INVESTIGATIONS INTO TENSILE STRENGTH OF JUTE FIBER REINFORCED HYBRID POLYMER MATRIX COMPOSITES

P. Prabaharan Grcaeraj* – G. Venkatachalam

School of Mechanical and Building Sciences, VIT University, Vellore, India

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Abstract:

Nowadays several industrial applications require biodegradable or environment friendly materials in place of existing materials in use without any compromise on their properties or their improved performance. Natural fiber reinforced polymer resin composites are biodegradable composites as they are using fibers from renewable sources. Biodegradation of the above composites can further be improved by adding natural resin with synthetic polymer resin. The experimental research work has been carried out using composite of Polyester (Synthetic Resin) – cashew nut shell liquid (CNSL) resin (natural resin) with jute fiber as reinforcement. Tensile test was performed on specimens made of composites with various proportion of CNSL and polyester resin and jute fiber reinforcement with different alkali treatment, fiber length and fiber volume. Influence of the above factors on tensile strength was analyzed and the best combinations of factors are suggested for composite processing.

1 Introduction

As composites with fiber reinforcements have high stiffness and specific strength, they are preferred in various industrial and engineering applications [1]. These composites of polymer base, use thermo set or thermo plastics as matrix and natural or synthetic fiber as fillers [2] and behave as soft as matrix material and stiff and strong like fibrous reinforcement used [3]. As the requirement for environment friendly materials is growing, the research is being accelerated to develop green composite materials. These materials are cheap, renewable, completely or partially recyclable and biodegradable. Recent research in polymer composite focuses on the use of natural fiber reinforcement in synthetic resin matrix for green and environment friendly products [4-7]. Natural fiber is the material which was derived from plants, animal and mineral sources. Some of the natural fibers used in composites as reinforcement are jute, flax, cotton, hemp, ramie, kenaf, bamboo etc. The natural fiber containing composites are more environment friendly, and are used in industrial applications such as automobiles, railway coaches, aerospace, military applications, building and construction industries, packaging, consumer products etc. [8]. The literature study carried out on the matrix compound used in polymer composites revealed that polyethylene or other natural resins based composites are lagging in stiffness, flexural strength and a reduction of ductility. In order to achieve the desired mechanical properties, it requires intensive treatment of fibers, fiber compounding, fiber processing and

* Corresponding author. Tel: +918762358005
E mail addres: p_graceraj@yahoo.com

classification [9]. Hence this research was carried out on composite specimen made of polyester resin with mixture of cashew nut shell liquid (CNSL) as matrix base and jute fiber as reinforcement element.

2 Experimental procedure

2.1 Matrix material

Generally, two types of polymer matrix, namely thermosetting and thermo plastics are used in polymer composites. Polyester resin was chosen for experimentation as it is cost competitive and its tensile strength is about 50000~55000 KN/m^2 [10]. The matrix material was prepared with the mixture of polyester resin and cashew nut shell liquid (CNSL) in various proportions. The CNSL resin was chosen to enhance the biodegradation and recycling of composite specimen. As the increase in CNSL resin increases plasticity of the material, the best proportion of 5, 10, and 15% was chosen to mix with polyester resin and catalyst to prepare the resin matrix for the experimentation.

2.2 Reinforcement material

Fibers, used in composite, will increase the stiffness and strength. As the jute is abundantly available natural fiber and shows good tensile strength ranging from 20000~25000 KN/m^2, it was chosen as reinforcement material [11]. Jute fiber weighing 0.063 g was chosen as a standard fiber and the fiber parameters like alkali treatment of fiber, duration of treatment, weight of fiber used and continuity of the fibers are considered for the analysis of the effect of parameters exhibited on tensile strength.

2.3 Experimental design

The parameters of reinforcement fiber are the major influential factors in determining the tensile strength of the composite. Similarly, the recycling capability of composites rests predominantly on the percentage of concentrations of CNSL in resin matrix. Hence, the experiment was planned to be conducted with various values of fiber and resin parameters. The details of the fiber and the resin parameters and their values are given in Table1.

