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Investigation of Thermal Properties of Fabricated Plaster of Paris -Rice Husk Ash Composite with Varying Matrix-Filler Volume Fractions for Thermal Insulation Applications

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ABSTRACT: *This study investigated the thermal conductivity, thermal diffusivity, specific heat capacity, thermal resistance and density of fabricated Plaster of Paris-Rice Husk Ash (POP-RHA) composite material at varying matrix-filler volume fractions for thermal insulation (ceiling board) applications. Six samples of the POP-RHA composite were fabricated with the RHA (filler) being 0,10,20,30,40 and 50% volume fractions using manual mixing method and hand lay-up technique .Lee's Disc apparatus and Fourier's law of conductive heat transfer were used to determine the thermal conductivity of the fabricated POP-RHA composite samples. Calorimetric method of mixtures was employed in determining the specific heat capacity of the test material. The density, thermal resistance and thermal diffusivity were evaluated using appropriate formulas. Results reveal that thermal diffusivity, thermal conductivity and density decrease with increasing filler (RHA) content in the POP-RHA composite material. While thermal resistance and specific heat capacity increases with increasing filler content in the matrix. The fabricated composite material showed better thermal insulative characteristics than the ceiling boards made of POP but best the at 40% composition of the filler (RHA) in the composite. At this40% composition, the thermal properties were: thermal conductivity ,*$0.111Wm^{-1}k^{-1}$*, thermal diffusivity,* $3.11m^2s^{-1}$ *specific heat capacity,* $2253Jkg^{-1}k^{-1}$*and thermal resistance* $0.027m^2kW^{-1}$*. Also, the material was lighter in weight than the ceiling boards made of POP which is a good characteristic of new the engineering materials thought of. Conclusively, POP-RHA composite material ceiling board can replace ceiling boards made pure Plaster of Paris in terms of parameters investigated.*
KEYWORDS*: POP-RHA composite, thermal diffusivity and thermal resistance*

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I. INTRODUCTION

One of the major concerns of trained builders is to design a building that the interior environment is thermally tolerable and conducive for the occupants of the building [2]. Human comfort which is the end point of a technological quest is a crucial factor that must be considered in the design and construction of buildings. In our homes, the walls, ceiling, windows, door and roofing materials contribute largely to comfort of the home. Therefore, right choice of materials needed to be used in our buildings.

Engineers are often confronted with the challenge of evolving or producing new materials that have optimum thermal properties, light in weight and cheap. To combat this task is to use low density particulate materials like rice husk ash or wood ash in a polymer matrix to form a composite [6].

A composite material is a material made from two or more constituents with significantly different physical and chemical properties but when combined, produce a material with characteristics differ from individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for reasons being that the materials are stronger, lighter, or less expensive when compared to the traditional materials.

Plaster of Paris (POP) is a quick-setting gypsum plaster consisting of a fine white powder (calcium sulphate hemihydrates), which hardened when moistened and allowed to dry. Known since the ancient times, plaster of Paris is so called because of its preparation from the abundant gypsum found near Paris. Pop generally shrinks or crack when dry, making it an excellent medium for casting moulds. It is commonly used to precast and hold parts of ornamental plaster work placed in ceilings and cornices. Plaster of Paris is prepared by heating calcium sulphate dehydrate or gypsum to 120-180^{0}C. With an additive to retard the set, it is called wall, or hard wall plaster, which can provide passive fire protection for internal surface.

Rice husk is a bye product of rice milling. It is a unique crop residue with uniform size and of which 14-25% can be converted to rice husk ash (RHA) [7]. Rice husk is used as fertilizer and an additive for concrete and cement fabrication in construction industry because of its high availability, low bulk density (90-150kg/m^3), toughness, abrasive in nature, resistance to weathering and unique composition, additionally high porosity with very high surface area is essential requirement for filler in compositions, [4]. Rice husk(RH) , an organic agricultural waste, is abundantly available in rice producing countries like China, India, Brazil, US, South East Asia, Cambodia, Vietnam, Nigeria and Myanmar, which is used as fuel to generate steam. It contains about 75% organic volatile matter and the remaining 25% of the weight is converted into ash[3].

