A Study on Tensile Strengths of Randomly Oriented Coir/Plantain Hybrid Fiber Reinforced Polyester (CPFRP) Composites

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Abstract—This study focuses on determining the optimum tensile strengths of randomly oriented coir/plantain hybrid fiber reinforced polyester resin composites. The control factors of volume fraction, coupling agent and coir/plantain fiber ratio were used in forming the samples. Tensile test was conducted on the samples of Coir/plantain empty fruit bunch (CEFB) hybrid fibers and coir/plantain pseudo stem (CPS) hybrid fibers reinforced polyester resin composites respectively for the optimum tensile strengths. An OKH-600 Digital Display universal Testing Machine was used for conducting tensile tests in order to establish the control factor levels quality characteristics needed to optimize the mechanical properties being investigated. The highest signal-to-noise ratio (S/N ratio) for the quality characteristics was investigated by applying Taguchi robust design technique for the greater-the-better. The optimum values of the control factors were established for CEFB and CPS hybrid fibers reinforced polyester resin composites. The CEFB hybrid fibers reinforced polyester resin composites has the optimum tensile strength of 73.949 N/mm² while CPS hybrid fibers reinforced polyester resin composites has the optimum tensile strength of 75.498N/mm². The control factors contributed greatly to the tensile strength; and the CEFB hybrid fibers reinforced polyester resin composites are less in tension than that of CPS hybrid fiber.

Index Terms—Coir/Plantain Hybrid Fiber, Composites, Taguchi, Tensile Strength.

I. INTRODUCTION

The properties of natural fiber reinforced polymer composites are generally governed mainly by the manufacturing process of the composites. The recognition of the potential weight savings that can be achieved by using the advanced composites, which in turn means reduced cost and greater efficiency was responsible for growth in the technology of fiber reinforcements, matrices and fabrication of composites [1]. The facts that composites in general can be custom tailored to suit individual requirements; have desirable properties in corrosive environment provide higher strength at a lower weight; and have lower life-cycle costs have aided in their evolution [2]. It provides a good combination in mechanical and thermal properties, and insulating protection. Binshan et al., [3] observed that these qualities in addition to the ability to monitor the performance of the material in the field via embedded sensors give composites an edge over conventional materials.

All plant-derived cellulose fibers are polar and hydrophilic in nature, mainly as a consequence of their chemical structure; so far, the utilization of sisal, jute, coir, plantain and bagasse fibers has found many successful applications. Hence, hybrid of two or more natural fibers, like coir and plantain fibers need to be explored for possible application in reinforcement of polymer. The selection of suitable fibers is determined by the required values of stiffness and tensile strength of a composite [4], [5]. The environmental issues have resulted in considerable interest in the development of new composite materials with addition of more than one reinforcement that are biodegradable resources, such as natural fibers as low-cost and environment-friendly alternative for synthetic fibers [6]. The hybrid fibers in the composites can withstand higher load compared to single-fiber reinforcements in different direction based on the reinforcement, and the surrounding matrix keeps them in the desired location and orientation, acting as a higher load transfer medium between them. The hybrid fiber reinforced composites enhances the mechanical, thermal, damping properties compared to single-fiber reinforced composites; and the hybrid composites are used for many application and replacing wood, wood fiber composites and conventional materials [7].

Jute-coir fiber reinforced hybrid polypropylene composites was studied for mechanical properties according to filler loading variation [8]. In the work, jute and coir hybrid fiber reinforced PP composites were manufactured using hot press machine. The level of fiber loading was varied at 5, 10, 15 and 20 wt% with jute/coir ratio of 1:1. The tensile strength of the composites decreased with an increase in fiber loading. The Young’s modulus increased with fiber loading. Flexural strength, flexural modulus, charpy impact strength and average hardness values increased with an increase in fiber loading. Scanning electron microscopic analysis indicated strongest adhesion between the fiber and matrix when 20% fiber was reinforced into polypropylene polymer. As a result of the study, 20% fiber composite yielded the best set of mechanical properties compared to other composites.

