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Improving Impact Strength and Water Absorption Properties of Enset Fiber Reinforced Polyester Composite

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ABSTRACT

This study investigated the utilization of natural Enset fiber which is extracted from a perennial herbaceous plant cultivated in south-western Ethiopia as reinforcement in Polyester resin matrix for non-load bearing structural elements. The composite samples have been developed by manual hand layup followed by a compression technique. The fiber was treated with a 5wt% NaOH solution (Alkali treatment) for better fiber-matrix adhesion. The fiber percentages (10wt%, 20wt% and 30 wt% by weight) were used for the preparation of the composite. Impact strength and water absorption properties of both raw and alkali-treated fiber-based composite were studied. The result obtained shows that NaOH solution treatment has a positive effect on the impact strength and water absorption properties of the composite. For raw fiber-based composite optimum impact strength was recorded at 20wt% fiber content. However, for treated fiber-based composite highest value was obtained at 30wt% fiber content. For both raw and treated fiber-based composite water absorption is directly proportional to fiber content and it is high for raw fiber-based composite.

Key Words: Natural Fiber, Polyester Resin, Alkali Treatment, Impact Strength, Water Absorption.

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1. INTRODUCTION

Currently worldwide environmental and economic interests stimulate research in developing new materials whose substantial portion is based on renewable resources in order to avoid further pressure on the environment. Natural fibers are renewable and obtained from natural resources that present several advantages, including: low density, acceptable specific strength properties, low abrasiveness, low cost, high biodegradability and existence of vast resources. One of the suitable plants with great potential for the production of natural fiber is enset (**Ensete ventricosum**) which is a perennial herbaceous plant that is grown in Southern and South Western Ethiopia primarily cultivated as source of food. For many years the enset filers have been extracted from the leaves of this plant as major material for the weaving, ropes and cord production, as well as for baskets production [1]. In these few years researches are pointing enset fibers which are obtained from the stalk of enset plant, offer possibilities for engineering applications [2-4]. Enset fiber possesses good specific strength and stiffness properties comparable to those of conventional materials and has potential to replace synthetic fibers in different application area. As a result, composite material developed from this fiber has high strength to weight ratio and high stiffness to weight ratio; which increases its engineering applications. Previous studies have shown that alkali treatments have been proven effective in removing impurities from natural fibers, decreasing moisture absorption and enabling mechanical bonding, and thereby improving matrix-reinforcement interaction and mechanical properties [5-8]. A review by [9] implies that good compatibility of fibers and matrix resulted in reduction of water uptake of the composite. In order to obtain these improved properties, the extracted enset fiber is treated by 5wt% of sodium hydroxide solution. Several investigations made on natural fibers such as bamboo, kenaf, hemp, and jute studied their effects on the impact strength of composite materials for structural applications [10, 11]. Impact strength of natural fiber reinforced polyester composite increases with fiber content until there is better wettability of the fibers by the matrix [12, 13]. The present work focuses on investigating the reinforcement potential of randomly oriented short enset fiber in general purpose polyester resin and characterizing its impact strength and water absorption property.

2. MATERIALS AND METHODS

2.1 Materials

The fiber was extracted from the matured stalk of enset plant. In the current investigation, short chopped enset fibers with average 10 mm length was used as the reinforcement in the composite. General purpose resin Orthophthalic type bought form World fiber and water proofing Engineering, Addis Ababa, Ethiopia was used as matrix material. The resin has thixotropic features and it is a range of unsaturated polyester resins in styrene which is suitable for both hand & spray lay-ups in all general laminating applications. The standard Polyester Gel Coat was used as finish over the composite. The curing agent applied for the liquid resin and gel coat is Hardener with brand name of ***BUTANOX M-50.*** The chemical nomenclature of the hardener is (MEKP) Methyl Ethyl Ketone peroxide.

