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Exploring Eggshell Waste and *Calotropis gigantea* Fibers for Eco-Friendly Ceiling Board Applications

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Abstract. The prohibition of asbestos in ceiling board production due to its serious health risks has prompted the search for safer, more sustainable alternatives. Current solutions often rely on non-renewable synthetic fibers, which pose environmental concerns. In Indonesia, eggshell waste from households and the food service industry amounts to approximately 483,920 tons annually, while *Calotropis gigantea* grows widely along the country's coastal areas. These two abundant resources represent promising renewable materials for sustainable product development. This study aims to develop and evaluate an eco-friendly biocomposite ceiling board using *C. gigantea* leaf fibers and eggshell-derived calcium carbonate as renewable reinforcements. The research objectives include assessing the resulting board's density, water absorption, impact resistance, and thermal stability to determine its feasibility as a sustainable alternative to conventional ceiling materials. The biocomposites were formulated by combining leaf fiber powder and eggshell-derived calcium carbonate (32.63–33.92% $CaCO_3$) in a resin matrix at various ratios. The resulting panels were evaluated for density, water absorption, drop resistance, and gradual heating. All samples exceeded the national density standard (SNI 03-2105) and demonstrated superior water and thermal resistance compared to commercial gypsum and kalsiboard panels. No sample failed under impact or heating up to 200°C. The presence of $CaCO_3$ contributed to improved mechanical and thermal performance while supporting the substitution of cement-based materials. These findings demonstrate the feasibility of using post-consumer and plant-based tropical waste to produce environmentally friendly construction materials, offering a promising pathway for sustainable resource use, waste reduction, and green building practices in tropical regions.

Keywords: biocomposite materials; *Calotropis gigantea* fibers; eco-friendly ceiling boards; eggshell waste; sustainable construction

I. INTRODUCTION

Ceiling boards serve essential architectural functions such as concealing utilities, improving interior aesthetics, and providing thermal and moisture protection [1]. Traditionally, ceiling boards were manufactured using asbestos mixed with cement. However, inhalation of asbestos fibers is associated with serious health risks, including lung cancer and mesothelioma, which has resulted in national and international regulations prohibiting its use in construction materials [2].

In Indonesia, Government Regulation No. 5/2018 on occupational health and safety and Law No. 32/2009 concerning environmental protection further emphasize the elimination of hazardous synthetic materials and encourage the adoption of safer, natural-fiber-based alternatives [3].

Composite materials—comprising a matrix and a reinforcing component—are widely explored as environmentally friendly substitutes for conventional building products. The reinforcement component, which may be in the form of fibers or particles, contributes mechanical strength, while the matrix binds and protects it against environmental factors such as moisture [4, 5]. Numerous studies have examined the use of natural fibers as reinforcement in composites, including palm [6], wood [7], pineapple [8], oil palm empty fruit bunches [9], corn husks [10], umbrella grass (*Cyperus alternifolius*) [11], wool [12], and *Calotropis gigantea* [13-15]. These materials have drawn increasing attention due to their renewability, availability, and compatibility with sustainable construction goals.

Calotropis gigantea (Figure 1) is a robust plant species native to Southeast Asia and commonly found across Indonesia's extensive coastal landscapes. It thrives in dry, saline environments and produces cellulose-rich leaf fibers suitable for short-fiber composite applications [16-17]. These fibers have a natural toughness and structural integrity that support their use as reinforcement materials in biocomposites. Their compatibility with resin matrices and ease of processing further strengthen their potential as sustainable alternatives to synthetic fibers.

Figure 1. *Calotropis gigantea* [18].

Eggshells (Figure 2), another abundant agricultural waste product in Indonesia with an estimated annual production of 483,920 tons, contain approximately 95% calcium carbonate ($CaCO_3$). This mineral content makes eggshells a promising filler material that can improve density, reduce shrinkage, and enhance mechanical and thermal stability in composite formulations. Utilizing eggshell waste also aligns with circular-economy principles and supports waste-reduction initiatives [19].

In recent years, increasing attention has been directed toward the use of biological and plant-based fibers in ceiling board production, reflecting a global shift toward sustainable construction materials. Studies have demonstrated the feasibility of using banana fiber [20-23], coconut coir [24, 25], rice husk [26], and sugarcane bagasse [27] as reinforcements in composite boards, achieving satisfactory mechanical and thermal performance comparable to or even superior to asbestos-based boards. These developments underscore the potential of plant-derived materials as safe, renewable, and high-performing alternatives—providing the key rationale for the present study's exploration of *C. gigantea* fibers and eggshell-based fillers in biocomposite ceiling boards.

Figure 2. Chicken Eggshells [22].

