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EVALUATION OF THERMOPHYSICAL AND STRENGTH PROPERTIES OF COMPOSITE PANELS PRODUCED FROM SUGARCANE BAGASSE AND WASTE NEWSPAPERS

ABSTRACT

Large quantities of waste newspapers and sugarcane bagasse are prevalently discarded by open burning or indiscriminate dumping, thereby posing severe danger to the environment and public health. This study sought to examine the feasibility of managing the wastes by recycling them into value-added products for building construction. Composite panels were fabricated using waste newspaper paste (WNP) with sugarcane bagasse particles (SBP) varied at 0, 25, 50, 75, and 100 % by weight of the composite mix. Epoxy resin was thoroughly mixed with its hardener and applied as binder. The samples were developed in triplicates per proportion of the SBP adopted and then dried completely before their thermophysical and strength properties were evaluated. It was observed that variations in mean values of water absorption (28.57 – 39.43 %), thickness swelling (6.21 - 8.33 %), specific heat capacity (1232 - 1312Jkg^{-1}K-1) trended positively with increasing proportions of the SBP. Whereas nailability remained 100.0 % in all the cases, bulk density (689.4 - 640.5 kgm^{-3}), thermal conductivity (0.1186 - 0.1163 Wm^{-1}K^{-1}), thermal diffusivity (1.396 - 1.384 x 10^{-7} m^{2}s^{-1}), and flexural strength (2.572 - 2.280 N/mm^2) correlated inversely with the added fractions of the SBP. Generally, it was found that the samples could perform satisfactorily if applied as ceiling or partition elements in building design. Therefore, recycling of sugarcane bagasse and waste newspapers as described in this study could serve as a promising way of solving their disposal problems and also enhance achievement of low-cost and safe buildings.

Keywords: *bulk density; nailability, recycling; thermal conductivity; thickness swelling; water absorption*

INTRODUCTION

Most times, potential raw materials get buried, discarded, burnt or thrown away for lack of knowledge on their usefulness. This makes such materials to be tagged ‘wastes’. It must be noted that what is regarded as waste from one product may not be absolutely so. What is considered a waste material may be a potential raw material for manufacturing of another useful product if properly harnessed. Jain and Rao [1] considered waste as any substance, object or material that comes into existence as a result of human or animal activities which is meant to be considered and discarded as unwanted or useless. According to them, disposal of

each type of waste is considered based on constituents/composition, or substance of the waste in addition to its reusability, sustainability and harmful effect or hazardous nature (including leachable toxic constituents, reactivity, ignitability among others). Currently, waste materials are either disposed of by hi-tech methods or indiscriminate dumping rather than burying them. As no material is all together a waste, the law of conservation can be extended to products and un-utilized parts of materials.

One of such materials considered a waste is sugarcane (*Saccharium officinarum*) bagasse. Sugarcane is a potential plant in *Poaceae* family. It grows on a soil having P^H of 7.5 to 8.5 with organic matter content. Under such conditions, it grows to a height of 2 m to 5 m. Report from Food and Agriculture Organization (FAO) of the United States [2] shows that over 100 countries grow sugarcane. It was considered to be the twelveth most valuable crop globally [3]. As at 2017, the first ten countries with most record of sugarcane production worldwide included Brazil, India, China, Thailand, Pakistan, Mexico, Colombia, Indonesia, Philippine, and United States with their production capacities ranging between 739,300 and 27,900 metric tons in descending order [4]. States with the highest production of sugarcane in Nigeria include Kwara, Niger, Kano, Jigawa, Sokoto, Katsina, Adamawa, Kebbi, and Kaduna [5, 6].

Uses and benefits of sugarcane are numerous. It is a raw material for sugar production [7]. The juice extracted from it has medicinal benefit [8]. Due to the fact that sugarcane can change 1% of solar energy into biomass, it is categorized as C4 plant [9]. Moraes et al [10] and Renouf et al [11] reported on energy, chemical synthesis, and refueling contribution of sugarcane as well as being a source of ethanol. Several authors including Patil and Deshannavar [12], Jittabut [13], Signh et al [14], Adigun et al [15], Jorapur and Rajvanshi [16], Martins et al [17], Etuk et al [18], and Patil et al [19] have reported on sugarcane leaves application as biomass, raw material for board, and activated charcoal production among others.

