EFFECT OF PRODUCTION METHODS AND MATERIAL RATIOS ON PHYSICAL PROPERTIES OF THE COMPOSITES.

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Abstract

Plastic waste and bamboo fibres can be used to produce composites for the construction industry. This would reduce the environmental problems associated with plastic waste and also reduce pressure on conventional materials such as wood from forest resources. Recent interests in reducing the environmental impact of waste materials and forest cover enhancement have led to the development of composites. Fillers and reinforcements are used in the plastic industry to produce composites for load carrying structures. Bamboo, sisal and hemp are strong and renewable plant fibres that can replace synthetic fibres. This research focused on the effects of the production methods on the physical and mechanical properties of recycled plastic - bamboo fibre boards. Recyclable plastic wastes were cleaned, dried and shredded before melting to mix with bamboo fibres. The thermo plastics were heated poured into moulds where they were mixed with bamboo fibres and then allowed to cool completely before removal in the case of open casting. In compression moulding, the mould charge was pressed using the mould lid. Water absorption, thickness swelling, bending strength and impact strength were carried out in according to standard procedures. The fibre content and production method influenced the physical and mechanical properties of the composites. Higher fibre content resulted in higher water absorption and thickness swelling. It was noted that water absorption was significantly influenced by the fibre content at $\alpha = 0.05$. The hydrophilic nature of natural fibres increased water absorption and thickness swelling significantly leading to dimensional instability of composites. Moulded composites showed better physical properties than open casting method, possibly due to reduced void space during polymerization. These tests suggested that reducing void space and incorporating fibres into the plastic improves the end use properties.These findings could be used to develop alternative materials for the construction industry.

Keywords: Bamboo fibres, plastics waste, composites

1. Introduction

Fibre reinforced composite materials are an important class of engineering materials. They offer outstanding mechanical properties, unique flexibility in design capabilities and ease of fabrication. Composites using high strength fibres such as graphite, aramid and glass are commonly used in broad range of applications from aerospace structures to automotive parts and from building materials to sporting goods (Arib *et al.*, 2006). However, the development of natural fibre reinforced composites become an attractive research lines due to the non recyclability, high density and health hazards of composites reinforced with synthetic fibres such as glass, carbon and aramid fibres. Besides, the greatest problem of using such materials is how to conveniently dispose of them once they have come to the end of their useful life span (Bodros *et al.*, 2007).

Therefore, there has been growing interest in the use of natural cellulosic fibres as the reinforcement for polymeric matrix and was noted that, adding natural powder or fibre to plastics provides a cost reduction to the plastic industry and improves the physical and mechanical properties**.** Much of the research has concentrated on using a compatibilizer to make the hydrophobe (plastic) mix better with the hydrophilic (lignocellulosic). These materials are usually referred to as natural fibres cum thermoplastic blends. Recent interests in reducing the environmental impact of waste materials are leading to the development of newer materials or composites that can reduce the stress on the environment (Sanadi *et al*. 1994 a). Fillers and reinforcements are used in the plastic industry to enable the production of composites for load carrying structures. The use of additives in plastics is likely to grow with the introduction of improved compounding technology and new coupling agents that permit the use of high filler and reinforcement content (Katz and Milewski, 1987).

Currently, bamboo utilization is confined to domestic use due to lack of modern skills, inappropriate processing skills and technology. This has resulted in wasteful processing and utilization (Benard, 2005). Composite materials refer to solid materials composed of more than one substance that is a binder and matrix that surrounds and binds together fibrous reinforcements. Binders are usually in the form of plastic resin while matrix materials are such as metals or ceramics. Polymeric (plastic) composite materials represent about 90% of all composites (Strong, 2000). They are made of fibrous reinforcements which are usually fibre glass or carbon fibres which are coated or surrounded by plastic resin. The material is placed in a mould and solidified, either by thermoplastic or thermoset moulding methods. The fibres give strength and toughness to the plastic. Nonpolymeric composites have either metal or ceramic as the binder material around the matrixes which can be made by the mixture of plastic and natural fibres. These nonpolymeric composites are used when temperature, strength or some other property or other operating conditions prohibits the use of a polymeric composite (Strong, 2000). Bamboo, sisal and hemp are strong and renewable plant fibres. They are finding an expanding market as alternatives to synthetic fabrics. All synthetic fabrics are made from plastics. Even though there is a significant market for recycled plastics, most plastic materials are not biodegradable and will remain in the land fill forever (Murali and Mohana, 2007).