Conventional ceiling boards—such as gypsum, kalsiboard, and other fiber–cement products—still present limitations related to water absorption, durability, and environmental impact [28, 29]. Combined with the mandated elimination of asbestos-based boards, these issues highlight the urgency of developing safer, renewable, and environmentally responsible materials. In response, this study investigates a biocomposite ceiling board reinforced with C. gigantea leaf powder and eggshell-derived $CaCO_3$ within a resin matrix. The resulting composites are evaluated through density, water absorption, impact resistance, and thermal stability tests to determine their feasibility for sustainable ceiling applications.

II. MATERIALS AND METHODS

Research Site and Period

This research was conducted between January and February 2021 at the Materials Laboratory, Department of Civil Engineering, Udayana University, Bali, Indonesia.

Experimental Design

The factorial structure applies specifically to the formulation stage (Table 1), in which eggshell powder and leaf powder serve as the independent variables. The subsequent performance evaluations—including density, water absorption, impact resistance, and thermal stability—were conducted as individual procedural tests. These tests were designed to characterize material behavior and were not part of the factorial structure used for formulating the composite mixtures.

Fiber Preparation

C. gigantea leaves and chicken eggshells were separately sun-dried, then ground using a household blender and sieved to produce a fine powder suitable for homogeneous mixing (Figure 3a and 3b).

TABLE 1.
EXPERIMENTAL DESIGN

Sample No.	Eggshell (%)	Leaf (%)	Resin (%)	Catalyst (%)
P1	30	10	40	40
P2	20	20	40	40
P3	10	30	40	40

Biocomposite Production

The powdered leaf and eggshell materials were mixed with resin and catalyst in accordance with the proportions detailed in Table 1. The mixture was stirred until a uniform dough-like consistency was achieved, then poured into pre-designed molds (Figure 3c and 3d). The composites were allowed to cure at room temperature overnight. Each formulation was replicated three times to ensure reproducibility.

Density Test

The density of each cured ceiling board was calculated using the standard mass-to-volume formula:

$$\text{density } (\rho)\ (\text{kg/m}^3\text{m}^3) = \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$$

Water Absorption Test

Water absorption was tested in accordance with ASTM C1186-08. Each sample was submerged in water for 24 hours, then removed, surface-dried with paper towels, and weighed. The water absorption percentage was calculated using:

$$\text{WA } (\%) = \frac{\text{Final mass-initial mass}}{\text{initial mass}} \times 100\%$$

Drop Test

To assess impact resistance, each cured sample was weighed and then dropped from approximately 2 meters. After the fall, the samples were reweighed to determine mass loss and assess structural integrity (Figure 3e).

Gradual Heating Test

Thermal resistance was assessed by placing samples in an oven at 120°C, increasing the temperature by 20°C every 10 minutes to 200°C [30]. Heating was stopped when material deformation, melting, or structural failure was observed. This procedure served as a simple incremental heating assessment to determine material tolerance and was not structured as a factorial experiment.

These four tests were selected to evaluate the key performance criteria required for ceiling board applications: density, water resistance, impact resilience, and thermal stability

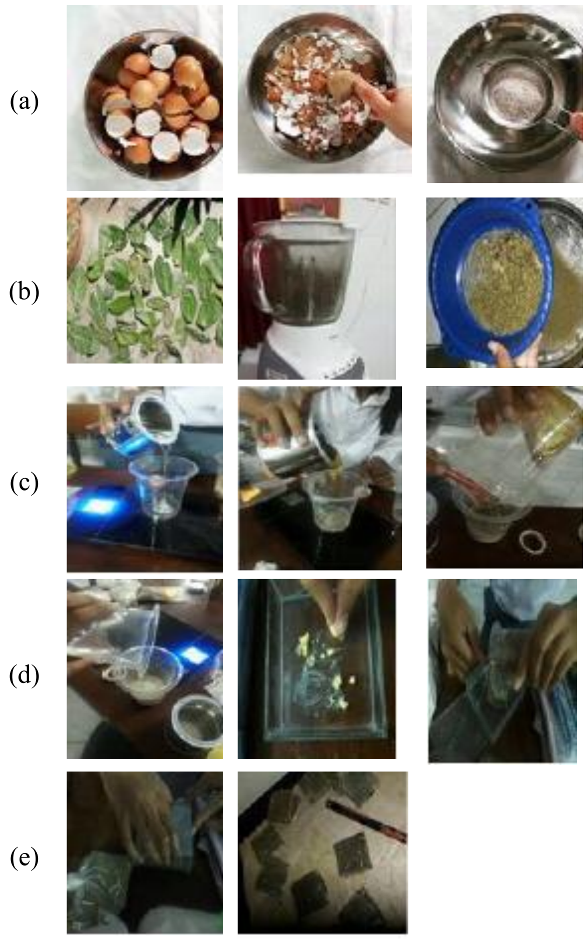

Figure 3. Composite Preparation and Testing Procedures. (a) Eggshell powder preparation, (b) *C. gigantea* leaf powder preparation, (c–d) Molding and casting of composite boards, (e) Drop test simulation

III. RESULTS AND DISCUSSION

The factorial design is applied exclusively to the formulation stage; therefore, the performance tests (density, water absorption, impact resistance, and thermal behavior) are presented descriptively rather than analyzed through factorial interactions.

