Manufacturing and Analysis of Banana- Epoxy Composite fibre

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Abstract. The usage of natural fibre as reinforcement in polymer composites has increased in the recent years with rising concerns of environmental pollution and the heavy dependence on synthetic fibres from petroleum products of the middle east and the amount of material available in the tropical countries for such low prices. These materials can decrease our dependency on conventional materials like plastics, thereby decreasing the amount of pollution we cause on disposal and manufacturing of those. In general, the impact strength of the natural fibre composites is considered to be low and this experiment quantifies these results. This research describes the fabrication of a polymer composite, using banana fibre as the reinforcement and epoxy as the polymer matrix. A sequence of samples was prepared by varying various parameters like length, volume fraction and treatment of the fibre. The parameters were optimized using Taguchi’s DOE and the combination of parameters which yields us the best result and the contribution of each parameter. The impact strength has been studied using IZOD impact tester. The work has quantified that the impact strength of the composite depends mostly on the volume fraction and also only up to a certain range and then decreases as we increase the quantity of fibre. The same goes with both alkali treatment and length of the fibre which also contribute respectively. The optimum length, volume fraction and chemical are 1mm, 25 wt% and 2% NaOH treatment shows better result.

1. Introduction

Recent years, the usage of natural fibre as reinforcement in polymer composites has increased with rising concerns of environmental pollution and the heavy dependence on synthetic fibres from petroleum products of the middle east and the amount of material available in the tropical countries for such low prices. These materials can decrease our dependency on conventional materials like plastics [1]. The manmade fibres were replaced by natural fibre to reduce the amount of pollution we cause on disposal and manufacturing of those synthetic fibre [2,3]. Natural fibre also has some advantages compare to synthetic fibre are low cost, eco-friendly nature, high strength per unit weight, nontoxicity, and biodegradability [4-6]. Some of natural fibres are banana, sisal, hemp, ramie, coir, vakka, flax, jute, and pineapple leaf fibre [7,8]. Natural fibres cell wall contains hemicellulose, cellulose and lignin. These organic components of the fibres report the stiffness and strength [9-12]. Natural fibre with thermoset matrix possesses good mechanical [13,14]. Composites materials are widely used in leisure, aerospace, sports, construction, automobile and packaging industries [15,16].

The production of banana was ~70 million metric tons in every year by subtropical and tropical regions of the world [17-19]. In 100g of Banana pulp consist of 1.15g of protein; 18.8g of carbohydrates; 73.9g of water; 0.18g of fat; 0.83g of vitamins C1 B1 B2 B6 E and 81kcal of other minerals [20]. Banana fibre has 64% of cellulose content and 11° low microfibrillar angle indicates it is suitable for
reinforcement in composite [21]. The banana fibre reinforced composites are widely used in building application [22]. The dynamic mechanical property of banana fibre composite was high, if the composite consists of 40% of fibre content [23]. Cement reinforced with kraft pulped banana fibre gives better flexural strength [24]. The optimized fibre length to obtain maximum tensile and impact strength was 30mm and 40mm respectively [25].

The main drawback in natural fibre was non-uniformity, moisture absorption, low mechanical properties and hydrophilic in nature [26]. Due to hydrophilic nature, the bonding between fibre and matrix was reduced. To overcome this chemical treatment was induced. Chemical treated fibre composite gives better mechanical strength compare to untreated [27-29]. In that NaOH treatment gives better result compare to any other [30].

For optimization process the best technique was Taguchi’s method [31]. In this work L9 array was incorporate for optimization. For that length of the fibre (0.1mm, 1mm, 10mm), Volume fraction (15wt%, 25wt%, 35wt%) and chemical treatment (0%, 2%, 5%) are selected as parameters. The objective of the research is to develop a polymer matrix composite from the banana fibre and epoxy polymer and test its impact strength. For the polymer to be useful in practical field especially in automobiles and aerospace they should have enough impact strength. Results can be drawn at which combination of the levels of parameters gives us the maximum toughness values. It even helps us in determining the percentage of impact by the parameters. By this an understanding can be made on how much each parameter influences the toughness. An understanding of correlation of the parameters involved in the experiment can be found out. The result was calculated by using MINITAB software.

2. Experimental

2.1. Materials
Banana fibre was bought from Bharatiya natural fibres, Coimbatore, Tamil Nadu, India. NaOH from SD fine-chemical Ltd, Mumbai, India. Epoxy (Araldite LY 556) and Hardener (HY 951) are bought from SM composites, Chennai, India.

