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Production and Evaluation of Composite Rainwater Storage Tanks from Recycled Materials Part 1: Material Characterization

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Received: 4 April 2018; Accepted: 18 May 2018; Published: 21 May 2018

Abstract: Solid waste management and potable water supply are two of the major challenges in Nigeria. Recycling of wood and plastic wastes as cement-bonded composite rainwater storage tanks can play a major role in addressing both challenges. The aim of this study was to determine acceptable composite formulations for tank production and their short-term effects on stored rainwater. This paper reports the experimental results on composite formulations using varying proportions of *Gmelina arborea* sawdust, water sachet and acrylic plastic waste and determining their moisture content, density, water absorption (WA), thickness swelling (TS), thermal conductivity (TC), and impact energy. The moisture contents (14.7–16.5%) and densities (1.24–1.53 g/m^3) exceeded the minimum value specified for cement-bonded composites. WA in all samples containing plastic materials were relatively low (<6%), an indication of suitability for water storage. However, only the samples containing water sachet exhibited an acceptable thickness swelling (approximately 2%). Density and WA had positive correlations with TS of the composites. The TC values (0.044–0.051 W/mK) were acceptably low. A strong, positive linear correlation was also observed between density and TC. Samples produced with a combination of cement, sawdust, water sachet and acrylic plastic exhibited the highest impact energy.

Keywords: solid wastes; cement-bonded composite; rainwater; storage tanks

1. Introduction

Access to potable water supply is one of the challenges in many urban and peri-urban areas in Nigeria today. Commercially sold drinking water, commonly referred to as pure water and packaged in plastic sachets, is ubiquitous in Nigerian cities. As noted by Aderogba [1], about 50–60 million units of used water sachets are disposed daily across the country. Besides, plastic materials have, over time, largely become a major packaging material in the country. Acrylic, a clear, colorless and transparent plastic material, is widely used in the manufacture of transparent roofing sheets, automobile parts, paint, etc. resulting in the generation of large quantities of acrylic plastic wastes [1,2]. Plastic waste products, therefore, constitute a high percentage of the municipal solid waste stream in Nigerian cities. A significantly large portion of these waste products are disposed of by open-air burning either in situ or in dump sites, thus creating environmental hazards with the emission of greenhouse gases especially methane (CH_4) and carbon monoxide. In the same vein, large quantities of sawdust are generated from sawmills, many of which are located in the urban centers [3].

In tackling the challenge of domestic water supply, many of the urban dwellers in the country engage in rainwater harvesting [4]. However, one of the major constraints to optimal utilization of rainwater is the availability of affordable storage tanks. The afore-mentioned plastic and wood waste products can be recycled in the form of cement-bonded composites to produce low-cost water storage tanks. Cement-bonded composites are made from a mixture of cement, water, wood or other lignocellulosics. The lignocellulosic (sawdust in this case) is expected to reduce the weight and enhance crack resistance, ductility and energy absorption [5], while plastic waste is expected to enhance the dimensional stability and impact strength of the composite tank. A previous study by Aladenola et al. [6] indicated that the use of gmelina (*Gmelina arborea*) sawdust for the construction of cement-bonded rainwater storage tank had no significant negative effect on the quality of the stored water. However, there was no report on the dimensional stability, impact strength and thermal conductivity of the composite. It was also considered necessary to explore the possibility of combining sawdust and plastic waste materials in the production of such tanks for the reasons earlier stated. The objective of this aspect of the study, therefore, was to evaluate the effects of partial replacement of gmelina sawdust with disused water sachet and acrylic plastic waste on selected properties of cement-bonded composites for use in the construction of rainwater storage tanks.

