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Production of composite bricks from sawdust using Portland cement as a binder

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Abstract

A study was conducted between October 2004 and April 2005 in Kampala District, with the objective of investigating the feasibility of making sawdust-cement composites using saw dust. A total of 48 bricks were made in the Faculty of Forestry and Nature Conservation laboratory based on volume ratios of sawdust to cement (3:2 and 2:1). Mass was measured using a weighing balance and density calculated from mass and volume of the bricks. The composites were tested for compressive strength using a universal testing machine, as they cracked due to compression. The mean compressive strength values were 1.61 N mm^{-2} and 1.986 N mm^{-2} for 50 x 50 x 50 mm composites with sawdust to cement ratios of 3:2 and 2:1 respectively; and 1.778 N mm^{-2} and 2.21N mm^{-2} for 100x100x100mm composites with sawdust to cement ratios of 3:2 and 2:1 respectively. Analysis of variance (ANOVA) indicated significant differences (P<0.05) in strength values of the two compositions. Soaked composites swelled irrespective of the cement to sawdust ratio. The compressive strength for the soaked bricks was approximately 40% of the dry weight strength. The composite bricks were found to be unfit for paving and medium heavy load wall construction. Due to their light weight, by imparting decorative mosaics they can be used for interior wall paneling and decoration, where minimal wetting is experienced.

Introduction

The wood utilisation industry in Uganda is characterised by poor harvesting and processing methods, limited value addition and high wastage (Kambugu, *et al*, 2005*)*. There are currently 130 sawmills operating in Uganda with installed capacities of about 3,000 m^3 of logs per year (Forest Department, 2002). Most of them are the small mobile circular or band saw type with an average recovery of 45% (Jacovelli and Carvalho, 1999). Thus over 50% of the round wood processed is wasted as sawdust, slabs and off cuts. These wastes seldom have commercial use.

Sawdust is one of the major underutilized by-products from sawmilling operations in Uganda (Plate 1). The wood loss in Uganda in the form of sawdust is estimated to be 18-20 % of the log volume (Ministry of Water Lands, and Environment, 2002). According to some timber dealers in Kampala suburbs, by December 2005, one cubic meter of Pine timber cost about Uganda shillings 430,000. This implies that on average about Uganda shillings 77,400 was lost per cubic meter in the form of saw dust. The underlying reasons for the inefficiency and waste in the saw milling industry included the use of inappropriate processing technologies,

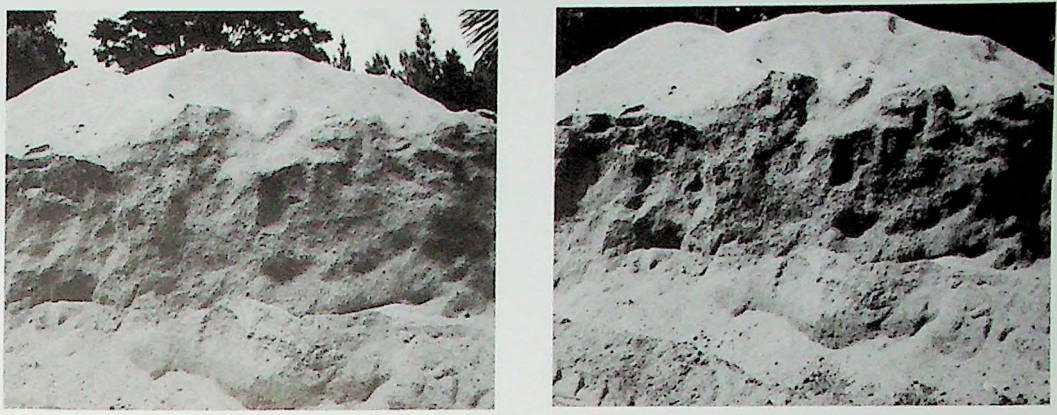


Plate 1: Heaps of unutilized sawdust at Nyabyeya Forestry College

poor maintenance of sawmill machinery, poor management and lack of proper technical skills by the sawmill operators (Kambugu, 2004).