Kenaf fiber as another natural fiber has find its way in serving the same purpose as synthetic glass fiber whereby a hybrid material of natural kenaf and synthetic glass fiber served as reinforcement on Improving Mechanical Properties of kenaf fiber reinforced composite for Automotive Structures[9]. This study focused on the mechanical properties of a hybrid kenaf/glass reinforced composites for utilization in passenger car bumper beam since the hybrid of

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synthetic glass fibers and kenaf fibers can still be used to enhance the mechanical properties. A twisted kenaf hybrid material, which is fabricated by hot impregnation method present a good mechanical properties. Their comparison charts shows some mechanical advantages. This implies that a hybrid kenaf/glass reinforced material could be utilized in automotive structural components such as bumper beams and front end modules.

Another investigation was undertaken on mechanical properties of banana-coir hybrid composite using experimental and fem techniques [10]. The tensile and impact tests showed that treated banana-coir epoxy hybrid composites have higher tensile strength and impact strength than untreated composites. However, untreated fiber composites have greater flexural strength than the treated fiber composites. The stresses at the interface of the banana-coir and matrix, induced by the different loading conditions, were applied to predict the tensile, impact, and flexural properties by using the FEA models. The analysis is useful for realizing the advantages of hybrid fiber reinforced composites in structural applications and for identifying where the stresses are critical and damage the interface under varying loading conditions. Khalif [11] undertook an experimental investigation of effect of fiber diameter on tensile properties of Jute – Banana fiber (hybrid) reinforced epoxy composite. Fibers are of diameter 1mm, 2mm and 3mm in the form of yarns. As the diameter of fibers (volume fraction) increases the tensile strength increases. From the obtained results the percentage of elongation of jute, banana and hybrid (jute-banana) fiber reinforced composites is 14%, 9% and 8.5% respectively when it is loaded along the orientation of fibers and 10%, 7.5% and 6.7% when it is loaded perpendicular to the orientation of fiber. And it is found that the stress is maximum when it is loaded along the orientation of fibers and minimum value of stress when it is loaded perpendicular to the orientation of fiber. Increase in tensile strength is achieved by hybridization of jute and banana fibers. There is an enhancement of 39.39% and 24% in tensile strength because hybrid based epoxy composite when compared to jute and banana reinforced epoxy composites.

Furthermore, Essabir [12] studied the mechanical and thermal properties of hybrid composites: Oil-palm fiber/clay reinforced high density polyethylene. The evolution of thermal, mechanical, and dynamic mechanical performances of the hybrid composites as a function of filler content was investigated. The morphological study showed that the alkali treatment of OPF fibers enhanced their surface interaction with the polymer, while the addition of a coupling agent increased the interfacial adhesion between both fillers and the polymer matrix leading to improved filler dispersion/distribution (homogeneity). The tensile properties results showed that the 12.5:12.5 hybrids composite had the best tensile properties with a gain of 49% in Young’s modulus and 11% in tensile strength. For the dynamic mechanical characterization, an increase in the complex modulus was observed with filler addition. The thermal stability of the hybrid composites increased with clay addition which is more thermally stable than OPF. The results obtained confirmed the viability of the combination between fibers and particles.

In the Investigation of Bending Test on Hybrid (Sisal and Banana) Fiber Reinforced Polyester Composite Material [13], the bending tests were conducted by preparing varying percentage of standard specimen. It was found that there was appreciable improvement in bending Properties of 10%, 20%, 30% and 40% HFRPC material. This Study suggested 30% and 40% of HFRPC material may be suitable for the different application in the replacement of human bone. From the Experimental results, it was found that increasing the weight fraction of the fiber or percentage of fiber will increase the bending strength and also increases the density and mass of composite specimen. The study suggested that the 30% and 40% HFRPC material which is low density and high strength biocompatible material may be suggested for implant, especially for cortical bone.

