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STRUCTURAL PERFORMANCE OF MASONRY BLOCKS REINFORCED WITH PLANTAIN PSEUDO-STEM FIBER

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Abstract: Renewable fiber derived from plantain pseudo-stem was used as reinforcing material in improving selected engineering properties of masonry blocks. The blocks were made from two sets of mixtures: the first, which acts as reference sample, consists of cement, lime, and sand in the ratio of 1: 0.25: 6, respectively with water-cement ratio of 0.52; the second set consists of the composition of the reference sample in addition to the inclusion of varied weight percentages (1 - 4%) of plantain pseudo-stem fiber replacing the binders. The wet mixtures were manually cast into block of 150 mm cube size for tensile splitting and water absorption tests; and 115 mm x 110 mm x 80 mm size for compressive strength and density tests. The tensile splitting strength of the masonry blocks recorded its optimal value of 0.66 N/mm^2 at 28 days with 3% weight fiber content. The compressive strength values were observed to decrease as the fiber content increases; however, with 4% weight fiber content the compressive strength values were noted to be higher than the minimum strength specified for both non-load bearing and load bearing walls. The density and water absorption were found to decrease as the fiber content increases. It was observed that all the investigated properties, except water absorption, have their values increases with curing time. The study therefore concluded that the inclusion of 4% weight plantain pseudo-stem fiber, having satisfied the minimum requirements of the properties investigated, is adequate for the masonry blocks production.

Keywords: *Compressive strength, density, plantain pseudo-stem, tensile splitting strength, water absorption.*

1.0 Introduction

Blocks are indispensable materials predominantly used as walling units in the construction of shelter especially in Nigeria and in other developing countries. According to Onwuka, Osadebe and Okere (2013) the percentage of walling materials made of sandcrete blocks account for over 95% of all walling materials. It has been in use throughout West Africa for over 50 years as a popular building material and its technology is becoming the backbone for infrastructural development for developing countries.

Within the building and construction industry, there is an increasing concern for the reduction of global warming and environmental pollution through the adoption of sustainable and green building approach. Accordingly, several researches have been tailored towards providing sustainable production of masonry materials and cellular light weight technology blocks as an alternative to the red bricks, since they are environment friendly (Siram, 2012).

Natural fibres are being considered as an environmentally friendly alternative for synthetic fibres in fibre-reinforced polymer composites. A common feature of natural fibres in composite construction is the reduction in density, healthier in use due to their natural origins; and less abrasive to the processing equipment (Sparnins, 2006) and have good stiffness, lower pollution level during production, and lower cost; but do not reach the same level of strength as the glass fibre composite (Oksman and Selin, 2003).

Nigeria being a tropical country has abundance and wide diversity of cultivated vegetables that provide fibres, and the uses of these fibers in the construction industry will improve the physical and mechanical characteristics and yielding of a better structural performance (Izquierdo and Ramalho, 2013). This craves the focus of this research to investigate the application of green materials such as vegetable fibre, extracted from plantain pseudo-stem as new materials for sustainable construction of masonry blocks.

It is reported that Nigeria is one of the largest producers of plantain in the world (FAO, 2013), and ranked first in Africa and fifth in the world producing 2,722,000 metric tonnes in 2011 (FAO, 2012). Plantain fibre can be obtained easily from the plants which are rendered as waste after the fruits have ripened. So plantain pseudo-stem fibre can be explored as a potential reinforcement in masonry block production due to its availability and less cost, if any, in processing.

The most significant enhancement resulting from the inclusion of fibers in cementitious matrices is the improvement in post-cracking behaviour; therefore, crack control is one of the most exciting applications of fiber reinforced cement. The fibers can prevent larger crack widths that could permit water and contaminant penetration and cause corrosion in reinforcing steel (ACI 544, 2002). In addition to crack control and serviceability benefits, use of fibers at high volume percentages (5%–10% or higher with special production techniques) is reported to substantially increase the matrix tensile strength (Shah, 1991). The only disadvantage of the use of fiber in cement based matrices could be due to the creation of permeable voids which in turn may lead to the permeability of the material (Izquierdo and Ramalho, 2013). The standard NBR 12118 (2007) established that the water absorption for concrete structural blocks must be less than or equal to 10%. The presence of fibres in the concrete caused a greater absorption of the units, indicating a higher incidence of permeable pores. However, the values obtained for some units with fibres are only slightly larger than the threshold, which can be considered acceptable.

