# Effect of Production Methods and Material Ratios on Mechanical Properties of the Composites

**G.K. Matoke**
Department of Industrial and Energy Engineering
Egerton University, Box 536-20115
Egerton, Kenya

**S.F.O. Owido**
Associate Professor, Department of Crops
Horticulture and Soils, Egerton University
Box 536-20115, Egerton
Kenya

**D. M. Nyaanga**
Associate Professor, Department of Agricultural Engineering
Egerton University Box 536-20115
Egerton, Kenya

## 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. Bending strength and impact strength were carried out in according to standard procedures. The fibre content and production method influenced mechanical properties of the composites. Mechanical properties of the composite were influenced by the method of production and materials ratios. The addition of bamboo fibres to the polymer improved the mechanical properties. Impact and bending strengths increased with increase in fibre content upto 30% then started decreasing. Tensile strength increased with increase in fibre content as fibres are strong and rigid in tension. Strain decreased with increase in fibre content as the enhanced fibre loading hardens the composite, thus reducing elongation. .These findings could be used to develop alternative materials for the construction industry.*

**Keywords:** Bamboo fibres, plastics waste, composites

## *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

## *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

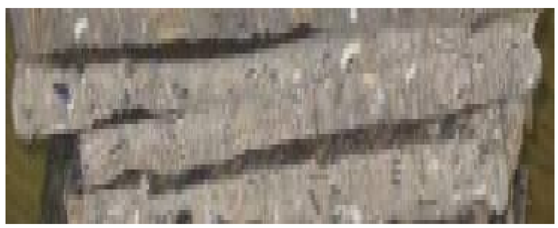
The fibres were mixed with molten plastic at varying ratios of 20%:80%, 30%:70% and 40%:60% (by weight) of bamboo fibres and plastics respectively. The molten mixture of plastic and bamboo fibres at 120$^o$C, melting point of plastic; were fed into the prepared moulds of dimensions of 300mm x 300mm x10mm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

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 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 mechanical properties.

70%:30% (Plastic:bamboo)



80%:20% (Plastic:bamboo)

60%:40% (Plastic:bamboo)

**Fig. 1 : Sample sizing, trimming and labelling**

**Impact Strength**

Five test samples were prepared according to KEBS standard KS1738/6. The pieces measuring 150mm by 75mm by 10mm from each of the materials ratios and processing methods were tested for impact strength.

A 45° notch was made on the test pieces, then supported at the ends. A standard mass, steel ball of 0.62 N. was dropped from varying heights. The height of drop in millimeters (mm) that produced visible failure on the opposite face of the test piece was noted. The height varied between 75 and 1700 mm. The mass and heights were used to calculate the energy using the following formula;

E= mgh …………………. 3.3

Where

E – Energy used to break the specimen (J)
m – The mass used (g).
h - The falling height of mass (mm).
g - The gravitational acceleration($m/s^2$)

**Bending Strength**

The test samples were prepared according to KEBS standard KS02-1249. Five samples of 150mm x 75mm x 10 mm thickness of composites were used for the test. A test piece was placed on two supports and force applied at midspan as shown in Plate 3.*1* until failure.

The bending strength is calculated from the ultimate force, the distance between the supports, width and thickness of the test pieces. Two parallel cylindrical supports adjustable in the horizontal place, of length exceeding 75mm and a diameter of 30mm if the thickness piece is 10mm. A loading head, placed parallel to the supports and equidistant to them adjustable in the vertical plane and having the same length and radius as of those of the support is used

The test piece was placed flat on the supports, its length axis being at right angles to those of the supports, so that the transverse axis of the test piece and the axis of the loading head are in the same plane. The load was applied through the loading head continuously until the failure of the test piece and maximum load recorded.

The bending strength (σ) of each test piece is given by the formula;

$$\sigma = \frac{3pl}{2bt^2} \text{ ---------------------------3.5}$$

Where

σ - is the bending strength ($N/mm^2$)
P – the maximum load (N)
l- is the distance between the supports (mm)
b- is the width of the test piece (mm)
t- is the thickness of the test piece (mm)

The equipment used to measure bending strength was AUTO 2000 compression and flexural testing machine. The machine gives the strength values automatically on the control panel.

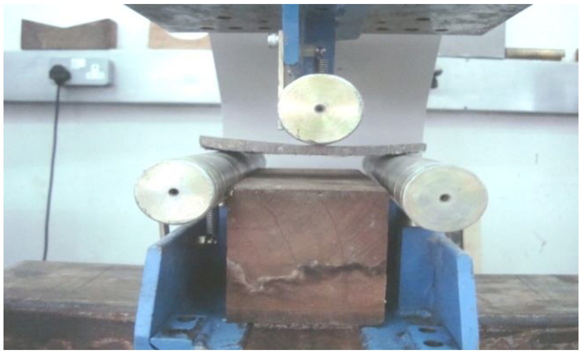


Plate 3.1: Bending Test Machine, Auto 2000

## Tensile Strength

Tensile strength indicates the ability of a composite material to withstand forces that pull it apart as well as the capability of the material to stretch prior to failure. Tensile test of the samples were done in accordance to KEBS standard KS02-624.

