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PRELIMINARY INVESTIGATION OF TERNARY BLENDED COMPOSITE WALL PANEL REINFORCED WITH COCONUT HUSK FIBER

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ABSTRACT

Purpose: The blending of naturally/locally sourced materials in the production of Building components such as concrete, bricks and mortar has been found to have a lot of advantages over the conventional construction materials. The aim of this study is to produce hybrid wall composite of cement, gypsum, and bamboo leaf ash and coconut husk fiber as natural reinforcement that will serve as an alternative to sandcrete blocks.

Design/methodology/approach: To achieve the aim, binders of cement, gypsum and Bamboo Leaf Ash in the ratio of 45: 45: 10 by weight were blended together, and Coconut husk fiber in the range of 0-3% content by weight of the binders was added to the blend as reinforcement. A single water/binder ratio of 0.55 was maintained for all the mixes. The wet mixtures were cast in wooden moulds of sizes 160 mm × 40 mm × 40 mm and 100 mm × 100 mm × 40 mm and tested for compressive strength, density, and water absorption, respectively at ages of 7, 14 and 28 days.

Findings: The result of the compressive strength decreases with addition of coconut fiber but increases with hydration period. The density was observed to reduce with increase in fiber content and had values between 600 kg/m^3 to 1800 kg/m^3 which are comparable to other wall panels. The water absorption increases with increased in fiber content but decreased as curing age increases

Research limitations/Implications: The limitations include the use of mix ratio of 45: 45: 10 (gypsum: Portland cement: Bamboo Leaf Ash) by weight and blended with Coconut husk fiber up to 3% content by weight of the combined binders as reinforcement with a water-to-cement (w/c) ratio of 0.55. The contribution to knowledge is that the study has established the fact that the blending of these locally sourced materials in the production of wall panels is suitable for used in both internal and external conditions

Practical implications: The properties of the panel investigated satisfied the requirements for wall panels

Originality/value: The study revealed that the use of eco-friendly materials such as bamboo leaf ash and coconut husk fiber could go a long way in the production of innovative and sustainable building element such as for wall panel.

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Keywords: Bamboo leaf ash; coconut husk fiber; composite wall panel; compressive strength; density; gypsum

1. INTRODUCTION

The last three decades has witness tremendous efforts in the studying and use of mineral admixtures, particularly those derived from industrial/agricultural wastes, as constituent in the production of mortar and concrete. Those mineral admixtures of interest had been fly ash, blast furnace slag, rice husk ash, periwinkle shell ash, bamboo leaf ash and oil palm fiber ash (Yan and You, 1998; Dwivedi, Singh, Das and Singh, 2006; Villar, Valencia, Santo, Savastano and Frías, 2011). Similarly, the application of natural fibers such as coconut fibers, bagasse, jute, flax, sisal, and other vegetable fibers as alternative materials to conventional/synthetic fibers is equally gaining wider acceptability in the Building and Civil Engineering construction industry (Toledo Filho, Scrivener, England and Ghavami, 2000) probably due to their eco-friendly disposition, availability and affordability.

Many studies on the use of coconut fiber over other vegetable fibers as reinforcement in cement based matrixes have shown that it has the advantages of excellent insulation against temperature and sound, unaffected by moisture and dampness; and that it is tough, durable and resilient. For instance, John, Cincotto, Sjostrom, Agopyan and Oliveira (2005) investigated the deterioration of coir fibre used as reinforcement in both internal and external walls of a 12 year old house. The findings revealed that the fibres were undamaged and that no significant difference was found in the lignin content of fibres removed from external and those removed from internal walls. This shows that Coir fibre is usually elastic, resistant to water and mechanical wear and as such, it is readily used for heat insulation and sound proofing (Uwubanmwen, Nwawe, Okere, Dada and Eseigbe (2011).

