



## Suitability of *Lagenaria breviflora* Rind filled plaster of Paris ceilings for building design

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### Abstract

Plaster of Paris (POP) has choice preference over other ceiling materials. However, reliance on it cannot guarantee low-cost housing development nowadays due to incessant rise in its price. Also, *Lagenaria breviflora* rind is usually produced in large quantity as waste and prevalently disposed of by indiscriminate dumping or burning, a practice that poses a serious threat to the environment. Thus, this study was designed to assess the feasibility of solving the above identified problems by utilising *Lagenaria breviflora* rind particle (LRP) as filler for development of cost-effective and thermally-safe composite plaster of Paris (POP) ceilings for building design.

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Using hand lay-up technique, samples in which the LRP was used to replace POP at various volumetric levels (0, 10, 16.5, 20, and 28.5 %) were fabricated in triplicates per formulation. After they had been sun-dried completely, their thermophysical and mechanical properties were investigated experimentally. The results showed changes in the samples' water absorption (24.13 – 34.99) %, bulk density  $(1.224 - 0.933) \times 10^{-3} \text{ kgm}^{-3}$ , thermal conductivity  $(0.2746 - 0.2007) \text{ Wm}^{-1}\text{K}^{-1}$ , specific heat capacity  $(1.407 - 2.246) \times 10^3 \text{ Jkg}^{-1}\text{K}^{-1}$ , thermal diffusivity  $(1.594 - 0.958) \times 10^{-8} \text{ m}^2\text{s}^{-1}$ , abrasion (0.953 – 1.341) %, and flexural strength (2.749 – 1.311)  $\text{N/mm}^2$  as proportion of the LRP in them increased. It was also noticed that thermal insulation tendency of the samples improved with increasing fractions of the LRP used. Comparatively, the samples exhibited better performance ability than conventional ceilings like Isorel and asbestos, thus portraying LRP to be a promising modifier for POP ceiling. Hence, in addition to solving the disposal problem, recycling the *Lagenaria breviflora* rind as described in this research

could ensure availability of inexpensive and thermally-safe POP ceilings for building design.

**Keywords:** Abrasion; Bulk density; Flexural strength; Thermal diffusivity; Thermal insulation; Waste material

## 1.0 Introduction

Nowadays, thermal comfort has become a legitimate concern to humans due to tremendous adverse effects of global warming on environment. Etuk *et al.* (2016) asserted that global warming is a consequence of human activities and looking for comfort of environment is imperative. Under this consideration, shelter (house/building) is not left out because it is one of the basic necessities of life. Notably, ceiling is an important requirement for thermal insulation in buildings when considering the possibility of heat to enter a room from the roof. Various types of panels usually applied as ceilings have been identified to include polyvinyl chloride (PVC), plywood, plaster of Paris (POP), and asbestos (Gesa *et al.*, 2014). Though POP ceiling has several advantages for selection over others, relying on it can hinder progress in attempt to ensure low-cost housing development as a result of incessant rise in its price (Robert *et al.*, 2021a). This is worrisome considering the fact that provisions in Goal II of the United Nations Agenda for Sustainable Development emphasize increased access to safe, sufficient, and inexpensive housing for the world's poorest people living in slums by the year 2030 (Ojoko *et al.*, 2016).

In the literature, few reported studies have shown that inclusion of certain waste materials as fillers in POP matrix could yield composite POP ceilings capable of performing satisfactorily. For instance, improvement in thermal insulation efficiency could be achieved by utilising rice husk ash (Ochang *et al.*, 2018), wood shavings (Pedreño-Rojas *et al.*, 2017),

groundnut seed coat and waste newspaper paste (Robert *et al.*, 2020a). Similar performance tendency is possible by using rice husk and wheat straw (Ejaz *et al.*, 2022) as well as wool and coir fibres (Guna *et al.*, 2021). More so, incorporation of cigarette butts as filler can enhance better mechanical behaviour of the resulting POP ceiling (Mórales-Segura *et al.*, 2020). According to Fantilli *et al.* (2021), wool fibres improve mechanical performance better than hemp fibres if used as fillers to develop POP ceilings. Since waste materials are cheaply available, it is obvious that several such panels can be produced from a small amount of POP powder thereby reducing the cost and at the same time ensure improved thermal comfort in buildings.

