

Effect of Pineapple Leaf Fiber on the Physico-mechanical Properties of Gypsum Board

Esan, M. T., Khairulzan, Y., Zaiton, H., Gambo, M. D. and Hassan, H.

Abstract: Gypsum is a common interior construction material, especially when used as a finishing element. However, interest in prospective uses of gypsum as a finishing component has diminished in recent years as a result of its weak mechanical strength and brittle character, which is essential in interior construction. Therefore, to overcome this challenge, the effect of pineapple leaf fiber on gypsum was investigated. Five different composite configurations of 2%, 3%, 5%, 10%, and 20% pineapple leaf fibre (PALF) with two PALF sizes of 5 mm and 15 mm were prepared and tested after 7 and 28 days of curing. The results of the tests show that materials reinforced with 2% PALF have significantly improved mechanical properties. The compressive strength of a gypsum composite increased by 12.4% when 2% PALF was added. Flexural strength increased by 59% when 2% PALF was added to the mixture. The study provided a means of making gypsum composites having greater mechanical strength than those made from fossil oil-based polymers. It also found relevant use of pineapple leaf, an agricultural waste.

Keywords: Gypsum; natural fibre; pineapple leaf fibre; physical properties; mechanical properties; microstructure.

I. Introduction

Gypsum is a common interior building material that is frequently used in building, especially as a finishing component. The most popular gypsum mineral product is gypsum board, sometimes referred to as drywall, plasterboard, or wallboard. A gypsum plaster core is bonded to a durable paper liner to create gypsum board. In both residential and commercial projects, gypsum plasterboards are a reliable and affordable method of providing compact partitioning components. According to study conducted by [1] gypsum is a low-density, energy-saving, acoustically and thermally insulating, fire-resistant, and easily processed construction material that is not polluting. Gypsum ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) is one of the most environmentally friendly solutions for a binder since it can be calcined with a lot less energy than cement or lime.

Gypsum is only calcined at 200 degrees Celsius, while lime is burnt at over 1000 degrees and cement at over 1400 degrees. Gypsum is the name for hydrated, untreated gypsum powder; gypsum plaster is the name for refined, unprocessed gypsum powder [2]. The three chemical phases that made up gypsum plaster are calcium sulphate anhydrite (CaSO_4), calcium sulphate hemihydrate ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$), and calcium sulphate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). The ratio of these chemicals impacts the final product's physical and mechanical characteristics [2]; [3]. Alpha- and beta-calcium sulphate hemihydrate are two forms of $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ that are frequently found, depending on the calcining technique used during the manufacturing stage.

One of the most commonly used building materials for partition walls, ceiling design, and wall covering is gypsum plaster. Gypsum-based materials like mortar, composites, and boards are now frequently used in construction industries as a result of its desirable qualities, such as high fire resistance, thermal properties, and sound

Esan, M. T., Khairulzan, Y., Zaiton, H.

(Department of Structure and Materials, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia)

Esan, M. T., Gambo, M. D. and Hassan, H.

(Federal Polytechnic, Ede, Nigeria)

Corresponding Author:

Tel.: +234-8038194026; Email: esanmartins@yahoo.com

insulation qualities [4]–[9]; [10]–[12]. But like other inorganic cements, gypsum plaster has a high compressive strength with a poor flexural strength [13]–[15]. These brittle qualities will very certainly seriously harm the cast structure when exposed to applied stresses. To improve mechanical properties like compressive and bending strength, fibres like steel fibre, polyester fibre, glass fibre, carbon fibre, polyamide, and polypropylene fibre can be added to gypsum composites [7], [16]–[19]. Gypsum's fibre increases mechanical characteristics, particularly post-cracking behaviour by reducing brittleness [20]. In order to broaden the range of gypsum's uses, new varieties of gypsum-based materials have lately been studied. In the literature, fillers such as blast furnace slag (BFS) [21], nanotubes [21], iron oxide [22], calcium carbonate [23], silica gel [24], and silica and fume [24] have been employed in gypsum-based composites. [25] looked at the impact of polypropylene fibres and waste polyurethane foam had on the gypsum matrix. Mechanical studies were done on flexural strength, surface hardness traits, and thermal parameters. In contrast to unmodified gypsum, the results showed that polypropylene fibre had high polymer and gypsum matrix adhesion, which improved mechanical characteristics under stress. Materials made of glass fibre and gypsum have also been discovered to offer better quality [26]. These reinforcements help, to some extent, enhance the mechanical properties of gypsum plasterboard. However, because it uses a lot of energy and is harmful to humans, the majority of synthetic fibre manufacturing has negative environmental effects, such as contributing to global warming associated with carbon dioxide emissions from synthetic fiber production [27]–[31]. The researchers used

natural fibrous materials to address these problems [27]. Palm, cotton, wheat, barley, date palm, abaca, sisal, cellulose, and straw fibres are examples of natural fibres that have been used to strengthen gypsum matrix [20], [32]–[37]. According to these studies, gypsum board was strengthened using natural fibres in order to generate a cleaner product with a smaller environmental impact.