In Nigeria, coconut palm is commonly found in the South-South and South-East regions of the country. Odewale, Odiowaya, Agho, Enaberue and Okoye (2012) reported the presence of coconut palm in the South-West region, and that Badagry Local Government area of Lagos State had the largest coconut palm plantation in the country. Coconut palms can also be found along banks of small streams and stagnant pools of water in some Northern States (Akpan, 1998). The husk and fiber generated as waste, after the edible coconut has been extracted, makes it a source of concern for use in the construction industry. The development of coconut husk fiber reinforced panelling wall is expected to contribute weight reduction, increase labour productivity in the construction of walls, and superior finishes, when compare to the traditional brick wall or block wall.

Some studies on the properties of coconut husk fibres panel boards and walls have shown low thermal conductivities thereby making it possible for use as thermal isolating materials (Khedari and Suttisonk, 2001); and improved compressive strength (Mohammed, 2005). Yao and Li (2003) carried out flexural strength studies on bamboo-fiber-reinforced mortar sandwich plates and recorded a remarkable improvement in flexural values of the plate. The results of these studies portrayed the fact that reinforced panels can be made using natural fiber materials such as coconut husk fiber.

Gypsum is a non-metallic mineral that composed of 79.1% calcium sulphate and 20% water by weight. The use of gypsum in the production of some building components is restricted to use in dry environment as its exposure to continued damp condition, or intermittent wet conditions can affects it strength performance. Hence, the blending of gypsum with cement to ameliorate this weakness, and thereby, making it suitable for production of wall panels to be used in both internal and external conditions.

However, it has been reported (Bentur, Kovler and Goldman, 1994) that mixing gypsum and Portland cement can lead to the formation of entringite or thaumasite which causes expansion and deterioration in concrete depending on the amount of gypsum. To overcome this durability problem, it has been established that ternary blending of gypsum with Portland cement and pozzolan has the potential for improved durability in humid environment. For instance, the blending of 75% gypsum, 20% Portland cement, and 5% silica fume as pozzolan in the production of gypsum based material is reported to enhance the resistance of the material in humid environment (Bentur, Kovler and Goldman, 1994). 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. Similar studies on the use fly ash, granulated blast furnace, or natural pozzolan in ternary blended mix revealed almost the same results (Yan and You, 1998; Singh, Garg and Rehsi, 1990; Singh and Garg, 1996; Colak, 2001). A study by Colak (2002) recommended that gypsum-portland cement-natural pozzolan blend of composition 41: 41: 18 and 41: 41: 18S1 (S1 means 1% superplastizer) give excellent retention properties after ageing in water at 20 ℃ for 95 days.

The potency of bamboo leaf ash (BLA) as mineral admixture has been investigated (Dwivedi, Singh, Das and Singh, 2006; Singh, Das, Singh and Dunvedi, 2007; Villar, Valencia, Santo, Savastano and Frías, 2011; Fríasa, Savastano, Villar, De Rojas and Santos, 2012). All the investigation pointed out to the fact that BLA is a good pozzolanic material that can be blended with cement or other binders. Though a lot of researches have been focused in the last three decades on use of various mineral admixtures in producing cement based components, but literature search has revealed that very little information is available on ternary blending of gypsum, cement and bamboo leaf ash reinforced with coir fiber in the production of wall panels. Therefore, this study attempts to follow current trend thrust in innovative masonry products for improved sustainable housing forms by evaluating some structural properties of gypsum-bamboo leaf ash blended cement composite wall reinforced with coconut husk fiber with a view to establishing its quality as a walling unit.

2. Literature Review

Vegetables fibers are complex natural composite with a cellular structure. 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, Scrivener, England and Ghavami, 2000) and in other matrix components. A study using other part of coconut fruit, such as the coconut shell has been studied (Mohd Saman, Bahron and Ibrahim, 2002). The study investigated the use of grounded coconut shell on the properties of particle board and reported an improvement on the bending strength as well as enhanced resistance to water absorption by the board. In another study conducted by Fadhadli (1989) on the use of coconut husk fiber in cement roofing sheet, it was reported to have significantly increased the flexural strength of flat plates roofs; and as such, coconut husk fiber has the potential to be used as reinforcement in internal wall paneling system with binder component of cement and gypsum.