Plastics disposal problem in Kenya is overwhelming. Plastic wastes cause environmental problems such as blockage of water ways, clogging of sewer systems, choking of animals to death when they feed on them, affecting the fragile eco-systems and aesthetic deterioration of landscapes. An estimated 4,000 tonnes of thin plastics were produced each month in Kenya (UNEP, 2005). Nairobi alone generated 225 tonnes of polyethylene bags and other plastics of which 1% was recycled in 2005 (KAM, 2006). Efforts have been made by Small and Medium Enterprises (SMEs) and large enterprises to invest on recycling technologies.

There is need for a shift from wood based composites in order to reduce pressure on forest resources. Forest area in Kenya is fast diminishing due to excisions for human settlement and less reforestation to match harvesting. According to the United Nations (UN) standards, forest cover should be at least 10% of a Country's total area. For Kenya, whose area is 582,646km^2 minimum forest cover should be 58,265km^2 (Kamau, *et al.* 2005). Current forest cover is below 3%, due to deforestation. Actual government owned forest is 1.7% (Kenya Forest Research Institute, 2007). There is also a need to protect environment from pollution associated with plastic wastes. The banning of the use of plastic bags in the packaging and wrapping industry by the Kenya Government (GoK) in 2007/2008 financial year budget was not the best alternative as this will have a devastating impact on industries dealing in plastic products which may result in loss of jobs and income. The government banned the manufacture and importation of plastics below 30 microns and introduced a 120 % excise duty on other polythene bags (GOK, 2007).

2. Materials and methods

Material preparation and composite production

In this research, recyclable plastics and bamboo fibres were used. High density polyethylene (HDPE) and low density polyethylene (LDPE) are the recyclable plastic wastes of environmental concern identified for the composites. LDPE and HDPE have similar linear structure, but LDPE has lower density (0.938 g/cm^3) than HDPE (0.963 g/cm^3). LDPE and HDPE have lower melting point among plastics which make them processable at temperature below the degradation temperature of natural fibres. Bamboo culms were purchased from Kenya Technical Teachers College (KTTC) in Nairobi. The culms were planed to remove the skin, crushed and then sieved to obtain short fibres.

Processing equipment included mould, digital weighing scale, personal protective equipment (PPE), melting pan, stirring stick, brushes, flexural test machines, tape measure, vernier calipher and product testing facilities. The plastic wastes were collected; LDPE and HPDE sorted from other plastics waste through visual method and thereafter cleaned to remove dirt before shredding. The clean dry plastics were then shredded using shredding machine and melted to mix with the fibres from the bamboo plant.

Composite production

The fibres were mixed with molten plastic at varying ratios of 20%:80%, 30%:70% and 40%:60% (by weight) of bamboo fibres and plastics respectively. The molten mixture of plastic and bamboo fibres at 120^{o}C, melting point of plastic; were fed into the prepared moulds of dimensions of 300mm x 300mm x10mm thick.

Two processing methods were used in this study namely; compression moulding and open casting. In open casting, the molten plastic waste was mixed with bamboo fibres and then poured into a mould where polymerization took place. In compression moulding, the material charge was pressed between two halves of the mould and allowed to transform into a solid product. Mould patterns were fabricated using wooden boards.
The material ratios under study were 80%; 20%. 70%:30% and 60%:40% plastic to bamboo fibres respectively. The samples were divided into 5 parts for each production and composition. They were carefully marked and labeled for the two production methods and three material ratios. For each method and ratio, data on water absorption, thickness swelling, impact strength, bending strength, tensile strength and strain was collected.

Five (5) samples were made for each ratio and production method. Samples for different material ratios and production methods were labeled and kept separately. For each method and composition, data was collected on the water absorption and thickness swelling.