Some developing countries like Nigeria are not properly utilizing agricultural wastes such as rice husk ash which constitute environmental hazards for gainful engineering production. Rice husk ash causes health hazards like silicosis, cancer, tuberculosis, chronic cough and sight disorder in areas where it is dumped. Therefore there is need to develop more ways of reducing the amount of the waste in the environment[6] . One of the easiest ways of solving the problem is to use rice husk ash as filler in POP matrix to form pop-rice husk ash composite as a means of meeting the quest of new engineering that have optimum thermal properties, light in weight and cheap.

Thermal conductivity of a material indicates the material's ability to conduct heat. Good insulators have low values of thermal conductivity. thermal diffusivity is a property that measures the rate of transfer of heat of a material from a hot side to a cold of a material. Low values of thermal diffusivity are ascribed to thermal insulators but, high values for conductors. Thermal resistance is a measure of opposition to the flow of heat energy. Just like specific heat capacity, thermal resistance values for insulators are high.

This research therefore, seeks to develop a new kind of composite material using POP and RHA and to investigate its thermal properties in order to ascertain its suitability to be used as ceiling board for thermal insulation .This study will among other advantages identify the best volume fraction of pop-RHA ash composite to be used as ceiling material , explore the potentials of RHA as filler in the composite production, it helps in reducing environmental pollution due to rice husk waste, provide useful information on the thermal properties of pop-RHA composites to engineers, builders and researchers in the composites industry and may provide baseline information for further investigations on POP-RHA composite material of different volume fractions.

This study is limited to the investigation of the thermal properties of pop-RHA composite only, which include the specific heat capacity (using the method of mixture), density, thermal diffusivity, thermal resistance, thermal conductivity, using the Lee’s Disc Apparatus method.

II. MATERIALS AND METHOD

The materials used in this study include the following: POP (matrix material), RHA (filler material),fibre, disc-shaped mould, Lee’s disc apparatus, two thermometers, steam boiler, calorimeter, gloves, digital venier callipers, weighing balance, Bunsen burner, retort stand and with clamp, water, brass disc, screw gauge, digital stopwatch, threads and 300μm sieve.

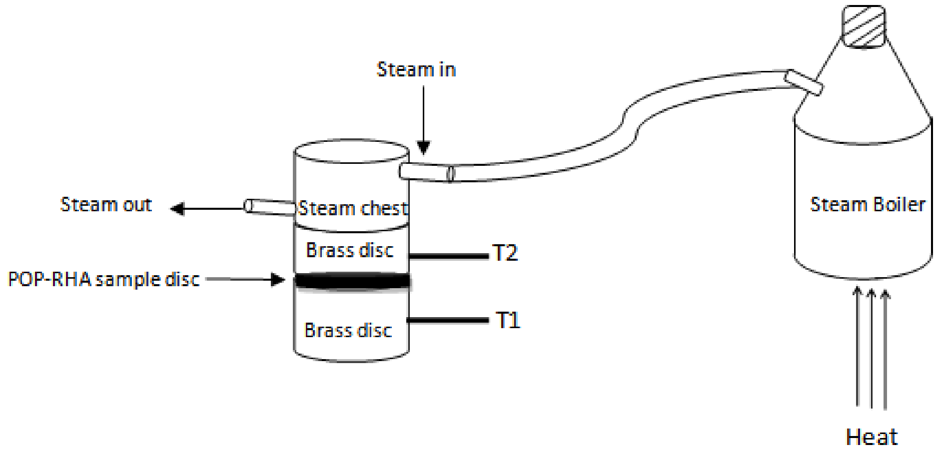
Samples preparation

The test samples of the POP-RHA composite were produced using manual mixing method and hand lay-up technique. The composites were produced by mixing the powdered POP and 300μm sieved RHA collected from The Gboko Rice Mill, Benue State in the following volume ratios 10%,20%,30%,40% and 50% of RHA respectively in a container, little quantity of water was added and the mixture was stirred until the mixture became uniform and plaster- like. Before casting the plaster, the mold was first rubbed with wax releaser that allows easy de-molding after the sample eventually sets .The composite mixture was then poured into the mould half-filled which was placed on a smooth surface. Then, fibres of negligible mass were evenly distributed on the top for reinforcement and after which the mold was covered up to the brim with the plaster composite. The molded samples set, were de-molded and cured under sun light for seven (7) days(see Plate I). The dry samples were smoothened using sand paper. The diameter of each sample was chosen to be the same with the brass disc such to provide good contact during heat conduction.

