

# Influence of Fiber Content and Effect of Chemical Pre-Treatments on Mechanical Characterization of Natural Abaca Epoxy Composites

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## Abstract

The focal point of this research work is on the preparation of untreated and chemically treated abaca reinforced epoxy composites and the impact of these pre-treatments on tensile and flexural behavior of the composites. Alkali treatment, acrylation, permanganate treatment and benzenediazonium chloride treatments were carried out on abaca strands. Unprocessed and chemically processed fibers were used in the fabrication of epoxy composites with different fiber loadings of 20%, 30%, 40%, 50% and 60% using compression moulding technique. Tensile tests and flexural tests were performed using ASTM D638 [Type III] and ASTM D790 standards respectively. From these studies it can be concluded that chemical treatments are very effective in modifying the fiber surface, reducing the hydrophilic nature of fiber, improving fiber matrix adhesion there by increasing the mechanical performance of composites. Untreated Composites with 40% fiber loading and 10 mm fiber length showed maximum tensile strength of 36.48 MPa. For untreated as well as for all chemically treated abaca-epoxy composites, as the fiber loading surged from 10% to 40% , increment in tensile strength values were observed and beyond 40% it showed a decline. Benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum tensile strength of 58.62 MPa, followed by acrylic acid treatment, permanganate treatment and alkali treatment with tensile strength values of 50.28, 48.84, and 43.78 MPa respectively. Flexural strength also showed same trend as that of tensile strength. Benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum flexural strength of 67.86 MPa, followed by acrylic acid treatment, permanganate treatment and alkali treatment with flexural strength values of 60.24, 58.56, and 56.46 MPa respectively. Most of the studies were carried out for alkali treated composites but this study focused on acrylation, permanganate and benzenediazonium chloride treatments. These treatments enhanced tensile strength and flexural strength.

**Keywords:** Abaca Fibers, Chemical Treatments, Epoxy Resin, Fiber Loading, Mechanical Properties

## 1. Introduction

Conventionally, in aerospace, automotive and packaging industries synthetic fiber reinforced composites are

widely used as they are having greater toughness and rigidity. But synthetic fibers are expensive and not ecofriendly. So, of late biofibers are replacing synthetic fibers which are extensively used as reinforcements in composites and these materials are gaining

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popularity as potential structural materials because they are abundantly available renewable, sustainable, light weight, non abrasive, biodegradable, economical and ecofriendly. Biocomposites are promising materials of the future because of their good mechanical performance. In spite of these positive points, natural fibers as reinforcements suffer certain drawbacks. The constituents of natural fibers contain hydroxyl groups which make these fibers hydrophilic and increases moisture sensitivity, where as matrix material is hydrophobic in nature. As a consequence the interfacial bonding between fiber and matrix will not be so strong. The main role of matrix is to transfer the load on to the fibers at the interface. Efficient load transfer is possible if there is proper bonding between fiber and matrix. Poor adhesion does not give optimum properties for the composites. Compatibility between fiber and matrix can be enhanced by suitable chemical treatments. Moisture absorption in a composite is influenced by volume fraction of fiber, voids, viscosity of the matrix, humidity and temperature. Moreover the properties of natural fibers depends on the climate, location and weather from which they are grown and also depends on fiber length, age and separating techniques of the fiber and hence very difficult to predict the composite properties<sup>1-10</sup>.

Natural fibers are the composites in which cellulose fibrils are embedded in lignin and hemicelluloses matrix. The efficiency with which the natural fiber can act as reinforcement mainly depends on cellulose and its crystallinity. The major ingredients of natural fibers are cellulose, hemicelluloses, lignin, pectin and waxes.  $\beta$ -1,4 glycosidic linkages at C1 and C4 positions are present in the structure of cellulose. Every monomer present in cellulose consists of three hydroxyl groups which are capable of forming hydrogen bonds. Cellulose is crystalline, linear, and resistant to alkali and oxidizing agents but hydrolyzed by acids. Toughness, rigidity and structural stability of the fiber are attributed to its cellulose content. Tensile strength and flexural strength of fibers enhances with increment in cellulose content. Hemicelluloses are polysaccharides consisting of several 5 and 6 carbon ring sugars. They are branched, non crystalline and degree of polymerization is less than that of cellulose. They are having affinity towards water, miscible in alkali and undergo acid hydrolysis. Lignin is amorphous, hydrophobic and is responsible for rigidity of plants. It is a derivative of 4-hydroxy-3-methoxy phenyl propane. It is immiscible in most of the solvents and cannot be reduced to simpler

monomer units. Pectin provides flexibility to the plants and waxes consists of different types of alcohols<sup>11-13</sup>.

Fibers with high crystallinity i.e. high cellulose content, high aspect ratio i.e. ratio of length of the fiber to the diameter of the fiber, and low microfibrillar angle i.e. the angle between fiber axis and the micro fibrils, possess superior mechanical properties. Microfibrillar angle is a measure of the stiffness of the fibers<sup>14</sup>.

