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Natural Fiber Composites: A Review

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March 2010

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Abstract

The need for renewable fiber reinforced composites has never been as prevalent as it currently is. Natural fibers offer both cost savings and a reduction in density when compared to glass fibers. Though the strength of natural fibers is not as great as glass, the specific properties are comparable. Currently natural fiber composites have two issues that need to be addressed: resin compatibility and water absorption. The following preliminary research has investigated the use of Kenaf, *Hibiscus cannabinus,* as a possible glass replacement in fiber reinforced composites.

Introduction

Research on natural fiber composites has existed since the early 1900's but has not received much attention until late in the 1980's. Composites, primarily glass but including natural reinforced composites, are found in countless consumer products including: boats, skis, agricultural machinery and cars[1,2,3]. A major goal of natural fiber composites is to alleviate the need to use expensive glass fiber ($3.25/kg) which has a relatively high density (2.5 g/cm^3) and is dependent on nonrenewable sources[1,3].

Fiber	Density (g/cm^3)	Tensile Strength (Mpa)	Specific Tensile Strength (Mpa)	Elastic Modulus (Gpa)	Specific Elastic Modulus (GPa)
Cotton	1.5-1.6	400	250-267	5.5-12.6	3.5-8.1
Kenaf	1.45	930	641	53	36.5
Sisal	1.5	511-635	341-423	9.4-22	6.3-14.7
E-glass	2.5	2,000-3,500	800-1,400	70	28
Carbon	1.4	4,000	2,857	230-240	164-171

Table 1. Selected properties of natural and synthetic fibers[1].

Recently, car manufactures have been interested in incorporating natural fiber composites into both interior and exterior parts. This serves a two-fold goal of the companies; to lower the overall weight of the vehicle thus increasing fuel efficiency and to increase the sustainability of their manufacturing process. Many companies such as Mercedes Benz, Toyota and DaimlerChrysler have already accomplished this and are looking to expand the uses of natural fiber composites[1].

Natural fibers primarily consist of: cellulose, hemicelluloses, pectin and lignin. The individual percentage of these components varies with the different types of fibers. This variation can also be effected by growing and harvesting conditions. Cellulose is a semicrystalline polysaccharide and is responsible for the hydrophilic nature of natural fibers. Hemicellulose is a fully amorphous polysaccharide with a lower molecular weight compared to cellulose. The amorphous nature of hemicelluloses results in it being partially soluble in water and alkaline solutions[4]. Pectin, whose function is to hold the fiber together, is a polysaccharide like cellulose and hemicellulose. Lignin is an amorphous polymer but unlike hemicellulose, lignin is comprised mainly of aromatics and has little effect on water absorption[5,6].

