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Influence of Sisal-Fiber Content on the Tensile and Bending Strength of Sisal-Epoxy Composites

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Abstract: Specimens of sisal-fiber reinforced epoxy composites were prepared using a fiber content of 0.5, 1.0 or 2.0% by weight while control samples had no fiber. The length of the fiber in the composites was 10, 20 or 220 mm for tensile specimens and 10, 20 or 78 mm for flexural specimens. After casting and allowing for the recommended curing period, the samples were tested for ultimate tensile and bending strength. The tensile stress was found to range from 31.3 to 56.3 MPa while the flexural stress ranged from 83.7 to 113.2GPa. Both the tensile and flexural strength of the composites increased with increase in sisal fiber content within the range of 0-2%. The highest increase in a structural property due to increase in fiber content (136.6%) was observed in the modulus of elasticity of tensile specimens. The increase in the modulus of elasticity in the flexural specimens as a result of an increase in fiber content however was only a moderate 34.3 %. The tensile strain decreased as the fiber weight was increased from 0-1% but increased slightly when the fiber content was further increased to 2%. Increasing the fiber length had no or little effect on the tensile strength, strain or modulus of elasticity of composites under tension. However, there was a marked increase in flexural strength and flexural modulus of elasticity when the fiber length was increased from 0-78 mm. These results indicate that adding limited quantities of sisal fiber to epoxy resins has some structural benefits.

Key words: Composite, sisal fiber, content, length, structural properties

INTRODUCTION

More consumers today are insisting on products that are either wholly or partly made from natural products and some governments are also giving subsidies to companies that produce such goods in an effort to encourage cleaner production[1]. As a result the introduction of environmentally friendly industrial techniques and production processes has been growing rapidly in recent years. It was reported by Peijs[1] that the use of natural fiber was increasing by 100% every year between the years of 1996 and 2000 while MRAC[2] predicted an accelerated growth in the use of natural fiber in the near future. This tremendous growth has been attributed to the attention that natural fibers have received from scientists and engineers in recent years[3-6].

Natural products and particularly plant-fiber have a number of important advantages over traditional structural materials and are therefore being used in a number of industrial production processes. Wood flour from waste is replacing mineral materials as a filler material. Plant fibers are also being used as alternatives to glass fiber mainly because of their low cost but also because they are an environmentally sound alternative[7,8]. The fibers are used to make many composites which are in turn used in aerospace applications, automobiles, domestic products, industrial packaging as well as in building construction. The mechanical properties of plant fiber composites are reasonably high although they are highly dependent on other factors such as fiber type, amount of fiber in composite, fiber length, method of processing of the fiber as well as age. Another factor which has been considered important is the durability of composites made from plant fiber when compared to that of composites made from traditional fibers. The effect of moisture on the structural properties of the plant fiber composites has also attracted considerable interest from chemists, material scientist and engineers[3,9-1s2].

Researchers have also recognized that the current industrial composite production processes in many parts of the world are not well adapted to plant fiber[10-13]. Therefore, suitable processes and techniques for the efficient automation of plant fiber composites production have to be developed. At the moment, manual production

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methods can and are being used in some developing countries and these methods are likely to continue being used in these regions for along time to come. Also, large quantities of these plant fibers are also being produced in the developing countries and finding some local use is an attractive option to the bulky export of raw fiber[14].

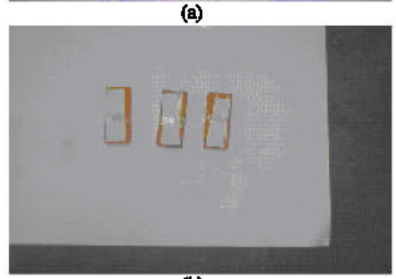
The sisal plant in its better days used to contribute significantly in the production of packaging materials and many other woven products. However, although it still remains a major fiber crop, it has been losing ground to synthetic materials since 1963 and the United Nation Industrial Development Organization (UNIDO) has recognized the need to intensify research in alternative uses of this fiber crop. One such area where this crop can be used is as reinforcement material for structural components and the objective of this research is therefore to investigate the effect of sisal fiber content and fiber length on the structural properties of sisal-fiber epoxy composites.

