RMUTL. Eng. J
Rajamangala University of Technology Lanna (RMUTL) Engineering Journal

Enhancing Gypsum Ceiling Sheets with Malt Waste: Optimal Composition for Strength and Insulation

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Received: 15 October 2025, Revised: 23 February 2026, Accepted: 23 February 2026

Abstract

This study investigates the use of malt waste, a byproduct of the beer production process, as a bio-based additive in gypsum ceiling sheets to enhance mechanical performance while improving thermal insulation properties. Gypsum composite specimens were prepared by incorporating malt waste at weight ratios of 100:0, 90:10, 85:15, 80:20, 75:25, and 70:30, and the effects on density, thermal conductivity, and bending strength were systematically evaluated and compared with those of conventional gypsum boards complying with TIS 219-2009. The results show that increasing malt waste content led to a reduction in density from 1.16 g/cm³ for pure gypsum to 0.76 g/cm³ at a 70:30 ratio, representing a decrease of approximately 34.5%. Similarly, thermal conductivity decreased to a minimum value of 0.094 W/m·K, indicating improved insulation performance compared with conventional gypsum boards. However, the 85:15 gypsum-to-malt waste ratio demonstrated the optimum balance between thermal insulation and mechanical performance, achieving the highest longitudinal flexural force of 297.57 N and a thermal conductivity of 0.097 W/m·K. These findings highlight the potential of malt waste as a sustainable reinforcement material for the development of eco-friendly gypsum ceiling applications.

Keywords: Malt Waste, Gypsum, Ceiling Board, Composite Materials, Sustainable Materials

1. Introduction

Composite materials are widely used in modern construction due to their improved strength, durability, and performance achieved by combining different materials. They are commonly applied in ceiling and wall panels, where lightweight materials with good thermal insulation and structural integrity are required.

Natural fibers have increasingly been utilized in composite materials due to their availability, cost-effectiveness, and environmental benefits. Various studies have investigated the use of plant-based fibers such as coconut coir, bagasse, and water hyacinth in gypsum board production, aiming to enhance mechanical and thermal properties while addressing waste management issues. These natural fibers contribute to improved bonding strength and lower thermal conductivity, making them ideal for sustainable building materials.

Despite extensive research on natural fiber composites, the use of malt waste as an additive in gypsum boards remains largely unexplored. Malt waste, a byproduct of the beer brewing industry, is rich in cellulose fibers that can enhance the structural performance of gypsum-based materials. The rapid growth of the beer industry generates significant quantities of malt waste, raising environmental concerns related to disposal and pollution. Compared with many conventional natural fibers that often require additional processing before use, malt waste is readily available as an industrial byproduct, making it a promising and sustainable alternative for gypsum-based composite materials [1-4].

Previous research on fiber-reinforced gypsum boards has primarily focused on commonly used agricultural residues such as bagasse, coconut coir, and corn husks. These studies have demonstrated the benefits of adding natural fibers to gypsum in terms of reducing density, enhancing thermal insulation, and increasing flexural strength. For instance, studies on bagasse-reinforced panels have shown promising results in achieving lower thermal conductivity values and improved mechanical performance, making them suitable for architectural applications [2]. Similarly, research on coconut coir-based composites has indicated improvements in water resistance and strength [1].

However, despite these advancements, the potential of malt waste as a reinforcing fiber in gypsum composites has not been fully explored. Unlike other natural fibers, malt waste has a unique fiber structure and chemical composition that could offer distinct advantages in composite applications. Additionally, the environmental impact of malt waste disposal remains a challenge for the brewing industry, highlighting the need for innovative recycling and upcycling strategies.

Furthermore, while previous studies have demonstrated the benefits of natural fiber incorporation, there is limited research on optimizing fiber content to achieve the best balance between mechanical strength and thermal insulation. Excessive fiber content can lead to reduced structural integrity due to increased porosity, which weakens interparticle bonding in the composite material [5, 6]. Therefore, it is essential to determine the optimal gypsum-to-malt waste ratio that ensures enhanced performance without compromising material durability.

