# A Study on The Effectiveness of Coir Fiber as A Reinforcement for Gypsum Board

***Nicole M. Pingul [1], Mariella T. Raquipiso [1], Cindy G. Paclaon [1], Jimboy F. Maun [1], Jamaica Desiree R. Pamintuan [1], Katelyn A. Reyes [1], Michael Einstein L. Valencia [1], Princess Kimberly C. Sabiniano [1], Charles G. Lim [1]***

[1]*College of Engineering and Architecture, Department of Civil Engineering, Don Honorio Ventura State University, Cabambangan, Bacolor, Pampanga, Philippines.*

*Corresponding Author: pingulnicolem@gmail.com*

**Abstract: -** Coir fiber, an easily accessible and cost-effective natural material, was studied as a reinforcement for gypsum boards. Different coir fiber and gypsum ratios were tested, and mechanical properties were evaluated. The results showed improved properties with the addition of coir fiber, particularly at a 30% ratio. However, higher fiber ratios increased water absorption and thickness swelling. Longer curing periods also enhanced mechanical properties. Coir fiber shows potential as a sustainable and affordable solution for improving construction materials, but further research is needed for optimal fiber ratios and long-term durability assessment.

**Key Words: —** ***Coir, Gypsum, Reinforcement.***

## I. INTRODUCTION

Nowadays, the usage of green building materials in construction is eminent. Global and local communities and organizations introduce and promote eco-friendly building materials to develop sustainability in the construction sector. One of the green building materials used in construction is natural fibers. Natural fibers are those that come from the bodies of plants or animals or that are created by geological processes. One type of natural fiber is coir, also known as coconut fiber. It is a seed-hair fiber extracted from the outer shell of the coconut.

Currently, there are tons of coir produced annually throughout the world.

Manuscript revised July 18, 2023; accepted July 19, 2023. Date of publication July 20, 2023.

This paper available online at www.ijprse.com

ISSN (Online): 2582-7898; SJIF: 5.59

The Philippines is the second-largest producer of coconuts in the world, where coconut farming is thought to occupy around a quarter of all agricultural areas.

According to the Department of Agriculture (2014), it produces 14.69 billion nuts a year, of which 9 billion husks are either burned or left on the ground as farm trash. Large amounts of coir fiber are left unutilized after industrial processing, posing environmental issues. It contributes to greenhouse gas (GHG) emissions due to the bacterial breakdown of coconut trash processing where the effects of GHG emissions and environmental changes are felt around the world. Also, it imposes health issues and further economic loss due to the pile shells of coconut that serve as mosquito and rhinoceros beetle breeding grounds. Furthermore, the emission of phenolic chemicals from coconut waste landfills causes fire dangers and groundwater contamination (Gopal et al. 2001).

Despite the negative impacts of the vast amount of coir fiber, it has several good characteristics and properties that can be used to our advantage. Greer (2008) states that this vast quantity of husks could be a major natural resource. Some of the good characteristics and properties of coir fiber include insect proof, providing good insulation against temperature and sound, does not require chemical processing, and one of the most lignin-rich natural fibers and it is more resistant to microbial growth and seawater damage.

Thus, several studies have used coir fiber as a reinforcement or additive in cement paste, mortar, and concrete that show great results, especially in terms of their strength.

Ceiling tiles are one of the most common building materials, particularly in industrial and commercial structures, according to Guna et. al (2021). One of these ceiling tiles is the gypsum board. It is a common building material, particularly in interior design projects because of its lightweight, good thermal and heat insulation, and flame resistance. However, it is susceptible to moisture and fungal growth and has poor mechanical properties. Thus, the researchers thought to use these coir fibers as a reinforcement to gypsum board considering the good mechanical properties of coir fiber.

This study aims to create an improved gypsum board with the use of coir fiber and compare its mechanical properties to commercially produced gypsum board. Moreover, to maximize the use of coir fiber to lessen the coir waste and alleviate its negative impact on society. The proponents considered the coconut tree's availability in creating an improved gypsum board.

## II. METHODOLOGY

### *2.1 Research Design*

Quantitative research is a research method that involves measuring variables with a numerical system, analyzing these measurements with any of some statistical models, and reporting relationships and associations between the variables studied. These variables could be testing scores or reaction time measurements, for example. The goal of collecting quantitative data is to understand, describe, and predict the nature of a phenomenon, especially through the development of models and theories. Experiments and surveys are examples of quantitative research techniques (St. Clair, 2022).

Building upon the rationale, the research design for this study was grounded in quantitative research methodology and utilized an experimental research design. The aim was to investigate the relationship between the volume of coir fiber added to the gypsum board and its mechanical properties. Through controlled laboratory experiments, prototype-reinforced gypsum boards with different coir fiber volumes were subjected to rigorous testing. The mechanical properties of the boards were systematically measured and recorded as part of the data collection process.

This research design enabled the exploration of how varying coir fiber volumes influence the mechanical characteristics of the gypsum board.

### *2.2 Research Setting*

For this study, the collection of coir fibers was conducted at the Kapampangan Development Foundation Inc., located in Maliwalu, Bacolor, Pampanga. This organization was chosen as the collection site due to its affiliation with coconut processing and its expertise in fiber extraction. The researchers acquired four sacks of coir fibers from the foundation, which proved to be sufficient for creating prototypes with varying coir fiber ratios of 20%, 30%, and 40% by volume. Additionally, the defibering process was carried out at the same facility, ensuring consistency and controlled conditions during fiber extraction.