The botanical name of abaca is *Musa textilis* which is a species of banana grown extensively in Philippines. It is also called Manila hemp. Abaca plant belongs to the banana family *Musaceae*, Genus *Musa* and species *Musa textilis*. The Republic of the Philippines is the largest producer producing around 50,000 tons per annum. Abaca fibers find extensive applications in fashion accessories, decorative accessories, furniture, garments, textile, packaging materials, and table-top accessories. Sinamay is the fabric made from abaca fibers and the benefits of sinamay materials are in making gift boxes, packaging materials, decorative accessories, wall coverings, fashion accessories, footwear, tabletop accessories etc. Currency and bank notes, tea bags, coffee filters are all the products of abaca fibers. The utility of abaca fibers is also seen in medical applications such as for orthopedic materials, surgical caps and masks. These fibers are promising materials in composites and act as good substitute for glass fibers in the manufacturing of various components in automotive industry. Mercedes Benz used abaca fiber reinforced polypropylene composites in automobile body parts. Daimler Chrysler used these abaca fiber reinforced composites in under floor protection of passenger cars<sup>15,16</sup>. The use of abaca fiber instead of glass fiber reduces the weight of automotive parts, bringing about 60% savings in energy and reduces CO<sub>2</sub> emissions making it environment friendly. These composites are also used in construction as well as packaging industries.

Abaca is prized for its great mechanical strength, buoyancy, resistance to salt water damage, and long fiber length up to 3 m<sup>17</sup>. Ease of availability, sustainability, high tensile strength, resistance to rotting and specific flexural strength in proximity to that of glass fibers makes abaca fibers superior<sup>18</sup>. But the disadvantages of using these fibers as reinforcements are: fibers are hydrophilic and matrix is hydrophobic which results in uneven distribution of fibers in the matrix leading to difficulties in fabrication of composites. Like other natural fibers abaca fibers also absorb large quantities of water and causes

swelling reducing the dimensional stability of the composites. All these things results in decreased mechanical performance of the composites. Most of these drawbacks can be overcome by chemical treatments.

Alkali treatment helps in the elimination of hydrogen bonding from the fiber network structure which substantially reduces moisture absorption and also changes the surface morphology. Acrylation and acetylation reduced the diffusion of water into the fiber making it more water repellent. This is attributed to the fact that during these treatments, hydrophilic hydroxyl groups were substituted by hydrophobic ester groups<sup>19</sup>. In permanganate treatment more reactive permanganate ions combine with cellulose hydroxyl groups forming cellulose manganate. This reduces hydrophilic nature of the fiber and also improves the mechanical inter locking with the matrix<sup>20</sup>.

Matrix is the binding material which holds fibers in position and transfers the load to the fibers when external load is applied. The binding material is a thermoset resin. The advantages of using a thermoset resin are these resins are having low resin viscosity, good fiber wetting, excellent thermal stability once polymerized, and chemically resistant. But at the same time they are brittle and non-recyclable. The matrix will react with the surface molecules of the fiber in composite fabrication<sup>21</sup>.

Tensile Strength is the capacity of a material to withstand the force exerted on it. Force exerted per cross-sectional area determines the tensile strength. A moulded dumbbell is used to measure the composite's tensile strength. The dumbbell shaped specimen is placed in between the grips in the appropriate position in the testing machine. The force is continuously exerted on the specimen till the failure occurs. The force applied on the specimen, when the failure of the specimen occurs constitutes the tensile strength. The size of the specimen does not influence the tensile strength as it is an intensive property but it depends on the fabrication methods of the specimen, the existence of surface defects and the temperature conditions under which the test was performed.

Flexural strength, a mechanical parameter is the capacity of the specimen material to oppose distortion under applied force. It is the ability of the material to bend without undergoing major deformities. It is the maximum stress that the material can withstand at the point of fracture. It is measured using a three point flexural test or bending test. It is an important calculation for many builders and designers in engineering and architectural fields

to know the weight bearing capacity of many materials. Based on these calculations it is possible to choose appropriate materials for buildings, industrial machinery, cars, basic consumer appliances etc. It plays a significant role in civil, mechanical, aerospace engineering and design.

This study mainly focuses on the preparation of untreated, alkali treated, acrylated, benzenediazonium chloride treated and permanganate treated abaca reinforced epoxy composites and the impact of these chemical pre-treatments and the influence of fiber content on the tensile properties and flexural behavior of the composites.

## 2. Materials and Methods

### 2.1 Materials

Abaca fibers were collected from the Maruthi Peach Finishing Company, Tirupur, Chennai, India and Analytical grade reagents were purchased from Qualigens Company and used as received. The epoxy resins and hardener were procured from Akolite Synthetic Resins, Mangalore.