Table 1. Details of fiber and resin used for specimen preparation

a) Classification of reinforcement fiber factors			
Reinforcement parameter	Parameter values		
Fiber weight in (g)	0.126	0.252	0.378
Fiber continuity	Continuous	One discontinuity	Two discontinuities
Fiber alkali treatment solution concentration	5% NaOH solution	10% NaOH solution	15% NaOH solution
Fiber alkali treatment duration at room temperature (Hrs)	6	12	24
b) Classification of matrix resin factors			
Matrix resin parameter	Parameter values		
% of concentration of CNSL in Polyester resin	5	10	15

2.3.1 Taguchi design of experiment

Five factors of matrix and reinforcement and three values of each factor were considered for the preparation of composite specimen. In order to minimize the number of samples to be prepared or number of runs of experiments to conduct, it was decided to proceed for statistical approach in experiment design. Among the available methods of experiment design by statistical methods, Taguchi's design of experiment (DOE) method is the most powerful as it is being used in various fields like new product development, process optimization and quality control. Philosophy of Taguchi's approach is based on the quality lose function. Quality is best achieved by minimizing the deviation from a target. The product should be designed so that uncontrollable environmental factors should have minimal impact on the product performance or on its characteristics. In other words, the signal (product quality) to noise (uncontrollable factors) ratio should be high. Design of experiment (DOE) procedure according to Taguchi is as follows [12]:

1) Define the Product / Process objective.
2) Determination of the design parameters affecting the product characteristics.
3) Selection of response variables & control parameters and their levels.
4) Selection of the orthogonal array.
5) Conducting the matrix experiments.
6) Analysis of the data and prediction of optimum level.

2.3.1.1 Definition of the problem and identification of noise factors

Objective of DOE was to analyze the influence of natural resin and fiber parameters on the tensile strength of hybrid polymer matrix composites made of natural fiber.

2.3.1.2 Determination of the influence of design parameters on product characteristics

The product characteristics are mainly affected by constituent material variants and proportions. Hence, various parameters related to resin and fiber were considered as design parameters that influence the properties of composite material.

2.3.1.3 Selection of response variables & control parameters and their levels

Response variable is the parameter which gives the performance of the product or process. Hence, the tensile strength was chosen as a response variable for the investigation. Control parameters are the variables which influence the output of the process or the product. Based on literature survey, reinforcement and matrix factors listed in Table 2 were chosen as control parameter and its values were chosen as their levels.

2.3.1.4 Selection of the orthogonal array

In the present investigation, five factors of matrix and reinforcement and three values of each parameter were considered as the influential parameters for the response variables. Hence, a L27 orthogonal array as shown in Table 2 was used for experimentation.

2.4 Specimen preparation and testing

Specimens were prepared for the various parameter values of hybrid matrix resin and natural fiber listed in Table 2. The matrix of polyester resin with CNSL resin and catalyst as ingredients were poured in the mold where reinforcement fiber was woven as shown in Fig. 1. The molded specimen was allowed to cure at room temperature. The specimen was ejected from the mould and prepared as per ASTM D3039. Fig. 1 shows various stages of the composite specimen preparation process like resin preparation, weaving of reinforcement fiber, molding and curing the specimen.

Figure 1. Various stages of the composite specimen preparation process.

The tensile test was carried out in accordance with ASTM D 638. The apparatus used for testing was the universal testing machine (UTM) of constant rate of grip separation type consisting of fixed member, movable member, grips, drive mechanism, load and extension indicators and plotters. As the specimen is polymer composite, speed of selected testing was 5 mm /min and nominal strain rate of selected testing was 0.1 mm/mm-min. Thickness and width of the specimen was measured with a micrometer and fed in the UTM. Gage length of 50 mm was marked in all specimens and was loadedin the UTM as shown in Fig. 2. The extension at break, percentage of elongation, modulus of elasticity and tensile strength were recorded for all the specimens that broke between gage marks.

Table 2. L27 Orthogonal array for DOE

Specimen No.	Concentration of CNSL in Polyester resin (%)	Fiber weight (g)	Fiber continuity	Fiber alkali treatment solution concentration (% of NaOH)	Fiber alkali treatment duration in room temperature (Hrs)
1	5	0.126	2 Discontinuity	5	6
2	5	0.126	2 Discontinuity	5	12
3	5	0.126	2 Discontinuity	5	24
4	5	0.252	1 Discontinuity	10	6
5	5	0.252	1 Discontinuity	10	12
6	5	0.252	1 Discontinuity	10	24
7	5	0.378	No Discontinuity	15	6
8	5	0.378	No Discontinuity	15	12
9	5	0.378	No Discontinuity	15	24
10	10	0.126	1 Discontinuity	15	6
11	10	0.126	1 Discontinuity	15	12
12	10	0.126	1 Discontinuity	15	24
13	10	0.252	No Discontinuity	5	6
14	10	0.252	No Discontinuity	5	12
15	10	0.252	No Discontinuity	5	24
16	10	0.378	2 Discontinuity	10	6
17	10	0.378	2 Discontinuity	10	12
18	10	0.378	2 Discontinuity	10	24
19	15	0.126	No Discontinuity	10	6
20	15	0.126	No Discontinuity	10	12
21	15	0.126	No Discontinuity	10	24
22	15	0.252	2 Discontinuity	15	6
23	15	0.252	2 Discontinuity	15	12
24	15	0.252	2 Discontinuity	15	24
25	15	0.378	1 Discontinuity	5	6
26	15	0.378	1 Discontinuity	5	12
27	15	0.378	1 Discontinuity	5	24

Figure 2. Tensile test at UTM.