Agro-wastes are usually generated in large quantities [20] and in most cases, sugarcane bagasse is subjected to burning especially in developing countries [21 – 23]. This practice enhances and increases environmental pollution as a result of release of carbon dioxide, thus calling for a serious research on how to put sugarcane bagasse to effective and beneficial uses. In this regard, the new material(s) anticipated ought to be more economical and valuable compared to conventional ones that could serve same purposes. Thus, this research aimed at recycling sugarcane bagasse with waste newspapers into composite panels and also assessing thermophysical and strength properties of the developed products so as to ascertain their suitability for applications in buildings. It is noteworthy that the quantity of papers considered as waste materials increases on daily basis [24]. In 2017, World Facts report showed that 215,125,083 tons of paper were produced by 10 countries worldwide [25] and according to McKinney [26], papers and paper products constitute approximately 25 – 40% of globally generated solid wastes. According to Sanjay et al [27], natural fiber composites exhibit comparable properties to those of synthetic fiber composites as regards tensile strength, impact strength, interlaminar shear strength, thermal, water absorption and tribological properties. However, the properties of the composites depend on various factors, such as type of resin, origin of the fiber, fiber orientation, fiber condition, and so on.

MATERIALS AND METHODS

Materials description and collection

Sugarcane bagasse, waste newspapers, epoxy resin and its hardener (K7001) were utilized in this study. The sugarcane bagasse and newspapers were gathered as waste materials from Nung Oku, Ibesipko Asutan Local Government Area, Akwa Ibom State,

Nigeria. As at the time of collection, the sugarcane bagasse had its juice extracted, leaving it dry.

Materials processing and analysis

The sugarcane bagasse was pulverized and then screened, and the quantity of it that passed sieve openings not larger than 2.0 mm was used in this work. Also, the waste newspapers were shredded with the aid of a pair of scissors. The pieces obtained were soaked in warm water in a plastic bucket. After 24 hours, they were removed from the water, squeezed lightly (to remove excess water from them), and then pounded into paste by means of Agate mortar and pestle. The paste was sun-dried completely. Morphology of the sugarcane bagasse particles (SBP) and waste newspaper paste (WNP) was scanned. The SBP and WNP were divided into two reasonable portions each and one portion per material was analyzed for chemical composition by employing established standards of Technical Association of Pulp and Paper Industry (TAPPI) method as adopted elsewhere [28 - 30].

Fabrication of test samples (Composite panels)

The remaining portion of each processed material was utilized at various weight proportions to fabricate test samples by hand lay-up technique. Table 1 shows the different composite mixes adopted in this work. Epoxy resin was thoroughly mixed with its hardener in 1:1 weight ratio and then applied as binder. The binder to composite mix ratio considered was 3:4 (by weight) throughout the fabrication process. Three replicate samples were prepared for each formulation. In the case of those meant for test of thermophysical properties, the composite mixes were cast and compacted in a circular mold measuring 110 mm in diameter and 9 mm in thickness whereas those for tests of strength properties were developed a mold of dimensions 150 mm x 150 mm x 14 mm. The compaction process lasted for 24 hours using a laboratory - made compacting machine maintained at 5 kN. All the samples were allowed to dry completely in air before subjecting them to the property tests.

Table 1. Composite mix design, wt.%

SBP	0	25	50	75	100
WNP	100	75	50	25	0

Testing of the samples

Modified Lee – Charlton's Disc Apparatus Technique fully described elsewhere [31] was employed for determination of thermal conductivity of each sample. An electric hotplate (Lloytron E4102WH) was used as the heat source and a thick cotton wool was applied (as lagging material) over the thickness of the sample. With the aid of Origin Software (Version 2019), modeling of cooling rate was performed. Using the data obtained, the value of thermal conductivity, k was computed based on the relation:

$$k = \left(\frac{Mcx}{A\Delta\theta}\right)\frac{dT}{dt} \qquad (1)$$

where M = mass of the disc, c = specific heat capacity of the disc, x = thickness of the sample, A = area of cross-section of the sample, $\Delta\theta$ = difference in temperatures across the sample's thickness at steady state, and $\frac{dT}{dt}$ = cooling rate of the disc.

Bulk density is one of the properties necessary for selection of thermal insulation materials [19, 32]. In this research, it was evaluated for each sample by using Modified water displacement method [33]. An electronic weighing balance (S. METTLER 0 – 600g) was used for measurement of masses. The water used was at 28 ^{o}C in a glass graduated measuring cylinder. White candle wax (discarded as waste) was melted and then used for the purpose of coating the surfaces of the sample under test. The required bulk density was calculated as [19, 34 - 36]

$$\rho = \frac{M_s}{V} \quad (2)$$

where ρ = bulk density, M_s = mass of the sample, and V = bulk volume of the sample.

