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ENGINEERING PROPERTIES OF ACRYLIC EMULSION POLYMER MODIFIED BAMBOO REINFORCED CEMENT BONDED COMPOSITES

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Abstract. In this study, bamboo fibres from *Bambusa Vulgaris* species were used as reinforcement materials for acrylic emulsion polymer modified concrete to determine their engineering properties and elemental compositions. Moisture absorption, density and percentage voids were investigated as well as the compressive strength, flexural strength and split tensile strength at 28, 45 and 60 days of air curing. Acrylic polymers reduced moisture intake, increased the densities and led to another increase in percentage of voids but composite samples with bamboo fibre inclusions at 1.5% and 10% polymers with 1.5% fibre an 15% polymers showed better physical properties than those with polymers only. Compressive and split tensile strength tests had similar results of optimum strength at 45 days while flexural strength test had optimum value at 60 days of air curing. This showed that the properties of unreinforced concrete could be improved through addition of fibres and polymers for use in structural applications.

Keywords: polymer, bamboo, fibres, composites, properties, acrylic, cement.

Introduction

Series of challenges from climate change faces the world due to the emission of carbon dioxide from industries among whom the construction and building industries play a major role (Pacheco-Torgal, Jalal 2011; Amziane 2016). It has been estimated that these industries produces about 30% of the world's yearly greenhouse gas emissions and uses up 40% energy for its various activities (UNEP 2009) which necessitates the need to develop a new, sustainable, energy efficient and renewable building materials with good engineering properties that could act as an alternative to the already existing conventional building materials and in this regards lots of work had been done on the use of natural fibre cement composites (Brandt 2008; Sim *et al*. 2005; Mathur 2006; Ardanuy *et al*. 2015; Ali 2012; Bentur, Mindess 2007). A lot of potentials have been discovered through the use of natural fibres in most developing countries where they are readily available from plants and could also be sourced from agricultural wastes (Andic-Cakir *et al*. 2014). Bamboo fibres have been used as reinforcement in cement composites to enhance the properties of the various structural elements in buildings (Bindu *et al*. 2016; Ni 1995; Ghavami 2005; Rodrigues *et al*. 2006). A composite has been defined as a material composed of two or more constituent materials with different physical and mechanical properties which when combined together results in a better property (Moffit 2013). Biocomposites which is the combination of natural fibres with polymer (Ramires *et al*. 2010) has minimal effect on the environment when compared with the conventional building materials. Priyadharshini and Ramakrishna (2014) developed a biocomposite from sisal fibre with natural rubber latex polymer with results

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showing substantial improvement in the compressive strength, flexural and split tensile strength properties. In another related study, kraft softwood and hardwood fibres were processed with an aqueous acrylic emulsion and alkylalkoxysilane before they were formed into wood-fiber-polymer composites and the observed values indicated the abilities of the composite to resist moisture cycling and temperature cycling deterioration which translates to its ability to be moisture resistant when used in humid environment (Blankenhorn *et al.* 1999). Chakraborty *et al.* (2013) also worked on the treatment of jute with alkali and carboxylated styrene butadiene (SBR) polymer before they were incorporated into cement mortars to form composites. The composites were said to have increased density with reduction in water absorption and apparent porosity, also an increased compressive strength, modulus of rupture and flexural toughness were observed. Ismail *et al.* (2008) carried out comparative studies of bagasse fiber polymer cement using three different polymers of styrene butadiene, vinyl ester, and styrene acrylic. The obtained results showed that the modulus of elasticity, impact toughness and flexural strength increased with increasing polymer content. Libo *et al.* (2016) evaluated the effects of coir fibre reinforcement in epoxy polymers and cementitious composites and the obtained results showed that alkali treatment of the fibres led to an increase in some of the considered engineering properties. The purpose of this study is to evaluate the engineering properties and to verify the elemental compositions of the produced bio-polymer composites in order to determine its durability in any environment and the role of its chemical composition in aiding its performance when used as structural elements.

