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Palm kernel fruit fiber reinforced gypsum-cement based wall panels: It's physical and mechanical characteristics

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ABSTRACT: Agricultural waste fibers have been found to be suitable as reinforcement in cement-based composites, but studies on oil palm fiber as reinforcement in gypsum-cement wall panels are scarce. A mixture of two equal weights of gypsum and cement, with water-binder ratios of 0.45 and 0.55 were prepared. In each mix a varying percentage of fiber contents of 2%, 3% and 4% by weight of the binders were added. The properties of the wall panels were determined from cast specimen sizes of 100x 100 x 40 mm for density, moisture content and water absorption; 160 x 40 x 40mm for compressive strength, and 650 x 100 x 25 mm for bending strength. The specimens were cured in water and tested at ages of 3, 7, 14, 21, and 28 days. The results of density of the wall panels were within the range of 1634–1742 kg/m^3, while the moisture content range of 3.30–8.45%, and the water absorption varies from 5 to 12%. The compressive strengths were found within the range of 1.92–5.20N/mm^2 and, generally, decreases with the increasing percentage of fiber contents, but increased with curing age. The bending strength falls within the range of 2.04–4.13 N/mm^{2}that increases with curing age and slightly increased with fiber content. It is concluded that oil palm fiber reinforced gypsum-cement wall panels are suitable as wall element.

Keywords: Bending strength, compressive strength, gypsum, oil palm fiber, wall panel

INTRODUCTION

A building acts as an enclosure for the activities that are carried on within it. It protects the occupants, equipment, or goods housed from various hazards of the external climate (rain, wind, sun, etc). However, for a building to act as an enclosure, it should have walls and be covered by roof. Wall has been described as the vertical continuous part of a building that encloses and also divides it into rooms and compartments (Barry, 1999; Seeley, 2002).

Wall panels are vertical elements within a building that serve the function of walls; they are made in different ways and with various materials. Mostly, wall panels are prefabricated, and factory-built units produced in an indoor environment. In Nigeria, the use of wall panel system, as partitions and cladding in institutional buildings, is fast gaining acceptance in preference to conventional walling system. Adedeji and Ajayi (2008) reported that wall panels can be made from various materials that include; timber, veneer, concrete, glass, polystyrene, polyurethane, aluminum, acrylics, fibers and composite materials among others. Recently, efforts have been strengthened in the use of vegetables fibers

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and other fibers in cement-based matrix in production of wall elements. Typical of such fibers, include coconut fibers, bagasse, jute, flax, sisal, vegetable fibers, and cellulose fibers as reinforcement in construction material (Toledo Filho et al., 2002). Coconut fiber has been studied in the production of thin plate concrete for replacing asbestos cement product (Fadhadli, 1989) and as mortar composite (Toledo Filho et al., 2002).

Gypsum and Portland cement are viable cemenitious materials used widely for production of building materials, including composite walls. It has been established that gypsum with an addition of Portland cement and pozzolan has the potential for improved durability in water environment. Gypsum occurs in abundant deposit in various parts of Nigeria, especially in the northeast, for instance, it is reported by United States Geological Survey (USGS) Mineral Resources Program (2011) that, in Sokoto State, about 1.46 million tons are mined annually by small scale miners from Wurzo, Gada, Donge, and Tajaye.

Oil palm fiber occurs in abundance in many countries of the world. In Nigeria, oil palm is mainly produced in the southern part of Nigeria, as more than 20 out of the 36 states in the federation are self-sufficient in oil palm production. In the oil palm extraction process the fruits, or nuts are first stripped from the fruit bunches, boiled and pounded, either manually, or with the use of machine, before the oil is pressed out from the fiber. The waste fiber is usually discarded and hence constitutes an environmental hazard. Therefore, there is a huge potential for oil palm fiber waste in Nigeria that can be used in building construction industry, especially, as natural fiber in the production of reinforced wall panels. Hence, the study aimed at determining the physical and mechanical properties of oil palm fruit fiber reinforced gypsum-cement based wall panels,to ascertain its suitability as wall element.