2.2. Preparation of Composites
Initially, the fibres obtained from the supplier where nearly one meter long so they had to be trimmed down to the required dimensions. The 1mm and 10mm strands were achieved using a scissor by hand (Fig.1). With the help of Pulveriser, the fibre length was reduced from 1mm to 0.1mm (Fig. 2).

![Fig 1. 1mm Banana fibre.](image1)

![Fig 2. Powdered (0.1mm) Banana fibre samples.](image2)
Before the treatments, the Banana fibre was washed with normal water. Then the fibre was immersed in a NaOH solution contains 2g for 100ml distilled water for 1 hr. After 1hr the fibre was washed with running normal water to neutralize and dried for two days in oven at 60°C.

Parchment paper has been used to prepare the moulds according to ASTM 6110 the standards. Though the paper moulds have good inner surface finish they do not have enough strength to hold the composite mixture, hence wooden moulds had been prepared of plywood to support the paper moulds. The wooden samples are prepared by giving slight tolerance to fit in the paper moulds (Fig.3).

![Figure 3. Wooden support.](image)

The fibre was mixed with 10:1 ratio of epoxy and hardener by mechanical stirring. Then the mixture is slowly transfer to the mould. The composite is then allowed to settle for 48 hours in the room temperature. Later the paper moulds are scrubbed with sand paper to remove the outer paper (Fig. 4).

![Figure 4. (a)Sample with wooden support; (b)Sample without wooden support](image)

Sequence of samples were prepared as per L9 orthogonal array with different composition in Table 1.

| S.No | Length of the fibre (mm) | Volume Fraction (%) | Treatment with NaOH (%) |
|------|--------------------------|---------------------|-------------------------|
| 1    | 0.1                      | 15                  | 0                       |
| 2    | 0.1                      | 25                  | 2                       |
2.3. Characterization
The impact strength of the specimen was determined using IZOD impact tester with Scale range: 2, 4, 7.5, 15, 25 Joules (Fig.5). The specimens are cut into as per ASTM D256-88 (64mm x 12.7mm x 3.2 mm) and 45° angle notch was made at the centre of the sample for impact testing. The toughness of the samples was evaluated by charpy impact test as per ASTM D6110. It shows the amount of energy required to break the sample. From that the toughness of the specimens were calculated and the test was carried at CIPET Hyderabad.

![Impact testing machine](image)

Figure 5. Impact testing machine.

3. Results and Discussion
The analyses and a mathematical model were developed by Design expert software for toughness using the input parameters (table 2)

| Length of the fibre (mm) | Volume Fraction (%) | Treatment with NaOH (%) | Toughness of sample (J/mm) |
|-------------------------|---------------------|--------------------------|---------------------------|
| 0.1                     | 15                  | 0                        | 0.55                      |
| 0.1                     | 25                  | 2                        | 0.65                      |
| 0.1                     | 35                  | 5                        | 0.40                      |
| 1                       | 15                  | 2                        | 0.45                      |
| 1                       | 25                  | 5                        | 0.65                      |
| 1                       | 35                  | 0                        | 0.40                      |
| 10                      | 15                  | 5                        | 0.40                      |
For the calculation purpose say the length of fibre be A, Volume fraction be B and NaOH treatment be C.

**Taguchi Calculations**

The optimum condition is calculated as follows:

\[
A_1 = \frac{\text{Sum of Toughness for samples with A factor as 1}}{\text{total no of levels}}
\]

\[
A_1 = \frac{0.55+0.65+0.40}{3} = 0.5334
\]

Similarly, the values are calculated for all the factors at all levels. The results come out to be,

\[
A_2=0.55; B_1=0.4666; C_1=0.45;
\]

\[
A_3=0.50; B_2=0.6166; C_2=0.60;
\]

\[
A_3=0.50; B_3=0.50; C_3=0.533;
\]

The best sample is the sample which is having the highest toughness value. So, the optimum condition is A_2, B_2 & C_2.

The analysis can also be done in MINITAB software:

![Figure 6. Taguchi Table design roadmap on MINITAB](image)

The optimum condition can be found by analysing the Taguchi’s design

![Figure 7. Option selection](image)
When analysing we have taken the condition to be Larger is better as the sample is good only when toughness is the highest.

