Kufa Journal of Engineering
Vol. 16, No. 1, January 2025, P.P. 450-462
Article history: Received 11 September 2024, last revised 3 November 2024, accepted 15 November 2024

CHARACTERISATION OF CEILING BOARDS PRODUCED FROM PLASTER OF PARIS REINFORCED WITH BANANA FIBRE AND COCONUT SHELL

Eugenia O. Obidiegwu[1*], Munirat A. Balogun[1] , and Paul A. Ajayi[1]

[1]Department of Metallurgical and Materials Engineering, University of Lagos, Akoka, Yaba, Lagos Mainland, Lagos, Nigeria

[*]Corresponding Author: eobidiegwu@unilag.edu.ng Tel: 08035812874

https://doi.org/10.30572/2018/KJE/160124

ABSTRACT

The need for environmentally friendly and affordable building materials has sparked researches for materials to use in the construction industry. This paper therefore, studied the characterization of ceiling boards manufactured from plaster of Paris (POP) reinforced with banana fibres (BF) and coconut shell (CS) particulates. The samples were produced by adding different ratios of BF and CS to the POP matrix. To evaluate the effectiveness of the samples, several tests, were conducted. The results demonstrated that the addition of reinforcements improved the properties. The sample with a mixture of POP, BF, and CS demonstrated superior properties with the lowest water absorption (2.77%), high compressive strength (7.74 MPa), least thermal conductivity (0.2157 kW/mK) and hardness value of (23.2 HVN), these are within the standard range. The Scanning Electron Microscopy (SEM) analysis confirmed the results obtained. This study established the possibility of using local accessible materials to produce high quality ceiling boards.

KEYWORDS

Ceiling board; Composite; Plaster of Paris; Banana fiber; Coconut shell.

1. INTRODUCTION

Ceiling boards are crucial components of a building's roofing framework, serving multiple purposes such as thermal insulation, moisture absorption, and protection from harsh weather conditions, thereby making the climate condition bearable (Adepitan et al, 2019).

Conventional materials like asbestos used in the production of ceiling boards generate issues, which is a traceable cause of cancer (Nwogbu et al., 2021). As a result of this issue and rising cost of materials, researchers embarked on studies for better materials that may be employed in the production of ceiling boards.

However, in recent times, we have witnessed this essential part of buildings evolve from its basic function to become an aesthetic feature, installed for the beautification and finishing of modern homes. Hence, ceiling shapes are constructed with architectural aesthetics as the primary goal (Kamiyo and Ekundayo, 2022). The performance of a ceiling board depends on the materials used (Koleoso et al., 2020). Hence, there is need to develop composite materials with suitable workable properties to achieve ceiling designs as preferred and also serve the essential requirements. Therefore, the need to develop ceiling boards, from materials with better properties, to meet the essential requirements such as; cheap, sustainable, non-harmful and naturally occurring materials triggered a lot of researches on using natural raw materials to produce ceiling board (Yusuf et al, 2021).

Atoyebi et al, (2023) researched on Assessing the Mechanical and Durability of ceiling Boards reinforced with Rockwool-Bamboo. The results of the research show that; 95% of the boards produced have required physical properties. Hence, they were recommended to be used for some purposes in buildings such as indoors and outdoors. However, the mechanical properties of the 70% of the produced boards were below standard.

Ohijeagbon et al, (2021) studied the Physical and mechanical properties of ceiling boards bonded with cement developed from teak and African locust bean tree wood residue. The study revealed that, there were improvement on mechanical properties of the ceiling boards produced from teak wood dust when compared with the mechanical properties obtained from the samples prepared from African locust bean tree wood dust.

The Development and investigation of mechanical properties of ceiling board using domestic waste materials such as palm kernel chaff, waste paper and sawdust was investigated by (Agaja et al, 2021). From the various tests conducted, the sample with the mixture of waste paper, sawdust and palm kernel chaff gave the most favourable result compare to others. This implies that these wastes can be used to produce a good composite ceiling board.

The production of ceiling board using waste and raw materials such as rice husk, epoxy, cassava starch, hardener and resin was studied. It was observed that as the cassava starch concentration increased till 60 wt.%, the water absorption decreased and later increased, while the density of the developed ceiling board increased with increase in cassava starch composition (Ameh et al., 2019). The development of Ceiling Boards by the mixture of Sugarcane Bagasse and Rice Husk was investigated by (Jesuloluwa and Bori, 2018). The result revealed that the ceiling board produced with only sugarcane bagasse has improved properties, when compare with the one prepared with rice husks.

The literatures reviewed above showed that many researchers have used different waste materials combined with cement. This study aims to produce high-quality, cheap and harmless ceiling boards using Plaster of Paris (POP) reinforced with banana fibres (BF) from banana stem and coconut shell (CS) particulate.

