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Physical and Mechanical Characterization of Gypsum and Luffa Cylindrica-Based Composites

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Abstract: The aim of the study was to evaluate the flexural and fracture resistance of a gypsum composite including luffa cylindrica as a volume aggregate substitute. Tests of compressive and flexural strength, as well as tests of elastic modulus, were performed. After 7 days of curing, the mechanical characteristics of many composite configurations with five weight ratios of luffa cylindrica to gypsum—2 percent, 3 percent, 5 percent, 6 percent, and 7 percent—were evaluated under typical circumstances. The results showed that the luffa cylindrica addition reduced the strength of the composite materials. Luffa cylindrica reduced the compressive strength and elastic modulus of composite materials by up to 29 and 37 percent, respectively, when compared to ordinary gypsum. In compression and flexural testing, the luffa cylindrica-gypsum composite materials showed fewer failure modes than the plain gypsum samples, according to visual examination. Composite materials made of Luffa cylindrica and gypsum are more malleable and ductile, and they have a number of properties that help stop cracks from spreading through the specimen.
Keywords: luffa cylindrica; natural fibers; gypsum; composite; mechanical properties.

1.0 Introduction

Gypsum, concrete, and mortar are examples of plain (non-reinforced) cementitious materials. These materials offer a variety of benefits, including low permeability, ease of production, stiffness, compressive strength, low cost, and accessibility. They have undesirable mechanical properties, such as poor flexural and tensile strengths, and are brittle. By adding different kinds of fibers to this material, its weaknesses may be partially addressed, creating a fiber-reinforced cementitious material. Fibers have long been thought of as a way to strengthen fragile materials. Since 2500 B.C., natural fibers have been used to strengthen delicate matrices. Clay was combined with straw and horsehair to create bricks and flooring (Brandt, 2008). Although a little improvement in strength can be made, toughness and ductility are the main objectives of fiber inclusion in cementitious materials. The most frequently utilized fibrous materials for reinforcing cementitious-based materials are nylon, glass, steel, polypropylene, and carbon fibers. One of two types of reinforcement is possible: either discrete short fibers, typically less than 50 mm long, processed through manufacturing techniques like spraying and mixing; or continuous fibers, usually in the form of a fabric, combined with the matrix through techniques like filament winding or hand lay-up (Peled et al., 2017). Improvements have also been made in the manufacture of fibers. Due to this, formerly "exotic" fibers like aramid and carbon are beginning to become more affordable to the point that researchers are thinking about using them in fiber reinforced cementous composites (Malkapuram et al., 2009). Gypsum matrix fibers can enhance toughness and mechanical properties, including tensile and flexural strength. This is because fibers' properties, such as their high tensile strength, length, and aspect ratio, allow them to bridge fractures. For instance, a rise in tensile stress on the bottom surface of a sinking beam member results in the formation of hairline vertical fractures when the tensile strength of the matrix is reached. If the fibers crossing these breaks have enough matrix binding strength, they will not be forced out and instead function as a crack-bridging force as they spread and widen. This force will prevent the spread of subsequent matrix cracks and decrease the crack's progression. Continuous-fiber fabrics also get better fiber anchoring and a stronger overall binding. The performance of fiber-reinforced cementitious materials is influenced by several factors. Important factors include fiber geometry (smooth, end-hooked, crimped, or twisted), fiber length, orientation, and distribution, matrix properties (such as matrix strength, stiffness, and Poisson's ratio), fiber material properties (such as fiber volume content, stiffness, and Poisson's ratio), interface properties (such as adhesion, frictional, and mechanical bond), and manufacturing process method (Mohanty et al., 2005). The precise reinforcing form and matrix material combination must be compatible with the processing methods (Arboleda, 2014). This depends on the shape of the reinforcement as well as the type of fiber. Fiber reinforced cementitious materials have drawn a lot of attention due to improvements in strength and toughness for applications in civil engineering. A fiber-reinforced cementitious material is utilized when thin portions—i.e., those not thick enough to cover rebars—are required, such as roofing and cladding materials. Examples of locations where localized deformations are large and/or unexpected include tunnel linings, industrial floors, maritime structures, and blast-resistant structures. Additionally, it is increasingly being utilized as a replacement for conventional asbestos cement sheet in light of the well-known revelations regarding the health risks associated with asbestos fibers.