Many investigations have been made on the potential of the natural fibers as reinforcements for composites and in several cases the results have shown that the natural fiber composites own good stiffness but most times the composites do not reach their optimal strength [14]; it was then realized that the full economic and technical potential of any composite manufacturing process can be achieved only while the formulation process is run with the optimum parameter combinations. The CEFB and CPS hybrid fibers reinforced polyester resin composites with the parameter combination of volume fraction, coupling agent and coir/plantain fiber ratio can result to optimum strength.

II. MATERIALS AND METHODS

In this study, the hybrid of coir and plantain fibers was used as reinforcement; aqueous sodium hydroxide (NaOH) and Maleic anhydride (MAH) were used for fiber chemical treatments; and polyester resin was used as the matrix.

A. Chemical Treatment and Process Variables

In this study, 5% of aqueous sodium hydroxide (NAOH) was used in treating coir fibers, empty fruit bunch plantain fibers and pseudo stem plantain fibers for 2 hours at room temperature. Afterward, the alkali treated fibers were air dried. Afterward, the fibers were esterified with maleic anhydride (MAH) solution of different percentages (conc. 0.1%, 0.25% and 0.5%) and left for 45 minutes under agitation for condensation and chemical bonding of maleic anhydride and cellulose fibers. Treated fibers were then washed to remove excess coupling agents.

After esterification of Coir fiber, Empty fruit bunch plantain fiber and Pseudo stem plantain fiber with the Coupling agent (maleic anhydride); the fibers were chopped at the same length of 10mm for reinforcement of composite samples.
Fig. 1: Treated coir fiber

Fig. 2: Treated CEFB fiber

Fig. 3: Treated CPS fiber

Considering the key areas of investigation as concern the hybrid arrangement of Coir/Empty fruit bunch plantain (CEFB) and Coir/Pseudo stem plantain (CPS) fibers, the experimental process variables (control factors) used in this study are Volume fraction (%), Coupling agent (%w/v) and Fiber ratio (-); while the response variables will be discussed in the materials testing and characterization section.

B. Composite Design and Preparation Techniques

1) Determination of Fiber Quantity

Fiber volume fraction is calculated by following the derivations from rule of mixture based on the procedures [15], [16]. The volume \( V_c \) and mass \( M_c \) of a particular composite specimen consist of volumes and masses of fibers and matrix respectively.

\[
V_c = V_f + V_m \quad (1)
\]

\[
M_c = M_f + M_m \quad (2)
\]

The volume of fibers \( (V_f) \) in a particular composite specimen is the ratio of the mass of fiber \( (M_f) \) to its density \( (\rho_f) \). Likewise, the volume of matrix \( (V_m) \) in a particular composite specimen is the ratio of the mass of matrix \( (M_m) \) to its density \( (\rho_m) \).

\[
V_f = \frac{M_f}{\rho_f} \quad (3)
\]

\[
V_m = \frac{M_m}{\rho_m} \quad (4)
\]

The volume of a particular composite specimen \( (V_c) \) is, in other words, the sum of (3) and (4).

\[
V_c = \frac{M_f}{\rho_f} + \frac{M_m}{\rho_m} \quad (5)
\]

The volume fraction of fiber \( (V_{fr}) \) and volume fraction of matrix \( (V_{mf}) \) in a particular composite specimen can be represented as follows:

\[
V_{fr} = \frac{V_f}{V_c} = \frac{V_f}{V_f + V_m} \quad (6)
\]

\[
V_{mf} = \frac{V_m}{V_c} = \frac{V_m}{V_f + V_m} \quad (7)
\]

Equations (5) and (6) show that once the volume of composite specimen, specified volume fraction, and density of fibers are known, the mass of the fiber for the specified volume fraction in a particular composite specimen can be determined and measured out for that same specified volume fraction.

2) Design of Experiment

The most important stage in the design of experiment lies in the selection of the control factors. The control factors (process parameters) of hybrid fibers and their three levels for preparing specimens are shown in Table I.