Abuh and Umoh (2015) undertook a study on oil palm fiber as reinforcement in gypsum- cement wall panels with mixture of two equal weights of gypsum and cement, water-binder ratios of 0.45 and 0.55, and in each mix a varying percentage of fiber contents of 2%, 3% and 4% by weight of the binders were added. The compressive strength values were reported to range between 1.92–5.20 N/mm^2 and generally decreases with increase in percentage of fiber contents, but increased with curing age; the bending strength falls within the range of 2.04–4.13 N/mm^2 but increases with curing age and slightly increased with fiber content. The density values were in the range of 1634–1742 kg/m^3, while the moisture content range from 3.30% to 8.45%, and the water absorption varies from 5 to 12%.

Mohammad (2005) investigated the properties of wall panels made of gypsum and cement as binders and coconut fibre as the reinforcement. Bending strength, compressive strength, moisture content, density, and water absorption were properties investigated. The results revealed that Coconut fibres did not contribute to bending strength, while compressive strength increased with the addition of coconut fibres but decreased with an increase in water content. There was no significant change in moisture content and water absorption with the addition of coconut fibres.

Aziz, Paramasivam and Lee (1981) reported the use of coconut fibres of different lengths and volume fractions in cement paste composites. The mechanical properties of the cement paste composites tested were tensile strength and modulus of rupture. The results showed that the tensile strength and modulus of rupture of the paste composite containing 38 mm length and 4% volume fraction of coconut fibres had the highest mechanical properties amongst all tested volume fractions.

Cook, Pama and Weerasingle (1978) had earlier investigated the properties of roofing member made from the incorporation of coir fibre as reinforcement in cement composite. The studied parameters were fibre lengths (2.5 cm, 3.75 cm and 6.35 cm). Fibre volumes (2.5, 5, 7.5, 10 and 15%) and casting pressure (from 1 to 2 MPa with an increment of 0.33 MPa); and the properties investigated included bending, impact, shrinkage, water absorption, permeability and fire resistance. It was discovered that a roofing member with fibre length of 3.75cm, and fibre volume fraction of 7.5% as well as cast pressure of 1.67 MPa was said to attained the optimum value of the properties examined and equally cheaper than the locally available roofing materials.

In a feasibility study conducted by Paramasivam, Nathan and Das Gupta (1984) on coir fibre reinforced corrugated slabs was made for use in low cost housing particularly for developing countries. Tests for flexural strength, thermal and acoustic properties were performed. For producing required slabs having a flexural strength of 22 MPa, a volume fraction of 3%, a fibre length of 2.5cm and a casting pressure of 0.15 MPa were recommended. The thermal conductivity and sound absorption coefficient for low frequency were comparable with those of locally available asbestos boards.

Asasutjarit, Hirunlabh, Khedari, Charoenvai, Zeghmati and Shin (2007) determined the physical, mechanical and thermal properties of coconut coir-base light weight cement board after 28 days of hydration. The parameters studied were fibre length, coir pre-treatment and moisture ratio. Boiled and washed fibres with 6 cm fibre length gave better results.

3. METHODOLOGY

3.1 Materials

Portland limestone cement with production conformance to the Nigeria Industrial Standard (NIS) NIS 444: 1 (2003) was used. The cement had a specific gravity of 2.96; initial and final setting times of 85 minutes and 146 minutes, respectively which falls within recommended minimum time of 45 minutes and the maximum time of 10 hours for initial and final setting time, respectively as approved by NIS 447 (2003) and BS EN 197–1 (2009).

