# Use of Coconut Fiber As Reinforcement in Bamboo Leaf Ash Blended Cement- Based Composite Panels

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## ABSTRACT

The study investigates the use of natural agro-wastes in cement-based wall composites. Bamboo leaf ash (BLA) and Portland cement were blended together in a ratio of 1:3 by weight, and a varying amount of coconut fiber at percentage levels of 0%, 1%, 2%, 3% and 4% by weight of the cementitious materials were added to the mix. Water to cementitious materials ratio of 0.55 was maintained for all the mixtures. Properties investigated were compressive strength, Modulus of Rupture (MOR), moisture content, density and water absorption. Specimens with sizes of 160 mm x 40 mm x 40 mm and 640 mm x 100 mm x 25 mm were cast and tested at 7, 14 and 28 days for compressive strength and MOR, respectively; and specimens with a size of 100 mm x 100 mm x 40 mm for moisture content, density and water absorption were cast and tested at 28 days only. The results show that compressive strength and MOR increase with the increase in curing age and fiber content up to 2%, and density decreases with the increase in fiber content; while the increase in fiber content increases both water absorption and moisture content. The study concluded that coconut fiber is suitable for use as reinforcement in the production of bamboo leaf ash blended cement-based composite panels.

**KEYWORDS:** Coconut fiber, Bamboo leaf ash, Compressive strength, Moisture content, Modulus of rupture, Water absorption.

## INTRODUCTION

The increasing demand on natural resources for housing provisions in developing countries have called for sourcing and use of sustainable local materials for building and housing delivery. Natural materials to be considered sustainable for building construction should be ‘green’ and obtained from local sources, including rapidly renewable plant materials like palm fronds and bamboo, recycled materials and other products that are reusable and renewable (Haggag and Elmasry, 2011). Accordingly, Olusola (2005) states that the need for shelter must be met with materials that the environment can afford, and such materials must therefore be readily available, appropriate to the environmental demand, thermally efficient, socially accepted, simple in technology and affordable.

A building acts as an enclosure for the activities that are carried on within it and protects the occupants, equipment and goods from the various environmental hazards of the climate (rain, wind, sun,… etc). However, for a building to act as an enclosure, it should have walls and be covered by a roof. Foster and Greeno (2007) described a wall as a vertical element of a building which encloses the space within it and which may also divide that space. Walls can be made of blocks, concrete, stones, metals, woods or any other suitable materials, and can be classified as

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internal, external, parapet, partition, panel or cavity walls depending upon their functions, their position in the building or their structural performance.

In Nigeria, the use of panel wall system in institutional buildings to improve functional requirements of walls is rapidly gaining acceptance in preference to conventional walling system (Adedeji, 2011). The majority of the existing internal wall system for residential buildings is made of clay bricks or blocks and requires up to 20 mm thick plastering on both sides. The disadvantages associated with this construction are that of heavy weight, labour intensive, handling waste and the fact that it requires skilled labour to be installed. Therefore, the use of locally produced reinforced wall paneling system may be an alternative to walling materials which is expected to offer improvement in terms of weight, ease of erection, handling waste and superior finishing compared to the traditional brick or block walls. Examples of such materials that could be utilized in the production of panel walls are coconut fiber and bamboo leaf ash.

Coconut fiber is an agricultural waste that occurs in abundance in many parts of the world. The seed extraction processes require fruits or nut to be stripped from bunches, leaving behind the empty fruit bunches as waste. The fibers are produced from empty bunch or husk of coconut fruits.

Their uses may lead directly to energy savings and conservation of the world scarce resources and have important environmental benefits. Their natural abundance and relative cheapness are some of the strong arguments to utilize them in the construction industry as natural fiber for reinforcement of panels (Swamy, 1990).

Bamboo, on the other hand, is a naturally occurring composite material which grows abundantly in most of the tropical countries. Over 1200 bamboo species have been identified globally (Wang Shen, 1987). The stem of the tree is round, smooth and hollow. The tree has no branches at the lower portions; that is, three-fourth of the tree has more spines between nodes. It has simple shiny, thin, stiff, smooth and dark green leaves. During dry season, most of the leaves are shaded off and constitute a waste which makes the soil or ground around it not suitable for planting. The leaves, when dried and burnt, produce ash which has been discovered to be pozzolanic (Dwivedi et al., 2007).

Therefore, the aim of the study is to investigate the properties of coconut fiber reinforced bamboo leaf ash blended cement wall paneling system with a view to determine an optimum fiber content for the production of wall panels.