MATERIALS AND METHODS

Sample preparation: Two mould types for casting the test specimens were made from a 15 mm thick timber board. The respective specimen shapes were sawn off the timber board in such a way as to allow each mould to be used to cast four specimens at a time. The dog-bone (or dumb bell) shape of the tensile sample was 220 mm long and 10 mm wide at the test cross-section while the flexural sample was 78 mm long and 30 mm wide (Fig. 1). After sawing off the respective shapes the stencil was then placed on top of a flat polished steel plates and a layer of petroleum jelly smeared on the mould surface in order to prevent the specimens from sticking to the mould. Fibre reinforced specimens could then be prepared by casting directly into the mould cavities of the 15 mm thick timber stencils.

To produce a test sample, a stoichiometric mixture of epoxy–resin and araldite hardener in the ratio of 1:0.6 by weight and well stirred as recommended by the manufacturer was made. The mixture was then poured gently into the mould cavities up to a depth of approximately 7.5 mm corresponding to half the stencil depth. The prepared fiber samples were then soaked manually to eliminate formation of voids and facilitate proper impregnation of the resin into the fiber. After all the fiber was embedded the remaining resin was carefully poured into the cavities and the mould covers were tightened. The samples were then left to cure under atmospheric conditions (24±2°C) for 24 h before testing could commence.

(a)



(b)

(c)

Fig. 1: The tensil and bending test samples (a) and (b) and the tensil samples under loading in the universal testing machine, (c)

Sample testing: Determination of the tensile strength of specimens was done under room temperature conditions using an Instron testing machine following British Standards, BS 2782 for mechanical properties[15]. Each specimen was loaded gradually over the gauge length at a crosshead speed of 0.03 mm per minute until the specimen fractured. The cross sectional dimensions of each specimen were measured and an average of readings from four specimens of similar composition determined. The stress was calculated by dividing the load at fracture with the corresponding cross sectional area. The gauge length was measured as the distance between the cross heads before loading commenced. The strain was then calculated as the ratio of change of levels of the moving crossheads over the gauge length while the tensile modulus of elasticity was calculated by dividing stress and strain for each specimen.

The testing of flexure specimens was done using the same machine and the same crosshead speed as for tensile testing and British Standards; BS 2782 for flexural properties[16] was used. The test specimen was placed symmetrically on the two flexure fixture supports and the force applied at mid span. The force was gradually increased until the specimen failed. The midpoint deflection of the specimen corresponds to the distance moved by the crosshead and this was automatically recorded during the test. The ultimate flexural strength and flexural modulus of elasticity as an average of four specimens of similar composition was calculated using Eq. 1-2.

$$\sigma_f = \frac{3FL}{2BH^2} \quad (1)$$

$$E_f = \frac{L^3F}{4BH^3X} \quad (2)$$

Where σ_f = Flexural stress (MPa)
F = Load (N)
B = Width of specimen (mm)
L = is span of specimen (mm)
H = Thickness of specimen (mm)
X = Deflection of the flexural specimen (mm)

Experimental setup: Test specimens were made with either no fiber content (for control specimens), or with fiber content of 0.5, 1.0 or 2.0% by weight for both tensile and flexural specimens. The length of the fiber used to make tensile specimens was 10 or 20 mm although some sample had fiber length running the entire length of the specimen which was equivalent to 220 mm. Similarly, flexural specimens had fiber lengths of 10, 20 or 78 mm. Thus 20 different specimens could be made and each was replicated four times. There were included two neat resin specimens to serve as controls for both tensile and flexural tests and 18 specimens (3 fiber contents x 3 fiber lengths x 2 load types).

RESULTS AND DISCUSSION

Effect of fiber content

Tensile strength: The results of the tensile stress tests are presented in Fig. 2 as a function of fiber content and length. It can be seen that the sample with no fiber at all had the lowest ultimate tensile stress of 31.34 MPa. The tensile stress however increased with increase in fiber content irrespective of the length of fiber in the specimen. The highest increase in tensile stress (79.5%) was recorded by the sample with the longest fiber (extending the entire length of the sample) and the highest fiber content of 2%. However the effect of fiber length on tensile strength was minimal when compared to the effect of fiber content. These results compare well with the Fig. of 30-120 MPa given by Pringle and Barker for epoxy resins[17]. The values of tensile strength for 1% fiber content in this study also compare well with the tensile strength of 44.25 MPa given by Biswas, Srikanth and Nangia[18] for some Indian products made of jute-polyester composites.

