Mechanical performance of coir and wood glue composite

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Abstract. Common wood glue is a widely available material for domestic applications. Given its adhesion properties, it is possible to create a low cost composites using such reinforcements as coir fiber to create a material that can be used for domestic repairs. In this work, a new multiscale composite material was developed using wood glue matrix reinforced with carbon nanofibers and coir fiber reinforcement. The main aim was to determine the suitability of such a material to be used for domestic DIY applications. According to literature, such a material has not been developed before. However, natural fiber has been used with other materials such as epoxy resin to form composites. A fit for purpose evaluation was conducted by testing the mechanical performance of the prepared composite specimens. It was found that mechanical properties of wood glue improved with an increase in carbon nanofiber and coir fiber content. It was also found that at low volume fraction ratios, the effect of carbon nanofibers was not significant. However, carbon nanofiber volume fraction ratios above 1% seemed to produce marginal improvement in performance. On the other hand, addition of coir fibers exhibited an increase in strength for volume factions of 2.5% to 6 %. However, the material ductility reduced significantly with increase in coir fiber volume fraction. Based on these findings, it was concluded that coir fiber / wood glue matrix composite is suitable for use in none structural domestic applications..

Keywords: CNF, Matrix, Composites, Natural fibers, Tensile testing.

1 Introduction

Over the years, materials have evolved not only to adapt to their applications but also to influence other processes such as manufacturing and recyclability. In simple terms, composites can be defined as combination of materials to form new ones with the aim of enhancing their properties [1]. Continuing research work on composite materials is the breeding ground for the development of improved materials. In this work, a need to develop a material for domestic applications was identified allowing different factors and performance requirements to be determined. Literature study has shown that wood glue (polyvlyn acetate) and natural fiber composites have not yet been reported. Developing this composite made it possible to determine what can be achieved with such materials.

Natural fibers are classified based on their origin, and are derived from plant materials. Natural fibers are subdivided into three main categories that is plant fibers, animal fibers and mineral fibers. Animal fibers include silk, wool, and hair. Mineral derived fibers include asbestos, wollastonite and palygorskite. Plant-based fibers on the other hand include cotton, hemp, jute, flax, ramie, sisal, bagasse, specialty fibers processed from wood etc. [2]. The properties of natural fibers are mostly dependent on the cellulose content in the fibers, the degree of polymerisation of the cellulose and the angle of the micro fibrils. Each type of cellulose has its own cell geometry, hence the type of cellulose present within the natural fiber defines the mechanical properties of that fiber [3]. Moreover, natural fibers are advantageous due to their low density, high relative toughness, comparable specific strength properties, reduction in tool wear when machining, ease of separation, and decreased energy of fabrication. Furthermore, they are recyclable and biodegradable [4]. This is an important positive factor given current global warming and climate change issues.

A composite is a material that is formed by combining two or more materials to achieve specific structural properties while minimizing the effects of their deficiencies. However, the materials still remain easily identifiable since the materials do not dissolve or merge into each other. The resulting composite has superior mechanical and physical properties compared to the mechanical and physical properties of its constituents [5].

Natural fiber composites combine plant derived fibers with a polymer binder. The natural fiber composites are light weight, require low energy for production and are environmentally friendly [6]. Both fiber length distribution and fiber orientation play a very important role in determining the mechanical properties of the composite [7]. In this work, there is need to establish the viability of using wood glue as a matrix for a natural fiber reinforced composite.

2 Experimental methods

2.1 Aim of experiments

The aim of the experiment was to develop a composite material using wood glue, coir fiber and carbon nanofibers (CNF’s) characterize the mechanical properties of the composite samples for varying fiber and CNF fractions.

2.2 Materials

The composite samples were made from wood glue, carbon nanofibers and coir fibers. Coir fibers are extracted from coconuts shells. The coir fibers were supplied by the Coir Institute of South Africa. In this project, the brown fibers were used. The wood glue used was bought from the local hardware store and is a polyvinyl resin glue. The properties of coir fiber are shown in Table 1 and those of wood glue in Table 2.

Table 1. Properties of wood glue (polyvinyl acetate) [8].

	Wood Glue
Density (g/cm^3)	1.19
Solubility parameter ($MPa^{1/2}$)	19.60
Glass Transition (K)	307.00
Enlargement molecular weight ($g\ mol^{-1}$)	9700.00

Table 2. Physical properties of coir fiber [9].

Mechanical Properties	Coir Fiber
Density (g/cm^3)	1.2
Elongation at break (%)	30
Tensile strength (MPa)	175
Young modulus (GPa)	4 – 6
Water absorption (%)	130-180

The CNF's were supplied by Aldrich Chemistry. The carbon nanofibers are graphitized, and composed of conical platelets. In this work, product PR-25-XT-HHT was used. The properties of the CNFs, according to the manufacturer's certificate, are given in Table 3.

Table 3. CNFs properties as provided by the manufacturer [10].

Mechanical Properties	CNFs
Nanofiber density including hollow core (g/cm^3)	1.4-1.6
Nanofiber wall density (g/cm^3)	2.0-2.1
Catalyst (Iron) content (ppm)	<100
Outer diameter (nm)	125-150
Inner diameter (nm)	50-70
Specific surface area (m^2/g)	24
Average pore volume (cm^3/g)	0.075
Average pore diameter (Angstroms, Å)	123.99

2.3 Specimen preparation

The specimens were manufactured in accordance to ASTM for tensile tests. The dimensions of the mold were determined in order to produce at least 5 specimens per batch. The mold dimensions are shown in Figure 1. The mold was manufactured from wood for ease of machining and lined with wax to ease release of the specimen slabs.

