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Full Length Research Paper

Durability based suitability of bagasse-cement composite for roofing sheets

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Accelerated and natural weathering of bagasse reinforced cement composite filled with rice ash pozollan used as roofing sheets were studied. In this paper, the durability of natural fibers such as sugarcane bagasse used as roofing sheets has been reported by conducting an experimental investigation. This investigation includes determination of mechanical strength properties such as compressive, tensile, modulus of rupture and flexural properties of the roof once every 3 months for a period of 8 years under alternate wetting and drying conditions and was exposed to ultraviolet light for the same period. The 8 years study showed no significant difference in the strength and sorption properties for the treated bagasse at 2% $CaCl_2$ and the 20% replacement of cement with rice husk ash. This confirms that treated bagasse cement composite is suitable for both external and internal construction purposes.

Key words: Bagasse, durability, weathering, pozollan and roofing sheets.

INTRODUCTION

Natural fibers are prospective reinforcing materials and their use until now has been more traditional than technical. They have long served many useful purposes, but the application of materials technology for the utilization of natural fibers as the reinforcement in concrete has only taken place in comparatively recent years. The distinctive properties of natural fiber reinforced concretes are of improved tensile and bending strength, greater ductility, and greater resistance to cracking and hence improved impact strength and toughness. Besides its ability to sustain loads, natural fiber reinforced concrete is also required to be durable.

Durability of vegetable fiber reinforced concrete is related to the ability to resist both external (temperature and humidity variations, sulfate or chloride attack etc) and internal damage (compatibility between fibers and cement matrix, volumetric changes etc). The degradation of natural fibers immersed in Portland cement is due to the high alkaline environment which dissolves the lignin and hemi-cellulose phases thus weakening the fiber structure (Silva and Rodrigues, 2007). Gram and Skarendahl (1978) was the first author to study the durability of sisal and coir fiber reinforced concrete. The fiber degradation was evaluated by exposing them to alkaline solutions and then measuring the variations in tensile strength. This author reported a deleterious effect of Ca^{2+} elements on fiber degradation. He also stated that fibers were able to preserve their flexibility and strength in areas with carbonated concrete with a pH of 9 or less. Toledo Filho et al. (2000) also investigated the durability of sisal and coconut fibers when immersed in alkaline solutions. Sisal and coconut fibers conditioned in a sodium hydroxide solution retained respectively 72, 7 and 60.9% of their initial strength after 420 days. As for the immersion of the fibers in a calcium hydroxide solution, it was noticed that original strength was completely lost after 300 days. According to those authors the explanation for the higher attack by $Ca(OH)_2$ can be related to a crystallization of lime in the fibers pores.

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Ramakrishna and Sundararajan (2005) also reported degradation of natural fiber when exposed to alkaline medium. Other authors studied date palm reinforced concrete reporting low durability performance which is related to fiber degradation when immersed in alkaline solutions (Kriker et al., 2008). Ghavami (2005) reported the case of a bamboo reinforced concrete beam with 15 years old and without deterioration signs. Lima et al. (2008) studied the variations of tensile strength and modulus of elasticity of bamboo fiber reinforced concrete expose to wetting and drying cycles, reporting insignificant changes, thus confirming its durability.

Ismail (2007) worked on the compressive and tensile strength of natural fiber-reinforced cement based composites and the results showed that the tensile strength of composite increases, this increase in strength is about 53% while the compressive strength decreases as the fiber volume fraction is increased. It has been observed that composites with roselle particle reinforcement showed more tensile strength which was followed by short fiber and long fiber reinforced composites and compressive strength of urea-formaldehyde resin matrix has been found to increase when reinforced with fiber. It was found that with particle reinforcement, compressive strength increases to a much more extent than short and long fiber reinforcement (Singha and Thakur, 2008).

Compressive properties results for alkaline pre-treatment done on banana fibers shows that fiber treatment is favourable for epoxy matrix composites but not favourable in the case of polyester composite matrix. The flexural strength of the banana fiber composite was found to be higher than the banana fiber alone and the higher the flexural strength and modulus of elasticity observed in the banana fiber composite, the more fiber interaction takes place (Lina-Herrera et al., 2006).

Fiber length has profound impact on the properties of composites. Besides holding the fibers together, the matrix has the important function of transferring applied load to the fibers. The efficiency of a fiber reinforced composite depends on the fiber-matrix interface and the ability to transfer stress from the matrix to the fiber (Karnani et al*.,* 1997).