The aim of this research is to assess the feasibility of solving the above-identified problems by utilising *Lagenaria breviflora* rind particle as filler for development of cost-effective and thermally-safe composite plaster of Paris (POP) ceilings for building design. *Lagenaria breviflora* (Benth.) Roberty is a perennial climber that belongs to *cucubritaceae* and is found in Central, East, and West Africa. Its name in English is wild colocynth. Local names of the plant in Hausa are *gojin jima* and *gunar jùmaà*. The fruit is widely used in folkore medicine especially as herbal remedy for treatment of human measles and digestive disorders. Livestock farmers utilise it for coccidiosis and Newcastle treatment in poultry and the fruit is perhaps also used in bating-bath to prepare skin to receive the tanning material (Adedapo *et al.*, 2013). The stem, when broken, has an unpleasant smell and a decoction from it is said to be used in Nigeria for headache (Karaye *et al.*, 2021). Adedeji *et al.* (2017a) experimented on the fruit extracts against wood rotting fungi on *Vitex doniana* wood and found that they could form a strong potential source of natural antifungals for industrial wood production. The main chemical constituents in

the fruit extracts include phenols, triterpenoids, alkaloids, saponins, tannins, anthraquinone, flavonoids, and terpenoids, which are vital instrumentalities that can be optimised for wood protection against fungi and termites (Adedeji *et al.*, 2017b). Observably, the rind is usually produced in large quantity and prevalently disposed of by indiscriminate dumping (or burning if allowed to dry). Like in the cases with other solid wastes, this practice poses a serious threat to the environment (Ekpenyong *et al.*, 2022; Umanah *et al.*, 2022) and thus warrants recycling the rinds into sustainable construction materials as a viable solution (Ekong *et al.*, 2022; Robert *et al.*, 2022a). Thermophysical and mechanical properties of the new materials will be assessed in order to determine the potential of the waste in question since materials with high economic worth can be thrown away in trash cans (Etuk *et al.*, 2020a).

## 2.0 Materials and Methods

### 2.1 Materials description and collection

*Lagenaria breviflora* rinds and plaster of Paris (POP) were the main materials utilised in this work. The POP was collected from a building construction site. Both materials were sourced in large quantities within Mkpato Enin Local Government Area, Akwa Ibom State, Nigeria.

### 2.2 Processing of the *Lagenaria breviflora* rinds

The rinds were washed thoroughly using clean tap water. This was done to remove dirt and other forms of impurities from them. After that, they were sun-dried completely in air. The dried rinds were pulverised and sieved to obtain particles of sizes not larger than 2.0 mm for use in the study. The sieved material was coded LRP. Figure 1 shows the appearance of the material.



**Fig. 1:** Appearance of the sieved LRP

### 2.3 Analysis of the materials

The POP and LRP were divided into two large portions each. Using one portion per material, Sieve analysis was performed (Robert *et al.*, 2021b) to determine the particle size distribution of the LRP. Also, repose angle was evaluated for the POP and LRP using fixed funnel method with some modifications as

described by Robert *et al.*, (2022b) and their loose bulk density was determined as the ratio of mass to untapped volume. Again, chemical composition analysis of the LRP was performed based on Technical Association of Pulp and Paper Industry (TAPPI) Standards as applied in other researches (Johar *et al.*, 2012; Bano and Negi, 2017).

## 2.4 Samples preparation

The remaining portions of the materials were utilised for fabrication of samples. Table 1 shows the mix design adopted for samples preparation in this study.

Proportioning of the LRP and POP was by volume method. In all the cases, the volumetric

ratio of water to composite mix was maintained at 1:3. For each formulation, samples were prepared in triplicates and subjected to complete sun-drying.

**Table 1:** Research mix design

Materials	Mix proportions (%)				
LRP	0.0	10.0	16.5	20.0	28.5
POP	100.0	90.0	83.5	80.0	71.5

Those meant for evaluation of themophysical properties were developed in circular moulds measuring 110 mm in diameter with thickness of 7 mm. For determination of mechanical properties, the samples were prepared using moulds of dimensions 150 mm x 115 mm x 14 mm. All the samples were subjected the tests intended for them.