2. Materials and Methods

Gmelina sawdust was collected from a local sawmill, and soaked in cold water for 24 h at room temperature (approximately 27.8 °C in line with conventional practice to remove the cold water-soluble substance(s) that may inhibit the setting of cement. It was then sun-dried and passed through 1.18 mm and 850 µm sieves. Particles that passed through 1.18 mm but were retained on the 850 µm sieve were used. Disused water sachets (Figure 1) were collected from cafeterias at the University of Ibadan, Nigeria. The sachets were thoroughly washed and air-dried for a couple of days. Acrylic plastic waste (Figure 2) was collected from a company. The sachets and acrylic waste were hammer-milled and sieved. Particles that passed through 1.18 mm but were retained on the 850 µm sieve were used. Portland cement was purchased locally from dealers in standard bags of 50 kg weight. Potable water sourced from the University of Ibadan water supply was used.

Figure 1. Disused water sachets packed in plastic bags.

Figure 2. Acrylic plastic waste.

Cement-bonded composites were produced using a cement:filler material (sawdust, plastic or acrylic waste):water ratio of 4:1:0.5. The control samples contained a mixture of cement and sawdust only. In the other experimental samples, sawdust was partially replaced with water sachet and acrylic waste particles by mass as follows:

Cement + sawdust (50%) + water sachet particles (50%)
Cement + sawdust (50%) + acrylic plastic waste particles (50%)
Cement + sawdust (50%) + water sachet particles (25%) + acrylic plastic waste particles (25%)

For property characterization, rectangular (150 mm × 100 mm × 20 mm) and circular (50 mm diameter) samples were produced. The mass of each composite constituent was determined using an electronic balance. Once weighed, the constituents were thoroughly mixed manually on a flat surface until high level of uniformity was obtained. Water was added gradually while mixing to avoid segregation of the mixtures and also to form uniform paste. The samples were then damp-cured for 28 days prior to testing, as reported by Ajayi and Olufemi [7]. Triplicate samples of the rectangular specimens were used for moisture content, density, 24-h water absorption and thickness swelling tests conducted in accordance with ISO standard [8]. In addition, triplicate samples of the circular specimens were used for thermal conductivity test. The rectangular and circular specimens are shown in Figure 3.

Figure 3. The composite test specimens.

For the thermal conductivity test, a specially designed apparatus was used. It consisted of a cylindrical container, an upper (hot) plate and a lower (cold) plate, all made of mild steel, a thermostat, voltage regulator and a digital temperature probe. The apparatus was calibrated using samples of known thermal conductivity values. The heat source was adjusted to maintain a temperature range of 61–64 °C. At the steady state condition, the temperature difference was recorded and used in calculating the thermal conductivity of the samples with the standard thermal conductivity equation. Impact energy is a measure of the work done to fracture a test specimen. Triplicate samples measuring 150 mm × 100 mm were evenly supported in rebated square frame and a long rod having a metallic hemispherical end was arranged to fall freely on to the center of the test specimen. The mass of the rod together with all associated falling parts was 3.5 kg. The rod was allowed to fall at different heights until failure of the test specimen occurred. The height of fall in meters causing failure for each specimen was recorded and the impact energy was calculated.

3. Results and Discussion

3.1. Moisture Content

The moisture contents of the different composite samples are shown in Figure 4. The values, ranging from 14.7% to 16.5%, exceeded the maximum moisture content of 12% specified in ISO [8] for cement-bonded composites, indicating a need for further drying. However, as would be expected, the control samples containing only sawdust and cement had the highest moisture content. This relatively high moisture content could be attributed to the water-retention propensity of the sawdust. The moisture contents of all the experimental samples containing plastic materials were about the same, but samples containing water sachet particles had the lowest moisture content.