The Universal testing machine (Model SDLATLAS) as shown in Plate 3.2 was used to perform the tensile strength and strain tests. Each test was performed until tensile failure occurred. The test was performed on five specimens sample. The maximum load was automatically recorded by the instrument. Tensile strength is given by the formulae;

$$T = \frac{F}{A} \text{-------------------------------} 3.6$$

Where

T - Tensile strength ($N/mm^2$)
F – Force required to break the specimen (N)
A - Cross-sectional area of the original test specimen ($mm^2$)


Plate 3.2: Tensile and Strain Testing Machine

## Strain

Strain test of the samples were done in accordance to KEBS standard KS02/624. The Universal testing machine (Model SDLATLAS) was used to perform the tests. The material displacement is the strain (ε) which is given by formula;

$$Strain \quad (\varepsilon) = \frac{\Delta l}{l} \text{------------------------} 3.7$$

Where Δl - change in length (mm)

l - the original length (mm)

The test was performed on five specimen's sample.

The standard specimen was mounted by its ends into the holding grips of the testing machine.

The machine is designed to elongate the specimen at a constant rate and to continuously and simultaneously measure the instantaneous applied load and the resulting elongations. The elongation is expressed as a percentage increase in length compared to the original length of the test specimen.

### Statistical Analysis of Data

A completely randomized experimental design (CRD) was used with a 3 x 2 factorial treatment, 3 plastic- bamboo fibre ratios and either open casting or compression moulding. The data was analyzed by the Statistical Analysis for Scientists (SAS). Analysis of Variance (ANOVA) was used to test the differences and significance effect of the independent factors.

Least Significance Difference (LSD) was applied to compare whether there was difference between treatment means at 5% level of confidence.

## *Results and Discussion*

### Impact Strength

A standard mass was dropped from varying heights onto the test piece and readings recorded when it broke. The mean values are as presented in Table 1. The increase in fibre content, increased the impact strength upto 30% fibres then dropped for both methods. The strength for compression moulding was significantly higher. But at higher fibres content (30%), the impact strength decreased in both production methods. This could be attributed to pressure applied during moulding which reduced the formation of pores.

**Table 1: Impact Strength (J) of the Composite**

| % Fibre content | Open casting | Compression moulding | mean effect | LSD |
|---|---|---|---|---|
| 20 | 10.24 | 25.30 | $17.77^{c}$ | N/A |
| 30 | 12.00 | 35.00 | $23.50^{b}$ | N/A |
| 40 | 11.70 | 27.40 | $19.30^{a}$ | N/A |
| LSD | N/A | N/A | 0.260 | N/A |
| Mean effect | $11.15^{x}$ | $29.23^{y}$ | 20.19 | 0. 212 |

*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)*

These results are graphically shown in Figures 1.

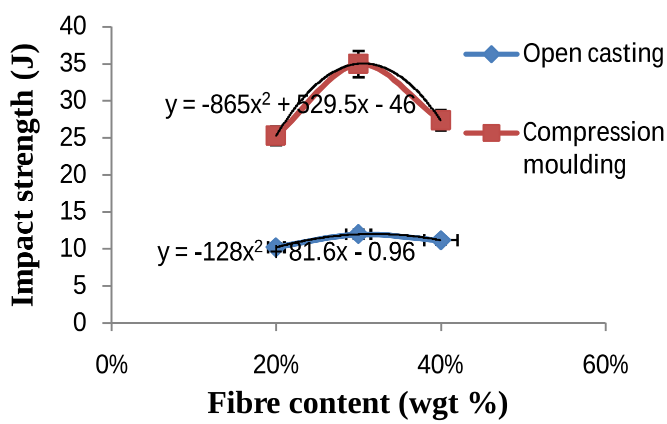



Fig. 1: Impact Strength of the Composite

## Bending Strength

The bending strength of the composites increased with increasing fibre content. This is shown in Table 2.

**Table 2: Bending Strength ($N/mm^2$) of Composite**

| % Fibre content | Open casting | Compression moulding | Mean effect | LSD |
|---|---|---|---|---|
| 20 | 5.20 | 9.30 | $7.25^{c}$ | N/A |
| 30 | 10.40 | 15.30 | $12.85^{b}$ | N/A |
| 40 | 8.30 | 13.90 | $11.10^{a}$ | N/A |
| LSD | N/A | N/A | 0.41 | N/A |
| Mean | $7.97^{x}$ | $12.83^{y}$ | 10.40 | 0.33 |

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

The increase of fibre content resulted in increase in bending strength upto 30%. This increase is due to the relationship between the interfaces of fibres and plastic in which the fibres strengthen the composite materials.

This agrees with the finding of Sapuan and Harimi (2003) in their work on mechanical properties of epoxy/ coconut shell filler particle composites. The strength increased with increased fibre content upto 30% then started decreasing as shown in Figures 2 due fibre fall out.

