Locust Bean Pod Solutions as Alternative Binder for Laterite – Rice Husk Fibre Composite Tile Production

[1]Neku, M. N., [2]Alao, T. O., [3]Mudashiru, S. A. and [4]Olawuyi, B. J.
[1,2,3,4]Department of Building, Federal University of Technology, Minna, Nigeria
*Corresponding Author E-mail: mathewneku@gmail.com
Tel: 07031943694

Abstract

The pursuit for locally sourced economical and environmentally safe materials has been on the increase in the development of composite ceiling tiles over the years. These locally sourced materials are organic materials from plants and livestock such as rice husk, locust bean pod, feathers, maize husk and bamboo fibre. Therefore, this study incorporated laterite (LAT) and Rice Husk Fibre (RHF) in the development of composite ceiling tiles. Composite ceiling tiles mixes studied with LAT and RHF of varied proportions (70:30 to 30:70 at 10% step intervals) with varied Locust Bean Pod Solution (LBPS) concentrations (50g/l, 30g/l and 10g/l) as the binders in comparison with Portland cement – PC (the control sample) at 0.6 water-binder ratio. 400 x 400 x 40 mm and 450 x 450 x 75 mm slates were produced for the water absorption and flexural strength tests using a compactive effort of 5MN/m^2 employed for the manual operated pressing. The specimens were tested after 14 days of air-curing after been oven-dried for 24 hours at a temperature of 80 °C. The results revealed that all the samples exhibited increased flexural strength as the LAT contents increases at a decreased RHF content with the 60:40 (LAT:RHF) mix observed as optimum for all LBPS concentrations. An increasing trend of water absorption rate was observed with an increase in fibre contents. The study therefore recommends 60:40 LAT:RHF with 50g/l LBPS concentration for composite ceiling tile production.

Keywords: Compressive strength, flexural strength, Laterite, Locust bean pod solutions (LBPS), Rice husk fibre (RHF), water absorption

Introduction

Building is one of the products of technology and an essential need of every member of society (Agbede *et al.*, 2016). Relatively, a building should not be costly to procure and should provide the necessary comfort for the users. As stated in the work of Ataguba (2016), a building is an enclosed structure intended for human occupancy. A building is made up of the structure itself and non-structural components like cladding, interior walls and ceilings. Bachman and Dowty (2008) assert that many structural components are assembled on-site to make up the building and this includes ceiling tiles, partition walls and exterior curtain walls. Thus, a building is composed of various components, including ceiling tiles that serve different purposes for the building users (Agbede, 2011; Nnamdi, 2011). Chuldley and Greeno (2014) defined a ceiling is one of the secondary elements (non-structural components) in a building which is attached to the underside of a suspended floor or roof above. Hence, the ceiling has its own functions in buildings. CGC (2010) reveals some functions of ceiling as including aesthetics, acoustic control, durability, fire-resistance, thermal insulation and accessibility to the plenum in the case of drop ceilings. However, to achieve some of the functional needs of a ceiling tile, the component mixes must not only be workable but also eliminate all air voids upon drying while achieving maximum dry density. This workability property enables further manipulation of ceiling tiles to attain desired good outlook and easy fixing during construction (Kartini, 2011; Onyemachi, 1994). To achieve effective performance of ceiling tiles, a material with suitable properties is needed.

Seeley (2010) stated that the common materials used for ceiling tiles/boards are asbestos, wood (solid or manufactured), Polyvinyl Chloride (PVC) and Plaster of Paris (POP). The *South African Building Interior System Association* - SABISA (2013) outlined standard materials for ceiling construction as plasterboard, plasterboard cove cornice, softwood rendering and batten, fibre-cement board and softwood studs for timber frames in buildings. These outlined materials possess different properties that include absorption of moisture and swelling, brittleness, fibrous and high cost. Such characteristics pose problems of maintenance/procurement and health to the building owners and users, as the materials to be used in the construction of a building are not expected to endanger human health in any form, both during construction and while dwelling in the building (*Occupational Safety and Health Administration* (OSHA), 2002, Seeley, 2010; SABISA, 2013). OSHA (2002) stated that asbestos particles enter the human body through inhalation, which can cause disabling or fatal diseases such as asbestosis, an emphysema-like condition, lung cancer, mesothelioma – a cancerous tumour that spreads rapidly in the cells of membranes covering the lungs and body organs and gastrointestinal cancer. Hence, the need for affordable and safe local materials.