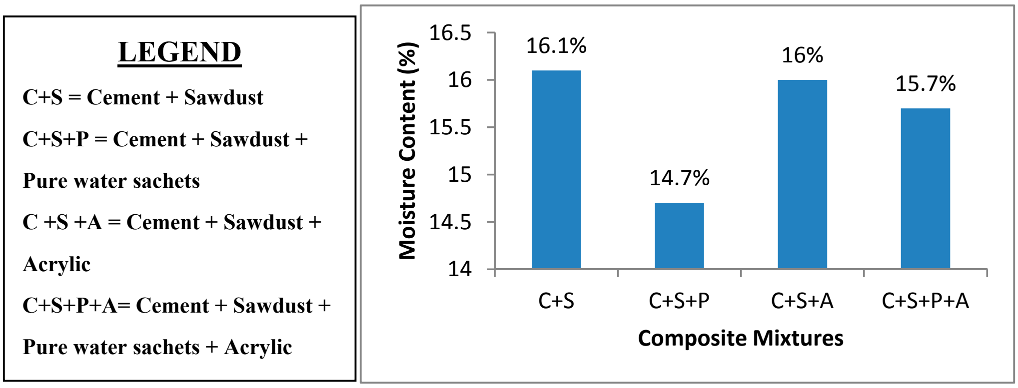

Figure 4. Moisture content of the composites.

3.2. Density

The densities of the composites are shown in Figure 5. The values, which ranged from 1.24 to 1.53 g/cm^3, exceeded the minimum value of 1 g/cm^3 specified for cement-bonded composites in ISO 8335 (1987). The addition of the plastic waste materials led to a general increase in the densities of the composites. One-way Analysis of Variance (ANOVA) showed that the observed differences in density values were significant at 95% confidence interval (Table 1). Incidentally, samples containing sawdust and water sachet particles that had the lowest moisture content also had the highest density, an indication that the particle density of the water sachet, a high density polymer, rather than the moisture content contributed materially to the density of the composites. It is expected, therefore, that incorporating plastic materials in the composites for the construction of rainwater tanks should enhance the strength and durability of the end product.

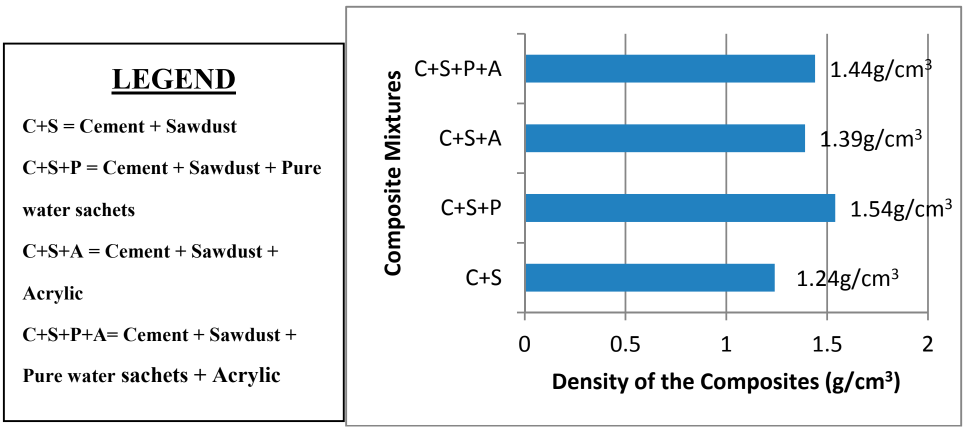

Figure 5. Density of the composites.

Table 1. One-way analysis of variance on the effects of composite material on product density.

Source of Variation	SS	df	MS	F	*p*-Value	F crit
Between Groups	0.138158	3	0.046053	12.30809	0.002291	4.066181
Within Groups	0.029933	8	0.003742			
Total	0.168092	11				

3.3. Water Absorption

The water absorption values presented in Figure 6 ranged from 2.9% to 8.8%. The ISO standard [8] has no specifications for water absorption. However, as would be expected, the control samples containing only sawdust and cement exhibited the highest water absorption due to the higher sawdust content. Water absorption in all the samples containing plastic materials was relatively low (below 6%), a good indication of the suitability of the materials for the construction of rainwater storage tanks. The samples containing sawdust and water sachet particles which had the lowest moisture content and the highest density also exhibited the lowest water absorption. This shows that the density of the composites was a major determinant of water absorption. In addition, the hydrophilic sawdust must have been encapsulated by the hydrophobic plastic material, hence reducing the rate and level of water absorption. These findings are in conformity with earlier reports [9–11] on wood–plastic composites. As noted by Olorunnisola [12], the presence of inordinate amount of water in cement-bonded wood composites could result in cracking (associated with swelling and shrinkable phenomena), biodegradation of the wood aggregates and the dissolution of the composites. Hence, addition of plastic materials in composites for water storage tank production should help address these issues.