The subsequent stages of prototype development and testing were carried out meticulously within the DOST-FPRDI (Department of Science and Technology- Forest Products Research and Development Institute) Laboratory in Los Baños, Laguna. This laboratory was selected as an ideal setting for its state-of-the-art facilities and expertise in the field.

The research endeavor spanned from January to May, during which the researchers dedicated substantial effort to thoroughly investigate and analyze the various aspects of this study. The extended timeframe allowed for comprehensive data collection, analysis, and interpretation, ensuring a robust and rigorous examination of the research question.

### *2.3 Data Gathering Procedure*

#### *2.3.1 Preparation of Coir Fibers*

After the collection of coir fibers, the subsequent step entails subjecting the coconut husks to a defibering process. To accomplish this, the coconut husks were carefully fed into the decorticating machine, where the fibers were separated from the husks. Following this extraction, the coir fibers were sun-dried for approximately 3-5 days.

This process ensures optimal moisture reduction, enhancing the fibers' overall quality and resilience. Once the drying process was completed, the coir fibers were cut to a uniform length of 2.5-5 cm, rendering them primed and ready for integration into the prototype.

### *2.3.2 Fabrication of Prototype*

Table.1. Materials of the Prototype Reinforced Gypsum Board

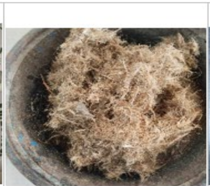
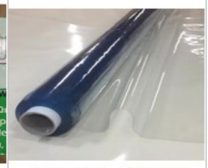
<table>
<tr><th colspan="3">MATERIALS</th></tr>
<tr><td><br>Gypsum Powder</td><td><br>Coir Fiber</td><td><br>Water</td></tr>
<tr><td><br>Kraft Paper</td><td><br>Glue</td><td><br>Plastic Sheet</td></tr>
</table>

Table.2. Laboratory equipment and supplies used in the production of the Prototype Reinforced Gypsum Board

<table>
<tr><th colspan="3">Laboratory Equipment and Supplies</th></tr>
<tr><td><br>Weighing Scale</td><td><br>Beaker</td><td><br>Basin</td></tr>
<tr><td><br>Mat-forming Frame</td><td><br>Thickness Calibrator</td><td><br>Metal Sheet</td></tr>
</table>

*Figure 5: Defibered Coir Fibers*

<table>
<tr><td><br>Chemical Resistant Gloves</td><td><br>Dust Mask</td><td><br>Board Press Machine</td></tr>
</table>

### *2.3.3 Material Preparation*

In this step, the raw materials, including gypsum plaster or gypsum powder and coir fibers, are carefully weighed according to the specified mixture proportions of 20%, 30%, and 40%. The coir fibers are then placed in a basin and lightly moistened with water. Gradually, the gypsum powder is added to the coir fibers, ensuring thorough mixing until a uniform consistency is achieved.

### *2.3.4 Mat Formation*

The mat formation process begins by preparing a flat surface covered with a plastic sheet. A mat-forming frame is placed on top of the plastic sheet, and 15.75 inches x 15.75 inches kraft paper, treated with glue, is positioned at the base of the frame. The gypsum-coir mixture is evenly distributed within the frame, ensuring uniform thickness. Manual pre-pressing is done to compact the mixture evenly.

### *2.3.5 Thickness Calibration*

Thickness calibrators are placed on top of the mixture to ensure consistent board thickness. Another 15.75 inches x 15.75 inches kraft paper, treated with glue, is positioned on top. The assembly is then covered with a plastic sheet to protect it during the subsequent steps.

### *2.3.6 Cold-Pressing*

Once the mat is formed, it enters a cold-pressing machine. The machine consists of a series of rollers that exert pressure on the mat, compacting the gypsum mixture and removing excess water. The pressure applied helps to consolidate the gypsum particles and promote bonding between them.

### *2.3.7 Drying and Curing*

The boards are typically cured for specific durations, such as 7, 14, 21, and 28 days. During the curing period, the boards continue to harden and gain strength, ensuring optimal performance and durability.

### *2.4 Testing of Samples*

The following tests enable the researchers to evaluate the impact of coir fiber on the mechanical properties, durability, and dimensional stability of the gypsum boards and determine its effectiveness in enhancing their overall performance.

#### *2.4.1 Bending Strength Test*

This test assesses a material's ability to withstand external forces without excessive deformation or fracture. By subjecting coir fiber-reinforced gypsum boards to controlled bending forces, valuable insights into their structural integrity and load-bearing capacity are gained. The results of this test indicate whether the inclusion of coir fiber effectively enhances the boards' bending strength, leading to improved structural performance and resilience. A high bending strength confirms the effectiveness of coir fiber in reinforcing gypsum boards.

A three-point bending test, following the ASTM D 1037-12 testing standard, was conducted to evaluate the impact of reinforcement on the ultimate strength and toughness of the gypsum board. Three samples, each measuring 5.91 inches x 1.97 inches, were prepared for testing, with varying proportions of coir fiber (20%, 30%, and 40%). For each sample, three trials were performed. The samples were subjected to typical curing periods of 7, 14, 21, and 28 days. The tests were carried out using a universal testing machine (UTM) with a 500N load cell. This method allowed for the determination of the bending behavior, ultimate strength, and toughness of the reinforced gypsum board, providing valuable insights into the effect of coir fiber content and curing duration on the mechanical performance of the boards.