**Materials**

Cement used for the study was Dangote brand of ordinary Portland cement of grade 42.5R manufactured in conformity to Nigerian Industrial Standard (NIS) 444-1 (2003). Bamboo leaves were collected from a bamboo forest in the hinterland of Ikpa Road, Uyo, Akwa Ibom State, and calcined to a temperature of 600$^{o}$C in a local kiln employing gas for burning until the leaves turned into ash. The ash was ground into a fine powder and sieved through a mesh size of 45µm. The coconut fiber (brown in colour) was obtained from coconut market in Oruk Anam Local government area; while tap water in the Department of Building Laboratory, University of Uyo, was used for all mixtures.

**Sample Preparation**

The cement and bamboo leaf ash were blended in a mix ratio of 3:1 (cement: BLA) by weight with a water cement ratio of 0.55. The coconut fiber was added to the blended mix in varied percentages of 0, 1, 2, 3 and 4% by weight of cementitious materials with the same water to cement ratio in all the mixtures.

Mixing of the constituent materials was done manually until a slurry was formed, and care was taken to ensure that fibers in the matrix were even distributed without agglomeration. The wet mix was filled in wooden moulds in three layers and manually compressed with the use of a tamping rod. The moulds for the casting of samples were made of 12 mm thick plywood. The sizes of the moulds were 160 mm x 40 mm x 40 mm for compressive strength test; 640 mm x 100 mm x 25 mm for modulus of rupture test; and 100 mm x 100 mm x 40 mm for density, moisture content and water absorption tests.

The cast samples were covered with polythene and de-moulded after 24 hours, then immersed in a water bath until their testing ages.

**Testing**

The compressive strength test of the samples was carried out in a compression testing machine of 1000 kN capacity. Three specimens were tested for each hydration period of 7, 14 and 28 days for each mixture with the mean computed. The compressive strength was calculated from equation 1:

$$C_p = W/A \quad (1)$$

where $C_p$ is the compressive strength (N/mm$^2$), W is the maximum load applied to the test specimen at failure (N), A is the cross-sectional area of the test specimen (mm$^2$).

The modulus of rupture (MOR) test was carried out as specified by BS 5669: 1 (1989). Two specimens were tested at 7, 14 and 28 days for each mixture. The MOR (in N/mm$^2$) was calculated using equation 2:

$$\mathrm{MOR} = \frac{3PL}{2Bd^2} \quad (2)$$

where P is the maximum applied load for the specimen (N), L is the span between the centers of the supports (mm), B is the width of the test specimen (mm) and d is the mean thickness of the test specimen (mm).

The density, water absorption and moisture content of the composite wall panel were tested at 28 days. The density test was carried out by measuring the sample mass and volume, and the value of the density was calculated by using equation 3:

$$D_P = \frac{M}{V} \quad (3)$$

where $D_P$ is the density (kg/m$^3$), M is the mass of the sample (kg), V is the Volume of the sample (m$^3$).

Water absorption test was conducted by immersing the samples in water in a flat bottom container for 24 hours, and the difference between masses before and after immersion was recorded. Water absorption was calculated from equation 4:

$$W_a = \frac{M_2 - M_1}{M_1} \times 100\% \quad (4)$$

where Wa is water absorption (in %), $M_1$ is the mass of the test sample before immersion (kg), $M_2$ is the mass of the test sample after immersion (kg).

For moisture content determination, the specimens were weighed before keeping in the oven at a temperature of 105ºC for 24 hours. The oven-dried masses were recorded after cooling the specimens at room temperature. The ratio of the difference between natural and oven-dried masses to the oven-dried mass expressed in percent is the moisture content of the panel, as expressed in equation 5:

$$M_c = \frac{M_1 - M_0}{M_0} \times 100\% \quad (5)$$

where $M_c$ is the moisture content (%), $M_1$ is the mass of the test specimen before drying (g), $M_o$ is the mass of the test specimen after drying (g).

Three samples were tested for the hydration period of 28 days for each mixture with the mean computed. All tests were carried out as specified in BS 5669: Part 1 (1989).

## RESULTS AND DISCUSSION

**Materials**

The physical properties of the cement used had a consistency of 29.20%, initial and final setting times of 101 minutes and 202 minutes, respectively. The setting time values obtained were within the recommended range as specified by NIS 446 (2003) which stipulated a minimum of 45 minutes for initial setting time and a maximum of 10 hours for final setting time.