Plate 1: Curing of Moulded POP-RHA samples.

Determination of thermal conductivity of fabricated POP-RHA composite

The mass , thickness and diameter of the fabricated POP-RHA were determined using electronic weighing balance, micrometer screw gauge and Vernier caliper gauge respectively. The steam boiler filled with 2000mL of water, steam chest , POP-RHA sample disc, metallic disc , thermometers and other component of experimental set up are as shown in Fig.1 below.



The heating started by sending steam through the heating chamber. The temperatures T_1 and T_2 were monitored at regular interval till they reached steady State. The steady state temperatures T_1 and T_2 were noted .The heating chamber was lifted and both the sample and the metallic disc were removed. Then, heating chamber was then placed directly on the brass disc. The brass disc was allowed to heat at least 10^{o} C above the steady state temperature T_1 measured in the first part of the experiment. The heating chamber is then removed. The sample was placed back on the brass disc and the thermometer was used to monitor the temperature of the brass disc at an interval of 60seconds as it cools down for ten minutes. The brass disc was allowed to cool down to at least 5^{o}C below the steady state temperature T_1. The above procedure was then repeated for the remaining POP-RHA composite samples. The rate of cooling for all the samples was also determined .The thermal conductivity of the POP-RHA composite samples was determined using Fourier's law of conductive heat transfer. The thermal conductivity of the POP-RHA composite is thus given as

$$K = \frac{ms\left(\frac{dT}{dt}\right)x}{A(T_2 - T_1)} \qquad (1)$$

Where m = mass of brass, s = specific heat capacity of the brass disc, $\frac{dT}{dt}$ = the rate of cooling (obtained from the graph),A = the cross sectional area of the sample

(T_2-T_1) = temperature difference across the sample and x = thickness of the sample.

Determination of specific heat capacity fabricated POP-RHA composite

With the aid of Electronic weighing balance model XY2000JB, the masses of empty copper calorimeter and the POP-RHA composite sample where measured and recorded as $M_c\ and\ M_s$. Reasonable quantity of water was poured into the empty calorimeter. The calorimeter and its content was weighed and temperature taken recorded as $M_{cw}\ and \theta_1\ respectively$. The POP-RHA composite was then heated in a furnace to a temperature of θ_2 and then removed by the tongs and quickly transferred to calorimeter with water. The mixture was stirred gently until a final temperature was reached at θ_3. The following precautions were observed in the experiment: The mixture of POP-RHA composite and water was stirred gently in order to have uniform distribution of heat in the mixture and to avoid splashing of the calorimeter and its content. Also the copper calorimeter was well lagged to avoid heat lost or gain from the surrounding. The specific heat capacity was calculated from the principle of heat transfer which states that the heat lost by the POP-RHA composite in cooling from θ_2 to θ_3 is equal to heat gained by water and calorimeter heating from $\theta_1$toθ_3 if no heat is lost to surroundings. This is mathematically expressed as

$$M_s C_s(\theta_2 - \theta_3) = M_w C_w(\theta_1 - \theta_3) + M_c C_c(\theta_1 - \theta_3) \quad (2)$$

Where Mass of water $M_w = M_{cw} - M_c$, Specific heat capacity of water $C_w = 4200Jkg^{-1}k^{-1}$,Specific heat capacity of copper calorimeter $C_c = 400Jkg^{-1}k^{-1}$ and Specific heat capacity of POP-RHA composite $C_s\ determined$ from equation 2 above.

Determination of Thermal Diffusivity of POP-RHA composite material

The thermal diffusivity of POP-RHA composite material is calculated from equation 3 below

$$\alpha = \frac{k}{\rho c} \quad (3)$$

where α = thermal diffusivity of the material, k = thermal conductivity of material, ρ = density of material and c = specific heat capacity of the material.