Lack of information on appropriate equipment required to process the small, poor quality plantation logs, has forced entrepreneurs to import a wide range of mobile sawmill machinery, which include rolling-table sawmills, band sawmills, and dimensional swivel sawmills. Most of the sawmill machinery imported is suitable for processing large hardwood logs as opposed to the small softwood plantation logs (Carvalho and Pickles, 1994; Jacovelli and Carvalho, 1999). These saw mills use thick saw blades that cut wood with a wide kerf thereby producing large quantities of sawdust (Plate 1). In addition, there are several types of small mobile sawmills that have been fabricated locally without considering their sawing efficiency.

Kambugu *et al.* (2005) studied the relative efficiency of the different sawmill types operating in the softwood plantations of Uganda and generated information to guide entrepreneurs to make rational choice for saw milling equipment, ensure efficient processing of wood and minimize waste. The authors noted that band sawmills exhibited the most efficient sawmill technology for converting logs into sawn timber. Even if the findings were to be fully implemented, wood waste in form of saw dust would not be totally eliminated. Therefore, finding an appropriate use of sawdust would help to offset production costs and increase the profitability of sawmilling operations in Uganda's plantation forests.

Portland cement is commonly used in the manufacture of panel products as a binder. Wood to cement ratio, shape and size of the wood particles affect the strength and suitability of the composites (Sorfa 1984; Wolfe and Gjinolli, 1999). Dinwoodie and Paxton (1989) observed that cement wood particle composites consisting of 20% wood by weight in which the wood was in the form of flakes of 10 to 30 mm long and 0.2 to 0.3 mm thick had densities ranging between 1,200 to 1,300 kg m^{-3} and bending strength from 10.1 to 12.9 N mm^{-2}. The proportion of wood had little effect on the bending strength of cement bonded composites (Dinwoodie and Paxton (1991; Blankenhor, 1994). Results from a pilot study conducted by Wolfe and Gjinolli (1996) to characterize mechanical properties of cement-bonded wood composites showed that they have the potential for structural applications. It was noted that despite their relatively low strength compared to other structural materials, composites can have sufficient strength and bending resistance to serve as in-fill wall panels and offer enhanced resistance to a range of threats to wood and wood-based composites including rot, borers, termites and fire (Stahl, *et al.* 2002).

The high dimensional stability exhibited in cement bonded boards is because the wood particles are encased in a cement matrix and are restricted in hydro-expansion (Hachmi, *et al*, 1990; Yaguang Zhou and Kamdem, 2002). However, many wood species posses a number of organic components, which have deleterious effects on the wood-cement bond. Stahl *et al.* (2002) noted that this inhibitory effect appears to be more pronounced in hard wood than softwood due to the existence of a high percentage of extractives that inhibit cement setting. Cement wood particle-boards have been found to be good substitutes for hollow concrete blocks, plywood, particleboard and other resin bonded boards. It is a very versatile material that can be used as eaves, exterior wall, ceiling, partition wall, flooring, cladding and even roofing provided that proper coating is applied and wire meshes imbedded to enhance the interlocking capacity especially for longer spans. In an attempt to address the above problem a study was carried out to investigate the possibility of making composite bricks from saw dust using cement. The specific objectives were (1) to make composite bricks using varying sawdust to cement ratios; and (2) determine the density, mass and compressive strength of the composites. The study also contributes to the achievement of the Uganda Forest Policy's objective of reducing wastage and inefficiency in the wood processing industries and improving the environment.

Materials and Methods

Portland cement was mixed with sawdust from plantation grown *Pinus caribea* of 22 to 25 years old at the Faculty of Forestry and Nature Conservation laboratory. The sawdust particles were between 2.5-3.5 mm in diameter. Prior to brick formation, particles were soaked in water for 24 hours to reduce the amount of water-soluble sugars and tannins in accordance with (Pablo, 1989) and were finally air-dried to approximately 5% moisture content. Wood particles were mixed with cement (sawdust to cement ratio of 3:2 and 2:1) by volume with no other additives. This was intended to ascertain the effect of cement composition on the composite strength. The ratios of sawdust to cement used were based on literature, economic considerations and permissible impact strength ascertained using the dropping method, where preliminary trial specimens of varying compositions of sawdust and cement were made, dried and dropped from waist height (approximately 1 m) to assess their structural integrity. The mixtures were placed in a forming mould and pressed to provide the required compaction within 5 minutes. Preparation of specimens for testing strength properties was based on (ASTM D 198-1992) procedure (ASTM, 1979; Gong, *et al.*, 1993).

