Rice Hull Ceiling Board

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Abstract

The purpose of this research study was to develop a *Rice Hull Ceiling Board.* The study focused on the design and fabrication of *Rice Hull Ceiling Board;* determine the appropriate proportion of raw materials; evaluate the quality of the rice hull ceiling board in terms of performance, reliability, usability, and durability; and determine the significant differences among different mixture proportions of materials. The study adapted the developmental and descriptive method. To evaluate the durability, laboratory tests were conducted on drop, flexural strength, thermal resistance and water absorption. A researcher-made questionnaire was used to gather the information on the quality and acceptability of the products among Architects, Civil Engineers and practitioners in the construction industry. One way and two-way ANOVA, t-test and the Means were used to analyze the data gathered. For the quality on performance, reliability and usability the product was rated as very satisfactory. As to the drop testing, flexural strength, and thermal resistance the product was rated as much accepted while a rating of accepted for water absorptivity. As to the drop, flexural strength, thermal resistance and water absorptivity testing there were no significant differences on the different properties tested among the proportions of *Rice Hull Ceiling Board*. Based on these findings, *Rice Hull Ceiling Board* can be fabricated out of Plaster of Paris which is available in local hardware and rice hull which is abundant in Bacolod City and nearby cities and municipalities. Furthermore, the *Rice Hull Ceiling Board* possesses physical characteristics comparable to the existing ceiling boards, therefore can substitute the traditional ceiling boards.

Keywords: Rice hull, ceiling board, Plaster of Paris, flexural strength, thermal resistance, drop testing, water resistance

Bio-note:

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Introduction

Nature of the Problem

Since the beginning of civilization man ingeniously adapt his dwelling to fit the environment, finding suitable material to protect them from the weather. Materials used to build these shelters are almost as varied as their locations, ranging from mud, wood, rocks, leaves and stone to modern synthetic materials such as concrete and steel or even materials made from recycled plastic and newspaper.

Roof and its accessories have undergone many revisions since the beginning of civilization. Man devises shapes, colors and materials of roofs including its insulation and ceiling materials to suit man's needs to adapt also to his surroundings. Ceiling materials may range from simple bamboo "sawali" to ordinary plywood, fiber cement boards and gypsum boards. Man tried varied materials, combined such materials to come up with durable but beautiful ceiling materials.

Rice hulls are unique within nature. ASTM testing conducted by R & D Services of Cookeville, Tennessee reveals that rice hulls do not flame or smolder very easily, they are highly resistant to moisture penetration and fungal decomposition, they do not transfer heat very well, they do not smell or emit gases, and they are not corrosive with respect to aluminum, copper or steel. In their raw and unprocessed state, rice hulls constitute a Class A insulation material, and therefore, they can be used very economically to insulate the wall, floor and roof cavities.

Based on the stated properties of rice hull, it may become an important item in construction industry but also may become an increasing problem in our environment if we cannot dispose the material properly. Due to this problem of dispensing rice hull, it is much important to find ways in which we can use the materials therefore reducing problem in environment and make rice hull into usable material.

A *Rice Hull Ceiling Board* was developed by this study as an alternative to the regular material used in homes, offices and school. Appropriate proportion of raw materials in the fabrication of ceiling board was evaluated in terms of performance, reliability, usability, and durability in drop, flexural strength, thermal resistance and water absorption.

This study is anchored on I.O. Poladele of the Department of Mettallurgical and Materials Engineering, Akure, Ondo State of Nigeria (2009). In his study entitled, Development of Fibre Reinforced Cementitious Composite for Ceiling Applications, he concluded that *natural organic fibers* have very important role in the alleviation of housing problems. These fibers being fairly strong and stiff as well as cheap and plentiful with low energy demand during manufacture are strong contenders for the reinforcement of cement based materials.

Rice hull being tough, good insulator, hard yet flexible and elastic are some of the good qualities needed for good construction materials.

The study sought to design a 30 centimeters by 30 centimeters of ceiling boards. Thickness of the board is approximately 12.5 mm. Furthermore, the ceiling was installed using T-runners only not by nailing or by riveting to the ceiling joists.

The mixture includes rice hull and Plaster of Paris. Also rice hull sample was taken from nearby rice mill house only.

The study did not design a 1.2 meters by 2.4 meters ceiling board, which is the usual size of plywood and fiber cement boards.

Current State of Knowledge

The Rice Hull

When nature decided how to package a grain of rice, she wrapped this tiny bundle of nutrients with what is often referred to as "bionic opal". The chemical structure of the rice hull, containing amorphous silica bound to water, resembles that of the opal, and this gives the rice hull some amazing properties.

The hull is a very tough and abrasive packaging material, consisting of two interlocking halves. It encapsulates the tiny space vacated by the milled grain, and in proximity to a myriad of other hulls, it forms a thermal barrier that compares well with that of excellent insulating materials (Velupillai, 1996).

Anyone who has tried to set a match to loose rice hulls understands how difficult they are to burn. Since air cannot flow freely through the pile of rice hulls to provide the oxygen needed to sustain rapid combustion, they do not easily and cleanly combust. A lighted match, tossed into the pile of rice husks will generally burn out without producing a self-sustaining flame in the husks (Beagle, 1978, p9, quoted from Burrows, 109A).

All organic materials will absorb or release moisture until they come into equilibrium with the relative humidity of the surrounding air. The high concentration of opaline silica on the outer surface of the rice hull impedes the atmospheric transfer of moisture into the hull. Also, 2.1% to 6% of the rice hull consists of a biopolyester called cutin (Juliano, 1985, p696), which in combination with a wax produced by the rice plant, form a highly impermeable barrier. Nature employs several effective strategies to protect the kernel of rice from the water and high humidity generally associated with the cultivation and growth of this plant.