#### *2.4.2 Water Absorption Test*

This test evaluates the susceptibility of coir fiber-reinforced gypsum boards to moisture-related issues. By subjecting the samples to water exposure and quantifying water absorption, the researchers assess their resistance to warping, swelling, or degradation caused by moisture. Comparing the water absorption of the coir fiber-reinforced boards to a maximum allowable limit of 40%, the researchers determine if the inclusion of coir fiber effectively reduces water ingress. Meeting or surpassing this criterion confirms the effectiveness of coir fiber reinforcement in mitigating moisture-related concerns.

The water absorption in reinforced gypsum board was assessed over time in this study. Three samples, each measuring 1.97 inches x 1.97 inches, were prepared for testing, with varying proportions of coir fiber (20%, 30%, and 40%). For each sample, three trials were performed. The samples were subjected to typical curing periods of 7, 14, 21, and 28 days. The samples were tested for water absorption using the 24-hour water immersion method specified in the PNS 230:1989 standards. Prior to the immersion, each sample was weighed to obtain the initial weight (w1). Subsequently, the samples were placed in separate beakers filled with water for a duration of 24 hours. After the immersion period, the samples were carefully removed from the water, dried with soft tissue, and weighed again (w2). This process allowed for the evaluation of water absorption characteristics of the reinforced gypsum board, considering variations in coir fiber content and the influence of three sample trials.

**Equation**

$$\textbf{Water Absorption \%} = \frac{W2-W1}{W1} \, x \, 100$$

**Where:**

**W1** = initial weight of the dry sample before water immersion.

**W2** = weight of the sample after water immersion and subsequent drying.

#### *2.4.3 Nail Head Pull-Through Test*

This test assesses the boards' resistance to fastener dislodgement under load. By subjecting coir fiber-reinforced gypsum boards to increasing pull-out forces, the researchers measure the load required to remove the fastener. High nail pull resistance indicates effective mechanical interlocking properties, ensuring reliable and secure fastening. Surpassing the expected threshold for nail head pull-through resistance confirms the effectiveness of coir fiber reinforcement in enhancing the boards' fastening capabilities.

The Nail Head Pull-Through Test in reinforced gypsum boards, comprising samples with different volumes of coir fibers (20%, 30%, and 40%), was conducted following the ASTM D 1037-12 testing standard. Three samples, each measuring 5.91 inches x 1.97 inches, were prepared and subjected to a curing period of 7, 14, 21, and 28 days. For each sample, three trials were performed.

The test involved clamping each sample onto a base plate and applying two loads (nails) at different locations on the board's surface. Gradually increasing force was applied perpendicular to the surface to measure the maximum force required for the nail heads to pull through the board. This test provides insights into the nail head pull-through strength of the reinforced gypsum board and evaluates the effect of different coir fiber volumes and curing durations on the board's mechanical properties.

#### *2.4.4 Thickness Swelling Test*

This test evaluates the resistance of coir fiber-reinforced gypsum boards to changes in thickness when exposed to moisture. Comparing the swelling or expansion of the samples to a maximum limit of 20%, the researchers determine the effectiveness of coir fiber reinforcement in mitigating dimensional instability. Coir fiber inclusion helps maintain the boards' dimensional stability, making them suitable for diverse construction applications.

The Thickness Swelling Test in reinforced gypsum boards was performed according to the PNS 230:1989 testing standard. Three samples, each measuring 1.97 inches x 1.97 inches and containing 20%, 30%, and 40% coir fibers, were prepared. The samples underwent a curing period of 7, 14, 21, and 28 days. The test involved immersing the samples in water for a duration of 24 hours. After the immersion period, the thickness of the samples was measured to determine the extent of swelling. This test provides insights into the water resistance and dimensional stability of the reinforced gypsum board, allowing for the evaluation of the effect of different coir fiber volumes and curing durations on the board's swelling behavior.

**Equation**

$$\textbf{Thickness Swelling \%} = \frac{Tf - To}{To} \times 100$$

**Where:**

**To** = original thickness of the sample before water immersion.

**Tf** = final thickness of the sample after water immersion.

Conducting these tests is crucial in this research study on coir fiber-reinforced gypsum boards.

By evaluating bending strength, water absorption, nail head pull-through resistance, and thickness swelling, the effectiveness of coir fiber as a reinforcement material will be able to determine. Meeting criteria for bending strength, nail pull resistance, water absorption, and thickness swelling demonstrates the effectiveness of coir fiber in enhancing mechanical properties, durability, moisture resistance, fastening capabilities, and dimensional stability of gypsum-based construction products. These test outcomes provide valuable insights for developing sustainable and high-performing construction materials with coir fiber reinforcement.

### *2.5 Data Analysis*

The collected data from the various tests conducted on the reinforced gypsum board will be analyzed and compared to the commercial gypsum board, using the American Society for Testing and Materials (ASTM) standard specification for gypsum board (ASTM D 1037-12) and the Philippine National Standards (PNS) 230:1989.

To analyze the data, graphical representations, such as bar charts or line graphs, can be used to visually present the comparison between the reinforced gypsum board and the commercial gypsum board across different properties and curing durations.

Overall, the data analysis will provide a comprehensive evaluation of the performance of the reinforced gypsum board in relation to the commercial gypsum board, based on the ASTM and PNS standards. The results will contribute to a better understanding of the potential benefits and suitability of reinforced gypsum boards for various applications in the construction industry.