LITERATURE REVIEW

Gypsum is a non-metallic mineral that composed of 79.1% calcium sulfate and 20% water by weight. It is a major rock-forming mineral that produces massive beds, usually, from the precipitation of highly saline waters. Pure gypsum, like limestone, is white, however, in presence of impurities the gypsum rock may appear gray, brown, pink, or even black.

According to Adams (2002), heating hydrated gypsum ($CaSO_4 .2H_2O$) to drive off part, or all water of crystallization will produce gypsum of various forms, depending on the level of heat applied. By strong heat, the water is driven off completely and anhydrous gypsum plaster ($CaSO_4$) is formed; and with less heat, only three-quarter of the water is removed, giving the hemihydrates, usually written as $CaSO_4.½H_2O$.

Some of the building components produced with gypsum alone met strength and fire- resistance requirements and do not experience abnormal volume changes. However, some of them are not well-adapted for use under continued damp condition, or intermittent wet conditions. Hence, the blending of gypsum with cement will ameliorate this weakness, and thereby, making it suitable for production of wall panels to be used in both internal and external conditions.

Gypsum and Portland cement are viable cementitious material used widely for the production of building materials. Gypsum is added to clinker in grinding at the end of manufacturing process of cement to control the hardening velocity of the cement. Gypsum has an advantage of early hardening and fine finish, but it is limited to internal use due to its sensitivity to water. Hardened Portland cement is strong and durable, but it does not possess early hardening, or finishing characteristic for pre-cast components of building material.

It has been established that gypsum, with an addition of Portland cement, and pozzolan has the potential for improved durability in wet, or humid environment. Bentur et al. (1994) indicated that a blend of 75% gypsum plaster (calcium sulfate hemihydrate), 20% Portland cement, and 5% silica fume as pozzolan in the production of gypsum based material enhanced the resistance of the material in humid environment. Fadhadli (1989) also observed that the wet strength and the wet/dry strength ratio in the gypsum–cement–silica fume paste continued to increase, compared to pure gypsum alone, because of dissolution of gypsum in water over time.

The most commonly used types of fibers in fiber-reinforced composites are synthetics that include polypropylene, nylon, polyester, and polyethylene materials. Despite the fibres type, these are effective in crack control because they provide Omni-directional reinforcement to the concrete matrix. Depending on the fiber length and volume, the fiber can limit its size and spread of plastic shrinkage cracks, or both plastic and drying shrinkage cracks (Hannant, 1994). Further, benefits of fibers include improved cohesion within the concrete member and for corrosion-resistance structures.

Fibers introduced into paneling boards also suppress cracks, resulting from high-tensile cracking stress and failure strain. Some of the fibers have environmental and health risk, for example, it has been reported by Hollaway (1993) that asbestos fibers have carcinogenic effects. These synthetic fibers are neither renewable, nor biodegradable. They have both high-specific gravity and abrasive nature than natural fiber. Health risk is associated with the manufacturing and use of synthetic fiber that is, generally, used to reinforce wall paneling system (Hollaway, 1993). Therefore, the use of natural cellulose, or vegetable fibers in cementitious products, is gaining wider acceptance in both developing and developed nations. Hence, the authors studied the use of oil palm fiber as a potential reinforcement in wall paneling system..

MATERIALS & METHODS

Portland cement of grade 42.5R, manufactured in conformity to Nigerian Industrial Standard (NIS) 444-1(2003), which is equivalent to BS EN 197-1 (2009); and gypsum plaster powder produced by Nemja extra-fine powder plaster were used as the binding materials. Oil palm fiber was obtained from oil palm processing factory, where the fiber was discarded after extraction of the palm oil. The fiber was treated by boiling with water for 15 minutes and thereafter pounded for the oil in the fiber to be removed and was rinsed with lukewarm water to obtain an oil-free fiber. The wet fiber was then spread on the floor in the laboratory for 3–5 days to properly dry. Figure 1a shows the oil palm fruit while Figure 1b shows the oil palm fibers. The physical properties of the oil palm fruit are presented in Table 1. Granulated sugar was bought from the open market which was used as retarder in the mixture.