In the cases of water absorption and thickness swelling, an immersion method was used for their determination as applied elsewhere [28]. The mass and thickness of the dry sample were measured before immersing it completely in water. After 24 hours, the sample was carefully removed from the water and its surfaces were quickly dabbed with an absorbent paper. This was necessary in order to remove excess water from the sample's surfaces. The mass and thickness of the sample were measured again. Water absorption, WA was calculated using the equation

$$WA = \left(\frac{M_f - M_i}{M_i}\right) 100\% \quad (3)$$

where M_f= mass of the sample after immersion, and M_i = mass of the sample prior to immersion.

Similarly, thickness swelling was determined by calculation using the formula:

$$T_s = \left(\frac{T_f - T_i}{T_i}\right) 100\% \quad (4)$$

where T_s = thickness swelling, T_i = thickness of the sample prior to immersion in the water, and T_f = thickness of the sample after the immersion in the water.

SEUR's apparatus was employed for the purpose of specific heat capacity determination [37]. In this case, the device was designed to have an inner cavity measuring 60 mm x 60 mm for accommodation of three plates used as heat exchange accessories. Those plates were prepared from brown plywood sheet and aluminum sheet (each having thickness of 10 mm) as well as the sample (meant for the test). During each test schedule, the aluminum plate was heated in an electric oven to 60 ^{o}C before it was quickly transferred using a pair of tongs and inserted between the plywood plate and sample plate. Monitoring and measurement of temperature of each plate were carried out using digital thermometers (Model No. 305, calibrated and equipped with type-K probe). When thermal equilibrium was attained by the system, the quantity of heat lost by the aluminum plate, Q_a and the amount of heat gained by the plywood plate, Q_p were applied with the mass, M_s and rise in temperature, ΔT of the sample to calculate the specific heat capacity, C of the sample based on the relation [28].

$$C = \left(\frac{Q_a - Q_p}{M_s \Delta T}\right) \quad (5)$$

Also, the values of bulk density, thermal conductivity, and specific heat capacity obtained for a sample were used for computation of the corresponding value of thermal diffusivity, λ thus [38 - 41]

$$\lambda = \frac{k}{\rho C} \quad (6)$$

Nailability test was necessary in order to ascertain the ability of the samples to withstand nail penetration. The test was performed in this work by driving a 3"- nail with a carpenter's hammer through the thickness of each sample. When a successful penetration or visible crack

was observed, the process was discontinued. The sample's nailability, n_b was then calculated using the formula [28]

$$n_b = \left(\frac{H-h}{x}\right) 100\% \quad (7)$$

where H= total length of the nail used, and h = length of the nail remaining when nailing was discontinued.

Using three-point bending technique [42], the flexural strength of each sample was determined by means of a Computerized Electromechanical Universal Testing Machine (Model WDW – 10). A sample was placed on the flexure arrangement of the machine and loaded at the middle of the support span, applying a test speed of 1mm/min. When flexural failure was observed during a test schedule, the maximum value of load applied, L was used with the width, b as well as length of support span, d and sample's thickness, x to obtain the flexural strength, σ as [43]

$$\sigma = \frac{3Ld}{2bx^2} \quad (8)$$

All the tests were performed at temperature of (24 ± 1) ^oC and relative humidity of (50 ± 2) %. After that, the mean values of the investigated properties were computed with their corresponding values of standard error for each formulation.

RESULTS AND DISCUSSION

The results of chemical composition analysis showing the proportions of lignocellulosic constituents of the materials (SBP and WNP) utilized in this work are recorded in Table 2. It can be seen that the mean percentage of cellulose in SBP (40.6 %) is greater compared to the proportion (38.5 %) in WNP. Also, the hemicelluloses fraction in SBP (26.8 %) exceeds the proportion (19.7 %) in the WNP. It is only in the case of lignin that the proportion (21.1 %) in WNP is more compared to the case of the SBP (10.5 %). The morphology of each processed material is illustrated in Figure 1. It is observed that shorter fibers dominate the SBP unlike in the case of the WNP.

