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Analysis of the Thermal Insulation Properties of Rice Husk Ceiling Board Compared to Selected Fibre Based Ceiling Materials Used in Yola Metropolis, Adamawa State Nigeria

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Abstract: The thermal conductivity of a material therefore represents the quantity of heat that passes through a meter thickness per square per second with one degree difference in temperature between the faces. Thermal conductivity is regarded as the most important characteristic of a thermal insulation since it affects directly the resistance to transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heat transfer in a building material. Hence the study selected three materials namely: Plaster of Paris (P.o.P), Plywood and Isorel (Masonite) used as ceiling boards in Yola, Nigeria and compared to rice husk ceiling board. The selection of these ceiling materials is due to their predominant usage as ceiling materials in the harsh Yola metropolis. The objective of this study is to investigate the thermal insulation properties of rice husk ceiling boards compared to other conventional fibre related ceiling board used in Yola Metropolis in Adamawa State, Nigeria. To achieve this, the steady-state method using Lee-Charton's apparatus was adopted to analyze the thermal conductivities of the chosen materials. The results obtained showed that, P.o.P exhibits the best insulation property followed by rice husk ceiling board, plywood then Isorel ceiling board with thermal conductivities of 0.12W/mK, 0.48W/mK, 0.82W/mK and 1.08W/mK respectively. Their corresponding thermal resistivities are 6.44mK/W, 4.65mK/W, 2.98mK/W and 1.92mK/W. From the results obtained, it is concluded that P.o.P is the best insulation property followed by rice husk ceiling board among the materials used in the study area. The study therefore provides a guide to intending builders and civil Engineers on the selection of building heat insulation ceiling materials in Yola metropolis as well as other harsh weather zones of tropical Africa.

Keywords: Rice Husk, Thermal Insulation, P.o.P, Plywood, Isorel (Masonite), Lee-Charlton's Method

1. Introduction

Buildings in tropical regions such as Nigeria should be comfortable during the hot and humid seasons. These comfortable and convenient buildings can only be possible when good insulating materials are used. These insulating materials are usually made from varieties of materials like loose fill, rigid boards, pipes and foam. Proper selection of insulating material is based on the thermal property which includes the thermal conductivity, thermal resistivity and thermal diffusivity. Humidity is usually above 60% and often nearly 70% in many regions of Nigeria [1]. They further said simple low-cost buildings can be cool, dry, and humidity-free if they are carefully designed and constructed with proper materials. Rice husk can be used as a superior siliceous material for the manufacture of calcium silicate heat-insulating material with a good thermal control of 1000^{o}C [2]. This indicates that rice husk has relative heat resisting ability. A study of chemical composition of rice husk revealed that rice husk takes 30 to 50minutes to ignite. The study showed that rice husk recorded dawdling fire ignition [3].

Convenient and comfortable buildings are expected to serve the following functions as outlined by [4]: provide sufficient sound insulation, offer adequate resistance to fire, and provide adequate thermal insulation and aesthetics. The harsh weather in North-central Nigeria calls for building materials that can more efficiently insulate heat [1].

Buildings are expected to protect its occupants and content of the building from adverse weather effects by preventing the penetration of wind, rain and extreme weather such as heat. In tropical environments characterized by dry and hot season and short period of rainy season, there is need for ceiling boards that can control the harsh weather. In tropical regions like northern Nigeria there is need for heat-insulated roofs and ceiling system, perhaps using a vented roof and an insulated ceiling. If air can flow up inside the roof and out through the vents above, the roof stays cooler [5]. Reflective foil draped across the rafters help, or insulation made of materials that don't soak up humidity and possibly coolness out of the walls by using insulation at the base of masonry walls to stop them from being cooled by the soil below which causes condensation. Moreover, the use of light weight and well-insulated building materials which consequently make the building cool is the spotlight of building industry.