Fig. 1. Oil palm: a) fruits b) fibers

Table 1. Physical Characteristics of oil palm fruit fiber

Property	Value
Fiber length (mm)	10-50
Specific gravity	0.78-0.86
Fiber moisture content (%)	9.8-10.30
Fiber moisture absorption (%)	7.09-12.59

Trial tests were carried out to determine suitable mix proportions and water binder ratios that will produce a cohesive and workable mixture of gypsum-cement with percentage oil palm fiber content. A mix proportion of 1:1 (gypsum: cement) with two different water/ binder ratios of 0.45 and 0.55 were adopted. The mix with water/binder ratio of 0.45 was designated as set 'A', while that of water/binder ratio of 0.55 was designated as set 'B'. In each set, the fiber was added with 0, 2, 3, and 4% by the weight of the binders (i.e., cement and gypsum combined). Set 'A' mixes were identified as AO, A2, A3, and A4; while set 'B' were B0, B2, B3, and B4 for fiber content of 0, 2, 3, and 4%, respectively. In all the mixes, salt of 0.1% by weight of cement-gypsum binder was added as retarder. The mix proportion is as presented in Table 2.

Table 2. Mix proportions for gypsum-cement based wall panels

Designation	Water – binder Ratio	Cement (%)	Gypsum (%)	% of Fiber (by weight of cement-gypsum)	% of Retarder (salt) (by weight of cement-gypsum)
A0 (control)	0.45	50	50	0	0.1
A2	0.45	50	50	2	0.1
A3	0.45	50	50	3	0.1
A4	0.45	50	50	4	0.1
B0 (control)	0.50	50	50	0	0.1
B2	0.50	50	50	2	0.1
B3	0.50	50	50	3	0.1
B4	0.50	50	50	4	0.1

The cement and gypsum of equal weight were measured and poured into a mixing bowl, and a salt of 0.1% by weight of cement-gypsum binder added as retarder to the mix. Fiber of the required quantity was added followed by water, based on the required water-binder ratio. The whole constituents in the bowl were manually mixed for about 3–5 minutes until uniform slurry, with evenly distribution of the fiber in the paste, and of consistency attained. The wet mixture was placed in three layers into hardwood moulds of sizes 700 x 100x 40mm, 680 x 80 x 40mm, and 650x 100 x 25mm and each layer tamped evenly over the surface area of the paste. The cast samples were covered with wooden sack for 24 h, and after time expiry, it was uncovered and taken into water curing tank until their testing ages.

The cast sample size of 700 x 100 x 40mm were cut into specimen sizes of 100 x 100 x 40mm for density, moisture content and water absorption tests, while sample size of 680 x 80 x 40mm was reduced to specimen size of 160 x 40 x 40mm for compressive strength test; and for bending strength specimen size of 650 x 100 x 25mm was used. Figure 2a shows the cutting of the oil palm specimens to the required sizes that were ready for testing.

The density (ρ) which is the mass of a unit volume of hardened specimen expressed in kg/m^3 was determined at 3, 7, 14, 21, and 28 days, and calculated from the expression in Equation 1.

The density was calculated as $\rho = m/v$ (1)

where ρ is density (kg/m^3), m is the mass of sample (kg), v is the volume of sample (m^3).

The moisture content was determined by drying method at 3, 7, 14, 21 and 28 days. The specimens were weighed before placed them in an oven kept at temperature of 103°C ± 2°C for 24 h. The drying of the oil palm specimens is shown in Figure 2b. At the end of 24 h, the specimens were removed and kept to cool and the mass taken. Loss in weight, which expresses the moisture content of the specimens was calculated based on the difference between the weight of the specimen before and after drying all over the dry weight as in Equation 2.

$$M_C = (m_1 - m_2)/m_2 \times 100 \quad (2)$$

where m_1 = mass before drying, m_2 mass after drying.