### 2.2 Alkali Treatment of Fiber

Abaca fibers were immersed for 72 h in 1:2 mixtures of ethanol and benzene, and were dewaxed. These abaca strands were thoroughly washed with deionised water and then dried in air. The dewaxed fibers were then soaked in 6% NaOH solution at room temperature (30-32 °C) for 1h. The volume of NaOH solution utilized was 15 times the weight of the fibers. The fibers were dipped in alkaline solution for 36 hours at a temperature of 30 °C; then they were thoroughly washed under running water and to remove excess alkali, were neutralized with 2% acetic acid solution. Finally, to remove the last traces of acid adhering to it, the fibers were washed again under running water. Confirm the elimination of excess of acid by testing the pH so that the pH of the fibers was approximately 7. Then, alkali-treated fibers were obtained by drying these fibers for 48 hours at room temperature<sup>22,23</sup>.

### 2.3 Acrylic Acid Treatment of Fiber

During acrylation, first abaca fibers were subjected to alkali pre-treatment, and then these pretreated fibers were immersed in 1% Acrylic Acid (AA) solution at 50 °C for 1 h. Afterwards these fibers were thoroughly washed with distilled water and oven dried for 24 h at a temperature of 70 °C.

## 2.4 Permanganate Treatment of Fiber

The fibers were drenched in 6% NaOH solution for 30 minutes and then thoroughly washed with distilled water. These alkali pretreated fibers were treated with 0.5%  $\text{KMnO}_4$  in acetone solution for 2 min, washed with water and oven dried at 80 °C.

## 2.5 Preparation of Benzenediazonium Chloride

8 cm<sup>3</sup> of concentrated hydrochloric acid was added to a boiling tube containing 3 cm<sup>3</sup> of phenyl amine (aniline) and 10 cm<sup>3</sup> of water, the mixture was shaken until the amine has dissolved, and then the solution was cooled to 5 °C by cooling it in an ice bath. After that a solution of sodium nitrite (3 g in 8 cm<sup>3</sup> of water), previously cooled to 5 °C was added. During addition process the mixture temperature was maintained below 10 °C<sup>24</sup>.

## 2.6 Benzenediazonium Treatment of Fiber

The abaca fibers were cleansed with distilled water, and then dried in an oven at 70 °C for 24 h. Take a 2.0 L glass beaker and soak the dehydrated fibers in 6% NaOH solution for 10 minutes at about 5 °C. With continuous stirring, add slowly the freshly prepared benzene diazonium solution into the above beaker. Take out the fibers from the beaker, then wash them thoroughly with soap solution and distilled water. Lastly, dry them in open air for 48 h<sup>25</sup>.

## 2.7 Composite Fabrication

To remove the moisture content present in the abaca fibers, they were dried in air at room temperature for 24 h and then oven dried at 105 °C for 24 h. The dehydrated fibers were chopped into varying lengths of 5 mm, 10 mm and 15 mm; they were mixed with epoxy resin. The composite preparation method was carried out as mentioned here. Initially, 10 parts of the Epoxy-556 resin was mixed with 1 part of the HY951 hardener. Inside the mixing chamber, first add 50% of the resin and run it at 20 RPM for about 1 min. Then add the chopped fibers for a span of 2 min. Then, the remaining 50% of the epoxy resin was added to the mixing chamber and the mixing speed was augmented to 30 RPM for a period of 5 min. The resulting material was compression moulded.

The constant load of 50 kg was applied on the mould for 24 h at laboratory temperature, 30 ± 2 °C. In the end, the composites were kept at room temperature for a span of 15 days for curing. During the blending of the fibers into the matrix, the weight fractions 10, 20, 30, 40, 50, and 60 % of fiber was carefully guarded. The moulds have been prepared with dimensions of 300 × 300 × 10 mm<sup>3</sup>. Equation (1) was used in the composite fabrication.

$$V_f = \frac{\frac{W_f}{\rho_f}}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} \quad (1)$$

Where  $W_f$  is the weight of fiber (g),  $W_m$  is the weight of matrix (g),  $V_f$  is the fiber volume fraction (%),  $\rho_m$  is the density of matrix (g/cm<sup>3</sup>) and  $\rho_f$  is the density of fiber (g/cm<sup>3</sup>).

## 2.8 Composite Characterisation

After the fabrication of the composites, according to the suitable ASTM methods, they were sliced into required dimensions with the help of zig saw for performing the tests. Every test was carried out on five duplicate specimens and the outcomes were presented as mean of tested specimens. The tests were performed under standard conditions of 30 ± 2 °C laboratory temperatures and 65% relative humidity.

The tensile strength measurement was carried out according to ASTM D638 [Type III] standards. The dimensions of dumbbell shaped specimen were 250 mm total length, 100 mm gauge length, 22 mm width at gauge length section and 35 mm width at gripping section and 10 mm uniform thickness. The specimen was loaded in the computerised universal testing machine and force is exerted on the specimen till the development of fracture at laboratory conditions.

The 3-point bending test method was followed according to ASTM D790 standards while conducting flexural tests on a universal testing machine (Instron 5566). The dimensions of the test specimen were 100 mm (L) x 50 mm (W) and 10 mm (d) thickness. The specimens were tested at a crosshead speed of 2 mm/min. The bending stress is calculated from the measured load, as follows:

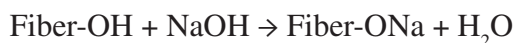
$$\sigma_{max} = \frac{3PL}{2bd^2} \dots\dots\dots(2)$$

Where,  $\sigma_{\max}$  = flexural strength,  $P$  = load at yield (maximum load),  $L$  = support span (mm),  
 $b$  = width (mm),  $d$  = thickness (mm).