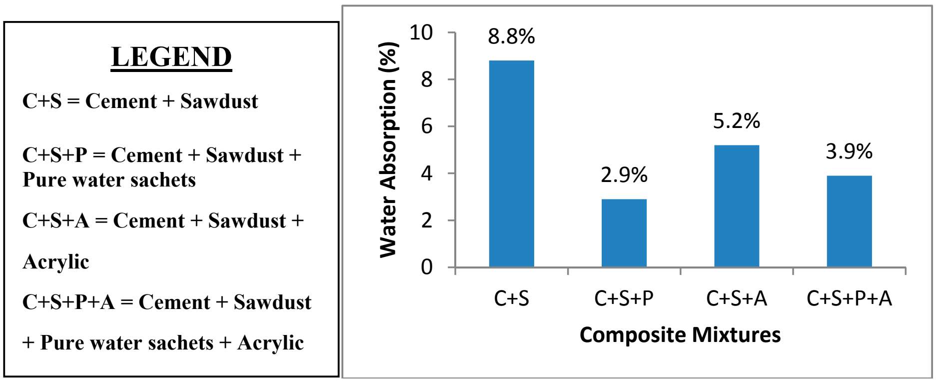

Figure 6. Water absorption of the composites.

3.4. Thickness Swelling

The thickness swelling of the different composite specimens ranged from 2.1% to 3.0% (Figure 7). Again, the control samples containing only sawdust and cement exhibited the highest thickness swelling. Only the samples containing water sachet particles exhibited the thickness swelling of about 2% in conformity with the stipulation of ISO standard [8]. The thickness swelling of each of the other samples containing plastic materials was less than 2.5%. One-way ANOVA (Table 2) confirmed that the observed differences in thickness swelling values were not significant at 95% confidence interval. Nevertheless, the slight reduction in thickness swelling to almost acceptable standardized levels is an indication than the plastic materials improved the dimensional stability of the composite samples and would ensure the dimensional stability of water storage tanks fabricated from them. The wood fibers might have been restrained by the plastic particles from swelling as elaborated by Aina et al. [10] and Behzad [13] who reported similar observations in wood–plastic composites.

Table 2. One-way analysis of variance on the effects of composite material on thickness swelling.

Source of Variation	SS	df	MS	F	*p*-Value	F crit
Between Groups	1.313333	3	0.437778	3.525727	0.068427	4.066181
Within Groups	0.993333	8	0.124167			
Total	2.306667	11				

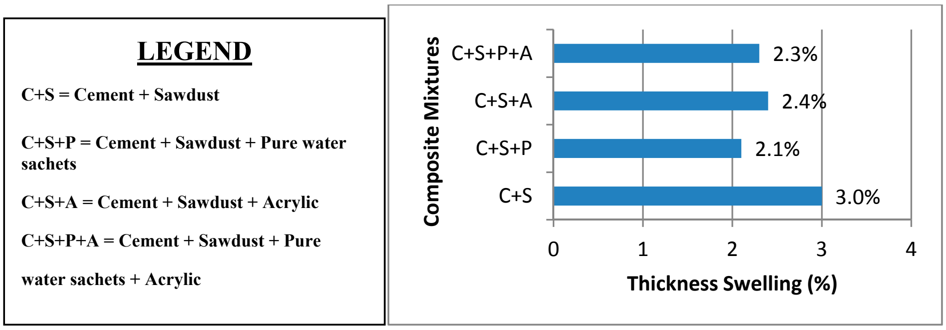

Figure 7. Thickness swelling of the composites.

As shown in Figures 8 and 9, there was a strong and positive linear correlation between the water absorption and the thickness swelling of the composites as well as a strong and negative non-linear correlation between the density of the composites and thickness swelling suggesting that the degree of compaction which directly contributes to water absorption of the composite had effects on their thickness swelling.