The soundness of the cement paste was 0.1mm which is less than 10 mm limit value recommended by NIS 446 (2003); while the specific gravity of cement was 3.10.

The physical and chemical properties of BLA are presented in Table 1. BLA has a specific gravity of 2.14, which is more than the value of 1.72 obtained by Umoh et al. (2013), where the bamboo leaves were calcined up to $600^0$C and sustained at that temperature in the furnace up to 20 minutes, and the value of 2.13 obtained for Rice Husk Ash (RHA) (Oyetola and Abdullahi, 2006).

The fineness of the ash retained on 45 µm sieve is 32.85% which is less than the maximum value of 34% stipulated by ASTMC 618 (2008). The strength activity index values with Portland cement at 7 and 28 days were 75.47% and 77.20%, respectively. These values are above the 75% stipulated by the same standard. The water requirement value is 48.76% of the control, whereas ASTMC 618 (2008) specifies values ranging between 103% and 112%.

The chemical composition shows a combined acidic content of over 70% which makes it a good pozzolanic material as recommended by ASTM C618 (2008).

The physical and chemical properties of coconut fiber are presented in Table 2. The results indicated that there is a huge difference in diameter and length of the coconut fiber. It has a water absorption which is compared to those obtained by Aggarwal (1992) and Toledo et al. (2005).

**Table 1. Physical and chemical properties of bamboo leaf ash**

| Specific Gravity | Fineness (%) | Strength Activity Index with Cement (%) 7 days | | | Strength Activity Index with Cement (%) 28 days | | | Water Requirement (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2.64 | 32.85 | 75.47 | | | 77.20 | | | 48.76 | | |
| Oxide | CaO | $SiO_2$ | $Al_2O_3$ | MgO | $Fe_2O_3$ | $K_2O$ | $MnO_2$ | $P_2O_5$ | $TiO_2$ | LOI |
| % | 4.43 | 78.00 | 4.96 | 1.02 | 2.01 | 3.09 | 0.23 | 0.72 | 0.36 | 1.58 |

**Table 2. Physical and chemical properties of coconut fiber**

| Physical Properties | |
|---|---|
| Length (mm) | 60-210 |
| Diameter (mm) | 0.4-0.8 |
| Moisture content (%) | 10.60 |
| Water absorption at saturation (%) | 160 |
| Density (kg/m$^3$) | 480 |
| Colour | Brown |
| **Chemical Properties** | |
| Hemi-cellulose (%) | 11 |
| Cellulose (%) | 46 |
| Lignin (%) | 43 |

**Compressive Strength**

The compressive strength values for the various curing ages and for different mixtures of various percentages of coconut fiber of 0%, 1%, 2%, 3% and 4% based on the cementitious materials content are presented in Table 3.

At 7-day hydration, the compressive strength ranged between 15.01N/mm$^2$ and 7.08N/mm$^2$ for 0%

and 4% fiber content, respectively. These values are higher than those obtained by Mohammed (2002) from gypsum reinforced coconut fiber wall panels. The percentage attainment of 1%, 2%, 3% and 4% fiber content compared to the control specimen (that is, 0% fiber content) are 56.96%, 76.14%, 50.36% and 47.16%, respectively; which reveals that 2% fiber content attained the optimum compressive strength.

**Table 3. Compressive strength of wall panel at 7, 14 and 28 days of hydration**

| Fiber Content (%) | Compressive Strength ($N/mm^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 7 days | | 14 days | | 28 days | |
| | Specimens | Mean | Specimens | Mean | Specimens | Mean |
| 0 | 16.90<br>15.63<br>12.50 | 15.01 | 16.66<br>16.44<br>19.37 | 17.49 | 19.23<br>19.59<br>18.42 | 19.08 |
| 1 | 9.40<br>8.75<br>7.50 | 8.55 | 9.61<br>10.62<br>14.10 | 11.44 | 13.64<br>13.82<br>14.09 | 13.85 |
| 2 | 11.25<br>12.17<br>10.89 | 11.43 | 15.53<br>14.82<br>14.95 | 15.10 | 17.82<br>17.82<br>18.12 | 17.92 |
| 3 | 7.50<br>6.87<br>8.33 | 7.56 | 9.34<br>9.61<br>10.62 | 9.85 | 11.25<br>12.00<br>11.85 | 11.70 |
| 4 | 7.50<br>6.87<br>6.87 | 7.08 | 8.33<br>8.75<br>9.37 | 8.82 | 8.97<br>9.61<br>10.00 | 9.52 |

The results at 14-day hydration indicated an increase in compressive strength of 16.52% for 0% fiber content, 33.80%, 32.11%, 30.29% and 24.58% for 1%, 2%, 3% and 4% fiber content, respectively. The compressive strength for 2% fiber content is 15.10$N/mm^2$ which is more than the compressive strength for 1%, 3% and 4% fiber composite walls with the highest value of 86.34% of the control when compared to those of 1%, 3% and 4% fiber content.