2.2 Experimental Method

In addition to sun drying at early extraction, enset fibers were dried in an oven at 40°C for 48 hours before any treatment or processing was done. This temperature is enough to vaporize the moisture present in the fiber without damaging the fiber. This solution is made on the basis of mass percent. Pre-dried fibers were soaked in prepared NaOH solution at ambient temperature. The fibers were kept immersed for two hours. In order to remove any traces of alkali from the fibers surface, the fibers were washed thoroughly by water. Finally treated fibers were then dried at 40°C for 48 hours. The present work was conducted by taking catalyst percentage as 1.5%. Gel coat is to be used as a finish over the composite with 2% catalyst. Heat which is used to cure the resin is created by a chemical reaction between catalyst and the resin

2.3 Composite Sample Preparation

Here for composite fabrication Hand lay-up technique was used. The mold used to fabricate the samples was made of wooden plate. A releasing agent (Vaseline) which is used to facilitate easy removal of the composite from the mold was lubricated on the mold. Gel coat, which is pigmented resin, was applied to the mold to give the part color and enhance the properties. Then raw and chemically modified weighted quantity of chopped enset fiber was mixed with polyester resin originally modified by hardener and added to the prepared mold. In order to evenly distribute the resin and removes air pockets the composite is pressed under pressure of 0.25MPa. The composite is cured at room temperature within 24 hours. After the part is cured it is removed from the mold. Excess material is trimmed off, and the part is cut into different specimens for testing. The following pictures describe the overall composite manufacturing process.

Figure 1. Fiber Extraction from Enset plant; a) Enset plant, b) separating pseudo-stem from leaves, c) slitting thin slice from the inner face of the layer, d) fiber decortication and e) final extracted fiber

a b c

Figure 2. a) Polyester resin modified by hardener and mixed with chopped fiber filled the mold b) mold is closed and pressed c) the composite product

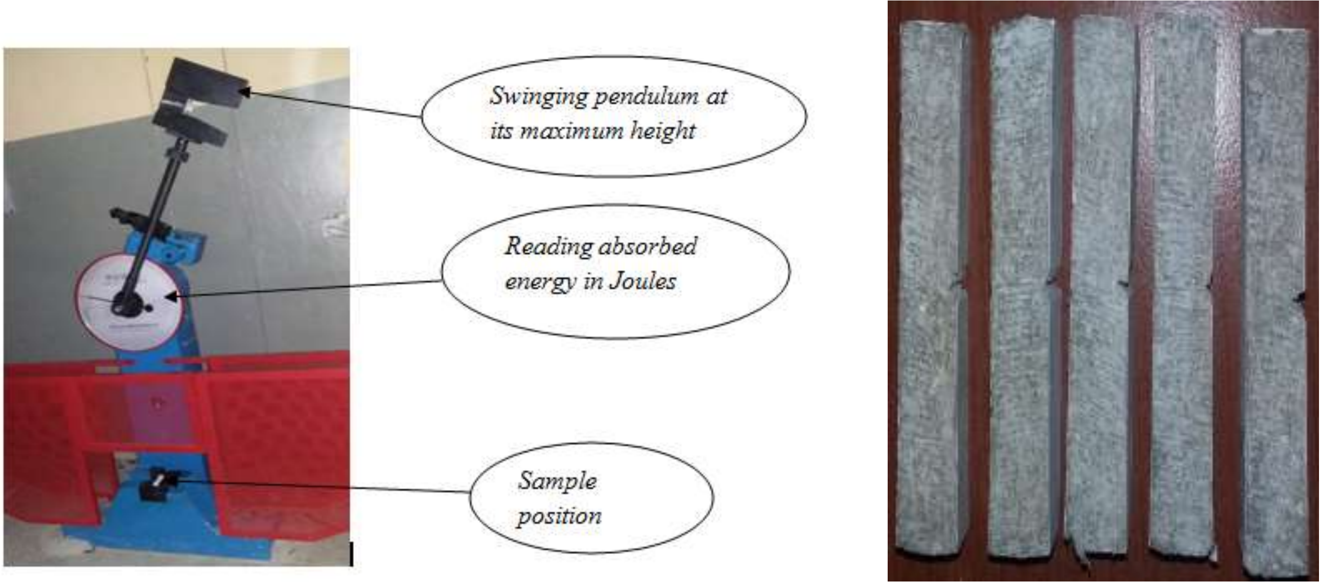
2.4 Testing Methods and Characterization