The water absorption test was determined at 28 days only. The mass of the specimen was recorded before and after it immersion in water at 20°C for 24 h, and the water absorption, W_{ab} was calculated using Equation 3.

$$\text{Water absorption, } W_{ab} = (M_3 - M_4)/M_4 \times 100 \quad (3)$$

where M_3 = mass before absorption, M_4 = mass after absorption.

Fig. 2. Oil palm specimens: a) cutting b) drying

The compressive strength test was done on the specimen size of 160 x 40 x 40 mm and in accordance to BS 5669: Part I (1989). The test was conducted with the use of compressive testing machine of capacity 2000 KN. The test specimen was placed between the loading surfaces of the testing machine with its vertical length. An increasing compressive load was applied on the specimen, until failure occurred to obtain the maximum compressive load. Three specimens were tested for each hydration period of 3, 7, 14, 21, and 28 days for each mixture and the mean computed. The compressive strength was calculated from Equation 4.

$$\text{Compressive strength, } Cs = M_L/A \quad (4)$$

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

Bending strength was conducted with the use of a modified ELE machine of capacity 100 KN. The flexural test was carried out by applying load at the centre of the specimen between the two supports was 25T, or 25 times the thickness of the specimen apart. Three specimens for each curing period of 3, 7, 14, 21 and 28 days for each mix were determined, and the mean computed. Bending strength, Bs was calculated using Equation-5.

$$\text{Bending strength, } Bs = 3PL/2Bd^2 \qquad (5)$$

where P is the maximum applied load for the specimen (Newton), 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).

RESULTS & DISCUSSION

The results of the density tests of the reinforced gypsum-cement wall panel specimens are presented in Table-3 for different curing ages and water-binder ratios of 0.45 and 0.55. The density increases with curing age, but decreases with increased percentage of fiber content. This could be due to the space occupied in the matrix by the fiber, that created voids as a result of weak bond. Further, the addition of fiber, being a lighter material than the binders, that will take up greater space than the binders of equal weight in the paste, thereby cause a reduction in the composite mass and leads to reduction in density of the composite. This confirms the assertion by Aggarwal (1995) and Mohammed (2005) that increasing the natural fiber content in composite materials, reduces the density of the composite. However, the increase in density with curing age could be attributed to the hydration of cement and gypsum content.

It was observed that the control specimens, i.e., AO and B0, and that of A2 and B2, which had 2% fiber content, had higher density values (range 1625–1780kg/m^3), whereas 3% fiber content, that is A3 and B3(range 1624–1700kg/m^3), while 4% content of fiber had a density in the region of 1575and 1700kg/m^3, respectively It was equally observed that, at 28 days hydration, the least density value was recorded with 4% fiber content in both Sets ‘A’ and ‘B’ mixes.

The density of the wall panels is lighter than that of bricks and blocks which Dugal (2003) reported to range between 2400 and 2800 kg/m^3. The values of the densities for the wall panels reinforced with oil palm fruit fiber up to 4% by weight of cement fall within the densities range for aerated blocks and other wall panels systems, which varies between 300 and 1800 kg/m^3.Therefore oil palm fruit fiber reinforced gypsum-cement based wall panels, with fiber content up to 4%, satisfied the density requirement for wall panels.

Table 3. Density of oil palm fruit fiber reinforced gypsum-cement based wall panels

W/B Ratio	Identification No.	Fiber content (%)	Density (Kg/m^3)				
			3 days	7 days	14 days	21 days	28 days
0.45	A0	0	1625	1700	1725	1750	1775
	A2	2	1625	1675	1700	1725	1750
	A3	3	1600	1650	1675	1700	1725
	A4	4	1575	1625	1625	1675	1700
0.55	B0	0	1650	1700	1700	1750	1750
	B2	2	1625	1675	1700	1725	1750
	B3	3	1625	1650	1650	1700	1700
	B4	4	1575	1600	1650	1675	1675