## III. RESULTS AND DISCUSSION

### *3.1 Mechanical Properties*

#### *3.1.1 Bending Strength*

The mechanical performance of gypsum board is indicated by its bending strength values over a range of ratios and curing periods. The bending strength is an important parameter for gypsum boards since it impacts the load-carrying capability and structural integrity of the board. The values of bending strength obtained from the boards with different ratios of coir fiber and gypsum and different curing periods are shown in the graph.

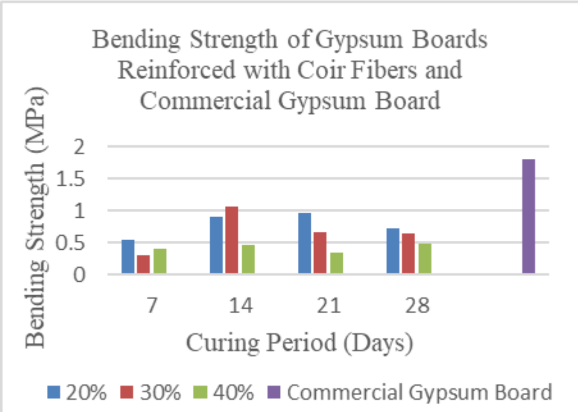



Fig.1. The bending strength values of the gypsum boards reinforced with different percentages of gypsum board after 7-day, 14-day, 21-day, and 28-day curing, and the commercial gypsum board

The bar graph shows the bending strength values of the composite boards with different ratios of coir fibers (20%, 30%, and 40%) after 7-day, 14-day, 21-day, and 28-day curing periods and the bending strength of commercial gypsum boards. The X-axis shows the different curing periods in days, while the Y-axis would show the bending strength values in megapascal (MPa). The bars are color-coded to differentiate the values obtained after 7-day, 14-day, 21-day, and 28-day curing.

Bending strength values for the various ratios over the 7-day curing period were 0.55 MPa, 0.31 MPa, and 0.41 MPa for the gypsum board having 20%, 30%, and 40% coir fiber, respectively. According to these findings, the boards with a larger proportion of gypsum had a higher bending strength. The board with 20% coir fiber had the greatest bending strength. The board with 30% of coir fiber had the lowest bending strength.

For the 14-day curing period, the bending strength values for the different ratios were 0.91 MPa, 1.06 MPa, and 0.47 MPa, for the gypsum board having a 20%, 30%, and 40% coir fiber, respectively. Interestingly, the bending strength values for the different ratios varied significantly from the values obtained during the 7-day curing period. The board with 30% of coir fiber had the highest bending strength. The board with 40% of coir fiber had the lowest bending strength value. There is a 65.45% increase in bending strength in the board with 20% of coir fiber, a 241.94 % increase in bending strength in the board with 30% of coir fiber, 14.63% increase in bending strength in the board with 40%. The board with 30% of coir fiber shows a higher increase in bending strength over the 14-day curing period.

For the 21-day curing period, the bending strength values for the different ratios were 0.97 MPa, 0.66 MPa, and 0.34 MPa, for the gypsum board having 20%, 30%, and 40% coir fiber, respectively. The board with 20% coir fiber has the highest bending strength and the board with 40% coir fiber has the lowest bending strength. These values are relatively lower compared to the bending strength values obtained from the coir-reinforced gypsum board cured for 14 days.

For the 28-day curing period, the bending strength values for the different ratios were 0.72 MPa, 0.64 MPa, and 0.49 MPa, for the gypsum board having 20%, 30%, and 40% coir fiber, respectively. The board with 20% coir fiber has the highest bending strength and the board with 40% coir fiber has the lowest bending strength. These values are greater than the values obtained from the coir-reinforced gypsum board cured for 7 days. However, these values are lower compared to the bending strength values obtained from the coir-reinforced gypsum board cured for 21 days.

The bending strength values obtained from the coir-reinforced gypsum board cured for different days are lower than the bending strength of the commercial gypsum board which is 1.8 MPa.

In conclusion, both the curing duration and the fiber-to-gypsum ratio impacted the bending strength values of the coir fiber and gypsum composite samples. The curing duration was important in increasing the mechanical characteristics of the composite, with longer periods generally resulting in increased bending strength. The optimal fiber-to-gypsum ratio varied depending on the curing period, with different ratios demonstrating the highest bending strength at different stages. These results highlight the significance of taking the curing time as well as the fiber-to-gypsum ratio into account when constructing fiber-reinforced gypsum composites with particular bending strength requirements. A deeper understanding of the underlying mechanisms may be gained by additional study and analysis, which can also improve the mechanical performance of the composite.

*3.1.2 Nail Pull Resistance*

Nail pull resistance is an important property for gypsum boards, as it measures the force required to pull a nail out of the board. The values of nail pull resistance for different ratios of coir fiber and gypsum, as well as different curing periods, are shown in the graph.