## 2.5 Properties investigation

### 2.5.1 Bulk density and Water absorption

For bulk density evaluation, the bulk volume of each sample was obtained by using modified water displacement method (Robert *et al.*, 2019). With the aid of a digital balance (S. METTLER – 600 g), the corresponding mass was measured and the bulk density,  $\rho$  was computed based on the relation (George *et al.*, 2010; Etuk *et al.*, 2020b; Okorie *et al.*, 2020; Robert *et al.*, 2020b):

$$\rho = \frac{M_s}{V} \quad 1$$

where  $M_s$  = mass of the sample, and  $V$  = bulk volume of the sample. Water absorption was determined in accordance with the procedure used by Etuk *et al.* (2023) for 24 – hour immersion. The masses before and after immersion were noted for each sample and the data obtained were used to compute water

absorption based on the equation Robert *et al.*, 2022b)

$$WA = \left( \frac{W_a - W_d}{W_d} \right) 100\% \quad 2$$

where  $WA$  = water absorption,  $W_d$  = mass of the sample before immersion, and  $W_a$  = mass of the sample after immersion.

### 2.5.2 Thermal conductivity

By employing Modified Lee – Charlton's Disc Apparatus technique, thermal conductivity was determined for each sample (Robert *et al.*, 2021c). In this study, the experimental set-up consisted of an electric hotplate (Model PHP – 402), ring clamp with stand, two thermometers, Lee – Charlton's discs made of nickel, a cylindrical block made of aluminium, and thick cotton wool (for lagging purpose), and other components as described in details in (Robert *et al.*, 2022b). Modelling of cooling rate functions were implemented by means of Origin Software (Version 2019) and the required thermal conductivity was obtained using the formula:

$$k = \left( \frac{Mcx}{A\Delta\theta} \right) \frac{dT}{dt} \quad 3$$

where  $k$  = thermal conductivity of the sample,  $M$  = mass of the disc,  $c$  = specific heat capacity of the disc,  $x$  = thickness of the sample,  $A$  =



area of the sample's cross-section,  $\Delta\theta$  = temperature difference between the sample's cross-sectional surfaces at steady state, and  $\frac{dT}{dt}$  = rate of cooling of the disc.

### 2.5.3 Specific heat capacity and Thermal diffusivity

SEUR'S apparatus was employed for determination of specific heat capacity (Etuk *et al.*, 2020c). The system consisted of square plates of aluminium and plywood each 60 mm x 60 mm x 8 mm. Temperature monitoring/measurement was performed by means of digital thermometers (Model No. 305, calibrated and equipped with type-K probe). When the system attained thermal balance during heat exchange, the quantity,  $Q_p$  of heat gained by the plywood plate and the amount,  $Q_a$  of heat lost by the aluminium plate were calculated. Using the data obtained, the specific heat capacity  $C$  was found using the equation (Etuk *et al.*, 2022a):

$$C = \left( \frac{Q_a - Q_p}{M_s \delta T} \right) \quad 4$$

where  $Q_a$  = quantity of heat lost by the aluminum plate,  $Q_p$  = quantity of heat gained by the plywood,  $M_s$  = mass of the sample,  $\delta T$  = rise in temperature of sample.

The values of bulk density, thermal conductivity, and specific heat capacity obtained for each sample were applied to determine the corresponding thermal diffusivity,  $\lambda$  in accordance with the formula (Etuk *et al.*, 2021; Robert *et al.*, 2021d; Etuk *et al.*, 2022b):

$$\lambda = \frac{k}{\rho C} \quad 5$$

### 2.5.4 Abrasion

This test was necessary for prediction of the durability of a material that can undergo tear and wear when being worked on. In this work, both faces of each sample were cleaned using a lint free cloth. The mass was also noted before a very hard shoe brush (on which 1 kg weight

was attached) was used to make 70 cycles of back-and-forth movements against each face of the samples. Both sides of the flaked samples were cleaned. The mass of the flaking was determined in each case as the difference between the masses of a sample before and after performing the abrasion test on it. Using the data obtained, the susceptibility to abrasion was computed based on the relation (Robert *et al.*, 2020a):

$$A_s = \left( \frac{M_f}{M_b} \right) 100\% \quad 6$$

where  $A_s$  = abrasion,  $M_b$  = mass of the sample before being flaked, and  $M_f$  = mass of the flaking.

