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# EFFECTS OF PARTICLE GEOMETRY AND CHEMICAL ACCELERATOR ON STRENGTH PROPERTIES OF RATTAN–CEMENT COMPOSITES

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***ABSTRACT:-*** *Rattan-cement composites were manufactured using 'as-received' rattan particles and those retained on 0.60mm and 0.85mm sieves. Cement: rattan mixing ratio (by weight) was 1: 0.11. Calcium chloride ($CaCl_2$) was incorporated at two levels, i.e., 0% (control) and 3% by weight of cement. Findings indicated that 'as received' particles produced denser, stronger and stiffer composites than the two other particles investigated. Addition of $Cacl_2$ resulted in an increase of between 1.6% and 9.9% in density and had significant effects on Modulus of Elasticity, Modulus of Rupture, and the compressive strength of the composites. Inverse relationships were observed between particle size and product density.*

**Keywords:** rattan-cement composite, calcium chloride, strength properties

## INTRODUCTION

Wood and other vegetable materials have been in use for ages in cement matrices to manufacture construction products (Bentur and Mindess 1990). These materials are added either in form of fibres or particles. Natural fibres exist in abundance and are readily available at low cost being derivable from various parts of vegetable materials such as leaves, stems, fruit surface or wood. These fibres are usually incorporated into the cement matrix in discrete, discontinuous form. Their major role is to reinforce, i.e., delay and control tensile cracking of the matrix, with a view to achieving reduction in stress and imparting a well-defined post-cracking and post yield behaviour (Swamy 1990). Wood particle-cement composites, on the other hand, are manufactured using wood particles. Such products are used in buildings as fire resistant and acoustic panels (Wolfe and Gjinolli 1996).

Wood particle-cement composites have been produced from a number of agro-forestry materials including sawdust, construction waste, bagasse, coffee husk, maize husk, and rattan furniture waste among others (Kasai *et al* 1998, Olorunnisola and Adefisan 2002, Ajayi 2002, 2003). However, when particles from many woody materials come in contact with cement slurry, their organic compounds such as carbohydrates, tannins, and flavonoids tend to retard or inhibit cement hydration and bond formation between the cement and wood particles. The effect is the slowing down of the strength development and delay in the demoulding of products (Biblis and Lo 1968, Zhengtian and Moslemi 1986, Hachmi and Campbell 1989, Swamy 1990, Miller and Moslemi 1991, Alberto *et al.* 2000).

While the precise mechanism of cement setting due to wood particle is yet to be fully understood, several means of minimizing the effect has been devised, including prolonged storage of the wood material, hot or cold water extraction of soluble sugars, and the use of chemical accelerators, namely dilute sodium hydroxide (NaOH), sodium silicate ($Na_2SiO_3$), calcium chloride ($CaCl_2$) and aluminum sulphate $Al_2(SO_4)_3$) among others (Hong and Lee 1986, Badejo 1989). The use of $CaCl_2$, has been reported by numerous researchers, some of whom reported that a dosage of less than 4% (by weight of cement), tends to accelerate the hydration of wood-cement mixtures thereby enhancing the wood-cement bond and the mechanical properties of the composites (Biblis and Lo 1968, Ahn and Moslemi 1980, Zhentian and Moslemi 1985, Moslemi and Pfister 1987, Badejo 1988, Olorunnisola and Adefisan 2002).

One other major factor influencing the strength properties of wood-cement composites is the particle geometry, i.e., the size dimensions of particles employed in the production of the composites. Badejo (1988) reported an improvement in Moduli of Elasticity and Rupture with increase in flake dimensions of hardwood-cement composites produced using wood flakes while Olorunnisola *et al.* (2005a) reported a decrease in both moduli and compressive strength with increasing particle size for rattan-cement composites for a rattan particle size range of 0.6 to 1.2 mm.

