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Effects of husk particle size and calcium chloride on strength and sorption properties of coconut husk–cement composites

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ABSTRACT

Coconut husks, residues generated during coconut processing, are available in abundant quantities in many parts of the tropics but are often treated as a waste material. This study investigated the effects of particle size and calcium chloride ($CaCl_2$) on strength and sorption properties of cement-bonded composites produced from coconut (*Cocos nucifera*) husk. Particle size, $CaCl_2$ and the interaction of both variables had significant effects ($p < 0.05$) on the density and the Modulus of Elasticity (MOE), while only particle size had significant effects ($p < 0.05$) on the Modulus of Rupture (MOR) of the composites. MOE, MOR, Water Absorption and Thickness Swelling (at 24 h) compare favourably with values reported for cement-bonded composites produced from similar lignocellulosics. These properties can be exploited in many applications where lightweight concretes are required.

1. Introduction

Cement-bonded particleboards (CBP) are low density products manufactured from a mixture of Portland cement and particles generated from lignocellulosics including wood and agricultural residues. These products tend to combine the good qualities of cement, i.e., relatively high resistance to water, fire, fungus, and termite infestation coupled with good sound insulation, with those of wood, i.e., high strength to weight ratio, nailability, and workability. They are used in building construction as fire resistant, insulation and acoustic panels (Badejo, 1989; Ramirez-Coretti et al., 1998; Wolfe and Gjinolli, 1999).

A candidate material for CBP production in Nigeria is coconut husk (*Cocos nucifera* L.). Coconut trees are available in abundant quantities (figures on specific quantities are currently unavailable) in many parts of the country, particularly along the coast of the Atlantic Ocean, while the husks are often treated as waste material. Coconut husks are made up of bristle fibre (10%), mattress fibre (20%) and coir dust and shorts or wastes (70%) (Wikipedia, 2008). The pith or dust, also known as cocopeat, is a byproduct of extracting fibres from the husk of a coconut. It is the binding material that comes from the fibre portion of the coconut husk. It has relatively high cellulose content and is biodegradable but takes at least 20 years to decompose. Once considered useless, it is now being used as mulch, soil treatment and a hydroponic growth medium in many parts of the world, particularly in India and Sri Lanka (Wikipedia, 2008). Previous studies have also shown that both coir fibre and coir dust can be incorporated in cement for the production of low-cost building materials (Filho et al., 1990; Savastano, 1990; Oyagade, 2000; Olorunnisola, 2005, 2006; Olorunnisola et al., 2005a).

A number of factors contribute to the properties of CBP products, including particle size and the presence of cement inhibitors in the wood material. Particle size tends to contribute to the degree of bonding achievable between lignocellulosic particles and cement, and hence the bend-

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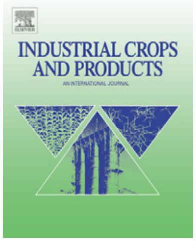

Table 1 – Sieve analysis of the ‘as received’ coconut husk particles.

Sieve aperture (mm)	Retained particles (%)	Passing particles (%)	Cumulative particles retained (%)
4.76	0.0	100.0	0.0
3.35	0.2	99.8	0.2
2.40	1.7	98.1	1.9
1.20	31.4	66.7	33.3
0.853	20.6	46.1	53.9
0.599	16.4	29.7	70.3
0.044	28.9	0.8	99.2
Pan	0.8	0.0	100.0

ing strength of cement-bonded composites. Previous study by Olorunnisola et al. (2005a) on the behaviour of coconut husk–cement systems also showed that *C. nucifera* husk contains cement inhibitors and that the inhibitory effects could be minimized with the use of calcium chloride ($CaCl_2$) as an accelerator. However, other previous studies have also shown that $CaCl_2$ tends to have some effects the bending elasticity, compressive strength and sorption properties of CBP products (Ahn and Moslemi, 1980; Badejo, 1989; Olorunnisola and Adefisan, 2002).

The objective of this work was to investigate the effects of husk particle size and $CaCl_2$ addition on strength and sorption properties of coconut husk–cement composites.