Woodwork activities in Nigeria have resulted in uncontrolled toxic waste. This uncontrolled waste is associated with the atmospheric air and consists of pollutants such as dust and particles (Ohijeagbon *et al.*, 2021). A report has shown that the daily generation of wood residue in Nigeria is estimated at 104,000 m^3 and 294,000 tonnes per year (Ohijeagbon, 2012). Ohijeagbon *et al.* (2021) further stated that as of 2010, an estimated value of 5.2 million tonnes of wood residue was produced each year in Nigeria. Hence, there is an increased pollution and environmental waste rate. Ceiling boards are commonly made from agro-industrial wastes particles, including planar shavings, wood chips, and sawdust, which are obtained from wood waste as well as other organic materials such as corn cobs, rice husks, rice straw, feathers, sugarcane bagasse, and so on (Kim, 2009). Previous studies (Aguwa, 2016; Aguwa & Okafor, 2012; Kumar, 2012; Okunlola *et al.*, 2011; Aguwa, 2009; Akabi *et al.*, 2005; Hassan & Umar, 2005; Hombostel, 1991) revealed that wood species such as beach pine, scots pine and Norway spruce have been in use in the development of ceiling boards which exhibited a good durability and strength properties. Portland cement (PC), on the other hand, has a detrimental effect of ozone depletion due to the carbon dioxide emission (CO_2), thus necessitating its augmentation that now led to the development and incorporation of Locust Bean Pod Solution (LBPS) in this study. This paper presents the result of an experiment on the use of laterite, rice husk as fibre and African locust bean pod solution (LBPS) as an alternative binder to Portland cement for the development of composite ceiling tiles. Addition of rice husk fibre is to reduce dead weight of the ceiling material while the LBPS has pozzolanic properties. The usage of these local materials will result in an effective waste management approach targeted at converting waste to wealth.

Materials and Methods

Materials

The materials used for the study were Laterite (LAT), Locust Bean Pod Solutions (LBPS), Portland cement (CEM II), Rice Husk Fibre (RHF) and water. Portland Cement Type – CEM II/A-LL, 42.5 N, whose properties conformed to BS EN 197-1 (2011) and NIS 444-1 (2003), bought from a cement store in Gidan-Kwano, Minna, Niger State, was used in this study.

The RHF used was collected from a local grain mill in Garatu Village along Minna-Bida Road, Bosso LGA, in Niger State. The collected RH was then sorted to remove dirt and pebbles. It was sun-dried for 2 days (6hrs/day) to remove the moisture present and then screened to two different sizes of 1.0 mm and 1.7 mm.

The LAT sample was collected within Minna town in Niger State. The criteria for selecting soil for this research were based on literature and field tests which included the soil classification, the plasticity index, chemical composition, moisture content, specific gravity and depth for soil extraction. Hence, the soil was extracted at a depth between 0.5 m and 1.5 m below ground level to avoid any organic material.

Locust bean pods were sourced and collected from their trees around Badegi Village, near Bida, Niger State, Nigeria. The epicarps (outer leathery cover of the pods) of the locust bean pods were cut to various sizes not exceeding 50 mm in length for the purpose of weighing and the particle size distribution was carried out before soaking for twenty-four hours in clean water for extraction in 50g/l, 30g/l and 10g/l concentrations.

Clean potable water, as specified by BS EN 1008 (2015), available within the Concrete Laboratory of the Department of Building, School of Environmental Technology, Federal University of Technology, Minna, was used for mixing.

Experimental program

This research investigated the varying composition of LAT and RHF (70:30, 60:40, 50:50, 40:60, and 30:70) as independent variables on water absorption and flexural and compressive strength tests as dependent variables of ceiling tiles production while trial mix was conducted prior to the casting of the experimental specimens and the composite mix LAT: RHF of 60:40 exhibited the best performance. Hence, the control specimen for this research is the composite mix LAT: RHF of 60:40 incorporating PC as a binder at a binder/composite ratio of 0.6 using 30% of the total materials as the water (following the work of Ataguba, 2016 and Ohijeagbon *et al.*, 2021).

Preparation of specimens

The ceiling tiles were developed through different proportioning of the base materials (LAT and RHF) and the binders (cement and LBPS), as shown in Table 1. RHF of 1000 µm sieve size was adopted on the basis of the analysis.