This study aims to investigate whether the incorporation of malt waste into gypsum boards can enhance thermal insulation performance without significantly compromising the mechanical strength of the material. To address this objective, the effects of malt waste incorporation on gypsum board properties were systematically evaluated, focusing on density, thermal conductivity, and bending strength. The findings of this research provide valuable insights into the feasibility of using malt waste as a sustainable additive in gypsum composites, thereby contributing to environmental sustainability and the development of eco-friendly construction materials.

2. Materials and Methods

2.1 Sample Preparation

2.1.1 Malt Waste Preparation

To develop gypsum composite boards reinforced with malt waste, high-quality gypsum powder and malt waste obtained from the beer production process were used. The gypsum powder, sourced from commercial suppliers, was selected for its fine particle size and high purity to ensure optimal bonding with malt waste fibers. Malt waste, a byproduct rich in cellulose, was collected from local breweries and subjected to a drying process to remove excess moisture. The initial moisture content of malt waste was approximately 65-69%, which was reduced to a final humidity of 4-7% through controlled drying in an oven at 200-250°C for 45-60 minutes.

Figure 1 illustrates the process of extracting water from malt waste and passing it through an oven, where steam is used to dry the waste. Inside the machine, a mechanism continuously turns the malt waste from bottom to top, ensuring even drying. The initial humidity of the malt waste ranges between 65% and 69%. As it exits the oven, its moisture content is significantly reduced. Before use, the waste must undergo a further drying process to achieve a final humidity of 4% to 7%, as shown in Figure 2(a). This drying step ensures that the malt waste is adequately prepared for mixing with gypsum in the next stage of processing.

2.1.2 Gypsum Preparation

Figure 2(b) shows Siam gypsum easy plaster 120, a 25 kg cement powder designed for joining gypsum boards. It has a smooth, uniform surface, is lightweight, and is easily mixable with water. The slow-drying formula allows for a 90-minute working time and 120-minute drying time, for flexibility during application. Once dried, it offers high adhesion, a fine, crack-free finish, and is easy to sand and decorate. The recommended mixing ratio is 2:1 (cement to water by weight), with a coverage of 50-60 square meters per package and a storage period of six months.