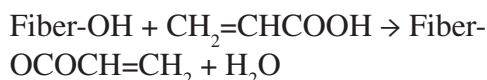
## 3. Results and Discussion

### 3.1 Chemical Treatment of Fibers

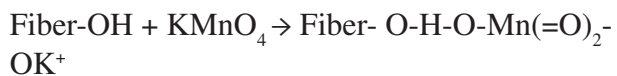
Fibers contain hydroxyl groups which are capable of forming hydrogen bonding with water making them hydrophilic. But when these fibers were treated with alkali, hydroxyl groups were replaced by 'ONa' making them incapable of forming hydrogen bonding which substantially reduces moisture absorption. After alkali treatment, amorphous cellulose content increases at the cost of crystalline cellulose. Abaca fiber morphology significantly changed due to alkali treatment.



Acrylation decreased the dissemination of water into the fiber making it more hydrophobic. Acrylic acid treated abaca fiber showed lower moisture absorption. This is attributed to the fact that during acrylation hydrophilic hydroxyl groups are substituted by hydrophobic ester groups.



In permanganate treatment, cellulose hydroxyl groups combine with highly reactive permanganate ions forming cellulose manganate. As a result of this treatment, chemical interlocking between the fiber and matrix improved which in turn facilitated superior fiber matrix adhesion. This treatment helped in reducing the water absorption property of the fiber.



Benzenediazonium chloride treatment is also used in decreasing the hydrophilic nature of fibers by increasing fiber matrix adhesion. It undergoes coupling reaction with OH groups of the fiber forming diazo cellulose compound.