As a result of global warming, currently experienced in the world mainly due to the climate change or simply daunting energy bills; nearly everyone is demanding more efficient and greener new buildings. Heat insulation is therefore a hot topic. This situation has prompted the search into natural building materials that can be good heat insulators and as well be affordable to average citizens. Studies are also focused on the potential of underutilized waste materials or by-products of agriculture for industrial products. Efforts have been made to convert rice, wheat straw, corn stover, and corncobs into industrially useful products [6]. In a study on the utility of rice husk and its derivatives in the building industry where rice husk was subjected to various tests to determine its chemical composition and properties [7]. They further found that rice husk density is less than 500 kg/m^3. Low density ceiling boards possess better thermal insulation properties compared to medium-density boards which are highly needed in hot-weather such as Nigeria. In order to meet the ever increasing demand for the energy efficient building construction materials there is a need to adopt cost effective, environmentally appropriate technologies and upgrade traditional techniques with available local materials [8]. There is also a great problem around the world regarding the decomposition of waste as they are not properly disposed or harnessed/utilized copiously for the benefit of human life.

In the past, ceiling boards were produced using different fibre related materials such as asbestos, waste paper among other agricultural residues. Some of these ceiling materials were afterward proscribed due to the hazard associated with their use. For instance, asbestos was discovered to be causing asbestosis, which leads to cancer [9]. As a result of this problem, manufacturers of ceiling boards went into research to find out substitutes that can be used in the production of ceiling boards. Due to the good thermal insulation of Plaster of Paris (PoP), [1] found that it is the most used ceiling material by elites in Nigeria. The PoP ceiling is expensive hence, not affordable by an average person who needs a comfortable and convenient building. It is observed that the natural substitute of these expensive ceiling materials includes shredded wood, cellulose fibre, agricultural waste among others. Rather than industrial products such as glass-fibre, iron fillings and other man-made materials; the fibres best suited for the socio-economic standard and circumstances of developing countries are natural fibres, as the natural fibres needs little input for processing compared to the industrial products. There is an urgent need for these thermal insulating ceiling materials in Yola. This study therefore is set out to determine among other things, better ceiling materials in terms of thermal conductivity or resistivity that can be produced locally using the available materials.

Buildings are less able to control the internal environment to comfortable conditions without mechanical air conditioning [6]. The only technique for reducing the scale of air conditioning is application of thermal insulation in walls and roofs. In a research to develop a new insulating material from renewable resources (jute, flax and hemp) with comparable physical and mechanical properties to commonly used insulations materials [10]. The tests result showed that the correct combination of natural materials is absolutely comparable with conventional materials. Though it becomes clear that improvisation on thermal conductivity of ceiling may be achieved either by molecular orientation or by the addition of conductive fillers, it is yet to be seen how the incorporation of natural fibers with poor heat conductivity affects the overall conductivity of any composite board [11].

Numerous theoretical and empirical models have been proposed in the past to estimate and predict the effective thermal conductivities of fiber reinforced polymer composites [12]. Comprehensive reviews of articles have discussed the pertinent applicability of many of these analytical models. The simplest alternative for a two-component composite system would be with the arrangement of materials in either parallel or series with respect to heat flow which gives the upper or lower bounds of effective thermal conductivity [8].

Insulation materials are the key tool in designing and constructing energy thrifty buildings. This is demonstrated by the increasing thicknesses used in buildings [13]. Despite the fact that the thermal properties of the materials has not improved significantly in the last decade, a series of other features, like reaction to fire and moisture or mechanical properties have improved, sometimes even at the cost of insulation abilities. Environmental and public health issues play an increasing role, both in the search for ‘optimum’ materials for given applications and in the aims set by the industry for future developments [14].

2. Methodology

This study was an experimental research work which investigated the thermal insulation properties of rice husk ceiling boards compared to other conventional fibre related ceiling board. The laboratory procedures that were carried out include mixing, moulding, drying, weighing and testing. The study was carried out in Mechanical and Civil

Engineering Departments' Laboratories, Adamawa State Polytechnic, Yola, Adamawa State and Physics Department Laboratory in Federal University of Agriculture, Makurdi Benue State. All the procedures presented by British standard institution (BS EN 520:2004+A1:2009) for particle board, plaster/ceiling board and related non-structural materials production specification were strictly observed which also specified the standard equipment required for boards production. The reliability of the instruments were ensured by trying and testing each instrument twice on separate occasions and comparing the result with the previous by the same equipment.