Density Test

The results of the density test for samples P1, P2, and P3, along with comparisons to commercial kalsiboard and gypsum board, are illustrated in Figure 4. The recorded densities for the experimental samples were 1410 kg/m³ (P1), 1320 kg/m³ (P2), and 1170 kg/m³ (P3). In contrast, the commercial kalsiboard and gypsum board exhibited densities of 1180 kg/m³ and 630 kg/m³, respectively.

Among the tested composites, sample P3 showed a density closely resembling that of commercial kalsiboard, while all three samples significantly outperformed gypsum board in terms of material compactness. The trend indicates that increasing the proportion of eggshell powder correlates with increased density, a finding consistent with previous research by Matschei et al. [28], which identified calcium carbonate as an inert filler that enhances material packing in composites.

All three biocomposite samples satisfied the minimum density requirement of 1000 kg/m³ stipulated by SNI 03-2105 for particleboard and kalsiboard standards [1]. Notably, these densities are significantly higher than those reported for ceiling boards fabricated from waste paper and urea-formaldehyde adhesive, which ranged between 46.62 kg/m³ and 76 kg/m³ depending on the material ratio [31].

In terms of comparative performance, samples P1 through P3 exhibited greater mass than gypsum board but were still lighter than traditional asbestos boards, as also reported in previous studies [31]. This balance between weight and strength underscores the potential of these natural-fiber-reinforced composites for environmentally friendly ceiling applications. In addition to the $CaCO_3$ contribution from eggshells, the presence of *C. gigantea* fibers also supports the overall density profile by providing a natural fibrous framework that helps the matrix retain structural cohesion during curing.

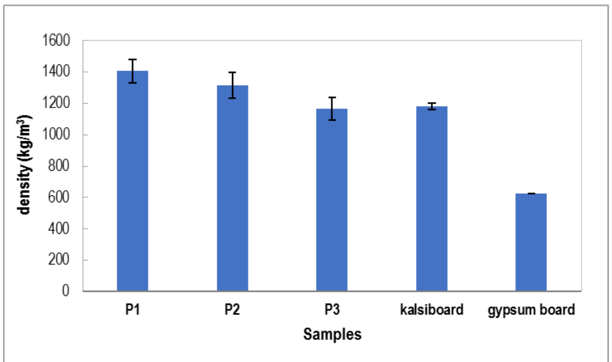

Figure 4. Density of ceiling board samples

Water Absorption Test

The water absorption capacities of the composite samples P1, P2, and P3 were measured at 1.82%, 14.36%, and 9.23%, respectively. For comparison, commercial kalsiboard absorbed 25.4% of its initial weight, while gypsum board absorbed 75.5% of its initial weight (Figure 5). Among the biocomposites, sample P2—which contained an equal ratio of eggshell and *C. gigantea* powders—exhibited the highest water uptake.

Despite variations in absorption, all biocomposite samples complied with the maximum allowable water absorption limit of 50%, as specified by SNI 03-2105 for ceiling boards [1]. In contrast, gypsum board exceeded this limit, highlighting its relative vulnerability to moisture.

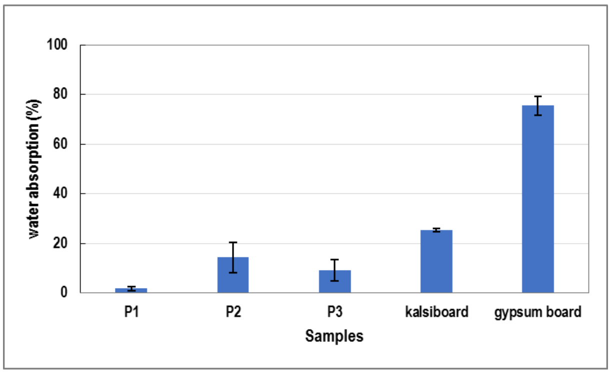

Figure 5. Water Absorption Values of Ceiling Boards

The superior performance of the experimental samples, particularly P1, with the lowest absorption rate, is largely attributed to the epoxy-based resin matrix, which provides strong hydrophobicity. These results compare favorably with ceiling boards made from waste paper and urea-formaldehyde adhesive, which demonstrated significantly higher water absorption rates of 115.68% and 84.93% depending on the formulation [31].

