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Study on using rice husk ash from ceramic kiln as a partial alternative for cement in mortar

Nghiên cứu sử dụng tro trấu từ lò nung gốm để thay thế một phần xi măng trong vữa

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ABSTRACT

The production of cement requires a significant amount of energy and resources. Rice husk ash is known as a highly active pozzolan material and can partially replace cement in the production of mortar and concrete. This paper presents the use of rice husk ash that is recovered from burning rice husks in a local ceramic kiln. In this study, rice husk ash is used as a replacement for cement in different dosages of 0%, 5%, 10%, 15%, and 20%. The strength of the specimens was assessed at 7, 28, and 56 days of age. According to the results, rice husk ash added in amounts ranging from 5% to 15% performed equivalent to ordinary mortar in compressive strength.

Keywords: Rice husk ash; pozzolan; cement supplementary material; mortar.

TÓM TẮT

Quá trình sản xuất xi măng tiêu tốn một lượng lớn năng lượng và tài nguyên. Tro trấu, được biết đến như một loại vật liệu puzolan có hoạt tính cao, có thể thay thế một phần xi măng trong sản xuất vữa và bê tông. Bài báo trình bày nghiên cứu về việc sử dụng tro trấu thu hồi từ quá trình đốt vỏ trấu tại một lò gốm địa phương. Trong nghiên cứu, tro trấu được dùng để thay thế một phần xi măng với các tỷ lệ 0%, 5%, 10%, 15%, và 20%. Cường độ của các mẫu thí nghiệm được đánh giá ở các mốc thời gian 7 ngày, 28 ngày và 56 ngày tuổi. Kết quả cho thấy, việc sử dụng tro trấu với tỷ lệ từ 5% đến 15% mang lại hiệu quả tương đương với vữa thông thường về cường độ chịu nén.

Từ khóa: Tro trấu; puzolan; vật liệu bổ sung xi măng; vữa.

1. INTRODUCTION

The construction industry, particularly cement production, is facing significant challenges related to environmental sustainability and natural resource consumption. Cement, as one of the most essential materials in construction, plays a critical role in producing concrete and mortar. However, its production is energy-intensive and contributes approximately 7-8% of global CO_2 emissions, making it one of the largest sources of carbon emissions [1][2][3]. This situation underscores the urgent need for alternative solutions to mitigate the negative environmental impacts of cement production, driving research in sustainable construction materials.

In this context, rice husk ash (RHA), a by-product of the agricultural sector, emerges as a promising alternative. When rice husks are burned, they produce RHA, which is rich in amorphous silica (SiO_2) [4][5]. As a highly reactive pozzolanic material, RHA has the potential to react with calcium hydroxide ($Ca(OH)_2$) during the cement hydration process to form additional binding compounds, enhancing the strength and mechanical properties of mortar and concrete [6][7]. Furthermore, utilizing RHA offers dual benefits by reducing cement consumption and repurposing agricultural waste, thereby minimizing environmental impact across multiple industries [8]. Both the hydration and pozzolanic reactions proceed according to the following mechanisms:

Hydration reaction:

$$H_2O + C_3S \ or \ C_2S \ \rightarrow Ca(OH)_2 + majorly \ C - S - H \ gel$$

Pozzolanic reaction:

$$Ca(OH)_2 + H_2O + RHA(SiO_2) \rightarrow minor \ C - S - H \ ge$$

Although numerous studies have demonstrated the potential of RHA in construction applications, its effectiveness is largely influenced by its source and processing method. RHA derived from local sources, such as ceramic kilns, may exhibit variations in chemical composition, structure, and pozzolanic activity due to factors such as burning temperature, duration and conditions [9][10]c Therefore, it is essential to investigate and evaluate the specific properties of RHA from each source to determine its practical applicability in construction.

This study focuses on the use of RHA recovered from a local ceramic kiln as a partial replacement for cement in mortar production (Fig. 1). RHA was tested at various replacement levels (0%, 5%, 10%, 15%, and 20%). The common replacement levels in previous studies typically range from 5% to 20% of the cement mass to ensure a balance between strength and workability of the material [9][11]. Mortar samples were evaluated at 7, 28, and 58 days to assess critical mechanical properties, including compressive strength. The findings provide empirical insights into the feasibility of RHA as a cement substitute while assessing its technical and environmental performance in real-world applications.