2. Materials and methods

Husks from freshly harvested, ripe coconut (*C. nucifera* L.) fruits were obtained from processors in Badagry, Lagos state, Nigeria. These were air-dried at a temperature of 27± 2 °C and relative humidity of 65 ± 5% for three weeks to reduce both the moisture and sugar contents. After hammer-milling, the longer, ribbon-like fibres were manually separated from the smaller particles (dust) and discarded. The retained particles were air-dried under the same ambient conditions for another three weeks after which the moisture content was determined in accordance with BS 812-109 (1990). A portion of the particles was retained for use “as received” (Table 1 shows the sieve analysis of the “as received” particles), while particles retained on 0.85 mm and 0.6 mm sieves were also kept for experimental purpose. The loose bulk density of the ‘as received’ as well as the sieved particles was determined in accordance with BS 3797 (1990).

Plastic moulds were used for composite production. The mould size for bending test specimens was 50 mm × 50 mm × 250 mm, and for compression test specimens was 50 mm × 50 mm × 50 mm. The coconut husk particles were dry-mixed manually in a container with cement in a cement–husk ratio (by weight) of 1:0.11. Distilled water in which $CaCl_2$ had been dissolved (in different proportions by weight of cement, i.e., 0% (control) and 3.0%), was then added at the rate of 0.25 ml/g of cement + 12.5 ml/g of coconut husk, based on preliminary experiments on water requirements for composite production. The composites were de-moulded and cured in a completely unsupported state at ambient room temperature (20 ± 2 °C) for the first seven days, and in a chamber maintained at a constant temperature and relative humidity of 20 ±2 °C and 65 ± 5%, respectively, for another 21 days. Their densities were then computed as the ratio of mass to the volume.

The specimens were subjected to 3-point bending test. They were loaded perpendicular to the direction of casting on a 100 kN capacity servo-hydraulic Universal Testing Machine (UTM) and tested at cross-head speed of 0.5 mm/min. The compression tests were conducted on the UTM at a crosshead speed of 1 mm/min as in Olorunnisola (2006). For the Water Absorption (WA) and Thickness Swelling (TS) tests, 50 mm × 50 mm × 125 mm specimens were obtained from the specimens previously used for bending test as reported in Olorunnisola (2005). They were completely submerged horizontally under distilled water maintained at a temperature of 20 ± 2 °C. Water Absorption after 2 and 24 h, respectively, were calculated from the increase in weight of the specimen during submersion, while the Thickness Swelling of each board was expressed as a percentage of the original thickness. Three replicate samples were used for all tests.

2.1. *Statistical analysis*

The experimental design consisted of two treatments – husk particle size and percentage concentration of $CaCl_2$ – and three replications per treatment. The results of the property tests were subjected to two-way analysis of variance at 5% level of significance. Post hoc multiple comparisons were performed based on Fisher’s Least Significant Difference (LSD) procedure.

3. Results and discussion

3.1. *Loose bulk density of the coconut husk particles*

The loose bulk densities of the coconut husk particles determined at a moisture content of 10.9% were generally low, ranging between 35.2 and 53.3 kg/m^3 (Table 2). The loose bulk density decreased with decrease in husk particle size. Low bulk density is an indication of the presence of relatively high volume of air voids and hence high porosity of the husk particles. Porosity has been noted to have some effects on the Water Absorption characteristics of cement composites (Savastano, 1990).

3.2. *Density of composites*

As shown in Table 2, the green densities of both the $CaCl_2$-treated and the untreated samples were greater than 800 Kg/m^3, excepting those produced from ‘as received’ par-

Table 2 – Density variations in husk particles and husk–cement composites.

Sieve aperture (mm)	Loose particle bulk density[a] (Kg/m^3)	Average composite density[a] (Kg/m^3)		Normalized density[b]	
		Untreated[c]	Treated[d]	Untreated	Treated
0.6	35.2 (0.8)	989.8 (131.9)	1210.6 (46.9)	0.51	0.62
0.85	43.0 (0.8)	896.8 (10.4)	942.7 (14.1)	0.46	0.48
'as received'	53.3 (0.3)	594.3 (37.9)	650.1 (29.8)	0.30	0.33

[a] Mean of three replicate samples; values in parenthesis are standard deviations.
[b] Ratio of the density of composite to that of the neat cement.
[c] Composites produced without $CaCl_2$ addition.
[d] Composites produced with $CaCl_2$ addition.