All materials were sourced from Benue State, Nigeria, where they were available and accessible to the researchers. The weighing scale was used to weigh the rice husk, potato starch, and Gum Arabic. Four mix ratios 'rice husk to potato starch to gum Arabic' were adopted for this study 0.75: 0.15: 0.10; 0.60: 0.25: 0.15; 0.75: 0.20: 0.05 and 0.65: 0.25: 0.10. These materials were thoroughly mixed manually by using wooden stick as a stirrer. Thereafter, the mixtures were poured into a wooden mould of rectangular cross-section measuring 600 X 450 X 5mm, then pressed using hydraulic jack. Twenty samples of ceiling boards were produced, five each from the four mix ratios for the study.

The thermal conductivity of the boards was determined by The Lee-Charlton's method as a steady state method. The samples were shaped to have equal cross-sectional areas. Using mass balance, micrometer screw gauge and vernier caliper, the mass (kg), height (m) and diameter (m) respectively of the samples were measured and related parameters calculated. The setup was then arranged. The steam boiler was filled with water to nearly half the capacity and heated to produce steam that causes the rise in temperature of the brass disc and sample specimen until steady temperatures T_1 and T_2 was obtained after a certain time interval. The specimen was removed and the brass disc heated directly by the steam chamber till its temperature was slightly above T1. The steam chamber was then removed and sample specimen placed on the brass disc. The initial temperature was recorded and cooling temperature drop noted continually in intervals of one minute till there was no observable change in temperature. The rate of heat flow, H is given by Fourier's law: $H = -kA\frac{\partial\theta}{\partial x}$ where k is the thermal conductivity, A is the area of the test piece normal to the heat flow and $\frac{\partial\theta}{\partial x}$ is the temperature gradient [1].

Thermal conductivity is regarded as the most important characteristic of a thermal insulation since it affects directly the resistance to transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heat transfers. The thermal conductivity of insulating materials has been found to vary with density, moisture content, temperature, direction of heat flow with respect to grain for fibrous materials, the presence of defects in the material and porosity [15].

2.1. Purpose of the Study

The purpose of this study is to investigate the thermal insulation properties of rice husk ceiling boards compared to other conventional fibre related ceiling board used in Yola Metropolis in Adamawa State, Nigeria. The specific objectives are to:

1. Determine the rate of thermal conductivity of the rice husk ceiling board,
2. Compare the thermal insulation properties of the rice husk ceiling board to other conventional fibre related ceiling boards.

2.2. Research Questions

The following research questions were posed to guide the study:-

1. What is the rate of thermal conductivity of the rice husk ceiling board?
2. What are the thermal insulation properties of the rice husk ceiling board compared to other conventional fibre related ceiling board?

3. Result

Research Question 1

What is the rate of thermal conductivity of the rice husk ceiling board?

Table 1. *Results of Rate of Thermal Conductivity of the Rice Husk Ceiling Board.*

Mix Ratios	Samples	Thermal Conductivity W/mK	Thermal Diffussion mK/W	Thermal Resistivity mK/W
Mix Ratio I	A	1.50	0.67	16.60
	B	1.08	0.93	18.11
	C	0.82	1.23	19.28
	D	0.78	1.28	20.19
	E	0.65	1.54	21.84
Mix Ratio II	A	0.92	0.58	17.38
	B	0.98	1.19	18.20
	C	0.71	1.26	21.07
	D	1.11	1.53	17.03
	E	1.19	1.34	16.39
Mix Ratio III	A	0.99	0.79	19.29
	B	0.78	0.16	18.03
	C	1.25	1.17	15.37
	D	0.96	1.72	16.36
	E	0.73	1.19	16.13

Mix Ratios	Samples	Thermal Conductivity W/mK	Thermal Diffussion mK/W	Thermal Resistivity mK/W
Mix Ratio IV	A	1.25	0.75	20.54
	B	1.11	1.28	17.35
	C	0.79	0.87	22.39
	D	0.96	1.21	18.20
	E	1.32	1.42	17.93