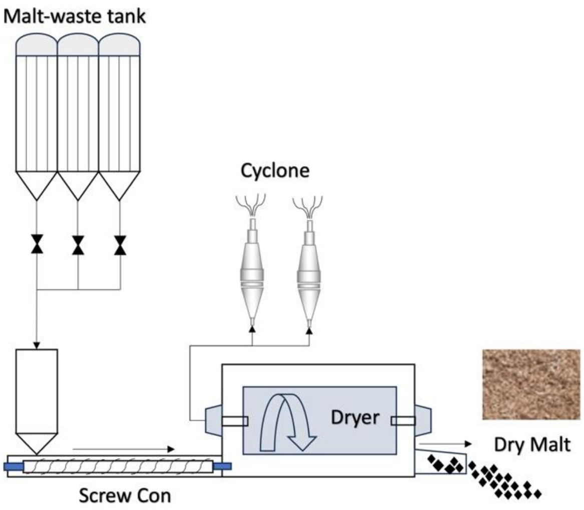

Figure 1 Malt drying process

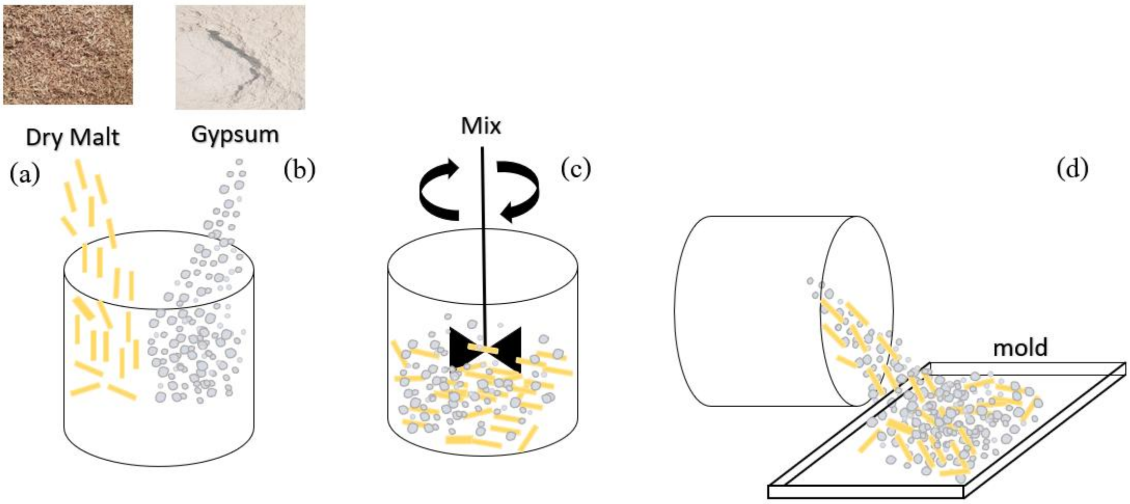

Figure 2 Forming schematic: (a) Dry malt, (b) Gypsum, (c) Mixing, and (d) Casting

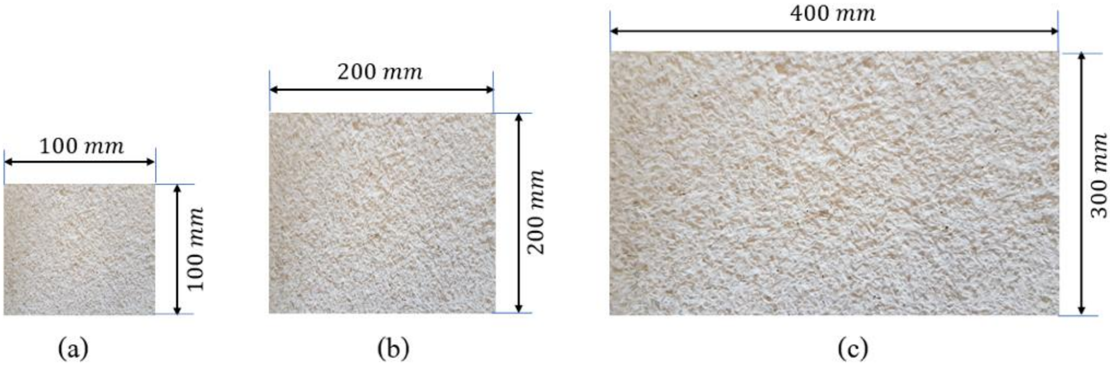

Figure 3 Specimen sizes: (a) Density, (b) Thermal conductivity, and (c) Bending testing

Table 1 Standard specimen size.

No.	Measurement and testing	Size (mm x mm)	Reference
(a)	Density	100 x 100	[1]
(b)	Thermal conductivity	200 x 200	[5]
(c)	Bending testing	300 x 400	[5]

2.1.3 Sample Preparation and Drying Process

Figure 2(c) illustrates the mixing process, in which an electric drill equipped with a mechanical stirrer was used to blend dry gypsum powder with malt waste in batch quantities. The mixing was conducted in an 18-liter polypropylene (PP) cylindrical container (milk-colored) with dimensions of 31.5 × 35.2 cm. (diameter x height). As shown in Figure 2(d), the mixer was operated until a homogeneous mixture was obtained, ensuring a uniform distribution of malt waste within the gypsum matrix. After mixing, the composite slurry was poured into molds according to the specified proportions and allowed to dry prior to mechanical and thermal testing. The hardened boards were then cut into test specimens with dimensions specified in Table 1 for subsequent property evaluation.

2.2 Experimental Study

2.2.1 Specimen Size

The dimensions of the test specimens are summarized in Table 1, while the corresponding specimen configurations are illustrated in Figure 3. The specimen sizes were determined according to the requirements of the Thai Industrial Standard for gypsum boards (TIS 219-2009) [7] for physical and mechanical property testing. To ensure accuracy and reliability, three specimens were prepared and tested for each mixing ratio.