Plaster of Paris (POP) is a fast-setting gypsum plaster comprising of a fine white powder (calcium sulphate hemihydrate), which hardens when damped and allowed to dry. Plaster of Paris (POP) is a brittle material that, when placed under mechanical load, leads to deformation and cracking, which affect the mechanical performance and durability of ceiling boards made from solely POP materials (Aqil et al, 2018). This mechanical deficiency in POP can be reduced with appropriate fibre and particulate reinforcements, hence, this research considers the use of coconut shell as filler material due to its high hardness and impact strength. Coconut shell is an agricultural waste and is available in very large quantities in tropical regions such as Nigeria in Africa (Aladenika et al, 2021). Employing the coconut shell particulate will not only reduce environmental pollution emanating from burning the shell, but will also contribute to economic growth of the country, as well as production of non-harmful and comfortable ceiling boards.

2. METHODOLOGY

2.1. Materials preparation

The Plaster of Paris (POP) cement was obtained from a shop in Jibowu, Lagos. The banana stems used to obtain banana fibre in this experiment were obtained from Ogijo, Ogun State, while the coconut shells were obtained from Badagry, Lagos State Nigeria. The method of water retting was employed in the extraction of banana fibre. While the coconut shell was crushed and ball milled to grain sizes of 300 microns (µ). The materials and ceiling board produced are shown in Figs. 1- 3.

POP cement and water were combined at a concentration of roughly 2:1 ratio respectively, after some previous experiments. Additionally, the fibre content was fixed at 2 to 5 percent of the weight (wt. %) of the matrix and placed in the mould in chopped form that was alternatingly oriented horizontally and vertically. The paste that serves as the delivery system for hardness was created by mixing POP with water. As soon as the POP cement was mixed with water, it was immediately stirred for 2 to 5 minutes to remove lumps. The matrix was carefully poured into a lubricated wooden mould for easy removal and air bubbles were allowed to escape.

Additionally, the coconut shell and banana fibre were mixed in various amounts (5, 10, 15 wt. %), also, the banana fibre, coconut shell and POP cement were combine as shown in Table 1. The materials were mixed with 50cl of water before being poured into the mould and supported by metal rods. The moulded samples were smoothened with the use of a straight-edged tool. When the materials had been hardened, the de-moulding was carried out. The samples were named: PC_1 - PC_3 (mixture of POP 5-15 wt.% and Coconut Shell), PBC_1 - PBC_3 (mixture of POP, Banaba Fibre and Coconut Shell 5-10%), PB_1 - PB_3 (mixture of POP and Banana Fibre 5-15 wt.%) and P (only POP 100 wt.%).

Fig. 1 POP cement

Fig. 2a Banana stem

Fig. 2b: Dried banana fibre

Fig. 3a: Coconut shell

Fig. 3b: Coconut shell particulates

Fig. 3c: Ceiling board

2.2. Water absorption (W. A.)

The water absorption test for the produced sample was done in conformity with ASTM C373-22 (Standard Test Method for Water Absorption). The samples of sizes 100mm x 100mm x 8mm were weighed to get the dry weight, immersed in distilled water for 3 hours. It was removed, cleaned and re-weighed to get the soaked weight. The percentage of water absorption was calculated using Equation 1 below.

$$\% \, W.A. = \frac{Soaked\ weight - Dry\ weight}{Dry\ weight} \times 100 \quad (1)$$

Table 1: Mix formulation of the ceiling board

S/N	Sample Code	Plaster of Paris (POP) wt. %	Coconut Shell (CS) wt. %	Banana Fibre (BF) wt. %
1	PC_1	95	5	-
2	PC_2	90	10	-
3	PC_3	85	15	-
4	PBC_1	85	5	10
5	PBC_2	80	10	10
6	PBC_3	85	10	5
7	PB_1	95	-	5
8	PB_2	90	-	10
9	PB_3	85	-	15
10	P	100	-	-

2.3. Flexural strength

It is defined as the maximum stress that a material can withstand without failing or breaking when subjected to a bending load. The test was carried out according to ASTM C473-19 (Standard Test Method for Physical Testing of Gypsum ceiling Products), with Universal testing Machine shown in Fig. 4 and calculated using Equation 2. The Vickers hardness test was also conducted using the machine as shown in Fig. 5.

$$\text{Flexural Strength} = \frac{3FL}{2bd\delta^2} \quad (2)$$

Where F=maximum Load, L = Length of the Sample, b = width of the sample, $\delta = thickness$

Fig. 4: Universal Testing Machine

Fig. 5: Vickers Hardness test Machine

2.4. Compressive strength

The test is carried out in accordance with ASTM C473-20 (Standard Test Method for Compressive Strength of Gypsum Board). It demonstrates how the sample will respond to compression. This is calculated using Equation 3.

$$\text{Compressive Strength (MPa)} = \frac{L}{A} \quad (3)$$

Where L= maximum Load; and A= Cross-sectional Area

2.5. Thermal conductivity

The rate at which heat is transported by conduction through a material's unit cross-section area when a temperature gradient exists perpendicular to the area is known as thermal conductivity. The test is conducted in accordance with ASTM C177-20.