Table 1: Proportioning of the constituent materials

Category	Sample ID	LAT: RHF (%)	Binders: Composite
Control	LFCCT	60:40	0.6
A (50g/l of LBPS)	LFBCT$_{1}$	70:30	0.6
	LFBCT$_{2}$	60:40	0.6
	LFBCT3	50:50	0.6
	LFBCT$_{4}$	40:60	0.6
	LFBCT$_{5}$	30:70	0.6
B (30g/l of LBPS)	LFBCT$_{6}$	70:30	0.6
	LFBCT$_{7}$	60:40	0.6
	LFBCT$_{8}$	50:50	0.6
	LFBCT$_{9}$	40:60	0.6
	LFBCT$_{10}$	30:70	0.6
C (10g/l of LBPS))	LFBCT$_{11}$	70:30	0.6
	LFBCT$_{12}$	60:40	0.6
	LFBCT$_{13}$	50:50	0.6
	LFBCT$_{14}$	40:60	0.6
	LFBCT$_{15}$	30:70	0.6

LFBCT$_{15}$30:700.6*LFCCT—LAT: RHF cement ceiling tiles; LFBCT–LAT: RHF biglobosa ceiling tiles,
*The subscripts 1 to 5, 6 to10 & 11 to 15 denote 50 g/l, 30 g/l and 10 g/l LBPS concentrations respectively.

The production procedures involved blending of the LAT: RHF in ratios (as described in Table 1) together with the binders (cement or LBPS), the blend was mixed manually using a stirrer. The mixture was gradually poured into a mould (using 400 x 400 x 40 mm moulds for water absorption and 450 x 450 x 75 mm moulds for flexural strength test) lubricated with mould oil and compaction was done using a manual pressing method at room temperature. The samples were all oven-dried under a temperature of 80 °C for 24 hours (as found in Ataguba, 2016; Ohijeagbon *et al.*, 2021 referencing ASTM D7433, 2013; ASTM C367/C367 (2009)).

The curing of ceiling tiles was for 7 days and it was then allowed to dry for another 14 days. The LFCCT (laterite: fibre cement ceiling tiles) mix was the control incorporating PC as the binder while categories A mixes (LFBCT$_{1}$ to LFBCT$_{5}$); B (LFBCT$_{6}$ to LFBCT$_{10}$) and C (LFBCT$_{11}$ to LFBCT$_{15}$) incorporated LAT:RHF with cement totally substituted by LBPS at 50 g/l, 30 g/l and 10 g/l concentrations respectively.

Water absorption test

The water absorption (WA) capacity of the ceiling tiles was done in accordance with ASTM D1037 (1999) and ASTM D7433-(2013) standards. The experimental samples were immersed in water for 2 hrs. and 24 hrs. at room temperature to examine the short and long-term percentage water resistance properties, respectively (Ohijeagbon *et al.*, 2021; Ataguba, 2016). The average of the triplicate sample tested gave the value for percentage water absorption recorded for 2 and 24 hrs. The mass of dried ceiling tiles was recorded as M_D and the mass of ceiling tiles after immersing in water for 2 or 24 hrs was recorded as Ms (Ohijeagbon *et al.*, 2021) and thus, Equation (1) was utilized to evaluate the percentage water absorption of the ceiling tiles.

$$\text{WA (\%)} = \frac{MS - MD}{MD} \; x\ 100 \qquad (1)$$

where M_s = mass of the saturated ceiling tiles; M_D = mass of the dried ceiling tiles.

Flexural test

Flexural strength (FS) was determined by evaluating the axial bending strength of the tiles in accordance with ASTM D1037 (1999) and ASTM C367/C367 (2009) standards as reported in Ohijeagbon *et al.* (2021) and Ataguba (2016), respectively using Universal Testing Machine (Model No CAP: 20T/200kN) at a loading rate of 50mm/minute. A concentrated bending load was applied at the centre of a beam using three-point loading on a length of 450 x 450 x 75 mm and the ultimate load was recorded. Flexural strength was calculated by load deflection with the ultimate load using the formula in Equation (2).

$$\text{FS} = \frac{3PL}{2BD2} \qquad (2)$$

where P = the ultimate load; L = the distance of the support or length of the sample (450 mm); B = width of the sample (450 mm); and D = depth of the sample (75 mm)

Results and Discussion

Materials Characterization

Figure 1 and Table 1 present the particle size distribution and summary of the physical properties of the LAT sample used for the study.