In a separate study, Ataguba [32] reported that ceiling boards made from waste paper and rice husks had water absorption values ranging from 7.5% to 14.5% and densities of 103-201 kg/m³. In contrast, the present biocomposites offered a superior balance of higher density and lower water absorption, both of which are critical for material durability in humid tropical environments.

The behavior of the composites is also influenced by the intrinsic properties of *C. gigantea* fibers. Their cellulose-based structure contains polar sites that interact with moisture; however, when embedded in the resin–$CaCO_3$ matrix, these fibers contribute to a more stable, interconnected internal structure, helping to moderate water uptake across the samples [33].

These findings suggest that the incorporation of eggshell-derived calcium carbonate, in conjunction with *C. gigantea* fibers and epoxy resin, can significantly improve the water resistance of composite ceiling boards, an essential property for environmental resilience and longevity in building materials.

Drop Test

The drop test results, summarized in Table 2, show that all tested samples—P1, P2, and P3—as well as commercial kalsiboard and gypsum board, remained intact and retained 100% of their initial mass after being dropped from a height of approximately 2 meters. This indicates that the biocomposite boards possess sufficient structural integrity for use as ceiling materials in real-world conditions.

Although this test provides only preliminary data on mechanical durability, it demonstrates promising impact resistance comparable to that of existing commercial products. These findings align with studies exploring natural fiber-reinforced materials as partial substitutes for conventional building components.

TABLE 2
DROP TEST

Sample	Initial Mass	Final mass	Integrity retained (%)
P1	18.6	18.6	100%
P2	25	25	100%
P3	28.6	28.6	100%
Kalsiboard	25	25	100%
Gypsum	28.6	28.6	100%

For instance, Bheel et al. [34] reported that while natural fibers such as *Costus englerianus* bagasse fiber and bagasse ash used in concrete mixtures tend to yield slightly lower compressive and flexural strengths than conventional cement concrete, the use of mineral-based fillers, such as bagasse ash, may enhance certain mechanical properties. In line with this, calcium carbonate ($CaCO_3$) has been extensively studied as a partial substitute for cement in concrete production, contributing to more environmentally sustainable formulations (Antoni, 2013). Furthermore, the addition of natural fibers, such as wool, has been shown to improve the structural performance of gypsum-based composites [12], supporting the feasibility of using biocomposite materials in building applications.

The impact resistance observed in the biocomposites is partly attributable to the reinforcing role of *C. gigantea* fibers, whose toughness and natural flexibility help distribute the applied impact energy throughout the matrix. This behavior is consistent with prior studies reporting the capacity of natural fibers to enhance crack resistance and reduce brittle failure in composite systems [35].

The drop test results thus reinforce the viability of using *C. gigantea* fiber and eggshell-derived $CaCO_3$ in composite materials, not only for environmental sustainability but also for meeting functional and safety standards in tropical civil engineering applications.

Gradual Heating Test

The results of the gradual heating test, presented in Table 3, reveal that none of the samples—P1, P2, P3, kalsiboard, or gypsum board—experienced melting or visible deformation when exposed to a controlled temperature increase from 120°C to 200°C. All samples remained solid and exhibited surface hardening within a few minutes upon cooling to ambient temperature. However, it was observed that sample P2, along with several replicates of P3, released a small quantity of water at elevated temperatures. This moisture is likely derived from residual content within the plant fibers themselves.

The material's stability at elevated temperatures also reflects the thermal characteristics of *C. gigantea* fibers, which possess inherent resistance to moderate heating due to their lignocellulosic composition. When combined with eggshell-derived $CaCO_3$, these fibers help maintain structural integrity during gradual thermal exposure [36].

These observations suggest that further research is necessary to better understand the influence of thermal treatment on *C. gigantea* fibers. Controlled heating may facilitate the removal of surface-bound compounds such as waxes, hemicellulose, and other non-cellulosic substances, resulting in cleaner fiber surfaces. This, in turn, may enhance the fiber–matrix interfacial bond and improve the overall mechanical performance of the biocomposite materials.

TABLE 3.
GRADUAL HEATING TEST RESULTS

Temperature (^{0}C)		120	140	160	180	200
P1	U1	0	0	0	0	0
	U2	0	0	0	0	0
	U3	0	0	0	0	0
P2	U1	0	0	0	0	0
	U2	0	0	0	0	0
	U3	0	0	0	0	0
P3	U1	0	0	0	0	0
	U2	0	0	0	0	0
	U3	0	0	0	0	0
Kalsi board	U1	0	0	0	0	0
	U2	0	0	0	0	0
	U3	0	0	0	0	0
Gypsum	U1	0	0	0	0	0
	U2	0	0	0	0	0
	U3	0	0	0	0	0

Note: "0" indicates no melting or visible change.