The experimental design involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied as proposed by Taguchi. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [17].

| Code | Parameters                        | Levels | Unit     |
|------|----------------------------------|--------|----------|
| A    | Coupling Agent                   | 0.1    | 0.25     | 0.5     |
|      | Volume Fraction                  | 10     | 30       | 50      |
| B    | Fiber Ratio (coir/plantain)      | 30/70  | 50/50    | 70/30   |

The signal-to-noise ratio measures the sensitivity of the
quality investigated to those uncontrollable factors (error) in this experimental design. The higher value of ratio is always desirable, because greater ratio will result in smaller product variance around the target value. In order to perform mean square deviation (MSD) and S/N ratio analysis for “the-larger-the-better” quality characteristic and ratio, the equations below were used [17], [18]:

\[
MSD = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2}
\]

(8)

\[
S/N = -10 \log_{10}(MSD)
\]

(9)

Where, \(y_i\) is a particular tensile property for \(i\)th replicate experiment.

3) Preparation of Composites

The composite production method adopted for this study based on open molding is the Hand Lay-up processing because the reinforcement is placed manually. This process is labor intensive and less expensive. The mold is first polished and then a mold-releasing agent (Polyvinyl alcohol) is applied on the surface to facilitate easy removal of the composite from the mold after curing. Initially, resin and hardener were mixed to form a matrix and then the chopped fiber reinforcement, as recommended by Ashby [19], is placed in discontinuous and randomly oriented manner on the top (see Fig. 4). A roller is used to impregnate the fiber with the resin. Another resin and reinforcement layer may be applied until a suitable thickness builds up.

![Fig. 4: Chopped fiber pattern in matrix for Composites forming. Source: Ashby et al., [19]](image)

The coir-plantain hybrid fiber reinforced composites were prepared for tensile test according to ASTM D638 Type I.

![Fig. 6: Tensile Test specimen](image)

Each specimen was loaded to failure using Universal Testing Machine.

![Fig. 7: Tensile Test Set-up](image)

![Fig. 8: Fractured Tensile Test Specimen](image)

The tensile properties were determined using equations (10) to (11).

The strain, \(\varepsilon\), is given by

\[
\varepsilon = \frac{l_f - l_0}{l_0}
\]

(10)

while the tensile stress, \(\sigma_t\), is given by

\[
\sigma_t = \frac{F_{\text{max}}}{bh}
\]

(11)

In the above equations, \(l_f\) is the final length, \(l_0\) is the original length, \(F_{\text{max}}\) is the maximum applied force, \(b\) is the specimen breadth, \(h\) is the specimen height or thickness.

III. RESULTS AND DISCUSSIONS

A. Tensile strength responses: ANOM and ANOVA

Traditional experimentation on replicate samples of CEFB and CPS hybrid fiber reinforced polyester composites were used to obtain the value of quality characteristics using different levels of control factors as in Table I; and Table II which shows Taguchi DOE orthogonal array that will be implemented in Design matrix for the larger the better signal to noise (S/N) ratio.

Taguchi design requires data analysis of means (ANOM) and analysis of variance (ANOVA). The ANOM is a process of determining the direct effects of each variable; while
ANOVA helps to ascertain the comparative importance of the parameters in terms of % contribution to the response and determine the error variance for the effects and variance of prediction error [21].

1) CEFB hybrid fiber reinforced polyester composite

The experimental results of tensile responses for CEFB composite in Table III according to their fiber parameters and levels were implemented in Minitab 17 software.

| Experiment Number | A | B | C | Mean ultimate Tensile response (N/mm²) | S/N Ratio |
|-------------------|---|---|---|--------------------------------------|-----------|
| 1                 | 1 | 1 | 1 | 76.22                                | 37.6414   |
| 2                 | 1 | 2 | 2 | 67.33                                | 36.5642   |
| 3                 | 1 | 3 | 3 | 66.44                                | 36.4886   |
| 4                 | 2 | 1 | 2 | 65.19                                | 36.2836   |
| 5                 | 2 | 2 | 3 | 69.33                                | 36.8184   |
| 6                 | 2 | 3 | 1 | 65.33                                | 36.3023   |
| 7                 | 3 | 1 | 3 | 72.07                                | 37.1551   |
| 8                 | 3 | 2 | 1 | 64.81                                | 36.2328   |
| 9                 | 3 | 3 | 2 | 67.48                                | 36.5835   |

The average responses of the control factors are summarized in Table IV.