Thus, this study seeks to use available materials such as plantain pseudo-stem fibre as air incorporator and lime as cement replacement for the production of lightweight wall composite with a view to verifying its characteristics for appropriate recommendations for use in masonry wall constructions.

2.0 Review of Related Works

Fibres are reported as most ductile and energy absorbent material. They have the potential to be used in composites for different purposes. Fibres are utilized in different ways for masonry products production; they are used in cement paste, sand mortar, concrete, non-structural components, plaster, roofing material, slabs, boards, wall panelling system, soil slope stabilization and in cement-bonded composite materials.

Aziz *et al*. (1981) reported the use of coconut fibres in cement paste composites. The study revealed that the tensile strength and modulus of rupture of cement paste increased up to a certain length and volume fraction of the fibre and beyond a certain volume fraction the strength decreases; and that coconut fibres with a length of 38mm and a volume fraction of 4% gave maximum strength of cement paste composite.

Izquierdo and Ramalho (2013) evaluated the incorporation of sisal fibres of 20 mm and 40 mm in length and volume fraction of 0.5% and 1% for concrete masonry structural blocks, and used the blocks to build prisms and mini-walls. The physical properties of the blocks with and without the sisal fibre complied with the standard requirements established to validate their use. The obtained results showed that the fibre-reinforced mini-walls attained values higher than those obtained for the mini-walls without fibres, demonstrating better performance than the blocks and prisms without fibre.

Adedeji (2011) investigated composite panels for sustainable housing provision in Nigeria. The study focused on the potentials of using agro-waste composite panels, a constituent of cement reinforced with palm kernel fibre. The research utilised two research methods namely experimental and survey methods. The experimental observation was used to determine chemical properties and the suitability of the agro-waste product for building while the empirical survey (case studies) was used to make a comparative analysis of the use of composite agro-waste panels with conventional types. Analysis of data shows that stable cement-bonded composite panels produced from palm kernel fibres are comparatively cheaper, improved sound-proof, durable, lighter-weight and environmentally friendly than the conventional sandcrete blocks.

Muntohar and Rahman (2014) made an experimental study on the development of the shellcrete masonry block that made use of palm kernel shell (PKS). The masonry block was called shellcrete. The study focused on the physical, compressive and flexural strengths of shellcrete. The shellcrete was made by mixing the Portland cement (PC), sand, and oil palm kernel shell (PKS). A control specimen made of PC and sand mixture (sandcrete) was also prepared. The maximum strength obtained was 22 MPa by mixing proportion of 1 PC:1 Sand:1 PKS, but the recommended mix proportion of the shellcrete for building materials was 1 PC:1 Sand:2 PKS as an optimum mix design for eco-friendly shellcrete. The best mix design was 1:1:2 (OPC: sand: PKS). The study revealed that the shellcrete was acceptable for lightweight materials and masonry block.
Awwad, Choueiter and Khatib (2013) conducted a study on the use of Industrial Hemp Fibers and Hurds on green concrete masonry blocks production. To investigate the behaviour of the hemp fiber on the masonry blocks, four concrete mixes were prepared: a control mix (no fibers) and three hemp-concrete mixes with about 1%, 2%, and 4% hemp material by concrete volume. The tests results confirm the potential of incorporating raw hemp material in local masonry blocks while satisfying minimum strength, water absorption, density, and reducing thermal conductivity requirements.

Mazlan and Abdul-Awal (2012) examined the properties and usage of oil palm stem fiber as discrete reinforcing material in cement matrix. Cement mortar mixes containing 1 to 4% fiber were made to investigate workability, water absorption and strength of the matrix. Results revealed that the workability of cement mortar decreased with increase in oil palm stem fiber. The water absorption capacity on the other hand was found to increase with the increasing amount of fiber content. Regarding strength, the compressive strength decreased gradually; the tensile and flexural strength showed a positive response in terms of fiber content.

