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EXAMINING THE EFFECTS OF PROCESS VARIABLES ON THE TENSILE AND FLEXURAL PROPERTIES OF BANANA FIBRE REINFORCED POLYMER COMPOSITES EXPOSED TO ENVIRONMENTAL WEATHERING ACTION

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Abstract

Synthetic fibres (such as glass, carbon, ceramic fibres, etc) which were imported at huge cost could be replaced by natural fibres such as flax, hemp, jute, kenaf, etc. and widely used. In this research work, banana fibre reinforced vinylester matrix composites have been developed by hand layup moulding technique with varying parameters, such as fibre condition (untreated and chemically treated), fibre sizes 10,30 and 50 cm and fibre content (10%, 30% and 50% by weight). The developed banana fibre reinforced composites were then characterized by chemical methods. The results show that tensile strength increases with increase in the fibre size and content; however, after a certain size and fibre content, the tensile strength decreased again. The maximum Tensile strength was 1127N/mm^2 at a fibre length of 2.2cm and volume fraction of 36%. The maximum flexural strength was 67.15N/mm^2 occurring at 9cm fibre length and 50% vol fraction. The minimum creep strength was $2x10^{-4}5^{-1}$ occurring at 3.2cm fibre length and 30% vol fraction.

Key words: Polymer composite, hydrophilic fibre, hydrophobic matrix, Tensile strength, Flexural strength.

INTRODUCTION

Newer polymer matrix composites reinforced with fibres such as glass, carbon, aramid, etc. are getting a steady expansion in uses because of their favourable mechanical properties. However, they are quite expensive materials. For this, natural fibres such as jute, flax, hemp, etc. can be alternately used to reduce the cost of composites (Mohanty et al, 2004). Moreover, production of environmentally friendly materials is another important issue. Natural fibre composites focus well into this ecological image. The use of natural fibres, derived from annually renewable resources, as reinforced fibres in both thermoplastic and thermoset matrix composites provide positive environmental benefits with respect to ultimate disposability and raw material utilization (Rowel et al,1998).

The prominent advantages of natural fibres include acceptable specific strength properties, low cost, low density, high toughness, good thermal properties, low specific weight, which results in a higher specific strength and stiffness than glass is a benefit especially in parts designed for bending stiffness. In the fields of automotive industries, reduction of energy consumption in production of motor vehicles and improvement of their day fuel economy are growing upwards due to accelerating use of natural fibre composites (Razera et al,2004). In the case of thermoset composites, adhesion between the hydrophilic fibre (such as banana fibre) and hydrophobic matrix (such as vinylester) is poor (Karmaker & Youngquist, 1996). Therefore, the bond between them needs to be improved. This may be improved by alkali treatment. It is believed that the alkali treatment results in an improvement in the interfacial bonding by giving rise to additional sites for mechanical interlocking, hence promoting more matrix/fibre interpenetration at the interface (Gassan & Bledzki, 1997). In this work, banana reinforced vinylester composite were prepared under various processing parameters using hand layup moulding technique. The goal of this work was to understand the changes of tensile strength under various process parameters.

REVIEW OF RELATED LITERATURE

Natural fibres especially bast (bark) fibres such as flax, hemp, jute, heneguen and many others were investigated by some researchers as fibre reinforcement for composites in recent years. Advantages of natural fibres over manmade fibres include low-density, low cost, recyclability and biodegradability. These advantages make natural fibres potential replacement for glass fibres in composite materials. Banana (musa acuminata) is an annual crop used both for fibre and it is edible, the major fibre components are cellulose, hemicelluloses, lignin, pectin, waxes and water-soluble substances. Lignin and pectin act mainly as boding agents (Karmarker & Schenider, 1996). The composition of some natural fibre is shown in Table 1 cellulose is a hydrophilic glucan polymer of D- glucopyanose units which are linked together by α (1- 4) glycosidic bonds (Joseph et al, 2002) and (Kamaol et al, 1997). The large amount of hydroxyl group in cellulose gives natural fibre hydrophilic properties when used to reinforce hydrophobic plastic matrices, the result is a poor interface and resistance to moisture absorption (Sameni et al, 2003). The hemicelluloses and pectin materials play important roles in fibre bundle integration and fibre bundle strength and individual fibre strength. Hemicelluloses polymers are branched, fully amorphous and have a significantly lower molecular weight than cellulose because of its open structure containing many hydroxyl and acetyl groups, hemicelluloses is partly soluble in water and hygroscopic lignins are amorphous, highly complex, mainly aromatic polymers of phenyl propane units, but lignins have the least water absorption among natural fibre components.