### 3.2 Tensile Strength

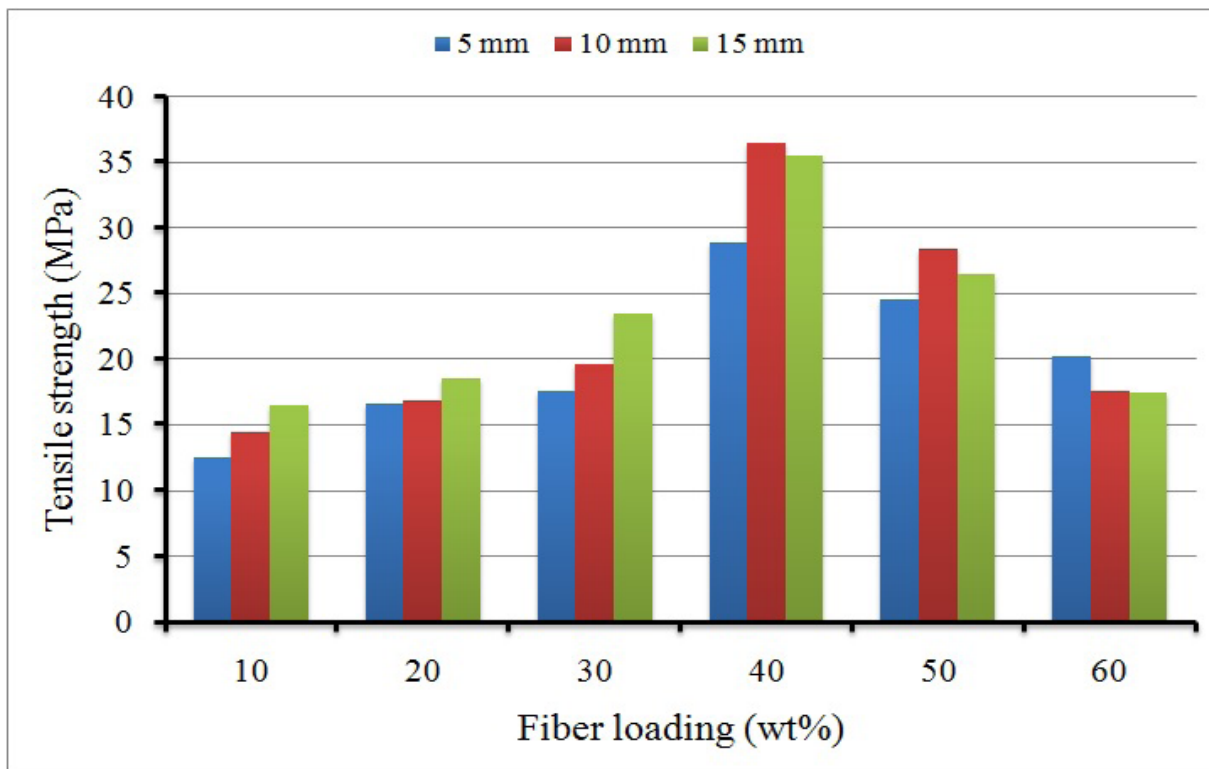
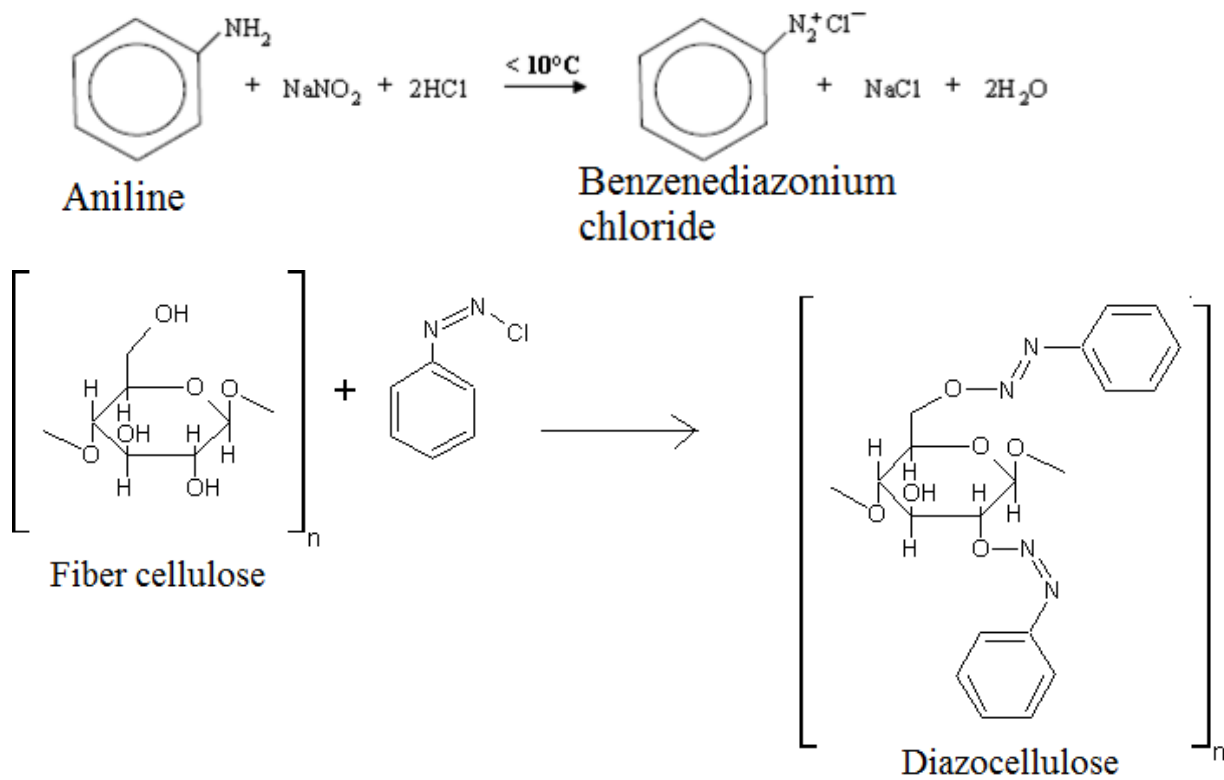
The properties of biocomposites are not only determined by the components constituting it, but also affected by many other factors. However, fiber geometry, fiber orientation, fiber length and fiber loading plays key role in determining the properties. When external load

is imposed on to the matrix, stress is transferred from matrix to the fiber throughout the length of the fiber from one end of the fiber to the other end of the fiber and hence fiber length becomes one of the key parameters in determining the magnitude of stress transfer.

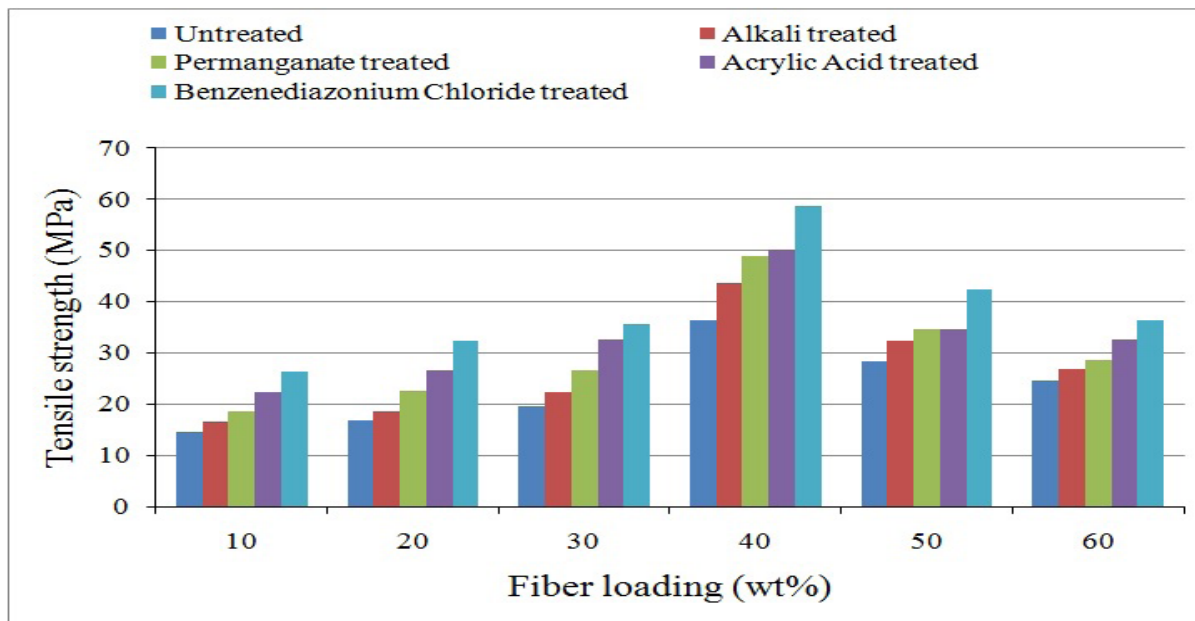
In this work, abaca fiber reinforced epoxy composites were fabricated with different fiber lengths of 5 mm, 10 mm, and 15 mm and different fiber loadings of 20%, 30%, 40%, 50% and 60% and were evaluated for tensile properties. It is a must to know optimum fiber loading to get good tensile properties. So, the variation of tensile strength with different fiber lengths and different fiber loadings were studied.

