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OPTIMIZATION OF AXIAL LOAD CHARACTERISTICS OF RAMIE – EPOXY COMPOSITES USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Lignocellulose fiber has recently become attractive to researches, engineers and scientists as an alternative reinforcement for Fiber reinforced polymer (FRP) composites. Due to low production cost, fairly better mechanical properties, they are exploited as a replacement for the conventional synthetic fiber, such as glass, aramid and carbon. The use of natural fibers reinforced polymer (NFRP) composites in automobile industries and domestic application stands as an evidence for remarkable development in NFRP composites. The impregnation of bio particles in composites has improvement in the mechanical properties, which extended the use of NFRP composites as engineering materials. The present paper comprises of fabrication of Ramie – epoxy polymer composites, followed by the analysis of its axial load properties like tensile strength, and compressive strength. Also to compare the properties of composite samples on the basis of different length of the fiber and fiber weight fraction. By using Response Surface Methodology (RSM) to obtain the optimum fibre length and fibre weight percentage for the best axial load characteristics. Regression equations are also generated to predict the best axial load characteristics at intermediate fiber length and fiber weight fraction.

Keywords*— Ramie, Epoxy, Axial load properties, Response Surface Methodology (RSM)*

1. Introduction

There is a growing need to develop bio based products. Bio based products can form the basis for sustainable and environmentally friendly materials [1]. A composite can be defined as the material created when two or more dissimilar components are combined to get a system with more useful, structural and functional properties [2]. The objective of using the composite material is for its high strength to weight ratio And to meet the applications with predefined properties many composite materials comprised just two Phases; one termed the "matrix", which is spread throughout and surrounds the other phase, often referred as the "reinforcement" [3]. The properties of composites are mostly dependent on the type of reinforcement, their ratios, orientation, and the geometry of the reinforcement [4]. There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, and polymer) and the second is based on the reinforcement material structure [5].

For making composite of reinforcement polymer, the use of natural fibers; it includes those produced by plants animals, and geological process [6]. Now there is much interest in natural fiber-reinforced polymer composite materials because of their industrial applications and fundamental research [7]. These are renewable, cheap, completely or partially recyclable, and biodegradable. Plants, such as flax, cotton, hemp, jute, sisal, pineapple, ramie, bamboo, banana, etc., are used as a source of lingo cellulosic fibers, and are more and more often applied as the reinforcement of composites [8]. Even though most of the research has been carried out on ramie-Epoxy composites, there is a possibility to find the optimum value of mechanical properties using optimization methods in order to suggest suitable applications and corresponding values of fabrication parameters while manufacturing the products using ramie-epoxy composites

2. EXPERIMENTAL WORK

2.1 Ramie fiber

Ramie is a flowering plant; native to eastern Asias. Ramie is one of the strongest natural fibers and it

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exhibits even greater strength when wet. Ramie fiber is known especially for its ability to hold Shape, reduce wrinkling. Because of its high molecular crystallinity, ramie is stiff and brittle and will break if folded repeatedly in the same place. Despite its strength, ramie has had limited acceptance for textile use.

The fiber's extraction and cleaning are expensive, chiefly because of serval steps involving scraping, pounding, heating, washing, or exposure to chemicals. Ramie is used to make such products as industrial sewing thread, packing materials, fishing nets and filter cloth. It is a lengthy fiber because of it has good tensile and stiffness. Its property can improve by chemical treatment. Table 1shows Properties of ramie fiber.