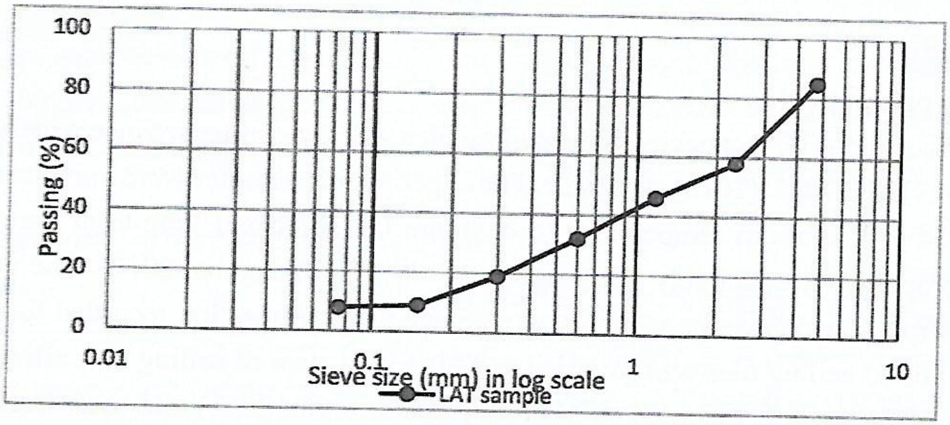

Figure 1: Particle size distribution of Laterite sample

Table 2: Summary of Other Properties of Laterite Sample

Property	Values	AASHO Requirement for A-2-7
% passing 75 um Sieve size	8	≤ 35
Fineness Modulus	3.51	2.0 to 4.0
Liquid Limit (%) - LL	47.7	≥ 41
Plastic Limit (%) - PL	23.32	
Plastic Index (%) = LL - 30	24.38	≥ 11
Natural moisture Content	14.75	
Specific Gravity	2.67	
Silica-sesquioxide (S-S) ratio	1.30	

The LAT sample used for the study can be classified based on the fineness modulus of 3.51 as a coarse/granular laterite sample with a percentage passing 75 um (i.e. BS No 200) sieve obtained as 8%, far below the maximum 35% specified for A-2-7 LAT of AASHO soil classification. The liquid limit of the sample (47.7) > 41 as required by AASHO, while the Plastic Index (24.4) > 11 also fits well with the requirements for the A-2-7 Laterite of AASHO. The natural moisture content of the soil sample (14.75%) also conforms to the range of 5-50% reported by Emesiobi (2000) for gravel and sand. The specific gravity (2.67) of the sample lies within 2.6 and 2.8 range stated by Ogunribido (2012).

The oxide content of the LAT, as presented in Table 3, reveals it as a Class F pozzolanic material according to ASTM C618 (2019), having 53% SiO_2 content and total useful oxide ($SiO_2 + Fe_2O_3 + Al_2O_3$) content of 95%, far greater than the 50% as required by the ASTM C618 (2019). The silica-sesquioxide (S-S) ratio, as summarized in Table 1, further fits the sample well as a true laterite sample. The LBPS on the other hand, is also Class F pozzolan with 46% SiO_2 content and total useful oxide content of 51 %. On the basis of the oxide composition, it can be deduced that the LBPS might be less reactive than the Laterite sample. The two materials are, however, suitable for Class F pozzolan of ASTM C618 (2019).

There was an increase (18% to 25%) in water absorption from 2 hrs compared to 24 hrs duration for the control mix (LFCCT). The composite matrix with LBPS as binder on the other hand reveals water absorption increases slightly as the LBPS concentrations decreased (from 50g/l to 10g/l). The water absorption also decreased for LAT contents change from 70% to 60% (i.e. as RHF content changed from 30% to 40%) before a progressive increase again as the LAT content further decreased – 50% to 30% (RHF contents further increased – 50% to 70%), implying the 60: 40 LAT: RHA mix as the optimum for low water absorption. The same trend was observed for all LBPS concentrations and the mix with the lowest RHF content (LFBCT$_5$, LFBCT$_{10}$ and LFBCT$_{15}$) having the highest water absorption values (10%, 11% & 16% at 2 hrs and (18%, 21% & 22% at 24 hrs) at the respective LBPS concentrations (50 g/l, 30 g/l & 10 g/l) respectively. The control mix, however, has water absorption of 18% (at 2 hrs) and 25% (at 24hrs), making it to exhibit the highest water absorption properties.