At 28-day hydration, it was observed that the compressive strength shows a remarkable improvement than at 7 and 14 days of hydration, respectively. For instance, the compressive strength increases to 19.08$N/mm^2$ for 0% fiber content, 13.85 $N/mm^2$, 17.92 $N/mm^2$, 11.70 $N/mm^2$ and 9.52$N/mm^2$ for 1%, 2%, 3% and 4% fiber content, respectively. The compressive strength for 2% fiber content is higher than for 1%, 3% and 4% fiber content, indicating that the strength did not increase linearly with the increase in fiber content. In other words, the increase in strength was only up to a certain fiber content (2%). It can be deduced that specimens with higher content of fiber cannot carry extra load because of the congestion of fiber; and that fiber congestion or clumps turn into weak spots in the matrix subsequently leading to a reduction in compressive strength (Chun and Naik, 2004). A similar observation have been made by Awal et al. (2011) who found that the compressive strength of fiber reinforced mortar increased linearly with the increase in fiber content up to a certain limit. Accordingly, Soroushian and Marikunle (1990) stated that high fiber content in cement composite can lead to a reduction in compressive strength due to the increased amount of entrapped air as a result of much fiber.

The reduction in compressive strength of specimens with fiber contents compared to the control specimens (that is 0% fiber content) can be attributed to the water absorbed from the cementitious matrix by the fiber thereby affecting the hydration process. Naik et al. (2003) also suggested that fibers with lignin or other chemicals can have adverse effects on the setting and hydration of cement, leading subsequently to a reduction in compressive strength of the composite panels. However, for the use of coconut fiber as reinforcement in bamboo leaf ash blended cement composite wall panels, the inclusion of 2% fiber content could be considered as an optimum for attaining the highest compressive strength when compared to 1%, 3% and 4% fiber content.

**Modulus of Rupture**

The results of the modulus of rupture (MOR) of blended cement-based composite wall panels are presented in Table 4. It is observed that the MOR increases with curing age in both the control and the fiber composites. The least MOR of 3.42 N/mm$^2$ and the highest MOR of 9.05 N/mm$^2$ were recorded with fiber composites of 1% and 2% at 7 and 28 days, respectively. The addition of coconut fiber in the blended cement increased the MOR up to 2% fiber content, and further fiber addition decreased the MOR value. However, it was observed that composites with higher fiber addition had a higher MOR than the control (that is, 0% fiber content), especially after 28 days of curing. This high value could be associated with the even distribution of the fiber in the blended cement composites; which resulted in better crack arrest in the composite (Zhu et al., 1994).

This confirms a similar finding by Khedari et al. (2003) on the use of coconut fiber on the plates and affirms that with a constant fiber content of 4% the MOR was better than for cement plates without fiber, but less than for polypropylene reinforced plates.

**Table 4. Modulus of rupture of wall panel at 7, 14 and 28 days of hydration**

| Fiber Content (%) | Modulus of Rupture (N/mm$^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 7 days | | 14 days | | 28 days | |
| | Specimens | Mean | Specimens | Mean | Specimens | Mean |
| 0 | 3.05 | 3.34 | 6.44 | 6.34 | 7.06 | 7.30 |
| | 3.62 | | 6.24 | | 7.54 | |
| 1 | 3.40 | 3.42 | 5.40 | 5.53 | 6.14 | 6.28 |
| | 3.44 | | 5.66 | | 6.42 | |
| 2 | 4.78 | 4.82 | 6.82 | 6.75 | 9.12 | 9.05 |
| | 4.86 | | 6.68 | | 8.98 | |
| 3 | 4.72 | 4.67 | 6.02 | 6.12 | 8.40 | 8.70 |
| | 4.62 | | 6.22 | | 9.00 | |
| 4 | 4.10 | 4.04 | 5.92 | 6.08 | 8.32 | 8.61 |
| | 3.98 | | 6.24 | | 8.90 | |

**Density**

The results of density test at 28 days are shown in Figure 1. The density of the composite wall panels ranged between 1802 kg/m$^3$ and 1597kg/m$^3$ with 0% fiber content having the highest density, and the least value was recorded for composites with 4% fiber content. Generally, the results show that increasing the coconut fiber content decreases the density. This could be a result of the fact that the addition of fiber, being a lighter material than the cementitious materials, in the composite means occupying the space which would have otherwise been filled by the cementitious paste and thereby causing a reduction in the composite mass and by implication a decrease in density of the composite. This confirms the assertion by Aggarwal (1995) and Mohammed (2005) that increasing the natural fiber content in composite materials decreases the density of the composite.