Ramakrishna and Sundararajan (2005) investigated the resistance of cement sand mortar (1:3) slabs to impact loading. The slab specimens (300mm x 300mm x 20mm) were reinforced with natural fibres (coconut, sisal, jute and *hibiscus cannabinus* fibres) having four different fibre contents (0.5, 1.0, 1.5 and 2.5% by weight of cement) and three fibre lengths (20, 30 and 40 mm). A fibre content of 2% and a fibre length of 40mm of coconut fibre showed best performance by absorbing 253.5 Joules impact energy among all tested fibres. All fibres, except coconut fibres, showed fibre fracture, at ultimate failure whereas coconut fibre showed fibre pull out failure.

Aguwa (2013) investigated the use of coir in lateritic blocks. They reported that the inclusion of coir has the potential to increase the compressive strength of laterite blocks by ten percent (10%) at 28 days curing and reduction in mass by two percent (2%). This increase in strength with reduction in mass is essential qualities of a structural material. Laterite blocks were reinforced with coir content of 0, 0.063, 0.125, 0.188 and 0.25% by mass of the laterite, respectively and cured in the laboratory under atmospheric conditions. The result of compressive strength test on the blocks were 2.11, 2.18, 2.18

and 2.26 N/mm^2 for 0.063, 0.125, 0.188 and 0.25% coir content, respectively; and that the determined strengths of coir reinforced laterite blocks were higher than those for ordinary laterite blocks.

3.0 Materials and Methods

3.1 Materials

The Portland limestone cements (CEM 11/B-L 32.5R) produced in conformity to the Nigeria Industrial Standard (NIS 444-1, 2003) was used. The limestone powder was purchased from Building Materials Market, Uyo, Nigeria. Fine sand was used as fine aggregate, and the sieve analysis conducted on the sand satisfied the requirement of ASTM C 144 (1991) for sand suitable for use in mortar; and the water used for mixing and curing was tap water available in the Soil and Concrete laboratory of Building Department, University of Uyo. Plantain pseudo-stem fiber (PPF) was manually extracted from pseudo-stem. After extraction and allowed for one day, they were then soaked in a 5% NaOH solution for 4 hours; and thereafter removed and further treated with a solution of water and methanol (Saline treatment) in the ratio of 4: 6. This was then neutralized with dilute acetic acid in the ratio of 100: 10 and then washed with water (Figure 1); and finally dried at ambient temperature for 72 hours. The treatment of the fiber was to decrease the fiber high capacity to absorb water, and to protect them against alkaline aggression. The fibers were then cut into sizes range of 30-40 mm as shown in Figure 2 for use in the mixtures.

Figure 1: Fiber after being treated in chemical solutions and washed in water.

Figure 2: Fiber cut to 30-40 mm sizes

3.2 Mix Proportion and Production

Mix ratio of 1: 0.25: 6 (cement: lime: sand) by weight was used for the production of composite blocks which was referred to as the reference mixture. Plantain pseudo-stem fiber of length 30 – 40 mm and of varied volume of 1, 2, 3 and 4% by weight of the binder (Lime and Cement) were added to the reference mixture. A water-to-binder ratio of 0.52 was maintained for all the mixtures. The Limestone powder was first blended with the cement until a uniform colour was attained, thereafter; sand and fiber were added and mixed thoroughly before water was added. The whole mixture was thoroughly mixed until a paste of uniform texture was achieved and the fiber where seen evenly spread in the paste, see Figure 3. The wet mixture was then manually cast into block size 150 mm cube for tensile splitting and water absorption tests; and 115 mm x 110 mm x 80 mm for compressive strength and density tests as shown in Figure 4 after 7, 14, and 28 days curing. Curing of the block specimens was done by spraying of water on it every morning and evening and discontinued two days to their testing ages.

Figure 3: Homogenous mixture of binders, sand, water and fiber ready for casting.

