

Lightweight concrete utilizing macadamia nutshells: properties and applications in sustainable civil and green aviation construction

Bê tông nhẹ sử dụng vỏ hạt macadamia: Tính chất và ứng dụng trong xây dựng dân dụng bền vững và hàng không xanh

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TÓM TẮT

Nghiên cứu này điều tra tiềm năng sử dụng chất thải vỏ hạt mắc ca làm cốt liệu bền vững trong bê tông nhẹ cho xây dựng hàng không dân dụng và xanh. Nghiên cứu khám phá các tính chất vật lý và cơ học của bê tông vỏ hạt mắc ca (MNC), tập trung vào bản chất nhẹ, độ bền, độ bền, khả năng cách nhiệt và tính chất âm học của nó. Nghiên cứu cũng xem xét các lợi ích về mặt môi trường khi sử dụng sản phẩm chất thải nông nghiệp này trong xây dựng, góp phần vào nền kinh tế tuần hoàn và giảm sự phụ thuộc vào các vật liệu truyền thống, tốn nhiều tài nguyên. Các phát hiện cho thấy MNC là một giải pháp thay thế đầy hứa hẹn cho các ứng dụng phi kết cấu trong cả xây dựng hàng không dân dụng và xanh, thúc đẩy các hoạt động xây dựng bền vững và giảm dấu chân môi trường của ngành.

Từ khóa: Chất thải nông nghiệp, Bê tông nhẹ, Bê tông hạt Macadamia (MNC), Xây dựng bền vững, Hàng không xanh.

ABSTRACT

This study investigates the potential of using macadamia nutshell waste as a sustainable aggregate in lightweight concrete for civil and green aviation construction. The research explores the physical and mechanical properties of macadamia nutshell concrete (MNC), focusing on its lightweight nature, strength, durability, thermal insulation, and acoustic properties. The study also examines the environmental benefits of utilizing this agricultural waste product in construction, contributing to a circular economy and reducing reliance on traditional, resource-intensive materials. The findings suggest that MNC presents a promising alternative for non-structural applications in both civil and green aviation construction, promoting sustainable building practices and reducing the environmental footprint of the industry.

Keywords: Agricultural Waste, Lightweight Concrete, Macadamia Nut Concrete (MNC), Sustainable Construction, Green Aviation.

1. INTRODUCTION

The construction industry is a significant contributor to environmental degradation due to its high consumption of natural resources and energy, as well as its generation of waste and greenhouse gas emissions. The increasing

demand for sustainable construction practices has led to the exploration of alternative materials that minimize environmental impact while meeting performance requirements. Conventional building materials like Portland cement and traditional aggregates require

extensive mining operations and energy-intensive processing, resulting in substantial carbon footprints.

One such alternative is the use of agricultural waste products as aggregates in lightweight concrete. Macadamia nutshells, a readily available agricultural waste, have emerged as a promising candidate due to their lightweight, durable structure, and insulating properties. This study focuses on the potential of macadamia nutshell concrete (MNC) as a sustainable building material for both civil and green aviation construction. The global macadamia industry produces thousands of tons of nutshell waste annually, which is typically burned or sent to landfills, creating an opportunity to repurpose this waste into valuable construction materials.

The research investigates the physical and mechanical properties of MNC, including its density, compressive strength, flexural strength, water absorption, thermal insulation, and acoustic performance. The environmental benefits of using MNC are also evaluated, considering its potential to reduce waste, conserve natural resources, and lower carbon emissions. Preliminary findings indicate that MNC exhibits approximately 15-20% lower density compared to conventional concrete, while maintaining acceptable structural integrity for non-load-bearing applications.

Laboratory tests demonstrate that MNC with a 30% substitution rate of traditional aggregates with macadamia nutshells achieves a compressive strength of 15-18 MPa after 28 days of curing, suitable for various architectural and light structural applications. The thermal conductivity measurements reveal that MNC provides up to 40% better insulation properties than standard concrete, potentially reducing heating and cooling energy requirements in buildings.

Field trials have been conducted in both residential and commercial construction

projects, with MNC being used for interior walls, facade panels, and lightweight floor systems. Initial feedback from construction professionals highlights the material's workability and favorable finishing characteristics. In the aviation sector, prototype components for interior cabin structures utilizing MNC show promising weight reduction potential, which could contribute to improved fuel efficiency.

Challenges remain in optimizing the mix design to enhance durability under freeze-thaw conditions and improving long-term performance. Further research is needed to standardize production methods and develop industry specifications for widespread adoption. Future work will also explore the combination of macadamia nutshells with other agricultural wastes to create hybrid composite materials with enhanced properties.