The density of the material ρ is calculated from the relation

$$\rho = \frac{mass}{volum\ e} \quad (4).$$

$$Volume\ of\ the\ merial = cross\ sectional\ Area \times thickness \quad (5)$$

$$cross\ sectional\ Area = \frac{\pi d^2}{4} \quad (6)$$

III. RESULTS

The results of the experimental work carried out in this study are presented in the tables and figures below.

TABLE 1: COMPOSITION OF FABRICATED POP-RHA COMPOSITE MATERIAL

Volume (%)	
POP(matrix)	**RHA(filler)**
100	0
90	10
80	20
70	30
60	40
50	50

TABLE 2. STEADY TEMPERATURES OF THE POP-RHA COMPOSITES

RHA%	T1 ℃	T2 ℃
0	79	96
10	74	96
20	72	96
30	71	96
40	67	96
50	65	96

TABLE 3: COOLING OF THE POP-RHA COMPOSITE

Time(s)	Temperature (°C)					
	0%RHA	10%RHA	20%RHA	30% RHA	40%RHA	50%RHA
0	88	87	84	80	79	77
60	84	82	79	75	74	72
120	81	79	76	72	71	69
180	79	76	74	71	69	67
240	78	74	72	70	67	65
300	77	73	71	69	66	64
360	76	72	70	68	65	63
420	75	71	69	67	64	62
480	74	70	68	66	63	61
540	73	69	67	65	62	60
600	72	68	66	64	61	59
660	71	67	65	63	60	58

TABLE 4: DIMENSIONS AND THERMAL PROPERTIES OF FABRICATED POP-RHA COMPOSITES

RHA Composition (%)	Thickness x m	Diameter d m	Volume V X10^{-5} m^3	Mass m kg	Density (ρ) (kg/m^3)	Thermal Conductivity k ($Wm^{-1}k^{-1}$)	Specific Heat $Jkg^{-1}k^{-1}$	Thermal diffusivity $\alpha \times 10^{-8} m^2s^{-1}$	Thermal resistance R (m^2kW^{-1})
0	0.003	0.107	2.6979	0.0466	1727.27	0.186	1872	5.75m.	0.0161
10	0.003	0.107	2.6979	0.0454	1682.79	0.175	1983	5.84	0.0171
20	0.003	0.107	2.6979	0.0445	1649.43	0.143	2036	4.26	0.0210
30	0.003	0.107	2.6979	0.0436	1616.07	0.146	2199	4.11	0.0205
40	0.003	0.107	2.6979	0.0428	1586.42	0.111	2253	3.11	0.0270
50	0.003	0.107	2.6979	0.041	1519.70	0.112	2317	3.18	0.0268