Figure 4: Wet block specimens after casting

3.3 Testing of Specimens

The compressive strength of the composite block specimens was determined using a compression testing machine of 2000 KN capacity and performed in conformance to BS EN 12390-3 (2009). The block specimens of dimensions 115 mm × 110 mm × 80 mm were placed centrally on the bottom plate of the testing machine and the top bearing plate aligned with the one below (Figure 5). The machine was loaded, and the reading taken at a point where failure of the specimens occurred. The metre reading at this point was recorded as the failure load, F and the compressive strength, S_p was calculated from equation 1.

$$S_p = \frac{\text{Failure load (F)}}{\text{Area of wall panel specimen (A)}} \tag{1}$$

Tensile Splitting Strength test was carried out using composite block specimens of cube size 150 mm. The test was done in line with BS 1881: 117 (1983). The specimen ends were smoothed and laid on the bottom plate of the testing machine. Round bars were symmetrically placed at the top and bottom of the specimen within the bearing plates. The specimen was then loaded and the metre reading was carefully observed until the point where the specimen splitted into two halves. The metre reading at this point was recorded as the Splitting load, F_s and the tensile splitting (S_T) was calculated from equation 2.

$$S_T = \frac{Splitting\ load,\ F_S}{\text{Surface area of specimen, A}} \tag{2}$$

The density of the composite block specimens was determined in conformance to NIS 584 (2007). The density was conducted on specimen sizes of 115 mm × 110 mm × 80 mm. The weight of the composite block specimen, M (kg) was measured using a digital weighing balance (Figure 6). The volume of the specimen, V (m^3) was computed geometrically from the shape of the block. The density, B_d of the composite block specimens were calculated from equation 3.

$$B_d = \frac{M}{V} \tag{3}$$

Water Absorption test was conducted in conformance to BS 1881 Part 122 (2011). Composite block specimens of dimensions 150 mm cube. The specimens were taken out of the curing tank, wiped with cloth and weighed. The weight of each specimen was recorded as the wet weight (Ww). The specimens were then dry in an oven and weighed at intervals of 10 minutes until at a point where there was no further decreased in weight. This final weight was recorded as the dry weight (Wd). The water absorption (Wab) of the specimen was expressed as a percentage of the initial mass of the specimens and calculated as in equation 4:

$$\text{Wab} = \frac{\text{Ww} - \text{Wd}}{\text{Wd}} * 100\% \tag{4}$$

Figure 5: Compressive strength testing of block specimens

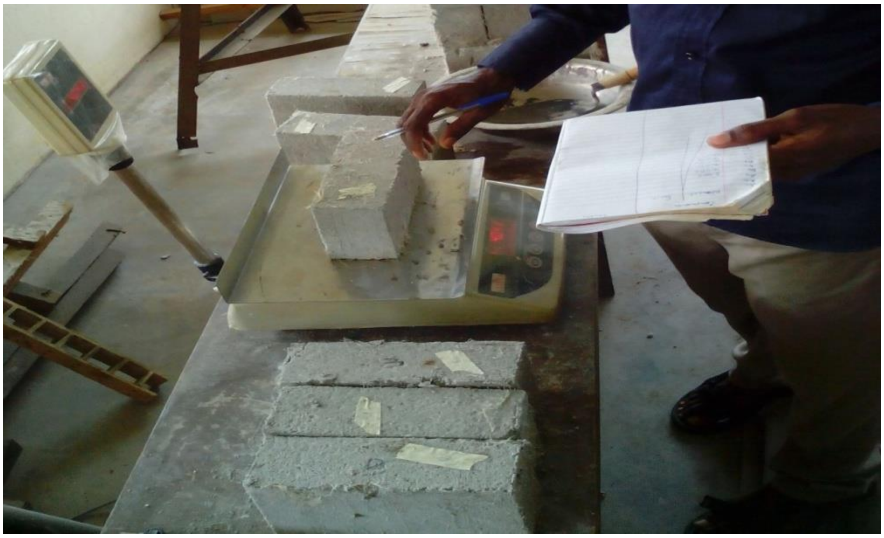

Figure 6: Weighing of Block Samples for Density Determination

4.0 Results and Discussion

4.1 *Compressive Strength*

The results of the compressive strength of masonry block as presented in Figure 7 indicate that generally the strength increases with curing age but decreases as the fiber content increases. At 1% fibre content, it was observed that the compressive strength values, when compared to the control, recorded a lesser value of 1.25 N/mm^2, 1.65 N/mm^2 and 0.56 N/mm^2 at 7, 14 and 28 days, respectively. Similarly, the values obtained with 2%, 3% and 4% fiber contents were 1.22 N/mm^2, 1.19 N/mm^2 and 0.69 N/mm^2; 1.67 N/mm^2, 1.27 N/mm^2 and 1.17 N/mm^2; 0.33 N/mm^2, 1.07 N/mm^2 and 0.89 N/mm^2 at 7, 14 and 28 days, respectively. However, all the reinforced masonry blocks attained a compressive strength value which is higher than the minimum compressive strength value of 2.45 N/mm^2 specified by Nigeria Industrial Standard (NIS 587, 2007) for load bearing wall and also satisfied the minimum compressive strength of 2.00 N/mm^2 specified by National Building Code (NBC, 2006) for load bearing walls. It is noted that masonry block with fiber content of 4% compete favourably with that of the reference and therefore, 4% plantain pseudo-stem fiber is recommended to be used in the production of masonry blocks.

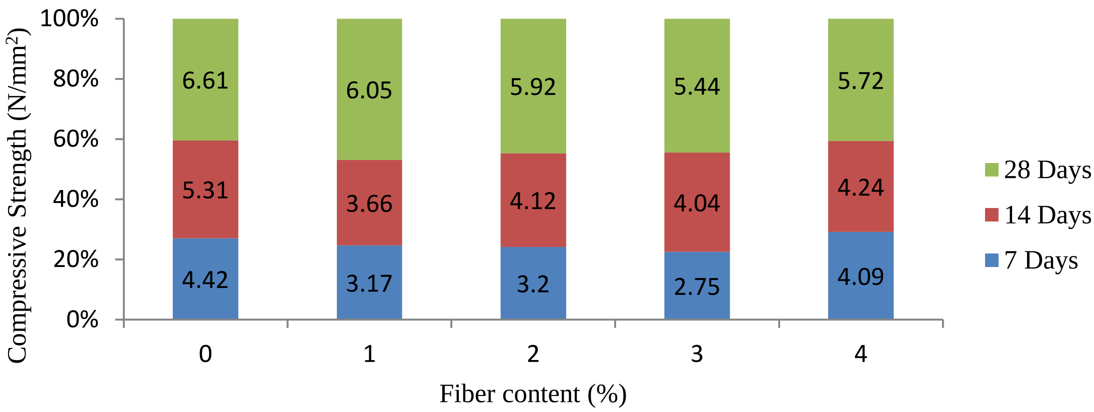

Figure 7: Variation of fiber content with Compressive strength of masonry blocks reinforced with PPF.

4.2 *Tensile Splitting Strength*

The results of tensile splitting strength as presented in Figure 8 indicated that the strength increases with curing age up to 28 days tested. It was observed that the strength increased reached its peak at 3% fiber content and start to decline beyond this level of fiber content in all the curing ages. For instance, the least tensile splitting strength of 0.382 N/mm^2, 0.400 N/mm^2 and 0.42 N/mm^2 at 7, 14 and 28 days, respectively were attained with the reference blocks (that is, 0% fiber content); while the highest values of 0.386 N/mm^2, 0.518 N/mm^2 and 0.660 N/mm^2 at 7, 14 and 28 days, respectively were recorded with reinforced masonry blocks containing 3% fiber, and beyond this fiber content level the strength start to decline. This supported an earlier finding by Aziz *et al*. (1981) in the use of coconut fibres in cement paste composites, which revealed that the tensile strength of cement paste increased up to a certain length and volume fraction of the fibre and beyond a certain volume fraction the strength decreases; and that coconut fibres with a length of 38 mm and a volume fraction of 4% gave maximum strength of cement paste composite. Therefore, in this study 3% plantain pseudo-stem fibre content is recommended for use in masonry blocks for the improvement of tensile splitting strength.