### 2.5.5 Flexural strength

Using a Computerised Electromechanical Universal Testing Machine (WDW – 10) in three-point bending configuration, the flexural strength of each sample was examined as outlined in ASTM C367/367M (2022). A sample was inserted as a beam on the machine's flexure assembly and loaded at its middle. When fracture occurred, the maximum load,  $F$  applied, sample's width,  $b$  and span length,  $L$  were noted and utilised in the computation of flexural strength,  $\sigma$  adopting the formula (Robert *et al.*, 2021e):

$$\sigma = \frac{3Fd}{(2bx^2)} \quad 7$$

The tests were carried out at room temperature with  $\pm 1.0$  °C variations.

## 2.6 Statistical consideration

Using the values obtained for the representative samples per formulation, the mean and standard error were determined for each property investigated. The final results obtained were tabulated.

## 3.0 Results and Discussion

The results of tests performed on the LRP are presented in Table 2. It is observed that the

LRP has a smaller repose angle value compared to the POP. Since repose angles correlate inversely with materials' particle sizes (Lu *et al.*, 2015), it can be inferred in this case that the POP particles are finer than those of the LRP. The repose angle values also signify that cohesivity is greater in the POP than the LRP. Considering the fact that repose angle values of

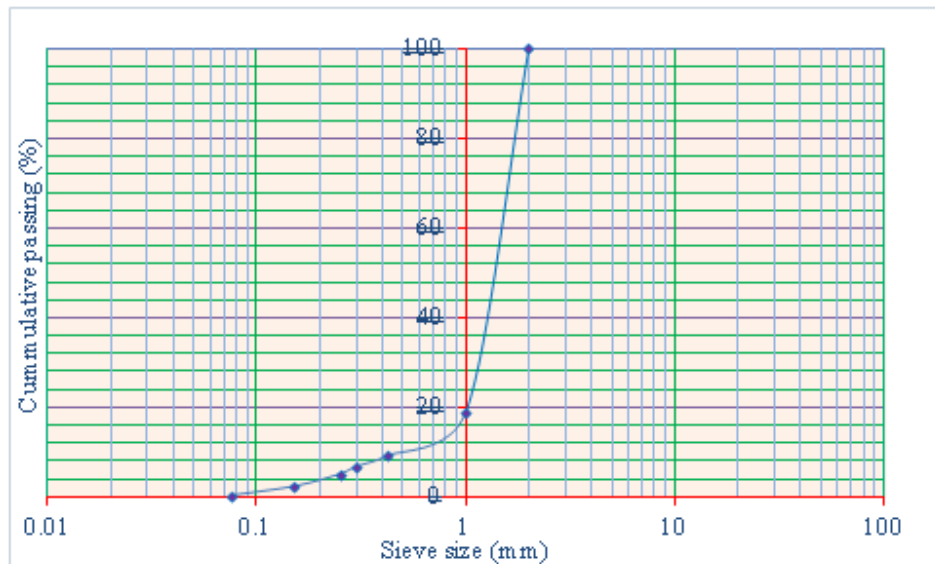
30 ° to 35 ° signify good flowability and those ranging from 41 ° to 45 ° are interpreted to mean passable flow property (European Pharmacopoeia, 2010), it is appropriate to adjudge that both materials have flow characteristics suitable for manufacturing purpose as considered in this research.

**Table 2:** Results of each analysis performed on the processed materials

Materials	Values for three determinations of the parameters assessed				
	Chemical composition (%)			Repose angle (°)	Loose density ( $kgm^{-3}$ )
	Cellulose	Hemicelluloses	Lignin		
LRP	17.79 ± 0.04	13.81 ± 0.02	8.78 ± 0.01	35.30 ± 0.02	362.4 ± 0.2
POP	-	-	-	43.85 ± 0.01	750.5 ± 0.1

Figure 2 reveals that sizes of the LRP are not uniform. About 100 %, 6.8 %, and 0.32 % of them measure 2 mm, 0.3 mm, and 0.075 mm respectively in size. The LRP has mean loose density value of 51.72 % less than that of POP. This clearly shows that the LRP can yield a

composite panel with reduced weight if a remarkable volume of it is used to develop ceiling with the POP. From assessment of chemical constituents, the LRP contains more cellulose than lignin thus signifying that it has high affinity for water uptake.