Studies done on rice hulls at 25^0C indicates that the equilibrium moisture of rice hulls at 50% relative humidity is at or below 10%, while at 90% relative humidity, the equilibrium moisture content of rice hull remains at or below 15% (Juliano, 1985). A Moisture Vapor absorption Test (ASTM C739, Section 12) conducted by R and D Services indicates a gain in weight of only 3.23%. This well below the moisture content needed to sustain the growth of fungi and mold (Section ASTM C1149 or Section 11 of ASTMC739). Following this standard, R&D Services inoculated rice hull with five different fungal species and the rice hulls passed these test without the addition of fungicides or any other chemicals. The high concentration of opaline silica on the outer surface of the rice hull also establishes the effective hardness of the rice hull at roughly the same values of 6 on the Mohs scale as reported for opal (Juliano, 1985, p696). However due to the presence of lignin within the rice hull, this hardness is tempered with flexibility and elasticity. Since the rice hull is hard and yet elastic, it resists settling and compression far better than shredded newspapers. Also, since it is not necessary to add fire-retardants, fungicides or any other chemicals to the rice hull, R&D Services has determined that this benign and stable biomas does not emit offensive odors (ASTM C739). Likewise, R&D Services determined that rice hulls do not corrode aluminum, copper or steel (ASTM C739, Section 9).

With rice hulls, we need not engage in a mining or manufacturing process that generates air pollution, water pollution or erosion. With rice hulls, we need not engage in a manufacturing process that depletes our reserves of fossil fuels. With rice hulls, we do not use chlorine based chemicals such as phosgene, propylene chlorohydrins or any ozone-depleting chlorofluorocarbons. With rice hulls, we do not have to worry about irritability or carcinogenicity of dust and fibers. Since rice hulls require no shredding, hammer-milling, fluffing, fiberizing, binding and stabilizing, they possess, surely in those states where hulls are available, far less embodied energy than even cellulose installation. Since rice hulls do not burn very easily, they require no flame or smolder retardants, and since they are so tough and durable, nothing prevents them from being used and recycles over and over again.

Development of Ceiling Board

The construction industry uses different types of ceiling boards with each having specific purpose. This specific purpose maybe for aesthetic, for insulation or for acoustic and because of this man also revises and modifies ceiling boards to suit man's needs.

The following were the different type of ceiling boards solve in the markets:

Gypsum Board

Gypsum board is the generic name for a family of panel products that consist of a noncombustible core, composed primarily of gypsum, and a paper surfacing on the face, back and long edges. Gypsum board is one of several building materials covered by the umbrella term "gypsum panel products." All gypsum panel products contain gypsum cores; however, they can be faced with a variety of different materials, including paper and fiberglass mats.

Gypsum board is often called drywall, wallboard, or plasterboard. It differs from other panel-type building products, such as plywood, hardboard, and fiberboard, because of its noncombustible core and paper facers. When joints and fastener heads are covered with a joint compound system, gypsum wall board creates a continuous surface suitable for most types of interior decoration.

To produce gypsum board, the calcined gypsum is mixed with water and additives to form slurry which is fed between continuous layers of paper on a board machine. As the board moves down a conveyer line, the calcium sulfate recrystallizes or rehydrates, chemically combining with the water that was removed during calcination and reverts to its original rock state. The paper becomes chemically and mechanically bonded to the core. The board is then cut to length and conveyed through dryers to remove any free moisture.

Cement Bonded Board

Cement - bonded fiber is a composite material manufactured throughout the world. It is made from wood, usually waste wood, chipped into a specially graded aggregate that is mineralized and combined with Portland cement.

Cement-bonded wood fiber is used to manufacture a wide variety of products primarily for the construction industry (products like insulating concrete forms, siding materials and noise barriers.

Cement bonded wood fiber materials can be classified as low density, medium density and high density. The density of the material will determine to a large extent, the various properties of the end product. Other factors determining the overall performance of a cement bonded wood fiber material are, wood particle type, wood particle gradation, cement to wood ratio and level of sugar content in the wood particle at the time of bonding.

Most common is low-density cement bonded wood fiber. It is known for its use in green building. The material itself is 100% recyclable, and is known for its insulating and acoustic properties. Cement-bonded wood fiber is more commonly known under original patent holder Durisol.

Cement board is composed of aggregated Portland cement with a glass-fiber mesh on the surfaces. This 5/16 inch (7.9 mm) thick cement board is designed as an underlayment for tile floors. These are 3 by 5 foot (91 by 152 cm) sheets.

A cement board is a combination of cementhttps://en.wikipedia.org/wiki/Cement and reinforcing fibers formed into 4 feet by 8 feet sheets (or 3 feet by 5 feet sheets), 1/4 to 1/2 inch thick that are typically used as a tile backing board. Cement board can be nailed or screwed to wood or steel studs to create a substrate for vertical tile and attached horizontally to plywoodhttps://en.wikipedia.org/wiki/Plywood for tile floors, kitchen counters and backsplashes. It can be used on the exterior of buildings as a base for exterior plaster (stuccohttps://en.wikipedia.org/wiki/Stucco) systems and sometimes as the finish system itself.

Cement board adds impact resistance and strength to the wall surface as compared to water resistant gypsum boards. Cement board is also fabricated in thin sheets with polymer modified cements to allow bending for curved surfaces.

