flexural and Impact properties

Flexural strength of the cured vinyl ester resin increases with fiber content as shown in Fig.3. Composites also reached the flexural strength and modulus of the cured un-reinforced resin at 20wt% and 20wt%. The maximum flexural strength was obtained in the composites having fiber content of 40wt%. The percentage of improvement was 51.07% when compared with unreinforeced neat resin composite. The flexural modulus also increased linearly up to 55 wt%. The 55wt% fiber composite shows a maximum flexural modulus of 1528.4 MPa. Matrix failure, fiber breakage and fiber matrices de-bonding are some of the failure modes observed during the flexural test. Fig. 4 shows the fractured image of the composite during the flexural test.

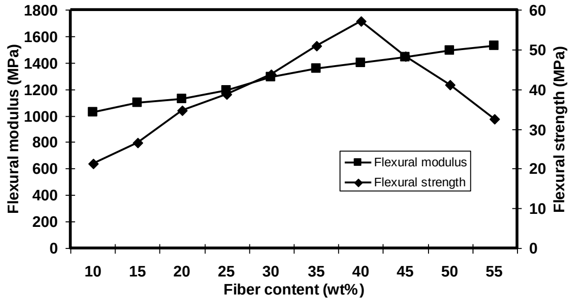


Fig. 3. Effect of fiber content on flexural strength and modulus

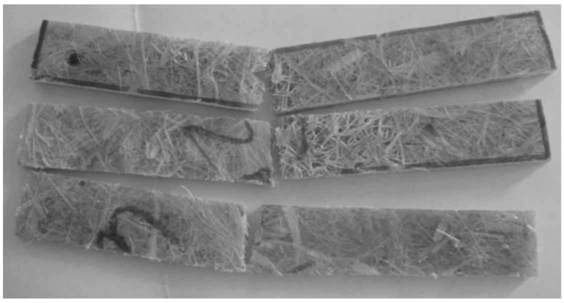


Fig.4. Digital image of fractured composite specimens after the flexural test

Impact strength of the cured polyester resin increases with roselle fiber contents. Composites reached the impact strength of the cured unreinforced resin at 15 wt%. The maximum impact strength value was observed in 35wt% fiber composite. Increasing in impact strength with the fiber content was observed up to 35%, above 35% which decreased as shown in Fig.5. It could be attributed to the fact that the increase of the fiber content above certain limit leads to the poor wetting of the fiber by resin which results in loss of the mechanical properties. Fig.6 shows the fractured surface of the composite specimen during impact test.

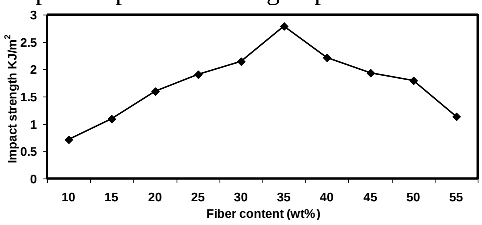


Fig.5. Effect of fiber content on impact strength

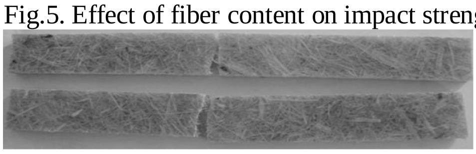


Fig.6. Digital image of fractured composite specimens after the impact test

3.3. Theoretical and statistical prediction of mechanical properties

3.3.1. Hirsch and Series models

Several theoretical models have been proposed to predict the tensile properties of composite material in terms of different parameters [1, 13]. The strength of the composites is obtained theoretically and compared with experimental results. Hirsch and Series models are most important models, which are useful in determining the tensile properties. The strength is calculated from these models and the results thus obtained are compared with the experimental values and are shown in Fig. 7 for various fiber contents. For the present study the value of X is taken as 0.51 which gives close results to the experimental values. From Fig. 7, it is observed that as the wt% of fiber increased, the tensile strength of the composites increased. When the wt% of fibers was 10wt%, 30wt% and 20wt%, the tensile strength of the composite followed Hirsch and Series models.

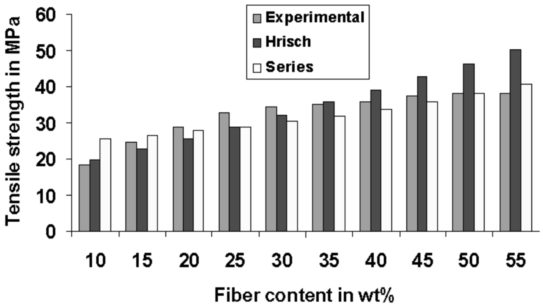


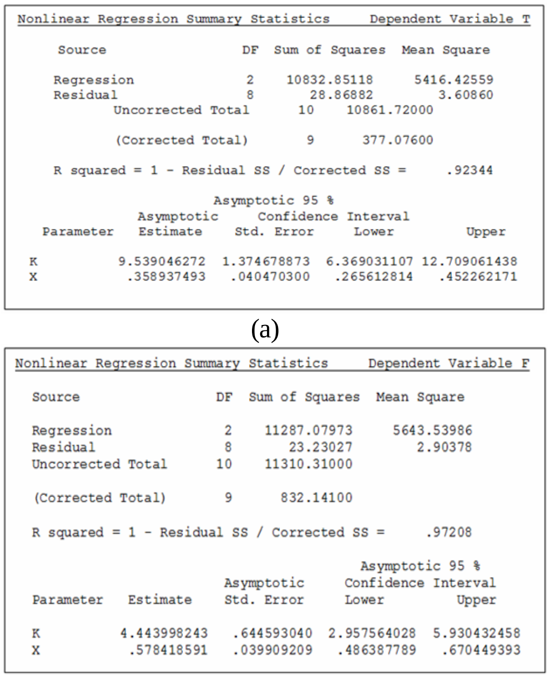
Fig. 7. Variation of tensile strength for Hirsch and Series models