Figure 1. Burning rice husks in a ceramic kiln (**Photo Credit:** baovinhlong.com)

This research not only sheds light on the potential of RHA in sustainable construction but also contributes to the development of environmentally friendly solutions for the construction industry. Utilizing RHA, a widely available agricultural by-product, can reduce the resource pressures associated with cement production and offer a pathway toward creating circular and sustainable construction practices.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1. Materials

2.1.1 Fine aggregate

The fine aggregate utilized in this study was locally sourced natural river sand, characterized by a fineness modulus of 1.6. Comprehensive assessments of its particle size distribution (according to TCVN 7572-2:2006 [12]) and physical properties were conducted to ensure its suitability for incorporation into the experimental specimens, as detailed in Figure 2 and Table 1, respectively. The river sand is surface dried before casting.

Table 1: Physical properties of river sand

Property	Values
Specific gravity (g/cm^3)	2.78
Fineness modulus	1.60
Density (kg/m^3)	1530
Water absorption (%)	2.61
Moisture (%)	2.76

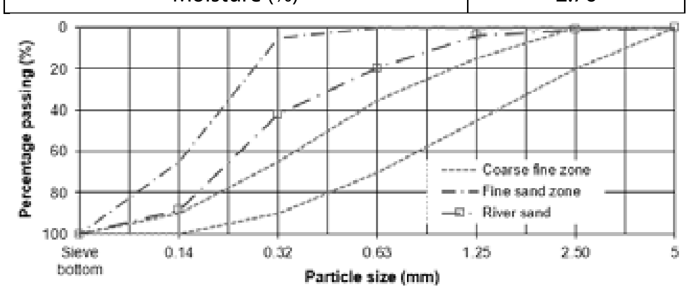


Figure 2. Particle size distribution of river sand

2.1.2 Cement

Ordinary Portland Cement (OPC) of type PCB40, conforming to the Vietnam Standard TCVN 6260:2020 [13] and equivalent to ASTM C595 [14], was utilized in this study. Its physical properties are summarized in Table 2.

Table 2: The physical properties of the OPC

Characteristic	Testing Methods	Test result
1. Specific gravity (g/cm^3)	TCVN 4030-2003	3.10
2. Consistency (%)	TCVN 6017-2015	28.8
3. Setting time Initial (minutes) Final (minutes)	TCVN 6017-2015	 139' 3h45'
4. Soundness (Lechatelier method) (mm)	TCVN 6017-2015	0.71
5. Fineness, retained 0.09 mm (%)	TCVN 4030-2003	6.50
6. Compressive strength (MPa) 3 days 28 days	TCVN 6016-2011	 22.20 44.0

2.1.3 Rice Husk Ask

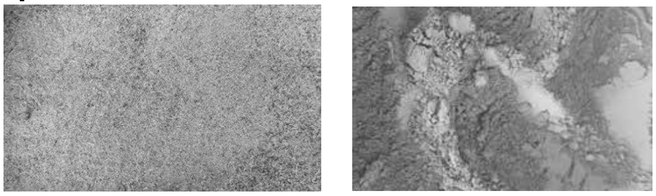
RHA was collected from a ceramic brick kiln located in the Mang Thit Ceramic and Brickmaking Village in Vinh Long Province (as shown in Fig. 3-a). The kiln uses rice husk as its primary fuel source, with combustion temperatures ranging from 700°C to 900°C. The burning process lasts approximately three days, providing sufficient thermal energy for the production of ceramic bricks while simultaneously generating ash as a by-product. The RHA was collected after the kiln had cooled and was subjected to a preliminary cleaning process to remove coarse impurities such as unburnt husks and brick particles. After initial cleaning, the RHA was further processed by grinding in a Los Angeles abrasion machine for 6 hours at a speed of 22 rpm to achieve particle sizes smaller than 45 µm (Fig. 3-b), in accordance with TCVN 8827:2011 standards [15]. This process ensured material uniformity and enhanced the pozzolanic reactivity of the RHA. The processed RHA was then stored in airtight bags under dry conditions to prevent moisture absorption.

The collected RHA is in the form of a light gray powder with a relatively fine texture. The chemical composition of the RHA was determined using Energy Dispersive X-ray Spectroscopy (EDS), and the results are summarized in Table 3.