Fathoni et al. [30] emphasized that thermal treatment can enhance bonding between natural fibers and the surrounding matrix by eliminating volatile compounds, such as waxes and hemicellulose. This process improves fiber surface roughness and enhances interfacial adhesion, both of which are critical to the mechanical integrity of fiber-reinforced composites.

When left untreated, fiber surfaces often retain impurities or exhibit a smooth texture, both of which hinder effective bonding to the matrix and reduce the tensile strength of the final material. Heat treatment promotes surface etching and the evaporation of oils and moisture, which in turn increases the available bonding surface area and supports mechanical interlocking between fiber and matrix—a phenomenon illustrated in Figure 6 [37].

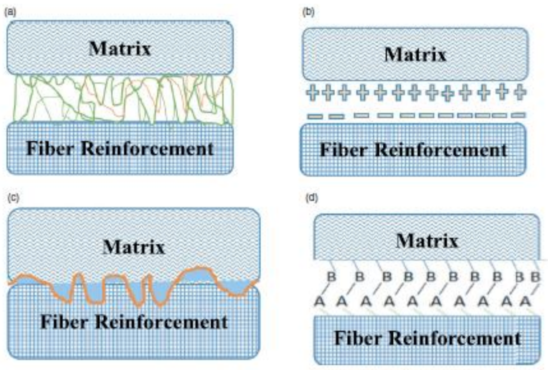

Figure 6. Types of interfacial bonding in fiber reinforcement composites [37].

In addition to fiber behavior, the thermal stability and structural integrity of the biocomposites may also be attributed to the presence of calcium carbonate ($CaCO_3$) from eggshells. According to Cao et al. [38], $CaCO_3$ reduces pore size in composites, thereby enhancing adhesion between filler and aggregate materials. Under heating, calcium carbonate decomposes into calcium oxide (CaO) and carbon dioxide (CO_2), as represented by the reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

This reaction is particularly vigorous when $CaCO_3$ is in fine powder form, due to the higher surface area available for heat transfer [39]. Reddy et al. [39] also reported that the addition of $CaCO_3$ in concentrations between 0.025 g/L and 0.3 g/L to blended cement concrete significantly improved its compressive strength.

Conversely, Purnawan & Prabowo [40] found that incorporating limestone reduced the compressive strength of cement composites, illustrating that the mechanical effects of $CaCO_3$ may vary depending on formulation. Nevertheless, $CaCO_3$ is widely acknowledged to improve the workability of cement pastes, enhance particle packing, and increase the overall durability of concrete [41].

Importantly, calcium carbonate ($CaCO_3$) can be derived from various natural and waste-based sources, including cuttlebone powder, periwinkle shell ash, and even captured CO_2 emissions [42, 43]. Demonstrating that green concrete incorporating cuttlebone-derived $CaCO_3$ achieved compressive strengths comparable to those of traditional cement-based formulations. Furthermore, $CaCO_3$, when combined with biochar, can act as a carbon storage medium, contributing to climate mitigation efforts [44]. As noted by Antoni [45], replacing a portion of cement with natural materials, such as $CaCO_3$, is a promising approach to producing environmentally friendly construction materials with adequate mechanical performance.

Collectively, these findings support integrating $CaCO_3$-rich waste—such as eggshells—into tropical biocomposites to reduce environmental impact in the construction sector. In parallel, the contribution of *C. gigantea* fibers is equally significant in this formulation. Their natural cellulose-rich structure, intrinsic thermal tolerance, and surface roughness enhance fiber–matrix interactions, thereby supporting mechanical integrity under impact and heating. The combination of mineral-based $CaCO_3$ and plant-based *C. gigantea* fibers therefore provides a complementary reinforcement system: the $CaCO_3$ improves packing density and thermal stability, while the fibers contribute to structural resilience and moisture performance. Together, these attributes align with the objective of developing a sustainable, plant-integrated composite suitable for tropical building applications.

Taken together, the dual contribution of *C. gigantea* fibers as a natural reinforcement and eggshell-derived $CaCO_3$ as a mineral stabilizer demonstrates a synergistic pathway for developing robust, eco-friendly ceiling materials suitable for tropical environments.