3.3.2. Non-linear regression model

In this work, the positive effect is obtained in tensile and flexural strength properties. So, as an attempt, a non-linear regression model has been implemented to get the relation between tensile and flexural strength properties and fiber content. Regression equation and their squared residual values (R2) for tensile and flexural strength for all the three conditions were developed as given in Table 1. Fig. 8 shows the non-linear summary statistics obtained from SPSS software for tensile and flexural strength. The comparison of experimental and predicted tensile and flexural strength values is shown in Fig. 9(a) and 9(b). It is observed that as the wt% of roselle fibers is increased, there is agreement with the Regression model in the case of tensile and flexural strength. While considering the squared residual (R2) and average absolute error values, the regression model is found to be in agreement with experimental results.

Table 1. Regression equations and their corresponding R2 values of tensile and flexural strength.

Condition	Tensile strength (σ_t)	squared residual values (R^2)	Flexural strength (σ_b)	squared residual values (R^2)
Experimental	$9.54 x C^{0.36}$	0.92	$4.44 x C^{0.58}$	0.97


Nonlinear Regression Summary Statistics   Dependent Variable T

Source	DF	Sum of Squares	Mean Square
Regression	2	10832.85118	5416.42559
Residual	8	28.86882	3.60860
Uncorrected Total	10	10861.72000	
(Corrected Total)	9	377.07600	

R squared = 1 - Residual SS / Corrected SS = .92344

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
K	9.539046272	1.374678873	6.369031107	12.709061438
X	.358937493	.040470300	.265612814	.452262171

(a)

Nonlinear Regression Summary Statistics   Dependent Variable F

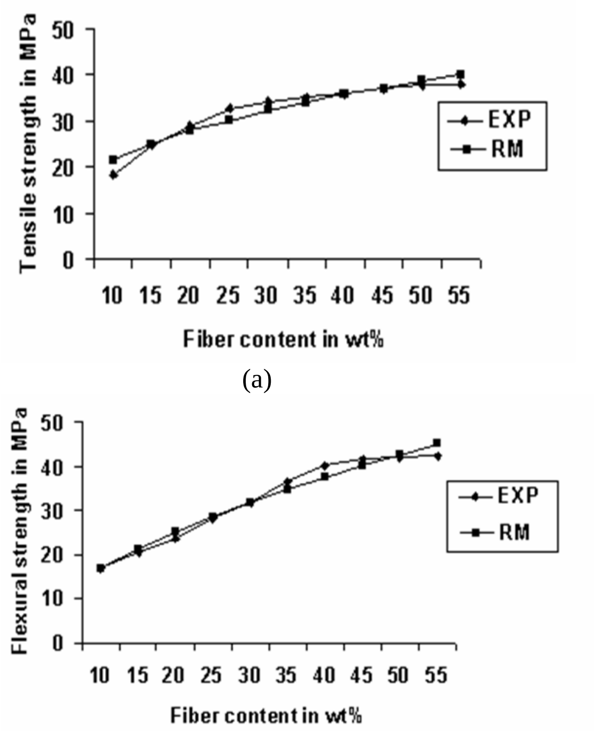
Source	DF	Sum of Squares	Mean Square
Regression	2	11287.07973	5643.53986
Residual	8	23.23027	2.90378
Uncorrected Total	10	11310.31000	
(Corrected Total)	9	832.14100	

R squared = 1 - Residual SS / Corrected SS = .97208

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
K	4.443998243	.644593040	2.957564028	5.930432458
X	.578418591	.039909209	.486387789	.670449393

(b)

Fig.8. Non-linear summary statistics obtained from SPSS software for (a) tensile strength, and (b) flexural strength



(b)

Fig.9. Comparison of experimental and predicted (a) tensile strength and (b) flexural strength values

IV. Conclusion

The mechanical properties of the chopped agave sisalan variegata/banana hybrid fiber composites were studied. Tensile and flexural strength of the chopped composites increased with fiber content. The tensile and flexural strength values showed an increase up to 40wt% and above that decreased. Tensile and flexural modulus increased up to 55 wt%. The 40 wt% fiber composite shows maximum tensile and flexural strength of 51.7Mpa and 57.6 MPa respectively.

The maximum impact strength was observed with the composites having the fiber content of 40wt%. These results suggest that the optimum fiber content to obtain the maximum strength properties is 40wt%. Theoretical and statistical model values were in good agreement when compared with experimental values.

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