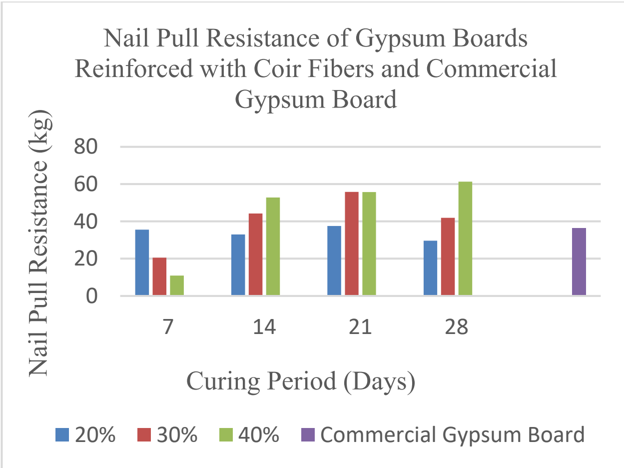



Fig.2. The nail-pull resistance values of the gypsum boards reinforced with different percentages of gypsum board after 7-day, 14-day, 21-day, and 28-day curing, and the commercial gypsum board

The bar graph shows the nail-pull resistance values of the composite boards with different ratios of coir fibers (20%, 30%, and 40%) after 7-day, 14-day, 21-day, and 28-day curing periods and the nail-pull resistance value of commercial gypsum board. The X-axis shows the different curing periods in days, while the Y-axis shows the nail-pull resistance values in kilogram (kg). The bars are color-coded to differentiate the values obtained after 7-day, 14-day, 21-day, and 28-day curing.

The results show that the nail-pull resistance values vary significantly with the ratio of coir fiber and gypsum and the curing period.

For the curing period of 7 days, the nail-pull resistance values of the composite boards with 20%, 30%, and 40% coir fibers are 35.58 kg, 20.55 kg, and 10.95, respectively. The highest nail-pull resistance value was obtained from the board with 20% coir fiber, which is 35.58 kg. The nail-pull resistance values decreased as the coir fiber content was increased, with the lowest value of 10.95 kg obtained from the board with 40% coir fiber.

For the 14-day curing period, the nail-pull resistance values of the composite boards with 20%, 30%, and 40% coir fibers are 33.03 kg, 44.25 kg, and 52.85 kg, respectively. The nail-pull resistance values increased significantly compared to those obtained for the 7-day curing period. The highest nail pull resistance value was obtained from the board with 40% coir fiber, which was 52.85 kg indicating that this ratio may have a desirable balance between coir fiber reinforcement and gypsum strength.

For the 21-day curing period, the nail-pull resistance values of the composite boards with 20%, 30%, and 40% coir fibers are 37.53 kg, 55.82 kg, and 55.75 kg, respectively. The nail-pull resistance values increased across all coir fiber ratios. The samples with 30% and 40% coir fiber content displayed higher nail pull resistance, surpassing the commercial gypsum board.

For the 28-day curing period, the nail-pull resistance values of the composite boards with 20%, 30%, and 40% coir fibers are 29.68 kg, 41.95 kg, and 61.33 kg, respectively. The benefits of the inclusion of coir fiber were further underlined by the 28-day curing time. The results for nail pull resistance were much improved, particularly for coir fiber ratios of 30% and 40%. These samples significantly outperformed the commercial gypsum board in terms of nail pull resistance, proving that coir fiber reinforcement enhances mechanical performance over time.

The board with 40% coir fiber cured for 28 days obtained the highest nail-pull resistance among the other boards cured for different days.

These findings show that adding coir fiber to the gypsum matrix improves the mechanical characteristics of the composite material. The nail-pull resistance of the composite is significantly influenced by the curing time as well as the coir fiber ratio. According to the results, an ideal coir fiber content and sufficient curing time can produce a fiber-reinforced composite with exceptional mechanical characteristics, making it a possible contender for a variety of applications where nail pull resistance is an important consideration.

### *3.2 Physical Properties*

#### *3.2.1 Water Absorption*

Understanding a board's physical qualities and durability requires determining its water absorption. Water absorption is defined as a material's ability to absorb water and is often represented as a percentage of the material's initial dry weight. Higher water absorption numbers indicate that the material has a stronger ability to absorb and hold moisture. This feature is critical in many applications where the board is exposed to moisture or humidity, including building, furniture, and outdoor constructions.

A board's water absorption can impact its weight, strength, stiffness, and dimensional stability, all of which are important performance variables. If a board absorbs too much water, it may swell, bend, or fracture, jeopardizing its structural integrity and shortening its lifespan. However, if a board does not absorb enough water, it may become brittle and shatter, particularly in arid regions. Thus, the water absorption values of gypsum boards reinforced with different ratios of coir fibers were investigated after 7-day, 14-day, 21-day, and 28-day curing periods, and the results are shown in the graph.

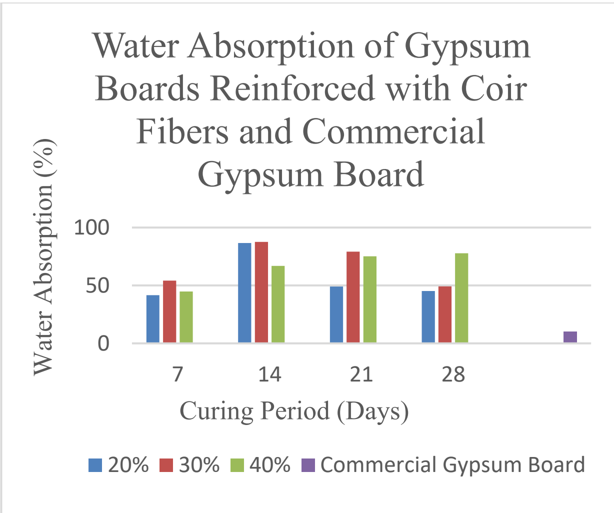



Fig.3. The water absorption values of the gypsum boards reinforced with different percentages of gypsum board after 7-day, 14-day, 21-day, and 28-day curing, and the commercial gypsum board

The bar graph shows the water absorption values of the composite boards with different ratios of coir fibers (20%, 30%, and 40%) after 7-day, 14-day, 21-day, and 28-day curing periods and the water absorption value of commercial gypsum boards. The X-axis shows the different curing periods in days, while the Y-axis shows the thickness swelling values in percentage. The bars would be color-coded to differentiate the values obtained after 7-day, 14-day, 21-day, and 28-day curing.