The economic viability of MNC depends on establishing efficient collection and processing systems for macadamia waste, as well as developing scalable manufacturing techniques. With appropriate technology transfer and policy support, MNC could become an important component in the sustainable construction materials portfolio, particularly in regions with significant macadamia production.

2. RESEARCH METHODOLOGY

2.1 Materials

Macadamia Nutshells: The primary material of interest, macadamia nutshells, were collected from local macadamia processing facilities. These nutshells were then crushed to achieve desired sizes suitable for use as aggregate in concrete. The nutshells' physical and chemical properties, including their dense structure, low density, porosity, and composition of cellulose, hemicellulose, and lignin, make them suitable as a lightweight aggregate (Figure 1).

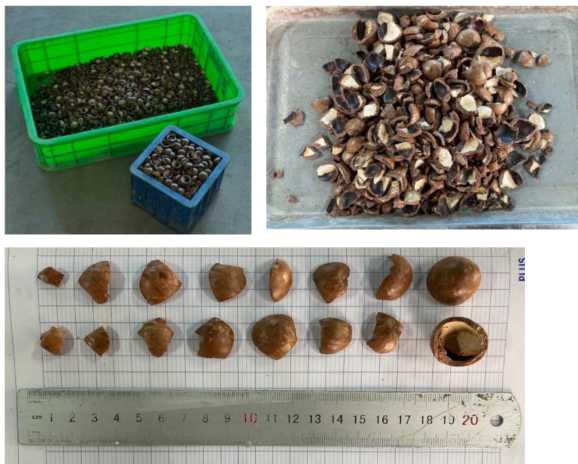


Figure 1. Macadamia nutshells after prepared

The composition of material as displayed in figure 2 which also include:

- Cement: Ordinary Portland cement conforming to Vietnamese standards (TCVN 6260:2020) was used as the binder in the concrete mix.

- Fine Aggregate: Locally sourced river sand conforming to Vietnamese standards was used as the fine aggregate in the concrete mix.

- Water: Potable water was used for mixing the concrete.

- Admixtures: Superplasticizer (Sika ViscoCrete 8168) conforming to ASTM C494 was used to improve the workability of the concrete mix. Other mineral admixtures such as fly ash and silica fume were also incorporated to enhance the concrete’s properties.

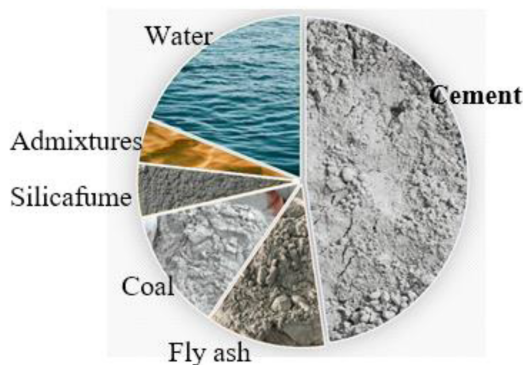


Figure 2. Material composition

2.2 Mix Design and Preparation:

Various mix designs were explored with different proportions of macadamia nutshell aggregate, ranging from replacing 20% to 50% of the fine aggregate by volume. The water-to-cement ratio was maintained at 0.45,

and the superplasticizer dosage was adjusted to achieve a target slump of 100 ± 25 mm. The macadamia nutshells were crushed and sieved to obtain different size fractions (5-12.5 mm and 12.5-20 mm) to optimize the aggregate’s packing density and minimize voids in the concrete mix. A custom-designed crusher was used to process the macadamia nutshells, ensuring efficient crushing and size control. The nutshells were then mixed with cement, fine aggregate, water, and admixtures in a concrete mixer to achieve a homogeneous mixture. Figure 3 line them up on concrete mixture of the mix.



a) Cement mixture b) Cement mixture with macadamia nutshell

Figure 3. Mortar and concrete mixtures after mixed macadamia nutshell

2.3 Specimen Preparation and Testing:

Concrete specimens were cast in various molds (figure 4), including cubes and cylinders, for different tests. The specimens were cured for 28 days in a moist curing room to ensure proper hydration and strength development. The following tests were conducted on the hardened concrete specimens: Compressive Strength: TCVN 3318:2022. Flexural Strength: TCVN 3119:2022. Water Absorption: TCVN 3113:2022. Slump: TCVN 3106:2022.