Table 1: Composition of natural fibre

Type of Fibre	Cellulose (%)	Henucellulose (%)	Pectin (%)	Lignin (%)	Wax (%)
Bast fibre					
Flax fibre	64.1 – 71.0	11.0 – 20.6	1.8 – 2.3	2.0 – 2.9	1.5
Seed flax	43 – 47.0	24.0 – 26.0		21.0 – 23.0	
Kenaf	31.0 – 57.0	15.0 – 19.0	21.5 – 23.0		2.0 – 5.0
Jute	45.0 – 71.5	12.0 – 26.0	13.6 – 21.0	0.2	0.5 – 2.0
Hemp	57. 0 – 77.0	3.7 – 13.0	14.0 – 22.4	0.7	0.8
Ramie	68.6 – 91.0	0.6 – 0.68	5.0 – 16.7	1.9	
Coir fibre					
Kenaf	37.0 – 49.0	15.0 – 21.0	18.0 – 24.0		2.0 – 4.0
Jute	41.0 – 48.0	21.0 – 24.0	18.0 22.0		0.8
Leaf fibre					
Sisal fibre	47.0 – 78.0	7.0 – 11.0	10.0 – 24.0	10.0	0.6 – 1.0
Henequen	77.6	13.1	4.0 – 8.0		

Source: (Ikezue, 2016)

Banana fibre is a type of a leaf with botanical name musa accuminata", "musa balbisiana", leaf fibre such as Sisal, Abaca, banana and benequen are coarser than bast fibres. The coarse texture and high mechanical properties of many bast fibre and leaf fibres have many them common cordage fibre for rope, twine and string (Wambua et al, 2003), in addition, Abaca and Sisal have been both used historically for paper fibres (Khan et al,2001). Abaca and Sisal are hard fibres obtained from the leaves of their plants and they are considered to be the strongest of all plant fibres, whereas the leaf fibre strands display the characteristically long length of bast fibres, the ultimate fibre comprising these strands are typically less than 12mm long. like most of the plant fibres , the leaf ultimate fibres have typical diameter of approximately 30cm. Banana fibre which can be gotten easily from the banana plant cut down after the fruit must have ripen can be explored and used as a potential fibre for polymer reinforced composites (Sahib & Jog, 1999), Banana fibres have found many applications in engineering for the manufacture of ropes, twine, string. Vegetable or plant based natural fibres are lignocellulosic consisting of cellulose micro fibril in an amorphous matrix of lignin and hemicelluloses (Ray et al,2001). They consist of several hollow fibrils which run all along the length. Each fibril exhibits a complex layered structure with a thin primary wall encircling a thicker secondary layer and is similar to the structure of a single wood pulp fibre. Natural fibre are themselves cellulose–fibre reinforced materials in which the micro fibril and cellulose content determines the mechanical properties of the fibre i.e. elongation at break, tensile and compressive strength creep rate, modulus of elasticity, toughness, flexural strength (Wollerdorfer & Bader, 1998).

MATERIALS AND METHODS

Materials

In this research selected specimens were observed under metallurgical microscope. Then tensile specimens were prepared according to ASTM specification and were tested using a universal testing machine the Hounsfield tensometers. The composite was produced for

10cm, 30cm and 50cm for all lengths of fibres composites with 10%, 30% and 50% (% weight) of banana fibre.