The results showed that the water absorption of the composite boards increased with an increase in the ratio of coir fibers, and decreased with an increase in the curing time.

After 7-day curing, the water absorption values of the composite boards with 20%, 30%, and 40% coir fibers were 41.66%, 54.15%, and 44.74%, respectively. These values were significantly higher than the water absorption value of the commercial gypsum board which is 10%. The higher water absorption values for the composite boards reinforced with coir fibers can be attributed to the porous nature of the fibers. Coir fibers have a high porosity, which allows water to be absorbed easily.

After 14-day curing, the water absorption values of the composite boards with 20%, 30%, and 40% coir fibers were 86.71%, 87.57%, and 66.95%, respectively. These values were also higher than the water absorption value of the commercial gypsum board which is 10%. The higher water absorption values for the composite boards reinforced with coir fibers after 14-day curing can be attributed to the incomplete curing of the gypsum matrix in the presence of coir fibers. The coir fibers may hinder the hydration process of the gypsum, leading to incomplete curing and higher water absorption values.

Water absorption values for composite boards with 20%, 30%, and 40% coir fibers were 49.10%, 79.17%, and 75.24%, respectively, when the curing duration was prolonged to 21 days. The composite board with 30% coir fiber has the highest water absorption value while the composite board with 20% coir fiber has the lowest water absorption value. However, it is still higher than the water absorption value of the commercial gypsum board which is 10% and compare to the maximum limit of 40%.

At a 28-day curing period, the water absorption values for the same ratios were 45.24%, 49.23%, 77.80%, and 10%, respectively. The water absorption values decreased slightly compared to the 21-day curing period but were greater than the water absorption values of the composite boards cured for 7 days and to the maximum limit of 40%.

These findings imply that the addition of coir fiber to the composite increased water absorption compared to the composite board without coir fiber or the commercial gypsum board, regardless of the curing period. The highest water absorption values were commonly obtained for the 30% and 40% ratios, demonstrating that a larger coir fiber content led to enhanced water absorption.

In conclusion, the findings of this study reveal that adding coir fibers to gypsum boards enhances water absorption, which may restrict their durability and performance in wet conditions. Further investigation and assessment of the mechanical characteristics and long-term performance of these composites would offer a more thorough knowledge of their applicability for certain applications.

*3.2.2 Thickness Swelling*

Thickness swelling is a measure of the dimensional change in the thickness of the board due to water absorption, and it can affect the board's mechanical strength, structural integrity, and overall performance. The thickness swelling values of gypsum boards reinforced with different ratios of coir fibers were investigated after 7-day, 14-day, 21-day, and 28-day curing periods, and the results are shown in the graph.

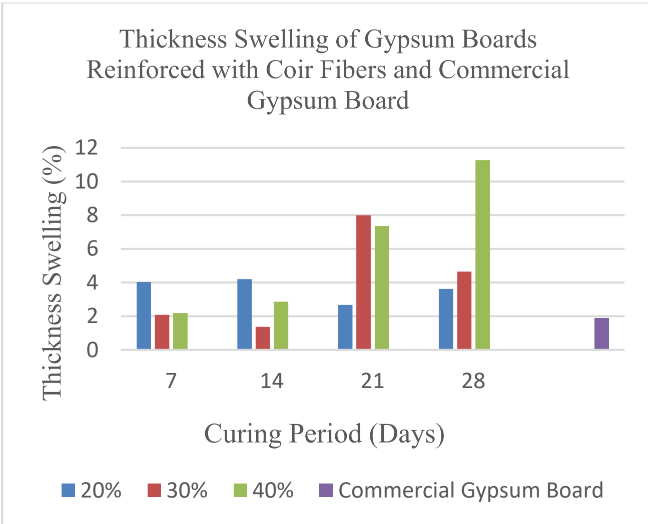



Fig.4. The thickness swelling values of the gypsum boards reinforced with different percentages of gypsum board after 7-day, 14-day, 21-day, and 28-day curing, and the commercial gypsum board

The bar graph shows the thickness swelling values of the composite boards with different ratios of coir fibers (20%, 30%, and 40%) after 7-day, 14-day, 21-day, and 28-day curing periods and the commercial gypsum board. The X-axis shows the different curing periods in days, while the Y-axis shows the thickness swelling values in percentage. The bars are color-coded to differentiate the values obtained after 7-day and 14-day curing.

The thickness swelling values of gypsum boards reinforced with different ratios of coir fibers were investigated after 7-day, 14-day, 21-day, and 28-day curing periods.

After 7-day curing, the thickness swelling values of the composite boards with 20%, 30%, and 40% coir fibers were 4.03%, 2.08%, and 2.19%, respectively. These values were higher than the thickness swelling value of the commercial gypsum board which is 1.9%. The higher thickness swelling values for the composite boards reinforced with coir fibers can be attributed to the porous nature of the fibers. Coir fibers have a high porosity, which allows water to be absorbed easily.