2.4.1 Impact Strength Testing

Charpy impact test specimens were prepared in accordance with EN ISO 179-1. The specimen has dimensions of 80 mm length, 10 mm width and 10 mm thickness. A notch with included angle 45° was drawn across the center of the saw cut at 90 ° and *2mm* depth to the sample axis to obtain a consistent starter crack. The samples were fractured in a Charpy impact testing machine and the impact strength is calculated based on absorbed energy ***(E)*** and specimens dimension according to the following relation:

$$IS = \frac{E}{h.b} \times 10^3$$

Where: *E* is absorbed energy in joules by breaking the specimen; *h* is thickness of the specimen in millimeters and *b* is the remaining width of the specimen after notching.



a b

Figure 3. a) Charpy Impact testing machine setup, b) Impact specimen

2.4.2 Water Absorption Test

Composite water resistance was tested in accordance with ISO 62: 1999. The effect of water on the composite was investigated by immersing the test specimen in water. After immersion for 24 hrs, the specimens were taken out of the water and all the surface water was removed and cleaned by dry cloth to remove excess water and weighed by 0.001g sensitive balance. Three samples from each sets of specimen were tested. The percentage of water absorption is calculated using the expression:

$$\text{Water absorption (\%)} = \frac{Wf - Wi}{Wi} \times 100$$

Where W_i is the initial weight of the sample and W_f is the final weight of the sample after 24 hours of immersion in water.

Figure 4. Water absorption specimen

3. RESULT AND DISCUSSION

3.1 Effects of Fiber weight percentages and NaOH Solution Treatments on Impact strength of the Composite

Being one of the most widely specified mechanical properties of the engineering materials; the variation of impact strength with the variation of fiber content on the composites of both raw and alkali treated is shown in the ***figure 5 below***. It was observed that 20wt% of raw enset fiber based composite has higher value of the impact strength than 10wt% and 30wt%. At 20wt% fiber content, the matrix is enough to wet the surfaces of the fibers and consequently, the fibers are enough to carry stress transferred from the matrix to the fibers. In addition the spongy structures of the fibers absorb more impact loads and enhance impact strength. Hence such good energy absorption is achieved with this new kind of enset fiber reinforcement. For 10wt% fibers content, there is sufficient matrix (resin) to wet the surfaces of enset fibers, but the fibers are not enough to carry the stress transferred from the matrix. As a result, it fails earlier. But the main reason for lower value of impact strength from 30wt% enset fiber is insufficient matrix material to wet the surfaces of the fibers and to create better interfacial bonding between the matrix and the fibers. As the alkali treatment have been proven effective not only in cleaning filer's surface by removing impurities & hemicellulose from fibers but also make the fiber surface coarser leading to better interface between fibers and matrix. Further, the analysis made by [14, 15] proved that interfacial bonding between polymer matrix and fiber depends on the surface topology of these natural fibers. Alkali treatment also causes fibrillation i.e., breaking of fiber bundles into smaller fibers which would increase the effective surface area available for wetting by the matrix material. After fibrillation due to the reduced diameter of fibers, the aspect ratio of fibers increase and yields rough surface topography which in turn offers a better fiber-matrix interface adhesion. This results in obtaining the enhanced Impact properties [5]. It was also observed that 30wt% treated enset fiber composite had higher impact strength than 10wt% & 20wt% treated fiber composites due to high fiber-matrix compatibility. It can be noticed from ***figure 6. a***, that at the point of fracture for raw fibers, the failure was due to fibers pull out. Because of poor interfacial adhesion between the fibers surface and the matrix, the fibers were easily pulled out of the resin material and resulting in poor mechanical properties. The fiber-matrix compatibility can be seen from ***figure 6, b***; the NaOH solution treated fibers didn't pull out of the matrix. At failure point instead of being pulled out; the fibers were completely broken down. The reason behind this is that there is good mechanical bond between the fibers and the matrix that result in better mechanical properties