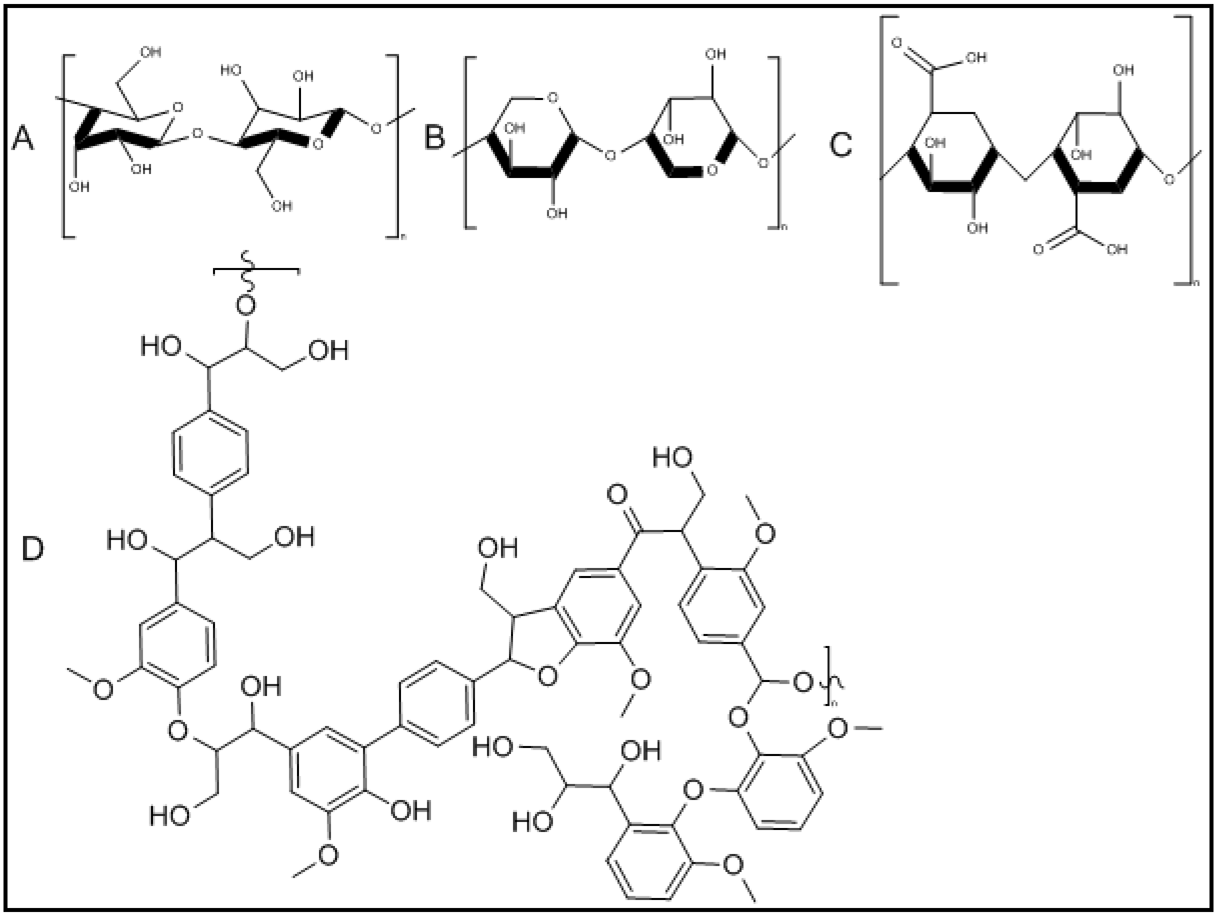

Figure 1. Structural representations of cellulose (a), hemicellulose (b), pectin (c) and lignin (d)[7].

The largest advantages to using natural fibers in composites are the cost of materials, their sustainability and density. Natural fibers can cost as little as $0.50/kg, and can be grown in just a few months[8]. They are also easy to grow and have the potential to be a cash crop for local farmers. Natural fibers are also significantly lighter than glass, with a density of 1.15-1.50 g/cm^3 versus 2.4g/cm^3 for E-glass[9].

Two major factors currently limit the large scale production of natural fibers composites. First, the strength of natural fiber composites is very low compared to glass. This is often a result of the incompatibility between the fiber and the resin matrix. The wettability of the fibers is greatly reduced compared to glass and this constitutes a challenge for scale up productions. Though when comparing specific strengths, natural fibers are not much less than glass fiber composites.

The second factor limiting large scale production of natural fiber composites is water absorption. Natural fibers absorb water from the air and direct contact from the environment. This absorption deforms the surface of the composites by swelling and creating voids. The result of these deformations is lower strength and an increase in mass. Additionally, with water absorption rates as high as 20 wt% the light weight advantage is often nullified.

The treatment of fibers is currently an area of research receiving significant attention. The absorption of water is commonly thought to occur at the free hydroxyl groups on the cellulose chains. With a ratio of 3 hydroxyl groups per glucose repeat unit the amount of water that can be absorbed is substantial. By capping the hydroxyl groups this ratio can be reduced. There are several promising techniques that have been studied by various groups[4-6,10-14]. Among these treatments mercerization (alkaline) treatment has had the most reviews[4-6,10,11]. Utilizing silanes as coupling agents is a treatment commonly used in glass composite production and is starting to find uses in natural fiber composites[4,6,10,12,13]. Acetylation is another treatment that is common with cellulose to form a hydrophobic thermoplastic and has the potential to have the same results on natural fibers[4,5,6,14].