The results of the moisture content of the oil palm fiber reinforced gypsum-cement wall panel are presented in Table 4. The control specimen (0% fiber content) had moisture content values ranging between 8.45and 5.60%, at 3 and 28 days curing age, respectively. The moisture content, generally, increases with increasing percentage of fiber contents. This is in agreement with Mazlan and Abdul Awal (2012) who reported that increasing the fiber content results in an increase in moisture value. This could be due to the space occupied in the matrix by the fiber and void created by them because of weak bond. Also the result of moisture content tests shows that moisture content decreases with curing age probably due to hydration of cement and gypsum content. At 28 days hydration, the moisture content of specimens in set 'B' was found to be higher than those of set 'A'. The reason for difference in moisture content could be attributed to higher water-binder ratio of mixes in set 'B'; that left with excess water in the pores of the specimens, after using the needed water in the hydration process of the cementitious paste compared to mixes in set 'A' which has low water-binder ratio. In set 'A', the moisture content ranged 5.60–.67% and 6.10–8.45% for mixes of set 'B'. However, the moisture content met the specification of NIS 587 (2007).

Table 4. Moisture content of oil palm fiber reinforced gypsum-cement based wall panels

W/B Ratio	Identification No.	Fiber content (%)	Moisture content (%)				
			3 days	7 days	14 days	21 days	28 days
0.45	A0	0	8.45	8.10	6.94	6.67	5.60
	A2	2	12.82	10.00	8.82	6.94	6.67
	A3	3	13.04	11.43	9.10	6.93	5.56
	A4	4	11.60	11.28	9.86	6.94	6.67
0.55	B0	0	8.46	6.93	6.67	6.62	6.10
	B2	2	13.04	8.65	8.89	8.10	6.94
	B3	3	11.28	10.00	9.10	8.82	5.60
	B4	4	12.82	11.60	11.43	9.86	8.45

The results of the water absorption as presented in Table-5 indicated that at 28 days for 0.45 water-binder ratio, the water absorption increases from 5% for control specimen (A0) to 12% for mixture A4; while mixes of water-binder ratio of 0.55 range from 6% for the control specimen to 12% for mixture with 4% fiber content (B4). Apart from the difference in water absorption values of the control specimens in both the mix proportions, there is no significant difference found in values of water absorption in other mixes in both water-binder ratios of 0.45 and 0.55. This increased in water absorption, as a result of higher fiber content, could be due to the space occupied in the matrix by the fiber and voids created by them; and can be attributed to their low density, and hence higher porosity in the composite panel. According to Asasutjarit *et al.* (2007) low density of composite cement reinforced with natural fibers had more void spaces than dense ones, so that more water can be absorbed. However, the result is found to be within the range of 6–12% stipulated by NIS 587 (2007); and also in agreement with values obtained by Audu -War and Obam (2006), and Mohammed (2005) on coconut fiber panel wall.

Table 5. Water absorption of oil palm fiber reinforced gypsum-cement based wall panels

Water-binder Ratio	Identification No.	Fiber content (%)	Water absorption (%)
0.45	A0	0	5.0
	A2	2	8.1
	A3	3	9.0
	A4	4	12.0
0.55	B0	0	6.0
	B2	2	8.3
	B3	3	9.0
	B4	4	12.0

The compressive strength (Table 6) showed that the compressive strength decreases with the increase in fiber content, but increases with curing age in each of the water-binder ratio. The oil palm fruit fiber content might be responsible for the loss of compressive strength, probably due to weak bond with fiber; while the increase in strength with curing age could be due to hydration of cement paste. The compressive strength was found to be ranged from 1.92N/mm^2 for 4% fiber content at 3 days to 5.20N/mm^2 for 0% fiber content at 28 days, in each of the water-binder ratio. The compressive strength values of the fiber reinforced panels for water-binder ratio of 0.45 at 28 days hydration were 90.19%, 89.62% and 86.15% for 2%, 3% and 4% fiber content, respectively, when compared with the reference mix at the same age. Similar trend was obtained with the mixes with water-binder ratio of 0.55. The compressive strength, for all the mixes, meets the strength requirement for sandcrete blocks for wall construction as specified by NIS 587 (2007). Therefore, gypsum-cement wall panel reinforced with oil palm fiber up to 4% content of the weight of binder is adequate for the production of wall panels.