Composition

Cement boards are mainly cement bonded particle boards and cement fiber. Cement bonded particle boards have treated wood flakes as reinforcement, whereas in cement fiber boards have cellulose fiber, which is a plant extract as reinforcement. Cement acts as binder in both the cases. The fire resistance properties of cement bonded blue particle boards and cement fiber boards are the same. In terms of load-bearing capacity, cement-bonded particle boards have higher capacity than cement fiber boards. Cement particle boards can be manufactured from 6 mm to 40 mm thickness making it ideally suitable for high load bearing applications. These boards are made of a homogeneous mixture and hence are formed as single layer for any thickness. Cement fiber boards are more used in decorative applications and can be manufactured from 3 mm to 20 mm thickness. Fiber boards are made in very thin layers, making it extremely difficult to manufacture high thickness boards.

Advantages

As a tile backing board, cement board has better long-term performance than paper-faced gypsum core products because it will not mildew or physically break down in the continued presence of moisture or leaks. Cement board is not actually waterproof, but it is highly resistant to absorbing moisture and has excellent drying properties. In areas continually exposed to water spray (i.e. showers) a waterproofing barrier is usually recommended behind the boards or as a trowel-applied product to the face of the boards behind the finish system.

Disadvantages

One major disadvantage of cement board is the weight per square foot. It is approximately twice that of gypsum board, making handling by one person difficult. Cutting of cement board must also be done with carbide-tipped tools and saw blades. Due to its hardness, pre-drilling of fasteners is often recommended. Finally, cement board is initially more expensive than water resistant gypsum board but may provide better long term value.

Installation

Cement board is hung with corrosion resistant screws or ring-shank nails. Cement board has very little movement under thermal stress, but the boards are usually installed with a slight gap at joints in shower pans, bathtubs, and each other. These joints are then filled with silicone sealant or the manufacturer's taping compounds before applying a finish. The filled joints are taped like conventional gypsum board, but with fiberglass tapes that provide additional water resistance. Combined with a water impermeable finish, cement board is a stable, durable backing board.

Water Resistance

The category of construction material known as cement board includes both water resistant and waterproof board. Each has its own best use.

Typically water resistant cement board is composed of a treated gypsum core with a non-organic fiber reinforced covering, either on one or both faces. This type of board requires fastidious sealing of all cut edges and penetrations to maintain the manufacturer's warranty for wet area installations. Gypsum core "cement" board panels are ideal for moist but not truly wet installations of tile and/or stone walls.

There is a class of cement board strictly constructed of a Portland cement based core with glass fiber mat reinforcing at both faces. This type board is truly waterproof. These panels can be immersed in water without any degradation (excluding freeze thaw cycles). These panels do not require the sealing of edges and penetrations to maintain their structural integrity. These Portland cement based products are smaller in size compared with the gypsum core based products.

Typically, they range in size from 30" x 48" to 36" x 60". They are, as one would expect, considerably heavier than the gypsum core type panels.

Portland cement based panels are ideal for truly wet locations like shower surrounds and for locations where a Portland cement based thin-set material is used for bonding tile and stone surfaces to a substrate. They are also ideal for floor tile and stone installations over a structural subfloor.

Cement boards may be classified as water resistant as in not affected by water exposure; however, they do allow penetration and passage of water and water vapor. To waterproof cement boards, a liquid or membrane waterproofing material is applied over its surface.

Plaster of Paris

Plaster of Paris is a quick –setting gypsum plaster consisting of a white powder (calcium sulfate hemihydrate), which hardens when moistened and allowed to dry. Known since ancient times, plaster of Paris is so called because of its preparation from abundant gypsum found near Paris (Editors of Encyclopedia Britannica, 2000).

Plaster of Paris does not generally shrink or crack when dry, making it an excellent medium for casting molds. It is commonly used to precast and holds parts of ornamental plasterwork placed on ceilings and cornices. It is also used in medicine to make plaster casts to immobilize broken bones while they heal. In medieval time and Renaissance times, gesso (usually made of plaster of Paris mixed with glue) was applied to wood panels, plaster, stone or canvas to provide the ground for tempera and oil painting (Editors of Encyclopedia Britannica, 2000).

Reinforcement

Reinforcement for ceiling boards come in many forms. Treated Wood Flakes are used as reinforcement for cement bonded particle boards used as ceiling and walls. Cellulose fiber, which is as plant extract, is used in as reinforcement in fibre boards. In the research conducted by I.O.Poladele, Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Ondo State, Nigeria.A.D. Akinwekomi, Department of Science Laboratory Technology Rufus Giwa polytechnic Owo, Ondo State, NigeriaS. Aribo1, and A.K. Aladenika, Corresponding Author: wolesuccess 2000@yahoo.com, akeemzy@yahoo.com.*Development of Fibre Reinforced Cementitious Composite for Ceiling Application***,** they used natural sponge fibre (Acanthus montanus) as reinforcement for ceiling materials. This fiber, being fairly strong and stiff as well as cheap and plentiful with low energy demand during manufacture, are strong contenders for the reinforcement of cement based materials. The fiber, whose mass fraction was the variable in this work, was cut down into smaller sizes and mixed with pulverized waste paper, cement and water.

According to them, Natural organic fibers have a very important role in the alleviation of the housing problem. They not only occur in luxurious abundance in many parts of the world, but can also lead directly to energy savings, conservation of the world's most scarce resources and protect human and environment. Natural and vegetable plants and fibers have thus a unique irreplaceable role in the ecological cycle. Despite the fact that natural fibers generally have poor mechanical properties compared with synthetic fibers (Benjamin, 1990), Fabrication and Performance of Natural Fiber-Reinforced Composite Materials," 35th. International SAMPE Symposium, pp.970-978), their use as reinforcement material has been adopted by mankind to make straw reinforced huts and other articles (Al-Qureshi, 1999), *The* Use of Banana Fiber Reinforced Composites for the Development of a Truck Body, (Second International Wood and Natural Fiber Composites Symposium, Kassel/Germany, pp.1-8). Their natural abundance, plentiful supply, relative cheapness and swift replenish ability are the strongest arguments to utilize them in the construction industry (Swamy, 1990), Vegetable Fiber Reinforced Cement Composites- A False Dream or a Potential Reality, Proceedings of Second International RILEM Symposium,1st edition, Chapman & Hall, London (ed. H.S Sobral, pp. 3-8).