2.2.2 Specimen Forming Process

As illustrated in Figure 2(d), test specimens were prepared by mixing gypsum cement with malt waste at ratios of 100:0, 90:10, 85:15, 80:20, 75:25, and 70:30 by weight. These ratios were selected to systematically evaluate the influence of increasing malt waste content on the physical and mechanical properties of gypsum boards and were determined based on preliminary trials and previous studies on natural fiber-reinforced gypsum composites. The mixture was poured into molds to produce boards with dimensions of 300 × 400 × 9 mm, allowed to harden at room temperature, and then oven-dried at 200-250 °C for 45-60 minutes to remove residual moisture and ensure suitability for subsequent testing.

2.2.3 Bending Testing

As depicted in Figure 3(c), the bending test is conducted in accordance with the Thai Industrial Standard 219-2009 of Gypsum Boards (TIS 219-2009) [7]. A 300 mm × 400 mm specimen is positioned longitudinally, and a load is applied at the center of the plate over a 350 mm span. A pressing head exerts force at a constant rate of 250 Newtons per minute until the specimen fractures, following the standard testing criteria.

2.2.4 Theoretical Basis of Measurement and Testing

The density of the fabricated workpiece is determined using Equation (1), which requires information on both the specimen dimensions and volume, as illustrated in Figure 3(a), together with its actual weight measured using a digital scale. The equation used to calculate the density is presented as follows:

$$p=\frac{m}{v} \tag{1}$$

Where: ρ = Density (kg/m^3); m = Weight (kg); v = Volume (m^3)

The thermal insulation performance of the material is evaluated using Equation (2). This equation is used to determine the optimal material ratio by ensuring that the sheet has the lowest possible thermal resistance. The specimen dimensions used for the thermal insulation test are illustrated in Figure 3(b). The heat transfer through the material is calculated as [6]:

$$Q=\frac{kA(T_1\text{-}T_2)}{\Delta x} \tag{2}$$

Where: Q = Heat transfer rate (W); k = Thermal conductivity (W/m·K); A = Heat flows (m^2); T_1-T_2 = Difference temperature (℃); Δx = Thickness

For bending moment and mechanical strength analysis, to evaluate the bending moment capacity, Equations (3) and (4) are used. These equations help determine the flexural behavior of the material when subjected to a bending load [8]. The modulus of elasticity (E) is determined using Equation (3) [9]:

$$E = \frac{Fl3}{48\delta I} \tag{3}$$

$$\sigma = \frac{Mc}{I} \tag{4}$$

Where: E = Modulus (N/mm^2); δ = Deflection distance (m); l = Original length of sheet (m); F = Reaction force (N); I = Moment of inertia (m^4); σ = Bending stress (N/m^2); M = Bending moment (N·m); c = Distance from the axis of the sling (m)

The modulus of rupture (MOR), which indicates the maximum compressive strength the sheet can withstand, is determined using Equation (5) [10]:

$$MOR=\frac{3PL}{2bt^2} \quad (5)$$

Where: MOR = Modulus of rupture (kg/cm^2);
P = Maximum load received (kg);
L = Distance between supports (cm);
b = Width of workpiece sheet (cm);
t = Thickness of workpiece plate (cm)

3. Results and Discussion

3.1 Effect of Malt Waste Content on Density

Figures 4(a) and 4(b) illustrate the variation in density of gypsum boards incorporating different proportions of malt waste. The specimen containing 90% gypsum and 10% malt waste exhibited a density of 0.91 g/cm^3. As the malt waste content increased to 15% (85:15), the density slightly decreased to 0.89 g/cm^3 and further declined to 0.88 g/cm^3 at a 20% malt waste ratio (80:20). With higher malt waste contents of 25% (75:25) and 30% (70:30), the density continued to decrease, reaching 0.86 g/cm^3 and 0.76 g/cm^3, respectively.