Gypsum board manufacturers at the top of their game regularly create new products using innovative methods, new materials, and highly competitive markets. This study focuses on examining the physical and mechanical properties of innovative pineapple leaf fiber (PALF) materials as a replacement for synthetic components in naturally derived fiber composite materials. Although the physical and mechanical properties of gypsum composites have been examined in the literature, little study has been done on the impact of fiber percentages and sizes on the optimal performance of gypsum composites. According to previous studies, fresh mixes with fibre doses greater than 3% by volume percentage may have mixing issues that change the properties of components made of gypsum [14], [38]. The ideal fibre percentage in the composite combination must thus be established.

Malaysia harvests a significant amount of PALF [39], in 2008, it produced 384,673 metric tons of waste, which is a large quantity. PALF is trashed in massive volumes all across the world every year. A considerable amount of this material is disposed of in a landfill. Much research has been done over the last few decades to identify and assess innovative applications for this massive volume of waste materials in order to lessen the disposal problem. Agriculture waste is also widely available for use in sustainable construction materials all around the world [39]. However, PALF-gypsum matrix reinforcement has yet to find

any commercial uses. Their physical-mechanical properties are usually vital in assessing whether composite materials are appropriate for use as building materials. The physical-mechanical properties of gypsum composites reinforced with grind PALF were investigated in this work to evaluate the impact of fibre size and percentages on the composite materials' optimal performance.

II. Materials and Methods

A. Materials

Gypsum which is the basic component of the composite in this experiment was obtained in the commercial market (Johor bahru, Malaysia). Ground PALF of 5mm and 15mm sizes was purchased from Chemical Engineering department, Universiti Teknologi Malaysia for the construction of a composite to strengthen the gypsum matrix, as indicated in Figures 1(a) and (b).

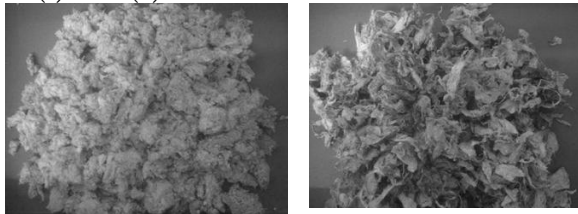


Figure 1: (a) Pineapple fibre with 5mm size (b) Pineapple fibre with 15mm size

B. Preparation of the PALF-Gypsum Composite Material

The main materials for making gypsum composite in the study were gypsum, PALF and tap water, two collections of samples of 5 mm and 15 mm fiber sizes with 0.6 water-gypsum ratio for different PALF percentage

were prepared. The PALF-gypsum composite mixtures were made with a constant water-gypsum ratio of 0.6. The ratio was chosen based on the results of earlier trial mixes, which showed that PALF-Gypsum with a 0.6 water-gypsum ratio provided excellent workability. A collection of control samples for comparison purposes, without PALF, were also prepared. The 2%, 3%, 5%, 10% and 20% of addition of PALF was replaced by C2, C3, C5, C10, C20 and F2, F3, F5, F10, F20, respectively. Table 1 indicates the experimental results of tests of gypsum-PALF composites.

C. Setting time

Investigations were conducted into the properties of fresh gypsum composites. The criterion for defining time and judging workability was applied (ASTM C472-99). According to ASTM C472-99, setting time measurements were taken using the VICAT needle apparatus depicted in Figure 2. Using a 1 mm VICAT needle, a standard-consistency paste held in a cylindrical mould was subjected to a periodic penetration study over the course of ten minutes. The first setting time was attained when the interval between the first time the gypsum and water came into contact and the depth at which the needle pierced the paste was 25mm. The final setting time test was conducted after the initial set test, and it was determined by measuring how long it took for a complete round needle impression to develop on the surface of the gypsum paste.

Table 1: Experimental results of tests of gypsum-PALF composites

Mixture code	Moisture content (wt%)	Water absorption (wt%)	Flexural strength (MPa)	Porosity (%)	Compressive strength (MPa)	Density(kg/m ³)
F0	37	37	2.2	41	3.3	1120
F2	10	40	2.5	44	3.34	1280
F3	12	46	2.4	45	3.32	1232
F5	15	66	2.2	47	2.49	1015
F10	20	97	2.1	57	2.41	1200
F20	23	112	1.8	58	1.25	880
C0	37	37	2.2	41	3.3	1120
C2	5	42	2.6	48	3.71	1280

C3	8	62	2.5	46	3.70	1312
C5	9	63	2.3	50	2.93	1128
C10	11	87	2.2	60	2.24	960
C20	12	89	1.0	68	1.35	880



Figure 2: VICAT Apparatus

C. Porosity Test

Using the Archimedes method, the porosity was completely evaluated. A set of control samples free of PALF was also produced for comparison. In accordance with Archimedes, the porosity of specimens after submersion in water for varied amounts of time is calculated using the relationship below:

$$= \frac{w_{sat} - w_d}{w_{sat} - w_{sub}} \times 100\% \quad (1)$$

Where, ϕ is the porosity of sample (%), w_d

is the oven dry gypsum sample weight in air (kg), w_{sat} is the weight of saturated surface

dry gypsum samples in air (kg) and w_{sub} is

the submerged gypsum samples weight in water(kg).