$$K = \frac{2.303MC\delta\,[\mathrm{Log}\left(\frac{\theta_1}{\theta_2}\right)]}{A\,X\,t}$$

K= Thermal Conductivity (w/m°C)

A = Area of sample (m^2)

M = Mass of water (kg)

C= specific heat capacity of water (J/kg°C)

δ = Thickness of the sample

$\boldsymbol{\theta}_1$= T_s-T_1 $\boldsymbol{\theta}_2$= T_s-T_2

T_1= Cold Water Temperature T_2= Final Temperature

T_s= Temperature of Steam t=time (10 mins=600 seconds)

3. RESULTS AND DISCUSSION

3.1. Chemical composition

The chemical composition analysis of the raw materials was conducted using XRF. The results are shown in Table 2. It was observed that Sulphur trioxide and Calcium oxide are the main constituents of POP, while Calcium oxide, Magnesium oxide and Alumina are the major constituents of coconut shell. This composition contributes to the solubility of the two mixtures and increase in hardness obtained when coconut shell was added to the mixture.

Table 2: XRF analysis of coconut shell and plaster of Paris cement

Elements (%)	CaO	SO_3	SiO_2	MgO	Al_2O_3	P_2O_5	Fe_2O_3	Na_2O	SrO	K_2O	TiO_2
Plaster of Paris	42.40	48.10	3.60	4.75	1.00	0.03	0.43	0	0.70	0.25	0.04
Coconut Shell	48.87	0.142	2.621	16.83	15.2	0.203	12.1	0.398	0	0.734	0.065

3.2. Water absorption

The results of water absorption shown in Fig. 6 indicate that sample PBC_2 (80, 10, and 10 wt. % of POP, coconut shell and Banana fibre respectively) demonstrated the most favourable water absorption capacity for a ceiling board among the given samples. With a water absorption of 2.77%, it had the lowest percentage, indicating that it would absorb less moisture compared to other samples. The improved water absorption capacity of sample PBC_2 can be attributed to its composition. The combination of 80g of POP cement, 10g of coconut shell particles, and 10g of banana fibre created a material structure that is well fortified which minimised porosity, reduces permeability and water penetration. The reinforcing effects of the coconut shell particles and the moisture-resistant properties of the banana fibre likely played a role in reducing water absorption, making sample PBC_2 an excellent choice for a ceiling board.

On the other hand, sample P (100% POP) had the highest water absorption of 9.23%. It consists of 100 wt. % of POP without any coconut shell particles or banana fibre. The water absorption for sample P indicates that it will absorb more water compared to other samples. The absence of reinforcement materials, such as coconut shell particles or banana fibre, contributed to the high-water absorption of the sample. This result followed the same trend with the research conducted by (Agaja et al., 2010).

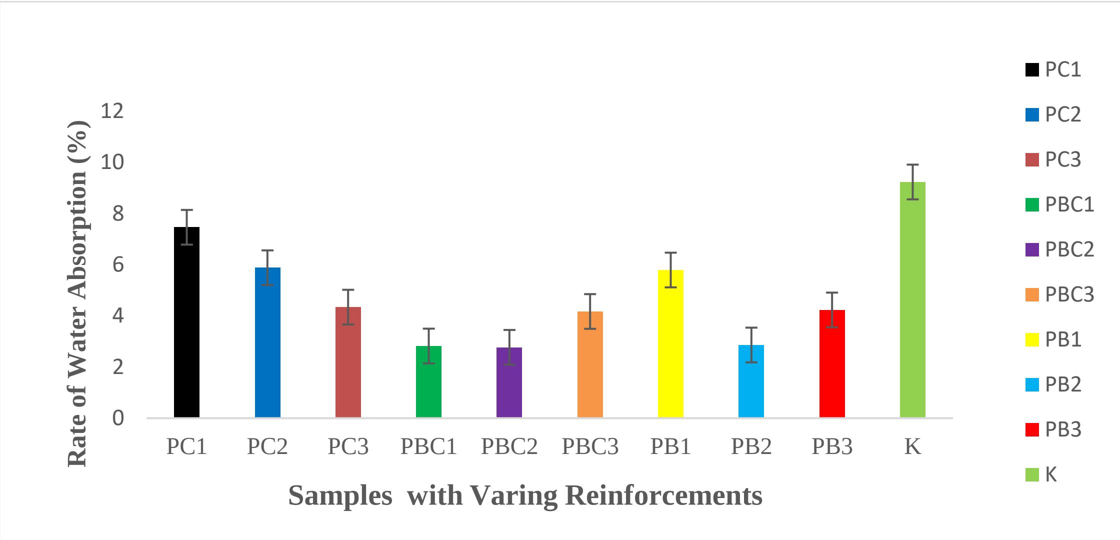

Fig. 6: Variation of water absorption with the amount reinforcement

3.3. Compressive strength

The results in Fig. 7 show the compressive strength of the samples. Sample PBC_2 demonstrated the highest compressive strength of 7.743 MPa which is within the standard value, indicating its superior mechanical strength. The inclusion of coconut shell particles and high tensile strength of banana fibre in the mixing ratio is believed to have likely contributed to this enhanced strength. Samples PBC_1 and PB_2 also exhibited relatively high compressive strength values of 6.366 MPa and 5.776 MPa, respectively. These samples showed favourable mechanical strength due to their specific mixing ratios. Samples PC_1, PC_2, PC_3, PB_1, PBC_3, and PB_3 displayed moderate compressive strength values ranging from approximately 3 MPa to 5 MPa, indicating reasonable mechanical properties for ceiling board applications. Sample P has the lowest compressive strength of 2.524 MPa, suggesting that the absence of reinforcement materials in its mixing ratio led to a decrease in mechanical strength.