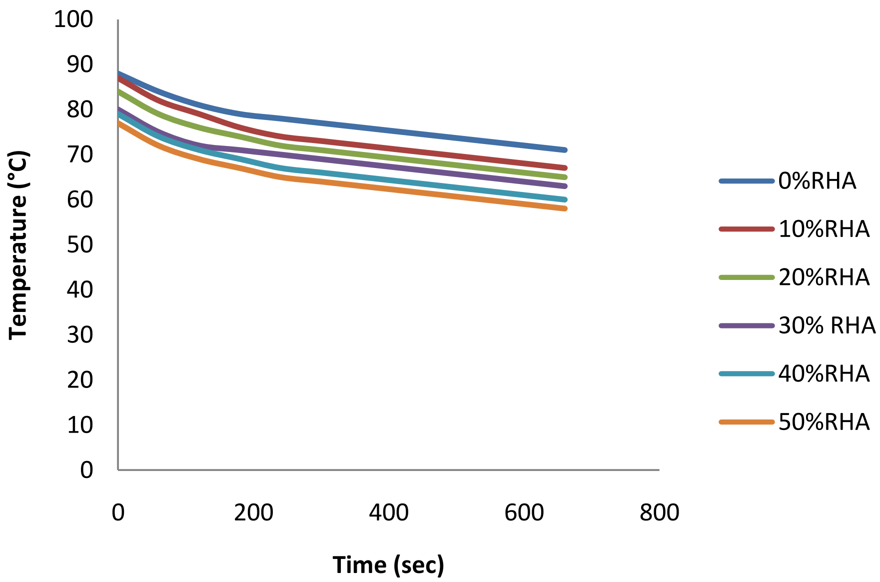


Figure2: Cooling curve for POP-RHA composites

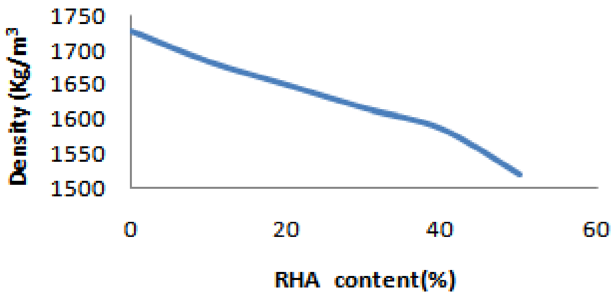


Figure 3: variation of density of POP-RHA composite with RHA content

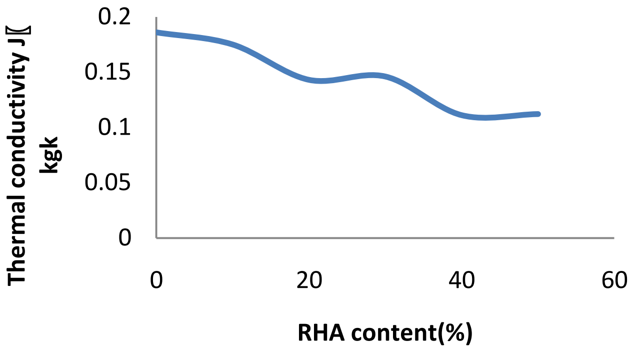


Figure4: variation of thermal conductivity of POP-RHA composite with RHA content

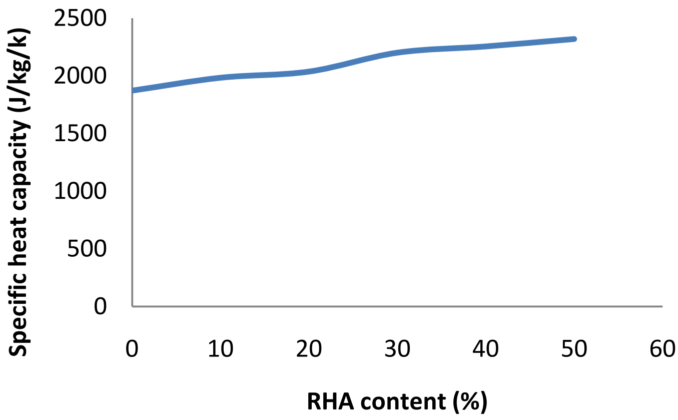


Figure5: Variation of specific heat capacity of POP-RHA composite with RHA content