Natural fibers include lignocellulosic materials including softwood kraft, rice husk, wheat straw, sea grass, sisal, pineapple leaf fiber, flax, date palm, coconut, coir, jute, hemp, bamboo, abaca, maize, sabia, oil palm, cotton, banana, mesta, roselle, oat, kapok, ramie, and rachis (AL-Oqla et al., 2014; Bajpai et al., 2012; Dawit et al., 2020; Ho et al., 2012; Jawaid & Khalil, 2011; Silva et al., 2020). In this study, the effect of biomass (luffa cylindrica) on gypsum composite material will be examined. The possibilities for this normally discarded material have increased because of the availability of luffa cylindrica in Nigeria. The agriculture and forestry sectors produce a significant quantity of trash in the form of underused biomass. Finding applications for biomass in building materials has seen a rise in interest in recent years. Some studies looked at epoxy, polyester, resorcinol-formaldehyde, vinyl ester, and other thermoplastics and thermosets (Daniel-Mkpume et al., 2019; Kalusuraman et al., 2018; Sivakandhan et al., 2020). Other studies looked at luffa as a pure material (without a matrix). Mani et al. (2014), discovered that the tensile strength of luffa mat/epoxy natural fiber composites rose, then decreased, as the fiber content was raised beyond 40 wt. percent. However, when chopped luffa fibers were taken into account, 50% showed the maximum strength. In a sandwich structure, the tensile strength of a luffa natura fiber composite was increased by raising the fiber content up to two luffa layers and then lowered by adding a third layer (Mohanta & Acharya, 2015). When a luffa natura fiber composite is hybridized with flax fibers Sabarinathan et al. (2016) or glass fibers Mohanta & Acharya, (2015), greater flexural strengths are demonstrated, especially when luffa is used as a core layer in a laminate structure (Mohanta & Acharya, 2013). The tensile strength of luffa natural fiber composites was also improved by fly ash filler by improving matrix-to-fiber adhesion (Jino et al., 2018). On the other hand, the physical and mechanical properties were improved by mixing in wood powder, rice husk, and pulverized nut shell (Dhanola, Bisht et al., 2018). Additionally, using chopped luffa fibers to reinforce resorcinol-formaldehyde resulted in a compressive strength of 81 MPa, compared to the lower compressive characteristics of luffa natural fiber composites made with a geopolymer matrix (31 MPa) and concrete matrix (around 29 MPa). As a consequence, pure luffa has a maximum compressive strength of 0.74 MPa.

The researchers found that composites with such fibers in the matrix "display more scattered cracking" than composites without fiber reinforcement. Luffa cylindrica is a major contributor to environmental litter and landfill waste. New techniques for processing and using this waste material are thus needed. This innovation opens the door for the use of luffa cylindrica in composite construction materials. To determine the physical and mechanical characteristics of a bio-composite gypsum material that contains varying amounts of luffa cylindrica was the aim of the investigation detailed in this paper. The impacts of different luffa cylindrical fiber concentrations on physical and mechanical properties were examined.

2.0 Materials and Methods

2.1 Materials

Luffer cylindrica was collected at Universiti teknologi Malaysia. The sieving was finished to learn more about the luffa cylindrica fiber's size. The particle size distribution of the luffa cylindrica that was used to make the samples of gypsum composite materials. Figure 1 show the sample of luffa cylindrical used for the experiment.

Figure 1. Luffa and its internal structure.