**Fig. 2:** Particle size distribution of the LRP

Consequently, water absorption of the samples increases as the proportion of LRP increases in them as presented in Table 3. That is to say, the samples become more hydrophilic as the LRP loading increases. At 10 % LRP content level,

approximately the same water absorption (30 %) was reported by Robert *et al.* (2021a) for POP ceiling fabricated with 25 % fraction of untreated wood dust. From the results, it can be deduced that utilisation of LRP at 10, 16.5, 20,

and 28.5 % volumetric replacement levels decreases mean bulk density of the resulting panels by 7.92, 13.48, 18.46, and 23.38 % respectively. Considering density of  $1810 \text{ kgm}^{-3}$  reported for asbestos ceiling board (Oyekunle *et al.*, 2018), the studied samples are less dense than it. Since application of light-weight materials is a practical way of reducing dead loads in buildings, inclusion of the LRP could enhance choice preference in building designs. All the thermal conductivity values obtained for the samples fall within the recommended range given as  $0.023$  to  $2.900 \text{ Wm}^{-1}\text{K}^{-1}$  for heat-insulating and construction materials (Rajput, 2015). Conventional heat insulation ceilings like Isorel and asbestos have thermal conductivity of  $0.4498 \text{ Wm}^{-1}\text{K}^{-1}$  (Gesa *et al.*, 2014) and  $0.319 \text{ Wm}^{-1}\text{K}^{-1}$  (Twidell and Weir, 1990) respectively. It can therefore be remarked that heat transmission restriction from building roof could be enhanced more efficiently by applying the samples developed in this work compared to the case of installing either Isorel or asbestos.

Figure 3 shows that bulk density and thermal conductivity of the samples trend inversely with proportion of the LRP used. That is to say, for POP ceilings, weight reduction with improved heat-restricting ability is possible by modifying it using the LRP. The case of density is simply because LRP is lighter than POP as earlier remarked. In the case of thermal conductivity, it could be understood that introduction of the LRP into POP matrix increases voids (interstices/pores) which constitute air space. Etuk *et al.* (2023) posited that void spaces are due to presence of interstices in a 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. Now that the samples in this study are completely dry and air is a good thermal insulant, the ability of the samples to restrict heat correlates positively with the volume of air

in them. This, in turn, causes their thermal conductivity to exhibit an inverse relationship with volume fraction of the LRP utilised.

Specific heat capacity is another thermal property that characterises the behaviour of a material. It is observed in this research that LRP gradually improves specific heat capacity of the samples as its utilised fraction increases. A similar trend was observed by Ochang *et al.* (2018) concerning POP ceilings produced with fractions of rice husk ash (RHA). At 10 % and 20 % levels, the use of RHA yielded increment in specific heat capacity by 5.93 % and 8.76 % respectively. In this study, LRP inclusion at similar levels (that is, 10 % and 20 %) improves specific heat capacity by about 18.12 % and 55.15 % respectively. Notably, the process variables in these separate researches were unaltered. Thus, the improvements noticed in specific heat capacity of the samples are mainly due to RHA or LRP utilised as the case may be. It is therefore appropriate to submit that prior to change in temperature of a kilogramme mass by one Kelvin; the LRP has potential to ensure better heat-storing capability that RHA if used for manufacturing of composite POP ceilings. In comparison with ceilings developed from waste materials, the use of LRP at 10 % level yields mean specific heat capacity ( $1662 \text{ Jkg}^{-1}\text{K}^{-1}$ ) that shows a good agreement with  $1636.971 \text{ Jkg}^{-1}\text{K}^{-1}$  reported by Okorie *et al.* (2020) for composite ceilings developed from waste carton paste and 25.6 % tiger nut fibre content with cassava starch slurry as binder.