The aim of study was to investigate the effects of particle size and $CaCl_2$ addition on strength properties of wood-cement composites manufactured from rattan cane. Lucas and Dahunsi (2004) reported that the carbohydrate contents of three major rattan species found in Nigeria - *Calamus deerratus*, *Eremospatha macrocarpa* and *Laccosperma secundiflorum* - exceeded 70%. Of the three species, *L. secundiflorum* had the highest carbohydrate content and therefore the highest probability of inhibiting cement hydration. Explorative investigations by Olorunnisola *et al.* (2005b) involving hydration tests only also confirmed the inhibitory nature of *L. secundiflorum* on Portland cement and the effectiveness of $CaCl_2$ in curtailing these negative effects.

## MATERIALS AND METHODS

Matured samples of *L. secundiflorum* from wild stocks were obtained from rattan harvesters in Ibadan, Western Nigeria. These were duly identified in the herbarium of the Department of Botany, University of Ibadan, Nigeria. The canes were cross-cut into about 6 cm long specimens, air-dried for four weeks and pulverized in a hammer-mill fitted with a sieve size of 6 mm. The particles obtained were further air-dried for three weeks to an average moisture content of about 11% (dry basis). A portion of the particles was retained for use "as received", while the rest were sieved using a set comprising 2.4 mm, 1.2 mm, 0.85mm and 0.6mm sieves. Particles retained on 0.85mm and 0.6mm sieves were also kept for experimental purpose. The loose bulk density of the particles was determined in accordance with BS 3797. Rattan-cement composites were produced using each of the three particle sizes.

Composites were manufactured in three replicates using plastic moulds, 50 mm (length) x 50 mm (breadth) x 50 mm (height) for compression strength test samples, and 250 mm (length) x 50 mm (breadth) x 50 mm (height) for bending strength test samples as in Olorunnisola *et al.* (2005a). The cement : rattan mixing ratio (by weight) was fixed at 1:0.11. The cane particles were dry-mixed manually in a container with cement. Distilled water in which $CaCl_2$ had been dissolved (in two proportions by weight of cement, i.e., 0% (control) and 3.0%), was added at the rate of 0.25 ml/g of cement + 7.5 ml/g of rattan particles as in Olorunnisola *et al.* (2005a and b). The composites were de-moulded after about 24 – 48 hours, cured under wet cloth at room temperature (20 ±2 $^0$C) for a period of 5 to 6 days, and then kept in a controlled chamber at the same temperature (20 ±2 $^0$C) and a relative humidity of 65 ±5% for another 21 days.

The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of the composites were determined using the three-point bending test approach. Specimens 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. Compressive strength tests were also conducted on the UTM at a cross-head speed of 1 mm/min.

## RESULTS AND DISCUSSION

### Bulk Densities of the Rattan Particles

The loose bulk densities of the different rattan particles (Table 1) were relatively low, ranging between 78.0 kg/m$^3$ and 120.2 kg/m$^3$. An inverse relationship was observed between rattan particle size and loose bulk density, attributable to the reduction in air volume with decreasing particle size. However, the bulk density values are comparable with those of a number of other ultra-light weight aggregates used for making lightweight concrete, e.g. perlite (40-200 kg/m$^3$) and vermiculite (60-200 kg/m$^3$) (Neville 1995), and cork (90-280 kg/m$^3$) (Karade 2003).

**Table 1: Bulk Densities of the Rattan Particles Used in the Production of the Composites**

| Particle Size (mm) | Loose Bulk Density (kg/m$^3$)* |
|---|---|
| 'as received' | 78 |
| 850 | 101.6 |
| 600 | 120.2 |

* Mean of two replicates

### Effects of Particle Size and $Cacl_2$ on Composite Density

Table 2 shows the density of the composites. It ranged between 1028 and 1340 Kg/m$^3$, for composites manufactured without the addition of $CaCl_2$, and between 1130 and 1361 Kg/m$^3$ for $CaCl_2$ treated composites. As illustrated in Figure 1, the density of the composites increased with decrease in rattan particle size, with the 0.6 mm rattan particles producing composites with the highest density. This observation may probably be linked to the