Key: W/mK = Welba per meter Kelvin, mK/W = meter Kelvin per Welba

Table 1 presents the rate of thermal conductivity of the rice husk ceiling board produced, it shows the calculated thermal parameters such as thermal conductivity (k), and thermal resistivity (r), for the four mix ratios. Mix ratio I has thermal conductivity ranging from 0.65 to 1.50W/mK. The variation in thermal properties was taken to be due to time taken for each sample (A to E) to undergo the experiment. The resistivity is also high which is corroborating with the insulating properties. Mix ratio IV has the highest thermal conductivity ranging from 0.79 to 1.32W/mK. The results show that all the mix ratios of the rice husk ceiling board produced are good insulating materials since their thermal conductivities fall within the acceptable standards for construction materials (0.023 - 2.9W/mK) as given by the [16].

Research Question 2

What are the properties of the rice husk ceiling board compare to other conventional fibre related ceiling board?

Table 2. *Results of Thermal Insulation Properties of the Rice Husk Ceiling Board Compare to Other Conventional Fibre Related Ceiling Board.*

Specimen	Density kg/m^3	% water absorption	Thermal Conductivity w/mk	Thermal Resistivity mK/W
RH ceiling	413	6.81	0.48	4.65
Isorel (Masonite)	931	9.50	1.08	1.92
Plywood	622	10.01	0.82	2.98
PoP	854	11.42	0.12	6.44

Key: RH = rice husk, kg/m^3 = kilogram per meter cube, W/mK = Welba per meter Kelvin, mK/W = meter Kelvin per Welba

Table 2 presents the thermal insulation properties of the rice husk ceiling board produced compared with three other fibre based ceiling boards, it shows the density, percentage water absorption, compressive strength and thermal conductivity. Isorel, popularly called Masonite ceiling, has a thermal conductivity of 1.08 W/mK, density of 931Kg/m^3, water absorption of 9.50%. Properties of P.o.P indicate a thermal conductivity of 0.12W/mK, density of 854Kg/m^3, and water absorption of 11.42%. Plywood has a thermal conductivity of 0.82W/mK, density of 622Kg/m^3, water absorption of 10.01%, while rice husk ceiling board produced has a thermal conductivity of 0.48W/mK; density of 413Kg/m^3; water absorption of 6.81%. It can therefore be concluded that PoP possess better thermal insulation properties among the four materials. The rice husk ceiling board has insulation properties comparable to PoP. From the result of thermal insulation properties test, the rice husk ceiling is however, superior to both Isorel and Plywood in terms of heat insulation, density, percentage water penetration. The result is further plotted in the figure below.