Table 1.Properties and chemical composition of ramie fiber

Properties and chemical composition	Ramie fiber
Density (g/cm^3)	1.5
Elongation (%)	2.0 – 3.8
Tensile strength (MPa)	220-550
Young's modulus (GPa)	44 - 120
Cellulose (%)	68.6 – 76.2
HemiCellulose (%)	13.1-16.7

2.2 Epoxy resin

Thermoset resins are usually liquids or low melting point solids in their initial form. By its three-dimensional cross-linked structure, they have high thermal stability, chemical resistance, good dimensional stability and also high creep properties. The most common thermosetting resins used for composite manufacturing are unsaturated polyesters, epoxies and vinyl esters. The epoxy matrix comprises three member bond having two carbon atoms and one oxygen atom in its chemical structure. The epoxy resins lend high strength, durability and better chemical stability to composite system. Epoxy is a copolymer and is formed from two different chemicals namely, resin and the hardener. The resin consists of monomers of short chain polymers with an epoxide group at either ends. Most common epoxy resins are resultant products of chemical reaction between epichlorohydrin and biphenyl-A, though the latter may be replaced by similar chemicals. Each NH group reacts with an epoxide group from distinct prepolymer molecules, so that the resulting polymer is duly cross linked and therefore rendering rigid and strong structure. The process of polymerization is called curing and can be controlled by temperature, choice of resin and hardener compounds. The hardener comprises polyamine monomers, for example triethylenetetramine. When these compounds are mixed together, the amine groups react with the epoxide groups to form a covalent bond.

2.3 Fabrication parameters

Fiber length (mm) and fiber content (%) are the fabrication parameters of this present investigation. Both fiber length (mm) and fiber weight percentage were varied in four levels. Natural Fiber composites are stronger along the direction of fiber orientation and comparatively weaker in the perpendicular direction of fiber orientation. Randomly oriented natural fiber composite material act as an isotropic material. Force on Fiber is minimum at the end and maximum at the middle. To achieve effective strength and stiffness, length of fiber should be larger than critical length .

2.4 Composite fabrication

2.4.1 Compression molding

The Compression molding procedure for required Composite fabrication, are given below, by this method we can able to get required dimension composite plates. A compression molding machine was used for composite fabrication.

A stainless-steel mold having size of 300 mm×300 mm×3 mm was used for composite fabrication in compression molding process. The operating pressure of 2.6 MPa and temperature of 60°C was maintained for 1 hour for uniform curing of composite sheets. The mold is held between the heated platens at a temp around 80°C of the hydraulic press.

A prepared quantity of ramie fiber & epoxy matrix compound is placed in the mould, usually by hand, and the mould placed in the press at a pressure range of 2.6MPa.The press closes with sufficient pressure to prevent or minimize flash at the mold part line. The compound softens and flows to shape, the chemical cure then occurs as the internal mould temperature becomes high enough. If necessary, cooling takes place, although for the vast majority of thermosets this is not needed. The press is opened and the molding removed. Frequency, the mould is removed from the press and opened on the bench to extract the molding. It is reloaded with a fresh charge before returning it to the press to commence another cycle. Figure 1 shows the image of compression molding machine.

Figure 1. Compression molding machine

Table 2. Different fiber length and weight percentage for composite plate fabrication

Sl. no	Fiber content (%)	Fiber length (mm)	Weight of fiber (g)	Weight of resin (g)
1	15	10 30 50 70	50	328
2	30	10 30 50 70	101	270
3	45	10 30 50 70	151	212
4	60	10 30 50 70	202	155

2.5 Testing methods and procedures

The prepared fabricated composites tested for various mechanical testing are done by experimentally investigated. And it has important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material is to be used as part of an engineering structure that will be subjected to a load, it is important to know that the material is strong enough and rigid enough to withstand the loads that it will experience in service. As a result, engineers have developed a number of experimental techniques for mechanical testing of engineering materials subjected to tension, compression, bending or torsion loading.

2.5.1 Tensile Test

The static tensile test samples were cut according to ASTM D638 for the specimen dimension of 165 mm×25 mm×3 mm and the tensile behavior of Ramie- Epoxy composite was measured using a Tinius Olsen, Make 10 kN, Dual Column Table Top Universal Testing Machine. The tensile specimen had straight-sided, constant cross-section. The tensile specimen was held in a testing machine by wedge action grips and pulled at a crosshead speed of 1.5 mm/min. Five readings for each identical specimen were taken and their average result was determined.