2.2 Sample Preparation

For the moisture content test, gypsum composite boards were created using a hardwood mould that was 190.5 mm x 190.5 mm x 10 mm in size. The wooden molds were placed on a firm, non-absorbent surface and filled with gypsum mixed with luffa cylindrica fibers at varied percentages of fiber volume fractions (2, 3, 5, 6, and 7 wt percent). The fiber and gypsum were weighed precisely on a 0.01 kg scale before being measured in volume. Finally, the wooden mold was hacked apart to release the rectangular samples. The samples' moisture content was examined. A control board was among the boards, and it was devoid of luffa cylindrica. A part of the gypsum was replaced with increasing weights of luffa cylindrica to create the remaining five gypsum boards. The 50 mm x 50 mm x 50 mm prepared compression and density mold sizes are shown in Figure 2. To stop samples from sticking together while being demolded, grease was added to the molds. The samples were taken out of the molds after 24 hours and subjected to air curing in the lab. According to ASTM C473-12, the compressive strength of gypsum composites was tested by putting all of the samples in a laboratory with a relative humidity of 50% for 7 days.

Figure 2 : Cubic moulds (50 mm x 50 mm x 50 mm) for density and compressive test according to ASTM C473-12.

A spreadsheet was utilized to determine the ideal constituent ratios to employ for each gypsum composite material. The finished composite's density of 0.785 g/cm3, which is regarded as a medium-density board, was used to calculate the material proportions by weight (Karlinasari et al., 2012). The table below lists the material ratios for each composite material sample that was created. The quantities in table 1 are, on average, 5% greater than the estimated amounts.

Table 1: Material amounts for luffa cylindrica-gypsum composite boards.

Material samples	**Luffa cylindrica (kg)**	**Gypsum (kg)**
Control	5.00	0
2% luffa cylindrica	4.87	0.43
3% luffa cylindrica	3.66	1.03

5% luffa cylindrica	3.18	1.49
6% luffa cylindrica	2.15	2.10
7% luffa cylindrica	1.65	1.5

All of the gypsum composite samples were created on the same day. The right proportions of luffa cylindrica and gypsum were measured in advance of mixing. To start the mixing process, the luffa cylindrica fiber was added to a drum mixer. While the mixer was operating, gypsum powder was shot into its center using a pneumatic gravity-feed sprayer. Once all of the luffa cylindrica had been distributed, the drum mixer was switched off.

2.3 Physical Properties Testing

2.3.1 Moisture Content and Density Test

The moisture content and density information were calculated using the Archimedes technique. For comparison, a set of control samples that did not include luffa cylindrica was also generated. The test specimens were submerged in water and weighed regularly after being removed from the bath following a 24-hour drying process in the oven. Then, using a fresh, dry towel, the surface water was removed. The specimen was then weighed, and an analytical balance was used to determine the percentage weight change. After that, the specimens were put in an air oven that could reach 105 °C and maintained there until every specimen had a consistent mass within 0.1. The samples were then weighed, and the percentage weight was computed. The amount of water absorbed in the composites was calculated using the weight difference between the dried samples and the samples that were exposed to water. The percentage absorption was estimated in accordance with ASTM C473-19.

2.4 Mechanical properties testing

Compressive and flexural strength characteristics of the reference and luffa cylindrica-gypsum composite materials were investigated. According to ASTM C 473-12, tests for compressive strength were performed on samples of the luffa cylindrica-gypsum composite. Using dry cube specimens of 50 mm x 50 mm x 50 mm, Figure 3 depicts a universal testing device with a pressure capacity of 25 kN and a loading rate of 0.02 kN/s. Using ASTM C348 and a three-point stress with a 75 mm span, rectangular specimens with dimensions of 40 mm x 40 mm x 160 mm were evaluated for flexural strength. Specimens with 0.6 water to binder ratios were compared, and the controlled specimen strength was assessed. The weight was placed directly against the surface of the board. Maximum load data was gathered when the machine was run at a load rate of 0.005 kN/s up until the fracture. Three different samples were utilized for each test, and their arithmetical means were recorded.

Figure 3: Compressive machine according to ASTM C473-12.