Another good comparison is the mean specific heat capacity value ( $2183 \text{ Jkg}^{-1}\text{K}^{-1}$ ) obtained by utilising the LRP at 20 % level in the light of  $2140.930 \text{ Jkg}^{-1}\text{K}^{-1}$  reported by Etuk *et al.* (2021) for compressed sugarcane leaf ceiling board. Decrease in thermal diffusivity, as observed, is feasible because although thermal conductivity and bulk density exhibit direct relationships, specific heat capacity shows

inverse trend with increasing percentages of the LRP.

Table 3: Results of property tests on the samples

Fraction of LRP (%)	WA (%)	$\rho$ ( $10^3 \text{ kg m}^{-3}$ )	$k$ ( $\text{W m}^{-1} \text{K}^{-1}$ )	$C$ ( $10^3 \text{ J kg}^{-1} \text{K}^{-1}$ )	$\lambda$ ( $10^{-7} \text{ m}^2 \text{ s}^{-1}$ )	$A_s$ (%)	$\sigma$ ( $\text{N/mm}^2$ )
0.0	24.13 ± 0.08	1.224 ± 0.004	0.2746 ± 0.0003	1.407 ± 0.004	1.594 ± 0.001	0.953 ± 0.004	2.749 ± 0.005
10.0	30.36 ± 0.03	1.127 ± 0.003	0.2617 ± 0.0005	1.662 ± 0.004	1.397 ± 0.004	1.021 ± 0.004	2.298 ± 0.003
16.5	32.02 ± 0.07	1.059 ± 0.001	0.2293 ± 0.0003	1.965 ± 0.006	1.102 ± 0.003	1.132 ± 0.003	1.817 ± 0.005
20.0	33.34 ± 0.02	0.998 ± 0.005	0.2183 ± 0.0005	2.183 ± 0.005	1.005 ± 0.003	1.242 ± 0.003	1.440 ± 0.004
28.5	34.99 ± 0.04	0.933 ± 0.004	0.2007 ± 0.0004	2.246 ± 0.003	0.958 ± 0.002	1.342 ± 0.004	1.311 ± 0.005

This means that LRP fraction is capable of reducing the speed at which thermal disturbance diffuses within the samples and propagates temperature from one side to the other across the thickness. Arguing on the basis of heat transfer through the samples, it is obvious that as LRP proportion increases, thermal resistivity (reciprocal of thermal conductivity) increases thereby leading to enhanced opposition to heat transmission through them. During such process, specific heat capacity increases and brings about reduction in heat diffusion tendency thereby leading to delay in temperature change. With that, it becomes possible for the diffusion of any absorbed heat to be slowed down resulting to decrease in thermal diffusivity of the resulting sample. The resistances to wear by friction are expressed by abrasion test results. For the samples, the values obtained range from (0.953 ± 0.004) % to (1.341 ± 0.004) % due to utilisation of 0 % to 28.5 % of the LRP for their fabrication. In this case, the highest mean abrasion is less compared to  $2.0 \times 10^{-2}$  (which is 2.0 %) reported by Berge (1963) for asbestos ceiling. This means that if subjected to abrasion under same conditions in service, the samples would appear more durable than asbestos. In the case of flexural strength, the mean values obtained by increasing the fraction of LRP beyond 10 % are less than the maximum value of 1.97 N/mm<sup>2</sup> reported by Oladele and Okoro (2015) for composite ceiling sheet made from rattan particulate fibre, starch slurry, and waste newsprint paper pulp. However, the least mean value obtained (1.311 N/mm<sup>2</sup>) is 31.1 % greater compared to the value of 1.00 N/mm<sup>2</sup> reported (Berge, 1963) for asbestos ceiling.

It can be observed in figure 4 that increase in proportion of the LRP brings about increase in susceptibility to abrasion but decrease in flexural strength of the samples. Plausibly, this may be due to the fact that the since the filler (LRP) is refractory in nature, its inclusion



weakens the mechanical interlocking and consequently reduces cohesiveness within the POP matrix. Eventually, this promotes

decrement both in abrasion resistance and flexural strength with increasing fraction of the LRP.