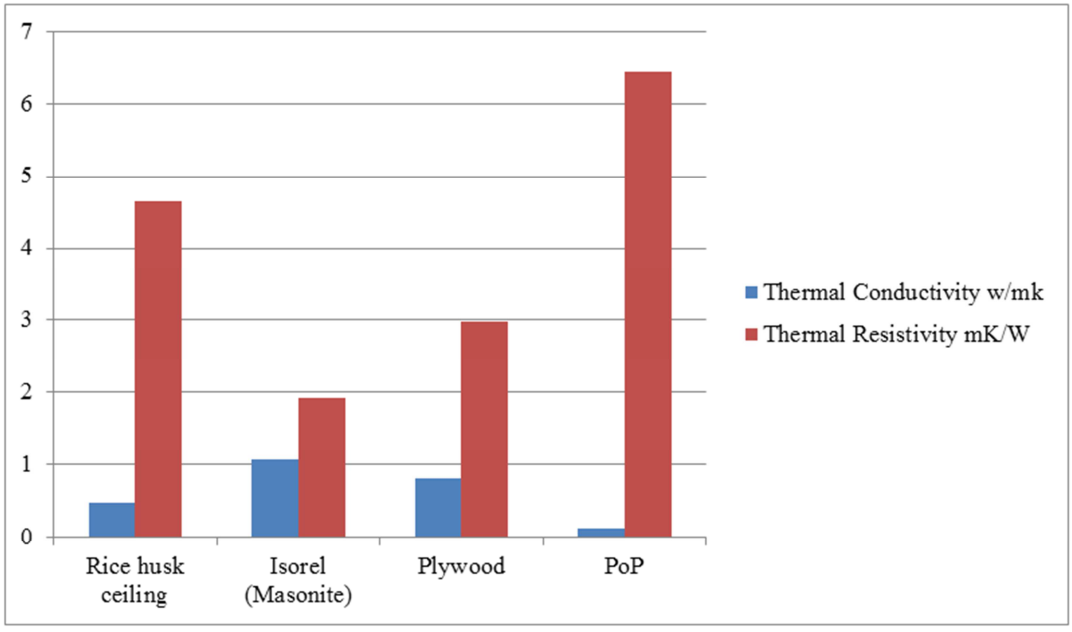

Figure 1. *Chart of the Thermal Properties of Four Ceiling Materials Compared.*

4. Discussion of Findings

Thermal conductivity result in table 1 indicates that all the mix ratios of the rice husk ceiling board produced are good insulating materials since their thermal conductivities fall within the conductivities of heat-insulating construction materials (0.023 - 2.9w/mk). The result is in agreement with [2] who noted that rice husk can be used as a superior siliceous material for the manufacture of calcium silicate heat-insulating materials with a good thermal durability of 1000^{o}C. This finding is in consonance with a study by [7] who subjected rice husk to various tests to determine its chemical composition and properties. Defeasibility test was also carried out to determine the thermal conductivity of the rice husk which yielded low thermal conductivity and in turn offer good insulating properties.

Findings on thermal insulation properties of the rice husk ceiling board compared to other conventional fibre related ceiling board indicates that rice husk ceiling board can be placed second to PoP. The thermal parameters of Isorel and Plywood ceiling boards such as thermal conductivity, thermal diffusivity, and thermal resistivity reveal they possess less insulating ability (figure 1). The results showed that most of the materials are good insulating materials since their thermal conductivities fall within the acceptable standards for construction and heat insulating materials of 0.023-2.9W/mK according to [16]. Thermal diffusivity therefore increases with the ability of a body to conduct heat and decreases with the amount of heat needed to change the temperature of a body as more or less steady state conditions normally exist in many thermal insulation systems. At steady state, heat conducted through the bad conductor (sample disc) per second was equal to heat radiated per second from the exposed portion of the metallic disc. These findings are in line with [12] who stated that as a performance standard, it is recommended that thermal conductivity of ceiling boards should be within 0.50-1.15 W/mK. The ceiling board produced with rice husk had thermal conductivity value within acceptable range, falling only behind PoP in the heat insulating abilities.

5. Conclusion

The ever increasing cost of building materials makes the search for cheap ones very necessary. In Nigeria and many other developing countries, asbestos were used extensively in the building industry but were outlawed due to its health hazards. In this study efforts have been made to determine the thermal insulation properties compared to three other fibre based ceiling boards. The composite specimen boards were subjected to thermal conductivity test. Thermal conductivity result indicates that all the mix ratios of the rice husk ceiling board produced have good insulating properties since their thermal conductivities fall within the acceptable standards for construction and heat-insulating materials, between 0.023 - 2.9W/mK given by [16]. The comparative analysis of rice husk ceiling boards to conventional fibre based ceiling board reveals that that PoP possess better ceiling properties. However, the rice husk ceiling board produced has properties comparable to PoP. Result of ceiling board properties test have shown that the rice husk ceiling is superior to both Isorel and Plywood in terms of heat insulation, density, percentage water penetration and fire resistance but weaker in both compressive and tensile strength. Many types of ceiling and roofing materials exist in the market, such as hard boards, paper boards and asbestos cement flat sheets boards.

Recommendations

The thermal conductivity of the rice husk ceiling boards indicate that more rice husk in the mixture produce better heat insulation. Hence the production of rice husk ceiling board should have more of rice husk than the adhesives, perhaps in a ratio of 6:2. The construction industry may therefore consider the use of rice husk ceiling boards as it possess good thermal insulation properties compared to the likes of PoP as recorded in the tests.

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