Table 2. *Chemical composition of the materials used*

Material	Proportions (%) obtained from five determinations		
	Cellulose	Hemicellulose	Lignin
SBP	40.6 ± 0.2	26.8 ± 0.1	10.5 ± 0.2
WNP	38.5 ± 0.1	19.7 ± 0.3	21.2 ± 0.1

Table 3 shows results of the properties investigated for the samples. It is found that water absorption increases with increase in percentage content of SBP. The same trend is observed in the case of thickness swelling. As a matter of fact, lignin content aids in binding particles together, hence water resistance in nature whereas hemicellulose component causes swelling of the pulps, tensile strength bonding of fibers and tear resistance [44] among others. Consideration of such findings based on the fractions of those lignocellulosic components in the SBP and WNP explains why the water absorption and thickness swelling recorded for the

samples exhibit the observed trends. Figure 2 reveals that both properties increase non-linearly in value as fractions of the SBP increase in the studied samples.

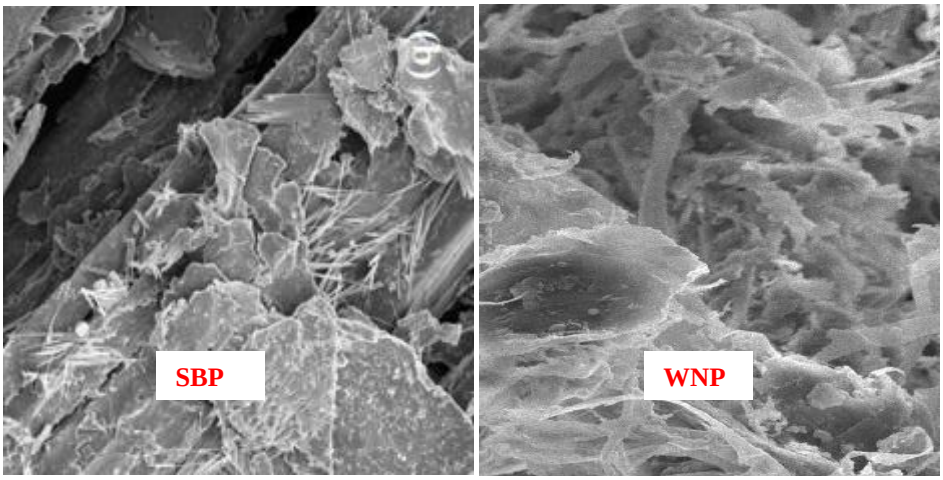


Fig. 1. Morphology of the sugarcane bagasse particles and Waste newspaper paste

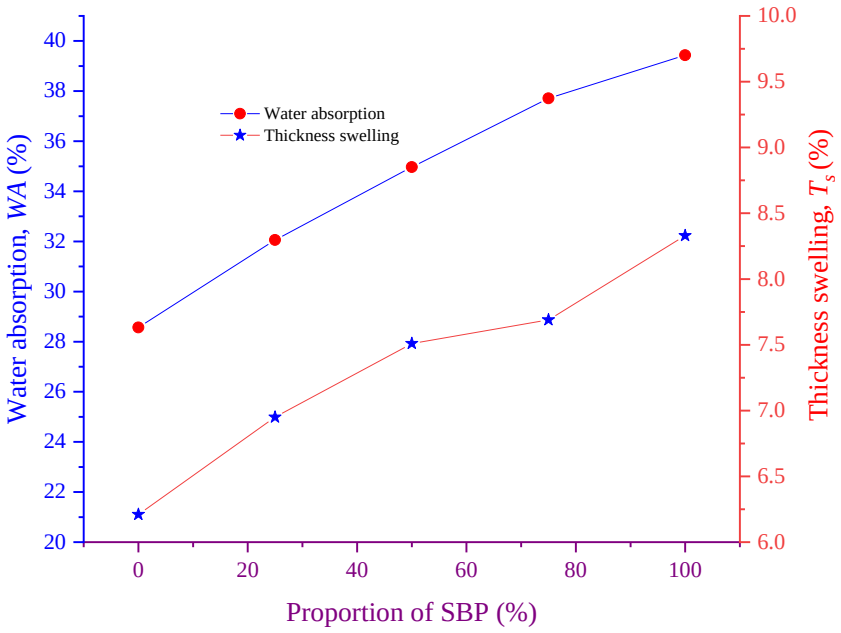


Fig. 2. Variations of Water absorption and Thickness swelling with loadings of SBP