3 Results and discussions

3.1 Evaluation of tensile strength of the composite specimen

Table 3 provides the tensile test results obtained from the experiment conducted on 27 composite specimens which were prepared based on the parameters values of L27 orthogonal array. It was found from the result that various factors of resin and fiber exhibited a significant influence on tensile strength of the specimen. The engineering stress-strain diagrams of the all 27 specimens tested is shown in Fig. 3.

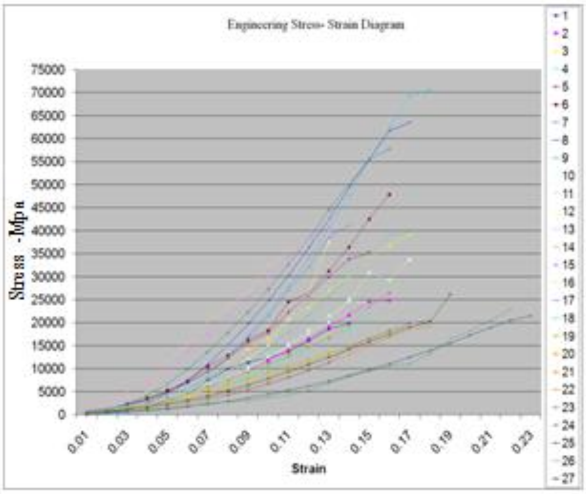

Figure 3. Engineering stress – strain diagram of specimens tested.

3.2 Influence of various factors of resin and fiber on tensile strength

In order to evaluate the influence of various factors on tensile strength, an analysis was conducted on Minitab 15 software based on Taguchi's design. The factors influencing the tensile strength were given as input and the larger function was chosen for analyzing the data. The Signal to Noise (S/N) ratio was calculated as given in Eq. (1):

$$S/N \text{ ratio} = -10*\text{Log10}\,(\text{sum}(1/Y**2)/n). \quad (1)$$

The effects of influence of various factors on tensile strength are plotted with Minitab software and given in Fig. 4. It is evident from the graph that percentage of CNSL on strength was above the mean strength for 5% and 10% and it is substantially low in the case of 15% mixture of CNSL in polyester resin. The fiber weight of 0.378 g yields a good mean strength compared to 0.126g and 0.252 g of fiber weight.

Table 3. Tensile test results

Sample No.	1	2	3	4	5	6	7	8	9
Tensile strength @ peak load- KN/m^2	19861	24940	39365	21706	35263	47928	57809	63590	70662
% of Elongation @ peak load	13.44	15.22	16.82	14.86	14.48	14.34	15.76	16.84	12.86
Young's Modulus - Mpa	148	164	234	146	244	334	367	378	549

Sample No.	10	11	12	13	14	15	16	17	18
Tensile strength @ peak load- KN/m^2	23924	33636	37636	23472	42411	40000	35827	41223	39606
% of Elongation @ peak load	14.5	21.9	11.82	14.12	13.04	13.4	10.9	12.88	16.1
Young's Modulus - Mpa	165	154	318	166	325	299	329	320	246

Sample No	19	20	21	22	23	24	25	26	27
Tensile strength @ peak load- KN/m^2	17142	17004	19355	19240	22160	26496	21471	22901	26209
% of Elongation @ peak load	15.4	14.14	16.48	17.38	18.28	13.62	22.6	21.72	17.76
Young's Modulus - Mpa	111	120	117	111	121	195	95	105	148

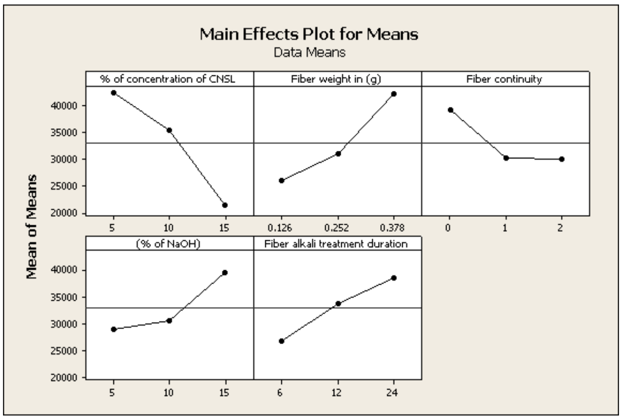

Figure 4. Effects of various factors on tensile strength of the composites.