Table 2: Comparison of Properties of the Rattan-Cement Composites[1]

| Rattan Particle Size | Density (Kg/m3) | | Compressive Strength ($N/mm^2$) | | MOE ($N/mm^2$) | | MOR ($N/mm^2$) | |
|---|---|---|---|---|---|---|---|---|
| | Untreated | Treated | Untreated | Treated | Untreated | Treated | Untreated | Treated |
| **0.6 mm** | 1587.9 | 1613.1 | 22.0Aa | 13.0Aa | 1885.4a | 2832.4Aa | 4.5a | 5.2a |
| **0.85 mm** | 1473.9a | 1554.3a | 14.1Aa | 30.7Aa | 2816.8a | 4253.1Aa | 4.3a | 5.8a |
| **As received** | 1181.0a | 1301.4a | 29.1Aa | 25.5Aa | 2509.9a | 3970.8Aa | 6.8a | 7.4a |

[1]Mean of three replicate samples
A capital letter A indicates significant difference between composites produced with different rattan particle sizes. A lower case letter "a" indicates significant difference (at 0.05 level of significance) between untreated and treated composites.

bulk density of the rattan particles. Besides, smaller wood particles tend to bond better with Portland cement than bigger particles in wood-cement composites, thereby minimising the presence of air voids (Karade 2003).

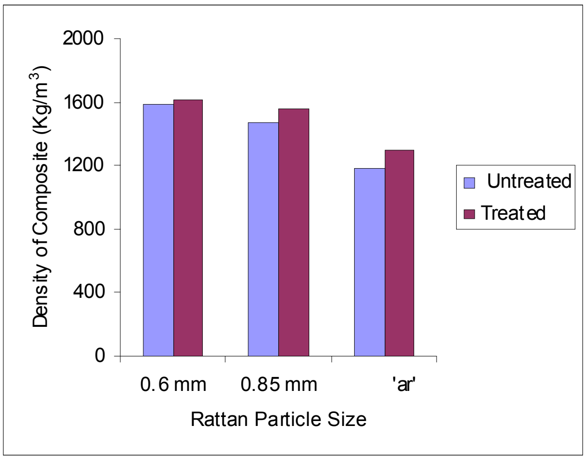


Figure 1: Effects of Particle Size and $CaCl_2$ on the Density

There was also an increment of between 1.6 and 10 % in product density with $CaCl_2$ addition. These observed differences in density were significant (at 0.05 level of significance) for composites produced using the 850µm and the 'as received' rattan particles. Ahn and Moslemi (1980) had observed that $Cacl_2$ tends to improve the bond between wood and cement. Such an improvement in bonding might be accountable for the observed increase in density.

## Hardening Time and Appearance of Composites

The time taken for the composites to become sufficiently hard for de-moulding ranged between 24 and 48 hours for the untreated samples and between 24 and 36 hours for the $CaCl_2$ treated samples, i.e., there was a time reduction of between 25 and 33% due to $CaCl_2$ addition. Composites produced using smaller rattan particles generally took longer time to harden than the 'as received' particles. One plausible explanation for this observation is that smaller particles with relatively larger surface areas interacted more with the cement resulting in greater inhibition. The larger surface area may also have accounted for the greater effect that $CaCl_2$ had on composites produced with smaller rattan particles than those manufactured using larger 'as received' particles.

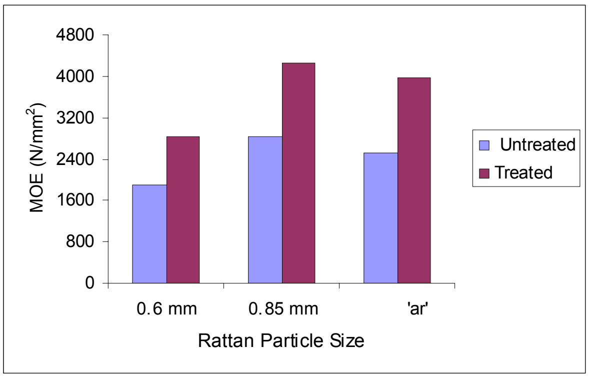


Figure 2: Effects of Particle Size and $CaCl_2$ on MOE

Besides reducing the hardening time, $CaCl_2$ also had some noticeable influence on product colouration. All the treated composites had shiny surfaces, the degree of shininess decreasing with increasing rattan particle size. No plausible explanation could be proffered for this phenomenon at this time.