Gypsum, with trademark Dr. Mix, made in Torkiye and in conformity with CSN EN 13279-1 (2008), was obtained from a distributor in Uyo, Akwa Ibom State, Nigeria. Bamboo leaf ash was processed from the bamboo leaves picked from a bamboo forest along the new International Stadium road, in Akwa Ibom State. The leaves were spread on the floor of the laboratory until they were all dried and turn grey in colour. The dead and dried leaves were then parked and taken for burning at the Department of Fine and Industrial Art, University of Uyo, where it was first charred in a metallic constructed container before being transferred into a gas kiln and calcined to a temperature of 600-700^{o}C for 5 hours. The ash obtained was then sieved in 150 µm wire mesh. Physical and chemical analyses were conducted on the ash and the results are presented in Table 1.

The coconut (*Cocos nucifera var. Typical*) husk fibre was extracted from coconut husk (or shell), the physical and chemical properties are as presented in Table 2. Tap water in the Department of Building laboratory, University of Uyo, was used for both mixing and curing of the specimens.

Table 1: Physical and chemical properties of bamboo leaf ash

Physical properties	
Specific gravity	2.64
Fineness retained on 45 um sieve (%)	32.85
Water requirement (%)	48.76
Strength activity index with cement at:	
7 days	75.47
28 days	77.20
Chemical properties	
Oxide	%
CaO	4.43
SiO_2	78.00
Al_2O_3	4.96
MgO	1.01
Fe_2O_3	2.01
K_2O	3.09
MnO_2	0.23
P_2O_5	0.72
TiO_2	0.36
LOI	1.58

Table 2: Physical and chemical properties of coconut husk fiber

Physical Properties	
Length (mm)	60-210
Diameter (mm)	0.4-0.8
Moisture content (%)	10.60
Water absorption at saturation (%)	160
Density (Kg/m3)	480
Colour	Brown
Chemical properties	
Hemi-cellulose (%)	11
Cellulose (%)	46
Lignin (%)	43

3.2 Specimens Preparation and Testing

A mix proportion consisting of gypsum, Portland cement and Bamboo Leaf Ash in the ratio of 45: 45: 10 by weight were blended together, and Coconut husk fiber of 0, 1, 2, and

3% content by weight of the combined binders was added as reinforcement and followed by water which was calculated from a water-to-cement (w/c) ratio of 0.55. The binders were measured out as specified, placed in a big bowl and properly mixed to form homogenous colour. Thereafter, the required quantity of the fiber and water were measured and added to the blended mixture in the bowl and the whole contents thoroughly mixed to form a workable slurry paste and the strands of the fiber seen evenly spread over the paste. The wet slurry paste was immediately placed in wooden moulds, produced to sizes based on the requirements of the structural property of the wall panel to be evaluated, and manually compressed with the fist of the hand. Excess paste in the moulds was smoothened off with the aid of trowel. Upon completion of the casting of the specimens they were covered with sack bag and allowed undisturbed in the laboratory for 24 hours. At expiration of 24 hours, they were removed from the moulds and cured in water until their testing ages.

The compressive strength was determined on specimens of dimension 160 mm × 40 mm × 40 mm, while water absorption and density were determined from specimens sizes of 100 mm × 100 mm × 40 mm in accordance with BS 5669 -1 (1989). The tests were done at 7, 14 and 28 days curing. A total of 108 specimens were involved in the test with three specimens tested for each hydration period and for each mixture and the mean computed.

4. PRESENTATION AND DISCUSSION OF RESULTS

4.1 Compressive Strength

The results of compressive strength as presented in Table 3 indicated that the compressive strength increases with curing age but decreases with increased fiber content. For instance, the compressive strength for the control (that is, 0% fiber content) is 5.63 N/mm^2 at 28 days hydration but decreases to 4.12 N/mm^2 with fiber content of 3% at the same age. The reduction in compressive strength with increased in fiber content could be caused by the lignin content in the fiber which may have hindered the strength development of the matrix. Naik, Chun and Kraus (2003) made a similar suggestion that fibers with lignin or other chemicals can have detrimental effects on cement hydration and thereby lead to reduction in compressive strength of the composite panel. Another possible reason as noted could be the entrapped air in the mix as a result of much fiber content in the composite which lead to compressive strength reduction (Soroushian and Marikunle 1990; Chun and Naik, 2004). However, the compressive strength, for all the mixes, meets the requirement for sandcrete blocks for wall construction as specified by NIS 587 (2007). Therefore, the ternary blended composite panel with coconut husk fiber up to 3% content could be considered appropriate for the production of wall panels.