1. Experimental work

1.1. Materials

Bambusa Vulgaris species were cut and dried in the open with natural air for 30 days, splitted into strips with a sharp metal, reduced into bits and hammer milled. The bamboo fibres that passed through a 2.0 mm sieve had maximum length of 23.74 mm with thickness of 1.5 mm and a minimum length of 5.09 mm with 1.25 mm thickness was used for the production of the composite specimen. Acrylic emulsion surface coating supplied by Chemstar Industries was used for the polymer as recommended by Hamel and Cox (2013). River sand passing through 2.0 mm sieve was also used and all organic materials were removed before the sieving process was carried out. The ordinary Portland cement that conforms to ASTM Type I was also used as the binder while potable water was obtained from the tap within the Laboratory. Batches of bamboo fibres were then soaked in diluted 10% weight of NaOH solution for 24 hours at 23 °C in a container of 0.018 m^3 capacity, washed with hands and spread on a flat platform within the laboratory at same temperature for air drying.

1.2. Sample preparation

Predetermined weight of sand from Table 1 was measured out and mixed with predetermined weight of cement for 2 minutes, thereafter bamboo fibres of 1.5% of total weight of composites were mixed with the constituents. The polymer contents of the mix were varied by 5%, 10% and 15% of the cement mass while the sand and cement proportions were kept constant. Part of the water needed for the entire mixing process was halved and used to dilute the acrylic emulsion polymer before the solution was added to the mixture. The remaining water was then added to the acrylic emulsion polymer modified bamboo reinforced composites (AEPBRC) matrix to form samples B, O, C, R, N and Y. A total of 27 samples were produced for each composition to cater for 9 samples to be used for compressive, flexural and split tensile tests for each curing period and a curing regime of 28, 45 and 60 days were used which gave a sum total of 27 samples per composition.

For the mechanical properties test, 150×150×150 mm moulds made by CONTROL were used to

Table 1. Experimental mix design (source: created by the author Akinyemi 2017)

S/N	Polymer (% of cement mass)	Sand (kg)	Cement (kg)	Fibres(%)	Water:Cement	Water:Polymer
B	0.05	30	10	0	1:0.6	1:6.1
O	0.05	30	10	1.5	1:0.6	1:6.1
C	0.1	30	10	0	1:0.56	1:5.2
R	0.1	30	10	1.5	1:56	1:5.2
N	0.15	30	10	0	1:0.45	1:4.6
Y	0.15	30	10	1.5	1:0.45	1:4.6

produce compressive test samples, 145×150×360 mm moulds were used to produce flexural test samples and 150×350 mm cylindrical moulds were used to produce split tensile samples and a total of 162 samples were produced altogether. The moulds were oiled with waste engine oil to ensure easy de-moulding process, fresh mortar composite was poured into it and compacted manually using a rammer. They were allowed to cure naturally in the air within the laboratory at 24 °C for 28, 45 and 60 days before the various tests were conducted as recommended by ACI 548 for latex modified concrete for polymer film formation to develop properly. For the tests on density, absorption and voids properties, 24 cylindrical samples of AEPBRC were produced each of 12 mm thickness and 44mm diameter and allowed to cure in the laboratory for 28 days using ASTM C 642 standard.

1.3. Test procedures

1.3.1. Physical properties

Absorption after immersion, absorption after immersion and boiling, dry bulk density, bulk density after immersion, bulk density after immersion and boiling, apparent density and finally voids (%) were done according to ASTM C 642-06 and the following formulae were used:

1. Absorption after immersion (%) =

$$\frac{(B-A)}{A} \times 100; \tag{1}$$

2. Absorption after immersion and boiling (%) =

$$\frac{(C-A)}{A} \times 100; \tag{2}$$

3. Bulk density, Dry = $\frac{A}{(C-D)} \times \rho;$ (3)

4. Bulk density after immersion =

$$\frac{B}{(C-D)} \times \rho; \tag{4}$$

5. Bulk density after immersion and boiling =

$$\frac{C}{(C-D)} \times \rho; \tag{5}$$

6. Apparent density = $\frac{A}{(A-D)} \times \rho;$ (6)

7. Voids (%) = $\frac{C-A}{C-D} \times 100,$ (7)

where A – mass of oven dried sample in air (g), B – mass of surface dry sample in air after immersion (g), C – mass of surface dry sample in air after immersion and boiling (g), D – apparent mass of sample in water after immersion and boiling (g) and ρ – density of water at 1 g/cm^3.