Materials

Kenaf, chopped (5cm) pieces, supplied from Bast Fiber LLC, was prepared by retting in water prior to arrival from Bangladesh. DERAKANE 782, containing 40 wt% styrene, Low Profile 2016, Modifier E and Modifier M, supplied from Ashland Chemical company were used as received. Tert-butyl peroxybenzoate (TBPB), supplied from Akzo Nobel was used as received.

Methods

I. Preparation of Kenaf

Raw Kenaf fiber (50g) was passed through a commercial electric carder, supplied by Louet North America, for two minutes producing a rough bat of uniaxially orientated fiber. The rough bat was then rerun through the carder for an additional two minutes producing a finely orientated bat of Kenaf. The Kenaf bat was then cut into five 15.24x15.24cm squares (mats). The mats were then stored in an 80°C circulating air oven for 3 hours to remove any surface moisture.

II. Impregnation of Vinyl Ester resin

To a 1000mL beaker, DERAKANE 782 was added (60 wt%). LP4016 (35 wt%), Modifier E (0.2 wt%), and Modifier M (3 wt%) were then added to the beaker. The resin was then thoroughly mixed for three minutes. TBPB (1.5 wt%) was then added and the final resin was stirred for three minutes. Using a proprietary technique, dried Kenaf mats (48g) and chopped 5cm mats of glass (98g) were respectively impregnated with Vinyl Ester resin to form a prepeg.

III. Compression Molding

Test panels (15.24x15.24x0.3175cm) were prepared using a Wabash compression molder. Panels were molded at 135°C for 25 minutes using a pressure of 8MPa.

IV. Mechanical Testing

Panels were cut, using a TensilKut, for tensile and flexural specimens respectively. Specimens were then conditioned at 50% relative humidity for 48 hours. For each series five specimens were tested after conditioning and another five were tested after immersion in deionized water for 24 hours. Testing was performed in accordance with ASTM D790 and ASTM D638 standards respectively.

V. Moisture Uptake

The mass of samples was taken after conditioning in 50% relative humidity for 48 hours. To measure moisture uptake samples were immersed in deionized water for 24 hours, patted dry to remove surface moisture and their mass was taken again.