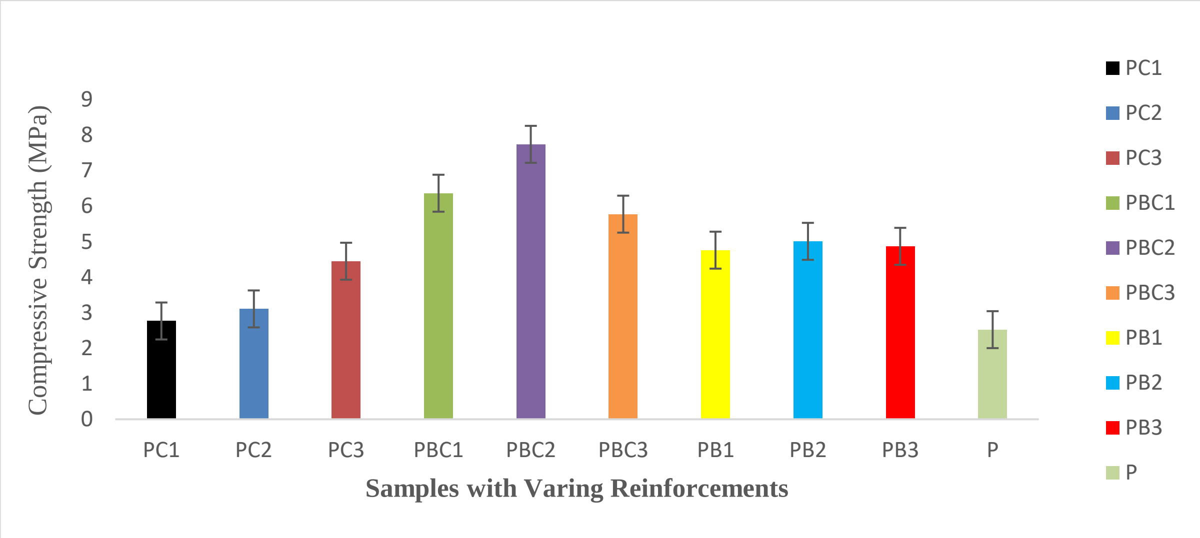

Fig. 7: Variation of reinforcement on compressive strength of the composite.

3.4. Flexural strength

The flexural test results of the samples are shown in Fig. 8**.** Sample PBC_2 stands out with the highest flexural strength value of 1.2458 MPa. This indicates that the specific mixing ratio used in this sample, which includes POP cement, coconut shell particles, and banana fibre, resulted in a composition that provided superior resistance to bending forces. This result followed the trend of the result of the study made by (Ejiofor et al., 2024). Samples PBC_1 and PBC_3 also exhibit relatively high flexural strength values of 1.19473 MPa and 1.03886MPa, respectively. This suggests that the mixing of POP with reinforcement both in particulate and fibre, which include coconut shell particulates, and banana fibre, resulted in samples with favourable resistance to bending stresses.

Samples PC_1, PC_2, PC_3, PB_1, PB_2, and PB_3 demonstrate moderate flexural strength values ranging from approximately 0.33802 MPa to 0.63283MPa. Although not as high as samples PBC_2, PBC_1, and PBC_3 but the values still indicate reasonable resistance to bending forces. Sample P displays the lowest flexural strength among the samples, with a value of 0.29341 MPa. This suggests that the absence of reinforcing materials, such as coconut shell particulates or banana fibre, in this sample adversely affected its ability to withstand bending stresses.

3.5. Hardness

The results of the hardness of the samples shown in Fig. 9 reveal that Samples PBC_2 and PBC_3 demonstrate the mean hardness, of 23.2 and 22.9 HVN respectively. This can be attributed to high alumina content of coconut shell which was used as one of the reinforcing materials in these samples. This resulted to increase in hardness compared to the other samples. Samples PC_1, PC_2, PC_3, PBC_1, and PB_2 also exhibit relatively high hardness values, indicating that their respective compositions and reinforcing materials contributed to their hardness characteristics.

Samples PB1, PB_3, and P display lower hardness values, suggesting that their compositions or reinforcing materials may be less effective in enhancing hardness compared to the other samples.

