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Effect of Banana Peel in Plaster of Paris Composite: A sustainable reinforcement material

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KEYWORDS

Banana peel
Porosity
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Composite

ABSTRACT

This study investigates the potential of banana peel (BP) as a sustainable and cost-effective substitute for traditional reinforcement materials in Plaster of Paris (PoP) composites. The research aims to evaluate the mechanical property, physical characteristics, and environmental impact of BP-reinforced PoP composites. Density, porosity, and water absorption measurements were carried out to characterize physical properties while compressive testing was conducted to assess mechanical strength. The results demonstrate that the incorporation of BP fibers can enhance the mechanical property of PoP composites, particularly in terms of compressive strength. However, the composites exhibited slightly lower density, porosity, and water absorption compared to the unreinforced PoP. Although the composites were generally weaker and less stiff than corresponding materials, their comparable porosity suggests potential applications in acoustic, craft, and art materials. This study highlights the feasibility of using BP as a sustainable reinforcement material in PoP composites, offering a promising alternative for various applications while promoting environmental sustainability.

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1.0 INTRODUCTION

The development of sustainable and cost-effective construction materials has become a pressing concern in recent years, driven by the increasing demand for environmentally friendly solutions and the rising costs of traditional materials (1–3). However, the reliance on these synthetic materials can contribute to environmental pollution and increase production costs (4,5).

In recent years, there has been a growing interest in exploring natural and renewable materials as alternatives to synthetic fibers in composite materials. Banana peel (BP), a readily available agricultural waste product, offers a promising option due to its abundance, low cost, and potential for enhancing the mechanical properties of composite materials. (6–8).

While some research has been conducted on the use of BP as a reinforcement material in polymer-based composites, limited studies have explored its application in cement-based materials like Plastic of Paris (PoP) (2,9,10). Understanding the impact of BP on the mechanical properties, durability, and environmental performance of PoP composites is crucial for evaluating its potential as a viable alternative to synthetic fibers.

This study aims to investigate the effects of incorporating BP as a reinforcement material in PoP composites. Specifically, the research will focus on assessing the mechanical properties, physical characteristics, and environmental impact of BP-reinforced PoP composites. By understanding the relationships between BP content, composite properties, and environmental performance, this research will contribute to the development of sustainable and cost-effective construction materials.

The findings of this study will have significant implications for the construction industry, offering a potential alternative to traditional reinforcement materials. By utilizing a readily available and renewable resource like banana peel, this research aligns with the growing emphasis on sustainable and environmentally friendly practices in construction. Additionally, the insights gained from this study can inform future research on the use of other natural fibers as reinforcement materials in PoP-based composites.

2.0 METHODOLOGY

2.1 Banana Peels Powder Preparation

Banana peels (BP) were sourced from Chukai, Kemaman. A 4 wt% sodium hydroxide (NaOH) solution was used for an alkaline treatment to remove lignin and hemicellulose from the peels (11). This chemical process was carried out in a round-bottom flask and stirred continuously for two hours. Following the treatment, the banana peels were dried, rinsed multiple times with distilled water, and then further dried in sunlight. The dried BP were subsequently milled and sieved to obtain uniform particle sizes (12).

2.2 Composite Preparation

Samples without banana peel (BP) were prepared using 25g of Plaster of Paris (PoP) powder sourced from Sigma Aldrich. For samples containing BP, a fixed percentage of BP (1%, 3%, and 5% by weight) was mixed with 95% to 99% PoP powder. Water was added gradually to the mixture at different PoP-to-water ratios: 1:1.5, 1:1, and 1:0.8, after the dry components were combined. The weight of each powder component was measured using an analytical balance. The powders and distilled water were thoroughly mixed to achieve a uniform consistency. Once mixed, the material was poured into mould and left to dry in sunlight for 4 hours (13). After drying, the 12 prepared samples underwent characterization tests for density, water absorption, porosity, and mechanical properties. The sample compositions are detailed in Table 1.

