Green Surface Modifier for Coirdust Waste in Cement Composite

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Abstract. This study investigates the use of sodium silicate as surface modifier for coir dust waste in cement composite. The improvement of interfacial bond between the lignocellulosic coir dust material and cement matrix could increase potential application of coir dust waste in civil industry, an added value and a solution to its disposal problem. A coir dust-cement composite was produced using a ratio of 1:0.11:0.75 by weight of cement (cement: coir dust: water). The specimen sizes of 50mmx50mmx100mm for compression and 50mmx50mmx250mm for modulus of rupture were prepared in triplicate and tested using Universal testing machine. Sodium silicate significantly improved compressive and flexural strength and effectively reduced sorption properties of the coir dust cement composite. Based on the mechanical properties test, produced composite was suitable for light weight construction material.

1. Introduction
The Philippines is considered as the second largest coconut (Cocos nucifera L.) producer in Asia and a home of some local coir fiber industries in the region. Unfortunately during the coir fiber extraction process, a large fraction of coir dust waste is produce and this waste is left to rot, thrown or burned [1, 2]. About 70% of coconut husk constitutes coir dust and is high in lignin and phenolic compounds [3]. Coir dust if not properly manage and dispose has negative environmental impact, and could serve a breeding place of insects and other organisms that could be a vector of diseases.

In the recent years, coir fiber and coir dust have gained recognition in cement composite as the industry shifts to alternative use of renewable energy to reduce environmental impact of production and cut production cost [4]. The incorporation of coir fiber for instance in concrete reinforcement resulted to an increase in tensile and flexural strength [5] by minimizing growth crack. Thus, natural fibers and their by-products are gaining attention in the development of environment friendly construction materials. These fibers are cheap, biodegradable and produce lighter product than its synthetic counterpart [6]. Coir fiber and coir dust have been studied for incorporation in cement for the production of low-cost building materials [7]. However, the effectiveness of this lignocellulosic materials in rendering better and improve mechanical performance of the brittle cement matrix is influence largely by the fiber-cement matrix interaction [8]. The difference in lignocellulose and cement compatibility is caused by inhibitory substance found in the materials which can be addressed using additives [9]. On the one hand, the interfacial bonding between these materials can be improved using chemical pre-treatments but some of these pre-treatments such as alkaline treatment resulted to poor composite durability [10] and negative environmental impacts e.g. release of harmful acids and
chlorine. On the other hand, another way to improve compatibility is to coat wooden materials prior to mixing [11]. The application of blocking layers can also be possible [12]. Despite the existence of these processes, the use of greener method is still dearth in literature. This study evaluated the use of sodium silicate as environment friendly alternative surface modifier acting as coating agent or blocking layers to improve interfacial bonding, durability or strength and remedy high water absorption property of the produce cement composite which may improve its potential application as lightweight construction material.

2. Materials and methods

2.1. Coir dust and Portland cement
Coir dust was obtained from mature coconut husk which was manually cut into small size of approximately 5 cm and retted for 24 hours. The water is then drained and the material is allowed to rest for 12 hours in an ordinary room temperature to remove excess water prior to the shredding process. The material is shredded twice to obtain optimum production of coir dust and fiber. The long fiber was manually separated and discarded from the coir dust. The coir dust is marked as received and used in the experiment. The produce coir dust was soaked to saturation in prepared solution of sodium silicate in different proportion, i.e., 0% (control), 1% sodium silicate/liter distilled water, 5% sodium silicate/liter distilled water, and 10% sodium silicate/liter distilled water. The treated coir dust was sundried for 3 days under full sunlight using tarp of the same dimension. This process makes it distinct and different with the process involved in the study of Olorunnisola (2009) wherein coir dust was screened and mixed with cement and dissolved CaCl2 treatment was added during the moulding process. Quartering method was performed to secure required sample materials for casting. This was done by dividing dried samples into four quarters and two opposite sides were taken and mixed thoroughly. Blended cement type IP of Portland cement with fly ash was utilized for coir dust-cement composite production.

2.2. Production of the composite
Fiber glass moulds were prepared and used to produce composite and a mould sizes of 50x50x100mm and 50 x 50 x 250 mm in triplicate were prepared for compression and flexural strength. Treated coir dust and cement were dry mixed manually in a plastic container in accordance with the ratio (1: 0.11 by weight of cement adopted from Olurunnisola, (2008) and distilled water was added to create composites. The filled fiber glass mould was vibrated using a fabricated vibrator for 5 minutes or until a glossy surface appearance occur. This was kept in ambient room temperature 28 ± 2°C for 24 hours and demoulded and cured in the same ambient temperature for 28 days in a completely submerged state using distilled water.