Cement and concrete matrices reinforced with short, discrete or long single/bundles of fiber present exciting and challenging new construction materials. The behavior and properties of cement-based materials may be better understood, designed, and predicted using a modern approach than was possible on the basis of traditional concrete technology (Brandt, A.M., 1995), Cement Based Composites: Materials, Mechanical Properties and Performance, 1st edition, Chapman and Hall, London, pp. 5-60, 77-97). These materials belong to a group of brittle-matrix composites. The major role of fibers is in delaying and controlling the tensile cracking of the matrix. This controlled multiple cracking reduces deformation at all stress levels, and imparts a well-defined post-cracking and post-yield behavior. The fracture toughness, ductility and energy absorption capacity of the composite are then substantially improved. These technical benefits can be utilized both in semi-structural elements such as thin sheets, flat sheets, corrugated and cladding panel as well as in load bearing members.

The invention of steel and the widespread use of steel in the construction industry have the great impact on this area. Steel can be used as the main structure or just the reinforcement in the structure. Sizes may range from as big as the manufacturer can imagine to as thin as possible. Smaller sizes of steel reinforcement are under the commercial name of welded wire and mesh wire.

Mixture Proportion and Materials

Typical cement fiber board is made of approximately 40-60% of cement, 20-30% of fillers, 8-10% of cellulose, 10-15% of mica. Other additives like aluminum stearate and PVA are normally used in quantities less than 1%. The actual recipe depends on available raw materials and other local factors.

Based on the study of the research "*Development of Fibre Reinforced Cementitious Composite for Ceiling Application"*, **t**he materials required for this research work were all sourced locally. These included fibers from the stem of the natural sponge plant (*Acanthus montanus*), waste paper, wooden rectangular molds, water, cellophane sheets and cement. The fibers from the natural sponge plant (*Acanthusmontanus*) were cut down into a size range of 35-40mm. This was done to avoid balling problem during mixing and to facilitate homogeneous mixing of the composite. The waste paper, which served as filler in this research work, was obtained from old newspaper pages. These were first cut down into smaller sizes and then soaked in water until they soften. Manual pounding using the mortar and pestle was used to pulverize them. The variable in this research work was fiber mass concentration. The recipe which was maintained constant was a mixture of cement and waste paper in the ratio 70:30 by weight.

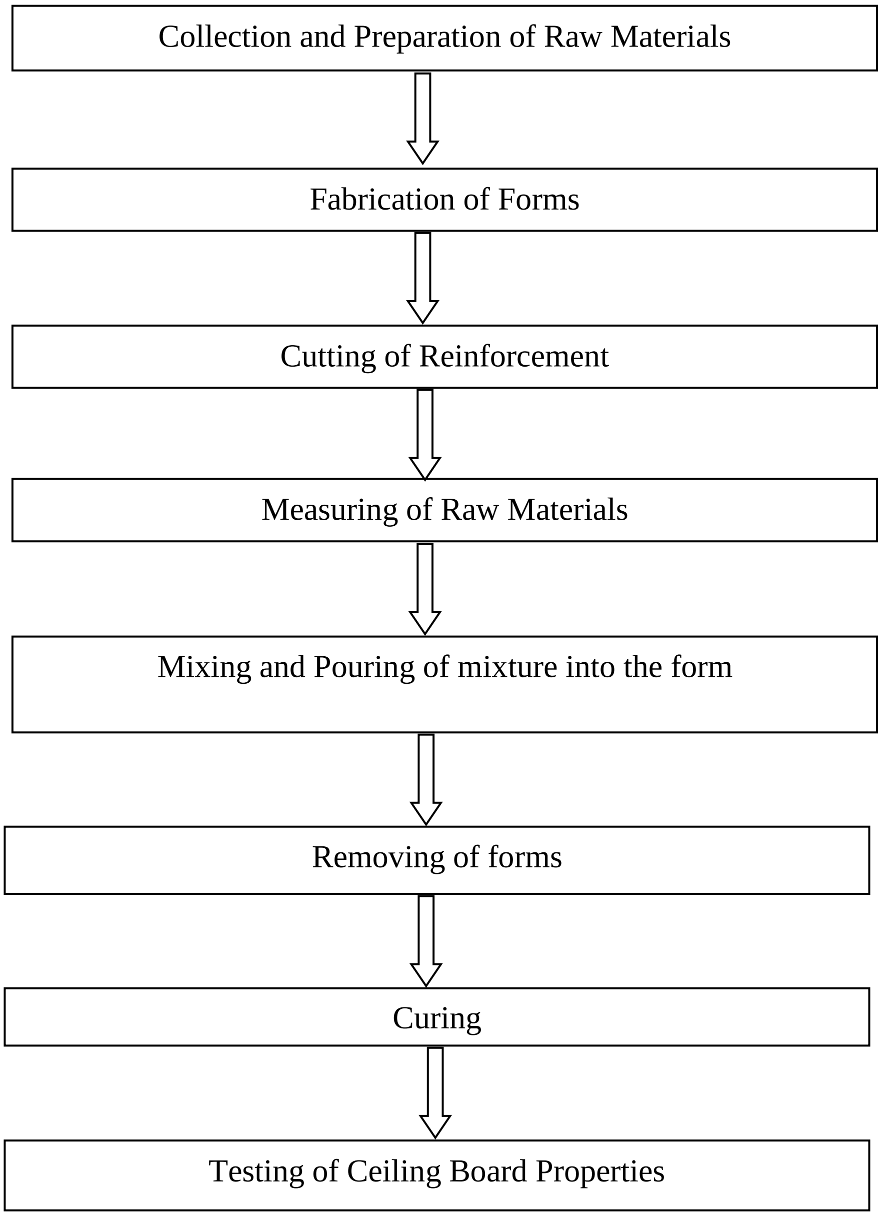
Materials and Methods

This is a developmental research that focused on designing, developing and fabricating *Rice Hull Ceiling Board*.