The mean MOE values of the untreated and treated composites (Table 2) ranged between 1885.4 $N/mm^2$ and 2816.8 $N/mm^2$ for untreated samples and between 2832.4

N/mm² and 4253.1 N/mm² for the $Cacl_2$ treated samples. Composites produced using 0.85 mm rattan particles (treated and untreated samples) had the highest MOE, followed by those manufactured with 'as-received' particles (Figure 1). It has been observed by Bentur and Mindess (1990) that one of the major roles of wood particles in cement composites is to reinforce, i.e., improve the ductility of the material. Hence, it stands to reason that bigger rattan particles produced composites of higher MOE values than smaller and mixed particles.

Composites produced with $Cacl_2$–treated particles also had higher MOE than those produced with untreated particles. Analysis of Variance also showed that $Cacl_2$ had significant effect ($p< 0.05$) on the MOE of the composites. This is an indication that the addition of is $CaCl_2$ of 3% is beneficial in terms of improved MOE of the rattan–cement composites. Olorunnisola and Adefisan (2002) reported a similar effect on cement composites produced using rattan furniture waste. Improvements in MOE of wood-cement composites traceable to the use of additives have been explained in terms of enhanced interfacial bonding between wood particles and cement (Huang and Cooper 2000).

### Effects of Particle Size and $Cacl_2$ on Modulus of Rupture of the Composites

The MOR values of the rattan-cement composites varied from 4.3 to 6.8 N/mm² for untreated samples, and from 5.2 to 7.4 N/mm² for the $Cacl_2$ treated samples. As shown in Figure 3, the "as received" particles produced composites with the highest MOR. This is probably due to the random distribution of the rattan particles in the composites. It has been suggested that the use of different particle sizes tend to enhance bending strength properties of wood-cement composites as opposed to the use of a single particle size (Huang and Cooper 2000).

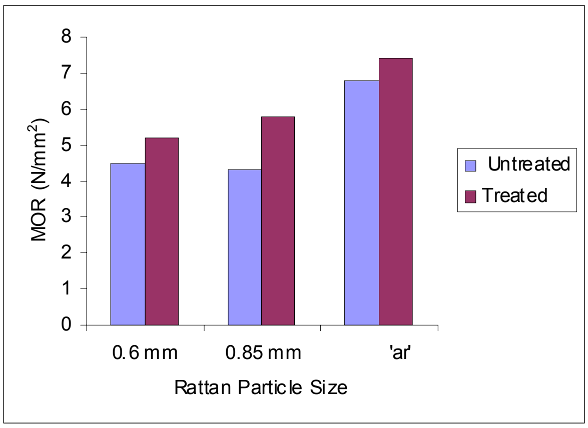


**Figure 3: Effects of Particle Size and $CaCl_2$ on MOR**

The $CaCl_2$ treated samples general had higher MOR than the untreated samples. Analysis of Variance showed that the addition of $CaCl_2$ had a significant effect ($p< 0.05$) on the MOR of the samples, i.e., the mean differences in the MOR values of the treated and untreated composites were significant. Ahn and Moslemi (1980) had investigated the effects of $CaCl_2$ on wood-cement bond, observing conical shaped crystals of hydrated cement embedded in wood, and concluded that their interlocking improved the bond between wood and cement, and hence improvement in strength.

A weak positive correlation ($y = 0.0007x + 3.4662$, $R^2 = 0.2725$) was observed between MOE and MOR of the composites (Figure 4). This in contrast to the findings of Badejo (1988) who observed a positive high correlation between MOE and MOR in wood-cement composites manufactured from mixed tropical hardwoods.