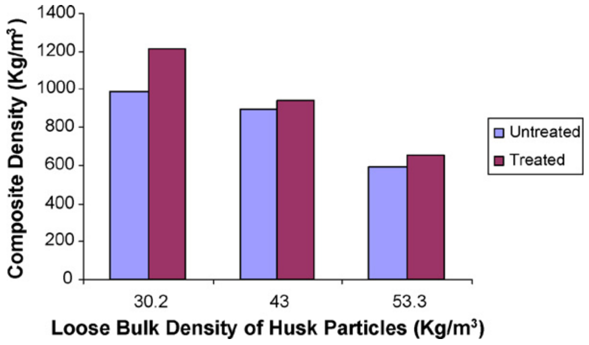

Fig. 1 – Relationship between loose bulk density of the husk and composite density.

ticles, while the normalized density ranged between 0.3 and 0.62. A similar range of values was reported by Blankenhorn et al. (1994) for hardwood–cement composites. The relatively lower density of composites produced with the 'as received' particles is not unexpected, given the fact that about 46.1% of the 'as-received' particles were made up of porous, low-bulk density particles that were either retained on, or passed through the 0.6 mm sieve (Table 1).

An inverse relationship was observed between bulk density of the husk and composite density (Fig. 1). The reason for this may be traced to the moisture contents of the composites. Moisture content contributes to the density of lignocellulosics. Cowan and Smith (1988) have also noted that moisture content plays a vital role in the density and strength properties of cement-based composites. As shown in Table 3, the moisture content of the composites produced with particles retained on the 6 mm sieve was higher than those produced with the other particle sizes. Hence, the observed higher density of composites produced with 6 mm particles could be attributed to moisture effects.

Addition of $CaCl_2$ also resulted in an increase in composite density. This effect is again traceable to moisture content. As observed by Anon. (1990), addition of $CaCl_2$ to Portland cement-based materials tends to reduce moisture loss through evaporation (at times by up to 50%) during the early hydration period by releasing the normal heat of hydration earlier and by accelerating the hydrating action. As shown in Table 3, the $CaCl_2$-treated composites exhibited higher moisture contents and hence higher densities (except those produced with husk particles retained on 0.85 mm sieve, in which the moisture content of both treated and untreated composites were virtually the same). The observed reduction in moisture loss with $CaCl_2$ incorporation in composites ranged between 14.2% (for composites produced with 'as received' particles) and 33.1% (for composites produced with particles retained on 0.6 mm sieve). ANOVA test (Table 4) showed that particle size, $CaCl_2$ addition and the interaction of both variables had significant effects ($p < 0.05$) on the density of the husk–cement composites.

3.3. *Compressive strength*

The compressive strength values of the husk–cement composites (Table 5) were relatively low, ranging from 2.6 N/mm^2 (for composites manufactured with untreated particles retained on 0.85 mm sieve) to 4.1 N/mm^2 (for composites produced with $CaCl_2$-treated particles retained on 0.85 mm sieve). There was a general increase in compressive strength with $CaCl_2$ incorporation, excepting composites produced with husk particles retained on 0.6 mm sieve. The positive effect of $CaCl_2$ on com-

Table 3 – Effects of moisture content on the density of husk–cement composites.

Sieve aperture (mm)	Loose bulk density of particles (Kg/m^3)[a]	Moisture content of composites (%)[a]		Density[a] of Composites (Kg/m^3)	
		Untreated	Treated	Untreated	Treated
0.6	35.2 (0.8)	25.5 (2.4)	38.1 (3.0)	989.8 (131.9)	1210.6 (46.9)
0.85	43.0 (0.8)	21.7 (5.5)	20.4 (1.4)	896.8 (10.4)	942.7 (14.1)
'as received'	53.3 (0.3)	25.4 (3.7)	29.6 (1.8)	594.3 (37.9)	650.1 (29.8)

[a] Mean of three replicate samples; values in parenthesis are standard deviations.