The load scenario for the flexural strength test was a simply supported and simply (center) loaded configuration. The gap between the spans was determined to be 304.8 mm based on the sample size and the standard. According to the specification, the testing speed (load actuation speed) was calculated and applied at a rate of 6 mm per minute (American Society for Testing and Materials, 2012).

3.0 Results and Discussion

3.1 Physical Properties

For each batch of new luffa cylindrica-gypsum composites, the slump (cm) was measured. The variation in slump for each batch is depicted in the figure 4.

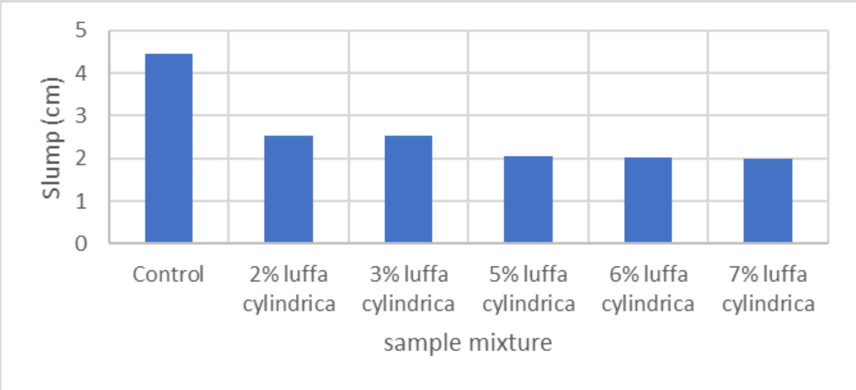

Figure 4 : Slump of fresh composite materials samples.

3.1.1 Moisture content and density

The moisture content was higher in the control gypsum composite materials (8.40%) than in the luffa cylindrica composite materials. Table 2 provides a detailed breakdown of each composite material's density and moisture content. Three samples of each kind of composite material were used to calculate the oven dry density.

Table 2: Physical properties of gypsum board samples

Samples	Moisture content (%)	Density (g/cm^3)
Control	8.40	0.732
2% luffa cylindrica	6.80	0.721
3% luffa cylindrica	6.50	0.710
5% luffa cylindrica	5.00	0.635
6% luffa cylindrica	5.10	0.602
7% luffa cylindrica	4.00	0.600

The moisture contents found for plain gypsum and composite materials were not similar because increasing amounts of luffa cylindrica, which was in charge of the bulk of the moisture contained in the composite materials, were used. During production, gypsum board with a final density of 0.785 g/cm3 was sought. In accordance with the ranges indicated by Karlinasari et al. (2012), gypsum boards fall into the category of medium-density particles.

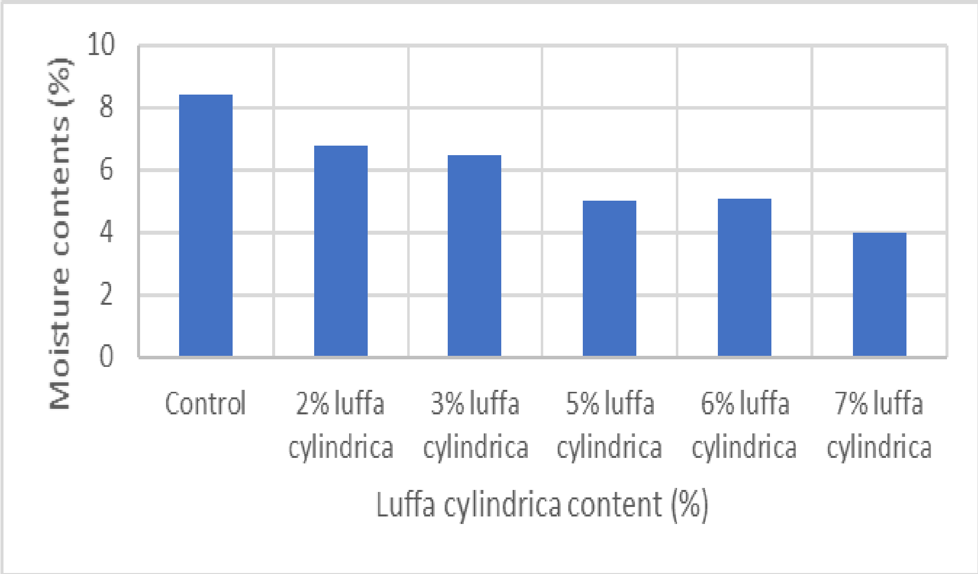

Figure 5 : Plot of means of moisture contents for each sample set.