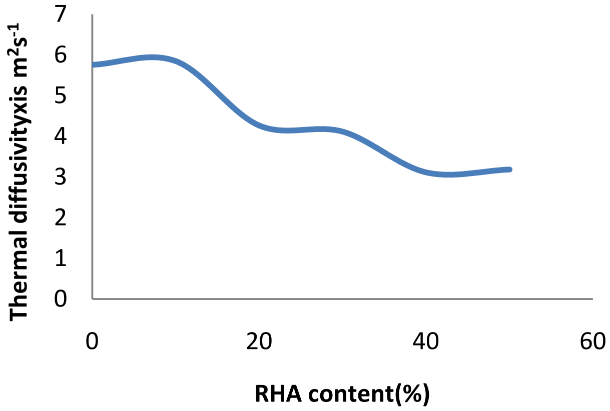


Figure 6: Variation of thermal diffusivity of POP-RHA composite with RHA content

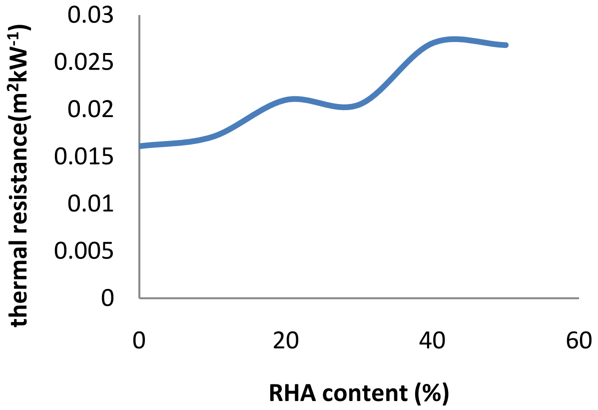


Figure7: Variation of thermal resistance of POP-RHA composite with RHA content

IV. DISCUSSION OF RESULTS

This research investigated the thermal properties(Thermal conductivity thermal, thermal diffusivity, specific heat capacity, thermal resistance and density) of fabricated POP-RHA composite material at varying matrix-filler volume fractions for thermal insulation (ceiling board) application. Six samples of the POP-RHA composite very fabricated with the RHA (filler) being 0,10,20,30,40 and 50% volume fractions.

Thermal conductivity :From table and figure 4, it is observed that thermal conductivity was highest (0.186 $wm^{-1}k^{-1}$) at 0% RHA composition and lowest (0.111 $wm^{-1}k^{-1}$) at 40% RHA composite by volume. Moreover, it is also observed that as the composition by volume. Moreover, it is also observed that as the composition of the filler increases, the thermal conductivity of the filler decreases from 0% RHA to 40% RHA and then begins to increase at 50% RHA composition in the composite material. This results suggest that between the (10-40)% RHA of POP-RHA composite, improves in its ability to prevent heat conduction from the roof through the ceiling to the interior of living room. However, coolest interiors of living homes will be obtained at 40% RHA composition in the composite that because at that RHA composition the thermal conductivity is lowest.

Specific heat capacity :From table 4 and figure 5, it is observed that the specific heat capacity of the POP-RHA composite increases with the content of RHA (filler) in composite. This implies that increasing the RHA content gives the material ability to absorb more heat that would have transmitted to the interior of living room. This character makes the composite more insulative than the pure POP ceiling board used in as ceiling boards today this is because POP has a lower specific heat capacity than POP-RHA composite.

Thermal resistance: We can also observe from the table 4 and figure 7 that the thermal resistance which indicates a material's ability to resist heat flow increases with increasing RHA composition in the POP-RHA composite. It is worthy of note that thermal resistance is highest (0.027)m^2k/W at 40% RHA composition. This implies that at 40% of RHA content, POP-RHA composite is more insulative.

Thermal diffusivity:Results also show that, thermal diffusivity which is a property that measures the rate of transfer of heat of a material from a hot side to a cold side decreases as the %RHA in the POP-RHA composite material increases as shown in 6. This behaviour suggests that as the filler content increases, the rate of heat transfer from the roof side of the composite to the interior of the living room decreases. The diffusivity of the composite is least (3.11)m^2s^{-1} at 40% of RHA content and tends to increase at 50% RHA as shown in fig 5. This still affirms POP-RHA composite material as a good thermal insulator.

Density: It is also obvious from fig.2 that, as the content RHA filler increases in the POP-RHA composite the density decreases making the composite lighter in weight than the conventional POP used as ceiling material. This an enviable characteristics of new engineering materials sort for. Though the variations of thermal conductivity thermal, thermal diffusivity, specific heat capacity, thermal resistance and density with RHA content in the composite material are conspicuous but the curves are not smooth. This is because of non-uniformity(non-homogeneity) in the distribution of the filler (RHA) particles in the matrix (POP).

V. CONCLUSION

This research investigated the response of POP-RHA composite material at varying matrix-filler volume fractions to heat transfer. The character of the composite material was evaluated in terms of Thermal conductivity thermal, thermal diffusivity, specific heat capacity, thermal resistance and density at different compositions of the filler (RHA) in the POP-RHA composite. From the results of the parameters studied, we can conclude that POP-RHA composite board is more thermally insulative than POP ceiling boards used in roofing. At 40% of RHA content in the composite, the fabricated material showed best thermal insulating behaviour. Thus, ceiling boards made of POP-RHA composite material can replace POP ceiling boards used in roofing and other thermal insulating applications in terms of the parameters investigated.

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