Table 3: Chemical composition of RHA

Component	Percentage (%)
Na_2O	0.18
MgO	0.90
Al_2O_3	2.82
SiO_2	90.06
P_2O_5	0.79
SO_3	1.45
K_2O	1.79
CaO	1.54
FeO	1.13
LOI (Loss on Ignition)	1.51

Compared to other reported RHA sources, the RHA in this study exhibits a high silica (SiO_2) content of 90.06%, which is within the optimal range (85–95%) for pozzolanic materials. Its low loss on ignition (LOI) of 1.51% indicates efficient combustion with minimal residual carbon, outperforming other RHAs that often have higher LOI values (2–6%). Additionally, the low SO_3 content (1.45%) and limited impurities, such as alkalis and metallic oxides, further enhance its suitability for use in cement and concrete. The experimental results indicate that this type of RHA meets the requirements of ASTM C618–19 [16] and TCVN 8827:2011 standards [15].



a) b)

Figure 3. (a) RHA before grinding and (b) after grinding

The Scanning Electron Microscopy (SEM) image of the RHA at 1000x magnification in Fig. 4 reveals a heterogeneous particle morphology with angular, irregularly shaped fragments and a rough surface texture. The particle size predominantly falls within the micrometer range, with smaller fine particles also present, making it suitable for pozzolanic applications. The microstructure exhibits a porous and uneven surface, which enhances the reactive surface area and improves interaction with cementitious components.

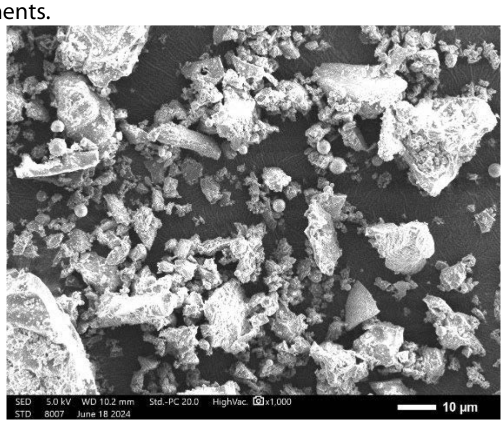


Figure 4. SEM for RHA particles.

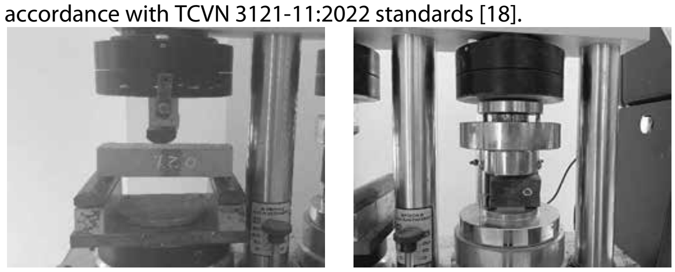
3.2 Experimental Methods

To investigate the effect of RHA replacement for cement on the strength of mortar, an experimental procedure was conducted as follows. OPC served as the primary binder, with RHA incorporated as a partial replacement for cement at levels of 0% (control), 5%, 10%, 15%, and 20% by weight. The mortar mix proportions comprised one part cement, three parts sand, and a constant water-to-cement ratio of 0.40, which was maintained across all mixtures to ensure comparability. The detailed mix proportions for the five mixtures are presented in Table 4.

Table 4: Mortar mix composition with RHA (gam)

% RHA by cement	Cement	Sand	RHA	Water
0	450	1350	0	180
5	450	1350	5.45	180
10	450	1350	5.45	180
15	450	1350	5.45	180
20	450	1350	5.45	180

The materials were first weighed according to the mix design. For each mixture, the dry components (cement, RHA, and sand) were blended to ensure uniform distribution. Water was then gradually added to the dry mixture and mixed using a standard mortar mixer for 2–3 minutes to achieve a homogeneous consistency. The prepared mortar was poured into standard molds (40 × 40 × 160 mm) and compacted. After 24 hours, the samples were demolded and transferred to a curing water tank, where they were cured for 7, 28, and 56 days in accordance with TCVN 6016:2011 [17]. To determine the compressive strength, the specimens were first split into two halves using flexural force (Fig. 5-a), and each half was then used for compressive strength testing (Fig. 5-b). The compressive strength result was taken as the average value of six specimens. The experiment was conducted in accordance with TCVN 3121-11:2022 standards [18].



a) b)