Extensive research has been conducted on the use of some of the natural fibers for cement particle board (CPB) production. The research, however, is limited to sorption and strength characteristics of boards at early age of about 28 days. This work examines the effects of production variables on the hydration of the fibers mixed with Portland cement. The work also compares and contrasts the functions and performance of these fibers. If these materials are suitable, the work can lead to production of a wide range of CPB with different durability properties and with diverse levels of long-term performance under internal and external exposure conditions. The work may provide economic and environmental benefits to local communities in West Africa.

MATERIALS AND METHODS

Experimental study

Mix and specimen casting

Materials used in the production of roofing sheets were bagasse, ordinary Portland cement, aggregates (sharp and soft sand), potable water, calcium chloride and pozzolans. Bagasse was obtained from Bodija in Ibadan, Oyo State as shown in Figure 1. The raw bagasse was received at about 30% moisture content. It was sun-dried for two weeks, manually depithed and further sun-dried for two weeks to a moisture content range of 7 to 10%. Part of the sun-dried bagasse was manually shredded to generate flakes while the rest was hammer-milled to produce bagasse particles as shown in Figure 2. Bagasse flakes were divided into three groups: short flakes (2.4 to 20 mm long), medium flakes (21 to 30 mm long) and long flakes (31 to 76 mm). The hammer-milled particles were passed through sieves of sizes 2.4 mm, 850 and 600 μm. Particles that passed through 2.4 mm but were retained on the 850 μm sieve were categorized as coarse particles while those that passed through 850 μm and were retained on the 600 μm sieve were classified as fine particles.

Bagasse moisture content was determined by the oven drying method using a representative small sample. The oven drying moisture content of the bagasse was determined at temperature of 103 ± 2°C in accordance with the ASTM D 1037 (1991) using three replicates.

Calcium chloride ($CaCl_2$) was obtained from the chemical laboratories at Ibadan as a cement accelerator. $CaCl_2$ was used in preference to other accelerators because it is cheaper and more effective (Li et al., 1997).

Ordinary Portland cement was procured from the local market in Ibadan, Oyo State. The cement meets the specifications of the British Standards for ordinary Portland cement BS 12 (1991). It was stored in air-tight containers and was used up soon after delivery to prevent strength deterioration.

Water source was from the University of Ibadan supply. The quantity of water required for the manufacture of the roofing sheets was determined using the relationship applied by researchers such as Fuwape (1995) and Sudin and Swamy (2000).

$$R_q = 0.35C + (0.30 - M)W \quad (1)$$

Where
R_q = water required (litres)
C = weight of cement (kg)
M = percentage moisture content of Bagasse on dry basis
W = oven-dry weight of the Bagasse (kg)

Rice husk used as pozzolan was obtained from rice processors in Erio Ekiti, Ekiti State, Nigeria while ashing of rice husk was done by both open air burning which involved the setting ablaze of the rice husk inside an open metal container and burning was supported by the use of kerosene while gently stirring the contents, this was later transferred to a furnace at 760°C. Sharp sand was obtained from the river flowing through the Nnamdi Azikiwe Hall while soft sand was obtained from a construction site at the Faculty of Technology both at the University of Ibadan. The sand was washed and dried to reduce the soluble matter and fine particle contents.

Two water/cement ratios (0.4 and 0.5) and three sand/cement ratios (1.0, 2.0 and 3.0) were investigated. The factorial

Figure 1. Unprocessed Bagasse

Figure 2. Processed Bagasse.

combination of the sand and water ratios gave a total of six treatments and three replications of each treatment were produced making a total of 18 samples. Bagasse contents were varied from 1 to 4% by mass of cement to determine the influence of bagasse mass fractions on the properties of roofing sheets. The factorial combination gave a total of 15 treatments with three replications.

Roofing sheet production processes involved blending together of cement, sand, water, $CaCl_2$ and bagasse (flakes and particles). These constituent materials were batched in proportions determined in experimental design depicted by the flow chart of Figure 3.

Measured quantities of cement and sand were dry-mixed until a high level of uniformity was achieved. The water was slowly added while mixing was continued for about 10 min until uniform consistency and colour were achieved. Bagasse was added at the end of mixing cycle to minimize damage. The roofing sheets were produced by vibration. The sand/cement/bagasse slurry was then placed on a polythene sheet spread on the surface of the moulding table and vibrated for about 40 s to ensure adequate consolidation and compaction with removal of void spaces (Dahunsi, 2000). The mixture was then transferred onto a corrugated plastic mould, covered with wet cloth, placed in a cool dry place for 24 h and then de-moulded. The specimens were subsequently cured in water for 28 days.

Testing

Compression tests

Figure 4 shows compression test in progress. An increasing compressive load at a rate of 1 mm/min was applied until failure occurred. The tests were conducted at 3, 7, and 28 days after curing.