TABLE IV: RESPONSE TABLE FOR SN RATIO AND MEAN TENSILE STRENGTH OF CEFB COMPOSITES BASED ON LARGER IS BETTER QUALITY CHARACTERISTICS

| Response | Signal-to-Noise Ratios | Means | A | B | C |
|----------|------------------------|-------|---|---|---|
| Delta    | 36.88                  | 37.03 | 36.73 | 70.00 | 71.16 | 68.79 |
| 2        | 36.47                  | 36.54 | 36.48 | 66.62 | 67.16 | 66.67 |
| 3        | 36.66                  | 36.44 | 36.81 | 68.12 | 66.42 | 69.28 |
| Rank     | 0.42                   | 0.58  | 0.33 | 3.38 | 4.74 | 2.61 |

The results of ANOM for CEFB composites in Table IV are represented in response graphs (Figures 9 and 10). The level of a process parameter with highest signal to noise (S/N) ratio value is the optimum level. As seen in Figures 9 and 10, the optimal combination of process parameter settings for maximizing the tensile strength of CEFB hybrid fiber reinforced polyester composite is A1, B1 and C3 i.e. the specimen (with hybrid fibers) having volume fraction of 10% with 0.1% w/v of coupling agent using coir/plantain fiber ratio of 70/30.

![Response graph of S/N ratio for Tensile strength of CEFB hybrid fiber reinforced composite](image)

However, the comparative magnitude among the process parameters has to be investigated through the ANOVA. Table V presents the summary of ANOVA result for tensile strength of CEFB hybrid fiber reinforced polyester composite material. From Table V, it can be seen that the coupling agent of MAH has major influence (33.58%) on the maximizing tensile strength and volume fraction has less effect (14.97%), where the coir/plantain fiber ratio does not have significant effect in maximizing tensile strength of CEFB hybrid fiber reinforced polyester composite material.

TABLE V: SUMMARY OF ANOVA ON S/N FOR TENSILE STRENGTH OF CEFB HYBRID FIBER REINFORCED COMPOSITE

| Source                 | Degree of Freedom | Sum of square | Mean square | F-Ratio | % contribution |
|------------------------|-------------------|---------------|-------------|---------|----------------|
| Volume Fraction (A)    | 2                 | 0.2611        | 0.13055     | 0.36    | 14.97          |
| Coupling Agent (B)     | 2                 | 0.5858        | 0.29288     | 0.81    | 33.58          |
| Fiber Ratio (C)        | 2                 | 0.1775        | 0.08874     | 0.25    | 10.18          |
| Residual Error         | 2                 | 0.7199        | 0.35996     | 0.41    | 41.27          |
| Total                  |                   | 1.7443        | 100         |         |                |

2) CPS hybrid fiber reinforced polyester composite

The experimental results of tensile responses for CPS composite in Table VI according to their fiber parameters and levels were implemented.

TABLE VI: EVALUATED SIGNAL TO NOISE RATIOS AND ORTHOGONAL ARRAY SETTING FOR EVALUATION OF MEAN TENSILE RESPONSES OF CPS HYBRID FIBER REINFORCED COMPOSITE

| Experiment Number | A | B | C | Mean ultimate Tensile response (N/mm²) | S/N Ratio |
|-------------------|---|---|---|--------------------------------------|-----------|
| 1                 | 1 | 1 | 1 | 71.56                                | 37.0834   |
| 2                 | 1 | 2 | 2 | 70.22                                | 36.9292   |
| 3                 | 1 | 3 | 3 | 68.44                                | 36.7062   |
| 4                 | 2 | 1 | 2 | 74.22                                | 37.4104   |
| 5                 | 2 | 2 | 3 | 73.78                                | 37.3588   |
| 6                 | 2 | 3 | 1 | 70.59                                | 36.9749   |
| 7                 | 3 | 1 | 3 | 69.04                                | 36.7820   |
| 8                 | 3 | 2 | 1 | 65.33                                | 36.3023   |
| 9                 | 3 | 3 | 2 | 72.30                                | 37.1828   |