It is worthy of note that the mean water absorption values obtained for the samples range from 28.57 % to 39.43 %. Interestingly, these values are comfortably accommodated by the standard limit allowed by FAO as 20 % to 75 % for particleboards [45]. Also, the mean thickness swelling values obtained for the samples range from 6.21 % to 8.33 %. These values are equally well below the maximum value of 25 % stipulated for 24-hour immersion of particleboards fabricated for common use [46]. Actually, variations in water absorption and thickness swelling of the samples depend on proportions of the SBP and WNP used in the composite mix. The results obtained in this study for the samples are supported by the report of De Souza et al [47] that high water absorption gives rise to high thickness swelling. By

considering 15 % as the stipulated maximum, and for heavy - duty load bearing based on the maximum swelling value put at 14 % for the same 24- hour immersion [48], the results of water absorption and thickness swelling tests carried out in this research simply suggest that the samples can be used as load-bearing particleboards. Law and Ishak [49] linked panel's dimensional stability level to thickness swelling which, in this case, implies that the studied samples satisfy the conditions for structural applications.

The bulk density trends negatively with increasing proportions of the SBP and ranges in mean values from 640.5 kgm^{-3} to 689.4 kgm^{-3}. This signifies that the SBP used is lighter than the WNP. That is to say, irrespective of the geographical location, the aggregate of matter in a given volume of the WNP is plausibly more compared to that of the same volume of SBP. Even so, by adjudging based on the standards for categorization of particleboards as stipulated in [48], the samples may be regarded as medium-density panels. At 100 % content level, sample made with WNP records $(1.232 \pm 1.0) \times 10^3$ $Jkg^{-1}K^{-1}$ whereas the one fabricated with SBP has specific heat capacity value of $(1.312 \pm 1.0) \times 10^3$ $Jkg^{-1}K^{-1}$. It is obvious from these results that, by increasing the proportion of WNP, less heat would be needed to raise temperature of a unit mass of the developed sample by one Kelvin in the case of the panel similarly produced using the SBP.

Thermal conductivity of a material is the measure of its heat flux density ratio to temperature gradient. It shows the capability of a material to conduct heat [50]. Thermal conductivity in the case of insulators is due to vibration of atoms and molecules. In the case of composites, it may depend on geometrical distribution of components. Moisture content and quantity of voids (air spaces) are some of the factors that affect thermal conductivity [51]. The void spaces are due to presence of interstices in the sample and the volume of air enclosed within any given sample is a function of pore sizes as well as the number of pores in the sample. Relying on such facts, it is obvious that the sample with 100 % WNP content contains less volume of entrapped air than its counterpart made with the SBP. Observably, the SBP appears to have more dusty particles than the WNP. Consequently, the sample that contains 100 % of SBP has more number of still air spaces compared to the one fabricated with the WNP only. It has been copiously reported that thermal conductivity of a porous material decreases with increase in the volume of still air (otherwise known as dead air space) within the material. In other words, the more the presence of still air space in a porous sample is, the lower is the thermal conductivity of the sample. The sample that contains 100 % of the WNP records thermal conductivity value that is 1.94 % more compared to the value obtained for the sample developed by utilizing the SBP at similar level. However, the values of thermal conductivity obtained in this study fall within the range of 0.023 $Wm^{-1}K^{-1}$ to 2.900 $Wm^{-1}K^{-1}$ recommended [52, 53] for heat insulation.

Thermal interaction between materials and their environment is bound to take place, owing to propagation of thermal waves resulting in changes in environmental temperature. For the studied samples, thermal diffusivity decreases as proportion of the SBP increases in the composites. This is possible because the SBP component has a lower thermal conductivity tendency and requires a greater amount of energy to heat up meaningfully at the exterior level before it transfers the heat by conduction through its thickness. Figure 3 reveals that both the thermal conductivity and thermal diffusivity trend negatively with the percentage of SBP utilized.

Table 3. *Experimental results of the property tests*

WNP:SBP	WA (%)	T_s (%)	ρ (kgm^{-3})	C $(10^3 Jkg^{-1}K^{-1})$	k $(Wm^{-1}K^{-1})$	λ $(10^{-7}m^2s^{-1})$	n_b (%)	σ (N/mm^2)
100:0	28.57 ± 0.62	6.21 ± 0.25	689.4 ± 1.1	1.232 ± 0.010	0.1186 ± 0.0001	1.396 ± 0.62	100.0 ± 0.0	2.572 ± 0.012
75:25	32.06 ± 0.77	6.95 ± 0.14	679.3 ± 1.1	1.246 ± 0.010	0.1177 ± 0.0002	1.391 ± 0.77	100.0 ± 0.0	2.516 ± 0.010
50:50	34.97 ± 0.57	7.51 ± 0.19	669.5 ± 1.2	1.262 ± 0.011	0.1173 ± 0.0002	1.388 ± 0.57	100.0 ± 0.0	2.424 ± 0.013
25:75	37.71 ± 0.54	7.69 ± 0.29	657.9 ± 1.2	1.281 ± 0.011	0.1168 ± 0.0001	1.386 ± 0.54	100.0 ± 0.0	2.381 ± 0.015
0:100	39.43 ± 0.43	8.33 ± 0.28	640.5 ± 1.1	1.312 ± 0.010	0.1163 ± 0.0001	1.384 ± 0.43	100.0 ± 0.0	2.280 ± 0.013

