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The Mechanical and Physical Properties of Coir Fiber Reinforced Gypsum Board

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Abstract— This research work focused on the use of coir fiber as reinforcement for gypsum board. The physical properties of composite ceiling board made from coir fiber and gypsum, as developed at the Chemical Engineering Laboratory of Nnamdi Azikiwe University, Awka were studied to determine their suitability for use in low-cost construction work. The results obtained showed that the flexural strength increased from 0.08 N/mm^2 to 0.1 N/mm^2 and modulus of elasticity from 1150 N/mm^2 to 1275 N/mm^2 as the percentage coir content increased from 4.26% to 17.02%. The water absorption capacity is very low and increased from 3.1% to 7.7% as the coir content increased. The thermal conductivity increased from 0.0426 KW/m K to 0.0433 KW/m K while very slight variation is observed in thermal resistivity. The results show that coir fiber can be used successfully to reinforce gypsum board.

Index Terms— **Agro waste, Bio-composite, Coir fiber, Gypsum board, Water seal.**

1. Introduction

The dominance of peasant farming in most developing countries, explains the abundance of agricultural and natural fibers in these countries. Research has shown that these natural fibers have very good physical and mechanical properties hence, making them potential raw materials for various building applications [1], [2].

A ceiling board is a building material required for ceiling system in commercial structures, residential, and institutional buildings. According to [3], Ceilings are panel sheet covering the upper layer of an internal section of a building which improves its aesthetics and reduces sound and heat transmission in the house; it is an essential part in the building process which plays a key role in the thermal comfort of a building. Ceiling as one of the main building elements is very important and has the main function of thermal Resistivity which reduces or decreases excessive heat in the room. Of recent, there has been an increase in the growth of the world's population [4]. The need for shelter and structural accessories such as ceiling sheets is in high demand. Studies have shown that Nigeria and other developing countries make use of asbestos and plaster of Paris (P.O.P) in buildings for covering the upper layer of the internal sections [5]. In the past, asbestos known as a fiber present in rocks were used for the production of ceiling boards due to its poor heat conductivity and high fire resistance. Ceilings with good quality upper surface and excellent heat insulation are good for hot climates. Hence, the use of materials with good thermal resistivity (such as gypsum) in production of ceiling tiles is imperative.

Gypsum is the base materials for the production of many building materials such as ceiling tiles. It is a mineral material known as calcium sulfate dihydrate ($CaSO4.2H_2O$) in its raw form, which can be transformed into calcium sulfate hemihydrate ($CaSO4.\ 0.5H_2O$) on heating [6]. Among the many ceiling tiles in the market, gypsum -based ceiling tiles predominate because of the low cost, relatively low weight, good thermal and heat insulation, flame resistance capabilities of gypsum [7]. Notwithstanding these positive qualities, gypsum-based boards can easily be damaged by moisture and growth of fungi [7] and are more susceptible to impact damage than other building components due to their brittleness and low mechanical strength [8]. Hence, an addition of reinforcing fibers to the gypsum binder has been proposed as a possible solution to these limitations [9]. These fibers can be natural or synthetic, but because of the economic and ecological burden associated with the production of synthetic fibers, natural materials, which would otherwise be discarded as waste, are mostly used [9]. These natural materials are readily available in large quantity at low cost and are biodegradable [7]. Natural fibers like wheat straw [9], wool and coir [7], wooden fiber [10], Jute fiber [6], hemp and banana [11] etc., have been used to reinforce gypsum board in order to improve the mechanical properties.

Indeed many studies have been done regarding the evaluation of physical and mechanical properties of fiber reinforced gypsum materials. Guna et al [7] used a blend of wool and coir to enhance the properties and performance of gypsum ceiling tiles. According to the authors, the fiber reinforced gypsum ceiling tiles showed higher strength and modulus, and also, better moisture resistance. Iucolano et al. [12] evaluated the use of bio-degummed hemp fibers in reinforcing gypsum material. They established that the fiber reinforcement improved the thermal resistance of the gypsum composite. In another study, Fantilli et al. [13] evaluated the capability of sheep wool fiber and hemp fiber to enhance the fracture toughness of the gypsum matrix. According to their report, sheep wool fiber improved the mechanical performance of the gypsum matrix better than hemp fiber.

These natural fibers have the disadvantages of weak

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interaction with binder matrices and high moisture adsorption capacity [8]. To overcome these limitations, natural fibers are usually treated with alkalis (mostly NaOH) to improve their adhesion with the matrices and reduce their moisture adsorption capacity [8], [11].