The density of coconut fiber reinforced bamboo leaf ash blended cement wall panels is low when compared to normal concrete density of 2400 kg/m$^3$, but when compared to other materials such as aerated blocks and other wall panel systems with densities varying between 300 kg/m$^3$ and 1800 kg/m$^3$, then coconut fiber in bamboo leaf ash blended cement wall in this study is within the range.

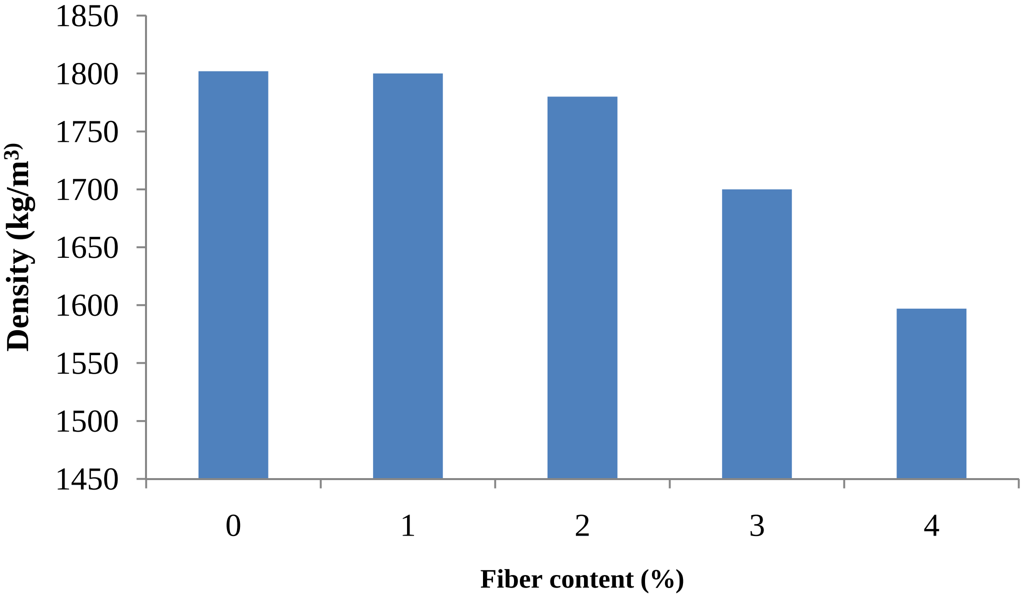


**Figure (1): Effect of fiber content on density of BLA blended cement wall panels**

**Water Absorption**

The results for water absorption of the specimens for the wall panels immersed in water for 24 hours are shown in Figure 2. It can be seen that the higher the fiber content, the higher the water absorption of the specimens. The highest value of water absorption is exhibited by 4% coconut fiber content. This can be attributed to its low density and hence higher porosity in the composite panels. This is in agreement with Nadzri et al. (2012) who opined that increasing the fiber content on the composites with fly ash as pozzolans exhibited higher water absorption, hence higher porosity in the composite.

It has also been reported by Asasutjarit et al. (2007) that low density of composite cement reinforced with natural fibers had more void spaces than dense ones, so that more water can be absorbed. This is to be expected, because water has been absorbed by the fiber on the surface of the specimen that penetrates *via* the voids of the specimens. However, water absorption was found to be within the range of 6%-12% which is within the range stipulated by NIS 587 (2007). The trend of water absorption is in agreement with existing literature reported by Audu-War and Obam (2006) and Mohammad (2005) for coconut fiber panel wall.