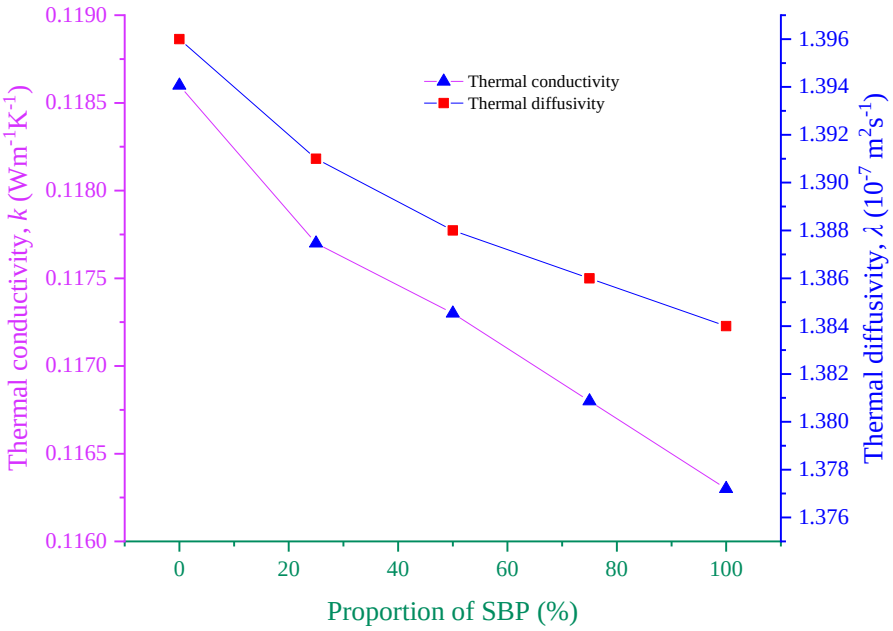


Fig. 3. Variations of Thermal conductivity and Thermal diffusivity with proportion of SBP

Considering the fact that insulating boards are mostly nailed such that the nail passes through the thickness of each board from its surfaces since nailing through the narrow edge is likely to split the boards [54], the 100 % nailability obtained for the samples can be attributed to the effect of the binder (epoxy resin with its hardener) used as earlier described in this study. This enhances a high bonding strength in all cases of composite mix resulting to nailability of 100 %, which implies successful penetration of nail. It can be observed from the results that the values for flexural strength recorded for the samples investigated are above the value of 0.1 N/mm^2 reported by Ataguba [55] for composite ceiling panel developed from

waste newspaper and rice husk. Equally observed is the fact that flexural strength increases with increase in the content of WNP as well as increase in bulk density of the panels.

CONCLUSION

The experiments conducted in this study have revealed that composite panels fabricated from sugarcane bagasse particles (SBP) and waste newspaper paste (WNP) could restrict heat transmission effectively. It was observed that increase in the proportions of SBP improved thermal insulation efficiency of the composite samples. The developed composites were found to have suitability for interior application as ceiling panels or partition elements in building design. Findings revealed that the samples could be installed by nailing. More so, it was found flexural strength decreased with increasing loadings of the SBP. Above all, the investigated properties portrayed that the samples could perform satisfactorily and even better than many already-known and costly panels usually applied for structural purposes in buildings.

Declarations:

Competing interests
The authors have no conflicts of interest to disclose.

Authors' contributions
SEE: Conception; data collection; data analysis and interpretation; critical revision of the article; and final approval of the version to be published. UWR: Research design; experimentation/data collection; data analysis and interpretation; a critical revision of the article; and final approval of the version to be published. OEA: Data collection, data analysis and interpretation, critical revision of the article, and final approval of the version to be published. NJI: Data analysis and interpretation, critical revision of the article, and final approval of the version to be published.

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