2.3. Physical and mechanical properties test
Specimens for compressive and flexural strength were tested using a 250 kN capacity MATEST Servotronic Compression Machine with a cross-head speed of 1mm/min and 3-point bending test with a crosshead speed of 0.5 mm/min. Bulk density, water absorption and apparent porosity were determined by adopting the method used in Brasileiro et al. (2013). The specimens were placed in an oven for 24 h at 100 ± 5°C and dry weight (Wd) was obtained and thereafter immersed in water for 24 hours. The immersed weight was determined using a hydrostatic balance (Wi). Saturated weight (Ws) was evaluated after the specimen was dried using absorbent paper. The following formulae were used in the calculation of the physical properties:

\[ BD (g/cm^3) = \frac{W_d}{W_s - W_i} \]
\[ WA(\%) = \frac{(W_s-W_d)\times100}{W_d} \]
\[ AP(\%) = \frac{(W_s-W_d)\times100}{(W_s-W_i)} \]

2.4. Chemical Characterization of Composites
Chemical characterization was done using SEM-EDX (Scanning Electron Microscope) to determine the elemental composition of the composites under study.
2.5. Statistical analysis

The experiment was consisted of four treatments and each treatment has three replicate. The physical and mechanical properties tests were analyzed using one way analysis of variance at 5% level of significance after Shapiro-wilk test confirmed normal distribution of samples (p>.05). Post hoc multiple comparisons of means were done using Tukey’s test. All analyses were carried out using IBM SPSS Statistical Software version 22.

3. Results and discussions

3.1. Bulk density

The use of sodium silicate as pre-treatment resulted to an increase in bulk density of the produce composite. As shown in the figure 1, mean bulk density values of the composites were 0.97g/cm³ (control), 0.92g/cm³ (1% SS), 1.04 cm³ (5% SS) and 1.04 cm³ (10% SS). Analysis of variance (ANOVA) showed a significant difference among the treatment means. Tukey’s test showed (Tukeys, P<0.05) that composites with 5% and 10% sodium silicate significantly differ from 1% sodium silicate application however comparable to control. The increase in bulk density of sodium silicate treated composite both at 5% and 10% was ascribed to the increase in weight gained by the coir dust during treatment. The increase in weight gained by the coir treated fiber is due to effective adhesion of silicate materials enveloping coir dust material. The formation of a hard glassy substance causing the material to gain weight. While moisture may contribute to increase density values e.g. control, only sodium silicate contributes in large part to the variation in density of treated composites.

Similarly, an increase in weight gain of briquette is observed by [10] following an increase in sodium silicate concentration in sawdust. The same observation was noted by [13] in fiber mat impregnated with sodium solution at a predetermined time showed weight gain after it was oven dried.

![Figure 1. Bulk Density of Composite (Data are means ± SD, N=3; Means with the same letter superscripts are not statistically significant from each other based on Tukey’s Test, p<0.05)](image)

3.2. Water absorption and apparent porosity

Result of the analysis reflected in figure 2 indicates that sodium silicate treatments were effective in reducing water absorption and apparent porosity compared to reference material or control. Mean water absorption values were 45.57% (control), 31.75% (1% SS), 27.15 (5% SS), 27.94 (10% SS) and mean apparent porosity values were 43.24(control), 29.12 (1% SS), 28.18 (5% SS) and 28.95 (10% SS) respectively. The treated composites significantly differ (Tukey’s test, P<0.05) from control. The discernible decrease in water absorption and apparent porosity of the treated composite implies an effective surface coating property of sodium silicate. The treated coir dust became granulized, hard and rigid after drying and eventually losses its soft porous character. This property may help improve coir fiber surface and cement matrix interaction and eventually limit water absorption.

The increase in moisture gained by the reference material or control affirmed the attribute of coconut husk as it has the ability to absorb moisture eight times its weight [5]. The results were consistent also with the findings [7] where water absorption of the treated composite was not more than 36% after 24 hours of submerging in cold water.
3.3. Compressive strength

The compressive strength generally increases in treated composites as indicated in figure 3. The use of sodium silicate both at 5% and 10% significantly higher than the control and 1% sodium silicate application. Mean values of the composite compressive strength were: 12.86 Mpa (control), 13.86 Mpa (1% SS), 17.71 Mpa (5% SS), and 18.77 Mpa (10% SS). These values are comparatively higher than the values obtained by Olorunnisola and Brasiliero (compressive strength of 3.5-4.5MPa). Analysis of variance (ANOVA) showed a significant difference among treatment means. Tukey’s test (Tukey’s test, P<0.05) revealed that sodium silicate treated composites with 5% and 10% significantly differed from control. The observed increase in compressive strength can be traced to increase bulk density which is evident only at higher concentration. Sodium silicate treatment resulted to the formation of gel around fiber which caused stiffness thereby increasing strength [11]. The coated fiber surface exhibits roughness that may help in fiber cement interaction during hydration process. The hard rigid nature of coir dust after treatment mimics the nature of sand which may also help induce better compatibility of the material to cement. It is evident during the process of mixing and moulding the composite that no balling effect has been observed as opposed to the control.