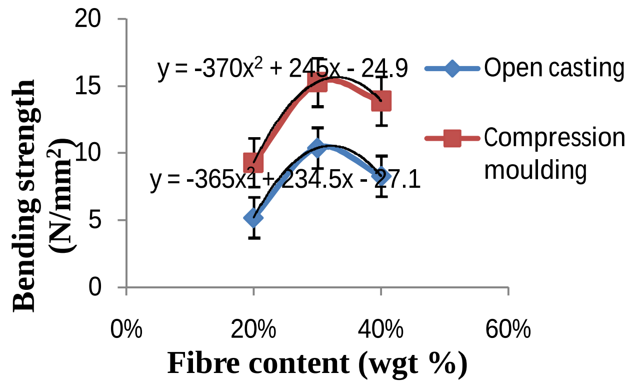



Fig.2 : Bending Strength of Composite

## Tensile Strength (MPa)

Table 3 and Figure 3 show the mean tensile strength of the three fibre composition. The tensile strength increased with increase in fibre content but was more significant in compression moulding.

**Table 3: Tensile Strength of Composite**

| % Fibre content | Open casting | Compression moulding | Mean effect | LSD |
|---|---|---|---|---|
| 20 | 0.075 | 0.317 | $0.196^{c}$ | N/A |
| 30 | 0.076 | 0.346 | $0.211^{b}$ | N/A |
| 40 | 0.085 | 0.352 | $0.218^{a}$ | N/A |
| LSD | N/A | N/A | 0.002 | N/A |
| Mean | $0.079^{x}$ | $0.338^{y}$ | 0.209 | 0.002 |

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

The trend observed in Figure 3 may be attributed to the fact that the fibre used may have occupied the spongy plastic matrix, creating some reinforcing effect and this possibly may have been responsible for the increase in tensile strength witnessed.

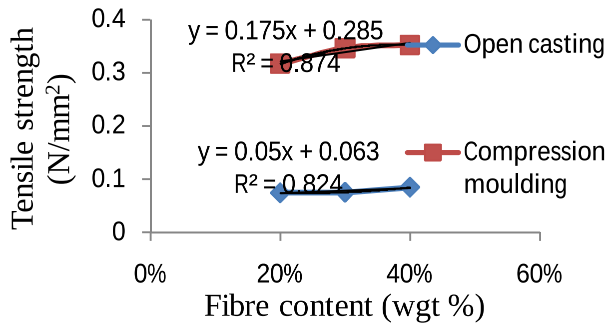



**Fig.3 : Tensile Strength of Composite**

Adding bamboo fibre into plastic significantly improved the tensile strength of the composites. Since fibre has a higher tensile strength than plastic, it can be used to reinforce the polymer. This agrees with the studies of Herrera *et al.* (2007), Fung *et al.* (2003a), and Oksman *et al.* (2003); who found out that the incorporation of natural fibre into plastic increased the tensile strength in comparison with the unreinforced plastic matrix.

**Strain**

From Table 4 strain decreased with increase inthe fibre content. This could be attributed to the fact that the composites become tough with the increase in fibre content.

**Table 4: Strain of Composite**

| % Fibre content | Open casting | Compression moulding | Mean | LSD effect |
|---|---|---|---|---|
| 20 | 1.823 | 7.255 | $4.539^{a}$ | N/A |
| 30 | 1.705 | 5.422 | $3.563^{b}$ | N/A |
| 40 | 1.269 | 3.965 | $2.617^{c}$ | N/A |
| LSD | N/A | N/A | 0.006 | N/A |
| Mean | $1.599^{x}$ | $5.547^{y}$ | 3.573 | 0.005 |

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

The mean strain values were graphically shown in Figures 4.

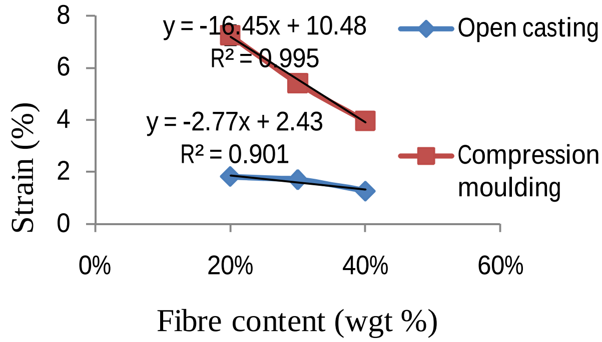



**Fig.4. : Strain of the composite**

The strain of plastic- bamboo composites decreased with increasing fibres content. This may be attributed to bamboo fibres, which once incorporated with plastic; it agglomerates and reduces the extensibility of the matrix in the composites. The resistance created by the bamboo fibres would reduce the deformability of the plastic macromolecules. This agrees with the finding of Lou *et al*. (2007). As the filler loading and crosshead speed increased, the composite became more brittle. As the filler loading increased, the fraction of thermoplastic polymer decreased and interfacial area increased, which increased the brittleness.

## *Conclusions*

Mechanical properties of the composite were influenced by the method of production and materials ratios. The addition of bamboo fibres to the polymer improved the mechanical properties. Impact and bending strengths increased with increase in fibre content upto 30% then started decreasing. Tensile strength increased with increase in fibre content as fibres are strong and rigid in tension. Strain decreased with increase in fibre content as the enhanced fibre loading hardens the composite, thus reducing elongation.

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