Fig. 1. Mold dimensions.

To prepare the composite slabs, predetermined quantities of glue, fibers and CNF's were thoroughly mixed until a uniform mixture was obtained. The coir fibers were all reduced to a length of 20 mm. No special functionalization treatments were applied to both the coir fiber and CNF's. This was meant to simplify the process that would be used under domestic application conditions. The mixture was then poured into a wooden mold as shown in Figure 2.

Fig. 2. Molding process.

The molded slabs were then left to dry at room conditions before being cut into specimen sizes using a band saw. Figure 3 shows the final specimens cut according to recommended standard dimensions.

Fig. 3. Specimens cut according to standard dimensions.

2.4 Equipment description

Tensile tests were conducted on an Instron 1195 tensile testing machine controlled by the Bluehill 2 software. A 10 kN load cell was used in all tests.

3 Results and discussion

3.1 Wood glue and CNF specimens

The first batch of tests was conducted on samples composed of wood glue only to provide bench mark parameters for the investigation. For the second batch, specimens with differing ratios of CNFs were prepared. The weight fraction of CNFs in the wood glue was varied from 0.002 to 0.008. The effect of this variation of CNF's in wood glue on the strength of the specimens is shown in Figure 4.

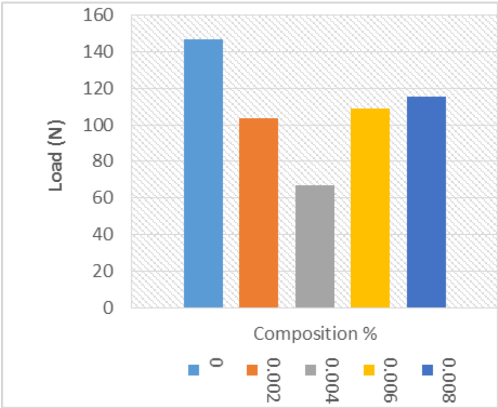

Fig. 4. Load vs CNF weight fraction.

From Figure 4, is can be seen that initially, addition of small amounts of CNF's results in a reduction in strength compared to the glue strength. This could be explained by lack of proper mixing leading to coagulation of CNF's. This would produce stress concentration sites. However, beyond 0.004 weight fraction, an increase in CNF's led to a corresponding increase in strength.

3.2 Wood glue, CNF and Coir fiber specimens

These specimens were prepared by keeping the CNF weight fraction constant at 0.008 while varying the coir fiber volume fractions for values of 2.5, 3.5, 5.0, 6.0 and 10.0 %. The results of the tensile test specimens are presented in Figure 5. Elongations are plotted in Figure 6.

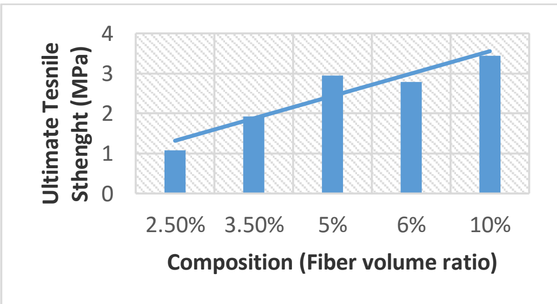

Fig. 5. Effect of volume fraction on tensile strength.

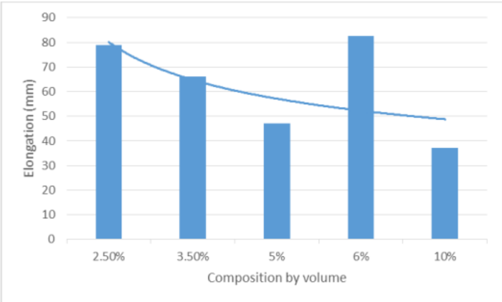

Fig. 6. Effect of volume fraction on elongation.

These results show that an increase in coir fiber volume fraction results in a corresponding increase in tensile strength from an average of 1 MPa at 2.5% volume fraction to about 3.5 MPa at 10% volume fraction. This represents a tripling of the tensile strength. The improvement in tensile strength seemed to be linearly related to the volume fraction. For low load structural applications, specifically domestic applications to repair cupboards etc., such a material would be sufficient. However, this would not be used in load bearing structures.

4 Conclusions

Wood glue and coir fiber composites were successfully produced and performance tested by varying the volume fraction of the fiber reinforcement. In addition, carbon nanofibers were also added to the glue in an attempt to further reinforce the wood glue. Coir and glue composites were developed with the CNFs content kept at 0.008%. From the tensile test results obtained, the following conclusions can be made:

1. Carbon nanofibers had a marginal effect on the strength of the glue matrix although they led to a significant reduction in material ductility
2. The strength of the carbon nanofiber and glue composite is directly proportional to the content of the nanofibers in the matrix
3. Coir and glue composites gained strength with increase in coir fiber volume fraction, while elongation reduced. From this, it is concluded that the coir and wood glue composites are improved by an increase in coir fiber volume ratio
6. Based on the fracture surface of the specimens, poor matrix to fiber adhesion was the main cause of failure.

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