Methods

The chopped fibres were sieved with 10, 30, and 50cm sieves for obtaining variation in banana fibre length. The fibres were conditioned at 80^0C for 24 hours to remove moisture and vinylester was also conditioned at the same temperature. Proper proportion of fibres 10, 30 and 50% by weight for each of 10, 30 and 50 cm length) and vinylester then properly blended to get a homogeneous mixture for each length type. The mixture was placed in a mould and composite allowed to cure for 5 hours. Tensile testing of the specimens was performed according to ASTM D 638-98 on a universal test machine operated at a crosshead speed 3 mm/min. three test specimens from every composition (combination of predefined fibre length and Weight percentage with vinylester) were tested at the same time and the averages of results were used.

RESULTS AND DISCUSSION

Selected specimens were observed under metallurgical microscope. Then tensile specimens were prepared according to ASTM specification and were tested using a universal testing machine the Hounsfield tensometers. The empirical model for predicting the composite properties, (Ikezue, 2016) is given as

$$y(x) = a_o + a_1 x_1 + a_2 x_1 x_2 + a_3 x_1 x_2 + a_4 x_1^2 + a_5 x_2^2 + a_6 x_1 x_2^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where x_1 = fibre length, cm, x_2 = fibre volume fraction (%)

y(x) is the measured property.

Tensile strength, flexural strength and creep rate

The typical load-stroke curve obtained from the tensile test is used to predict the failure behaviour of the banana fibre reinforced thermoset composite. The results were plotted as function of fibre length and fibre vol fraction. From these figures, it is clear that as the fibre length increases, the value of tensile strength increased and then decreases. This observation is true for almost all cases as per these plots, in general, as the fibre content of composite increases, the tensile strength also increases and then decreases.

From the curves (Figure 1), tensile strength was increased to a maximum at 2 cm fibre length and then dropped. Also, tensile strength was found to increase to a maximum at 30% fibre (by weight) and then decreased. 10% treated fibre composite gave better results than untreated fibre composite. Fibre length has profound impact on the properties of composites. Besides holding the fibres together, the matrix has the important function of transferring applied load to the fibres. The efficiency of a fibre reinforced composite depends on the fibre-matrix interface and the ability to transfer stress from the matrix to the fibre. In small fibre size i.e. 10 cm, tensile strength is low due to the fact that length may not be sufficient enough for proper distribution of load, as proper length is not available for stress distribution, failure occurs easily. On the other hand, for the composites of longer fibre size, i.e. 50 cm, tensile strengths were decreased compared to 30 cm fibre reinforced composites. The probably reason is that a long fibre may not become compatible with the matrix properly. Thus, improper bonding occurs between the fibres and the matrix. Moreover, fibres may be folded and there is no bonding between the folded and unfolded portion of fibre which resulted in a lower strength. Fibre entanglement may also contribute to reduce the strength (Joseph et al, 2002). For treated fibre composites, the exceptional behaviour is probably that 10 cm size of fibre is still not enough to create fibre entanglement or folding inside the matrix.