The bricks were made in batches of two dimensions; 100 mm x 100 mm x 100 mm large and 50 mm x 50 mm x 50 mm small according to the required tests (Plate 2). Batch 1 had sawdust : cement = 2:1 while batch 2 had sawdust : cement = 3:2.The specimens were cured under shade at room temperature for seven days in the mould and for another 28 days after removal from the mould for complete setting of the cement before testing.

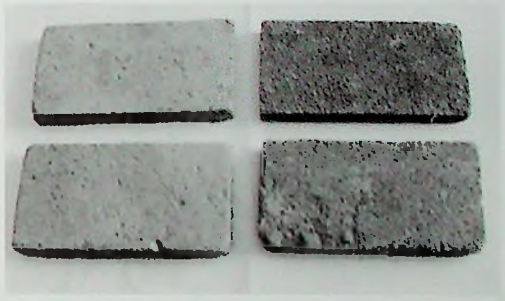


Plate 2: Sawdust-cement composites bricks

Volume of the bricks was estimated from the nominal dimensions of the sample batches whereas the mass was determined using a weighing scale. Density of the bricks was calculated from mass and volume of the bricks i.e. mass per unit volume. Twelve pieces of either dimension were tested for their compressive strength in the air-dry condition, by applying a gradually increasing load, to ascertain their suitability for indoor use and another 12 tested in wet condition to determine their suitability for

out-door use. The pieces were soaked in water at 20 ± 5°C for 24 hours and tested for compressive strength immediately upon removal from the water to examine the structural integrity of the composites in damp conditions. The tests were carried out using a universal-testing machine, in the Structures Testing Laboratory at the Faculty of Technology Makerere University, with attention focused on the maximum load causing failure (Plate 3 and 4). The test procedures used were based on the American Standards of Testing Materials (ASTM) D 1037-78(11) (ASTM, 1996). The test pieces were placed between a supporting base and a flat steel plate above it, onto which a plunger that applied a compressive load rested. The machine applied a uniform load and the specimen failed after 1.5±0.5 minutes. The maximum load (in Newtons) was recorded per test specimen and the compressive stress was calculated as Force per unit area.

Data Analysis

Minitab program (Version 13) was used to analyse the compressive strength and basic density data. Analysis of variance (ANOVA) was used to show the variation in compressive strength, density and weight in relation to sawdust to cement ratios and varying levels of moisture content. All statistical tests were carried out at 95% confidence level.

Results and Discussion

Density and Weight

Table 1 gives the pooled mean weight and density of the two sample batches of composites. The overall mean weights and densities of the test bricks were 703 g and 909 g and 0.7g cm^{-3} and 0.91 g cm^{-3} for bricks of 100 x 100 x 100 mm and sawdust to cement ratio 3:2 and 2:1 respectively (Table 1). Bricks of 50 x 50 x 50 mm had mean weights of 85 g and 108 g and densities 0.68 g cm^{-3} and 0.86 g cm^{-3} for sawdust to cement ratio of 3:2 and 2:1 respectively.

Table 1: Mean Weight and Density of the Bricks

			Treatment	
Wood:Cement Ratios	**3:2**	**2:1**		
Size[1]	Large	Small	Large	Small
Mean weight (g)	703	85	909	108
Mean density (g/cm^3)	0.703	0.64	0.91	0.86

Table 2 : Compression strength (N/mm^{-2}) by Cement and Sawdust ratios and test conditions (Dry Wet)

Sawdust: Cement Ratio	**3:2**	**2:1**		
Test Condition	Dry	Wet	Dry	Wet
Small	1.61± 0.024	0.983± 0.0378	1.986± 0.0273	1.22± 0.0483
Large	1.778 ± 0.045	0.994 ± 0.286	2.21 ± 0.043	1.378 ± 0.057

[1] Specimen dimensions. Large = 100 x 100 x 100mm, Small = 50 x 50 x 50 mm

Compression Strength

The strength properties were not comparable to those of normal concrete, but to that of *Pinus caribaea* used in making the composites. The strength of the composites were three fold less than normal wood. According to Gong *et al.* (1993) the compression strength values required for materials to be used as pavements range from 20 - 25 N mm^{-2} while that for beams ranges from 20-35 N mm^{-2} and up to 65 N mm^{-2} for reinforced concrete depending on the expected loads.