Table 4 – Analysis of variance on the effects of husk particle size and calcium chloride on density, compressive and bending strength properties of the husk–cement composites.

Source of variation	Degrees of freedom	Mean squares composite density	Mean squares compressive strength	Mean squares modulus of elasticity (MOE)	Mean squares modulus of rupture (MOR)
Replication	2	6460.62	0.02	310716.40	0.0795
Treatment	5	156000.70*	0.84	172755.40*	0.393*
Calcium chloride (A)	1	414159.20*	0.87	136576.30*	0.111
Particle size (B)	2	57889.91*	1.18*	134778.00*	0.878*
AB	2	125032.20*	0.49	228822.20*	0.048
Error	10	3153.13*	0.24	23478.52*	0.043
Total	17				

* Significant at 0.05 level.

pressive strength of concrete is well-documented. As noted by Anon. (1990), $CaCl_2$ can more than double the 1-day strength of Portland cement concrete and produce subsequent gains of 51% and 32% at 3 and 7 days, respectively. It may also increase the ultimate strength of concretes and mortars by 7% to 12%. The observed increase in the 28-day compressive strength of the husk–cement composites ranged between 8.8% (for composites manufactured with 'as received' particles) and 57.7% (for composites manufactured with particles retained on 0.85 mm sieve).

The observed compressive strength values are, however, much lower than those reported by Olorunnisola et al. (2005b) for rattan - cement composites of similar dimensions produced under similar conditions. The reason may not be unconnected with the relatively low bulk densities of the coconut husk particles (35.2–53.3 kg/m^3) compared to that of the rattan particles (120.2 kg/m^3), since density is often a good predictor of strength properties of cement-bonded composites and wood-based products (Mottonen and Luostarinen, 2006). ANOVA test (Table 4) shows that only the husk particle size had significant effect ($p < 0.05$) on the compressive strength of the composites.

3.4. *Bending strength and stiffness*

The moduli of elasticity and rupture (MOE and MOR) values of the composites (Table 5) compare favourably with values reported by Olorunnisola and Adefisan (2002) and Olorunnisola et al. (2005b) for rattan-cement composites. They are, however, lower than values reported for hardwood–cement composites (Badejo, 1988, 1989; Sarja, 1988). This is probably due to the relatively low loose bulk density of the coconut husk particles. The estimated average bulk density of sawdust and wood shavings from typical hard wood species (100 and 250 kg/m^3), as reported by Eriksson and Prior (2004), is about three to five times greater than that of the coconut husk particles (35–53 kg/m^3).

For composites produced with untreated coconut husk particles, the MOE and MOR increased with decreasing husk particle size. This may be due to a number of factors, one of which is the observed increase in the density of the composites (at about the same moisture content of around 25%) with decreasing particle size as shown in Table 3. Previous researchers have also attributed similar trends observed in wood-cement composites to increase in adhesion between cement and small-sized furnish (Badejo, 1988; Huang and Cooper 2000; Olorunnisola et al., 2005b). As suggested by Bentur and Mindess (1990), the major role of particles and fibres in cement composites is to improve the ductility of the material. In performing this role, distance (spacing) between the discrete fibres/particles is a significant parameter controlling the composite performance. It stands to reason to assume that the smaller husk particles which were likely to be blend better with cement in the matrix than the bigger particles would yield composites with higher MOE.

There was, however, no clearly discernible pattern in the observed variation in the MOE and MOR of the $CaCl_2$-treated composites, excepting the fact that $CaCl_2$-treated composites manufactured with particles retained on 0.85 mm sieve (having the lowest moisture content of 20.4%) gave the highest MOR of 2.2 N/mm^2, while $CaCl_2$-treated composites manufactured with 'as received' particles gave the highest MOE of 1013 N/mm^2. MOR, one of the key mechanical properties of engineering materials measured and presented as strength property for design, is a reflection of the maximum load-carrying capacity of a member in bending and is proportional to the maximum moment borne by the specimen. It usually exhibits an inverse relationship with moisture content. As noted by Lucas et al. (2006), the drier a lignocellulosic material is, the stronger it becomes. As would be expected, therefore, the mean MOR values of the drier composites were generally higher than those of the wetter ones.