Flexural test

The flexural test was carried out in accordance to BS 5669 (1993). The testing was carried out for 3, 7, 14 and 28 days after curing. Three replicates of each were tested. Flexural strength was determined in accordance with ASTM C 78 - 91 (1991). Three specimens (250 mm × 75 mm × 25 mm) were tested for each mixture, and the average strength reported.

Breaking strength test

Breaking Load/Strength: This test method consisted of supporting the sheet specimens on the ends of three cylindrical rods, arranged in an equilateral triangle form and applying load until the sheet specimen failed. The sheet strength was the load necessary to cause such roofing sheet failure. The roofing sheet strength recorded was based on average values of 3 replicates of the same composition mixes.

Impact strength test

The roofing sheets were tested for impact strength according to ASTM D 1037 (1991). The test was carried out at Forest Research Institute of Nigeria (FRIN) in Ibadan. Each test piece was cut into 300 mm × 300 mm × 6 mm and evenly supported in rebated square frame without fastenings.

Porosity test

Porosity was determined on 75 mm × 75 mm × 25 mm specimens using the method of vacuum saturation. The specimens were dried in the oven at 105 ± 3°C until no change in measured weight was observed. The specimens were kept dry in a vacuum chamber for 3 h before water was introduced to the chamber under vacuum. The vacuum was maintained for 6 more hours after which time the specimens were left in water for 18 h. The saturated surface dried weight was then determined. For the fiber reinforced specimens, the water absorbed by the fiber was accounted for in the vacuum saturated weight so as to obtain the effective porosity. Porosity of a plain (control) mortar was also determined for comparison.

Durability tests

Durability tests conducted included long term exposure to natural weathering, accelerated and grave-yard tests.

Long term exposure test: A building of area 1.83 × 1.83 m^2 (6ft × 6ft) was erected behind the Department of Agricultural and Environmental Engineering, University of Ibadan on the 5th of February 2007 to investigate the effects of natural weathering on the roofing sheets (Figure 13). The roofing sheets in Table 2 were installed by the use of specially designed nibs incorporated during the production (Table 3). Other samples were stored outdoors on rooftops. The properties of these roofing sheets were determined