Table 3: Oxide Content of Laterite and LBPS Samples and ASTM C618 Requirements

Oxide content	LAT	LBPS	Typical PC	ASTM C618 2019 Class N	Class F	Class C
SiO_2	53.4	46.2	17 - 20			
$Al2O_3$	23.3	0.0	3 - 8.0	≥ 70	≥ 50	≥ 50
Fe_2O_3	17.9	4.5	1 - 2.0			
CaO	1.4	14.9	60 - 67	N/A	≤ 18	> 18
MgO	0.5	0.0	0.1 - 4.0	N/A	N/A	N/A
SO_3	0.2		1 - 3.0	≤ 4	≤ 5	≤ 5
Na_2O	0.0					
K_2O	0.8	32.5	0.5 - 1.3			
Mn_2O_3	0.1					
P_2O_5	0.1					
Cl	0.0					
TiO_2	2.2	1.9				
Cr_2O_3	0.0					
ZnO	0.0					
SrO	0.0					
Total	100.0	100.0				

Water absorption

Figure 1 illustrates the water absorption rate of the ceiling tiles samples with different compositions of LAT:RHF at varying LBPS concentrations (50 g/l, 30 g/l and 10 g/l) after 2 hrs and 24 hrs, respectively.

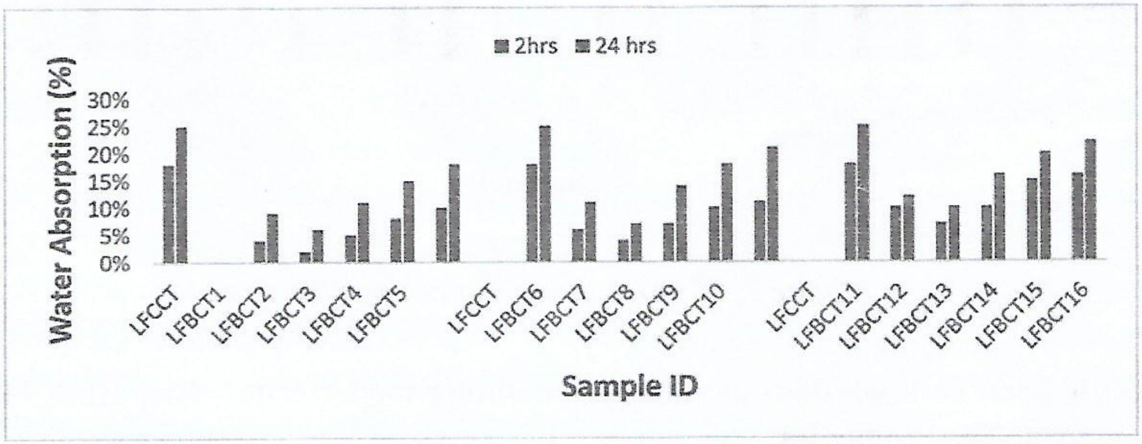

Figure 2: Water absorption of ceiling tiles

Furthermore, the results also show that a decrease in the concentration of the LBPS at an increase in the RHF incorporated increases the rate of water absorption and this could be attributed to the hydrophilic nature of the fibre (Ohijeagbon *et al.*, 2021) and the hydrophobic nature of binder. The water absorption values confirmed the claim that lignocelluloses generally tend to rise the hydrophilic nature of cement-bonded fibre composites due to a large number of porous structures, which accelerates water penetration through capillarity (Ataguba, 2016; Ohijeagbon *et al.*, 2021).

Flexural strength

The results of the flexural strength properties of the ceiling tiles mixtures cured at ordinary ambient temperature are presented in Figure 2. The results revealed that the higher the LAT content (i.e. lower RHF content), the higher the flexural strength, except for the 70: 30 LAT:RHF mix, which had a slightly lower flexural strength than the 60:40 LAT:RHF mix for all the LBPS concentration studied. The flexural strength decreased slightly as the LBPS concentration decreased. The 60:40 LAT: RHF mixes (LFBCT$_2$, LFBCT$_7$, LFBCT$_{12}$) had the best performance for flexural strength at the respective LBPS (50 g/l, 30 g/l and 10 g/l) concentrations studied with the flexural strength values (0.75, 0.72 and 0.68 N/mm^2), respectively.