3.2 Mechanical Properties

A total of 18 samples were examined for their mechanical qualities. These samples consisted of three replications of each of the six plain and gypsum composite materials. The bending modulus of rupture (MOR) and modulus of elasticity (MOE) for each of the 18 samples were computed. Average values were calculated for each of the six sample sets. More details on these measures are provided in the tables and graphs below.

Table 3: Modulus of elasticity of gypsum composite materials samples.

	Control	2% Luffa cylindrica	3% Luffa cylindrica	5% Luffa cylindrica	6% Luffa cylindrica	7% Luffa cylindrica
Mean modulus of elasticity (MPa)	1564.45	990.35	540.11	520.81	300.50	225.23
Percent change from control	-	37%	65%	67%	81%	86%

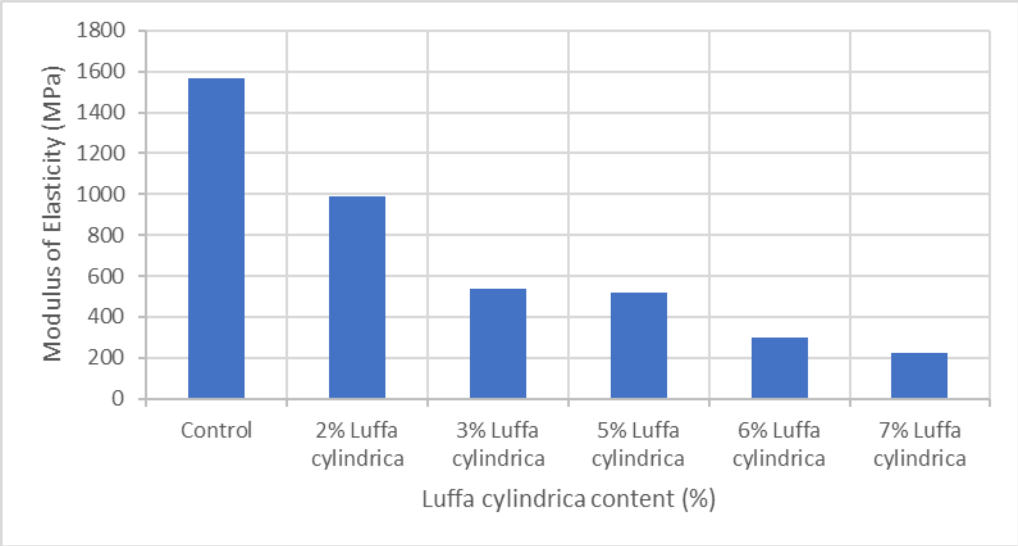

Figure 6: Plot of means of modulus of elasticity for each sample set.

The samples containing 2% of luffa cylindrica by weight differed from the control by 37%, as determined by the MOE means. The difference in luffa cylindrica between 3 and 5 percent was almost 67 percent, while the difference between 6 and 7 percent was more than 81 percent. It was clear that MOE fell off as the amount of luffa cylindrica in gypsum board rose. The mean MOE was reduced by almost 86 percent as a result of the overall reduction in MOE from the control sample to 7 percent, luffa cylindrica.

Table 4 : Modulus of rupture of gypsum composite materials samples.