Table 1: Composite Formulation of BP and PoP composites

BP (wt%)	PoP (wt%)	Water (weight ratio to PoP)
0	100	1.5
0	100	1.0
0	100	0.8
1	99	1.5
1	99	1.0
1	99	0.8
3	97	1.5
3	97	1.0
3	97	0.8
5	95	1.5
5	95	1.0
5	95	0.8

2.3 Composites Characterization

a) Density evaluation

Density (ρ) is a fundamental property of matter defined as the mass (m) per unit volume (V). It is calculated using the following formula:

$$\rho = m / V \ (g/cm^3) \tag{1}$$

In this experiment, the mass of the rectangular bar was measured using a digital weighing scale (14). The volume was calculated using the formula:

$$\text{Volume } (cm^3) = \text{Length (cm)} \times \text{Width (cm)} \times \text{Height (cm)} \tag{2}$$

b) Water absorption evaluation

The immersion method was used in this study to determine water absorption. Each specimen was weighed before being submerged in water at an initial temperature of 28°C. After 24 hours of immersion, the samples were taken out, allowed to dry on the surface, and then weighed again individually (15). Water absorption was calculated using the following equation:

$$\text{Water absorption, \%} = \text{wet weight} - \text{dry weight/dry weight x } 100 \tag{3}$$

c) Porosity evaluation

To quantify the porosity of the plaster after immersion in distilled water (16), the following equation was applied:

$$\text{Porosity} = W * ds / dw \tag{4}$$

where:

W = relative weight change in plaster after immersion

ds = dry density of the plaster

dw = density of distilled water

2.4 Compressive Test Evaluation

In this research, cube specimens measuring 50 mm × 50 mm × 50 mm were produced and tested to assess the compressive strength of the composite samples. The procedure adhered to the guidelines set out in ASTM C513-11 for determining the compressive strength of composite materials. Tests were conducted to determine the average compressive strength and the maximum load the samples could bear (17). A 2000 kN capacity machine was used for the compression tests, with a loading rate set at 3 kN/s. The average compressive strength for each mixture type was then calculated. The compressive strength (σ) was determined using:

$$\sigma = P/A \tag{5}$$

where (σ) denotes compressive strength in MPa, (P) is the maximum load, and (A) refers to the cross-sectional area of the specimen.

3.0 RESULTS AND DISCUSSION

The physical properties of these composites, including density, water absorption, and porosity, were characterized. Additionally, the mechanical property of Plaster of Paris (PoP) composites reinforced with banana peel (BP) were comprehensively investigated through compressive testing. The results demonstrate that the incorporation of BP significantly enhances the mechanical performance of PoP composites across various BP content and water-to-PoP ratios. A detailed analysis of the effects of BP concentration and water ratio reveals their profound influence on the overall composite properties.

3.1 Density Analysis

Density, a critical property of composite materials, significantly influences their strength, stability, and resistance to external pressures (18,19). In the context of PoP composites reinforced with BP, the density is a key factor to consider when evaluating the impact of BP on the composite's structural integrity and compressive strength.

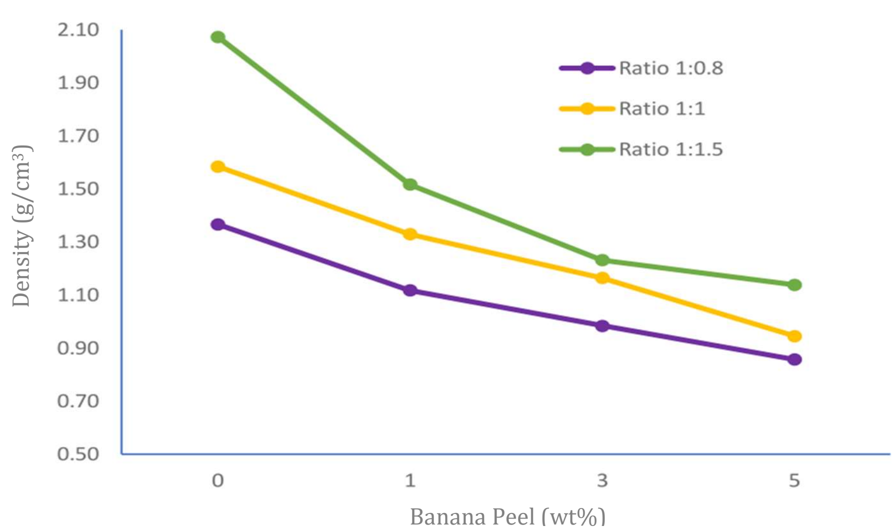

Figure 1: Density test results of prepared composites

Figure 1 illustrates the inverse relationship between water-to-plaster ratio and sample density across different BP weight percentages. As water content decreases, the initial mixture becomes denser, but the subsequent setting process results in the formation of voids and capillary spaces, leading to a lower final density. This phenomenon is attributed to the influence of water content on the plaster matrix microstructure (20,21). Higher water content promotes more complete hydration of plaster particles, resulting in a denser structure with fewer air pockets. Conversely, lower water content leads to an increase in the number and size of air pockets within the hardened matrix, resulting in a less dense and more porous material.