Density depended on the sawdust:cement ratio which explains the trend of increasing compressive strength and density in both batches (Table 2). Generally, the compression strength was greater in specimens of higher sawdust: cement ratio 2:1 and strength increased with density of the bricks (Table 2). At high-density indices, a material is more compact in lattice structure (Wolfe and Gjinolli, 1999). Analysis of Variance (ANOVA), showed significant differences ($P<0.05$) in strength properties between the two cement to wood batches. This implies that the greater the proportion of cement in the composite, the stronger it would be. The strength values for wet and dry samples were also significantly different ($P<0.05$). The strength of the bricks reduced due to wetting by up to 40% of dry strength (Table 2). This was an indication that the structural integrity of the composites was adversely affected by dampness and are consequently not suitable for out-door use. Probably the mechanical properties and dimensional stability of composites can be improved with increasing amounts of the additives as reported by Wei and Tomita (2000).

Premature failure of the composites due to compression indicated that the sawdust:cement matrix exhibited plasticity properties to some extent. The compressive strength values of the composites were far much lower than those of concrete bricks, meaning they are not fit for construction. The strength values were instead comparable to those of *Pinus caribaea* which was one of the materials used in the study. The compression strength values of the composites were three fold less than that of normal pinewood. The composites can not therefore be perfect substitutes for wood and concrete bricks since their strength values are lower than those of concrete and wood. They can be used as in-fill wall panels since their strength is probably suitable for such applications. The low strength was probably due to the particle geometry. Wolfe and Gjinolli (1999) observed that fine saw dust results in poor strength while slender particles give better strength properties.

There was a significant decrease in compression strength values, when the specimens were exposed to wet conditions. On soaking it was noted that swelling was considerable in all composites irrespective of the cement to sawdust ratio, an indication of dimensional instability in damp conditions. This implies that the composite bricks are not fit for use as pavement materials, especially that their strength is affected by dampness. Composites are suitable for interior wall paneling and interior decoration where no wetting occurs. There is a need for a detailed investigation into the possibility of reinforcing the composites with a wire mesh to improve their compressive strength especially for wide

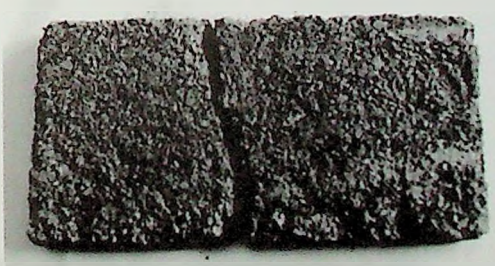


Plate 3: Failure mode in brick with sawdust:cement ratio of 2:1



Plate 4: Failure mode in brick with sawdust:cement ratio of 2:1

spans. The suitability of the sawdust:cement composites for various structural applications need to be studied. Modulus of elasticity (MOE) and modulus of rupture (MOR), static hardness and shear strength need to be established before composites can be utilized for construction.

Conclusions and Recommendations

The composite bricks did not qualify for use as high strength external construction materials since their strength is considerably low and their structural integrity is affected by damp conditions. The use of wood/cement composite bricks can reduce overall weight of the construction, since their densities and weights are generally low. By imparting decorative mosaics, the composite bricks can be used for interior wall paneling and decoration, where minimal wetting is experienced since they are light. The possibility of using the composites as ceiling and decorative materials should be studied. There is a need to study other strength properties of sawdust:cement composites such as bending strength (MOE and MOR), static hardness and shear strength prior to use in construction before concrete recommendations can be made regarding their appropriate use. There is a need for research into the possibilities of reinforcing sawdust:cement composites to improve the strength of wide spans. The mechanical properties and dimensional stability of cement-bonded board should be improved with increasing amounts of additives.

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