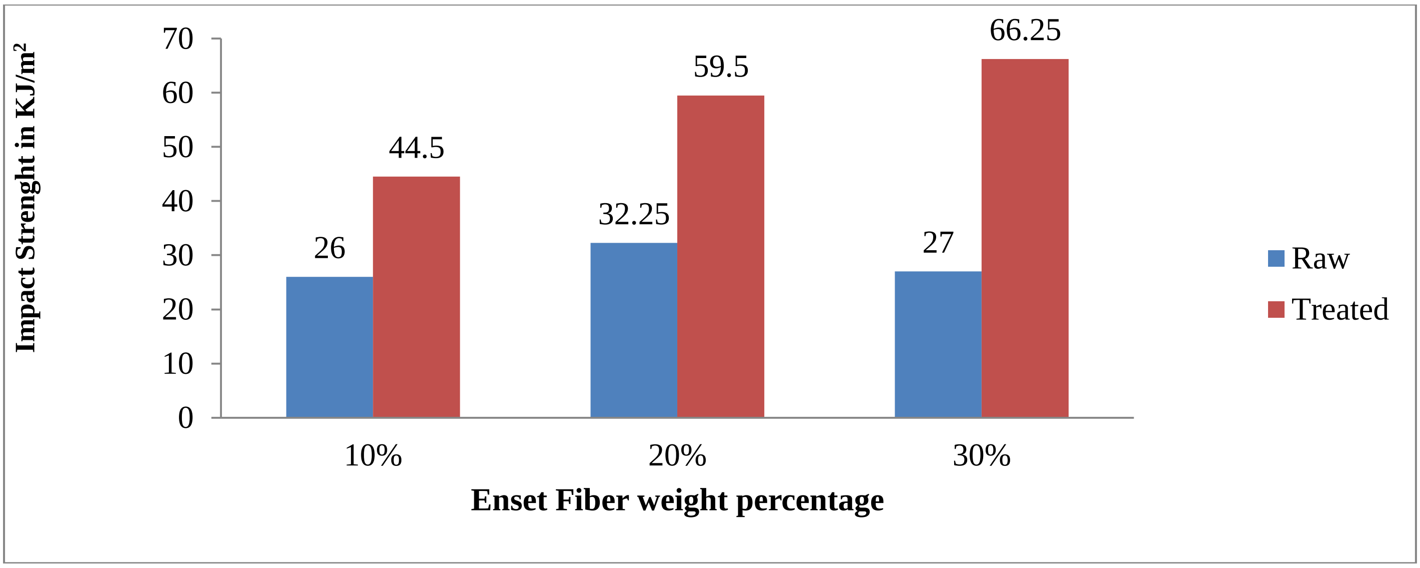


Figure 5. Comparison of Impact strength of raw and 5wt% NaOH solution treated enset fiber based composite on the basis of different fiber weight percentages

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Figure 6. Impact specimens after mechanical failure, a) raw fiber based composite b) alkali treated fiber based composite

3.2 Effects of Fiber weight percentages and NaOH Solution Treatments on Water Absorption of the Composite

The variation of water absorption properties of raw and alkali treated enset fiber based composite with different fiber content is shown in the ***figure 7 below***. The water absorption of the composite increased with increasing fiber content in both raw and treated fibers. The percentage of gain in water absorption for raw enset fiber composite within 24 hours at 10wt% is 1.95%, for 20wt% is 4.94% and for 30wt% is 7.25%. This shows that as fiber content increases in the composite, the rate of water absorption also increases. The increasing of water absorption is due to the hydrophilic nature of enset fiber and unclean fiber surface resulting in formation of void between fiber and matrix interface. The amount of water uptake by polyester resin is almost negligible as it is hydrophobic in nature. This proves that as the fiber content is increased the absorbed water becomes high. On the other hand when the composite is immersed in the water at this high fiber content the hydrophilic enset fibers containing many (-OH) groups are able to easily combine with water, resulting in swelling. Consequently, the swelling of the fibers causes swelling stresses, and these stresses resulted in micro cracking on the matrix material. This micro crack and high cellulose content in enset fibers further contributes to more water penetration into the interface of the fibers and the matrix. It can be seen that water absorption for alkali treated 10wt% fiber content is 0.32%, for 20wt% fiber content is 0.39% and for 30wt% fiber content is 0.95%. These results are very small when compared to their respective raw fibers content. The surface treatment of enset fibers by 5%wt NaOH solution for two hours has an influence on the water absorption property and the surface adhesion between fibers and matrix. The strong mechanical bond created between the fiber and the matrix as a result of the removal of impurities from fiber surface minimizes the possibilities of formation of voids which water. Although it is minimum, water absorption of treated enset fiber based composite increases as fiber content increases in the composite. In addition to better adhesion between the fiber and matrix, the polyester Gelcoat covering the external surface of the composite significantly reduces water uptake