3.2 Water Absorption Analysis

Water absorption testing is essential for understanding the durability and performance of PoP composites reinforced with BP. While high water absorption can negatively impact mechanical properties, it is important to balance this with the positive effects on specific qualities like adhesion and workability.

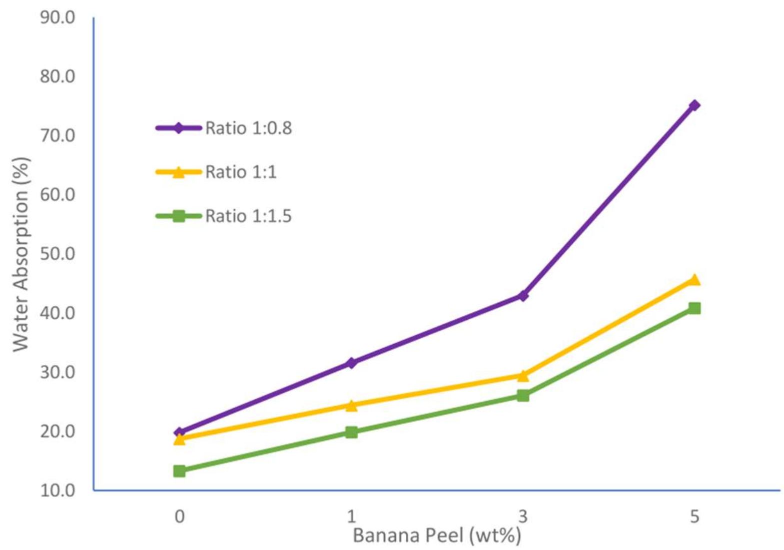

Figure 2: Water absorption test results of prepared composites

Figure 2 reveals a counterintuitive trend; water absorption increases with decreasing water content. This phenomenon can be attributed to the interplay between water content and the resulting microstructure of the PoP matrix (22,23). Higher water-to-PoP ratios facilitate complete hydration of plaster particles, leading to a denser and less porous structure with limited water absorption capacity. Conversely, lower water content results in incomplete hydration, creating a less dense and more porous matrix with abundant capillary channels and voids. These voids and channels effectively act as internal reservoirs, significantly enhancing the material's water absorption capacity. This highlights the critical role of water content in tailoring the porosity which will be discussed in section 3.3 and, consequently, the water absorption behavior of PoP composites.

3.3 Porosity Analysis

Porosity is a crucial factor influencing the mechanical properties, durability, and overall performance of PoP composites reinforced with BP. Higher porosity generally correlates with lower strength and increased water absorption, potentially limiting the material's suitability for load-bearing applications.