The reduction in density with an increasing malt waste ratio is attributed to the replacement of gypsum powder by malt waste particles. This substitution introduces voids and air pockets, leading to a lower overall density. The presence of these voids can be linked to the fibrous and porous nature of malt waste, which reduces the compactness of the gypsum matrix.

3.2 Effect of Malt Waste on Thermal Conductivity

Figures 4(c) and 4(d) present the thermal conductivity results of gypsum boards with varying malt waste content. The gypsum board without any malt waste exhibited a thermal conductivity of 0.133 W/m·K. When 10% malt waste was added, the thermal conductivity dropped to 0.105 W/m·K. As the malt waste content increased to 15% and 20%, the thermal conductivity further decreased to 0.097 W/m·K and 0.096 W/m·K, respectively. At higher malt waste ratios of 25% and 30%, the thermal conductivity stabilized at 0.094 W/m·K.

This trend indicates that the addition of malt waste improves the insulation properties of gypsum boards. The fibrous and porous structure of malt waste creates air pockets within the gypsum matrix, which act as thermal barriers and reduce heat transfer, resulting in lower thermal conductivity. These results highlight the potential of malt waste as an insulating material for energy-efficient construction applications.

3.3 Effect of Malt Waste on Flexural Strength

Figures 4(e) and 4(f) illustrate the longitudinal flexural force of gypsum boards with different malt waste ratios. The gypsum board without malt waste exhibited a longitudinal flexural force of 98.10 N. When 10% and 15% malt waste were incorporated, the longitudinal flexural force significantly increased to 196.2 N and 297.57 N, respectively. However, as the malt waste content increased beyond 15%, the bending strength began to decline. At 20%, 25%, and 30% malt waste content, the longitudinal flexural force dropped to 166.77 N, 156.96 N, and 107.91 N, respectively.

The increase in flexural force at 10-15% malt waste content indicates enhanced load-bearing capacity, which is associated with higher modulus of rupture (MOR) and improved stress distribution within the composite. This behavior is further supported by improved stiffness and reduced deflection, reflecting stronger fiber-matrix interaction and greater resistance to deformation at the optimal composition. However, at higher malt waste ratios (>15%), the decline in flexural performance can be attributed to reduced effective stiffness and weakened structural integrity due to increased porosity and poorer interfacial bonding.