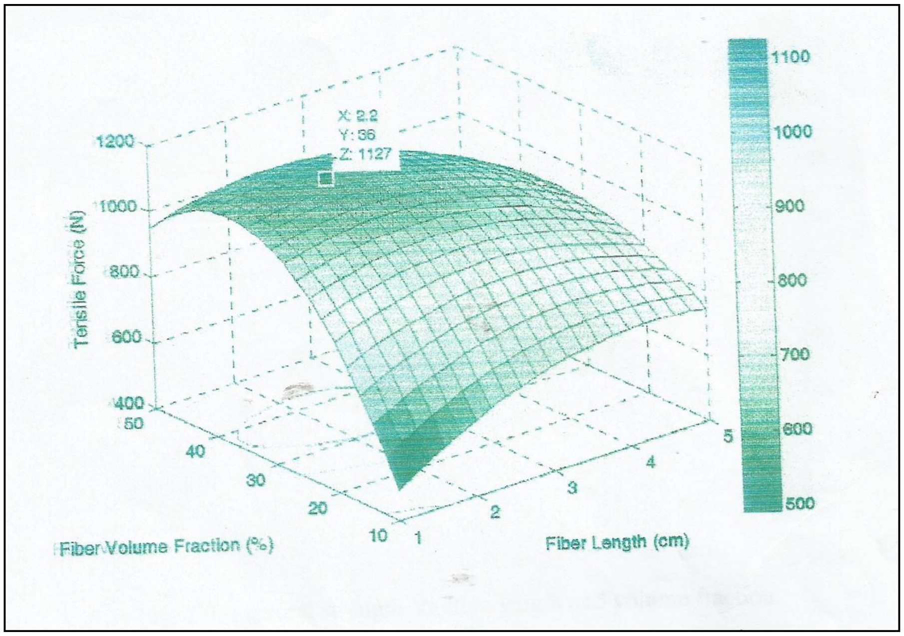

Figure 1: Tensile strength Vs Fibre length and volume fraction

In vinylester/banana fibre composites, with the increase of fibre length, tensile strength was found to be increased (Joseph et al, 2002). The trend of increase followed by a decrease of tensile strength observed in current work was found in banana/vinylester composite (Jayaraman, 2003). According to Figures 1, 2 and 3 after 30% wt. percent fibre tensile strength was decreased with higher percentages of fibre. The incorporation of fibres into thermosets leads to dispersion of fibres due to strong inter fibre hydrogen bonding which holds the fibres together. Improper adhesion hinders the considerable increment of tensile strength. Thus, as fibre percentage increases, gathering of fibres takes pace instead of dispersion and liquid vinylester cannot wet them properly. Since no adhesion is present between the fibres and fibres are also not bonded with matrix, failure occurs before attaining the theoretical strength of composite. Thus, high fibre content was limited by the incompatibility issue unless coupling agent is used (Wollerdorfer & Bader, 1998).