	Control	2% Luffa cylindrica	3% Luffa cylindrica	5% Luffa cylindrica	6% Luffa cylindrica	7% Luffa cylindrica
Mean modulus of rupture (MPa)	8.14	7.13	6.18	3.60	2.40	2.08
Percent change from control	-	12%	24%	56%	71%	74%

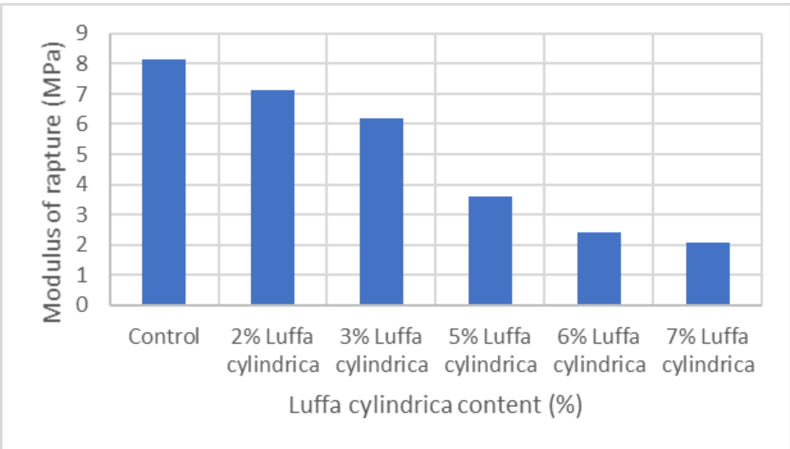

Figure 7 : Plot of means of modulus of rupture for each sample set.

According to the MOR means, the samples containing 2% luffa cylindrica by weight differed by approximately 12%. There was a difference of 24 percent between 3 and 5 percent of luffa cylindrica and a difference of 71 percent between 6 and 7 percent of luffa cylindrica. Gypsum board's MOR dropped as a result of an increase in luffa cylindrica content. MOR was reduced by approximately 74% when ordinary gypsum was replaced with 7% luffa cylindrica. Similar trends of MOR and MOE declines with increasing rubber content have been discovered in other investigations. In one study, Ayrilmis et al. (2009) examined the effects of two resin types on the percentages of rubber particle composition. Similar patterns were seen by Song & Hwang, (2001) when they examined the impact characteristics associated with a rubber composite particleboard and the impacts of MDI resin levels on it. Despite the fact that the rubber particle size used in their study was significantly bigger and the wood species examined was poplar, the MOR and MOE trends were comparable for (Xu & Li, 2012).

3.2.1 Compressive tests

The 18 compressive test cubes' results were averaged for the three cubes in each batch. The values for mean compressive strength are shown in the table below. The last column displays how each of the 18 cube sets' means compares to the control mean. Each sample set had a lower compressive strength. When luffa cylindrica was used in place of fine aggregate at volume levels 2 and 3, compressive strength decreased by 29 and 35%, respectively. This result is the same as what Sobanjo et al. (2015) found when they used rubber particles 0.42 mm instead of volume replacement. They found that compressive strength dropped by 56–76%.

Table 7: Compressive strength data with analysis.

Sample	Mean value (MPa)	Percent change from control
Control	30.73	
2% Luffa cylindrica	21.89	-29%
3% Luffa cylindrica	20.09	-35%
5% Luffa cylindrica	15.11	-51%
6% Luffa cylindrica	13.08	-57%
7% Luffa cylindrica	11.10	-64%

If luffa cylindrica is used to replace 5% of fine aggregate by volume, the compressive strength decrease is 51% when compared with the control.

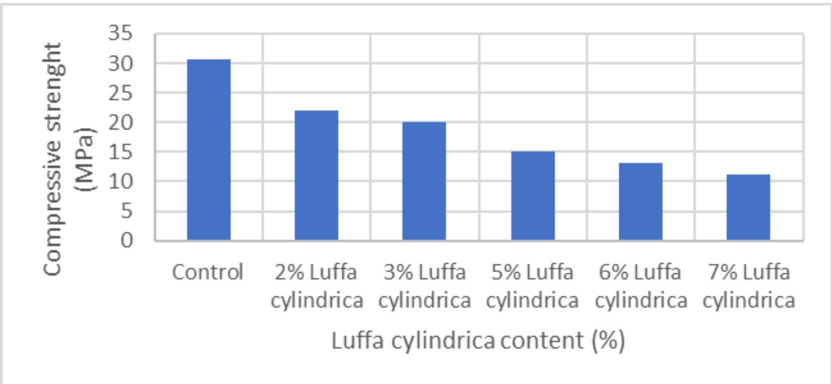

Figure 8: Plot of means of compressive strength for each sample set.