IV. CONCLUSION

This study demonstrated that biocomposite ceiling boards formulated with varying proportions of *Calotropis gigantea* leaf powder and eggshell-derived $CaCO_3$ met key performance requirements for tropical construction applications. All samples exceeded the minimum density standard (≥1000 kg/m³) and showed lower water absorption compared to commercial gypsum and kalsiboard. The boards also maintained full integrity in the drop test and exhibited thermal stability up to 200°C without deformation. These results confirm that the combination of $CaCO_3$ and *C. gigantea* fibers can produce ceiling boards with adequate mechanical strength, moisture resistance, and thermal tolerance.

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REFERENCES

[1] Sari, R. W. (2013). Pembuatan dan Karakterisasi Plafon dari Serbuk Ampas Tebu dengan Perekat

Poliester. 1(1). https://jurnal.usu.ac.id/index.php/sfisika/article/view/1717

[2] Akhadi, M. (2015). Health Impact of Asbestos Fibres Emissions from Chimneys. Energi dan Kelistrikan Jurnal Ilmiah, 7(1), 19–27. https://doi.org/10.33322/energi.v7i1.579

[3] Akhmaddhian, S. (2016). Penegakan Hukum Lingkungan dan Pengaruhnya terhadap Pertumbuhan Ekonomi di Indonesia (Studi Kebakaran Hutan Tahun 2015). Jurnal Unifikasi, 3(1), 1–35.

[4] Bethony, F. R. (2014). Mechanical Properties Analysis Spinach Wood Powder Epoxy Resin Composite. Dynamic Saint, 1(2). https://doi.org/10.47178/dynamicsaint

[5] Nordin, N. A., Yussof, F. M., Kasolang, S., Salleh, Z., & Ahmad, M. A. (2013). Wear Rate of Natural Fibre: Long Kenaf Composite. Procedia Engineering, 68, 145–151. https://doi.org/10.1016/j.proeng.2013.12.160

[6] Asyraf, M. R. M., Ishak, M. R., Syamsir, A., Nurazzi, N. M., Sabaruddin, F. A., Shazleen, S. S., Norrrahim, M. N. F., Rafidah, M., Ilyas, R. A., Rashid, M. Z. A., & Razman, M. R. (2022). Mechanical properties of oil palm fibre-reinforced polymer composites: A review. Journal of Materials Research and Technology, 17, 33–65. https://doi.org/10.1016/j.jmrt.2021.12.122

[7] Prasad, V., Sekar, K., & Joseph, M. A. (2022). Wood fibers, their composites and applications. In Plant Fibers, their Composites, and Applications (pp. 391–436). Elsevier. https://doi.org/10.1016/B978-0-12-824528-6.00019-9[43] Antoni, M. (2013). Investigation of Cement Substitution by Blends of Calcined Clays and Limestone. https://doi.org/10.5075/EPFL-THESIS-6001

[8] Santulli, C., Palanisamy, S., & Kalimuthu, M. (2022). Pineapple fibers, their composites and applications. In Plant Fibers, their Composites, and Applications (pp. 323–346). Elsevier. https://doi.org/10.1016/B978-0-12-824528-6.00007-2

[9] Tarkono, T., & Ali, H. (2015). Pemanfaatan Serat Tandan Kosong Kelapa Sawit (TKKS) dalam Produksi Eternit yang Ramah Lingkungan. Jurnal Sains Teknologi & Lingkungan, 1(1), 1–7. https://doi.org/10.29303/jstl.v1i1

[10] Sari, N. H. (2017). Studi sifat penyerapan suara komposit corn husk fiber pada frekuensi rendah. Jurnal Energi Dan Manufaktur, 10(2), 81–85.

[11] Yoedono, B. S., Sunik, S., & Inanta, C. A. (2020). Pengaruh Perlakuan Alkali Serat Rumput Payung (Cyperus alternifolius) terhadap Kekuatan Tarik Komposit dengan Matrik Epoxy. Jurnal Teknik Sipil, 15(3), 162–169. https://doi.org/10.24002/jts.v15i3.3729

[12] Fantilli, A. P., Jóźwiak-Niedźwiedzka, D., & Denis, P. (2021). Bio-Fibres as a Reinforcement of Gypsum Composites. Materials, 14(17), 4830. https://doi.org/10.3390/ma14174830

[13] Ashori, A., & Bahreini, Z. (2009). Evaluation of Calotropis gigantea as a Promising Raw Material for Fiber-reinforced Composite. Journal of Composite Materials, 43(11), 1297–1304. https://doi.org/10.1177/0021998308104526

[14] Raji, R., Elangomannan, S., Subramani, R., Louis, K., Periasamy, M., & Dhanaraj, G. (2022). Calotropis Gigantea Fiber─A Biogenic Reinforcement Material for Europium Substituted Hydroxyapatite/Poly(3,4-propylenedioxythiophene) Matrix: A Novel Ternary Composite for Biomedical Applications. ACS Omega, 7(7), 6024–6034. https://doi.org/10.1021/acsomega.1c06372