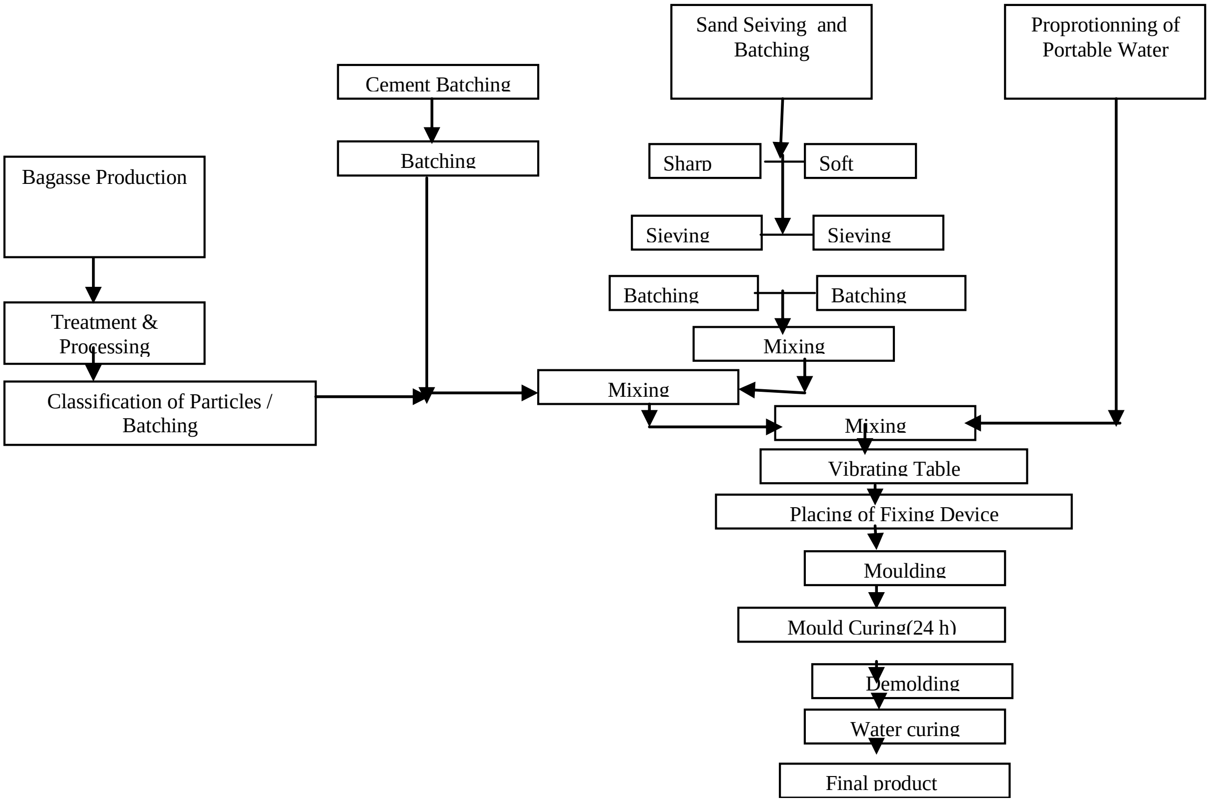

Figure 3. Flowchart of production process using randomly oriented flakes.

Figure 4. Compression test.

progressively over the duration of the experiment.

Hot water immersion test: The hot water immersion test method investigates the long term chemical interaction between the constituents in the composite. Wet conditions and elevated temperature were used to accelerate the deterioration. Specimens were saturated in water maintained at 60°C. The test procedure was in accordance with ASTM C 1185-91 with the specimen in hot water for 56 ± 2 days. Strength properties were evaluated at the end of the test duration and the result was compared to the control specimen.

Accelerated ageing test (Soak and Dry Cycles): Other specimens for each formulation were cured in the same way for 28 days of age and then they were submitted to the accelerated aging test (soak-dry cycles). This test consists of submerging the specimens into water for 18 h and after they were put into an oven at 60°C of temperature during the 6 h to complete 24 h. The aging test composed of 50 cycles and it was based on the methodology of the European Standards EN-494-98 section 7.3.5. After ageing, the samples were conditioned and tested for static bending, dimensional stability (thickness swelling and water absorption) and compression shear according to ASTM D – 1037 (1991).

Exposure cycling test for exterior use: This test was carried out to estimate the weathering qualities of roofing sheets under severe exposure conditions (.IS: 2380-1963). Each specimen was subjected to six complete cycles of accelerated ageing. Each cycle consisted of the following:

(i) Immersion in water at 49°C for 1 h.
(ii) Spraying with steam and water vapour at 93°C for 3 h.
(iii) Storing at -12°C for 20 h.
(iii) Heating in dry air at 99°C for 3 h.
(iv) Spraying again with steam and water vapour at 93°C for 3 h.
(v) Heating again in dry air at 99°C for 18 h.

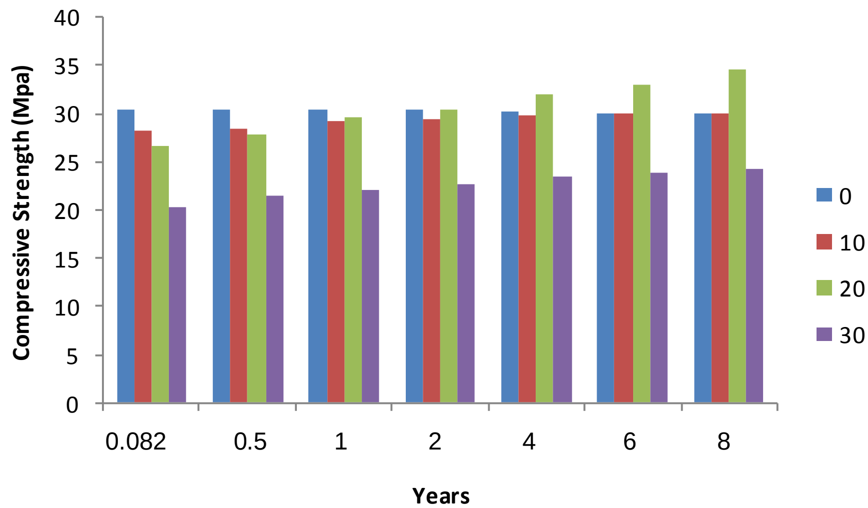

Figure 5. Eight years compressive strength of composites (0, 10, 20 and 30 are rice husk ash replacement levels).