D. Compressive and Flexural Strength

The reference material and the PALF-gypsum composite materials' compressive and flexural strengths were evaluated. According to ASTM C 473-12, the

compressive strength of samples of PALF-gypsum composites was tested. Figure 3 depicts a universal testing system that uses dry cube specimens that are 50 mm by 50 mm by 50 mm and has a pressure capacity of 25kN and a loading rate of 0.02kN/s. As per ASTM C348 and a span of 75 mm, the flexural strength of rectangular specimens measuring 40 mm x 40 mm x 160 mm was evaluated. Specimens with 0.6 water to binder ratios were compared, and the controlled specimen strength was evaluated. The weight was placed directly against the surface of the board. Maximum load data was gathered while the machine was run at a load rate of 0.005kN/s until fracture occurred. Three different samples were utilized for each test, and their arithmetical means were recorded.



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

III. Results and Discussion

A. Properties of Fresh PALF-gypsum Composite Material

i. Setting time

The initial and final setting time of the plain gypsum (control specimen) and with the addition PALF is shown in the Figure 4. As can be seen in the figure, when % of PALF is increased in the gypsum composite material, the samples proportionately reduce their initial and final setting time. The initial setting time of the control specimen was (9 minutes) and its final time to set has increased by double (17 minutes). This is in line with findings of [23]. At C2 the initial setting time decreased from 9 to 8 minutes and the final setting time decreased from 17 to 15 min, when the %PALF increased from 0 to 2% by volume. The hydrophilicity of PALF may be the cause of this. The initial and final setting time of C3 was 7 and 11 minutes respectively. The initial and final setting time of C5 was also the same as that of C3 with 7 and 11 minutes respectively (Figure 4). The C10 required 3 minutes to reach its final setting time while the C20 required shorter setting time which was 2 minutes to reach the final setting time. Similarly, setting time of series F are shorter for mixtures containing PALF compare to

the reference sample. As can be seen in Figure 4, for mixtures having higher percentage of PALF at F20; they have the fastest setting time of 10 minutes. Although the setting time values are close to each other for different PALF concentration, the initial setting time decreases with increasing amount of PALF despite having gypsum as a major constituent. The total setting time for all the samples in series F ranges from 5 minutes to 16 minutes. It can be said that the addition of PALF into gypsum changed the behaviours of the composites. The initial and final setting time of F2 is 7- and 16-minutes respectively. The initial and final setting time of F3 were lower by about 6 to 15 minutes respectively as compared to the control specimen.

Previous studies have indicated that since ASTM regulations prohibit the use of any composite or gypsum paste with a setting time greater than 20 minutes for construction or other purposes, it is unnecessary to identify the exact value of the setting time when it is longer than 35 minutes[23]. [40] claim that setting time is influenced by the amount of fibre in the composite. According to research done by [41], the amount of waste polystyrene in extruded polystyrene composites causes a reduction in the composites' setting time. When there is a larger proportion of polystyrene in the mixture, this can be because there is less water present.

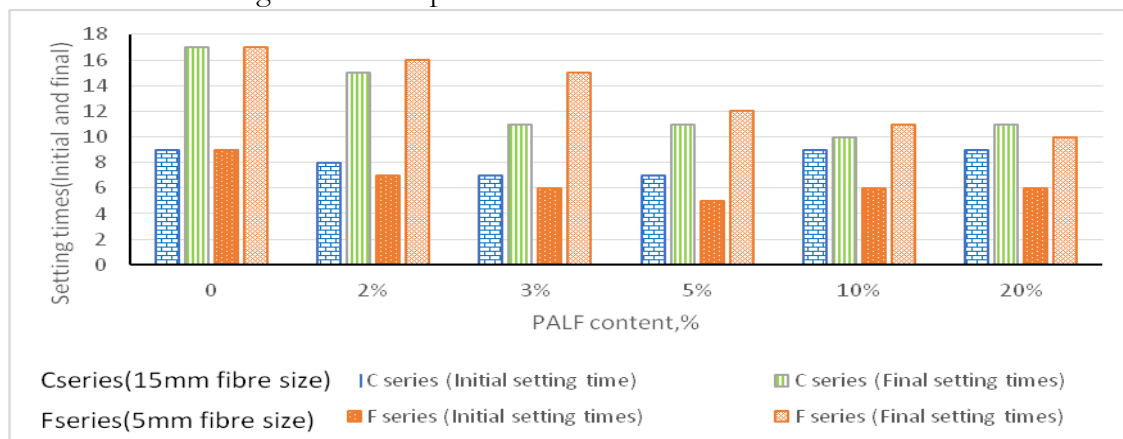


Figure 4: Setting time of gypsum composite containing different proportions of PALF