1.3.2. Mechanical properties

The mechanical properties tested include compressive strength, tensile splitting test and flexural test. The compressive strength test was performed in accordance with BS 1881 standard using a universal crushing machine Control Wizard Basic of model 50-C9083. Load was applied continuously without shock on samples from 150×150×150 mm cube moulds. The maximum load on the cube at failure (Fig. 1) was recorded and Eq. (8) was used to calculate the strength.

$$F_C = \frac{\text{maximum load}}{\text{cross} - \text{sectional area of specimen}}, \tag{8}$$

where F_C – compressive strength (kMPa) and P_{max} is the maximum load that cube sustained (kN), A – the cross sectional area of the cube (mm^2). The splitting tests were conducted using cylindrical samples of 150×350 mm in accordance with ASTM C496. Loading rate of 1.2 MPa/min was applied without shock until failure as seen in Figure 2 occurred.

The split tensile strength of each specimen was calculated using the Eq. (9):

$$T = \frac{2P}{\pi ld}, \tag{9}$$

where T – splitting tensile strength (MPa), P – maximum load applied (kN), l – length and d – diameter of specimen (mm). The flexural strength tests were conducted according to BS 1881 using beams with center

Fig. 1. Failure of cube
(Photograph by Author)

Fig. 2. Failure of cylindrical sample
(Photograph by Author)

point loading arrangement and loading was applied without shock. The flexural strength value was calculated using the Eq. (10):

$$f_b = \frac{PL}{bd^2}, \tag{10}$$

where f_b – flexural strength expressed as modulus of rupture, P – ultimate load (N), L – supporting roller distance (mm), *b* – width of beam (mm) and *d* – depth of beam (mm).

2. Results and discussions

2.1. Physical properties

Table 2 shows the variation in absorption (after immersion and after immersion and boiling), bulk density (dry, wet and after immersion and boiling), apparent density and volume of voids. The observed trends for polymer inclusions of 5, 10 and 15% without fibre inclusion showed a decrease in the water absorption tendencies which confirms the fact the polymer film has blocked the passage of moisture into voids within the composite but with the addition of fibres there was a increase in values at 5% polymer inclusion with 1.5% fibre inclusion as well as 15% polymer content and 1.5% fibre inclusion but a reduction in moisture absorption value was obtained at 10% polymer and 1.5% fibre which is the optimum value, these values showed that the fibres absorbed more moisture with its inclusion in the composite and the highest level of absorption was at 15% polymer inclusion with 1.5% fibre content. This result is similar to those obtained by Chakraborty *et al.* (2013).

The polymer film could be said to have retarded the propagation of tiny cracks in cement mortar by forming an interpenetrating structure with the modified cement mortar with lower rigidity. As seen from the Table 2, the densities of the composite samples without fibres increases with an increase in the acrylic emulsion polymer content, opposite was the case when fibres where introduced into the samples, as the observed trend showed a decrease in density as more polymers were added. The optimal polymer emulsion inclusion and fibre reinforcement that had the best density performance was at 15% polymer content and 1.5% fibre inclusion because the lower the density the better and lighter the material would be. The volume of permeable voids is determined by the type of cement and polymer inclusion, mix proportions and compaction and curing (Mohammad 2012). At control levels without fibre additions, the percentage voids were observed to increase as the polymer content was increased this showed that as more polymer are added, there is a related increase in voids which translates to reduced durability. Results from bamboo fibre inclusion showed reduction in voids with its introduction to the samples, the mix proportion of 15% polymer addition and 1.5% fibre inclusion had the least percentage of voids and therefore can be said to perform better in real structural application than the rest mix proportions.

Table 2. Density, absorption and voids results (source: created by the author Akinyemi 2017)

CODE	Absorption after immersion (%)	Absorption after immersion and boiling (%)	Bulk dry density (g/cm^3)	Bulk density after immersion (g/cm^3)	Bulk density after immersion and boiling (g/cm^3)	Apparent Density (g/cm^3)	Volume of permeable voids pore space porosity (%)
B	12.0179	5.8436	90.8	101.6	96.0	14.4	5.3
O	12.5523	7.4266	318.7	358.7	342.3	14.1	23.7
C	12.8571	6.6667	310.0	356.0	336.0	12.6	21
R	12.3095	7.0807	306.0	343.7	327.7	14.8	21.7
N	11.9343	5.4528	973.0	1089.1	1026.0	18.0	53.1
Y	14.3841	7.0194	289.7	331.3	310	15.0	20.3