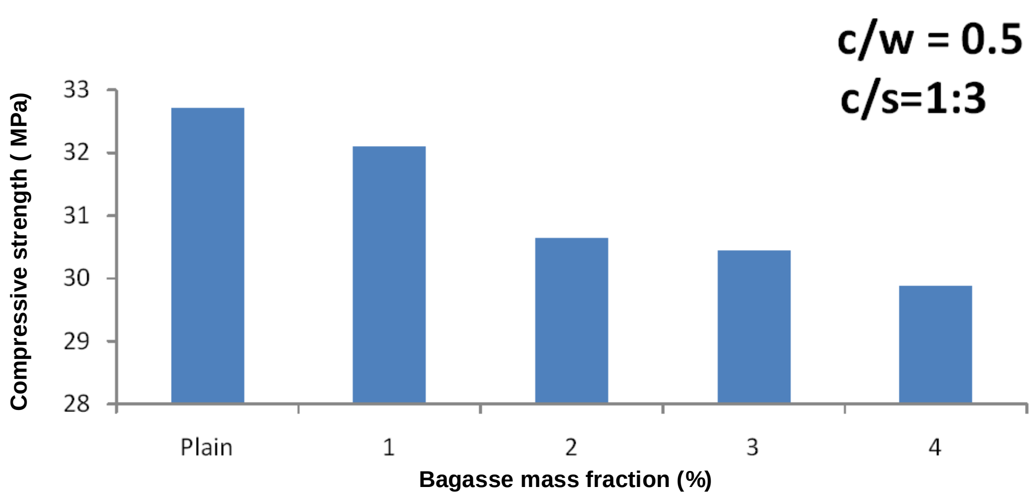

Figure 6. Comparison of 28-day compressive strength values of sheets with different bagasse contents.

After the completion of the six cycles of exposure, the material for test was further conditioned at a temperature of 27°C and relative humidity of 65% for at least 48 h before being subjected to tests such as water absorption, static bending, compression and flexural tests. Frequent inspections of the material were made during the ageing cycles for any signs of delamination or other disintegration.

RESULTS AND DISCUSSION

The compressive strength

Compressive strength decreased with the increase in the fiber contents. Highest compressive strength of 32.71 MPa was obtained for the plain concrete while the least value of 29.89 MPa was obtained at 4% bagasse contents as shown in Figures 5 and 6. The reduction in compressive strength due to increase in bagasse content could be attributed to the fact that the elastic modulus of bagasse is lower than that of the cement matrix. The study was conducted every six months for the 8 years study and it showed no significant difference in the compressive strength of samples treated with 2% $CaCl_2$ and the 20% replacement of cement with rice husk ash.

The flexural strength

Flexural strength was found to increase with fiber contents until an optimal fiber mass was reached and then the flexural strength decreased. The reason could be that, after curing and conditioning, there was an increased fiber-to-matrix bond, and the failure was

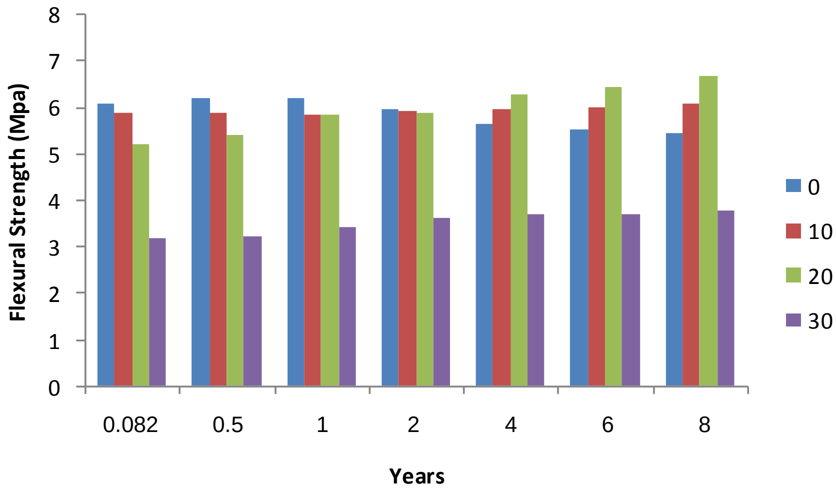

Figure 7. Eight years flexural strength.

Table 1. Impact strength of composites (%).

Percentage of fibers	Mass dropped (kg)	Height of failure (m)	Impact energy (mgh) Joules	Impact toughness KJ/m^2	Percentage improvement-over plain
0	4.5	0.03	1.32	1.47	0
1	4.5	0.05	2.21	2.46	67.42
2	4.5	0.08	3.53	3.92	167.42
3	4.5	0.10	4.41	4.9	234.1
4	4.5	0.08	3.53	3.92	167.42

Table 2. Graveyard test results for roofing sheets produced with pozolan.

Roofing sheets (Cement: Sand)	Percentage weight loss due to
50:50	16.1
60:40	14.8
70:30	14.2
80:20	12.9
90:10	12.9

Table 3. Porosity.