Development Process Flow

Figure 1

Development Process Flow



Collection and Preparation of Raw Materials

Ordinary plywood was purchased at lumber yard while Plaster of Paris was purchased at local hardware. Rice hull was collected from nearby rice granary enough for the researcher to have several trials for the desired proportions.

Fabrication of Forms

For the forms, 30 centimeters by 30 centimeters square on ½ inch thick plywood was measured. Then cut the plywood leaving a square hole on the plywood.

Cutting of Reinforcement

Gauge #18 welded wire was used as reinforcement. Cut 28cm x 28 cm welded wire. Placed it in the form lined with plastic cellophane ready for pouring of mixture.

Measuring of Raw Materials

Four (4) mixture proportions were prepared. Mixture 1, consists of one part Plaster of Paris by volume and ½ part by volume rice hull. Mixture 2, is one part Plaster of Paris, 1 part Rice Hull by volume. Mixture 3 is one-part Plaster of Paris and two parts Plaster of Paris while mixture 4 is one part Plaster of Paris and three parts rice hull. Table 1 showed the amount by volume which was utilized in this research. Volume of water for each mixture was also shown in the table.

Table 1
Various Volumes of Materials in Cubic Centimeters

Mixture	Volume of Plaster of Paris	Volume of Rice Hull	Volume of water
1	487.50 cm^3	243.75 cm^3	135.00 cm^3
2	487.50 cm^3	487.50 cm^3	180.00 cm^3
3	487.50 cm^3	975.00 cm^3	215.00 cm^3
4	487.50 cm^3	1,462.50 cm^3	270.00 cm^3

Mixing and Pouring of Mixture into the Form; and Curing of Samples

The measured Plaster of Paris, rice hull and water were mixed together until homogeneity was achieved. After homogenous mixture was obtained, the slurry was poured into the prepared form.

Samples of each proportion were made. The samples were allowed to set for forty-five (45) minutes to one (1) hour before they were de-molded. The sign that the mixture had hardened already when you can feel the increase in temperature of the board formed. After de-molding the samples were allowed to cure in open air for 15 days before ceiling board properties was tested.

Testing of Ceiling Boards Properties

Drop Test

In Drop Test, samples were dropped using different height and observed the extent of crack in the ceiling board. Height varies from one (1) foot, two (2) feet and three (3) feet.

To determine the durability of the product through drop test, a score card was used. The score card had the following score:

5 – No Cracks
4 – Few chips and cracks
3 – More cracks but did not break into fragments
2 – Broken into fragments
1 – Extensive damage

Flexural Strength

Flexural strength of ceiling board is the resistance of the board to bending using the Universal Testing Machine (UTM). Flexural test based on the three-point loading principle was carried out on each of the samples from which a computer generated results was obtained from the computer connected directly to the UTM.

Thermal Resistance

Thermal resistance is the heat transfer from one medium to another. To test the thermal resistance of the board, the board was exposed to the direct heat of sun for 6 hours. The temperature of the board before exposure was taken which we called T_1 and after 6 hours the temperature was taken designated by T_2. Rate of heat transfer in joule per second or watt was computed using the equation $\frac{Q}{t} = \frac{KA(T_2 - T_1)}{d}$, where K is the coefficient thermal conductivity of the material, A is the surface area of the material, $T_2 - T_1$ is the difference in temperature in materials and d is the thickness.

Water Absorptivity Test

This test quantifies the water absorptivity of the ceiling board. Being a product to be used for ceiling purpose, this test becomes pertinent to measure its response to water leakages from the roof after or during a down-pour. Three samples was used, weighed and soaked in water for 24 hours. Thereafter, they were removed from water, cleaned, and re-weighed. The difference between the original weight and the weight after soaking in water divided by the original weight multiplied by 100 was the percentage of water absorption.

Bill of Materials

Table 2 shows the amount and cost of materials used in the study. These materials include the raw materials in the development of ceiling boards including the forms.

Table 2
List of Supplies and Materials

Qty.	Unit	Description	Unit Cost	Total Cost
1	sheet	Ordinary Plywood, ½ tnk.x4'x4'	Php 260.00	Php 260.00
2	kilos	Rice Hull	(no cost)	
1	meter	Wlded wire, ga.18	78.00	78.00
1	kilo	Plaster of Paris	30.00	30.00
¼	kilo	Common Nail, 1"	60.00	15.00
		Total Cost:		Php 383.00

Tools and Equipment

Table 3 shows the different tools and equipment used in the study. These were used in the development of the ceiling board and in the testing of the properties of the ceiling board.

Table 3
List of Tools and Equipment their Functions

Tools	Functions
Clue Hammer	assembles the wooden forms.
Meter stick	measures the size of materials.
Palette	mixes raw materials.
Saw	cuts the wooden materials.
Thermometer	measures the temperature of samples.
Weighing Scale	weighs the raw materials
Equipment	
Universal Testing Machine	tests the flexural strength.