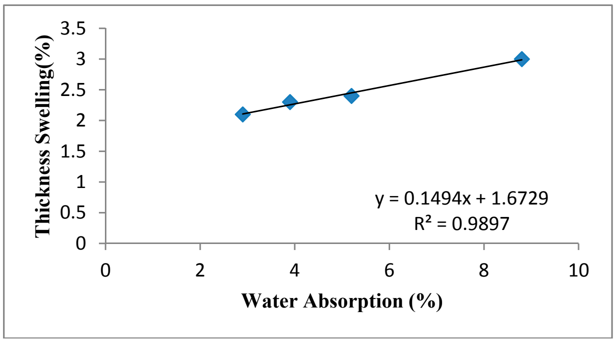

Figure 8. Correlation between water absorption and thickness swelling.

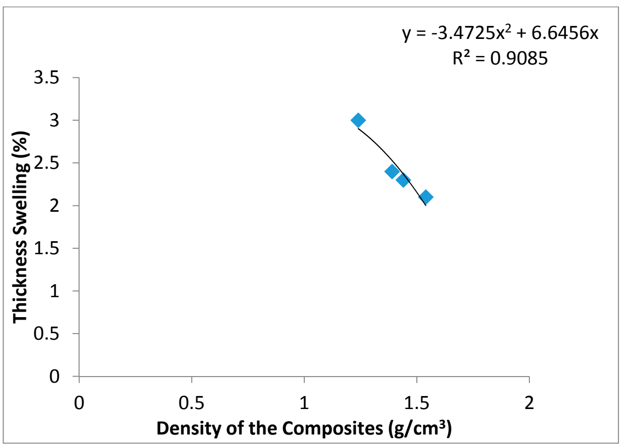

Figure 9. Correlation between density and thickness swelling.

3.5. Thermal Conductivity

The thermal conductivity values, presented in Figure 10, ranged from 0.044 to 0.051 W/mK. The values are lower than 0.125 W/mK as expected for a typical cement-bonded particleboard. There was a strong and positive linear correlation between the density and the thermal conductivity of the composites (Figure 11). The major advantage of the relatively low thermal conductivity the composites is the possibility of maintaining the coolness of rainwater to be stored in tanks fabricated with the materials.

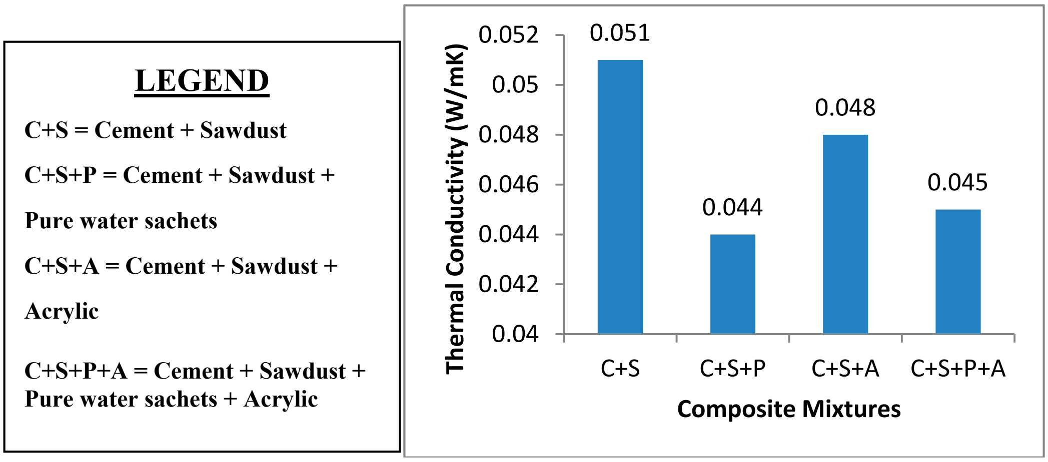

Figure 10. Thermal conductivities of the composites.