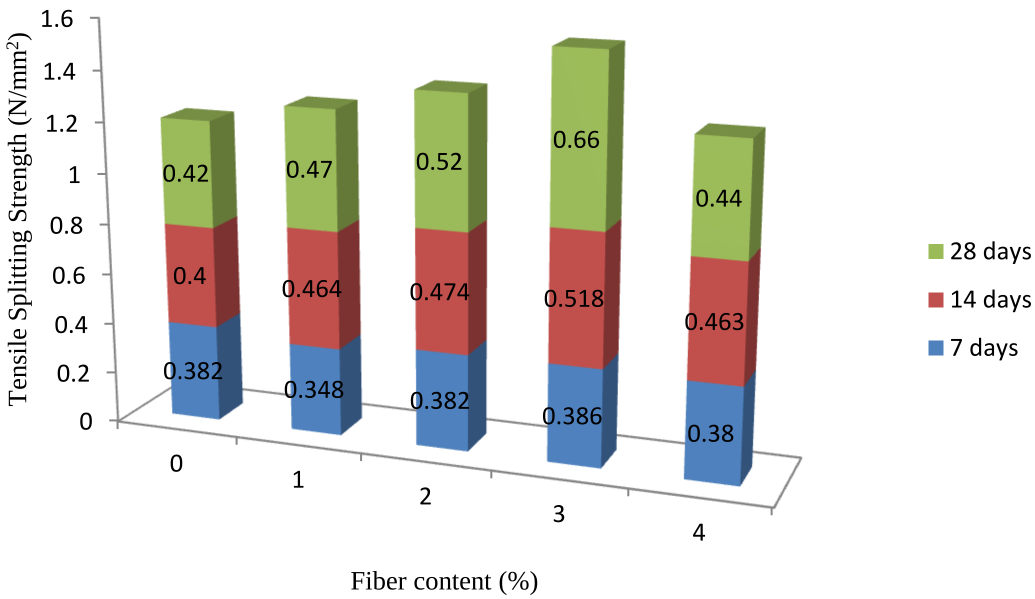

Figure 8: Variation of fiber content with Tensile splitting strength of masonry blocks reinforced with PPF.

4.3 Density

The results of density of masonry blocks as presented in Figure 9 indicate that a reduction in the density with increased in curing as well as in fiber content. It is observed that 0% fiber content had the highest density value at each of the curing age while the least value was recorded with masonry blocks reinforced with 4% fiber content. This reduction in the values of masonry blocks reinforced with fiber as compared with the reference (that is, 0% fiber content) could be ascribed to the fact that fiber being a lighter material than the cementitious materials (cement and gypsum), in the composite mean occupying the space which would have otherwise filled by the cementitious paste and thereby a reduction in the masonry blocks and by implication a decrease in density of the masonry blocks. This confirms the assertion by Aggarwal (1995) and Mohammed (2005) that increasing the natural fiber content in a composite materials, decreases the density of the composite.

The density of the plantain fiber reinforced masonry blocks with 4% content at 28 days recorded a value of 1864 kg/m^3 which is less than normal concrete density of 2400 kg/m^3, but greater than 1800 kg/m^3 of NIS 584: 2007 which requires that the average density of composite blocks should not be less that 1800 kg/m^3. Therefore, masonry blocks reinforced with up to 4% plantain pseudo-stem fiber is adequate in the production of masonry wall element.

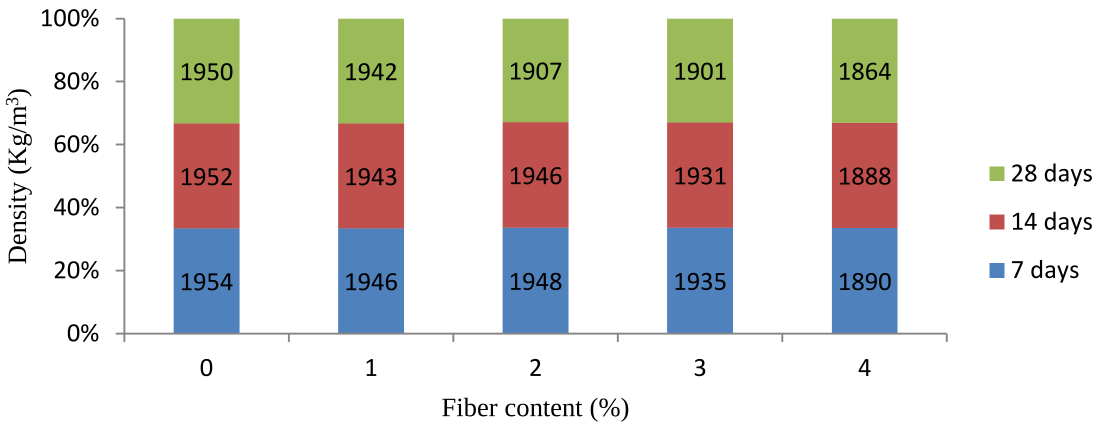

Figure 9: Variation of fiber content with density of masonry blocks reinforced with PPF