[15] Ramesh, G., Subramanian, K., Sathiyamurthy, S., & Prakash, M. (2022). Calotropis Gigantea Fiber-epoxy Composites: Influence of Fiber Orientation on Mechanical Properties and Thermal Behavior. Journal of Natural Fibers, 19(10), 3668–3680. https://doi.org/10.1080/15440478.2020.1848718

[16] Faradilla, M., & Maysarah, H. (2019). Prospect of Biduri (Calotropis gigantea (L.) W.T. Aiton) as Medicinal Plant. Jurnal Ilmu Kefarmasian Indonesia, 17(2), 246–250.

[17] Rahmanto, D. E., Fitroni, E. H., & Rudiyanto, B. (2020). Pemanfaatan Daun Biduri (Calotropis Gigantea) sebagai Perekat Pembuatan Briket Serbuk Gergaji Kayu Bayur (Pterospermum Javanicum). Jurnal Rona Teknik Pertanian, 13(1), 24–39.

[18] Alamendah. (2014). Biduri atau Widuri (Calotropis gigantea) yang Terabai. Alamendah's Blog. https://alamendah.org/2014/10/22/biduri-atau-widuri-calotropis-gigantea-yang-terabai/

[19] Darkun, K., Febrina, L., & Lutfansa, A. (2022). Utilization a Mixture of Eggshells and Husk Ash to Reduce Environmental Impact. Environmental Research, Engineering and Management, 78(3), 110–118. https://doi.org/10.5755/j01.erem.78.3.31084

[20] Rahayu, T. N., & Hanifa, S. (2017). Potensi Cangkang Telur sebagai Sumber Kalsium dengan Pendekatan Pengaruh Sterilisasi dengan Perebusan terhadap Kadar Kalsium dan Salmonella sp. Prosiding Seminar Nasional Tahunan Matematika, Sains dan Teknologi 2017.

[21] Wirakusumah, E. S. (2011). Menikmati Telur: Bergizi, Lezat, dan Ekonomis. Gramedia Pustaka Utama.

[22] Scattergood, G. (2017). Gary Scattergood. https://www.nutraingredients-asia.com/Article/2017/03/20/Egg-shell-powder-a-novel-treatment-against-inflammatory-bowel-disease?utm_source=copyright&utm_medium=OnSite&utm_campaign=copyright

[23] Rouf, Md. A., Alam, Md. R., Belal, S. A., Ali, Y., & Rahman, M. Z. (2025). Mechanical and Thermal Performances of Banana Fiber–Reinforced Gypsum Composites. International Journal of Polymer Science, 2025(1), 8120082. https://doi.org/10.1155/ijps/8120082

[24] Hasan, K. M. F., Horváth, P. G., Bak, M., & Alpár, T. (2021). A state-of-the-art review on coir fiber-reinforced biocomposites. RSC Advances, 11(18), 10548–10571. https://doi.org/10.1039/d1ra00231g

[25] Nissar, M., N., C. K., Birjerane, Y. A., Patil, S., Shetty, S., & Das, A. (2025). Coconut Coir Fiber Composites for Sustainable Architecture: A Comprehensive Review of Properties, Processing, and Applications. Journal of Composites Science, 9(10), 516. https://doi.org/10.3390/jcs9100516

[26] Suhot, M. A., Hassan, M. Z., Aziz, S. A., & Md Daud, M. Y. (2021). Recent Progress of Rice Husk Reinforced Polymer Composites: A Review. Polymers, 13(15), 2391. https://doi.org/10.3390/polym13152391

[27] Samanth, M., Hiremath, P., Deepak, G. D., Naik, N., H S, A., Heckadka, S. S., & Shivamurthy, R. C. (2025). Sustainable Composites from Sugarcane Bagasse Fibers and Bio-Based Epoxy with Insights into Wear Performance, Thermal Stability, and Machine Learning Predictive Modeling. Journal of Composites Science, 9(3), 124. https://doi.org/10.3390/jcs9030124

[28] Matschei, T., Lothenbach, B., & Glasser, F. P. (2007). The role of calcium carbonate in cement hydration. Cement and Concrete Research, 37(4), 551–558. https://doi.org/10.1016/j.cemconres.2006.10.013

[29] Rahmatika, E. (2022, December 25). 9 Jenis Plafon Rumah Yang Harus Diketahui. Dilengkapi Kelebihan Dan Kekurangannya! 99.co. https://berita.99.co/jenis-plafon/

[30] Fathoni, A., & Raharjo, W. W. (n.d.). Pengaruh Perlakuan Panas Serat terhadap Sifat Tarik Serat Tunggal dan Komposit Cantula-rHDPE.