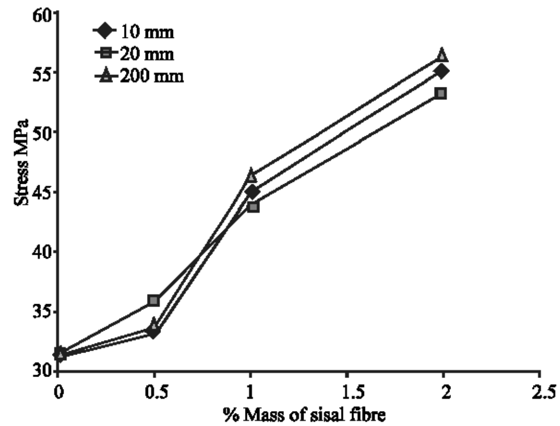


Fig. 2: Variation of tensile stress of sisal fibre reinforced epoxy resin as a function of fibre content and length

Maringa, Mutuli and Kashive[19] also recorded tensile strength value ranging from 20-70 MPa when dealing with sisal-epoxy composite of volume fiber contents ranging from 0-30%. They reported a small decrease in tensile strength as fiber content was increased from 0-7% which was then followed by a continuous increase in strength with further increase in fiber content. An increase in tensile strength with increase in fiber content has also been reported in sisal-fiber concrete sheets[20] and in natural-fiber-reinforced polyurethane microfoams[8].

Strain at failure: The variation of strain with both the fiber content and length of fiber is presented in Fig. 3. The highest strain of 1.15 corresponds to the sample with no fiber and it is clear from Fig. 3 that the strain decreased as the fiber content was increased from 0-1% but then increased slightly when the content was further increased to 2%. A decrease in longitudinal and lateral strain with increase in fiber content was reported in sisal fiber reinforced concrete sheets by Fihlo, Joseph, Ghavani and England[20] and in jute based polyurethane composites by Bledziki, Zhang and Chate[8]. This observation was also made by Sanadi and Caulfield[21] when working on kenaf-polypropylene composites. The decrease in strain is

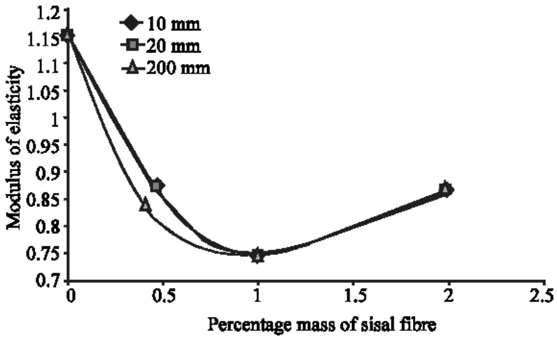


Fig.. 3: The strain of sisal fibre epoxy resin composites as a function of fibre content and length

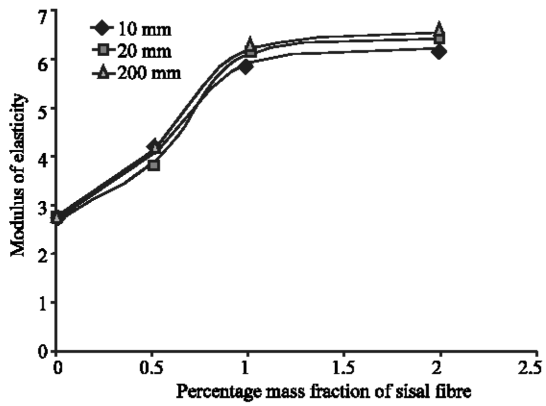


Fig. 4: Change in the modulus of elasticity of sisal fibre epoxy resin with both the fibre content and length

probably due to increased rigidity of the matrix after adding the fiber. The additional fiber restricts the ability of the polymer molecules to flow freely over one another thus causing premature failure.

Modulus of elasticity: The modulus of elasticity of the tensile samples as a function of both fiber content and length is presented in Fig. 4. Pure epoxy specimens with no fiber at all had the lowest values of modulus of elasticity of 2.77 GPa. The modulus increased rapidly as fiber content was increased from 0-1% and then continued to increase albeit at a gradual rate when fiber content was further increased to 2%. The highest increase in the modulus of elasticity when expressed as a percentage of that of pure epoxy specimens was found to be 136.6% and was recorded by the specimens with a fiber length of 220 mm and 2% fiber content. An increase in the tensile modulus of elasticity with increase in fiber content has also been observed by Maringa, Mutuli and Kashive[19] for both sisal and loafa fiber in an epoxy resin matrix. As is the study in this study Jules, Tsujikami, Lomov and Verpoest[22] also reported an initial rise in Young's modulus with increase in fiber content which then approached an asymptote with further increase in content. Other researchers who have also observed an increase in the modulus of elasticity with increase in fiber content are Pringle and Baker[17] and Ray, Sarkar, Rana and Bose[23].