Coir, a natural fiber, is that fibrous material found between the hard internal shell and outer coat of a coconut husk [14]. It has a lignin content which makes it resilient, strong and highly durable. It is grouped into brittle fiber and mattress fiber [15]. The individual fiber cells are narrow and hollow, with thick wall made of cellulose. They are pale when immature but later become hardened and yellow. The two varieties of coir are brown and white coir. Mature brown coir fiber contains more lignin and less cellulose. The fibers harvested from coconuts before they are ripe are white or light brown in color and smoother and finer, but also weaker. The coir is relatively water proof, and is one of the few natural fibers resistant to damage by salt water and fresh water [16]. This research work aims at the use of coir fiber, an agricultural waste, in reinforcement of gypsum board.

2. Materials and Method

A. Materials

The cocoa nut husk, from which the coir was extracted, was gathered as waste from a cocoa nut seller at Eke Awka main market, Anambra state of Nigeria. The gypsum powder, water sealant, used were purchased from Eke-Awka market, Awka and used without further treatment. The sodium hydroxide and acetic acid used were of analytical grade. Deionized water was used for the water absorption test.

B. Methodology

1) Preparation of Coir Material

The coir fibers were obtained by removing the outer part of the coconut husk with cutlass. The extracted coir fibers were washed with water to remove the sand and other impurities and sun-dried for 48 hours. Size reduction was done using grinder. 300 mm mechanical sieve was used to obtain fine uniform particles. The purpose of reducing the particle size is to prevent balling when mixing with other composite materials.

Fig. 1. Coconut coir fiber set up for sun drying

C. Alkaline Treatment of the Coir Fiber

The alkaline treatment was carried out on the coir fibers following the method described by Abir et al. [6]. The essence of this is to increase the free energy of the fiber on the surface as well as to improve the mechanical bonding at the fiber/matrix interface by making the fiber surface rough [11]. The cleaned fibers were immersed into 2 molar solution of NaOH for 3 h, with the ratio of fiber: NaOH solution being 1:15. The excess NaOH solution was drained off at the end of the 3 h period and then neutralized with a 1 molar solution of acetic acid for 1 h. after that, it was rinsed severally with plenty of water to maintain pH of 7. At the end, the fibers were sun-dried for 24 h, reduced in size by crushing and then stored properly for subsequent use.

D. Production of Gypsum Composite from Coir Fiber

Three different samples of the composite material (gypsum fiber board) were produced using the matrix shown in Table 1. The ingredients for the reinforced gypsum board were weighed according to the amount shown in Table 1. The powdered materials were mixed together after which 250ml of water was added and stirred continuously till a homogenous smooth mixture was obtained. The homogenous mixture was casted into a mould of size 180 x 150 x 10 mm. the samples were compacted using the hydraulic press. The hydraulic press was pumped till the pressure gauge reads 25 bars, and the pressure was maintained for 80 s. After the compaction, the samples were removed from the mould, sun-dried to a steady weight for 12 hours. After the 12 hours of drying, the board edges were trimmed with hand saw to avoid edge effect and then cut into square sizes of 4cm x 4cm for further test.

(a) (b)

Fig. 2. Treatment of Coir Fiber with (a) NaoH and (b) Acetic acid solutions

E. Physical Tests

1) Water Absorption Test

The moisture resistance of the gypsum-coir composite board was evaluated by measuring the percentage of water absorbed by the test samples over a period of 24 hours. Sample of known dimensions was hot dried in an ovum at 105oC until a constant weight (W1) is attained. It was then transferred into a beaker containing distilled water. The sample was withdrawn from the water at the end of every 24 hours, dried carefully with a soft tissue and reweighed to obtain a new weight, W2. The percentage of water absorbed was then calculated using the equation:

$$\frac{W_2-W_1}{W_1}\ x\ \frac{100}{1} \tag{1}$$

Where: W1 is the weight of the specimen before immersion and W2 is the weight of the specimen after 24 hours.

2) Density of reinforced Gypsum Board

The reinforced gypsum boards prepared were cut into small sections (dimensions: 4cm x 3xm x4cm). Each of the samples was weighed using a calibrated weighing machine and the weight (W) recorded. The bulk density of each sample is then determined by dividing the weight (W) of the sample by its volume (4 x 3 x 4cm^3).

3) Thermal Conductivity Test

To measure the thermal conductivity of the samples, a hot plate was connected to a power source at a temperature of 35°C. After a 60 s interval, the temperature rise of the hot plate was noted. The hot plate and the heat sensor were allowed to cool, then the samples were placed on the hot plate in turns, and the temperature rise after the 60 s interval (in each case) was noted and recorded. Then thermal conductivity of the samples was then calculated using Fourier's law of heat conduction (equation 2) [17]:

$$K = \frac{QL}{A\,\Delta T} \quad (2)$$

Where:

- Q is the amount of heat transferred through the material in Watts, in this case, Q is 200W
- L is the thickness of the sample
- A is an area of the sample specimen used for testing (i.e. 12cm² in this case)
- ΔT is the difference between the temperature of the hot plate and the temperature of the specimen after passing heat through it for 60s
- K is the thermal conductivity of the specimen

The thermal resistivity of the composite samples was evaluated as the reciprocal of the thermal conductivity and recorded.