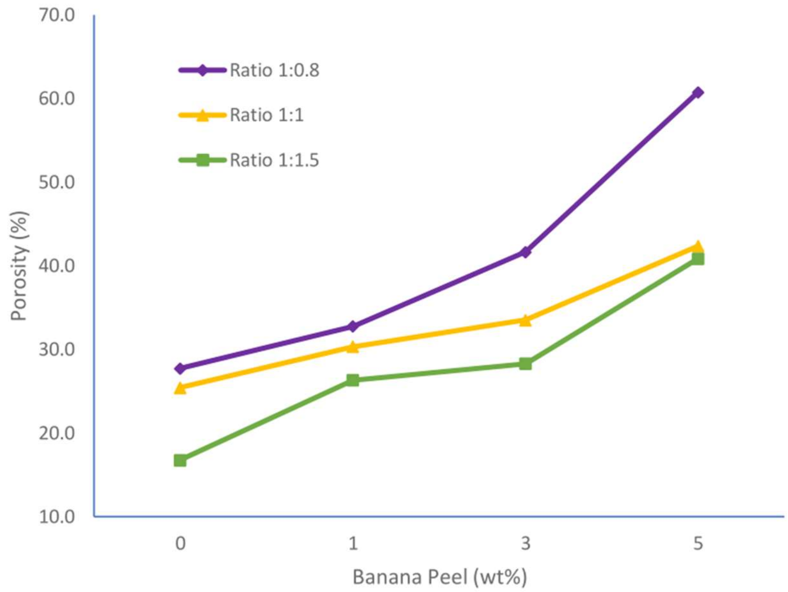

Figure 3: Porosity results of prepared composites

As depicted in Figure 3, the higher porosity observed with a reduced water-to-plaster ratio is primarily attributed to the decreased availability of water during the setting process. With less water, the mixture becomes denser, leading to incomplete filling of the inter-particle voids (24,25). Additionally, the incorporation of BP contributes to the formation of additional pores, further enhancing porosity. The presence of water facilitates the movement and packing of plaster particles, and its reduction results in a less fluid mixture, leading to increased air pockets. The inclusion of BP intensifies this phenomenon, leading to increased porosity levels. In summary, the water-to-plaster ratio plays a crucial role in determining porosity, where lower water content results in higher porosity due to the incomplete filling of voids, a condition further aggravated by the addition of BP.

3.4 Compressive Analysis

The compressive strength test is crucial for evaluating the structural integrity and load-bearing capacity of the PoP-BP composite material. Determining the maximum compressive stress allows for evaluating the material's appropriateness for use in applications subjected to high pressures and loads, thereby ensuring its reliability and effectiveness in construction and structural contexts (26).

Figure 4 illustrates a direct correlation between water content and compressive strength in the PoP-BP composites. As the water content decreases, leading to a denser initial mix, the compressive strength is observed to decline. This reduction can be attributed to the formation of voids and capillary spaces during the setting and drying process, which weaken the structural integrity (27, 28). The amount of water present is a key factor in the hydration of plaster particles, directly impacting bond formation and the cohesion of the matrix. Increased water content allows for full hydration, which leads to stronger bonds and a more solid structure. On the other hand, insufficient water limits hydration, causing incomplete bonding and resulting in a porous matrix with diminished compressive strength.

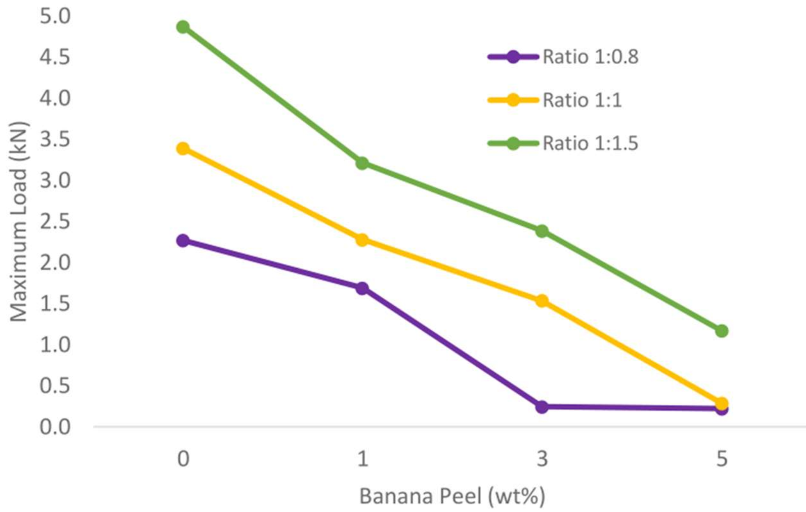

Figure 4: Compressive test results of prepared composites

The addition of BP to PoP matrices can result in a decrease in compressive strength due to the introduction of additional void spaces. Increased porosity, caused by the organic nature of the fibers, may also lead to enhanced water absorption, potentially compromising the material's durability over time (29,30). While BP offers sustainability benefits, its application in load-bearing applications may be limited due to its impact on compressive strength. However, the comparable porosity of BP-reinforced composites suggests their potential suitability for applications in acoustic, craft, and art materials, demonstrating the feasibility of BP as a sustainable reinforcement material in PoP composites.

4.0 CONCLUSIONS

While the addition of BP to PoP composites improves water absorption and offers environmental benefits, it negatively affects compressive strength and density. Optimizing the mix proportions is crucial for achieving a balance of desired properties. Future research should focus on enhancing interfacial bonding and conducting comprehensive environmental testing to ensure the long-term viability of these composites in practical applications. This study demonstrates the potential of sustainable waste management and the conversion of organic waste into valuable materials.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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