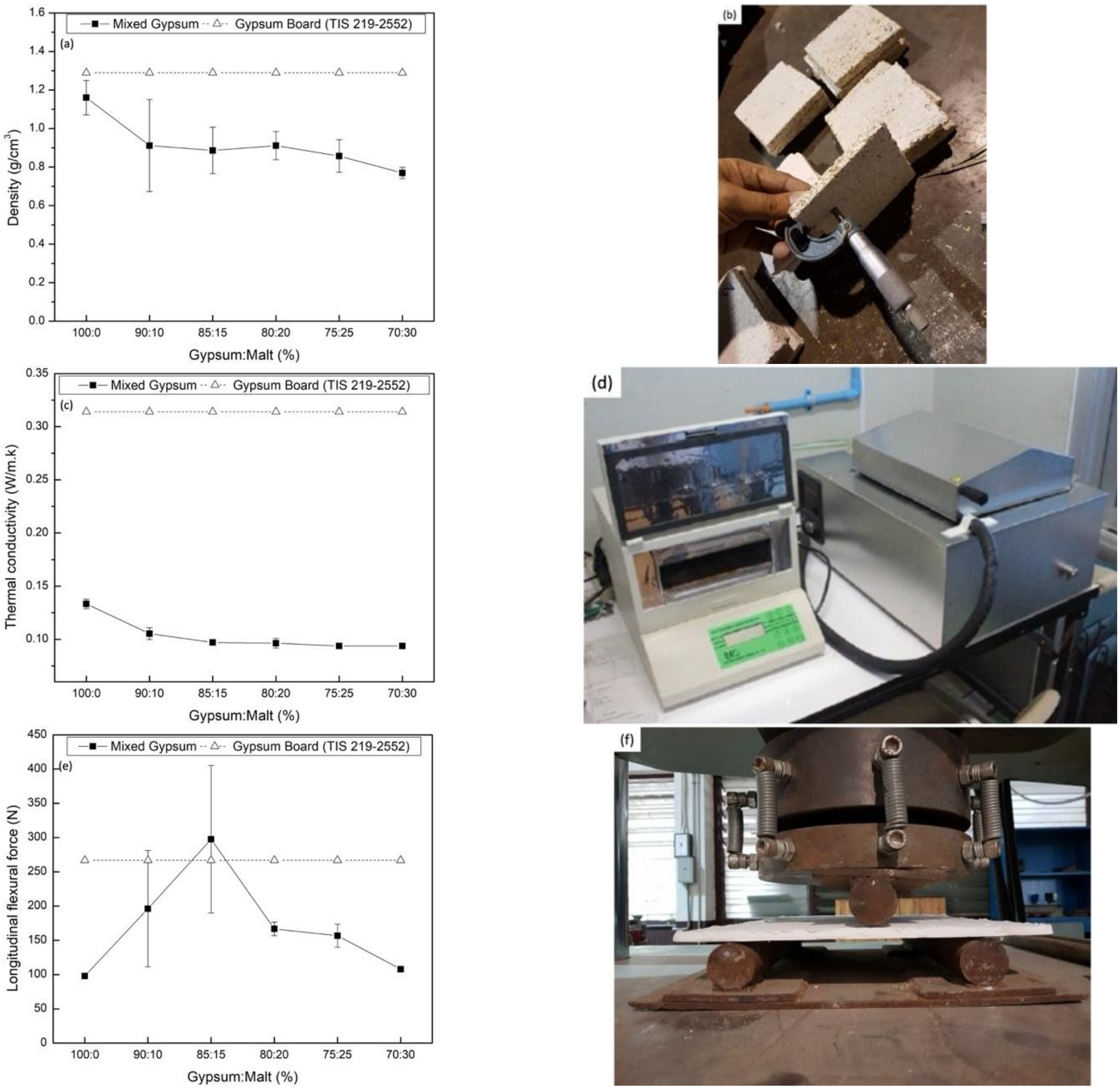

Figure 4 Measurement and testing results: (a) Density graph, (b) Density measurement, (c) Thermal conductivity graph, (d) Thermal conductivity testing, (e) Longitudinal flexural force graph, and (f) Longitudinal flexural force testing

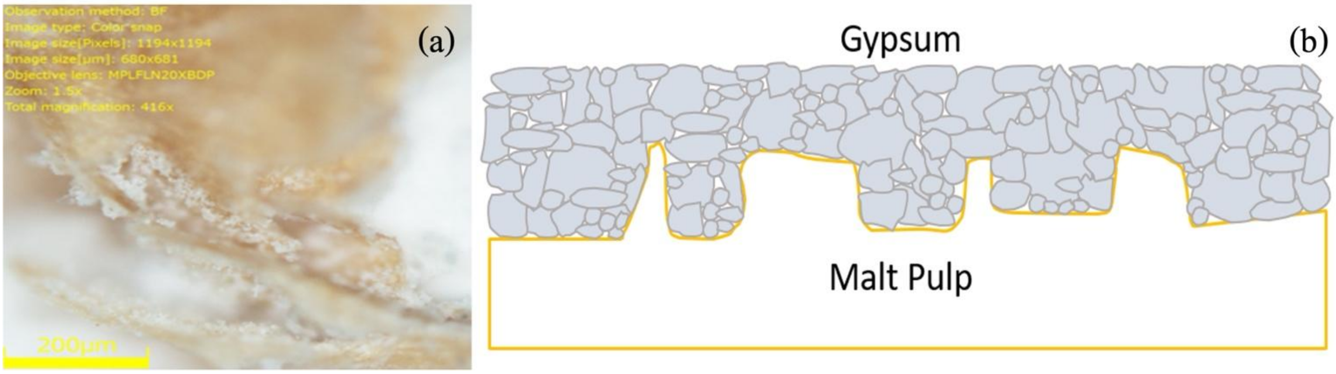

Figure 5 Mechanical adhesion: (a) Microscopic photo (1.5x) and (b) Adhesion distribution mechanism

3.4 Adhesion Characteristics of Gypsum and Malt Waste

Figure 5(a) presents an image captured using an industrial digital microscope (DSX510 series), which reveals surface adhesion characteristics that are not visible to the naked eye. The bonding mechanism between gypsum and malt waste primarily involves mechanical adhesion.