Percentage of bagasse	Porosity (%)
1	1.85
2	3.11
3	5.13
4	6.81
5	9.48

probably due to fiber fracture rather than fiber pull-out. The increase in the flexural strength was dominant up to 3% bagasse mass after which the influence of soft inclusion took place resulting in reduced flexural strengths at higher fiber mass. For samples incorporating bagasse particles, the trend was similar to that obtained for flakes, however for a given fiber mass, bagasse particles showed higher flexural strength. The reason could be that bagasse flakes because of larger surface area (larger aspect ratio) provided larger areas of preferential weakness in the matrix, resulting in a reduction in flexural strength. With increase in fiber mass beyond 3%, the flexural strength reduced and at about 4% fiber mass the flexural strength was essentially the same. At higher fiber mass, there were increased chances of fiber bailing, clumping, creating voids that led to the reduction of flexural strength. At 2% fiber contents over a period of 8 years, there was no significant difference in the flexural strength as shown in Figure 7.

Impact strength

All the bagasse reinforced composites had impact energy more than twice that of un-reinforced ones as shown in Table 1, Figures 8 and 9. At 1% bagasse content, the percentage improvement over plain sheets was 67.42%.

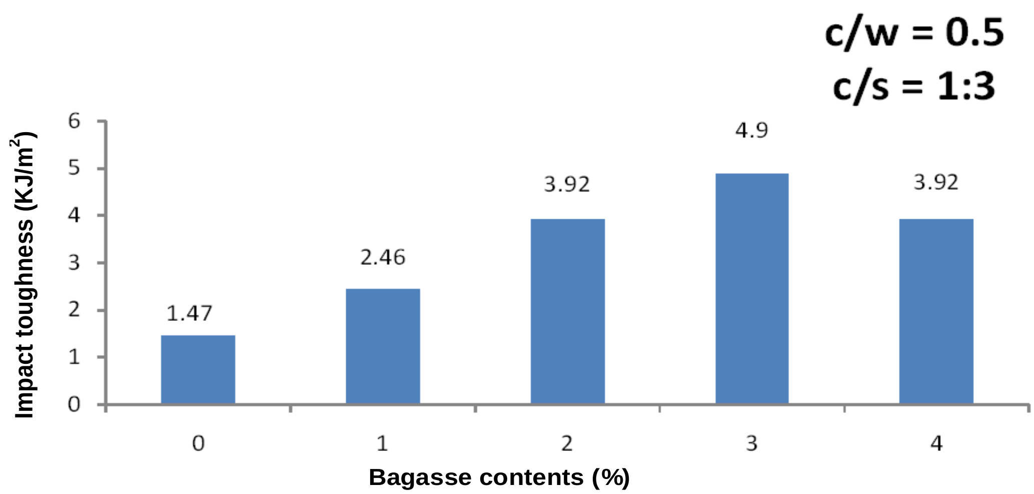

Figure 8. Impact strength test at different levels of bagasse content (%).

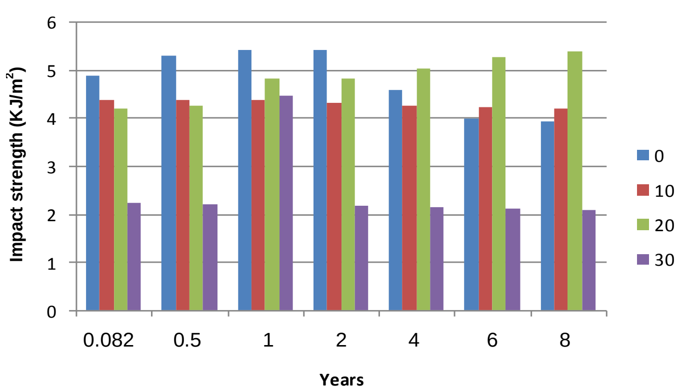

Figure 9. Eight years impact strength.

There was a progressive increase in the impact strength as the bagasse content increased until a maximum value was obtained at 3% bagasse content. The percentage improvement over plain mix at this bagasse content was 234.11%. When the bagasse contents exceeded 3% a decline in value was recorded probably due to bailing problems which contributed to lack of bonding between the matrix and the bagasse flakes.

The impact strength gives an indication of the resistance of a material to vibration or shock loading. It is also a measure of the work done in breaking a test piece (Dahunsi, 2000). The bagasse flakes in the matrix absorbed part of the shock loading on the composites, thereby reducing the load directly absorbed by the concrete. At the optimum impact energy (3% bagasse content), the reinforced mixes resisted up to four times the damage inflicted on the plain before reaching destruction. This improvement will be useful to the overall resistance of the roofing sheets to damage in storage, transportation and during installation and perhaps throughout the service life of the roofing sheet. However no marked difference was observed in the impact energy when the aspect ratios were varied by varying the lengths of the flakes (below 20 mm, 20 mm to 30 mm and above 30 mm) but at constant bagasse contents of 3%. The failure of the bagasse particles (below 20 mm) specimens took the form of complete fracture (chatter); while the long flakes (above 20 mm) specimens deformed with the flakes still holding the matrix together, The long flake is recommended to prevent complete shatter of the specimen during failure.