ii. Porosity

In Figure 5, the porosity after 28 days curing and the different volume of PALF were shown. As the percentages of fibre increases, the porosity values for both series increased. The porosity was increased by 48% with a 2% PALF addition and 50% with 10% PALF addition for the C series. The combination C20 in series C produced the highest increase in porosity value, at 68%. The C0 value, which includes 0% PALF, is the lowest at 41%. Series F further shows that as the percentage weight of PALF rises, the porosity of the composite material does as well. The lowest porosity is obtained in specimen with 2% PALF addition (48%), Since PALF is porous, the significant rise in porosity of the composite material can be explained to an increase in pores in the hardened matrix with increasing percentages of PALF. This result fits the description given in [10]. [10] found that in gypsum composites comprised of micro silica and calcium carbonate, porosity rose from 59.2 percent to 69.4 percent when 0.5 percent expanded perlite was used as a volume replacement. In the current investigation, when PALF and gypsum were combined, porosity increased when volume replacement was 20%, going from 41% to 58%. The larger void in the composite samples may help to explain this. According

to [6], adding more diatomite to the composites made them more porous. When [42] looked at how adding palm fibre changed the density, porosity and water outflow of natural zeolite ceramic, they found similar patterns. It shows a porosity graph where the presence of fibres significantly affects porosity yield. Ceramic becomes more porous the more fibres were added to it.

iii. Density

Figure 6 shows the density of series C and F gypsum composite materials in relation to their fiber content at 28 days.

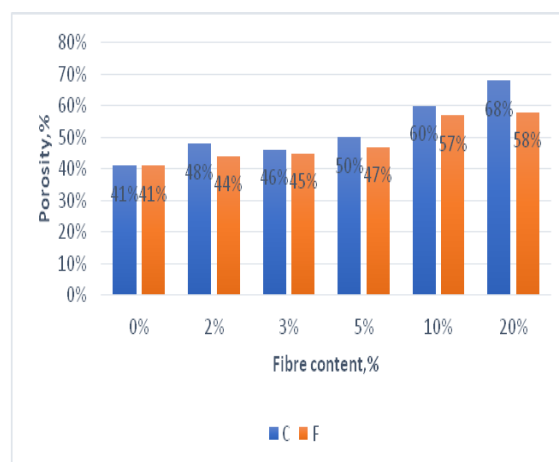


Figure 5: Relationship between porosity and percentage of PALF after 28-days curing age.

As can be observed, as compared to control samples, the densities of the series C and F samples were higher. For the C series, the initial density increased from 1120 kg/m^3 to 1280 kg/m^3 when 2% of PALF was added and 1312 kg/m^3 when 3% PALF was added to the mixture. The average density between C5 and C20 has decreased from 1128 kg/m^3 to 880 kg/m^3 , which is a small difference. Control specimen F has a density of 1120 kg/m^3 , which is lower than F2 (1280 kg/m^3) and F3 (1232 kg/m^3) but higher than F5 (1015 kg/m^3) and F20 (880 kg/m^3). Additionally, the studies showed that the density decreases as the fibre content rises. Porosity affects how much gypsum crystals interlock in composite materials, which is related to the causes of density loss. [40] found that the fibre material has a considerable influence on gypsum density. With more isostatic graphite filler added, the apparent density of gypsum-based composites rose and reached 1280 kg/m^3 . The F20 samples experienced the greatest density loss after 20 percent PALF was added to the gypsum matrix, with a reduction of 11.8 percent. The mass of the composites with the most PALF was lost because of a small disintegration process.