As illustrated in Figure 5(b), mechanical adhesion occurs when gypsum particles penetrate the pores on the surface of the malt waste. This process enhances physical interlocking by increasing the contact surface area between the gypsum and the malt waste, thereby improving hardness and overall strength. Initially, the liquid gypsum spreads across the surface of the material, filling the micropores before gradually hardening. During the drying process, the gypsum particles continue to infiltrate and anchor within the malt waste's structure, further reinforcing the adhesion [11, 12].

Additionally, chemical adhesion takes place when gypsum molecules interact with the surface of the malt waste. This adhesion mechanism is particularly strong due to molecular interactions at the interface. Since the malt waste surface is naturally rough and porous, these interactions further contribute to the overall bonding strength, enhancing the integrity of the composite material.

4. Conclusion

This study demonstrated that incorporating malt waste into gypsum ceiling sheets significantly enhances their thermal insulation and mechanical properties while contributing to sustainability. The experimental findings revealed that increasing malt waste content generally reduced the density and thermal conductivity of gypsum boards, making them more suitable for energy-efficient building applications. Among the tested ratios, the 85:15 gypsum-to-malt waste composition was identified as the optimal balance, providing the highest longitudinal flexural force (297.57 N) and an improved thermal conductivity of 0.097 W/m·K.

The observed improvements in mechanical properties at moderate malt waste levels can be attributed to enhanced fiber-matrix interactions. However, as the malt waste content exceeded 15%, the structural integrity of the boards declined due to increased porosity and weaker bonding between particles. This highlights the importance of optimizing material ratios to ensure durability while maintaining desired insulation properties.

An economic analysis indicated that gypsum boards incorporating malt waste could be produced at an estimated cost of approximately 135 baht per 3,240 cm³. For comparison, commercially available gypsum boards of similar dimensions (60 × 60 × 0.9 cm) in the Thai market are priced at approximately 415 baht for an equivalent volume. This represents a potential cost reduction of about 280 baht, or approximately 67%. These results suggest that gypsum boards containing malt waste may offer a cost-effective alternative to conventional gypsum products for construction applications.

Beyond performance enhancements, this study underscores the environmental benefits of using malt waste in construction materials. By repurposing a byproduct of the beer industry, this approach contributes to waste reduction, mitigates air pollution from malt waste disposal, and promotes the development of eco-friendly building materials. The integration of malt waste into gypsum boards offers a practical and scalable solution to both construction and environmental challenges.

Future research should further investigate the long-term performance of gypsum boards incorporating malt waste, including factors such as aging behavior, moisture resistance, and fire resistance, which are critical for practical construction applications. Evaluating these properties would provide a more comprehensive understanding of the durability and safety of the developed composite material under real service conditions. In particular, future studies may focus on enhancing fire resistance by incorporating flame-retardant agents, such as borax, or by adding sodium hydroxide (NaOH) solution [13]. These additives have the potential to improve the flame-retardant performance of the material and should be further explored to optimize the overall properties of gypsum-malt waste composites.

5. Acknowledgments

The researcher would like to express sincere gratitude to Chootrakul Siripaiboon, Thanakrit Chotibhawaris, and Weawboon Yamsaengsung for their invaluable guidance, support, and constructive suggestions throughout this research. Special appreciation is extended to BeerThai (1991) Public Company Limited and Rungroj Chakphira for their support in providing research facilities, materials, tools, and equipment. The researcher also gratefully acknowledges the lecturers and staff of Sukhothai Thammathirat Open University and Rajamangala University of Technology Lanna, Tak Campus, for their assistance and encouragement.

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