70%:30% (Plastic:bamboo)

80%:20% (Plastic:bamboo)

60%:40% (Plastic:bamboo)

Fig. 2 1 : Sample sizing, trimming and labelling

Water absorption

Water absorption is used to determine the amount of water absorbed by a composite. The water absorption test followed ASTM standard test method D570. The test specimen was in the form of a bar 75mm long, 50mm wide and 10mm thick. Before the measurement, the sample was dried in an air oven at 50°C for 24 hours, cooled in a desiccator, and immediately weighed to the nearest 0.001 g which is then taken as the dry initial weight of the sample. Then the specimen was immersed in distilled water maintained at a temperature of 23 ± 1°C for 24 hours.

After 24 hours, the specimen was removed from water and placed on blotting paper to remove excess water before weighing to the nearest 0.001 g. For each composite, five sub samples were measured. The water absorption of the sample was calculated as percent weight change (w %) as follows:

$$(W_a) = \frac{(M_2 - M_1)}{M_1} \text{ x } 100\%$$

where M_1 = weight of dry piece (gm)
M_2 = weight of wet piece (gm)
(W_a) = water absorption (%)

Thickness swelling

This test, like water absorption was important in ascertaining dimensional changes. The thickness swelling samples were 75 mm x 50 mm x 10mm. Five specimens for each method and ratio were tested. The samples were soaked in distilled water for 24 hours. The immersed samples were taken out and wiped by dry cloth to remove water from the surface. The thickness was measured using a vernier caliper to the nearest 0.01 along the length at room temperature and average results recorded. The thickness swellings of the samples were calculated according to ASTM standards D1037-03.

3. Results and Discussion

Water absorption

Water absorption is a disadvantage in composites. Natural fibre-thermoplastic composites have higher water absorption than the plastic polymer. Therefore, fibre surface modification, which can reduce the hydroxyl groups in the cell wall of cellulose molecules, is necessary in the reduction of water absorption in composites. Plastic-bamboo composites of various compositions were produced by open casting and compression moulding. Table 1 shows the average water absorption for the two production methods

Table 1: Percentage Water Absorption of the Composites

% Fibre content	Open casting	Compression moulding	mean effect	LSD
20	1.05	0.73	0.90^{c}	N/A
30	1.21	0.86	1.04^{b}	N/A
40	1.27	1.18	1.23^{a}	N/A
LSD	N/A	N/A	0.031	N/A
Mean effect	1.18^{x}	0.93^{y}	1.06	0.025

Means within a column or row followed by same letter are not significantly different at α=0.05, using least significant difference (LSD) and not applicable (N/A)

Water absorption in composites influences dimensional stability. From the data, it is evident that water absorption is significantly influenced by the fibre content at α=0.05. The higher the fibre content, the higher the water uptake and vice versa. This could be attributed to plastic which act as a barrier to the bamboo fibres, thus preventing the water from reaching the fibres. It is noted from these figures that, the incorporation of starch into the reinforced polymer latex composite increased the water absorption. This observation agrees with the findings of Ahmadzadeh and Zakaria (2009) and Matan & Kyokong (2003), who reported that water uptake increases with increase of the filler content. Since lignocellulose fibre is hydrophilic in nature, the increased amount of bamboo fibres used as filler in the composite showed significant effect on the water absorption. The percentage water absorption of the composites is expected to achieve equilibrium. As the filler loading increases, the formation of agglomerations increases hence it is difficulty to achieve homogeneous dispersion of a filler of high filler loading. This agglomeration of the filler in composite increases the water absorption of the composites. Dimensional stability of composite is important since construction materials should have the ability to withstand the stresses of shrinkage or swelling due to the changes of temperature and moisture. Also from the results, it is evident that water absorption is lower at all fibre content for composites produced by compression moulding than those by open casting due to reduction in voids as pressure is exerted during the forming process. Adequate fibre- matrix bonding decreases the rate of water absorption and offer superior dimensional stability.

These results are graphically shown in Figures 1.

