THE PRODUCTION METHODS AND MATERIALS RATIO EFFECT ON THE MECHANICAL AND PHYSICAL PROPERTIES OF BAMBOO-PLASTIC WASTE COMPOSITES USE FOR INFRASTRUCTURE DEVELOPMENT

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ABSTRACT

Plastic waste management has become a major concern environmentally across the globe, especially in developing countries. Plastic waste is synthetic and non-degradable material. However, it has great economic importance when recycle and used with other environmentally-friendly materials to produce composites for structural engineering works. The production and application of this product will minimise the environmental problems of plastic waste. The usage of this composite material globally, will help reduce the high dependency on the limited forest timbers of soft and hardwoods. Bamboo fibre and plastic waste can be used to produce this composite which will be used for all load carrying elements. Bamboo fibre as reinforcement in polymers is on the increase because is biodegradable and environmentally friendly. This study looks at the effects of the production methods and the materials ratio effect on the mechanical and the physical properties of bamboo fibre and plastic waste composites boards. The fibres were extracted by mechanical method, whilst the wastes plastics are clean, dried and shredded before melting to mix with the fibres. The molten plastics wastes were poured into moulds mixed with fibres and then allowed to cool completely, after removed from the case of open casting. In compression moulding, the mould charge was pressed using the mould cover. Water absorption, bending strength, impact strength and thickness swelling were carried according to standard measures. The fibre content and production method influenced the mechanical and physical properties of the composites. Higher fibre content in the composite resulted in higher water absorption and thickness swelling. It was observed that water absorption was significantly influenced by the fibre content at $\alpha = 0.05$. The hydrophilic nature of the fibres has increased water absorption and thickness swelling significantly leading to dimensional instability of the 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 construction and manufacturing industries where load bearing is required.

Keywords: Biodegradable, Construction, Compression Moulding Economic Importance, Hydrophilic, Open Casting,

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1. INTRODUCTION

Plastics play an important role in the daily used of products for consumers. (Dweib *et al*., 2004; Burguenoa *et al*., 2005; Athijayamani*et al*., 2010). However, most plastics are parts made from petroleum-based which has environmental harmful potentials. In pursuit to minimise or eliminate this harmful environmental challenges, there is the need to search for an alternative material which can be used to process these plastic wastes into another resourceful material which will be environmentally friendly and biodegradable. First, not only by replacing them, but also by creating and providing the materials which having the appropriate characteristics of mechanical, physical, and thermal performance while preferably also reducing the cost for the final product. For that reason, natural fibre plastic composites as an alternative are becoming widely accepted as part of the product in the plastics market (Dweib *et al*., 2004; Burguenoa *et al*., 2005; Athijayamani*et al*., 2010).

For some years now, natural fibres have attracted the interest of researchers, material scientists, and industries, owing to their specific advantages as compared to conventional or synthetic fibres from the past (Jawaid and Abdul Khalil, 2011). This is due to the outstanding mechanical properties, unique flexibility in design capabilities, attractive aesthetic features and ease of fabrication. The attractive and possible advantages, such as reduced tool wear, low cost, and low density per unit volume and acceptable specific strength, along with their sustainable renewable and degradable features are some of the important properties of the natural fibres, which make them suitable to use as filler in polymer composites. Large and wide varieties of natural fibres that are being applied as fillers or reinforcement are well recognized. The development of natural fibre reinforced composites has become an attractive research lines due to the non recyclability, high density and health hazards problems for the workers who manufacture their corresponding composites and the users of composites reinforced with synthetic fibres such as aramid fibres, carbon fibres and glass fibres (Jawaid and Abdul Khalil, 2011). Besides, the greatest problem of using these synthetic fibre materials is how to dispose them off conveniently once they have come to the end of their useful life span (Bodros *et al.,* 2007).

The use of natural fibres as the reinforcement for plastic waste will help in the reduction of the environmental problems faced in our societies today across the globe, especially third world countries. The process of adding fibres to the recycle plastics waste will provide cost reduction to the plastic industries that goes into its usage and also help improve the physical and mechanical properties of the polymeric matrix**.** This research concentrates on using a compatibilizer to process the hydrophobia (plastic) to mix better with the hydrophilic (lignocellulosic). These materials are usually referred to as natural fibres with thermoplastic blends. The current effort by researchers, industrialists, scientist, and environmentalists to find the needed measures to adopt in reducing the environmental impact of plastic waste materials, has led to the development of newer materials or composites that can reduce the pressure on the environment (van Rijswijk *et al*., 2001). Fillers and reinforcements are used in the plastic industry to enable the production of composites for load carrying structures. The application of additives in plastics is likely to increase with the introduction of improved compounding technology and new coupling agents that permit the use of high filler and reinforcement content.