From Figure 1 it is clear that, amongst all the composites prepared, composite with 40% fiber loading and 10 mm fiber length showed highest tensile strength of 36.48 MPa. Bledzki et al<sup>15</sup> reported that as the fiber content increased from 10% to 40%, there is surge in tensile and flexural strength values and beyond 40% fiber loading, decline in the values were observed in abaca reinforced Polypropylene composites. Better fiber distribution in matrix and less fiber fractures are responsible for this trend<sup>15</sup>. L.A. Pothan et al<sup>26</sup> showed through SEM analysis of banana fiber reinforced polyester composites that at 40% fiber loading there is good fiber matrix adhesion<sup>26</sup>. For 40% fiber loading, tensile strength increased by 26.40% when fiber length increased from 5 mm to 10 mm and decreased by 2.63% when fiber length increased from 10 mm to 15 mm. For 10%, 20% and 30% fiber loading, as the fiber length increased, rise in tensile strength values were observed. For 40%, and 50% fiber loading, tensile strength values enhanced with rise in fiber length from 5 mm to 10 mm and then it decreased for 15 mm length. In case of 60% fiber loading, tensile strength values declined with rise in fiber length. For a particular fiber length, tensile strength values augmented with rise in fiber loading up to 40% loading and henceforth it declined with rise in fiber loading.

Amongst different fiber lengths considered, highest tensile strength was shown by 10 mm fiber length, so, the composites were prepared with 10 mm fiber length and the influence of different chemical treatments and different fiber loadings on the tensile properties of abaca- epoxy composites was also studied. The observed tensile strength values of composites can be understood in terms of chemical constituents of fiber.



**Figure 1.** Effect of fiber length and fiber loading on tensile strength of composites.



**Figure 2.** Effect of fiber treatment on tensile strength of composites.

From Figure 2 it is observed that the untreated abaca fiber reinforced epoxy composite is having low tensile strength in comparison with chemically treated abaca fiber reinforced epoxy composites. This can be justified on the basis that the untreated fibers are hydrophilic where as the matrix is hydrophobic. This results in incompatibility between the fiber and the matrix.

Greater number of hydroxyl groups was exposed on the surface of the fiber making them accessible for bonding due to the removal of lignin and hemicelluloses after alkali treatment, thus enhancing fiber matrix adhesion. Not only that, alkali treatment also cleans the fiber surface, decreases the diameter of the fiber and augments the aspect ratio, increases stress transfer capacity thereby increasing the tensile strength. In case of alkali treated abaca-epoxy composites the tensile strengths of 30%, 40% and 50% fiber loadings are 22.45, 43.78 and 32.46 MPa respectively. For 40% fiber loading tensile strength increased by 95.01% compared to 30% fiber loading and for 50% fiber loading it decreased by 25.85% compared to 40% fiber loading. Srinivasa Babu et al<sup>27</sup> reported that after alkali treatment the tensile strength of the okra composites surged up by 154.17% in comparison with untreated okra composites<sup>27</sup>. Permanganate treatment provides better interlocking at the interface by making the surface rough and improves fiber matrix adhesion<sup>28</sup>.

In case of permanganate treated abaca-epoxy composites the tensile strengths of 30%, 40% and 50% fiber loadings

are 26.48, 48.84 and 34.56 MPa respectively. For 40% fiber loading tensile strength increased by 84.44% compared to

In case of permanganate treated abaca-epoxy composites the tensile strengths of 30%, 40% and 50% fiber loadings are 26.48, 48.84 and 34.56 MPa respectively. For 40% fiber loading tensile strength increased by 84.44% compared to 30% fiber loading and for 50% fiber loading it decreased by 29.24% compared to 40% fiber loading. Acrylation of the fiber results in boosting the stress transfer efficiency at the interface of fiber and matrix thereby augmenting the tensile strength. In case of acrylated abaca-epoxy composites the tensile strengths of 30%, 40% and 50% fiber loadings are 32.58, 50.28 and 34.56 MPa respectively. For 40% fiber loading tensile strength increased by 54.32% compared to 30% fiber loading and for 50% fiber loading it decreased by 31.26% compared to 40% fiber loading.