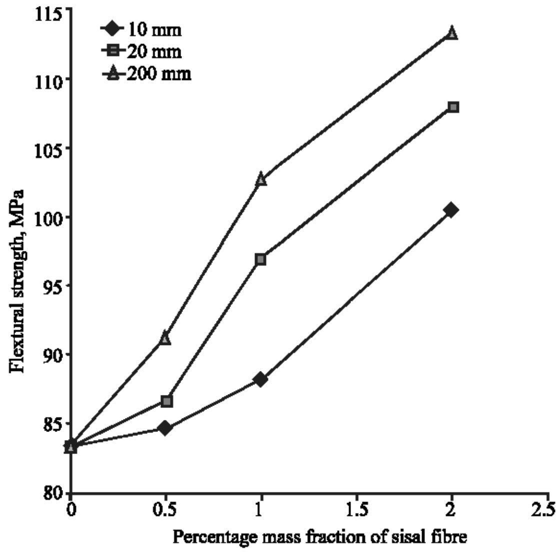


Fig. 5: Change in the flextural strength of sisal fibre epoxy resin composite with percentage mass and length of sisal fibres

Flexural strength: The variation of flexural strength with fiber content and fiber length is presented in Fig. 5. It can be seen in Fig. 5 that the flexural strength of the specimen with no fiber was the lowest at 83.7 GPa and that flexural strength increased with increase in the fiber content. The highest increase in flexural strength was recorded in a specimen which had 2% fiber content and fiber length of 78 mm and corresponded to an increase of 35.2%. Increase in flexural strength with increase in fiber content was reported by O'Dell[24] and Ray, Sarkar, Rana and Bose[23] for both untreated and treated jute fiber composites.

Flexural modulus of elasticity: The results of the flexural modulus of elasticity of the sisal fiber-reinforced specimens are presented in Fig. 6. From the Figure it is obvious that the modulus increased with increase in fiber content within the experimental range. From a moderate value of 0.96GPa for specimens with neat resin the modulus increased by 34.3% to reach a maximum of 1.29GPa for sample with 2% fiber content and fiber length of 78 mm. Several other researchers have also found the flexural modulus to increase with fiber content[20,23,24].

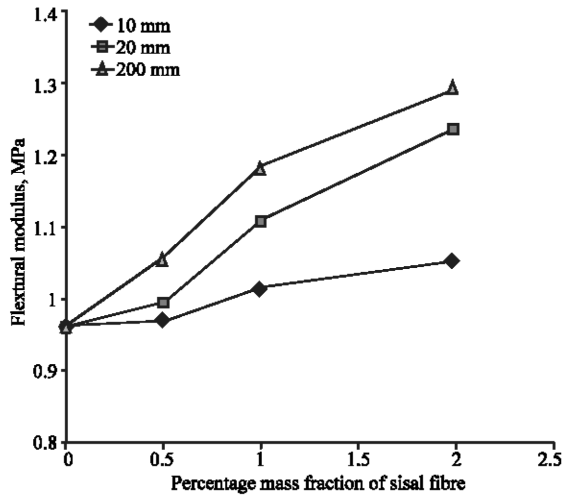


Fig. 6: Variation of the flexural modulus of sisal fibre epoxy resin with fibre content and length

Effect of length: The length of the fiber appears to have no effect on the tensile stress or strain as can be seen from Fig. 2 and Fig. 3. Also, the increase in the modulus of elasticity due to increase in fiber length was small and not significant as can be seen in Figure 4. This tends to confirm the findings of Jules, Tsujikami, Lomov and Verpoest[22] who found that young's modulus increased with fiber length up to a length of 3-4 mm after which it approached an asymptote with further increase in fiber length. However, in the flexural specimens, increasing the length of fiber caused a significant increase in both the flexural strength and flexural modulus of elasticity of the composite at 5% level of significance (Fig. 5 and 6). Clearly, it is beneficial to use long fiber in components that will be used to bear flexural stresses as opposed to components where tensile loading is prominent.

CONCLUSION

The present study has showed that the strength properties of epoxy composite material are significantly improved by the addition of sisal fiber. Increase in fiber content leads to an increase in strength and modulus of elasticity for both tensile and flexural specimens over the fiber content range of 0 to 2%. It can also be concluded that except in flexural specimens, the fiber length has little or no effect on the strength properties of the composite within the experimental range. Also, there was an overall decrease in the tensile strain of the composites as the fiber content was increased from 0 to 2%.

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