Figure 5. Three-point bending test (a) and compression test (b) on mortar prisms

3. RESULTS AND DISCUSSION

The compressive strength of mortar is significantly influenced by the RHA content, as shown in Fig. 6. At 7 days, the compressive strength decreases as the RHA content increases, particularly at 15% and 20%, likely due to the incomplete pozzolanic reaction at early ages. However, at 28 days, mixtures with 5% and 10% RHA demonstrate noticeable strength improvement, surpassing the control sample (0% RHA). By 56 days, the samples containing 10% and 15% RHA achieve compressive strength equivalent to or higher than the control sample, indicating the long-term contribution of the pozzolanic reaction. Specifically as follows:

At 7 days, the 0% RHA (control sample) shows a compressive strength of about 28 MPa. When 5% RHA replaced cement, the strength dropped to 27 MPa, a 3.57% decrease. With 10% RHA, it further decreased to 26 MPa (7.14% lower). At 15% RHA, the strength was 25 MPa (10.71% reduction), and at 20% RHA, it dropped to 23 MPa, a 17.86% decrease.

At 28 days, the 0% RHA (control) has a compressive strength of 32 MPa, indicating the hydration process is mostly complete. The 5% RHA sample shows a slight increase to 33 MPa (3.13% higher), due to the early pozzolanic reaction. The 10% RHA sample reaches 34 MPa, a 6.25% increase, considered optimal for strengthening the mortar. The 15% RHA sample maintains 32 MPa, indicating no further improvement. At 20% RHA, the strength decreases to 30 MPa (6.25% lower), likely due to insufficient cement hydration despite continued pozzolanic activity.

At 56 days, the 0% RHA (control) has a compressive strength of 35 MPa, indicating complete hydration. The 5% RHA sample shows a slight decrease to 34 MPa (2.86% lower), with minimal impact on strength. The 10% RHA sample achieves the highest strength at 36 MPa (2.86% higher), reflecting optimal pozzolanic reaction. The 15% RHA sample maintains 35 MPa, showing no significant change. The 20% RHA sample drops to 33 MPa (5.71% lower), likely due to excessive cement replacement, which hinders hydration and bond formation despite continued pozzolanic activity.

Among the mixtures, the 10% RHA replacement shows the most optimal performance, achieving the highest compressive strength at 28 and 56 days. Conversely, the 20% RHA replacement exhibits the lowest strength values across all curing ages, likely due to excessive clinker replacement, which reduces the availability of calcium hydroxide for the pozzolanic reaction.

In summary, RHA replacement levels of 5% to 15% are effective in enhancing the compressive strength of mortar over time, with 10% being the optimal replacement level. This demonstrates the potential of RHA as a sustainable cement substitute to improve performance and reduce environmental impact.

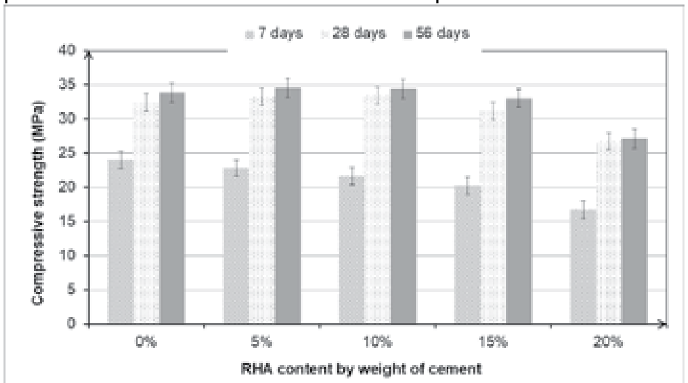


Figure 6. The effect of RHA content on the compressive strength of mortar

4. ASSESSMENT OF ENVIRONMENTAL AND TECHNICAL EFFICIENCY

The reduces transportation costs and supports sustainable construction practices by promoting the use of regional materials.

In practice, integrating RHA from ceramic kilns into building materials aligns with the principles of circular economy and sustainable development, fostering eco-friendly and cost-effective construction solutions. However, further studies on long-term durability and standardized processing techniques are necessary to optimize its performance and widespread adoption.

5. CONCLUSIONS

This study confirms that rice husk ash (RHA) can be effectively used as a partial cement replacement in mortar while maintaining structural integrity. The experimental results indicate that a 10% replacement level is optimal, offering a balance between strength development and sustainability. The use of RHA not only reduces cement consumption, thereby lowering carbon emissions, but also provides an eco-friendly solution by repurposing agricultural waste. Additionally, its high silica content enhances pozzolanic activity, contributing to long-term strength improvement. Future research should further investigate the long-term durability of RHA-based mortar and optimize processing techniques to enhance its performance and widespread application in sustainable construction.

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