2.5.2 Compression Test

The composites produced are tested for compressive strength as per ASTM D 3410 standards with sizes of 25 × 25 × 3 mm. Compression test is carried out using a Universal Testing Machine at a compression rate of 5 mm/min.

2.6 Response Surface Methodology

The user-defined designs were used to ensure the possible factor combinations from the candidate points in the design. Once the model was selected, Analysis Of Variance (ANOVA) is used to test the model as whole and individual terms in the model. After each response is analyzed, multiple response optimizations are carried out with the help of optimization tools. The optimization module searches for a combination of factor levels that simultaneously satisfy the criteria placed on each of the responses and factors.

3. Results and Discussions

Table 3. Tensile and compression test results

Sl. no	Fiber length (mm)	Fiber content (%)	Tensile Strength (MPa)	Compression Strength (MPa)
1	10	15	30.4	95.2
2	10	30	39.5	128.7
3	10	45	44.0	143.0
4	10	60	42.2	139.8
5	30	15	35.2	100.8
6	30	30	45.3	139.1
7	30	45	48.7	158.0
8	30	60	47.4	149.0
9	50	15	38.1	122.3
10	50	30	46.4	159.5
11	50	45	52.2	170.0
12	50	60	49.16	161.8
13	70	15	38.5	120.1
14	70	30	44.2	157.3
15	70	45	46.9	162.6
16	70	60	46.0	159.8

3.1 Effect of fiber length and fiber content on Tensile property

The figure 2 shows the tensile strength of ramie and epoxy polymer composites with different fiber length and weight percentage. The lowest tensile strength 30.4 MPa is obtained with inclusion of 15% fiber content and 10mm fiber length of composite plates. The highest tensile value as 52.2MPa is achieved with inclusion of 45% fiber content and 50 mm fiber length of composite plates.

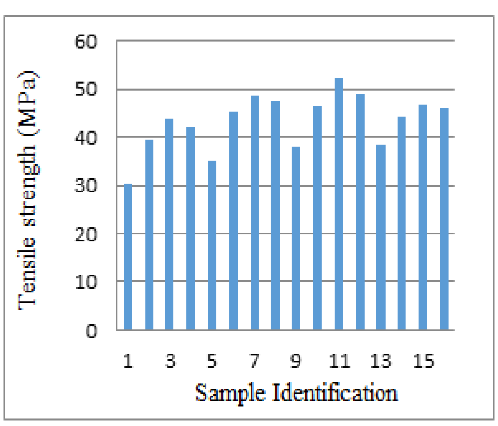

Figure 2. Tensile behavior of following specimen

3.2 Effect of fiber length and fiber content on Compression property

The figure 3 shows the compressive strength of ramie and epoxy polymer composites with different fiber length and weight percentage. The lowest compressive strength 95.2 MPa is obtained with inclusion of 15% fiber content and 10mm fiber length of composite plates. The highest compressive value as 170.0 MPa is achieved with inclusion of 45% fiber content and 50 mm fiber length of composite plates.

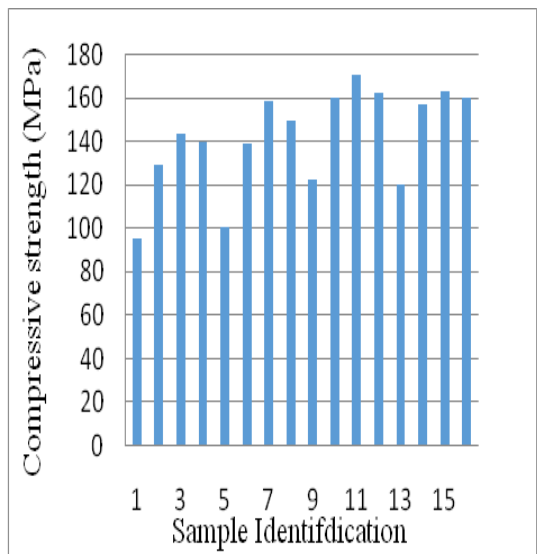

Figure 3. Compressive behavior of following specimen

3.3 Optimization using Response Surface Methodology

Response Surface Methodology includes design, analysis, and optimization and post optimization. As it is a statistical based optimization method, it absorbs the statistical terms initially as mentioned in Table 4.