Table 6. Compressive strength of oil palm fiber reinforced gypsum-cement based wall panels

W/B Ratio	Identification No.	Fiber content (%)	Compressive strength (N/mm^2)				
			3 days	7 days	14 days	21 days	28 days
0.45	A0	0	1.93	3.07	4.60	4.89	5.20
	A2	2	1.77	2.92	3.96	4.48	4.69
	A3	3	1.93	2.71	3.54	3.96	4.66
	A4	4	1.92	3.10	3.65	3.85	4.48
0.55	B0	0	1.93	3.02	4.60	4.79	5.20
	B2	2	1.77	2.92	3.96	4.38	4.68
	B3	3	1.93	2.71	3.33	3.96	4.64
	B4	4	1.92	2.70	3.34	3.94	4.46

The results of the bending strength of the oil palm fiber reinforced gypsum-cement wall panels are showed in Table 7. The bending strength increases with the increase in curing age, and slightly increased with the percentage content of fiber. It was showed that composite panels in mixes with water-binder ratio of 0.55 performed better than those with water-binder ratio of 0.45. This could be attributed that the water added in mixes BO-B4 must have been enough to enhance hydration of cement-gypsum content that led to reduction in voids and intra-cellular spaces. The bending strength values of specimens for the two water-binder ratios range within 2.04 and 4.26N/mm^2. The least value of 2.04N/mm^2 was recorded with the control specimen (A0) at 3 days hydration, and the highest value of 4.26N/mm^2 was noted with fiber content of 4% in mix with water-binder ratio of 0.55. It was observed that mixes with fiber content attained higher bending strength than the control. This high value with mixes containing fiber could be attributed to the evenly distribution of the fiber, which resulted in better crack arrest in the composites (Zhu et al., 1994). This was also confirmed the assertion that the addition of small closely spaced and uniformly dispersed fiber to concrete would act as crack arrester and would substantially improve the static and dynamic properties (Shetty, 2010). The trend of the results agreed with the observations of Mohammed (2005).

Table 7. Bending Strength of oil palm fiber reinforced gypsum-cement based wall panels

W/B Ratio	Identification No.	Fiber content (%)	Bending Strength (N/mm^2)				
			3 days	7 days	14 days	21 days	28 days
0.45	A0	0	2.04	3.27	3.65	3.72	4.04
	A2	2	2.34	3.16	3.33	3.98	4.06
	A3	3	2.39	3.08	3.54	3.90	4.16
	A4	4	2.76	3.22	3.58	3.95	4.10
0.55	B0	0	2.18	3.12	3.72	3.90	4.08
	B2	2	2.34	3.12	3.90	3.90	4.10
	B3	3	2.34	3.12	3.74	3.90	4.10
	B4	4	2.81	3.28	3.79	4.06	4.26

CONCLUSION

Based on the experiments carried out and the results showed on the effect of palm kernel fiber on the properties of gypsum-cement wall panels, the following conclusions are made:

a) The replacement of palm kernel fruit fiber with gypsum-cement binder decreased the density of the wall panel, and with 4% content of the density falls within the density requirement for wall panels

b) The inclusion of palm kernel fruit fiber in gypsum-cement wall panels increased both the moisture content and water absorption values of the panels, but with a fiber content up to 4%; the moisture content and water absorption met the specification of NIS 587 (2007), and therefore palm fruit fiber content up to 4% is suitable for use as reinforcement for gypsum-cement wall panels.

c) The compressive strength decreased with the increase in the fiber content, however, the compressive strength reinforced up to 4% fiber content met the strength requirement for wall construction, and therefore, palm kernel fruit fiber up to 4% replacement of gypsum-cement binder is suitable for wall panel construction.

d) The bending strength increased with the increased in the fiber content, and therefore enhanced the bending strength of gypsum-cement wall panels.

It is recommended that palm kernel fruit fiber up to 4% content of the weight of gypsum-cement binder is suitable as reinforcement in the production of gypsum-cement wall panels for use as walling element.

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