Currently, bamboo utilization is limited to domestic use due to lack of modern skills, inappropriate processing skills and technology FAO (2005). The weaker interfacial or adhesion bonds between highly hydrophilic bamboo fibres and hydrophobic plastic waste, non-polar organophilic polymer matrix, leads to considerable decrease in the properties of the composites and, thus, significantly obstructs their industrial utilization and production. However, several approaches and schemes have been established to supplement this deficiency in compatibility, including the introduction of coupling agents and/or various surface modification techniques Kalia *et al.,* (2009). This and many other limitations have resulted in its wasteful processing and utilization.

1.1. Composite Materials

The term "composite materials" refers to solid materials which composed of more than one substance that is a binder and matrix that surrounds and binds together fibrous reinforcements. The binders are usually in the form of plastic resin while matrix materials are either metals or ceramics. The polymeric (plastic) composite materials represent about 90% of all composites Strong (2000) and Bashir (2013). The polymeric composite materials are made of fibrous reinforcements which are usually fibre glass or carbon fibres that 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 material due to its mechanical rigidity. Non polymeric 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 non polymeric composites are used when temperature, strength or some other property or other operating conditions prohibits the use of a polymeric composite Strong (2000). Bashir (2013). Natural fibres such as bamboo, hemp and sisal are strong, renewable plant fibres and environmentally friendly. These natural fibres are finding a growing market as alternatives to synthetic fabrics. Synthetic fabrics are mostly made from plastics and even though there is a significant market for recycled plastics, most plastic materials are not biodegradable and will remain in the land fill permanently according to Murali and Mohana (2007).

1.2. Plastic Wastes and the Environment

Trillions of plastic wastes have been produced since their introduction over 30 years ago. There is an overwhelming problem with plastic waste disposal across the globe; especially in the third world countries which Africa is no exception. The U.S. alone produces over 100 billion plastic wastes annually. This is equivalent to throwing away over 12 million barrels of oil per year and in the U.S alone, over 85 billion plastic bags are thrown away each year. South Africa also uses 8 billion plastic bags a year which poses a lot of environmental problems to our society and the world at large. This problem of plastic waste disposal has been of a huge task on most governments across the world as most revenues goes into plastic waste disposal instead of investing these monies into infrastructure developments for the nations.

A research carried out on waste plastics materials disposed off indicate that, it takes over 1,000 years to degrade. They do not biodegrade, instead they photo degrade. The sun breaks down the plastic into smaller and smaller toxic particles. The degradation releases toxic waste into the environment, polluting land, air, and water (Bashir, 2013). Hundreds of thousands of these waste plastics are inhaled or eaten by animals each year. Cows, sheep, sea turtles, fish, whales, birds, and other animals fall victim to plastic wastes each year. Plastic wastes does cause environmental problems such as affecting the fragile eco-systems, blockage of water ways, clogging of drains, choking of animals to death when they feed on them and aesthetic deterioration of landscapes as shown in the figures 1- 4 below respectively.

Figure 1. Aesthetic deterioration of landscapes by plastic wastes at the beach

Figure 2. Aesthetic deterioration of landscapes by plastic wastes on a farm land

Figure 3. Clogged drains (gutter) by plastic wastes

Figure 4. Animals feeding on dump site of plastic wastes

A research carried out on most African countries on thin plastic waste production revealed that, discarded plastic materials are major challenges. In Kenya, it was revealed that over 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 (Bashir, 2013). Also, it is estimated that 40,000 tonnes of thin film plastics were produced annually in South Africa (Bashir, 2013; Nhamo, 2008). Furthermore, it is estimated that in Accra Ghana, a small city of 2.2 million people, up to 60 tonnes of plastic packaging is dumped on the streets every day, a figure that has risen by 70% over the past decades (South, 2014). Also according to a study by the Industry Modernization Center in Egypt, IMC, in 2008, Egypt's plastic annual consumption reached one million tons/year. Egypt produces annually about 16.2 million tons of waste; plastic amount is about 6% of this waste, this is around 970,000 tons of plastic waste per year in (2005/2006). Only 30% of this amount is recycled, 5% is reused, while the rest 65% of plastic waste is not collected. It is buried, burned, or piled up in streets and vacant areas between buildings (Marwa, 2014).