After 14-day curing, the thickness swelling values of the composite boards with 20%, 30%, and 40% coir fibers were 4.20%, 1.37%, and 2.86%, respectively. The thickness swelling value of the commercial gypsum board is still 1.9%. The lower thickness swelling values for the composite boards reinforced with coir fibers after 14-day curing can be attributed to the complete curing of the gypsum matrix in the presence of coir fibers. The longer curing time allowed for a more complete hydration process of the gypsum, leading to lower thickness swelling values.

The thickness swelling values of the composite boards with 20%, 30%, and 40% coir fibers after 21-day curing were 2.67%, 7.99%, and 7.36%, respectively. These values were more than the thickness swelling value of the commercial gypsum board which is 1.9%. The gypsum board with 20% coir fiber has the lowest thickness swelling value among the coir fiber-reinforced gypsum boards.

After 28-day curing, the thickness swelling values of the composite boards with 20%, 30%, and 40% coir fibers were 3.62%, 4.65%, and 11.27%, respectively. These values were also higher than the thickness swelling value of the commercial gypsum board 1.9%. The gypsum board with 20% coir fiber has the lowest thickness swelling value among the coir fiber-reinforced gypsum boards. Thickness swelling values tended to rise with increasing coir fiber ratios, especially after longer curing durations.

In summary, the addition of coir fibers generally increased the thickness swelling values of the composite boards as compared to boards without fibers. Yet, all the boards have thickness swelling values below the maximum limit of 20%. The lowest thickness swelling values were recorded at the 30% coir fiber ratio after 14 days of curing, whereas the highest thickness swelling value was observed at the 40% coir fiber ratio after 28 days of curing. These findings suggest that the coir fiber ratio and curing time can impact the thickness swelling behavior of composite boards. Thus, these results suggest that the gypsum board with 30% coir fiber achieves a balance between mechanical properties and water resistance.

## IV. Conclusion and Recommendations

### *4.1 Conclusion*

The study evaluated the mechanical and physical properties of coir-reinforced gypsum boards at different coir fiber ratios and curing periods. The findings are as follows:

Bending Strength: The board with 20% coir fiber showed the highest bending strength after the 7-day curing period. The 30% coir fiberboard had the highest bending strength after 14 days, while the 20% coir fiberboard had the highest value after 21 and 28 days. However, the bending strength of the coir-reinforced boards was still lower than that of commercial gypsum boards.

Nail Head Pull-Through: The nail-pull resistance test results varied with the coir fiber content and curing period. Higher coir fiber content resulted in lower nail-pull resistance after 7 days, but the opposite trend was observed after 14, 21, and 28 days. The board with 40% coir fiber cured for 28 days exhibited the highest nail-pull resistance.

Thickness Swelling: The board with 30% coir fiber had the lowest thickness swelling. As the coir fiber content and curing period increased, the thickness swelling values also increased, particularly after 21 and 28 days of curing.

Water Absorption: The board with 30% coir fiber had the highest water absorption values after 7, 14, and 21 days of curing. However, the board with 40% coir fiber cured for 28 days exceeded the maximum allowed water absorption value of 40%. This indicates the potential degradation of the material in humid or water-exposed environments.

Overall, the optimal coir fiber ratio was determined to be 30% as it showed the maximum improvement in bending strength, nail head pull-through, and thickness swelling. However, the water absorption properties did not improve with the addition of coir fiber. Additionally, the curing period was found to influence the mechanical and physical properties of the coir-reinforced gypsum board.

### 4.2 Recommendations

For the particular improvement of the "Effectiveness of Coir Fiber as a Reinforcement of Gypsum Board", the following are recommended:

- The study can be further developed by including additional tests such as sound absorption, thermal conductivity, compressive strength, tensile strength, impact resistance, wind load resistance, and fire resistance. By including these additional tests in the study, a more comprehensive understanding of the material's performance across various key properties can be obtained. This enhanced analysis will provide valuable insights for potential applications and improve the overall understanding of the material's capabilities.
- Further studies be conducted to investigate the optimal ratio of coir fibers to be added to gypsum boards and the appropriate curing period for achieving the best mechanical properties. By conducting these further studies, researchers can gain a deeper understanding of the relationship between coir fiber content, curing period, and the mechanical properties of the composite material. The results obtained from these investigations will provide valuable insights for optimizing the manufacturing process, determining the appropriate composition, and ensuring the production of high-performance coir-gypsum boards.
- Further developed by adding other materials that could improve the mechanical and physical properties. By incorporating other materials and implementing chemical treatments, researchers can potentially enhance the mechanical and physical properties of the coir-gypsum boards. These enhancements have the potential to improve strength, durability, moisture resistance, and other desirable characteristics. Furthermore, investigating the effects of different materials and chemical treatments will contribute to a deeper understanding of the composite material's behavior. This research will provide valuable insights for optimizing the composition and manufacturing process of the coir-gypsum boards, leading to the production of high-performance materials.
- Future researchers could make use of this as a reference study in developing the Effectiveness of Coir Fiber as a Reinforcement for gypsum board. The findings and insights obtained from this study can serve as a foundation for further investigations into enhancing the mechanical and physical properties of coir-gypsum composites. By building upon this research, future studies can contribute to the advancement of knowledge in this area and drive improvements in the use of coir fiber as a reinforcement in gypsum boards.

## References

[1]. Ali, M.J.I.H., Sankar, S. et. al. (2018). Experimental Study on Coir Fibre Mixed Concrete.