Results

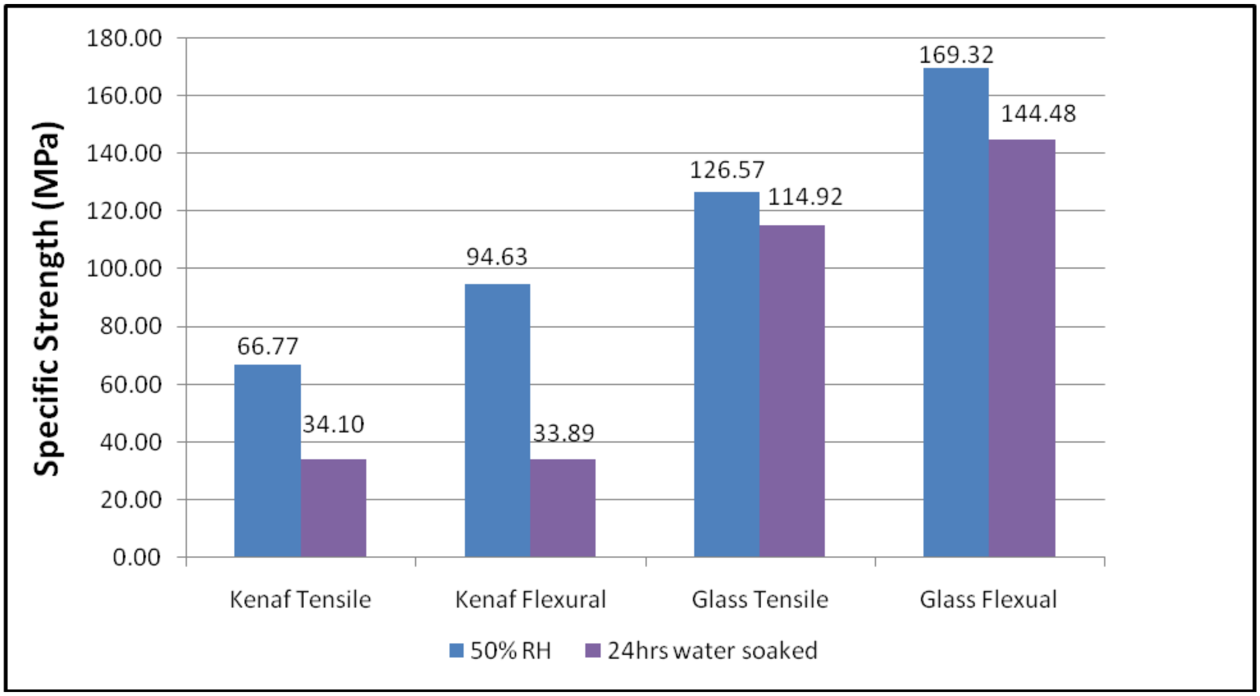

Figure2. Specific strength for Kenaf and glass composites, tensile and flexural shown respectively.

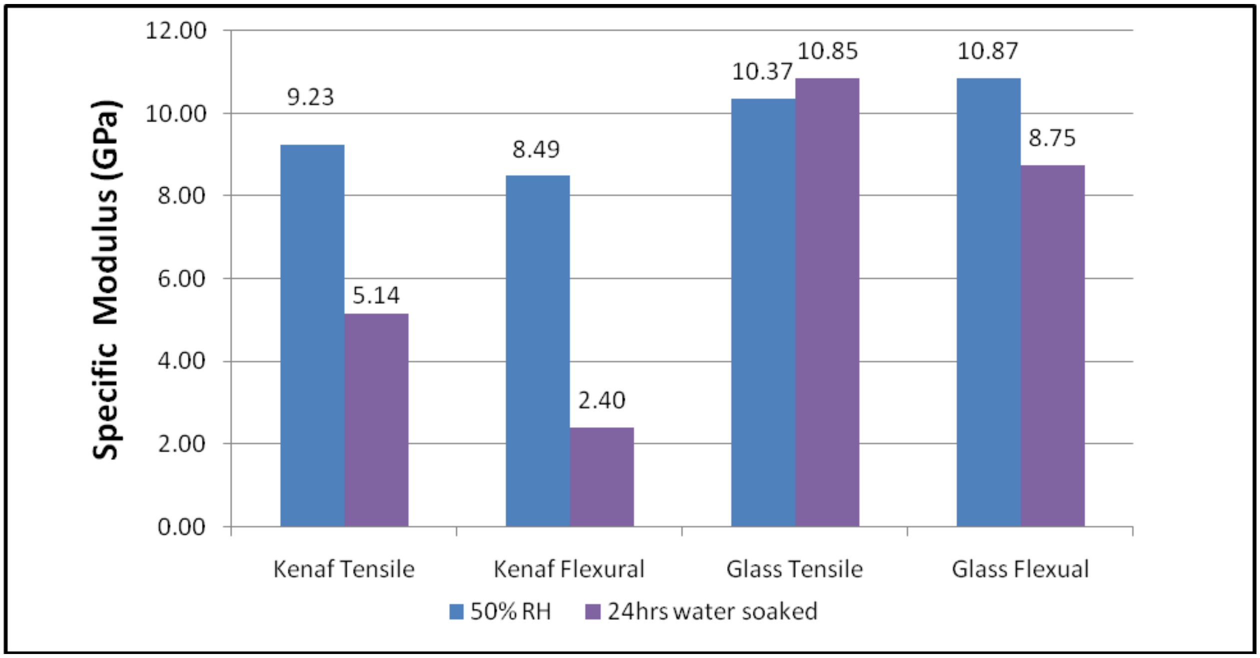

Figure 3. Specific modulus for Kenaf and glass composites, tensile and flexural shown respectively.