Similarly, continues fiber with 15% concentration NaOH treatment and 12 hrs/24 hrs of treatment duration showed a good strength over the other parameter values.

3.3 Combined effects of factors on tensile strength in combination with cnsL concentration

As the contribution of green components to the composite strength is the interest of this study, an analysis was done to study the influence of fiber factors combined with the percentage of concentration of CNSL on the strength of the composites. The results of interaction of various fiber factors combined CNSL concentration on tensile strength (denoted as C6 in graphs) revealed the following inferences as shown in the counter plots in Fig. 5.

1) The higher the tensile strength when fiber weighs more, the lesser concentration of CNSL is required in matrix composition. It can also be noted from the contour plot that higher strength is achievable above the weight of 0.3 g and up to 10% concentration of CNSL in composite matrix.
2) The higher the tensile strength with the less number of discontinuities, the lesser concentration of CNSL in matrix composition. The high strength band is moderate as the case (i).
3) The contour plot between percentage NaOH treatment with CNSL concentration on tensile strength depicts that the higher the strength with higher concentration of NaOH, the lower the CNSL percentage. This could be achieved with a moderate range of both NaOH and CNSL concentration.
4) The contour plot of the effect of NaOH treatment duration and CNSL concentration on tensile strength displays that higher strength can be achieved with wider range of duration of treatment, i.e., from 10 to 24 hours of alkali treatment.

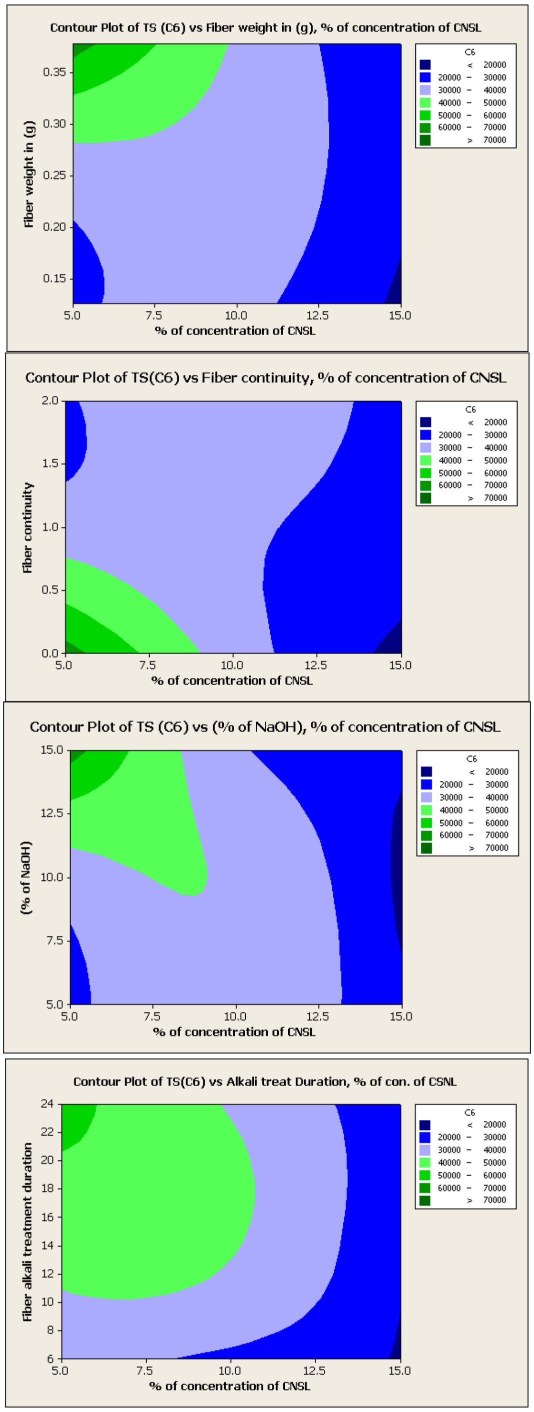

Figure 5. Contour Plots showing effects of various factors on tensile strength of the composites

4 Conclusions

The use of polymer composites, with natural and synthetic resin, is of great interest in view of reduction in the use of petroleum-based or nonrenewable resources of environmental concerns. These “green” composites can find several industrial applications, with limitations of less ductility, process ability and dimensional stability. This limitation can be reduced and material properties can be enhanced with the suitable parameter values of reinforcement and matrix components. In this research work it is experimentally and statistically proven that various parameters of reinforcement and polymer matrix like percentage of CNSL mixture in matrix, fiber weight, fiber continuity and alkali treatment of fibers have considerable influence on the tensile strength of the composite material. The experimental results also show that these composite materials with suitable fiber and matrix composition can be used in various industrial applications in place of plastics and metallic parts.

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