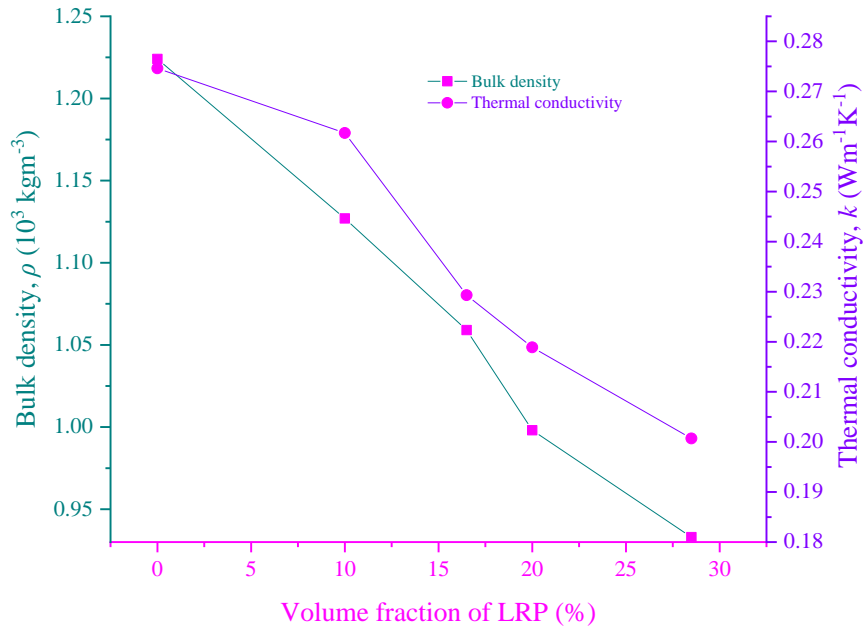


Fig. 3: Variation of bulk density and thermal conductivity with LRP loading

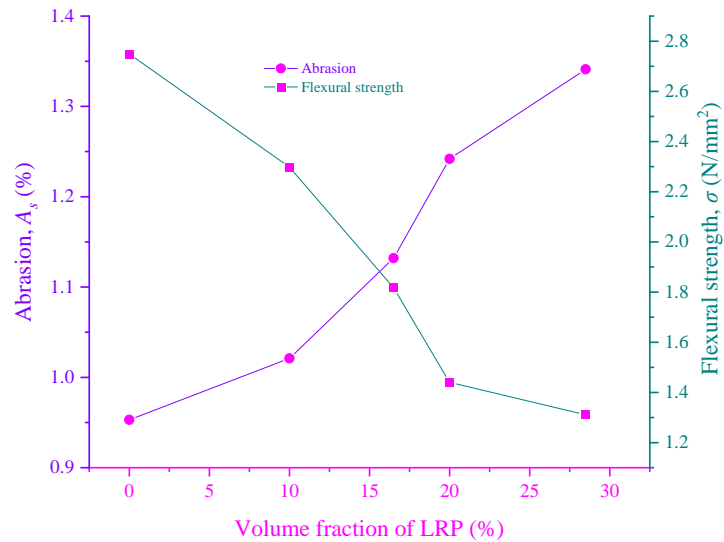


Fig. 4: Variation of abrasion and flexural strength with LRP loading

**Conclusion**

From the results of the experiments conducted on the fabricated samples in this

research, it was observed that water absorption increased with increase in volumetric proportion of LRP in the samples. Utilisation of the LRP improved thermal insulation efficiency of the resulting

samples. LRP was found to be lighter than POP and as such, can reduce the weight of the resulting ceiling significantly depending on the proportion of it that is utilised. Though a better performance could be achieved when compared to cases reported in the literature for some ceiling sheets, increasing content of the LRP resulted to increase in susceptibility to abrasion and decrease in flexural strength of the samples. Generally, the LRP exhibited desirable potentials for use as filler to modify POP for building design. Thus, putting *Lagenaria breviflora* rind into production cycle for development of composite POP ceilings is a practical way of solving its disposal problem and also ensuring availability of thermally-safe and cheap ceilings for low-cost building construction/ housing development.

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