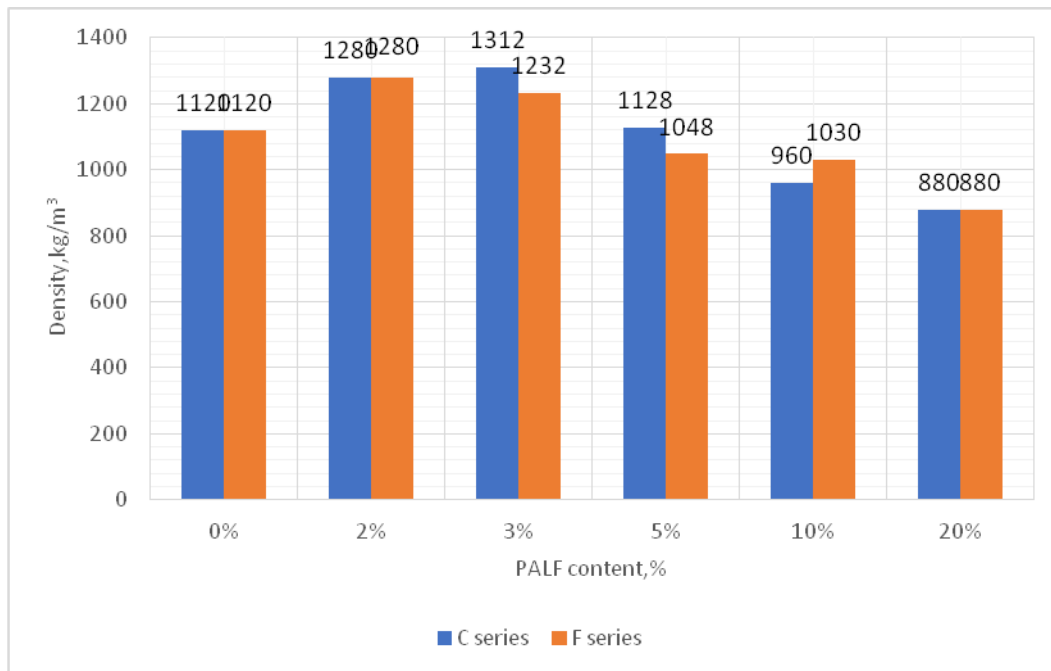


Figure 6: Density after 28-days curing age in relation to PALF volume fraction

B. Strength of Hardened Mixture

i. Compressive Strength

Figure 7 shows the compressive strength of series C and F gypsum composite materials in relation to their fiber content at 28 days. A remarkable drop as be found in the composites compared to plain gypsum. Strength did not increase linearly as fibre content (percentage) increased. In other words, the percentage of fibres present determines how much strength may be increased. For fibre content sequence C, 2% (C2) with 3.71 MPa is the ideal fibre content value. In general, the inclusion of PALF enhanced the compressive strength. With a 12 percent improvement over the control specimen, C2's outcome was better. When more than 3 percent fiber content is added, the compressive strength decreases, although it is still higher than the control (0%). Compressive strength values for C10 and C20 were -32 and -59 percent, respectively. Additionally, F2 and F3 in the F series had relative increases of 1% and 0.6% when compared to the reference sample. With values of 24 percent, 27 percent, and 62 percent, respectively, the intensity tends to drop at F5, F10, and F20

with the addition of the PALF material. The presence of PALF, which decreases the fibre's density, might be the cause of this. Therefore, due to fibre congestion, specimens with higher PALF concentrations are unable to withstand more stress. Congestion in the fibre might lead to decreased bonding and disintegration since it is more difficult to pack. Porosity and the number of gypsum interlocks were the main contributors to the strength loss at high PALF percentages; as porosity increased, the interlocking in the gypsum matrix decreased and the resistance of the composite materials to compressive stresses decreased. This result is consistent with [43], who discovered that replacing volume with duom palm fiber at a 2 weight percent concentration increased compressive strength by 2 to 3.95 MPa. In the current study, the 2 percent PALF added to both series with gypsum increased the compressive strengths by 1 percent and 13 percent for series C and F, respectively.

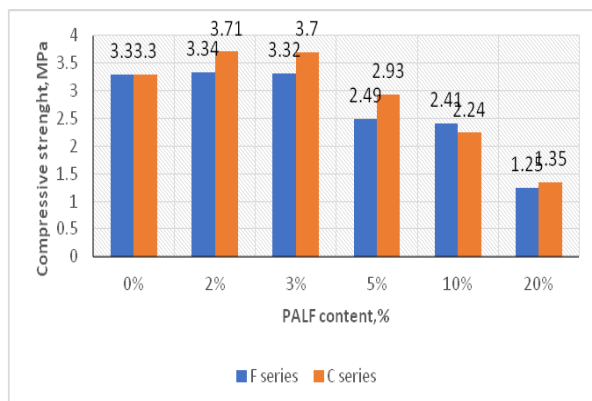


Figure 7: Compressive strength of the composites.

ii. Flexural Strength

Figure 8 shows the flexural strength results with different PALF percentages. Gypsum composites with PALF have a flexural strength increase of 2.2 to 2.6 MPa, or a 2% increase in fibre content. During the 28-day test, the addition of PALF caused a noticeably higher flexural strength. Both specimen series F and C had greater strength when PALF was first introduced, but when the amount of PALF in the composites rose, the strength declined. Series C specimens C2, C3, and C5 all had strengths greater than specimen C0, which averaged 2.20 MPa, 2.60 MPa, 2.50 MPa, and 2.30 MPa, respectively. The strength of C20 decreased by 55%, but the strengths of C2, C3, and C5 increased by 18%, 14%, and 5%, respectively. This implies that the higher PALF content resulted in matrices with insufficient composite cohesion. As a consequence, 2 vol.% was the ideal volume fraction for PALF-gypsum composites in the C series. In comparison to category F0 lower value of 2.2 MPa, the values for category F are significantly higher, measuring 2.5 MPa, 2.4 MPa, and 2.2 MPa, respectively, for F2, F3, and F5. [44] say that the fibres' most important job during a fracture is to act as bridge ligaments in the crack plane. This keeps the crack from opening and spreading and makes it take more energy to deform the material enough to cause a fracture.

In some cases, poor bonding in the composite fibre matrix bond may be indicated by the series C and F declining strength. The composite's higher volume percentage may have an influence on weak bonding, which would reduce strength. This is in line with the findings of [45], who discovered that the best flexural strength was obtained at a low caroa fiber content of 1%. Caroa fibers of various lengths and densities were utilized to make the composites. Different amounts and lengths of caroa fibres were used to create the composites. The flexural strength of gypsum decreases as fibre content increases. In addition, [35] investigation of natural wood fibres-gypsum composites revealed that their flexural strength is 4.4 MPa rather than the 5.2 MPa of plain gypsum. This discrepancy suggests insufficient adhesion between hydrophilic fibres and the hydrophobic gypsum matrix in the absence of proper fibre modification.