3.2.2 Flexural Strength

Flexural strength was reduced by 19% when luffa cylindrica was added to regular gypsum in comparison to the control mixture. It's also important to note that the flexural strength was lost the most in the combinations with a 3 percent volume substitution of luffa cylindrica. In every sample set, flexural strength declined. Replacement of luffa cylindrica at 2% and 3% volume amounts resulted in 19% and 32% decreases in flexural strength, respectively. This result is the same as what Sobanjo et al. (2015)found. They found that replacing volume with 0.42 mm rubber particles decreased flexural strength by 20–40%.

Table 8 Flexural strength data with analysis.

Sample	Mean value (MPa)	Percent change from control
Control	4.97	
2% Luffa cylindrica	4.01	-19%
3% Luffa cylindrica	3.40	-32%
5% Luffa cylindrica	3.20	-37%
6% Luffa cylindrica	2.10	-58%
7% Luffa cylindrica	1.80	-64%

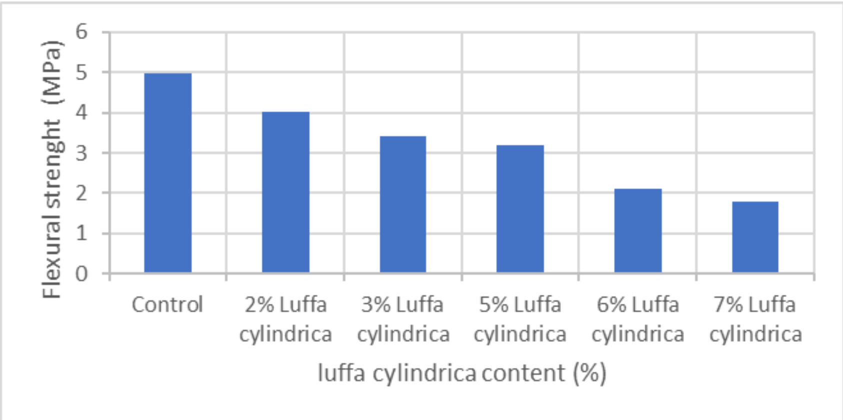

Figure 9: Plot of means of flexural strength for each sample set.

4.0 Conclusion

I. The density of gypsum composite materials was decreased when luffa cylindrica was added in comparison to regular gypsum. The strength of the gypsum board composites decreased as the luffa cylindrica fraction increased. As more luffa cylindrica was added to the gypsum board, the board became stiffer.

II. The compressive strength of gypsum composite materials containing luffa cylindrica was reduced by 29% as compared to plain gypsum when it was utilized as a volume replacement. The breakdown process of the composite materials was more gradual and less sudden than that of plain gypsum. The fissures appeared to spread more equally as compared to a plain gypsum specimen.

III. Similar to failure processes in compression, flexural failure for the luffa cylindrica samples was slower and less catastrophic than for the plain gypsum samples. Since luffa cylindrica was added to the composite material, it seems to be more flexible.

IV. The modulus of elasticity of the composite mixture decreased by 37% when luffa cylindrica was added compared to plain gypsum. A combination of properties in the more ductile composite materials created from luffa cylindrica aids in limiting the propagation of cracks inside the specimen.

V. A luffa cylindrica composite gypsum board could be useful when flexibility is more important than strength, like when building curved walls.

VI. This finding, which is in line with earlier studies, may be helpful when looking for lightweight gypsum boards with low strength needs. It could also be helpful when recycling or the project's impact on the environment are top priorities.

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