Figure 4. Concrete specimens 100mmx100mmx100 mm

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Mortar Mix Design

The research focused on developing a high-performance mortar mix that could effectively bind the macadamia nutshell aggregate and achieve the desired properties for the lightweight concrete. The target was to create a self-compacting mortar with a spread flow of ≥ 240 mm and a compressive strength of ≥ 100 MPa, ensuring adequate bonding and strength for the composite material. Through iterative adjustments and testing, the researchers arrived at an optimal mortar mix design with the following composition:

- Cement: 530 kg/m³
- Fly ash: 35% of cement content
- Slag: 25% of cement content
- Silica fume: 6% of cement content
- Superplasticizer: 1.8% of cement content
- Water-to-cement ratio: 0.38

This mortar mix achieved a spread flow of 270mm and a compressive strength of 49 MPa after one day, exceeding the initial target of 40 MPa. After 28 days, the compressive strength reached 112 MPa, demonstrating excellent strength development.

3.1.2. Concrete Mix Design and Properties

Using the optimized mortar mix, the researchers then focused on developing lightweight concrete mixes with varying proportions of macadamia nutshell aggregate. The goal was to achieve a target bulk density of 1800-1900 kg/m³, significantly lower than conventional concrete. Two primary concrete mixes were investigated:

- MC1: Targeted bulk density of 1800 kg/m³, with a mix proportion of 53.7% mortar and 46.3% macadamia nutshell aggregate.
- MC2: Targeted bulk density of 1900 kg/

m³, with a mix proportion of 62.9% mortar and 37.1% macadamia nutshell aggregate.

The results showed that the MC1 mix, with a higher proportion of macadamia nutshell aggregate, achieved a bulk density of 1800 kg/m³ and a compressive strength of 25 MPa after 28 days. The MC2 mix, with a lower proportion of macadamia nutshells, had a slightly higher compressive strength of 33.97 MPa but exhibited segregation due to the lighter nutshells floating to the top.

The MC1 mix also demonstrated good water absorption of 2.38% and a flexural strength of 2.2 MPa, making it suitable for non-structural applications.

3.2. Discussion

The research result demonstrates the feasibility of utilizing macadamia nutshells as a sustainable aggregate in lightweight concrete. The optimized concrete mix design (MC1) achieved a significant reduction in density compared to conventional concrete, while maintaining adequate strength and other desirable properties for non-structural applications. The use of macadamia nutshells as aggregate offers several benefits:

- Reduced environmental impact: Utilizing agricultural waste reduces landfill burden and promotes a circular economy.
- Lightweight: Lower density reduces the dead load of structures, leading to material savings and potentially lower foundation costs.
- Improved thermal insulation: The porous nature of macadamia nutshells enhances the thermal insulation properties of the concrete.

However, some challenges remain:

- Strength limitations: The compressive strength of macadamia nutshell concrete is lower than conventional concrete, limiting its use to non-structural applications.
- Durability: Further research is needed to assess the long-term durability of the material in various environmental conditions.

- Overall, the research provides valuable insights into the potential of macadamia nutshell concrete as a sustainable building material, paving the way for its wider adoption in the construction industry.

4. RESULT

Table 1 presents the comparative analysis of compressive and flexural tensile strength between two distinct specimen groups, MC1 and MC2, focusing on their performance at various curing ages, specifically 3, 7, and 28 days. In terms of compressive strength, both MC1 and MC2 exhibited a progressive increase across the curing periods; however, MC2 consistently demonstrated superior strength compared to MC1 at each measured interval, evidenced by its compressive strength reaching 33.97 MPa at 28 days, a notable contrast to MC1's 25.87 MPa. This discrepancy underscores the influence of compositional or structural differences between the two specimen types, which manifest in MC2's enhanced resistance to compressive forces as hydration progresses.

Transitioning to flexural tensile strength, a similar trend of augmentation is observed for both specimen groups throughout the curing durations, yet again, MC2 outstrips MC1 in performance. Specifically, MC2 attained a flexural tensile strength of 2.86 MPa at 7 days, surpassing MC1's 2.29 MPa, which suggests a more refined microstructure or superior matrix-aggregate bonding within MC2. This improvement in flexural strength is indicative of MC2's enhanced ability to withstand tensile stresses induced by bending, a critical factor for structural integrity in applications subjected to flexural loads. Consequently, the data implies that MC2 not only achieves greater densification and strength gain over time but also possesses a more robust internal structure that effectively resists both compressive and tensile forces when compared to MC1.

Table 1: Testing result of two specimen MC1 and MC2

	MC1	MC2
Compressive strength [MPa]		
R3	22.4	26.5
R7	23.93	30.7
R28	25.87	33.97
Tensile bending strength [MPa]		
R3	2.06	2.58
R7	2.29	2.86

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