The failure pattern of PALF-gypsum composite materials with 0% and 2% PALF is shown in Figure 9. In comparison to the unreinforced samples, which broke down like brittle materials, the 2% fibre-reinforced composites had significantly improved toughness, implying lower deflection capacity. The results were in line with those of [46], who observed that gypsum strengthened composite materials' flexural properties when a small amount of fibre was added to them.

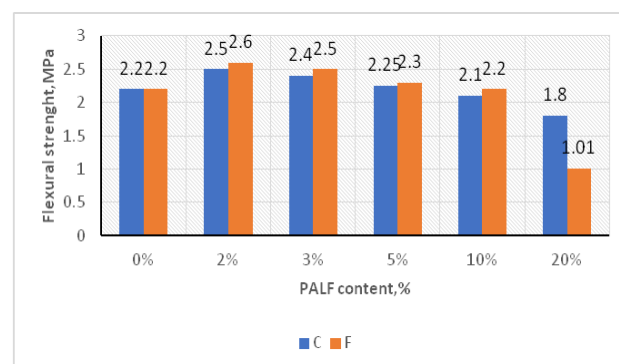


Figure 8: Flexural strength of the composites

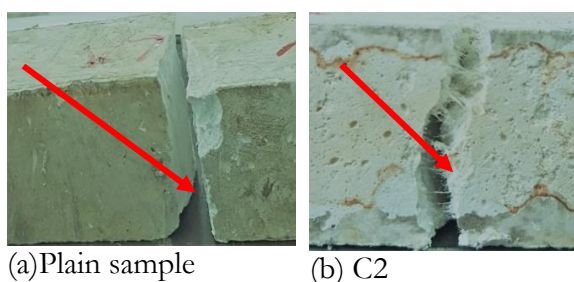


Figure 9: Comparison between fracture pattern of plain sample and composite C2.

IV. Conclusion

In the context of the effect of PALF on the physical and mechanical properties of gypsum paste studied in the present work, the following conclusion can be drawn in the study based on the experimental data. A porosity study shows that the number of pores rises as the PALF percentage increases. The analysis also showed that the area with PALF had bigger pores because of a gap left by PALF's poor contact at their interface. Moreover, 2% PALF has been found to have the best mechanical properties. Both series' compressive and flexural strengths, which were formerly 3.71 MPa and 2.60 MPa, respectively, have increased. The mechanical properties of the composites material firstly increased and later decreased with the addition of increase in PALF contents. The findings demonstrated that composite materials containing 2% PALF possessed the required consistency (> 150 mm), flexural strength (> 1 MPa), and compressive strength (> 2 MPa) properties. The findings of this experiment have conclusively shown that producing bio composite gypsum with a 2 percent PALF fraction is a viable option.

References

- [1] Ma, S., Bao, P., & Jiang, N., Experimental study of gypsum-concrete dense-column composite boards with external thermal insulation systems. *Applied Sciences*, vol. 6, no. 10, 2020, pp. 2076-3417.
- [2] Coburn, A., Dudley, E., and Spence, R., "Gypsum plaster," in *Gypsum Plaster: Its manufacture and use*, Practical Action Publishing, 1989, pp. 5–48.
- [3] Awang Ngah, S., Dams, B., Ansell, M. P., Stewart, J., Hempstead, R., and Ball, R. J., "Structural performance of fibrous plaster. Part 1: Physical and mechanical properties of hessian and glass fibre reinforced gypsum composites," *Construction Building Materials*, vol. 259, 2020, p. 120396.
- [4] Erbs, A., Nagalli, A., Querne de Carvalho, K., Mymrin, V., Passig, F. H., and Mazer, W. Properties of recycled gypsum from gypsum plasterboards and commercial gypsum throughout recycling cycles. *Journal of Cleaner Production*, vol. 183, 2018, pp. 1314–1322.
- [5] Jeong, S. G., Chang, S. J., Wi, S., Lee, J., and Kim, S., "Energy performance evaluation of heat-storage gypsum board with hybrid SSPCM composite," *Journal of Industrial and Engineering Chemistry*, vol. 100, no. 51, 2017, pp. 237–243.
- [6] Gencel, O., Del Coz Diaz, J. J., Sutcu, M., Koksall, F., Álvarez Rabanal, F. P., and Martínez-Barrera, G., "A novel lightweight gypsum composite with diatomite and polypropylene fibers," *Construction Building Materials*, vol. 100, no. 113, 2016, pp. 732–740.
- [7] Gutiérrez-González, S., Gadea, J., Rodríguez, A., Blanco-Varela, M. T., and Calderón, V., "Compatibility between gypsum and polyamide powder waste to produce lightweight plaster with enhanced thermal properties," *Construction Building Materials*, vol. 34, no. 6, 2012, pp. 179–185.
- [8] Toppi and L. Mazzarella, T., "Gypsum based composite materials with micro-encapsulated PCM:

- Experimental correlations for thermal properties estimation on the basis of the composition,” *Energy Building*, vol. 57, 2013, pp. 227–236.
- [9] Skujans, J., Vulans, A., Iljins, U., and Aboltins, A., “Measurements of heat transfer of multi-layered wall construction with foam gypsum,” *Applied Thermal Engineering*, vol. 27, no. 7, 2007, pp. 1219–1224.
- [10] Vimmrová, A., Keppert, M., Svoboda, L., and Černý, R., “Lightweight gypsum composites: Design strategies for multi-functionality,” *Cement Concrete Composites*, vol. 33, no. 1, 2011, pp. 84–89.
- [11] Iucolano, F., Liguori, B., Aprea, P., and Caputo, D., “Evaluation of bio-degummed hemp fibers as reinforcement in gypsum plaster,” *Composites Part B Engineering*, vol. 138, 2017, pp. 149–156, 2018.
- [12] Boccarusso, L., Durante, M., Iucolano, F., Mocerino, D., and Langella, A., “Production of hemp-gypsum composites with enhanced flexural and impact resistance,” *Construction Building Materials*, vol. 260, 2020, p. 120476.
- [13] Vasconcelos, G., Camões, A., Figueiro, R., and Vila-chã, N., “Gypsum-cork based composite material,” *1st International Conference of Natural Fibers*, 1999, pp. 1–10.
- [14] Deng Y. H., and Furuno, T., “Properties of gypsum particleboard reinforced with polypropylene fibers,” *Journal of Wood Science*, vol. 47, no. 6, 2001, pp. 445–450.
- [15] Ali M. A., and Grimer, F. J., “Mechanical properties of glass fibre-reinforced gypsum,” *Journal of Material Science*, vol. 4, no. 5, 1969, pp. 389–395.
- [16] Eve, S., Gomina, M., Gmouh, A., Samdi, A., Moussa, R., and Orange, G., “Microstructural and mechanical behaviour of polyamide fibre-reinforced plaster composites,” *Journal of the European Ceramic Society*, vol. 22, no. 13, 2002, pp. 2269–2275.
- [17] Çolak, A., “Physical and mechanical properties of polymer-plaster composites,” *Materials Letter*, vol. 60, no. 16, 2006, pp. 1977–1982.
- [18] Wu, Y. F., “The effect of longitudinal reinforcement on the cyclic shear behavior of glass fiber reinforced gypsum wall panels: Tests,” *Engineering. Structure*, vol. 26, no. 11, 2004, pp. 1633–1646.
- [19] Santamaría, V. I., Alameda, C.-R. L., Gutiérrez, G. S., Calderón, C. V., and Rodríguez, S. Á., “Design and Characterization of Gypsum Mortars Dosed with Polyurethane Foam Waste PFW,” *Materials*, vol. 13, no. 7, 2020, pp. 1497.
- [20] Iucolano, F., Caputo, D., Leboffe, F., and Liguori, B., “Mechanical behavior of plaster reinforced with abaca fibers,” *Construction Building Materials*, vol. 100, no. 99, 2015, pp. 184–191.
- [21] Yakovlev, G., Khozin, V., Polyanskikh, I., Keriene, J., Gordina, A., and Petrova, T., “Utilization of blast furnace flue dust while modifying gypsum binders with carbon nanostructures,” in *Environmental Engineering. Proceedings of the International Conference on Environmental Engineering*, vol. 9, 2014, p. 1.
- [22] Yakovlev, G., Polyanskikh, I., Fedorova, G., Gordina, A., and Buryanov, A., “Anhydrite and gypsum compositions modified with ultrafine man-made admixtures,” *Procedia Engineering*, vol. 108, 2015, pp. 13–21.
- [23] Khalil, A. A., Tawfik, A., Hegazy, A. A., and El-Shahat, M. F., “Effect of some waste additives on the physical and mechanical properties of gypsum plaster composites,” *Construction Building Materials*, vol. 100, no. 68, 2014, pp. 580–586.
- [24] Khalil, A. A., Tawfik, A., Hegazy, A.