The average responses of the control factors are summarized in Table VII.
TABLE VII: RESPONSE TABLE FOR SN RATIO AND MEAN TENSILE STRENGTH OF CPS COMPOSITES BASED ON LARGER IS BETTER QUALITY CHARACTERISTICS

| Response | Signal-to-Noise Ratios | Means |
|----------|------------------------|-------|
| Level    | A          | B          | C          | A          | B          | C          |
| 1        | 36.91     | 37.10     | 36.79     | 70.07     | 71.61     | 69.16     |
| 2        | 37.25     | 36.86     | 37.17     | 72.86     | 69.78     | 72.25     |
| 3        | 36.76     | 36.95     | 36.95     | 68.89     | 70.44     | 70.42     |
| Delta    | 0.49      | 0.23      | 0.38      | 3.97      | 1.83      | 3.09      |
| Rank     | 1         | 3         | 2         | 1         | 3         | 2         |

ANOM results for CPS composites in Table VII are represented in response graphs (Figures 11 and 12). The level of a process parameter with highest signal to noise (S/N) ratio value is the optimum level. Figures 11 and 12 present the optimal combination of process parameter settings for maximizing the tensile strength of CPS hybrid fiber reinforced polyester composite material. The volume fraction has more contribution (68−70% max) on the maximizing tensile strength followed by Coupling agent (39.73%) on the maximizing tensile strength followed by Fiber fraction (8.55%) in maximizing tensile strength of CPS hybrid fiber reinforced polyester composite material.

Fig. 11: response graph of s/n ratio for tensile strength of cps hybrid fiber reinforced composite

Fig. 12: Response graph of Means for Tensile strength of CPS hybrid fiber reinforced composite

The comparative magnitude among the process parameters were investigated through the ANOVA. The summary of ANOVA result for tensile strength of CPS hybrid fiber reinforced polyester composite material are presented in Table VIII. The volume fraction has more contribution (39.73%) on the maximizing tensile strength followed by coir/plantain fiber ratio (23.31%) and Coupling agent has least effect (8.55%) in maximizing tensile strength of CPS hybrid fiber reinforced polyester composite material.

TABLE VIII: SUMMARY OF ANOVA ON S/N FOR TENSILE STRENGTH OF CPS HYBRID FIBER REINFORCED COMPOSITE

| Source       | Degree of freedom | Sum of squares | Mean square | F-ratio | % contribution |
|--------------|-------------------|----------------|-------------|---------|----------------|
| Volume       | 2                 | 0.3806         | 0.19031     | 1.40    | 39.73          |
| Fraction     |                   |                |             |         |                |
| Coupling     | 2                 | 0.0819         | 0.04093     | 0.30    | 8.55           |
| Agent        |                   |                |             |         |                |
| Fiber        | 2                 | 0.2233         | 0.11167     | 0.82    | 23.31          |
| Ratio        |                   |                |             |         |                |
| Residual     | 2                 | 0.2723         | 0.13614     | 28.42   | 100            |
| Total        | 8                 | 0.9581         |             |         |                |

B. Estimation of expected responses based on optimum settings

The expected response is estimated using the optimum control factor setting from the main effects plots; by employing the response table for signal to noise ratio and the response table for mean [21], the expected response model is as in equation 12:

\[
M_{opt} = M_{ave} + \sum_{j=1}^{k_i} (M_{ij})_{max} - M_{ave}
\]

Where, \(M_{opt}\) = expected mean response, \(M_{ave}\) = average response, \((M_{ij})_{max}\) is the mean of optimum level \(i\) of factor \(j\) and \(k_i\) is the number of main design parameter that affect the response.