![Figure 3. Compressive strength](image)

3.4. Flexural strength

Flexural strength is usually 10-20% of the compressive strength. The same behavioural trend is observed in flexural property as shown in figure 4 of produced composite. Sodium silicate treatment generally resulted to an increase in flexural strength. Mean values of flexural strength were 1.11 (control), 1.86 (1% SS), 1.92 (5% SS), 2.21 (10% SS). Analysis of variance (ANOVA) showed a significant difference among treatment means. Tukey’s test (Tukey's test, P<0.05) indicated that sodium silicate treatment of 10% significantly differed from 1% sodium silicate, and control. An increased in concentration of sodium silicate treatments resulted to an increase in flexural strength. This result was however different with the findings [14] on sodium silicate treated moso bamboo particles where modulus of rupture or flexural strength increased with an
increase in sodium silicate treatment and reached a maximum peak of 27 MPa at 2% concentration. An observed decline at higher rate by the same author (5% and 10%) was not observed in this study. There was a consistent increase in flexural strength of the composite, though statistical analysis did not show significant difference in the observed increase in strength both at 5% and 10% respectively. Differences in observed values between 10% (SS) and 1% (SS) and the rest of the treatments can be attributed to differences in bulk density values.

**Figure 4.** Flexural strength of coir dust composite (Data are means ± SD, N=3; Means with the same letter superscripts are not statistically significant from each other based on Tukey’s Test, p<0.05)

### 3.5. Composite morphology

The SEM-EDS analysis to determine elemental composition is presented in Table 1 while samples of fractured specimens emphasize composite morphology is reflected in figure 5. Results of the analysis indicated higher concentration of sodium and silicon along with other elements on coir dust cement composite. The mere presence of these elements implies a difference in the density of the produced composite corroborating their contribution to the composites property.

| Elements | Composite A (Control) | | Composite B (10% Sodium Silicate) | | | |
|----------|----------------------|------------------|-----------------|-------------------|-----------------|
| Oxygen   | 42.9                 | 41.3             | 45.8            | 48.1              |
| Calcium  | 20.7                 | 26.9             | 18.6            | 25.6              |
| Carbon   | 34.3                 | 23.8             | 22.5            | 14.6              |
| Silicon  | 0.7                  | 3.8              | 7.1             | 5.9               |
| Sulfur   | 0.1                  | 1.2              | 1.2             | 0.4               |
| Aluminum | 0.3                  | 1.1              | 1.4             | 1.5               |
| Sodium   | 0.4                  | 0.4              | 1.8             | 1.1               |
| Magnesium| 0.1                  | 0.5              | 0.5             | 1.2               |
| Iron     | -                    | 0.7              | 0.8             | 1.7               |
| Potassium| 0.5                  | 0.4              | 0.4             |                   |

This finding was also consistent with the study [4] indicating elemental composition that influenced composite density. The element sodium and silicon in 10% treatment are relatively increasing in concentration at the spectrum identified compared to control. The adherence of sodium silicate to coir dust materials improves the density and the physical bond between cementitious matrix and coir dust particles.
Figure 5. Fractured surface of mechanically tested coir cement composite a (control), b (10%)

The fracture surface of the test specimens captured with a S7 samsung iphone shows a uniform distribution of coir dust in cement matrix with 10% sodium silicate treatment contrary to reference sample which has points of cement accumulation thus indicating a poor interfacial bond between the fiber and cement matrix. The treated coir dust is well dispersed in cement matrix with smaller micropores which implies better coir dust and cement interaction while reference specimen shows apparent macropores corroborating their contribution on composites mechanical and physical properties.

4. Conclusion

Improve interfacial bond between the lignocellulosic coir dust and the cement matrix was done using green method. Sodium silicate treatment significantly reduce sorption property of coir cement composite. Based on compressive strength 17.71 Mpa (5% SS), and 18.77 Mpa, the composite material is suitable for structural lightweight construction such as wall with an improved water repelling property.

5. References

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