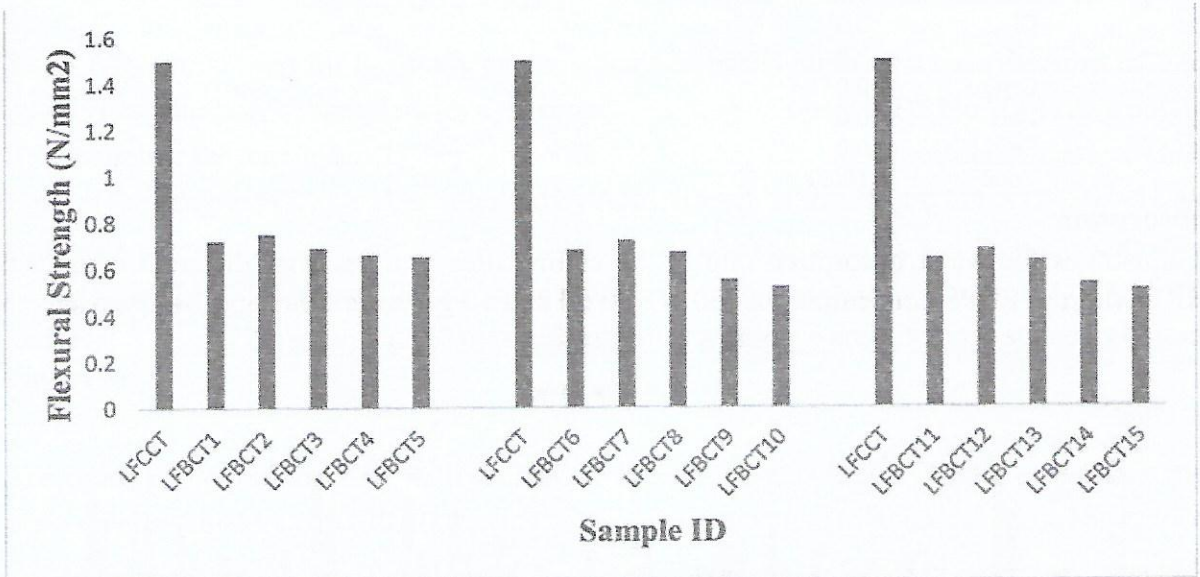

Figure 3: Flexural strength of ceiling tiles

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14TH – 18TH AUGUST, 2023It can be inferred from the results that the higher LAT presence up to the optimum of 60% LAT augmented the RHF in the presence of LBPS, contributed higher calcium ions (Ca^{2+}) and aluminium cations (Al^{3+}) in the ceiling tiles matrix for the reaction and forms the required bond (Aguwa & Okafor, 2012; Ohijeagbon *et al.*, 2021).

The optimum flexural strength value gotten was for the composite tile adopting LBPS as a binder (0.75 N/mm^2 for LFBCT$_2$ at 50 g/l LBPS concentration) was just half the flexural strength (1.5 N/mm^2) of the control sample (LFCCT) at which PC serves as the binder. These two specimens are, however, noted to be of the same LAT:RHF mix proportion; it thereby followed that the binding effect of the LBPS can only be adjudged to be about half of the achieved from Portland cement. This can be adduced to a higher reaction rate and bonding achieved in the composite matrix bonded by PC – the control mix (LFCCT).

Conclusion

i) The Laterite sample is suitable A-2-7 classification of AASHO and a Class F pozzolan classification of ASTM C618 (2019). The LBPS also fits well as a Class F well pozzolan of ASTM C618 (2019).

ii) Composite ceiling tiles made from 60: 40 (LAT: RHF) at 50 g/l LBPS concentration (LBCT$_2$) performed best for water absorption and flexural strength properties of all the composite ceiling tile mix having LBPS as binder studied.

iii) The water absorption increased slightly as the LBPS concentrations decreased (from 50g/l to 10g/l) while higher RHF content in the composite matrix generally resulted in increased water absorption except for the 70: 30 (LAT: RHF) mix, which had higher water absorption value to the 60: 40 (LAT: RHF) mix for all LBPS concentrations examined

iv) The control mix (LFCCT) in which PC was served as the binder exhibited the highest flexural strength value of 1.5 N/mm^2 to which the best LBPS binder-based composite ceiling tile (LBCT$_2$) flexural strength value (0.75 N/mm$_2$) is only 50%, despite been made of same 60: 40 (LAT: RHF) proportion. It therefore follows that reaction and bonding provided by the best LBPS binder-based composite tile is only half the reaction and bonding realised from the PC binder.

The study thereby recommends 60: 40 LAT: RHF at 50g/l LBPS for consideration in the production of composite ceiling tiles.

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