Accelerated ageing test results

The treated bagasse fibers offer both stiffness and strength to matrix after the initial cracking. The mechanical properties increased with increase in the fibers contents until the optimum value of 3% of bagasse fiber content. The mechanical results after 50 cycles of accelerated aging test as shown in Figure 10 showed that the formulations with higher percentage of bagasse contents were however more susceptible to the degradation after the ageing tests. This behaviour could probably be attributed to the degradation of bagasse fibers in cement matrix. Flexural toughness considerably deteriorated with ageing as shown in Figure 11. The flexural strength however increased with ageing. This was possibly due to the densification of the interfaces and petrification of bagasse flakes, thus improving the flexural strength and reducing the toughness of the roofing sheets. The flexural strength increased slightly and the toughness decreased considerably. The bagasse mass fraction also had drastic effect on the toughness reduction; the more the bagasse contents the more the toughness reduction due to accelerated wetting and drying. Values of the post cracking strength for the

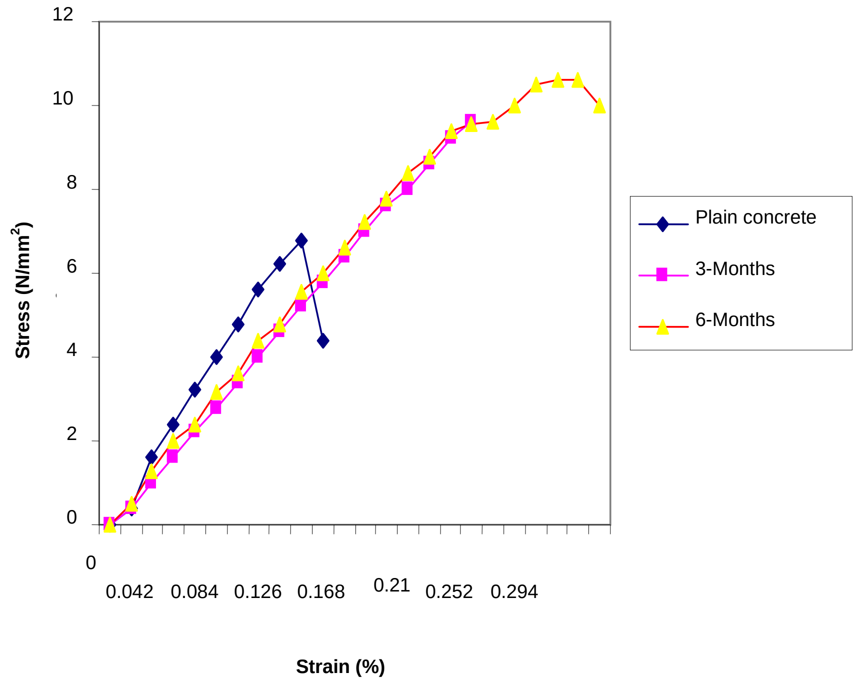

Figure 10. Effects of weathering on stress– strain behaviour of bagasse-cement roofing sheets.