Results and Discussion

Design and Fabrication of Rice Hull Ceiling Board

The product underwent a try-out and revision period through experimentation. Before starting on working with the actual ceiling board the researcher mixed several small amounts to familiarize with the material. The proposed design was 12.5 mm thick, 30cm x 30 cm.

Proportions of Raw Materials

The second objective was to determine the appropriate proportion of raw materials in the fabrication of ceiling board.

The experiment tried four proportions of raw materials, keeping the amount of Plaster of Paris constant and rice hull as the variable amount. The proportions tried were 1:1/2, 1:1, 1:2 and 1:3.

Table 4 shows the results of Drop Testing on the *Rice Hull Ceiling Board*.

Table 4
Rice Hull Ceiling Board Drop Testing Results

	Mixture Proportions			
	1:1/2	1:1	1:2	1:3
One (1) foot				
Replicate 1	4	4	4	4
Replicate 2	4	4	4	4
Replicate 3	4	4	4	4
Mean	4	4	4	4
Two (2) feet				
Replicate 1	4	4	4	4
Replicate 2	4	4	4	4
Replicate 3	4	4	4	4
Mean	4	4	4	4
Three (3)feet				
Replicate 1	3	3	3	3
Replicate 2	4	3	3	3
Replicate 3	3	3	3	2
Mean	3.3	3	3	2.6

It was observed from the drop testing results that the mean values in testing using heights of one foot and two feet is 4. This means that the ceiling board had few chips and cracks when dropped from these heights. For three feet the values range from 3.3 for proportions 1:1/2 and 2.6 for proportion 1:3. This means that proportion 1:1/2 has more cracks but did not break into fragments while proportions 1:3 was broken into fragments.

Table 5 shows the results of Flexural Testing on the *Rice Hull Ceiling Board*.

Table 5
Flexural Testing Results

	1:1/2	1:1	1:2	1:3
Proportion	Flexural Strength in MegaPascal (MPa)			
Replicate 1	104.1	114.8	67	109.3
Replicate 2	106.7	119.2	90.5	109.8
Replicate 3	104.5	114.2	110.6	110.9
Mean	105.1	116.1	89.4	110.0

As seen from the table, flexural strengths of ceiling boards ranges from 116.1 MPa as the highest to 89.4 MPa as the lowest. Evaluating these values using the mechanical properties of existing ceiling boards (Mechanical Properties of Gypsum

Boards, Department of Civil Engineering, University of Wisconsin – Madison, Madison, 2003), all the proportions surpass the values of these exiting ceiling boards.

Comparing the values obtained in flexural testing, proportion 1:1 has the highest value. This means that proportion 1:1 is the most flexible among the four proportions.

Table 6 shows the results in conducting thermal resistance testing on *Rice Hull Ceiling Board.*

Table 6
Thermal Resistance Testing Results

Mixture	1:1/2		1:1		1:2		1:3	
	T_1(⁰C)	T_2 (⁰C)	T_1 (⁰C)	T_2 (⁰C)	T_1 (⁰C)	T_2 (⁰C)	T_1 (⁰C)	T_2 (⁰C)
Replicate 1	28.4	32.5	28.1	32.8	28.4	32.2	28.2	32.5
Replicate 2	27.5	32.3	28.6	32.6	28.3	32.3	28.2	32.3
Replicate 3	28.4	31.7	28.2	32.5	28.3	32.3	27.7	32.6
Mean	28.1	32.2	28.3	32.6	28.3	32.3	29.0	32.4
$T_2 – T_1$	4.1		4.3		4.0		3.4	
Thermal Conductivity	0.177 J/s		0.186J/s		0.173J/s		0.147 J/s	

As to thermal resistance, thermal conductivity was computed, and as observed proportion 1:3 got the lowest value, meaning that the transfer of heat in this proportion is slow.

Table 7 shows the results in conductions water absorptivity testing.

Table 7
Water Absorptivity Testing Results

Mixture	1:1/2		1:1		1:2		1:3	
	W_1	W_2	W_1	W_2	W_1	W_2	W_1	W_2
Replicate 1	200	305	235	355	240	350	195	360
Replicate 2	225	305	235	350	250	360	170	360
Replicate 3	235	300	265	355	240	355	195	360
Mean	220	303.3	245	353.3	243.3	355	186.6	360
Water Content (%)	37.86%		44.22%		45.9%		92.9%	

For water absorptivity testing, as noticed mixture from table, mixture 1:3 absorbs more water than the rest of the mixture.

Quality of the Rice Hull Ceiling Board

The third objective the study was to evaluate the quality of the *Rice Hull Ceiling Board* in terms of; performance, reliability, usability, and durability. Under durability the product was subjected to drop, flexural, thermal resistance and water absorptivity testing.

Table 8 shows the computed mean scores on the evaluation the quality of Rice Hull Ceiling Board in terms of performance.

Table 8

Mean Scores on Performance Evaluation

CHARACTERISTIC	Mean	Verbal Interpretation
Performance.		
The Rice Hull Ceiling Board		
1. requires less time to install on the aluminum T- runners	**3.40**	**VS**
2. requires few manpower to install	**3.80**	**VS**
3. suitable for its desired purpose	**3.90**	**VS**
Average Mean	**3.70**	**VS**

The *Rice Hull Ceiling* Board was evaluated in terms of its performance. The mean average mean score was 3.70, which was interpreted as very satisfactory.

Table 9 shows the computed mean scores on the evaluation the quality of Rice Hull Ceiling Board in terms of reliability.