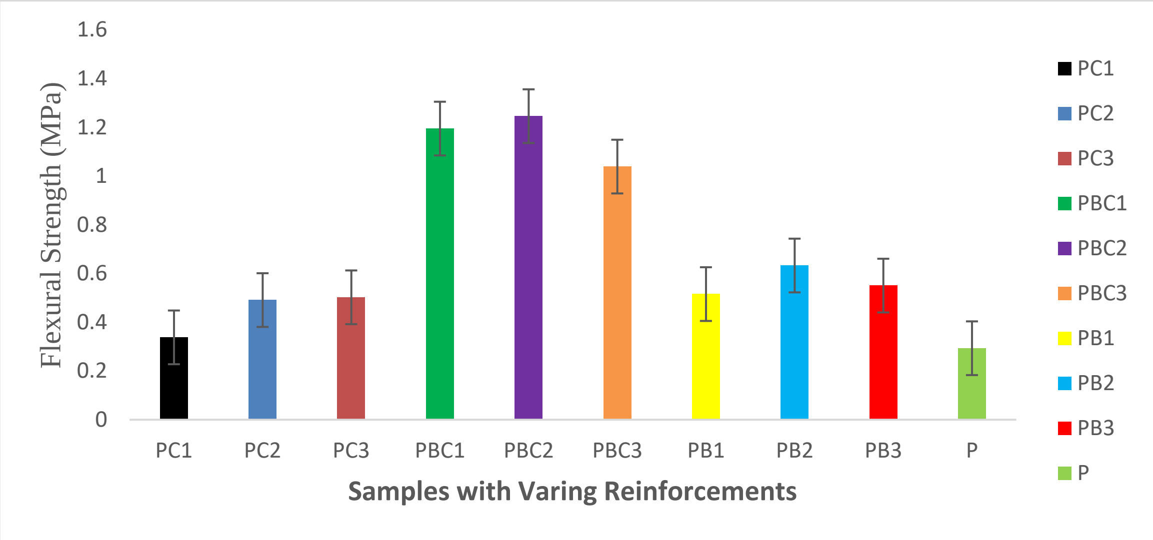

Fig. 8: Variation of reinforcement on flexural strength of the composites.

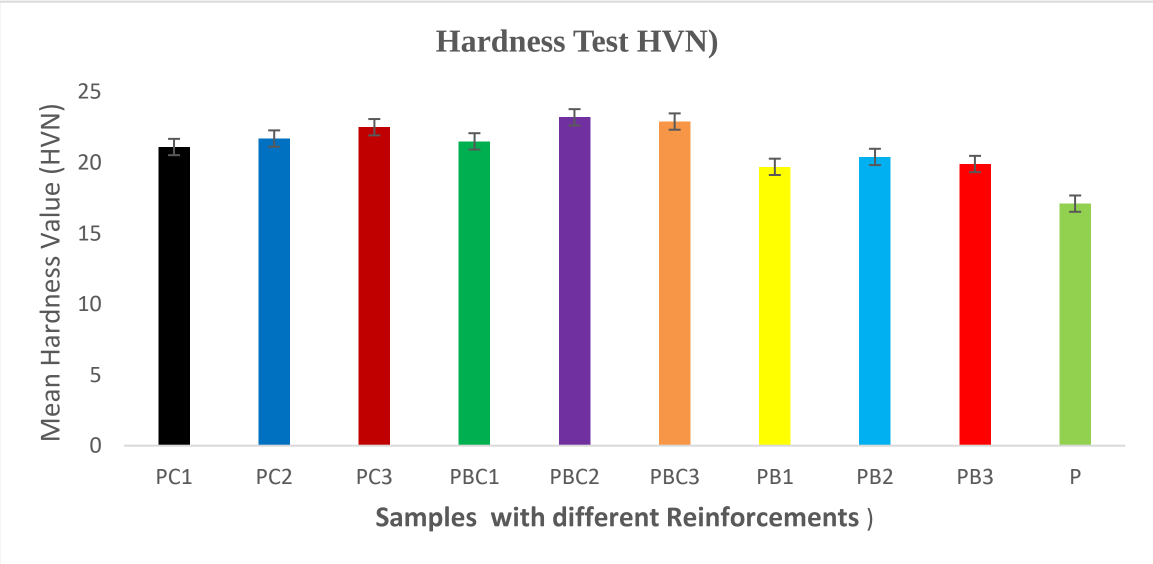

Fig. 9: Variation of reinforcement on hardness of the composites.

3.6. Thermal conductivity

The thermal conductivity results shown in Fig. 10 for the ceiling boards reinforced with banana fibre and coconut shell reveal variations among the samples. Sample PBC_2 stands out with the lowest thermal conductivity of 0.2157Kw/mk, indicating relatively superior heat insulation properties. This implies that the house roofed with such ceiling board will be cool and conducive even during hot weather. This is attributed to the composition of coconut shell and banana fibre, which contributed to achieving a lower thermal conductivity. The presence of banana fibre and coconut shell in the Plaster of Paris matrix demonstrates a synergistic effect on thermal performance. This is in conformity with research of (Adapitan, et. al, 2018; Obidiegwu et al., 2024).