There have been calls from many Governments over the past decades to Small and Medium Enterprises (SMEs) to invest on recycling technologies. There is also a need to protect the environment from pollution associated with plastic wastes. As measure of protecting the environment, some African countries such as Rwanda, Congo, Tanzania, Kenya and Uganda have passed laws banning or restricting the use of the ordinary plastic grocery bag in the packaging and wrapping industry (Bashir, 2013). In some countries too, governments have banned the manufacture and importation of plastics below 30 microns as a means to protect the environment as well as they tax those industries to help in disposing of these plastic wastes.

2. MATERIALS AND METHODS

2.1 Material Preparation and Composite Production

In this research, recyclable plastics waste and bamboo fibres were used. High density polyethylene (HDP) and low density polyethylene (LDP) are the recyclable plastic wastes which are of environmental worry identified for the composites. High density polyethylene (HDP) and low density polyethylene (LDP) have similar linear structure, but LDP has lower density (0.938 g/cm^3) than HDP (0.963 g/cm^3). High density polyethylene (HDP) and low density polyethylene (LDP) have lower melting point among plastics which make them possible for processing at a temperature below the degradation temperature of natural fibres. Bamboo culms were harvested from Kakum forest in the central region of Ghana. The culms were seasoned and the lignin was removed by peeling with sharp knife. The culm was crushed in a crushing mill machine and then sieved to obtain short fibres which were used for this process.

The processing equipment used to carry out this work included mould, digital weighing scale, personal protective equipment (PPE), melting pan, stirring stick, brushes, flexural test machines, tape measure, Vernier calliper and product testing facilities. The plastic wastes were collected; High density polyethylene (HDP) and low density polyethylene (LDP) 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.

2.2 The Composite Production

In producing the composite, first the fibres were mixed with molten plastic wastes at varying ratios of 20%:80%, 30%:70% and 40%:60% (by weight) of bamboo fibres and plastics wastes respectively. The molten mixture of plastic wastes and bamboo fibres was at a temperature of 120^{o}C, melting point of plastic; were fed into the prepared moulds of dimensions of 300mm x 300mm x10mm thick. The two processing methods adopted for this study includes 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, whilst in the compression moulding, the material charge was pressed between two halves of the mould and allowed to transform into a solid product. The mould patterns were fabricated using wooden boards. The material ratios under study were 20%; 80%. 30%:70% and 40%:60% bamboo fibres to recycle plastic wastes respectively. The samples were divided into five parts for each production and composition. The samples were marked and labelled for the two production methods and three material ratios. In each method and ratio, data on water absorption, thickness swelling, impact strength, bending strength, tensile strength and strain was collected. In all, five samples were made for each ratio and production method. Samples for different material ratios and production methods were labelled and kept separately as shown in the figures 5-7 below. In each method and composition, data was collected on the water absorption and thickness swelling.

Figure 5. Bamboo: Recycle plastic wastes-20%: 80%

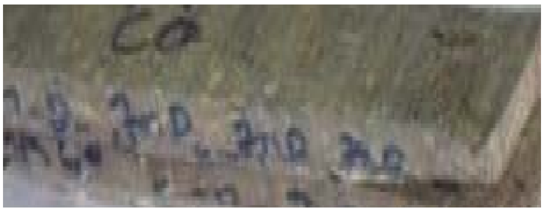

Figure 6. Bamboo: Recycle plastic wastes-30%: 70%

Figure 7. Bamboo: Recycle plastic wastes-40%: 60%

2.3 Water Absorption in Composites

Water absorption is a process used to determine the amount of water absorbed by a given composite. In this process, the water absorption test followed ASTM standard test method D570 to perform this process. The specimen's test was in the form of a bar 75mm long, 50mm wide and 10mm thick. The sample was dried in an air oven at 50°C for 24 hours before its measurement, cooled in desiccators, and immediately weighed to the nearest 0.001g which is then taken as the dry initial weight of the sample. The specimen was immersed in distilled water and maintained at a temperature of 23 ± 1°C for 24 hours. The specimen was then removed from the water and placed on blotting paper to remove excess water before weighing it to the nearest 0.001g after the 24-hour period. For each composite, five sub samples were measured. The water absorption of the sample was calculated as percentage weight change (w %) as shown in equation 1, below:

$$(W_a) = \frac{(M_2 - M_1)}{M_1} \times 100\% \qquad (1)$$

Where:

M_1 = weight of dry piece (gm)

M_2= weight of wet piece (gm)

(W_a) = water absorption (%)

2.4 Thickness Swelling

The thickness swelling of the composites was tested to determine the swelling rate of the material. This test, like water absorption was important in ascertaining dimensional changes. The thickness swelling samples were 75 mm x 50 mm x 10mm for each composite. 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 calliper 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

3.1 Water Absorption

From the study outcome, it was realized that water absorption is a disadvantage in composites materials. Findings shows that natural fibre-thermoplastic composites have higher water absorption than the plastic polymer. Therefore, the need for fibre surface modification, which can reduce the hydroxyl groups in the cell wall of cellulose molecules, as it is necessary in the reduction of water absorption in composites. Plastic-bamboo composites of various compositions were produced by open casting and compression moulding. The Table 1 below shows the average percentage of water absorption for the two production methods from this experiments.

Table 1: Percentage Water Absorption of the Composites

%Fibre content	Open casting	Compression moulding	Mean effect	LSD
20	1.05	0.73	0.89	N/A
30	1.21	0.86	1.04	N/A
40	1.27	1.18	1.23	N/A
LSD	N/A	N/A	0.031	N/A
Mean effect	1.18^{x}	0.92^{y}	1.05	0.025

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

It was realized that water absorption in composites materials does influence dimensional stability. From the data above, it was evident that water absorption is significantly influenced by the fibre content at $\alpha=0.05$. 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 in the composites. It was also noticed from the figures that, the incorporation of starch into the reinforced polymer latex composite increased the water absorption. This observation agrees with the findings made in a similar work by Sapaun and Harimi (2005) and Ahmadzadeh and Zakaria (2009), they reported that water uptake increases with increase of the filler content. This is because 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. Finding shows that, as the filler loading increases, the formation of agglomerations increases hence, it is difficult 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 needs to 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. Usually, 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. The Table 2 below, shows the percentage thickness swelling of the two composite produced for the two production methods.

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	1.72[a]	N/A
LSD	N/A	N/A	0.031	N/A
Mean effect	1.66[x]	1.46[y]	1.56	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 deduced from this work, it was observed that thickness swelling of the composite material increased with increase in fibre content. This was attributed to hydrophilic effect on bamboo fibres. The high cellulose content in bamboo fibres also contributed further to more water penetration into the interface through the voids induced by swelling of fibres, creating swelling stresses leading to composite failure. 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 a similar work carried by Kumar and Siddaramaiah (2005) who reported that swelling thickness is direct proportional to the fibre content in the composites due to hydrophilic nature of lignocellulosic fibres causing the thickness to swelling in composites. The thickness swelling from the two categories of the experiment shows that, it is more in open casting than compression moulding.

Conclusions

The outcome of this work gives some characteristics of composite materials, more especially natural fibres in polymeric materials as subsequently stated. Result shows that 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. It was also noted that 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%. Also it was seen that comparing the two methods processes, compression moulding method showed better physical properties such as significantly low water uptake and less thickness swelling as compared to open casting method. This could be attributed to reduced voids produced during polymerization. It was also clear from experimental results that water absorption and thickness swelling increased significantly with fibre content due to hydrophilic effect of natural fibres. This finally does lead to dimensional instability of the composite material as residual compressive stresses imparted to the material during composite processing are released. In all the composites material produced from the plastic waste and the fibre from bamboo was very successful and does have high potential as alternative constructional material for load carrying elements and to be used by industries which are into woods and wood products to producing of structures for buildings and other elements. This method when adopted by researchers, environmentalists, scientist and industrialist to recycle plastic waste in our societies and nations as well, it will help in total elimination or minimization of its effects on the society and help improve our society as well as the atmospheric conditions by preventing the negative effects on the ozone layer. This also will help to increase soil fertility in farmland as this material will be degradable in their life cycle.

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