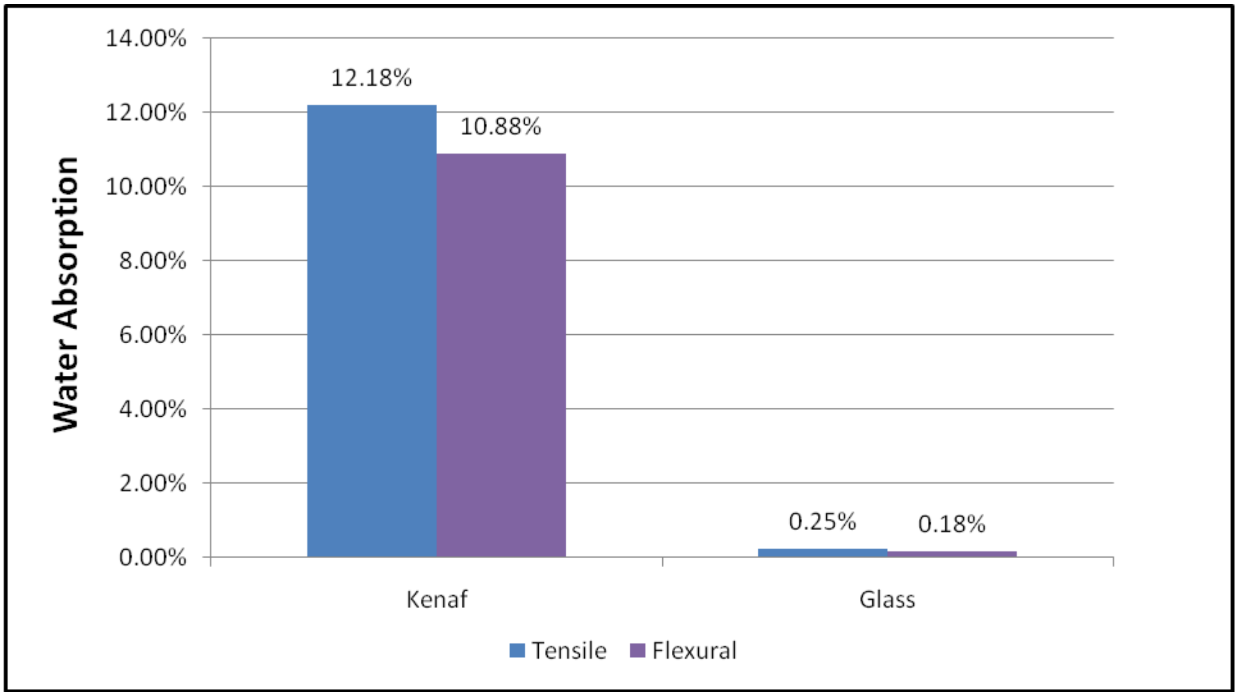

Figure 4. Water absorption represented by percent mass change for Kenaf and glass composites, tensile and flexural shown respectively.

Discussion

As predicted, the specific properties of Kenaf were less than that of the glass composites. (Figures 2 and 3) This is primarily explained by the interface between the Kenaf and the vinyl ester resin. The wettability of the chopped glass is significantly higher than the Kenaf mats which leads to stronger samples. Additionally, the Kenaf has only bidirectional orientation while the glass has a multidirectional orientation. This difference in orientation drastically changes how the stress is distributed across the composite.

(Figure 4) shows the 24hr water absorption of Kenaf and glass composite samples respectively. The percent mass increase was significantly higher for the Kenaf samples then the glass. As expected the tensile samples had the greatest percent of water absorption due to their greater contact area with the water. The Kenaf samples were heavily distorted including large bulges on the edges and warping of the surface. This attributed to the lower mechanical properties. (Figures 2 and 3)

Finally, the proceeding data has shown that in their native form Kenaf composites cannot compete with glass composites. While the dry specific properties were only slightly lower for the Kenaf composites, the wet samples were drastically lower. Fiber treatments will need to be explored to reduce the water absorption and increase the wettability of the fibers.

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