As shown in Table 5, within the 20–25% moisture content range, the MOE of the composites increased with increase in moisture content while the MOR decreased, suggesting that, up to a certain limit, moisture content had a notable contributory effect on MOE and MOR of husk–cement composites. Wetter lignocellulosics-containing materials are typically more elastic but weaker than drier ones. As rightly observed by Cowan and Smith (1988), both moisture content and density have contributory effects on strength and stiffness of cement-bonded materials and both parameters should always be indicated in test results.

ANOVA tests (Table 4) showed that while particle size, $CaCl_2$ and the interaction of both variables had significant effects ($p < 0.05$) on the MOE, only particle size had significant effects on the MOR of the composites. The non-significant

Table 5 – Strength property variations in the coconut husk–cement composites.

Sieve aperture (mm)	Composite density (Kg/m^3)^{a,b}		Compressive strength^{a,b} (N/mm^2)		MOE^{a,b} (N/mm^2)		MOR^{a,b} (N/mm^2)	
	U	T	U	T	U	T	U	T
0.6	989.8aA (131.9)	1210.6aA (46.9)	3.9a (0.53)	3.4 (0.11)	1069.4aA (422.3)	792.9aA (236.1)	1.8aA (0.5)	1.2aA (0.12)
0.85	896.8b (10.4)	942.7ab (14.1)	2.6aA (0.33)	4.1A (0.69)	919.7A (335.9)	478.9abA (195.0)	1.4A (0.35)	2.2abA (0.15)
‘as received’	594.3ab (37.9)	650.1b (29.8)	3.4 (0.52)	3.7 (0.21)	676.6aA (210.4)	1013.9bA (224.2)	1.3a (0.13)	1.5b (0.10)

U, untreated samples; T, $CaCl_2$-treated samples.

[a] Values in parenthesis are standard deviations based on means of three specimens.

[b] Means within columns followed by the same letter are significantly different at the 5% level based on Fisher's Least Significant Difference (LSD) test. Lower case letters indicate significant difference within the group, while upper case letters indicate significant difference between groups.

effect of $Cacl_2$ on MOR is contrary to findings reported in a previous study by Badejo (1989) on hardwood–cement composites. It is, however, not surprising. Anon. (1990) and Dhir and Jackson (1996) had observed that addition of $CaCl_2$ only tends to improve the strength of cement concretes in the early days, i.e., one to seven days, the expected increase in the ultimate strength of such concretes and mortars seldom exceeding 12%.

3.5. *Sorption properties*

The WA and TS values observed in the composites are shown in Table 6. Composites produced using 0.6 mm particles exhibited the highest WA. This could be attributed to their lower bulk density and hence higher porosity already alluded to. Also, $Cacl_2$-treated composites generally absorbed less water at 2 and 24 h, respectively, than the untreated ones. As noted by Anon. (1990), addition of $Cacl_2$ tends enhance both the density and water-resistance of cement concretes.

The mean WA in most of the composites was less than 25% at 2 h (excluding the untreated composites manufactured with particles retained on the 0.6 mm sieve), and not more than 36% at 24 h of immersion in cold water. The corresponding WA in the neat cement at 2 and 24 h, respectively, were 0.53 and 0.81%, confirming the assertion that lignocellulosics generally tend to increase the hygroscopicity of cement-bonded particleboards (Oyagade, 2000). Coconut husk, in particular, has a great affinity for water. Endowed with millions of capillary micro-sponges, it is able to absorb and hold large quantities of water, up to eight times its own weight (Sindhumole, 2008). As noted by Chittenden et al. (1975), materials such as coconut husk can be incorporated in cement-bonded composites if the products are to be used for interior applications. However, such composites should be kept under pressure after manufacture until curing is nearly complete.