2.2. Mechanical properties

For compressive strength result shown in Figure 3, it could be seen that for the 28 days result, control mixes without any fibre inclusion showed an increase as the quantity of polymer was increased. Compressive strength values of 65.5 MPa for 5% polymer content, 80 MPa for 10% polymer content and 87 MPa for 15% polymer content A similar trend was observed by Priyadharshini and Ramakrishna (2014) when it was reported that at 28 days compressive test of natural fibre reinforced latex modified concrete an increase in the value was recorded without any fibre inclusion at the control level. However, with the inclusion of fibres into the mix, the 15% and 1.5% composition had the highest value which is even more than the mixes with polymer composition only. 45 days test had a slightly different value with both B and C control mixes having similar values of 99 MPa while N had the highest value at 117.6 MPa. For 60 days result, reductions in the compressive values were obtained as more polymers were added. This reduction could be attributed to particle-size distributions of microfillers of the added acrylic polymer and the amount of the fine particles in such material influenced notably the strength. Another reason for this phenomenon as reported by Gorninski *et al.* (2004) is that an increase in polymer contents leads to an increase in the mechanical strength to an extent after this peak has been attained; there is loss in its strength. Fibre inclusion into the composites gave a clear improvement by increasing the compressive strength substantially in the range of 80–101 MPa compared with polymers only at 89–95 MPa at 28 days, for 45 days a further increase in values for fibre inclusion samples were observed in the range of 88.8–104 MPa while for samples with polymers only the range of 92.7–101.4 MPa were gotten which is an improvement with respect to the strength at 28 days. Finally, at 60 days, a slight reduction was obtained for all samples with the samples with fibre inclusion having values between the range of 80–101.5 MPa while the samples with polymers only had values between the ranges of 92.7–101 MPa. Generally, the optimum compressive strength was obtained at 45 days test. This was also corroborated by Stancato *et al.* (2005) that using greater amount of latex content in a natural fibre reinforced polymer modified concrete will significantly increase the compressive strength of the composite and also it has been widely stated that a certain level of fibre inclusion in reinforced concrete tends to improve the compressive strength value by acting as a bridge in any crack formation. Therefore, the composite material produced has an improved property which could not have been in existence if they both existed separately without being combined.

The result in Figure 4 showed that with fibre reinforcement included in the mix, there was an increase in the flexural strength until the optimal value was obtained at 5% polymer content and 15% fibre value with a flexural strength of 35.6 MPa and closely followed by 10% polymer content and 15% fibre addition with a flexural strength of 32.7 MPa at 60 days. At 45 days the samples with polymers only had flexural strength values between 23.4–41 MPa while samples with fibre inclusion had values in the ranges between 30.7–32 MPa which is also an improvement. For 28 days, samples with polymers only had flexural strength values between 15.6–22.4 MPa while samples with fibre inclusion had values in the ranges between 16.3–27.3 MPa. It could also be seen that from 28 and 45 days curing that the higher the polymer, the higher the

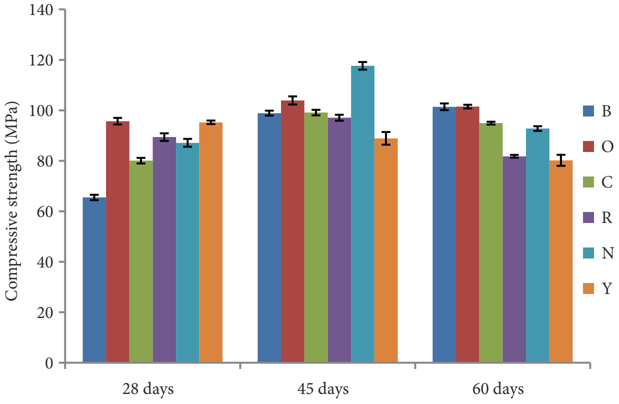

Fig. 3. Compressive strength test at 28, 45 and 60 days (source: created by the author Akinyemi 2017)

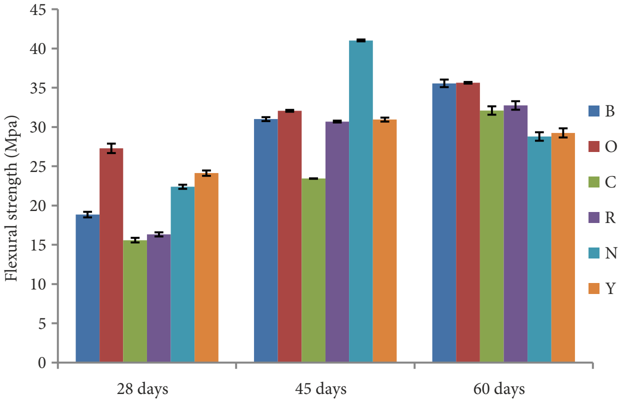

Fig. 4. Flexural strength test at 28, 45 and 60 days (source: created by the author Akinyemi 2017)