Table 4. Statistical inferences of tensile and compressive behaviors

Name	Tensile strength	Compressive strength
Units	MPa	MPa
Obs	16	16
Analysis	polynomial	polynomial
Minimum	30.4	95.2
Maximum	52.2	170
Mean	43.387	141.677
Std. Dev.	5.717	22.829
Ratio	1.713	1.785

The Quadratic models were selected for tensile and compressive behaviors of Ramie-epoxy composites based on the sequential sum of squares fit and better values of coefficient of correlation (R^2). The R^2 values of 0.97 and 0.97 were obtained for tensile and Compressive behaviors respectively.

3.4Response Surface Analysis of Tensile and Compressive behaviors

The response surface plots for tensile and compressive behaviors of ramie-epoxy composites are shown in Figures 4 and5 respectively. The curvatures were obtained in all the interactions, and the maximum value of the mechanical strength for various combinations of fiber parameters was studied using the 3D surface plots. The contour lines in the graph indicate the mechanical strength values for the interaction of the fabrication parameters, and the maximum value of the mechanical strength for various combinations of the fabrication parameters. The points within the contour lines were also identified and the better value of mechanical behaviors was obtained.

3.5 Regression Equations

The nonlinear regression models for the tensile and compression behaviors were developed and listed in Equation 1 and 2. The Quadratic models were generated using Design Expert 8.0.4. Software package. In the equations, T_S and C_S represent the tensile strength and Compressive strength respectively whereas F_l and Fc represents fiber length (mm) and fiber Content (%) respectively.

$$T_S = 10.95825 + 0.5232 \times F_L + 1.13687 \times F_C - 0.00148933 \times F_L \times F_C - 0.00478750 \times F_L^2 - 0.0011167 \times F_C^2 \quad (1)$$

$$T_C = 21.63797 + 1.24050 \times F_L + 4.60710\times F_C - 0.00350567\times F_L \times F_C - 0.00846719 \times F_L^2 - 0.046997 \times F_C^2 \quad (2)$$