1) CEFB hybrid fiber reinforced polyester composite

For the CEFB hybrid fiber reinforced polyester composite from Table IV, and Figures 9 & 10:

\[
M_{opt(CEFB)} = 68.244 + (69.997 - 68.244) + (71.160 - 68.244) + (69.280 - 68.244) = 73.949N/mm^2
\]

2) CPS hybrid fiber reinforced polyester composite

For the CPS hybrid fiber reinforced polyester composite from Table VII, and Figures 11 & 12:

\[
M_{opt(CPS)} = 70.609 + (72.863 - 70.609) + (71.607 - 70.609) + (72.246 - 70.609) = 75.498N/mm^2
\]

TABLE IX: OPTIMUM SETTING OF CONTROL FACTORS AND EXPECTED OPTIMUM TENSILE STRENGTH OF COMPOSITES

| Composite | Control factors | Optimum levels | Optimum settings | Expected optimum values |
|-----------|-----------------|----------------|------------------|-------------------------|
| CEFB      | A 1             | 10             |                  | 73.949N/mm²             |
|           | B 1             | 0.1            | 30/70            |                         |
|           | C 1             | 50/50          |                  | 75.498N/mm²             |
|           |                 |                |                  |                         |
| CPS       | A 2             | 30             |                  | 75.498N/mm²             |
|           | B 1             | 0.1            |                  |                         |
|           | C 2             | 50/50          |                  |                         |

C. Regression model for optimum values analysis

The relationship between tensile strength and combination of control factors is obtained using mathematical models and final prediction equations.
1) **CEFB hybrid fiber reinforced polyester composite**

For the CEFB, formula 13 is formulated from Table 10;

\[ Y = 68.2444 + 1.7522A - 1.6278A + 2.9156B - 1.0878B + 0.5422C - 1.5778C \]  

(13)

**TABLE X: ESTIMATED LINEAR MODEL ANALYSIS FOR MEANS IN CEFB**

| Term | Coef  | SE Coef  | T  | P   |
|------|-------|----------|----|-----|
| Constant | 68.2444 | 1.596 | 42.750 | 0.001 |
| A1 | 1.7522 | 2.258 | 0.776 | 0.519 |
| A2 | -1.6278 | 2.258 | -0.721 | 0.546 |
| B1 | 2.9156 | 2.258 | 1.291 | 0.326 |
| C1 | -1.0878 | 2.258 | -0.482 | 0.678 |
| C2 | -1.5778 | 2.258 | -0.699 | 0.557 |

S=4.789 R-Sq=59.7% R-Sq(adj)=0.0%

The coefficients of model for means in CEFB composites are shown in Table X. The parameter R-Sq describes the amount of variation observed in yield is explained by the input factors. R-Sq = 59.7% indicates that the model is able to predict the response with moderate accuracy. Adjusted R-Sq is a modified R-Sq that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R-Sq can be artificially high, but adjusted R-Sq (\(\text{R-Sq}^2\)) can be small. The standard deviation of errors in the modeling, S= 4.789, indicates that model can explain the variation in yield of CEFB to the extent of 59.7% which makes the model moderate to represent the process.

2) **CPS hybrid fiber reinforced polyester composite**

For the CPS, formula 14 is formulated from Table 11;

\[ Y = 68.2444 + 1.7522A - 1.6278A + 2.9156B - 1.0878B + 0.5422C - 1.5778C \]  

(14)

**TABLE XI: ESTIMATED LINEAR MODEL ANALYSIS FOR MEANS IN CPS**

| Term | Coef  | SE Coef  | T  | P   |
|------|-------|----------|----|-----|
| Constant | 70.6089 | 0.9853 | 71.664 | 0.000 |
| A1 | -0.5356 | 1.3934 | -0.384 | 0.738 |
| A2 | 2.2544 | 1.3934 | 1.618 | 0.247 |
| B1 | 0.9978 | 1.3934 | 0.716 | 0.548 |
| B2 | -0.8322 | 1.3934 | -0.597 | 0.611 |
| C1 | -1.4489 | 1.3934 | -1.040 | 0.408 |
| C2 | 1.6378 | 1.3934 | 1.175 | 0.361 |