[31] Hamid, N. B., Ngadiman, N., Kaamin, M., Mokhtar, M., Azmi, M. A. M., Abdullah, N. H., & Ramli, M. Z. (2022). A study on properties of ceiling board made from waste paper with urea-formaldehyde glue. 050024. https://doi.org/10.1063/5.0104479

[32] Ataguba, C. O. (2016). Properties of ceiling Boards Produced from A Composite of Waste Paper and Rice Husk. International Journal of Advances in Science Engineering and Technology, spl.issue(2), 117–121. https://doi.org/DOI:%2520https://doi.org/10.25134/unifikasi.v3i1.404

[33] [33] Handayani, L., Aprilia, S., Nasrul, N., & Bilad, M. R. (2025). Exploring the Prospects of Calotropis gigantea as a Sustainable Source of Fiber and Cellulose. Agrointek : Jurnal Teknologi Industri Pertanian, 19(2), 369–380. https://doi.org/10.21107/agrointek.v19i2.24200

[34] Bheel, N., Kennedy, C., Awoyera, P., Sohu, S., & Abbasi, S. A. (2022). Comparative Study on Mechanical Properties of Concrete Blended with Costus englerianus Bagasse Ash and Bagasse Fibre as Partial Replacement for Lime and Cement. Advances in Civil Engineering, 2022, 1–8. https://doi.org/10.1155/2022/8900167

[35] Seid, A. M., & Adimass, S. A. (2024). Review on the impact behavior of natural fiber epoxy based composites. Heliyon, 10(20), e39116. https://doi.org/10.1016/j.heliyon.2024.e39116

[36] Raja, T., Devarajan, Y., & Thanappan, S. (2023). Studies on the Mechanical and Thermal Stability of Calotropis gigantea Fibre-Reinforced Bran Nano Particulates Epoxy Composite. Scientific Reports, 13(1), 16291. https://doi.org/10.1038/s41598-023-42316-6

[37] Latif, R., Wakeel, S., Zaman Khan, N., Noor Siddiquee, A., Lal Verma, S., & Akhtar Khan, Z. (2019). Surface treatments of plant fibers and their effects on mechanical properties of fiber-reinforced composites: A review. Journal of Reinforced Plastics and Composites, 38(1), 15–30. https://doi.org/10.1177/0731684418802022

[38] Aarti, C. (2014). A Review on Pharmacological and Biological Properties of Calotropis gigantea. Inter Journal of Recent Scientific Research, 5(4), 716–719.

[39] Reddy, M., Kumar, D. P., & Sashidhar, C. (2015). Effect of Calcium Carbonate on Fly Ash Based Blended Cement Concrete. Global Journal of Engineering Science and Researches, 2(3), 105–112.

[40] Purnawan, I., & Prabowo, A. (2018). Pengaruh Penambahan Limestone terhadap Kuat Tekan Semen Portland Komposit. Jurnal Rekayasa Proses, 11(2), 86. https://doi.org/10.22146/jrekpros.31136

[41] Rad, P. R., Taghia, S. A. H. S., Darvishvanda, H. R., & Ebrahimib, M. (2022). Technical and Economical Approaches in Application of Micro Silica Gel and Calcium Carbonate Powder in Self-compacting

Concrete. International Journal of Engineering, 35(04), 760–773. https://doi.org/10.5829/IJE.2022.35.04A.16

[42] Hargis, C. W., Chen, I. A., Devenney, M., Fernandez, M. J., Gilliam, R. J., & Thatcher, R. P. (2021). Calcium Carbonate Cement: A Carbon Capture, Utilization, and Storage (CCUS) Technique. Materials, 14(11), 2709. https://doi.org/10.3390/ma14112709

[43] Mirzabagheri, S., Derhamjani, G., Maharati, S., Ziaee, Z., Vatankhah, F., & Mirzabagheri, D. (2018). Using Cuttlebone Powder to Produce Green Concrete. Journal of Applied Engineering Sciences, 8(2), 25–28. https://doi.org/10.2478/jaes-2018-0014

[44] Winters, D., Boakye, K., & Simske, S. (2022). Toward Carbon-Neutral Concrete through Biochar–Cement–Calcium Carbonate Composites: A Critical Review. Sustainability, 14(8), 4633. https://doi.org/10.3390/su14084633.

[45] Antoni, M. (2013). Investigation of Cement Substitution by Blends of Calcined Clays and Limestone. https://doi.org/10.5075/EPFL-6001.