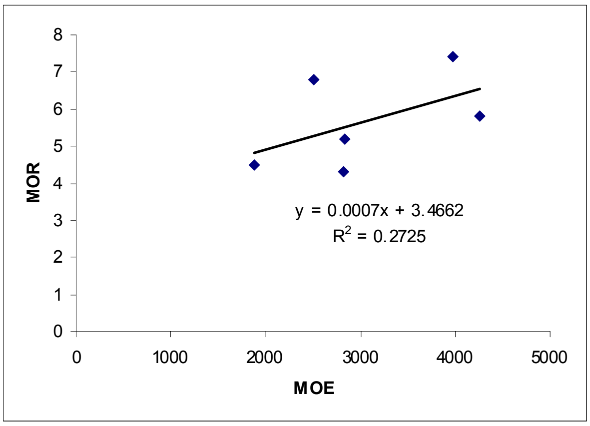


**Figure 4: Correlation Between MOE and MOR**

### Effects of Particle Size and $Cacl_2$ on Compressive Strength of the Composites

The compressive strength values of the composites (Table 2) ranged between 14.1 and 29.1 N/mm² N/mm² for untreated samples, and between 13 and 31 N/mm² for the $Cacl_2$ treated samples. These values fall between 26.9% and 59.1% of estimated compressive strength of the neat cement. As shown in Figure 5 an inverse relationship was observed between compressive strength and rattan particle size for the treated and untreated composites, while the "as-received" rattan particles produced composites with the highest compressive strength.

As noted by Bentur and Mindess (1990), wood fibres are generally not used to improve the compressive strength of cement-bonded composites, though a small improvement in strength may sometimes result from their use. Rather, their role is to control cracking and to alter the behaviour of the composite once the matrix has cracked. It may be assumed that the increase in strength observed in the composites produced with the "as-received" rattan particles is a result of the distribution of the particles.

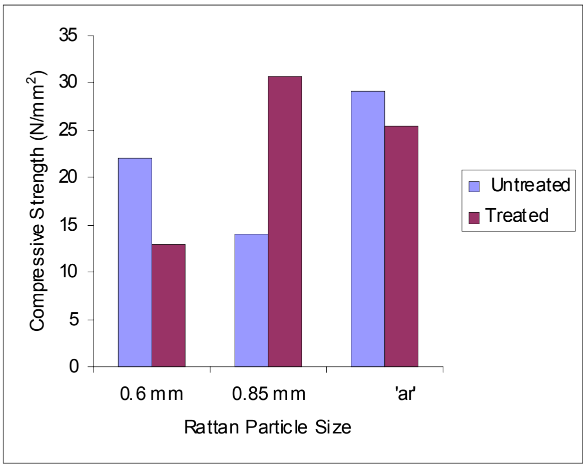


**Figure 5: Effects of Particle Size and $CaCl_2$ on Compressive Strength**

There were significant differences ($p < 0.05$) between the treated and untreated composites, attributable to enhanced bonding between the rattan particles and cement. However, as a shown in Figure 6, a weak negative correlation ($y = -0.021x + 52.95$, $R^2 = 0.2382$) was observed between density and compressive strength, suggesting that density is not a good predictor of the compressive strength of the rattan-cement composites.

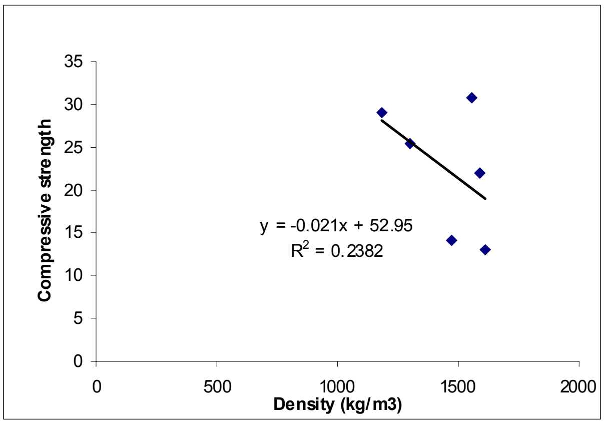


**Figure 6: Correlation between Density and Compressive Strength**

## CONCLUSIONS

The following are the conclusions drawn from the findings of this study:

i. The addition of $CaCl_2$ reduced the hardening time, improved the density, and the appearance, and had a significant effect on the bending stiffness and compression strength of the composite.

ii. Rattan particle size variation had a slight effect on bending stiffness and compression strength of the composite with smaller particles producing relatively denser, stiffer and stronger cement-bonded particle boards.

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