4.4 *Water absorption*

The results of water absorption are presented in Figure 10. The water absorption of masonry blocks was noted to increase as the volume of fiber content increases but decreases with increase in curing age. The increase in the water absorption as a result of increase in fiber content affirmed an earlier finding by Mazlan and Abdul-Awal (2012) who investigated the use of oil palm stem fiber (1 to 4%) as discrete reinforcing material in Cement mortar mixes and found out that the water absorption capacity of mortar specimens increased with increasing amount of fiber content.

It was noted that masonry blocks containing 4% fiber had the highest water absorption values in each of the curing age while 0% fiber content had the least. The highest water absorption of 8.42% and the least of 5.19% for 4% fiber content at 7 days and 0% fiber content at 28 days were recorded. This high water absorption associated with masonry blocks reinforced with fiber could be attributed to formation of permeable pores in the blocks as a result of the inclusion of the fiber. However, all the masonry blocks satisfied the requirement of NBR 12118 (2007) that the water absorption for concrete structural blocks must be less than or equal to 10%.

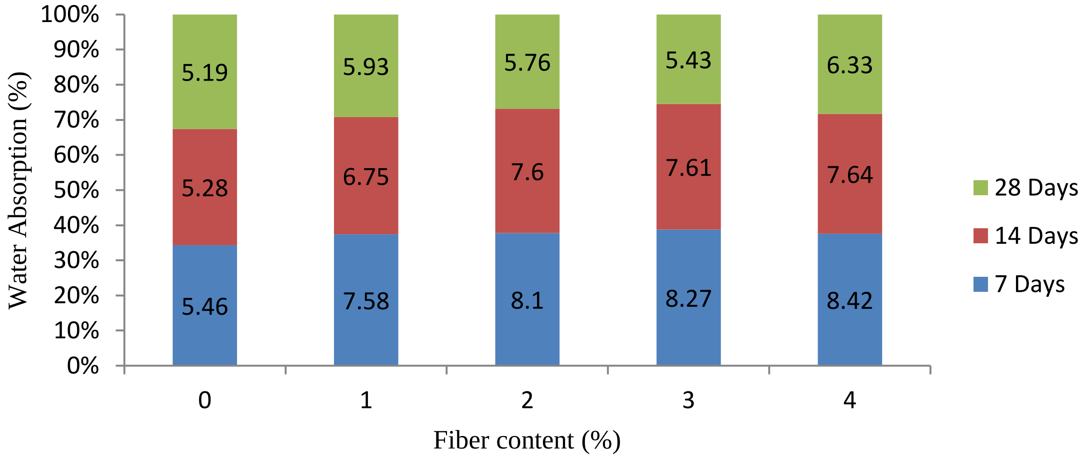

Figure 10: Variation of fiber content with water absorption of masonry blocks reinforced with PPF

5.0 Conclusions

The use of plantain pseudo-stem fiber, a waste obtained after harvesting of matured plantain fruits, in masonry blocks production had provided an avenue for the recycling of waste which otherwise will have constituted an environmental nuisance. In this study, the use of plantain pseudo-stem fiber as reinforcement in masonry blocks production recorded compressive strength values that range between 3.17 N/mm^2 for 1% fiber content at 7 days and 5.72 N/mm^2 for 4% fiber content at 28 days hydration, which satisfied the minimum compressive strength requirement of 2.45 N/mm^2 specified by Nigeria Industrial Standard (NIS 587, 2007) for load bearing wall; while 3% fiber content gave maximum tensile splitting strength of 0.66N/mm2 at 28 days. The highest reduction in density of the reinforced masonry blocks was recorded with 4% fiber content at 28 days; whereas, the highest water absorption of 8.42% for 4% fiber content and the least value of 5.19% for 0% fiber content were recorded at 7 days and 28 days, respectively and fall within the water absorption of 10% for concrete structural blocks.

The study therefore recommended the use of plantain pseudo-stem fiber as natural reinforcement in structural masonry blocks for housing delivery especially in developing countries where this material is found in abundant.

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