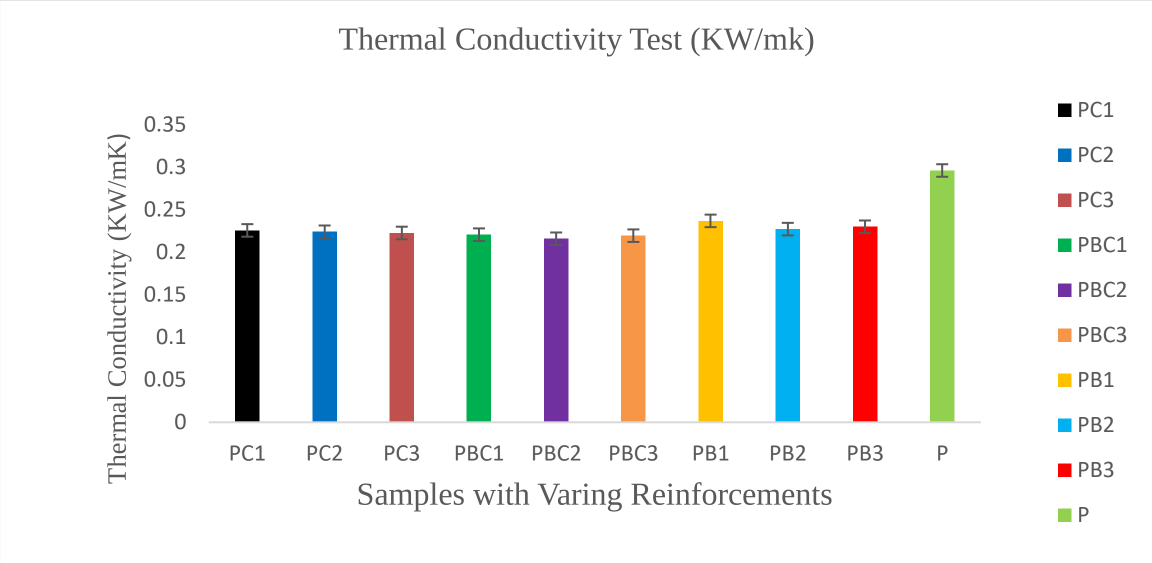

Fig. 10: Variation of reinforcement on thermal conductivity of the composites.

3.7. Scanning Electron Microscopy results (SEM)

The SEM micrographs shown in Figs. 11- 14 revealed the morphology of the samples, which supports the mechanical and thermal results obtained earlier. Compared to the control sample as seen in Fig 11**,** this composed solely of Plaster of Paris (POP), the structure is loosely packed. While the sample containing the two reinforcements (coconut shell particulates and banana fibre) exhibit distinct features Fig. 13. The addition of coconut shell particulates and banana fibre leads to closely packed structures, contributing to enhanced mechanical properties as witnessed in the results discussed above. These thin and longitudinally oriented fibres enhance the strength and reduce the permeability of the composite. In Fig 14**,** the structure is clustered and elongated showing the presence of fibre reinforcements only.

Overall, the SEM analysis confirms that incorporating reinforcing elements modifies the microstructure and improves surface characteristics, potentially leading to enhanced mechanical properties and durability in composite ceiling boards. This is in line with the study by (Obidiegwu et. al., 2023).

4. CONCLUSION

Ceiling board samples has been produced from POP with addition of coconut shell particulates and banana fibre as reinforcements. The result of the tests conducted showed enhanced compressive strength, hardness value, thermal conductivity and reduced water absorption capacity of the composite samples. It was observed that sample PBC_2 demonstrated superior mechanical strength with the lowest water absorption (2.77%), highest compressive strength

(7.74 Mpa), least thermal conductivity (0.2157kW/mK), and hardness value of (23.2 HVN) making it the most acceptable with the required standard values among all the samples. SEM analysis revealed distinct microstructural characteristics among the samples with reinforcement, including variations in surface roughness, porosity, and good oriented structures, providing visual evidence of the effects of reinforcement materials on the composite samples' structures. This study has developed ceiling boards from sustainable materials that are cheap, non-harmful and naturally occurring. Therefore, it has been established that ceiling boards produced from plaster of Paris reinforced with banana fibre and coconut shell particles offer a promising alternative to imported and harmful ceiling boards.