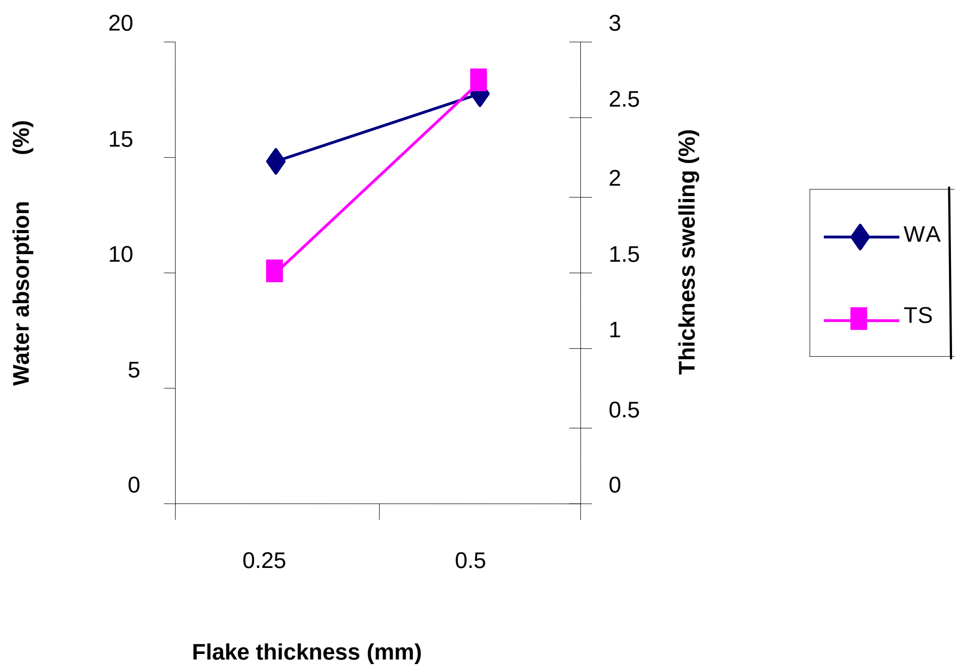

Figure 11. Influence of flake thickness on the water absorption and thickness swelling of the roofing sheets (with pozollan).

specimens aged outdoors reduced up to 30% probably due to embrittlement of the fibers in the cement matrix. This agreed with the past studies which have shown that the natural fibers are chemically decomposed in the alkaline environment of the cement matrix resulting in brittle composite which has reduced capacity to cracking. This led to the study of partial replacement of the OPC with rice husk ash as reported elsewhere in this report.

Figure 12. The roofing sheets.

Figure 13. Natural weathering test.

Performances of roofing sheets subjected to graveyard tests

The bagasse particles and flakes samples encased in concrete were observed to be safe from attack by termites. The matrix offered adequate protection for the bagasse samples. Bagasse particles and flakes that were not encased in cement matrix were completely destroyed by the termites at the end of the test period. It was observed that the performance of the samples subjected to graveyard test was independent of the treatment of the bagasse samples or flakes provided they were encased in cement matrix. However, roofing sheets produced with addition of pozzolan showed some effects of termite attack. The higher the proportion of pozzolan in the composite the more pronounced the termite attack. Figure 12 shows the result of termite attack which indicates that roofing sheets made with 50:50 cement pozzolan ratio had the highest effect of the termite attack with the mean of 16.21% while the least was obtained from the roofing sheets made cement to pozzolan ratio of 90:10. The use of pozzolan as a partial replacement for cement promotes the activities of termites when roofing sheets were exposed to termitarium the effects are however not significant.

Porosity

The increase in porosity with increasing bagasse mass can be explained by the fact that, bagasse particles in addition to being porous can absorb water. The high value of porosity with increase in bagasse content may be due to the tendency of the particles to clump together while mixing, entrapping water filled spaces, which consequently turn into voids. Increased bagasse mass enhances the potential for fibre bailing and clumping (Figure 13).

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APPENDIX

0% RHA	Years	Composite strength (Mpa)	Flexural strength (Mpa)	Composite strength (KJ/m^2)	Breaking strength (N)	Porosity (%)
0	0.083(28 days)	30.48	6.09	4.9	380	5.13
0	0.5	30.49	6.19	5.32	384	5.28
0	1	30.5	6.2	5.42	390	5.74
0	2	30.4	5.98	5.42	360	6.1
0	4	30.2	5.64	4.6	340	6.1
0	6	30.1	5.52	4	328	6.32
0	8	30	5.44	3.94	315	6.45
10 RHA						
10	0.083(28 days)	28.3	5.9	4.4	360	4.88
10	0.5	28.4	5.9	4.4	362	4.9
10	1	29.3	5.92	4.38	364	4.95
10	2	29.5	5.94	4.32	368	4.98
10	4	29.8	5.98	4.26	370	5
10	6	30	6	4.24	374	5.14
10	8	30.12	6.1	4.2	375	5.22
20 RHA						
20	0.083(28 days)	26.7	5.2	4.2	340	4.8
20	0.5	27.9	5.42	4.28	356	4.74
20	1	29.6	5.87	4.49	378	4.62
20	2	30.42	5.9	4.85	395	4.26
20	4	32.02	6.29	5.05	421	3.94
20	6	33.12	6.43	5.28	442	3.67
20	8	34.6	6.68	5.4	450	3.26
30 RHA						
30	0.083(28 days)	20.2	3.2	2.24	160	4.6
30	0.5	21.4	3.24	2.21	162	4.4
30	1	22	3.43	2.2	164	4.21
30	2	22.69	3.61	2.19	166	4.19
30	4	23.57	3.69	2.14	168	3.52
30	6	23.91	3.72	2.13	170	3.43
30	8	24.2	3.8	2.1	171	3