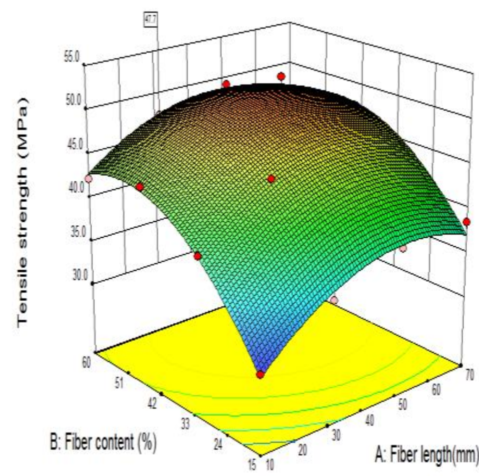

Figure 4. Response plot for tensile behaviours

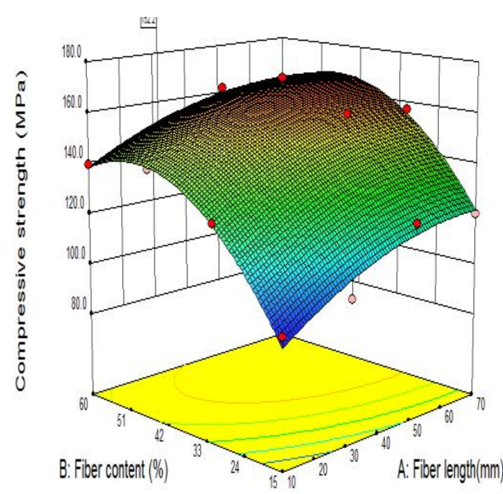

Figure 5. Response plot for compressive Behaviors

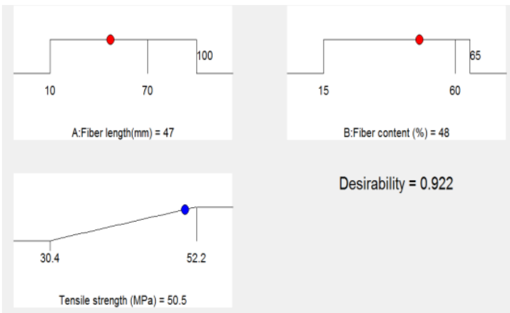

Figure 6.Response Surface Optimization of Tensilebehavior

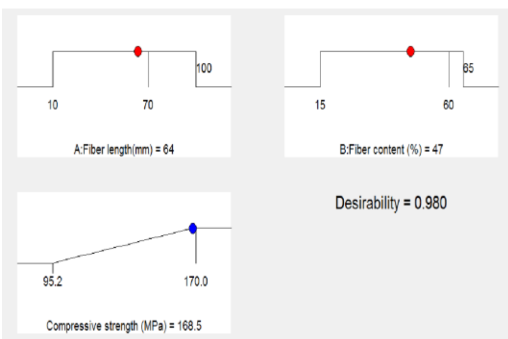

Figure 7. Response Surface Optimization of Compressive behavior

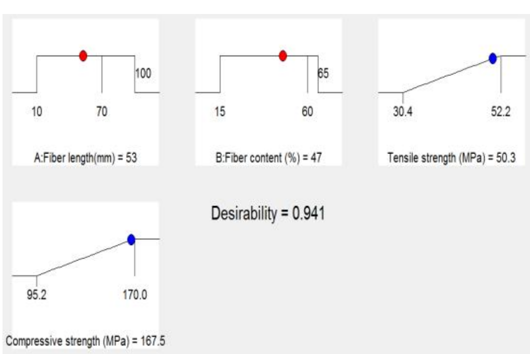

Figure 8. Response Surface Optimization of Tensile and Compressive behaviors

Figure 6 represents maximization of tensile behavior; Figure 7 represents maximization of Compressive behavior and figure8 represents maximization of both tensile and compressive behaviors (Multi objective optimization).

The better value of tensile strength of 50.5 MPa was obtained for the fiber length of 47 mm and fiber content of 48 % whereas the better value of compressive strength of 168.5 MPa was obtained for the fiber length of 64 mm and fiber loading of 47%. The better experimental values of tensile and Compressive strength are 52 MPa and 170 MPa respectively.

The optimum value of mechanical behaviors obtained by RSM is also closer to the experimental values which show the effective modeling and optimization of RSM procedure.

4. Conclusions

Single and multi objective optimization of tensile and compressive behaviors of ramie-epoxy composites were carried out using Response Surface Methodology in this present investigation. The systematic way of determining better value of tensile and compressive behaviors using Response surface Design, Analysis and Optimization were suggested in the present investigation. The better value of tensile strength of 50.3MPa, compressive strength of 167.5 MPa were obtained for the fiber length of 53 mm and fiber content of 47 % by weight. The results declared that there is possibility to further improve the mechanical behaviors of ramie – epoxy composites by improving better adhesion between ramiefiber and epoxy resin. It could be done with the help of treatment of fibers or fiber coating or particle inclusion.

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Nomenclature

Symbol	Meaning	Unit
F_C	Fiber Content	(%)
F_L	Fiber length	(mm)
T_S	Tensile strength	MPa
T_C	Compressive strength	MPa