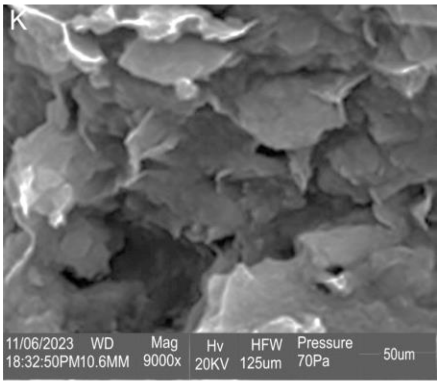

Fig. 11(a): SEM for Sample P (100 % POP)

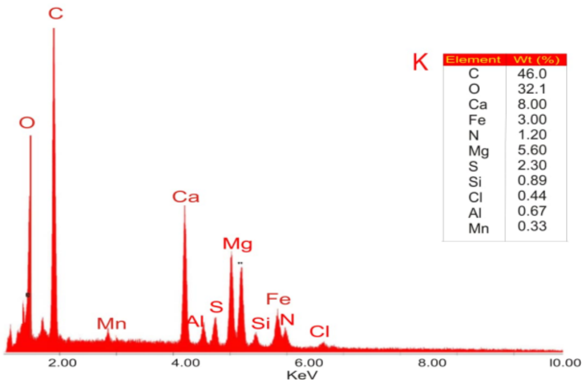

Fig. 11 (b): EDS for Sample P (100 % POP)

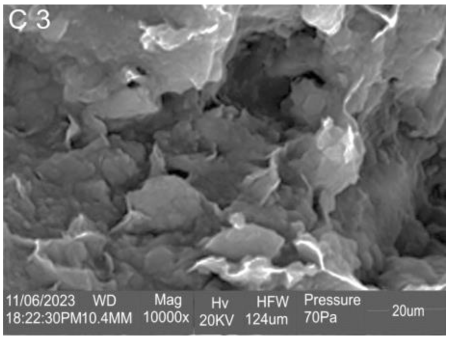

Fig. 12(a): SEM for PC$_3$ (85% POP, 15% CS)

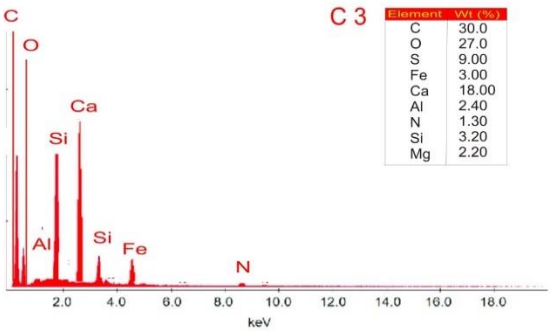

Fig.12 (b): EDS for PC$_3$ (85% POP,15% CS)

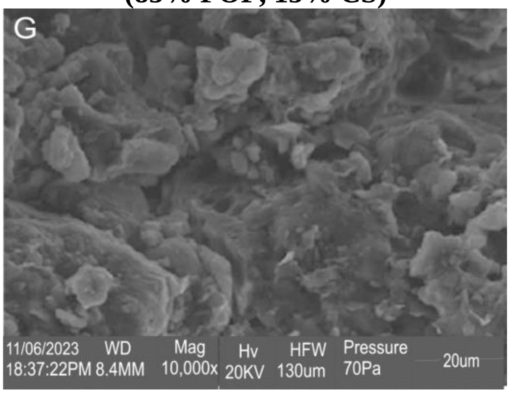

Fig. 13(a) SEM for PBC$_3$ (85% POP,10% CS,5% BF)

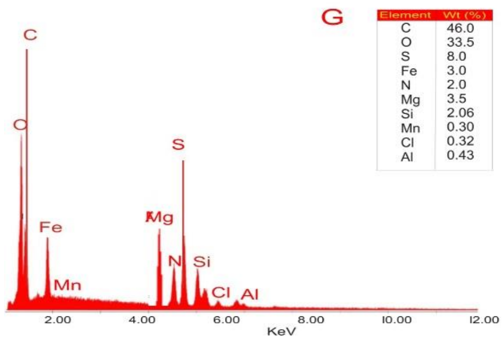

Fig. 13 (b): EDS for PBC$_3$

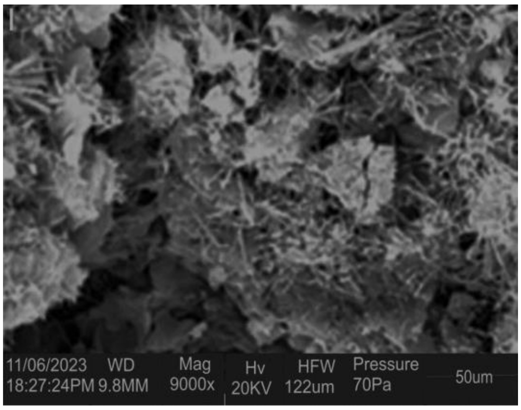

Fig.14 (a): SEM for PB_3 (85% POP, 15%BF)

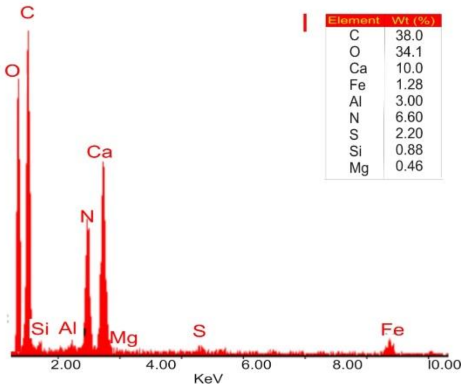

Fig. 14 (b): EDS for PB_3 (85% POP, 15% BF)

5. REFERENCES

Adepitan, J. O.; Ogunsanwo, F. O.; Ayanda, J. D.; Adelaja, A. D.; Oni, O. O. and Odumosu, O.O. (2019) 'Determination of thermal properties of some ceiling material commonly used in Ijebu-Ode, Nigeria', Nigeria Journal of Pure & Applied Physics, 9 (1), 23–27.