The observed WA values compare favourably with findings of previous studies reported) on WA in rattan-cement (Olorunnisola and Adefisan, 2002; Olorunnisola, 2005; Olorunnisola et al., 2005b) and other composites manufactured using agricultural and forestry residues such as maize, stalk and coffee husk (Oyagade, 2000; Ajayi, 2002, 2003). ANOVA tests (Table 7) showed that both particle size and $CaCl_2$ addition had significant effects ($p < 0.05$) on WA at 2 and 24 h, respectively, while their interaction also had significant effect ($p < 0.05$) on WA at 2 h.

The Thickness Swelling (TS) values of composites at 2 h (0.3–1.9%) and 24 h (0.5–3.1%) (Table 6) were relatively lower than values reported in previous works on rattan-cement composites of similar dimensions by Olorunnisola (2005). This may be attributed to the excellent water holding capacity of coconut husk as reported by Sindhumole (2008). Both particle size and $CaCl_2$ addition had some influence on the TS. Composites produced with the smallest particle size (0.6 mm particles) had the highest TS, while the $CaCl_2$-treated samples were generally more dimensionally stable, perhaps due to the higher density imparted by $CaCl_2$. Both husk particle size and $CaCl_2$ had significant effect ($p < 0.05$) on TS at 24 h (Table 7).

Table 6 – Water Absorption and Thickness Swelling of the coconut husk–cement composites.

Particle size	Mean WA^{a,b}, after 2 h (%)		Mean WA^{a,b}, after 24 h (%)		Mean TS^{a,b}, after 2 h (%)		Mean TS^{a,b}, after 24 h (%)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
0.6 mm	31.7abA (2.14)	20.4A (5.62)	35.5abA (1.72)	26.1A (3.24)	1.9ab (1.73)	0.6 (0.42)	3.1abA (1.25)	0.9A (0.47)
0.85 mm	22.1a (3.59)	19.9 (0.55)	29.9ac (4.43)	26.7 (0.66)	0.3a (0.11)	0.4 (0.27)	0.5a (0.15)	0.6 (0.26)
'as received'	15.7b (2.62)	16.4 (0.87)	24.5bc (2.75)	22.1 (0.82)	0.5b (0.35)	0.4 (0.13)	0.5b (0.36)	0.8 (0.57)

[a] Values in parenthesis are standard deviations based on three specimens.

[b] Means within columns followed by the same letter are significantly different at the 5% level based on Fisher's Least Significant Difference (LSD) test. Lower case letters indicate significant difference within the group, while upper case letters indicate significant difference between groups.

Table 7 – Analysis of variance on the effects of husk particle size and calcium chloride on sorption properties of the husk–cement composites.

Source of variation	Degrees of freedom	Mean squares Water Absorption (WA)		Mean squares Thickness Swelling (TS)	
		2 h	24 h	2 h	24 h
Replication	2	0.172	2.03	0.51	0.26
Treatment	5	100.10*	65.63	1.21	3.12*
Calcium chloride (A)	1	247.01*	165.50*	1.35	3.60*
Particle size (B)	2	104.48*	59.15*	1.13	2.66*
AB	2	22.28*	22.18*	1.22	3.36*
Error	10	11.37	7.95	0.58	0.41
Total	17				

* Significant at 0.05 level.

4. Conclusions

Wood-Cement composites were produced from coconut husk with and without the addition of $CaCl_2$ as an accelerator. The composites were tested for strength and Water Absorption properties. Results obtained compare favourably with lightweight concrete produced using similar ultra-light aggregate materials. Findings also showed that:

1. The coconut husk–cement composites were of low density suggesting that they are more suitable as insulation materials in building construction.
2. Coconut husk particle size had significant effects on the strength and sorption properties of the composites. Relatively denser, stronger and stiffer composites were obtained from the smaller husk particles.
3. Addition of 3% $CaCl_2$ had significant positive effects on the density and hence the Water Absorption properties of the husk–cement composites.

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