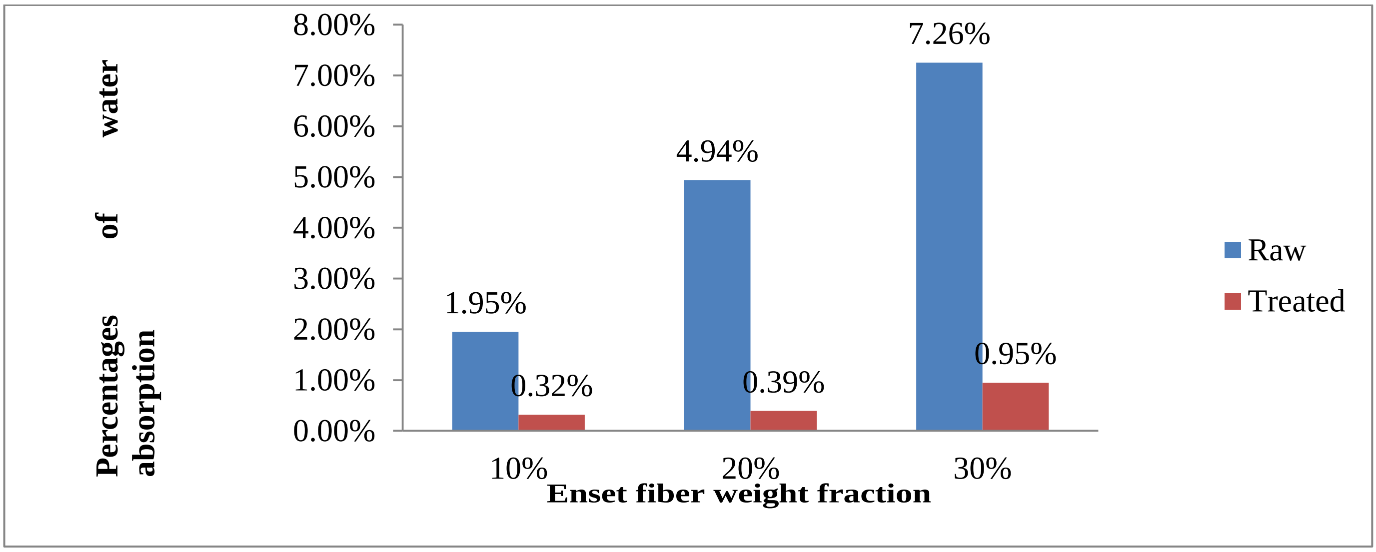

Figure 7. Comparison of Water absorption of raw and 5%wt NaOH solution treated *EFRUPR* based on different fiber weight percentages

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4. CONCLUSION

It can be seen that the investigation focuses on the potential use of enset fiber as reinforcement materials in general purpose polyester resin for the engineering applications where there is need of materials with high strength to weight ratio. The test result also shows that product properties track closely with that of glass fiber reinforced polyester products but more work is needed to improve fibers property, hardener addition and the interactions at fiber-matrix interfaces in order to obtain eco-friendly products with required property. For raw enset fiber based composite optimum impact strength was obtained at 20wt% fiber content. Because of low fiber content, low water absorption is achieved at 10wt% fiber content. For NaOH solution treated enset fiber reinforced polyester composite highest results of impact strength was obtained at 30wt% fiber content. However at this fiber content the composite has higher water absorption properties. The result obtained shows that enset fiber can replace synthetic fibers like fiber glass in manufacturing automotive interior parts like dashboard, seatback, sun visor, door trim and different industrial non load bearing parts.

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