Table 9

Mean Scores on reliability evaluation

CHARACTERISTIC	Mean	Verbal Interpretation
Reliability.		
The Rice Hull Ceiling Board		
1. ready to use	**3.70**	**VS**
2. accessible for use	**3.60**	**VS**
3. uses available materials (rice hull & Plaster of Paris)	**3.70**	**VS**
4. can function as intended despite slight product defects	**3.85**	**VS**
Average Mean	**3.71**	**VS**

The *Rice Hull Ceiling Board* was evaluated based on reliability. As seen from the table the average mean score was computed as 3.71, interpreted as very satisfactory.

Table 10 shows the computed mean scores on the evaluation the quality of Rice Hull Ceiling Board in terms of usability.

Table 10

Mean Scores on Usability Evaluation

CHARACTERISTIC	Mean	Verbal Interpretation
Usability		
The Rice Hull Ceiling Board	**3.95**	**VS**
1. appropriate for the user's needs		
2. safe to use	**3.85**	**VS**
3. easy to replace	**3.90**	**VS**
Average Mean	**3.90**	**VS**

The third quality was usability, where the *Rice Hull Ceiling Board* was evaluated and the average mean was 3.90, interpreted as very satisfactory.

Table 11 shows the computed mean scores on the acceptability of *Rice Hull Ceiling Board* in terms of the drop testing.

Table 11

Mean Scores on the Acceptability of Rice Hull Ceiling Board on Drop Testing

	Mixture Proportion			
Drop Height	1:1/2	1:1	1:2	1:3
One (1) foot	**4.30**	**4.05**	**3.90**	**3.90**
Two (2) feet	**4.05**	**3.85**	**3.85**	**3.60**
Three (3) feet	**3.60**	**3.10**	**3.15**	**2.95**
Average Mean	**3.98**	**3.67**	**3.63**	**3.60**
Verbal Interpretation	Much Accepted	Much Accepted	Much Accepted	Much Accepted

All four proportions were tested and evaluated base on the laboratory results presented. The proportions were 1:1/2, 1:1, 1:2, and 1:3. For the drop testing the average mean scores were 3.98, 3.67, 3.63 and 3.60 respectively. The verbal interpretations were much accepted, which implied that Rice Hull Ceiling Board was much accepted by architects, civil engineers and practitioners in terms of drop testing.

Table 12 shows the computed mean scores on the acceptability of *Rice Hull Ceiling Board* in terms of the flexural testing.

Table 12

Mean Scores on the Acceptability of Rice Hull Ceiling Board on Flexural Testing

Characteristics	**Mixture Proportion** 1:1/2	1:1	1:2	1:3
The Rice Hull Ceiling Board				
1. maintains the flatness of the surface when installed on the T –runners	4.25	4.20	4.05	4.05
2. does not need additional support to prevent sagging	4.20	4.20	4.05	3.90
3. does not bend easily under normal loading condition	4.15	4.15	4.10	4.00
4. can substitute the traditional ceiling in terms of flexural strength	4.15	4.15	4.11	4.05
Average Mean				
Verbal Interpretation	Much Accepted	Much Accepted	Much Accepted	Much Accepted

Flexural Testing was done using the Universal Testing Machine and the computer-generated results were taken. The laboratory results were used in the evaluation of the Rice Hull Ceiling. Acceptability of the *Rice Hull Ceiling Board* was based on the flexural strength of existing Gypsum Board, which range from 1 MPa to 4 MPa (ASTM C1396 Standard Specification for Gypsum Board)

The *Rice Hull ceiling Board* was evaluated based on its flexural strength capacity. The average mean scores were 4.15, 4.15, 4.11 and 4.05 for proportions 1:1/2, 1:1, 1:2, and 1:3 respectively. All proportions have verbal interpretation as much accepted, with proportions 1:1/2 and 1:1 having high points compared to other samples.

Table 13 shows the computed mean scores on the acceptability of *Rice Hull Ceiling Board* in terms of the thermal resistance testing.

Table 13
Mean Scores on the Acceptability of Rice Hull Ceiling Board on Thermal Resistance Testing

Characteristics	**Mixture Proportion** 1:1/2	1:1	1:2	1:3
The Rice Hull Ceiling Board				
1. has a tolerable increase in its	3.58	3.45	3.40	3.40
temperature when expose to				
sunlight for 6 hours	3.65	3.40	3.1	3.69
2. can reduce heat transfer by acting	3.60	3.42	3.25	3.54
as insulator	Much	Much	Much	Much
Average Mean	Accepted	Accepted	Accepted	Accepted
Verbal Interpretation				

Thermal resistance was also tested and evaluated. The computed rate of heat transfer was compared to the rate of heat transfer of existing ceiling boards (**Error! Hyperlink reference not valid.** ; **Error! Hyperlink reference not valid.**).These values were the basis for the evaluation of the thermal resistance of the Rice Hull Ceiling Board. The average mean scores were 3.60, 3.42, 3.25 and 3.54 for proportions 1:1/2, 1:1, 1:2 and 1:3 respectively and with verbal interpretation as much accepted for proportion 1:1/2, 1:1 and 1:3, while accepted for mixture 1:2.

Table 14 shows the computed mean scores on the acceptability of *Rice Hull Ceiling Board* in terms of the water absorptivity testing.

Table 14
Mean Scores on the Acceptability of Rice Hull Ceiling Board on Water Absorptivity Testing

Characteristics	**Mixture Proportions** 1:1/2	1:1	1:2	1:3
The Rice Hull Ceiling Board				
1. is moist resistant	3.25	3.10	2.90	2.40
2. can hold water when there is leakage on the roofing sheets.	2.85	3.10	3.10	3.60
3. can substitute the traditional ceiling boards in terms of water absorptivity	3.55	3.55	3.21	3.26
Average Mean	**3.22**	**3.25**	**3.07**	**3.09**
Verbal Interpretation	**Accepted**	**Accepted**	**Accepted**	**Accepted**

The last test was on water absorptivity. *The Rice Hull Ceiling Board* was evaluated based on the questions given and answers were based on the attached laboratory results. As seen from the table the computed average mean scores were 3.22, 3.25, 3.07 and 3.09 for proportions 1:1/2, 1:1, 1:2 and 1:3 respectively, and this was interpreted as accepted in terms of water absorptivity.