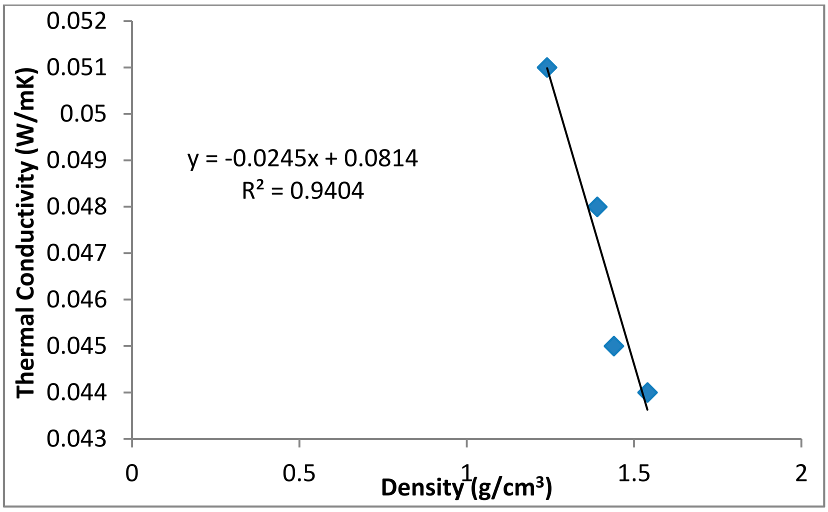

Figure 11. Correlation between density and thermal conductivity of the composites.

3.6. Impact Energy

As shown in Figure 12, the impact energy of the composites ranged from 0.043 to 0.053 J. Composite samples produced with a combination of cement, sawdust, water sachet and acrylic plastic particles exhibited the highest impact energy absorption capacity. However, the observed differences in impact energy were not significant ($p < 0.05$). This implies that it does not matter whether any of the two plastic materials is incorporated in the sawdust–cement composite. Since ISO standard [8] has no specifications for the minimum impact energy absorption capacity of cement-bonded composites, it was not possible to calibrate this parameter for the composite materials.

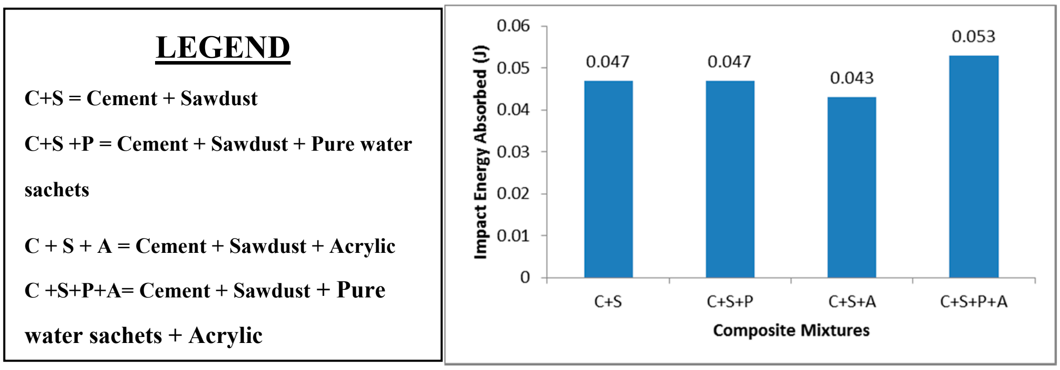

Figure 12. Impact energy of the composites.

4. Conclusions

Cement-bonded composites were produced from a mixture (at different ratios) of sawdust, disused plastic water sachets and acrylic waste and characterized for potential use in rainwater storage. Based on the results obtained, the feasibility of producing functional and durable water storage tanks from the recycled materials was established. Incorporating plastic materials, i.e., water sachet and acrylic plastic waste particles in the composites enhanced product strength and durability. These materials are, therefore, considered to be beneficial in cement-bonded composite rainwater storage tank construction.

Author Contributions: The first author, A.C.A. conducted the study reported in this article as part of her Master's degree programme and contributed to manuscript preparation. The corresponding author, A.O.O., conceived the research idea and supervised the study. He also contributed significantly to the preparation and revision of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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