[2]. Arrohman, S., Mustofa, A.S.H. & Diharjo, K. (2020). Characteristics of mechanical properties of coir- fibre/rubber composite. International Conference on Science Education and Technology Journal of Physics: Conference Series 1511 (2020) 012065 IOP Publishing.

[3]. Asasutjarit C. et. al. (2007). "Development of coconut coir-based lightweight cementboard", Construction and Building Materials vol.21, pp.277–288.

[4]. Beg, M.D.H. et. al. (2008). Mechanical performance of kraft fibre reinforced polypropylene composites: Influence of fibre length, fibre beating and hygrothermal ageing. Composites Part A: Appl. Sci. Manuf., 39: 1748-1755.

[5]. Chalk under a Microscope - Procedures and Observations. (n.d.). MicroscopeMaster. Retrieved December 18, 2022.

[6]. Devaraju A. et. al. (2018). Investigation on the Mechanical properties of Coconut Bunch fiber Reinforced Epoxy with Al 2 O 3 Nano particles Composites for Structural Application. Materials Today: Proceedings;5(6):142527.
[7]. Elizabeth St. Clair, M. (2022). City University of Seattle Library: Research Methods and Design: Quantitative Research Methods.
[8]. Flexural Test. (2019). Testresources.net.
[9]. Gabriel, D. et. al. (2007). Characterisation and performance of coconut fibre as packing material in the removal of ammonia in gas-phase biofilters. Biosystems.Eng.,97:481490.
[10]. Guna, V. et. al. (2021). Wool and coir fiber reinforced gypsum ceiling tiles withenhanced stability and acoustic and thermal resistance. Journal of Building Engineering, 41, 102433.
[11]. Gypsum Board - an overview | ScienceDirect Topics. (2016). Sciencedirect.com.Publishing.
[12]. Hasan, K. M. F. et. al. (2021). Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites. Scientific Reports, 11(1).
[13]. Hemp Fiber - an overview | ScienceDirect Topics. (n.d.).
[14]. History and Use of Horsehair Plaster. (2019, December 11). John Canning & Co.
[15]. Impedance tube buy in New Delhi. (n.d.). All-Biz Ltd. Retrieved December 18, 2022.
[16]. Iucolano, F. et. al. (2019). Hemp as eco-friendly substitute of glass fibres for gypsum reinforcement: Impact and flexural behaviour. Composites Part B: Engineering, 175, 107073.
[17]. Keerthi, M. et. al. (2017). Experimental study on coir fibre reinforced fly ash based geopolymer concrete for 10M. International Journal of Civil Engineering and Technology, 8(1), 464–472.
[18]. Main, N. et. al. (2014). Suitability of Coir Fibers as Pulp and Paper. Agriculture and Agricultural Science Procedia, Volume 2, 2014, Pages 304-311.
[19]. Merriam-Webster. (n.d.). Dictionary by. In The Merriam-Webster.com Dictionary.
[20]. Natural fibers and their composites. (2021).
[21]. Natural Gypsum – Al Ahlia Gypsum. (n.d.). Retrieved December 15, 2022.
[22]. Nazeer, A. (2014). To Study the mechanical properties of coconut coir fiber reinforced with epoxy resin AW 106 & HV 953 IN.
[23]. Nguyen X.T. et. al. (2016). A potential natural energy absorption material–Coconut mesocarp: Part A: Experimental investigations on mechanical properties. International Journal of Mechanical Sciences.;115:564-73.
[24]. Othman, M. et. al. (2013). Development of Paper Using Coir Fibers as a Packaging Product. Asian Journal of Scientific Research, 6:207216.
[25]. Pinto, C. C., & Carvalho, R. F. (2019). Thermal performance evaluation of a low-cost housing ceiling prototype made with gypsum and sisal fibre panels. IOP Conference Series: Earth and Environmental Science, 296(1), 012015.
[26]. Preston, G. (2019, September 9). Vertical Flame Test for Single Cable. Fire Safety Search.
[27]. Redispersion of Filter Cake - US. (n.d.). Www.silverson.com. Retrieved December 18, 2022.
[28]. Rejeesh, C. R., & Saju, K. K. (2017). Methods and materials for reducing flammability behaviour of coir fibre based Composite Boards: A Review. Materials Today: Proceedings, 4(9), 9399–9407.
[29]. Ruben, J.S & Baskar, G. (2014). Experimental Study of Coir Fiber as Concrete Reinforcement Material incement Based Composites. Int. Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 4, Issue 1(Version 3), January 2014, pp.128-13.
[30]. Susilawati, Doyan, A. & Muliyadi, L. (2021). Mechanical properties of composite board based on coconut coir and terminalia catappa fruit fibers with Polyvinyl Acetate (PVAc) Matrix. The 10th International Conference on Theoretical and Applied Physics (ICTAP2020) Journal of Physics: Conference Series 1816 (2021) 012013 IOP Publishing.
[31]. Tailor, J. (2020). Types of Gypsum Board. GharPedia.
[32]. Tech, G. W. (2019, March 25). 8 Painful Points of Chemical Coagulation Treatment Plants. Genesis Water Technologies.
[33]. Thyavihalli Girijappa, G. et. al. (2019). Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review. Frontiers in Materials, 6.
[34]. Tondo, M. (2020, December 27). Coconut husk, biomass from coconut: fibers are known as coir. Lampoon Magazine.
[35]. Verma, D. et. al. (2013). Coir Fibre Reinforcement and Application in Polymer Composites: A Review.