S/N is the Signal to Noise Ratio

The graphs for the results are as follows:

![Figure 8. Main effects plot for S/N Ratios](image)

We can see that the factor A which is the length of the fibre is having a slight increase till 2nd level which is 1mm and then from there is a sharp decrease in the toughness value. Hence the optimum value is 1mm. When it comes to factor B which is the % volume fraction you can see a massive increase in toughness when increased from 15% to 25% from there is a sharp decrease in the value. So, the optimum condition is 25% of volume fraction. For the factor C which is the % of NaOH treatment we can see the same trend as in the factor B which is increase and then decrease. So, the optimum condition is 2% NaOH treatment.

**Contribution of each parameter**

1) \[ ST = \frac{\sum y_i^2 - T^2}{N} \]

\[ T = \sum y_i = (0.55+0.65+0.40+0.45+0.8+0.4+0.4+0.4+0.7) \]

\[ T = 4.75 \]

\[ N = \text{no of rows in orthogonal array} \]

\[ N = 9 \]

\[ \sum y_i^2 = (0.55)^2 + (0.65)^2 + (0.4)^2 + (0.45)^2 + (0.8)^2 + (0.4)^2 + (0.4)^2 + (0.7)^2 = 2.6975 \]

\[ T^2/N = (4.75)^2/9=2.5069 \]

\[ ST = 2.6975 - 2.5069 = 0.1906 \]

DOF = Degrees of Freedom

DOF = Levels - 1

DOF\(_{\text{Total}}\) = 9 - 1 = 8

DOF\(_{\text{Factor}}\) = Level - 1 = 3 - 1 = 2

DOF\(_{\text{Error}}\) = DOF\(_{\text{Total}}\) - DOF\(_{\text{All factors}}\)

= (8) - (6)

= 2

\[ \text{SOS}_A = \frac{\Sigma A^2}{n - T^2/N} \]

\[ = \frac{\left((0.55+0.65+0.4)+0.45+0.8+0.4+0.4+0.7\right)}{3} - 2.5069 \]

\[ = 2.5106 - 2.5069 \]

\[ = 0.003 \]

Similarly, we get \( \text{SOS}_B = 0.0371 \)

and \( \text{SOS}_C = 0.0339 \)

\[ \text{SOS}_{\text{Error}} = ST - \sum (\text{SOS}) \]

\[ = 0.1906 - (0.003+0.0371+0.0339) \]

\[ = 0.1906 - 0.074 \]

\[ = 0.1166 \]

2) Variance = \( \frac{\text{SOS}_A}{\text{DOF}} \)

\[ = \frac{0.0037/2}{2} = 0.00185 \]

Variance of Error = \( \frac{0.1141}{2} \)

\[ = 0.05705 \]

3) PURE SUM = \( \text{SA}^1 = S_{A^*} \) (variance error*F)
\[
= 0.00185 - (0*0) = 0.00185
\]

Total sum = 0.00185+0.018+0.016965
= 0.036815

4) \% of Factor = (S1 factor/ total sum) *100
= (0.037/0.1913) *100= 19.3%

| Table 3. ANOVA Table |
|----------------------|
| Factor | DOF | SOS   | Variance | Pure SUM | % of Factor |
| A      | 2   | 0.0037 | 0.00185 | 0.00185 | 19.3       |
| B      | 2   | 0.0371 | 0.018   | 0.018   | 19.40      |
| C      | 2   | 0.0339 | 0.01697 | 0.01697 | 17.72      |
| Error DOF | 2 | 0.1166 |        |         | 60.95      |
| Total  | 6   | 0.1913 |        |         | 100        |

Similarly, we get the % of contribution by factor B i.e., % volume fraction is 19.40 and for factor C which is treatment with alkali is 17.72% and the error % which constitutes all the uncontrollable factors is almost 60%.

4. Conclusions
A sequence of banana fibre reinforced epoxy composite samples was prepared using the casting process. Different parameters, length of the fibre (0.1mm, 1mm, 10mm), Volume fraction (15wt%, 25wt%, 35wt%) and chemical treatment (0%, 2%, 5%) were incorporated for preparing the composites by casting method. Toughness testing investigation reported that the length of fibre plays a nominal role and the volume fraction plays a prominent role. However, the impact strength is not increasing continuously with increase in the volume fraction where it is reaching a maximum value and then decreasing. The same is the case with treatment with NaOH. The optimum length, volume fraction and chemical are 1mm, 25 wt% and 2% NaOH treatment shows better result.

Challenges include the homogenization of the fibre's properties and a full understanding of the crystallization and degree of polymerization, adhesion between the matrix and fibre, flame-retardant and moisture repellence properties.

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