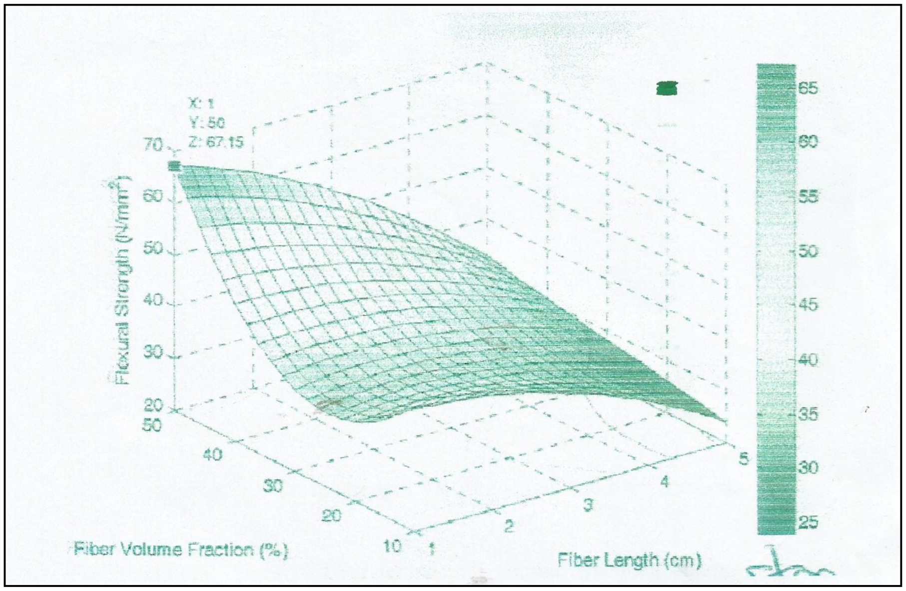

Figure 2: Flexural strength Vs fibre length and volume fraction

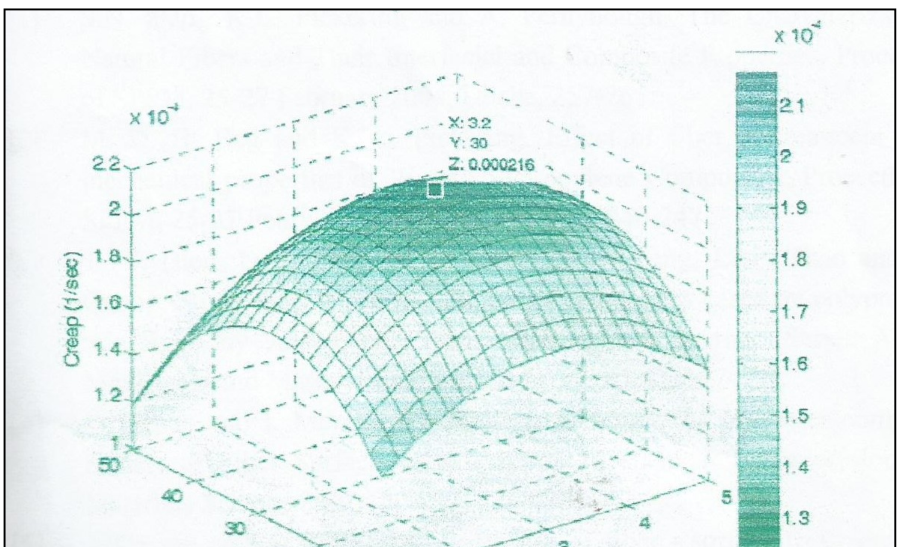

Figure 3: Creep Strength Vs fibre length and fibre volume fraction

It has been reported that initially strength may decrease after a slight increase in strength and then at very high fibre content it may again increase (Wambua et al. ,2003). The tensile strengths of the uncoupled composites have values in close range for all fibre percentage levels (Karmaker & Schneider 1996), (Rowell & Stout,1998). Without coupling agent fibre content and fibre length do not have significant effects on composite tensile properties. There exist incompatibilities between the different surface properties of the polar fibres and non-polar vinylester. Due to presence of hydroxyl and other polar groups in various constituents of natural fibre, the moisture uptake is high for dry fibres and these lead to poor wettability with matrix and weak interfacial bonding between the fibre and relatively more hydrophobic matrices. To improve affinity and adhesion between fibre and thermoset, chemical coupling agents can be used so that tensile strength increases (Khan et al,2001), (Sahib & Jog,1999). As a coupling agent, silane may be used to enhance interfacial adhesion that may react or interact favourably with the hydroxyl group on the fibre surface (Mohanty et al,2004), Use of coupling agent reduces the number of fibre pull-out (Gassan & Bledzki ,2000).

Alkali treatment generally increases the strength of natural fibre composites (Dieu et al, 2004), (Ganan & Mondragon, 2004), (Razera & Frollini, 2004). A strong sodium hydroxide treatment may remove lignin, hemicellulose and other alkali soluble compounds from the surface of the fibres to increase the numbers of reactive hydroxyl groups on the fibre surface available for chemical bonding. So, strength should be higher than untreated fibre composites. The probable cause of this phenomenon may be that alkali reacts on the cementing materials of the fibre especially the hemicelluloses which leads to the splitting of the fibres into finer filaments. As a result, wetting of fibre as well as bonding of fibre with matrix may improve which consequently make the fibre more brittle. Under stress, these fibres break easily. Therefore, they cannot take part in stress transfer mechanism (Ray et al, 2001). So, high concentration of sodium hydroxide may increase the rate of hemicelluloses dissolution which will finally lead to strength deterioration. Moreover, unnecessary extra time in treatment may also cause increment of hemicelluloses dissolution.

CONCLUSION

The results of the experimental work lead us to make the foregoing make conclusions i.e. that tensile strength has a maximum value at 30% (weight) (figure 1.0) compared to other fractions of fibre content figure 2.0 shows that flexural strength increases with an increase in fibre length and fibre volume fraction, The creep strength Figure 3.0 shows that creep increase with fibre volume fraction and fibre length up to a point of $0.000216s^{-1}$ at a fibre length of 3.2 cm and volume fraction of 30%. The maximum tensile strength (figure 1.0) was 1127 Nmm^{-2} occurring at a fibre length of 2.2 cm and volume fraction of 36%. The work has contributed to knowledge by highlighting the fact that mechanical and physical properties of polymer matrices could be enhanced by incorporating treated natural fibre samples. Also, empirical mathematical model for predicting the measured mechanical properties were stated and which shows the interactive effects of the process variables i.e. x_1(fibre length) and x_2 (fibre volume fraction)

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