Differences between the Different Properties Tested on the Rice Hull Ceiling Board

The fourth objective was to test whether there were significant differences between the different properties tested on the *Rice Hull Ceiling Board*. The SPSS program was used to analyze the data and results were generated and tabulated.

Table 15 shows the results in analyzing the significant difference between proportions in terms of drop testing.

Table 15
Test of Difference in terms of Drop Testing

Drop Testing –(1 foot, 2 feet and 3 feet)	Mean	Standard Deviation	F	p
1:1/2	4	0.0	-	-
1:1	4	0.0	-	-
!:2	4	0.0	-	-
1:3	4	0.0	-	-

Based on the result there were no significant differences were observed between the four proportions in all the three heights tested on the drop testing conducted.

Table 16 shows the results in analyzing the significant difference between proportions in terms of flexural strength using ONE-WAY ANOVA.

Table 16
Test of Difference in terms of Flexural Strength

Flexural Strength	Sum of Squares	df	Mean Square	F	*p*
Between Groups	262.500	2	131.250	0.623	0.558
Within Groups	1895.890	9	210.654		
Total	2158.390	11			

No significant difference exists between the flexural strengths of the four proportions tested as reflected by the SPSS results since the significance value is 0.558 higher than 0.05.

Table 17 shows the results in analyzing the significant difference between proportions in terms of Thermal Resistance and Water Absorptivity using *t* – test.

Table 17

Test of Difference in terms of Thermal Resistance and Water Absorptivity

	Levene's Test for equality of Variance		t –test for equality of means				
			95% Confidence Interval of Difference		t	df	p
	F	Significance	Lower	Upper			
Thermal Resistance	3.000	0.158	-1.13469	0.72469	-0.59	4	0.584
Water Absorptivity	0.000	1.000	-6.07	15.074	-1.732	4	0.158

For thermal resistance no significant difference was found between the four proportions tested as indicated by the significance value of 0.584 which is higher than 0.05.

There was no significant difference observed on the water absorptivity results in all proportions based on the generated significance result of 0.158 higher than 0.05.

Discussion

Based on the experimentation, the ceiling board can be fabricated using Plaster of Paris, rice hull and water with the dimension of ½ inch x 30 cm x 30 cm.

The laboratory results on the evaluation of the physical properties of *Rice Hull Ceiling Board* shows the edge of one mixture with respect to another mixture. When it comes to drop testing all the four mixture exhibited the same result in one foot and 2 feet height, however, on the third height, proportion 1:1/2 got higher mean than the rest of the proportions.

For flexural testing all the four got favorable results, for which sample mixture 1:1 obtained 116.1 as its mean, higher than the rest of the mixtures.

For thermal resistance, basing on the thermal conductivity, proportion 1:3 got 0.147 J/s, which shows that this mixture conduct heat slower that the rest of the mixture which a good characteristic of a ceiling board.

For water absorptivity testing, mixture 1:3 got 92.9% water content after 24 hours of soaking in water, being the highest in the group. This means that mixture 1:3 holds more water than the rest of the mixture.

The evaluation of the quality of ceiling board proceeded with the following results:

As to performance, the average mean was 3.70 which was interpreted as very satisfactory. As to reliability, the average mean was 3.71, verbally interpreted as very satisfactory. As to usability, the average mean was 3.90 with verbal interpretation of very satisfactory. As to durability, the following were the results:

For drop testing the average mean for all proportions were verbally interpreted as much accepted.

When it comes to flexural testing the average means were verbally rated as much accepted for all proportions.

The thermal resistance testing obtained a verbal interpretation of "much accepted" for proportions 1:1/2, 1:1 and 1:3 and "accepted" for proportion 1:2.

The water absorptivity testing for the *Rice Hull Ceiling Board* obtained a verbal interpretation of "accepted" in all proportions. No significant differences existed on the different properties tested among the proportions of the *Rice Hull Ceiling Board* in terms of drop testing results, flexural testing results, thermal resistance results and water absorptivity results.

The *Rice Hull Ceiling Board* can be fabricated out of Plaster of Paris which is available in local hardware and rice hull which is abundant in Bacolod City and nearby cities and municipalities.

Rice Hull Ceiling Board possesses physical characteristics comparable to the existing ceiling board. Evaluating the value, mixture 1:1 is the best among the four proportions. It passes the drop testing test, highest in flexural strength, although it got the highest value of thermal conductivity still it is still better than the existing ceiling board and for water absorptivity it falls between the middle four.

Rice Hull Ceiling Board was very satisfactory in terms of its performance, reliability and usability. In terms of durability, it was rated as much accepted, therefore it can substitute the traditional ceiling board.

On the basis of the findings and conclusions, the following are recommended:

1. Design a board that can be used as wall cladding using different shapes, thickness, textures and colors;

2. The *Rice Hull Ceiling Board* may be used as wall insulator by embedding between dry walls to provide insulation.

3. Redesigning the molder, the mixture of Plaster of Paris and rice hull maybe used as decorative blocks.

4. Further study utilizing the mechanized method of mixing Plaster of Paris and Rice Hull is recommended.

5. Method of casting should be studied by using compression on the mixture if there will be some effects on the durability of the board.

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