Table 3: Compressive strength at 7, 14 and 28 day hydration

Fiber content (%)	Compressive strength (N/mm^2)		
	7 days	14 days	28 days
0	4.93	5.38	5.63
1	4.60	4.83	4.95
2	3.75	3.90	4.28
3	3.25	3.65	4.12

4.2 Density

The density values of the blended cement composite wall reinforced with coconut husk fiber are as presented in Table 4. It was generally observed that the density reduces as the quantity of fiber inclusion in the mix increases. For instance, at 7 days hydration, the density reduces from 2294 Kg/m^3 with 0% fiber content to 1378 Kg/m^3 with fiber content of 3%. These values were observed to reduce from 2150 Kg/m^3 for the reference mix to 1388Kg/m^3 with 3% fiber content. A further density reduction was noted at 28 days hydration with 0% and 3% husk fiber content recorded 2130 Kg/m^3 and 1370 Kg/m^3, respectively. This decrease in the density value with increased in fiber content could be attributed to the reduction in the mass of the specimen as the fiber content increases, because fiber with specific gravity value lighter than other constituents in the mix means a greater portion of the specimen is occupied, with no corresponding change in the volume of the specimen, lead to decreased in density.

The least density values was noted to occur with the inclusion of 3% fiber content in each of the curing period, and the observed values not exceeding 1800 Kg/m^3, which is the highest density value for most panel system and aerated blocks. Therefore, 3% coconut husk fiber content in ternary blended composite wall panel could be considered satisfactory.

Table 4: Density of ternary blended wall panel reinforced with coconut husk fiber

Fiber content (%)	Density (Kg/m^3)		
	7 days	14 days	28 days
0	2294	2150	2130
1	1808	1733	1710
2	1663	1733	1558
3	1378	1388	1370

4.3 Water absorption

The results of water absorption as presented in Table 5 show that the water absorption ranged from 14.12% to 6.89% with 0% fiber content at 7 to 28 days curing ages, respectively. At 1% fiber content, the value is decreasing from 15.28% at 7 days to 7.15% at 28 days curing age. Similar trends were noted with 2% and 3% fiber contents as their water absorption values increased to 16.81% and 17.46%, at 7 days; and 8.24% and 10.61% at 28 days curing, respectively. The water absorption was noted to increase with increasing fiber content but decreases as curing age increases. This increase in water absorption value with higher fiber content may cause by the absorption capacity of the fiber and the creation of more pores in the matrix which lead to water penetration. This agreed with earlier finding (Asasutjarit *et al.*, 2007) that cement composite reinforced with natural fibers had more voids for more water penetration than composite without fiber. However, the water absorption obtained at 28 days period fall within the range of 6-12% stipulated by NIS 587 (2007) and for other composite wall panels (Mohammed, 2005; Abuh and Umoh, 2015).

Table 5: Water absorption at 7, 14 and 28 days hydration

Fiber content (%)	Water Absorption (%)		
	7 days	14 days	28 days
0	14.12	11.62	6.89
1	15.28	13.66	7.15
2	16.81	14.77	8.24
3	17.46	16.91	10.61

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5. Conclusion and Recommendations

The study found out that the use of coconut husk fiber up to 3% content as reinforcement in gypsum-bamboo leaf ash blended cement composite wall meets the compressive strength, density and water absorption criteria for wall panels. Therefore, the study concluded that wall panel can be produced from ternary blending of gypsum, bamboo leaf ash and cement as binders and reinforced with coconut husk fiber as reinforcement; and recommended for the use of this panel as an innovative approach in the production of sustainable walling elements.

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