Agaja, S.A.; Ayourim, P. and Nwaezeapu, A. O. (2021). 'Production and Test of Mechanical Properties of Ceiling Board Produced from Local Waste Materials'. International Journal of Advances in Engineering and Management (IJAEM), 3 (11), 99-105.

Aladenika, K.; Olanrewaju, O. M. and. Olaitan, S. K. (2021) 'Comparative Investigation of the Mechanical Properties of Coconut Coir Fibre and Synthetic Fibre Reinforced Plaster of Paris (POP) Based Composites for Ceiling Applications'. Journal of Materials Science Research and Reviews, 7 (3), 1- 6.

Ameh, E. M., Nwogbu, C.C. and Agbo A. O. (2019) 'Production of Ceiling Board Using Local Raw Materials', Advance Journal of Science, Engineering and Technology, 4 (6), 1-5.

Aqil, M.; Musawi, M.; Thulfiqar, L.; Hussein, S. and Muhaned, A. (2018) 'Effect of Temperature and sisal fibre content on the properties of Plaster of Paris', International Journal of Engineering and Technology, 7 (4), 205-206.

ASTM International. (2019). Standard Test Method for Physical Requirements of Gypsum Board. (ASTM C473-19), West Conshohocken, PA: ASTM International.

ASTM International. (2020). Standard Test Method for Physical Requirements of Gypsum Board. (ASTM C473-20), West Conshohocken, PA: ASTM International.

ASTM International. (2020). Standard Test Method for Steady-State Thermal Transmission Properties. ASTM C177-20), West Conshohocken, PA: ASTM International.

ASTM International. (2022). Standard Test Method for water absorption, bulk density and apparent porosity. (ASTM C373-22), West Conshohocken, PA: ASTM International.

Atoyebi, O.; Kolajo, O. O.; Alabi, O. O.; Aina, S. O. (2023) 'Mechanical and Durability Assessment of Rockwool-Bamboo Reinforced Ceiling Boards, Research Square, DOI: https://doi.org/10.21203/rs.3.rs-2762269/v1: 1-12.

Ejiofor, C.C.; Emembolu, L. N.; John, S. U.; Chinyelu, C. E. and Ajali, J. J. (2024) 'The Mechanical and Physical Properties of Coir Fiber Reinforced Gypsum Board', International Journal of Research in Interdisciplinary Studies, 2(2), 23-26.

Jesuloluwa, S. I. and Bori, I. (2018) 'Formation of Ceiling Boards by the Combination of Sugarcane Bagasse and Rice Husk', Proceedings of ICGET, 1(1), 140 – 143.

Kamiyo, O.M. and Ekundayo, O. E. (2022) 'Comparative Thermal Performance Analysis of Rooftops with Elevated Ceiling Configuration, Kufa Journal of Engineering 13 (4), 39-52.

Koleoso, A. O. Edmond, O. A. Godwin, K. O and Hyginus O. O. (2020) 'Production of Ceiling Tile with High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) Plastic Wastes as Main Ingredients', Journal of Engineering and Applied Sciences, 15 (1), 114-127.

Nwogbu, C. C.; Agbo A.cO. and Nwogbu, P. I. (2021) 'Producing Ceiling Sheets from Locally Sourced Materials', American Journal of Applied Sciences and Engineering, 2(10), 1-5.

Obidiegwu, E. O., Mgbemere, H. E. and Akande, O. T. (2023) 'Synthesis and Characterisation of Abrasive Materials Produced from Snail Shells and Silica', Kufa Journal of Engineering, 14(2), 57-70.

Obidiegwu, E. O., Mgbemere, H. E. and Akporehe, A. O. (2024) 'The Study of Insulating Properties of Refractory Bricks Produced Using Melon Seed Husks as Pore Former', Kufa Journal of Engineering, 15(2), 61-73.

Ohijeagbon, I. O.; Bello-Ochende, M. U.; Adeleke, A. A.; Ikubanni, P. P.; Samuel, A. A.; Lasode, O. A. and Atoyebi, O. D. (2021) 'Physico-mechanical Properties of Cement Bonded Ceiling Board Developed from Teak and African Locust Bean Tree Wood Residue', Materials Today Proceedings, 44 (1), 2865–2873.

Yusuf, I. T.; Aboshio, A.; Babatunde, Y. O. and Kolade, S. O. (2021) 'Effect of Coconut Shell and Fibre on the Strength of Concrete', Bayero Journal of Engineering and Technology (BJET), 16 (1), 52-61.