4) Flexural Strength Test

The hardened samples were subjected to flexural (bending) stress according to the method described by Ataguba [17]. The flexural strength is given by:

$$\sigma f = \frac{pl}{bd^2} \quad (3)$$

p is the maximum load on the beam
l is the span of beam
b is the width of the beam
d is the depth of the beam

5) Modulus of Elasticity

Modulus of elasticity (MOE) is defined as the ratio of tensile stress to tensile strain; it is the tendency of an object to deform along an axis when opposing forces are applied along that axis. MOE of the samples were calculated using equation 3 [17]:

$$MOE = \frac{PL^3}{4bdH} \quad (4)$$

Where: MOE = modulus of elasticity (N/mm^2):

- P = Ultimate failure load (N):
- L= the span of board sample between the machine supports (mm)
- b = width of the board sample (mm)
- d = thickness of the board sample (mm) and
- H = Increase in deflection (mm).

3. Result and Discussion

A. Water Absorption of the Reinforced Gypsum Board

One of the limitations in the use of natural fibers in the reinforcement of gypsum material is their hydrophilic nature [12]. Low water absorption capacity of gypsum boards is desirable because the presence of moisture can result to the presence of micro-cracking inside the composite, thereby, worsening the mechanical properties [12]. This limitation was taken care of by alkaline treatment of coir fibers used (which involves chemical modification of their surfaces), hence leading to reduced water absorption and increased surface roughness. The percentage water absorbed by each of the samples of coir– gypsum composites were evaluated and the result presented in Table 2. The water absorption capacity of these composites increases from 3.1 % to 7.7% as the content of coir increased from 4.26 to 17.02 %. A similar trend was reported by Ramsiya et al [18] in which the water absorption capacity of gypsum board reinforced with coir fiber was found to increase with the content of coir fiber.

Table 1
Gypsum cement and coir fiber composition

Materials compositions	Sample 1	Sample 2	Sample 3
Gypsum cement (g)	180	160	140
Coir fiber (g)	20	40	80
Water seal (binder) (g)	20	20	20
Water (ml)	250	250	250
Percentage composition of coir	4.26	8.51	17.02

Table 2
Water absorption of the reinforced gypsum board samples

Sample No.	Dry weight of sample (Kg)	Weight after immersion (Kg)	Percentage water absorption
1	7.70	7.94	3.1
2	7.33	7.68	4.8
3	7.26	7.82	7.7

B. Thermal Conductivity and Resistivity of Coir Reinforced Gypsum Board

The thermal conductivity of the coir-gypsum composites was tested to establish their ability to transfer heat. The low thermal conductivity of gypsum boards is desirable so that by acting as thermal insulators, they can help reduce building energy consumption [11]. The result of the analysis (Table 3) shows that the thermal conductivity increases as the percentage content of the coir is increased. Conversely, the thermal resistivity, which is the reciprocal of thermal conductivity decreased with increase in the content of the coir fiber. The increase in thermal conductivity may be due to increase in lignocellulose as a result of higher content of coir which is a lignocellulosic fiber [7]. In as much as the thermal resistivity

Table 3
Properties of the gypsum composite material

Sample No.	Thermal Conductivity (KW/m K)	Thermal Resistivity (m K/KW)	Flexural strength (N/mm^2)	Density (Kg/m^3)	MOE (N/mm^2)
1	0.0426	23.47	0.08	445	1150
2	0.0429	23.31	0.09	435	1260
3	0.0433	23.09	0.1	430	1275

decreased with coir content, the variation is not much, hence, the thermal insulation is not affected to a large extent. Guna et al, [7] observed that, of all the natural fiber reinforced gypsum tiles studied, the coir fiber reinforced gypsum tile has the highest thermal conductivity.

C. Flexural Strength and Modulus of Elasticity

The flexural strength and the modulus of elasticity of the test samples are shown in Table 3. The result indicates that the flexural strength and modulus of elasticity increase with increase in the coir fiber content. This implies that the strength of the board improved as the coir content increased, hence the coir fiber can be used to reinforce the gypsum board. On the contrary, Vavrinova et al., [9] reported a decrease in flexural strength with increase in content of crushed wheat straw.

4. Conclusion

This research work contains basic information on the properties of gypsum board reinforced with coir fiber. It is evident from the results obtained that with increasing content of coir fiber, the flexural strength and modulus of elasticity increases. Although there is a slight decrease in thermal resistivity and slight increase in water absorption, the variation is not much. Thus, this research work concludes that addition of coir fiber improves the strength of the gypsum board and hence can be used as reinforcing material for gypsum board reinforcement.

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