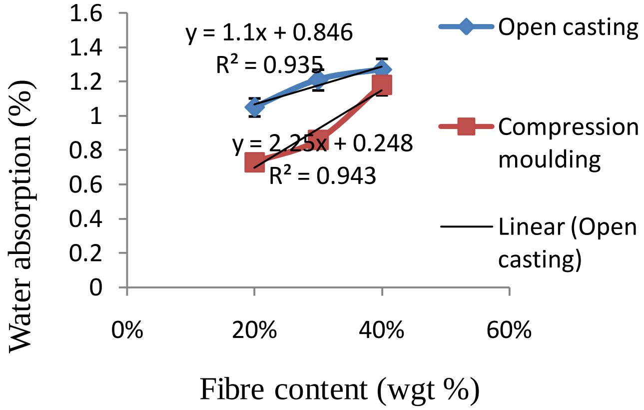

Fig.1: Percent water absorption for two production methods

This is evident by the correlation coefficient of 0.935 and 0.947. Normally, low density polyethylene plastic does not have good water absorption. Bamboo fibre is also not considered as a hydrophilic material, but the significantly increased water absorption of composites was likely to be attributed to the many pores and gaps in the bamboo fibre structure

Thickness swelling

Table 2: Percentage Thickness Swelling of the Composites

% Fibre content	Open casting	Compression moulding	Mean effect	LSD
20	1.51	1.32	1.42^c	N/A
30	1.60	1.48	1.54^b	N/A
40	1.86	1.57	1.69^a	N/A
LSD	N/A	N/A	0.031	N/A
Mean	1.64^x	1.46^y	1.55	0.025

Means with the same letter in the same column or row are not significantly different at α=0.05, using (LSD).

From the results, it is observed that thickness swelling increased with increase in fibre content. This could be attributed to hydrophilic effect on bamboo fibres. The high cellulose content in bamboo fibres further contribute to more water penetration into the interface through the voids induced by swelling of fibres, creating swelling stresses leading to composite failure. Figure 2 shows percentage increase in thickness swelling for the two production methods.

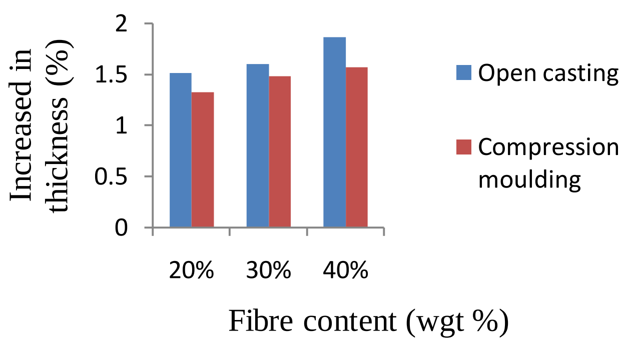

Fig.2: Thickness swelling for the two production methods

When the composite is exposed to moisture, bamboo fibre swells. As a result of fibre swelling, micro cracking of the brittle thermosetting resin (like unsaturated polyester) occurs. The high cellulose content in bamboo further contributes to more water penetrating into the interface through the micro cracks induced by swelling of fibres creating swelling stresses leading to composite failure.

As the composite cracks and gets damaged, capillarity and transport via micro cracks become active. The capillarity mechanism involves the flow of water molecules along fibre–matrix interfaces and a process of diffusion through the bulk matrix. The water molecules actively attack the interface, resulting in debonding of the fibre and the matrix. This agrees with the finding of Kumar and Siddaramaiah (2005) who noted that swelling thickness is direct proportional to the fibre content in the composites due to hydrophilic nature of lignocellolusic fibres causing the thickness to swelling in composites. Thickness swelling was more in open casting than compression moulding.

Conclusions

The composite formed at lower percentage of bamboo fibres as compared to plastic (resin), which acts, as a binder that surrounds and binds together the fibrous reinforcement. The physical properties of the composite were determined and was noted to be influenced by the method of production and fibre content at significance level of α=0.5%. Compression moulding method showed better physical properties such as significantly low water uptake and less thickness swelling as compared to open casting. This could be attributed to reduced voids during polymerization.

Water absorption and thickness swelling increased significantly with fibre content due to hydrophilic effect of natural fibres. This could lead to dimensional instability of the composite as residual compressive stresses imparted to the material during composite processing are released. The composites produced have high potential as alternative building and construction materials.

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