resultant flexural strength with the exception of sample C which had a reduction in strength possibly because of delayed setting but at 60 days curing the flexural strength did not increase markedly, and contrary to what was expected, it decreased. Consequently, a loss of effectiveness with the highest amount of added polymer. The optimum flexural strength value was obtained at sample N at 45 days curing with 41 MPa while higher strength values were also obtained at 60 days of curing in the range of 28.8–35.6 MPa. The same observation was also made by Ismail *et al.* (2008) who worked on bagasse fibre polymer composites and reported that flexural strength results showed increase in its value with an increase in the polymer content until the optimal value was reached. This condition is influenced by the diffusion of the emulsion latex into the hollows of the bagasse fibre. Other reasons given for this phenomenon is that when polymer emulsion is allowed to dry through loss of water by evaporation, the suspended resin or polymer particles are crowded together. Further evaporation of the retained water will exert considerable capillary pressure, leading to a closer contact between suspended polymer particles in the latex. So, the driving forces for the coalescence of the polymer particles arise from surface tension and capillary forces. These forces increase with decreasing particle size resulting from either water loss or from autohesion and the quantity of emulsion also exerts an influence on the development of the final mechanical properties (Ismail *et al.* 2008). This statement was also corroborated by Priyadharshini and Ramakrishna (2014) when they worked on a similar sisal fibre reinforced latex modified concrete.

A similar result with the compressive strength was observed in Figure 5 with the split tensile. At 28 days the split tensile values ranges between 9.8–12.3 MPa for samples with fibre inclusion compared with 7.4–11 MPa for samples with polymers only this showed a slight improvement with the addition of fibres to the samples, also for 45 days the values ranges between 9.3–14.5 MPa for composite samples with fibres while it is between 12–13.2 MPa for samples with polymers only, not much advantage of addition of fibres were observed in these values and for 60 days, the values ranged between 11.7–13 MPa for samples with fibres and polymers while it is between 9.6–13.8 MPa for samples with polymers only. The reason for this could be attributed to the fact that polymer inclusion alone without fibres had more strength to withstand tension forces because it is strong in tension as a result of latex network that was formed during commingling and inter-penetration of the latex and cement hydration products (Huang *et al.* 2010). However, the optimum split tensile strength value was obtained at 60 days at N with 13.7 MPa at 15% acrylic emulsion polymer and 1.5% bamboo fibre inclusion.

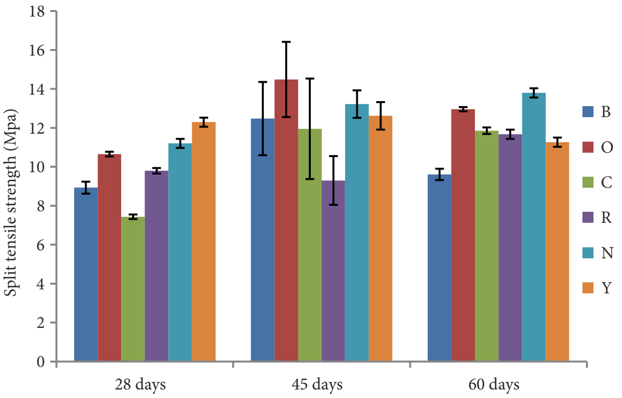

Fig. 5. Split tensile strength test at 28, 45 and 60 days (source: created by the author Akinyemi 2017)

Conclusions

The study considered the effects of adding alkali treated bamboo fibres as reinforcement in acrylic polymer modified concrete for structural applications. Additions of polymers into the composite samples reduced moisture intake but inclusion of bamboo fibres increased this rate until the optimum mix was gotten at 1.5% fibre and 10% acrylic polymer inclusion. Densities of composite samples without fibre addition were observed to increase while the inclusion of fibres into the mix caused a reduction in the densities at 1.5% fibre and 15% polymer additions. Increase in acrylic polymer content led to an increase in the percentage of voids at samples with polymers only but inclusion of fibres ensured voids reduction. Compressive strength value at 45 days curing gave the optimum strength, flexural strength at 60 days also gave the optimum value and a similar result with the flexural strength results was obtained for the split tensile strength test.

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