- A., and El-Shahat, M. F., "Influencia de distintas fuentes de sílice en las propiedades físicas y mecánicas de materiales derivados del yeso," *Materials Construction*, vol. 63, no. 312, 2013, pp. 529–537.
- [25] Alameda, L., Calderón, V., Junco, C., Rodríguez, A., Gadea, J., and Gutiérrez-González, S., "Characterization of gypsum plasterboard with polyurethane foam waste reinforced with polypropylene fibers," *Materials Construction*, vol. 66, no. 324, 2016, pp. 100.
- [26] Ingrao *et al.*, C., "Energy and environmental assessment of industrial hemp for building applications: A review," *Renewal Sustainable Energy Rev.*, vol. 100, no. 51, 2015, pp. 29–42.
- [27] Alhijazi, M., Safaei, B., Zeeshan, Q., and Asmael, M., "Recent Developments in Luffa Natural Fiber Composites: Review sustainability Recent Developments in Luffa Natural Fiber Composites: Review," vol. 12, no. 18, 2020, pp. 7683.
- [28] Behdinin, K., Moradi-Dastjerdi, R., Safaei, B., Qin, Z., Chu, F., and Hui, D., "Graphene and CNT impact on heat transfer response of nanocomposite cylinders," *Nanotechnol. Rev.*, vol. 9, no. 1, 2020, pp. 41–52.
- [29] Huzaifah, M. R. M., Sapuan, S. M., Leman, Z., Ishak, M. R., and Maleque, M. A., "A review of sugar palm (*Arenga pinnata*): Application, fibre characterisation and composites," *Multidiscipline Modeling in Materials and Structures*, vol. 13, no. 4, 2017, pp. 678–698.
- [30] Mazzanti, V., Pariente, R., Bonanno, A., Ruiz de Ballesteros, O., Mollica, F., and Filippone, G., "Reinforcing mechanisms of natural fibers in green composites: Role of fibers morphology in a PLA/hemp model system," *Composite Science and Technology*, vol. 180, 2019, pp. 51–59.
- [31] Sanjay, M. R., Madhu, P., Jawaid, M., Senthamaraiannan, P., Senthil, S., and Pradeep, S., "Characterization and properties of natural fiber polymer composites: A comprehensive review," *Journal of Cleaner Production*, vol. 172, 2018, pp. 566–581.
- [32] Belayachi, N., Hoxha, D., and Slaimia, M., "Impact of accelerated climatic aging on the behavior of gypsum plaster-straw material for building thermal insulation," *Construction Building Materials*, vol. 100, no. 125, 2016, pp. 912–918.
- [33] Braiek, A., Karkri, M., Adili, A., Ibos, L., and Ben Nasrallah, S., "Estimation of the thermophysical properties of date palm fibers/gypsum composite for use as insulating materials in building," *Energy Building*, vol. 140, 2017, pp. 268–279.
- [34] Gao Z., and Li, G., "Effect of Straw Fiber Modification on Performance of Gypsum Composite," *Trans Tech Publications Ltd*, vol. 168, 2011, pp. 1455–1458.
- [35] Hošťálková, M., Vavřínová, N., and Longauerová, V., "Mechanical properties of the gypsum composite reinforcement with wooden fibers," *International Review of Applied Sciences and Engineering*, vol. 10, no. 1, 2019, pp. 15–21.
- [36] Chang, W.-P., Kim, K.-J., and Gupta, R. K., "Moisture absorption behavior of wood/plastic composites made with ultrasound-assisted alkali-treated wood particulates," *Composite Interfaces*, vol. 16, no. 7–9, 2009, pp. 937–951.
- [37] Ramezani, H., Shahdab, S., and Nouri, A., "Study on effects of wood fiber content on physical, mechanical, and acoustical properties of wood-fiber-filled gypsum composites," *Materials Research*, vol. 15, no. 2, 2012, pp. 236–241.

- [38] Zhu, C., Zhang, J., Peng, J., Cao, W., and Liu, J., "Physical and mechanical properties of gypsum-based composites reinforced with PVA and PP fibers," *Construction Building Materials*, vol. 163, 2018, pp. 695–705.
- [40] Flores Medina N., and Barbero-Barrera, M. M., "Mechanical and physical enhancement of gypsum composites through a synergic work of polypropylene fiber and recycled isostatic graphite filler," *Construction Building Materials*, vol.100, no. 131, 2017, pp. 165–177.
- [41] San-Antonio-González, A., Del Río Merino, M., Viñas Arrebola, C., and Villoria-Sáez, P., "Lightweight material made with gypsum and extruded polystyrene waste with enhanced thermal behaviour," *Construction Building Materials*, vol. 93, 2015, pp. 57–63.
- [42] Respati, S. M. B., Soenoko, R., Irawan, Y. S., Suprpto, W., Wicaksono, D. K., and Purwanto, H., "The effect of palm fibers addition on density, porosity, water discharge and TDS of the natural zeolite ceramic," *AIP Conference Proceedings*, vol. 1977, no.1, 2018, pp.030007.
- [43] Fatma, N., Allègue, L., Salem, M., Zitoune, R., and Zidi, M., "The effect of doum palm fibers on the mechanical and thermal properties of gypsum mortar," *Journal of Composite Materials*, vol. 53, no. 19, 2019, pp. 2641–2659.
- [44] Russo, A., Zarrelli, M., Sellitto, A., and Riccio, A., "Fiber bridging induced toughening effects on the delamination behavior of composite stiffened panels under bending loading: a numerical/experimental study," *Materials*, vol. 12, no. 15, 2019, p. 2407.
- [45] Ferreira, S. E., Pedro Da, S. A., Cárdenas, O. N., Da Costa, P. A. F., and Da Silva, D. A. C., "Mechanical properties of a composite of gypsum reinforced with caroá fiber and pvac," *Materials Science Forum*, vol. 958, no. 4, 2019, pp. 57–61.
- [46] Dawood, E., "The Properties of Fiber Reinforced Gypsum Plaster," *Journal of Scientific Research and Reports*, vol. 3, no. 10, 2014, pp. 1339–1347.

Acknowledgement

The Universiti Teknologi Malaysia Research Management Centre (RMC), which provided assistance under Grant No. FRGS RJ130000.7822.4F887, is gratefully acknowledged by the authors. We greatly appreciate their assistance.

Conflict of Interest

The corresponding author says that all the other authors have no conflicts of interest.