The coupling reaction between fiber and benzenediazonium chloride facilitates fiber matrix adhesion and improves the tensile strength. In case of benzenediazonium chloride treated abaca-epoxy composites the tensile strengths of 30%, 40% and 50% fiber loadings are 35.68, 58.62 and 42.52 MPa respectively. For 40% fiber loading tensile strength increased by 64.29% compared to 30% fiber loading and for 50% fiber loading it decreased by 27.46% compared to 40% fiber loading.

For untreated as well as for all chemically treated abaca-epoxy composites from 10% to 40% and beyond 40%

it showed a decline. That means maximum tensile strength is exhibited by composites with 40% fiber loading. This is because at 40% fiber loading, there is better fiber distribution in matrix, less fiber fractures and efficient stress transfer between fiber and matrix. As fiber loading increased beyond 40%, tensile strength decreased due to lack of proper adhesion and ineffective stress transfer across matrix and fibers<sup>29</sup>.

When the tensile strength values of untreated fiber composites were correlated with different chemically treated composites of 40% fiber loading, alkali, permanganate, acrylated and benzenediazonium chloride treated fiber composites showed 20.01%, 33.88%, 37.83% and 60.69% increase in tensile strength respectively. These results clearly indicated that chemical treatments are effective in bringing about changes in surface morphology of the fiber and thus improving the mechanical behavior. Amongst all the treatments carried out, benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum tensile strength. So, these composites are best suited for applications where high tensile strength is required.

### 3.3 Flexural Strength

Flexural strength is an important property which tells about the materials ability to resist deformation under load. It is the maximum stress a material can withstand at the point of distortion. Flexural test is a measure of specimen's capability to endure the bending prior to the failure of the specimen.

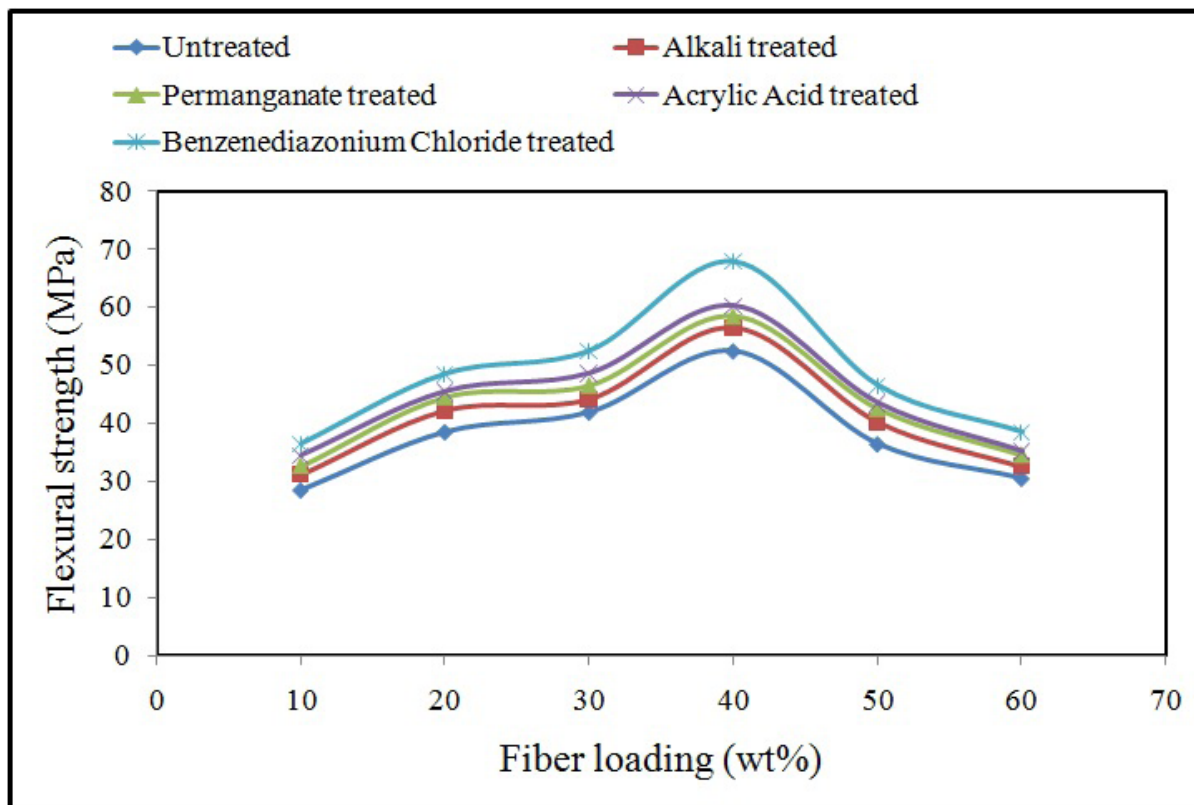
Flexural properties showed similar trends as that of the tensile strength. Many researchers revealed that increase in fiber loading as well as chemical treatment of the fibers resulted in superior mechanical properties of the composites like tensile and flexural properties<sup>30</sup>. Flexural strength of bamboo/epoxy composites increased as the fiber content surged to 30% and then decreased. This decrease is due to lack of proper bonding at the interface of fiber and the matrix resulting in voids generating a fragile structure. Chemical treatments increased flexural strength due to elimination of outer surface of the fiber, enhancement in cellulose content and improved adhesion across the fiber and matrix<sup>31</sup>.