S=2.956 R-Sq=71.8% R-Sq(adj)=0.0%

Table XI shows the coefficients of model for means in CPS composites. R-Sq = 71.8% indicates that the model is able to predict the response with high accuracy. Adjusted R-Sq (0.0%) is also zero. The standard deviation of errors in the modeling, S, is 2.956.

D. **Verification of experiment**

Predicting and verifying the performance characteristic of the experiment using the optimal level of design parameters are essential once the optimal levels of the process parameters have been identified for each of the properties. The predicted optimum value of S/N ratio (\(\eta_{\text{opt}}\)) of the response is determined by the formula [21], [22]:

\[ \eta_{\text{opt}} = \eta + \sum_{j=1}^{f_1} \left( \eta_{i,j} \right)_{\text{max}} - \eta \]  

(15)

where, \(\eta\) is the overall average of S/N ratio; \(\left(\eta_{i,j}\right)_{\text{max}}\) is the S/N ratio of optimum level \(i\) of factor \(j\) and \(k_1\) is the number of main design parameter that affect the response. The observed value of S/N ratio (\(\eta_{\text{obs}}\)) and the predicted value (\(\eta_{\text{opt}}\)) are used to verify the experiments.

The validation experiments at optimal levels of process parameters for each of the tensile properties of the coir/plantain hybrid fiber reinforced polyester composites were conducted, and their errors of prediction (\(\eta_{\text{opt}} - \eta_{\text{obs}}\)) were also evaluated. The conformity test results are presented in Table XII.

**TABLE XII: RESULTS OF THE VERIFICATION**

| Performance measure | CEFB | CPS |
|---------------------|------|-----|
| S/N predicted (\(\eta_{\text{opt}}\)) dB | 37.378 | 37.572 |
| S/N observed (\(\eta_{\text{obs}}\)) dB | 37.644 | 37.104 |
| Prediction error, dB | -0.2626 | 0.4712 |

From Table XII, it is observed that the calculated value of prediction error for CEFB and CPS are highly minimal. Thus, it clearly indicates the adequacy of the control factors of both tensile property models.

IV. **CONCLUSION**

Coir/plantain hybrid fiber reinforced composites of different compositions were prepared, and the samples were characterized for their tensile properties. The following deductions can be drawn from the work:

1. The CEFB hybrid fiber reinforced composite has the optimum tensile strength of 73.949N/mm² when the control factors (volume fraction, couple agent and coir/plantain fiber ratio) of the hybrid fibers are set 10%, 0.1%w/v and 30/70 ratio respectively, while CPS hybrid fiber reinforced composite has the tensile strength of 75.498N/mm² when the control factors (volume fraction, couple agent and coir/plantain fiber ratio) of the hybrid fibers are set 30%, 0.1%w/v and 50/50 ratio respectively;

2. The result indicates that coupling agent treatment of hybrid fiber is the most significant factors affecting the tensile strength of the CEFB hybrid fiber reinforced composites, followed by volume fraction of the same hybrid fibers. Although the effect of fiber ratio is significantly less; while volume fraction of hybrid fiber has the highest influence on the tensile strength of the CPS hybrid fiber reinforced composites, followed by coir/plantain fiber ratio of the same hybrid fibers. The effect of coupling agent treatment is though significantly less.

3. The validation experiments at optimal levels of process parameters for each of the tensile property models of the both CEFB and CPS hybrid fiber reinforced polyester composites are highly adequate; hence the minimal levels of the prediction error. Consequently, the composites of CPS hybrid fibers are stronger in tension than those of CEFB at their respective optimum settings which maintains common coupling agent percentage (0.1%w/v) treatment.
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