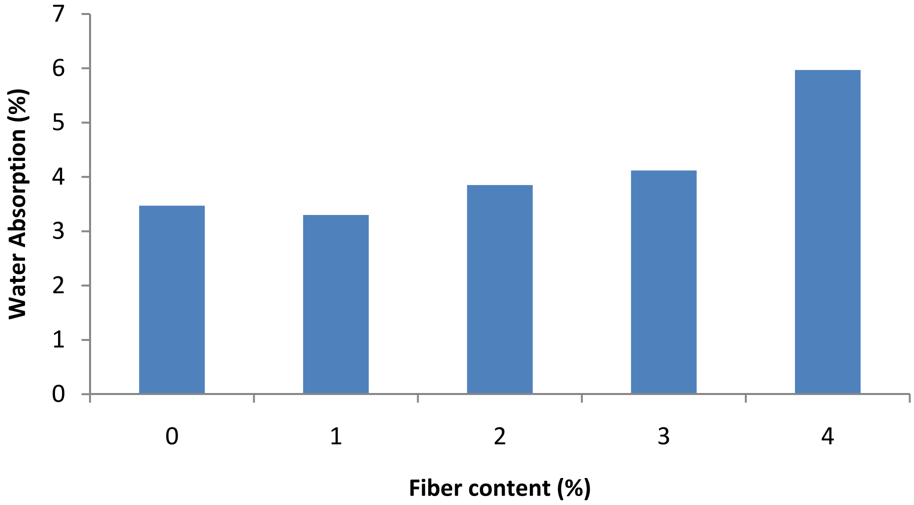


**Figure (2): Effect of fiber content on water absorption of BLA blended cement wall panels**

**Moisture Content**

The results for moisture content at 28 days are shown in Figure 3. The results show that increased fiber content increases the moisture content of the wall panels. The highest value of moisture content of 13.90% was exhibited by 4% coconut fiber content closely followed by the control (0% fiber content).

Moisture contents obtained are 6.54% for 0%, 5.41% for 1%, 6.10% for 2%, 10.96% for 3% and 13.90% for 4% coconut fiber. The results demonstrated that increasing coconut fiber content increases the moisture content. This is in agreement with Mohammed (2005) and Mazlan and Abdul Awal (2012) who reported that increasing the fiber content increases moisture content and also reduces compressive strength. Higher moisture content was reported by Alida et al. (2011) and Nadzri et al. (2012) to reduce mechanical properties, especially compressive strength. However, the moisture content with coconut fiber content of up to 2% met the requirement range of 5.60% to 6.67% specification of NIS 587 (2007).

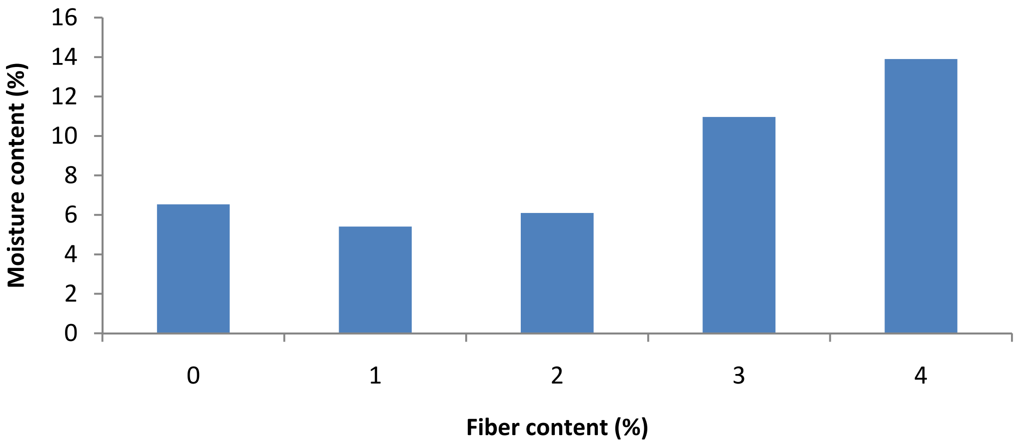


**Figure (3): Effect of fiber content on moisture content of BLA blended cement wall panels**

## CONCLUSIONS

From the study results, the following conclusions have been deduced:

Bamboo leaf ash used met both physical and chemical requirements as specified by ASTM C618 (2008). The compressive strength increases with curing age and fiber content up to 2%, and thereafter decreases with further increase in fiber content; subsequently the peak compressive strength is attained with 2% fiber composite which is therefore considered as the optimum. The MOR was found to increase with curing age in all the mixes, but decreased with fiber addition more than 2%. However, it was found that composites with higher fiber had a higher MOR than the control, particularly after 28 days of curing. The density was observed to decrease with increasing fiber addition, while water absorption and moisture content increased with the increase in fiber content.

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