The influence of fiber content and various chemical treatments on the flexural strength of abaca –epoxy composites is depicted in Figure 3.

It is clear that flexural strength is significantly affected by both fiber loading and the type of chemical treatment. As the fiber content surged from 10% to 40%, increment in the flexural strength values were observed and further rise in fiber loading resulted in dwindling of the flexural strength of composites regardless of the type of chemical treatment. The observed flexural strength values of composites can be understood in terms of chemical constituents of fiber. From Figure 3 it is observed that the untreated abaca fiber reinforced epoxy composite is having low flexural strength in comparison with chemically treated abaca fiber reinforced epoxy composites. This can be elucidated on the fact that the untreated fibers are hydrophilic where as the matrix is hydrophobic. This results in incompatibility between the fiber and the matrix. Greater number of hydroxyl groups was exposed on the surface of the fiber making them accessible for bonding due to the removal of lignin and hemicelluloses after alkali treatment, thus enhancing fiber matrix adhesion. Not only that, alkali treatment also cleans the fiber surface, decreases the diameter of the fiber and augments the aspect ratio, increases stress transfer capacity thereby increasing the flexural strength<sup>12,28</sup>.

In case of alkali treated abaca-epoxy composites the flexural strengths of 30%, 40% and 50% fiber loadings are 44.24, 56.46 and 40.24 MPa respectively. For 40% fiber loading flexural strength increased by 27.62% compared to 30% fiber loading and for 50% fiber loading it decreased by 28.73% compared to 40% fiber loading. Permanganate treatment provides better interlocking at the interface by making the surface rough and improves fiber matrix adhesion. In case of permanganate treated abaca-epoxy composites the flexural strengths of 30%, 40% and 50% fiber loadings are 46.59, 58.56 and 42.56 MPa respectively. For 40% fiber loading flexural strength increased by 25.69% compared to 30% fiber loading and for 50% fiber loading it decreased by 27.32% compared to 40% fiber loading.

As the fiber loading surged from 10% to 40%, increment in flexural strength values were observed and beyond 40% it showed a decline for untreated as well as for all chemically treated abaca-epoxy composites. This is because at 40% fiber loading, there is better fiber distribution in matrix, less fiber fractures and efficient stress transfer between fiber and matrix. As fiber loading increased beyond 40%, flexural strength decreased due to lack of proper adhesion and ineffective stress transfer across matrix and fibers<sup>29</sup>.



**Figure 1.** Effect of fiber treatment on flexural strength of composites.

When the flexural strength values of untreated fiber composites were correlated with different chemically treated composites of 40% fiber loading, alkali, permanganate, acrylated and benzenediazonium chloride treated fiber composites showed 7.50%, 11.50% and 14.70% and 29.21% increase in flexural strength respectively. These results clearly indicated that chemical treatments are effective in bringing about changes in surface morphology of the fiber and thus improving the mechanical behavior. Amongst all the treatments carried out, benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum flexural strength. So, these composites are best suited for applications where high flexural strength is required.

## 4. Conclusion

From these studies we can conclude that chemical treatments are very effective in modifying the fiber surface, reducing the hydrophilic nature of the fiber, improving the interfacial adhesion across the fiber and matrix thereby enhancing the mechanical performance of the composites. Untreated Composites with 40% fiber

loading and 10 mm fiber length exhibited highest tensile strength of 36.48 MPa. As the fiber loading surged from 10% to 40%, increment in tensile strength values were observed and beyond 40% it showed a decline for untreated as well as for all chemically treated abaca-epoxy composites. Amongst all the treatments carried out, benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum tensile strength of 58.62 MPa, followed by acrylic acid treatment, permanganate treatment and alkali treatment with tensile strength values of 50.28, 48.84, and 43.78 MPa respectively. Flexural strength also showed same trend as that of tensile strength. Amongst all the treatments carried out, benzenediazonium chloride treated fiber composites of 40% fiber loading showed maximum flexural strength of 67.86 MPa, followed by acrylic acid treatment, permanganate treatment and alkali treatment with flexural strength values of 60.24, 58.56, and 56.46 MPa respectively.

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