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Characterization of Concrete with Rice Husk Ash (RHA) Based on Density, Porosity, and Sound Absorption

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Abstract: This study addresses the growing need for sustainable construction materials by utilizing agricultural waste as a value-added resource. This study investigates the effect of incorporating rice husk ash (RHA) with different particle sizes on the physical and acoustic properties of concrete blocks. Rice husk ash is an agricultural waste product rich in silica, offering significant potential as a supplementary construction material while contributing to sustainable waste management. Therefore, this research aims to analyze the influence of RHA particle size on the porosity, density, and sound absorption characteristics of concrete blocks. Concrete block samples were prepared using mixtures without RHA as a control and mixtures containing RHA with particle sizes sieved at 0.1 cm, 0.2 cm, and 0.3 cm. Prior to mixing, the rice husk ash was thermally treated in a furnace at 500 °C to obtain stable ash with an appropriate mineral composition. Mineralogical analysis confirmed that the ash was predominantly composed of silica (Si). Porosity was determined based on the ratio of void volume to total volume, density was calculated from mass per unit volume, and sound absorption performance was evaluated using the sound absorption coefficient (α). The results show that RHA particle size significantly influences the properties of concrete blocks. The lowest porosity (9.38%) and the highest sound absorption coefficient ($\alpha \approx 0.25$) were achieved by the sample with a particle size of 0.1 cm, indicating improved acoustic performance. Meanwhile, the highest density of 663.33 kg/m³ was obtained from the 0.2 cm sample. These findings demonstrate that finer RHA particles enhance both the structural compactness and acoustic properties of concrete blocks, supporting their application as environmentally friendly construction materials.

Keywords: Concrete; Density; Porosity; Rice Husk Ash (RHA).

Introduction

Indonesia is a country rich in natural resources due to its highly fertile soil, which enables large-scale production of food crops such as rice. As a result, Indonesia is one of the world's largest rice producers, with annual production reaching tens of millions of tons [1]. This high production also generates significant agricultural waste, including rice husks, by-products of rice milling [2]. The large-scale production of rice and the resulting accumulation of rice husks contribute to increasing environmental pollution. With the advancement of technology and industrial development, environmental degradation has become more severe, particularly due to the increasing number of factories producing waste that is ultimately released into the environment [3]

Environmental pollution from rice husk waste is difficult to avoid due to the growing demand for rice, a staple food in Indonesia. However, such pollution can be minimized by utilizing rice husk waste as a more valuable alternative material. Traditionally, rice husks have been used as an alternative fuel in brick firing or simply burned in milling areas [4]. This combustion process produces rice husk ash, which has so far had very limited utilization [5].

According to Badan Pusat Statistik (BPS), in 2024, Indonesia produced approximately 53.14 million tons of milled rice with a harvested area of around 10.05 million hectares [6]. Such high production levels increase agricultural waste, including rice husks. Rice husks typically account for around 20% of total rice production, while the rice husk ash obtained from controlled combustion constitutes approximately 18% of the husk weight [7]. Rice husk ash is known to contain a very high silica content, ranging from 90% to 95% as silicon dioxide (SiO_2) [8]. Through controlled combustion, rice husks can be converted into ash containing amorphous silica, which has the potential to be used as a raw material in various industries [9].

Utilizing rice husks is considered economical because the material is readily available and generally concentrated at milling locations. If rice husk waste is not properly managed, its natural decomposition proceeds very slowly, leading to accumulation that can pollute the environment and harm human health [10]. Therefore, proper technological approaches are needed to process this agricultural waste into useful by-products. One such approach is to use rice husk ash as an additive in construction materials. The ash produced through combustion contains pozzolanic compounds and a high silica content, which can react with cement to improve the strength of the resulting material.

Concrete (batako) is a cement-based construction material with conventional aggregates such as sand and gravel [11]. They are widely used in various construction projects, including residential buildings, commercial buildings, bridges, and road infrastructure [12].

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Commercially available concrete blocks typically have a density of 2.0-2.5 g/cm³ [13]. With this density, the blocks are relatively heavy, requiring additional labor or mechanical assistance during transportation and installation.

In construction, concrete blocks must possess sufficient load-bearing capacity to accommodate the rapid modernization and development of infrastructure, as well as environmental conditions that may lead to unexpected natural events [14]. The strength of concrete blocks is generally influenced by several factors, including the quality of fine and coarse aggregates, cement type, water content, and others. The most important properties for construction materials are their physical characteristics, such as porosity, water absorption, and sound absorption.

Based on these considerations, this study investigated the effect of adding rice husk ash with varying particle sizes on the physical characteristics of concrete blocks, including density, porosity, and sound absorption. Previous studies have reported that incorporating RHA into concrete can improve mechanical strength, reduce porosity, and enhance durability due to its pozzolanic reactivity and microfiller effect [15].

Recent research has also explored the influence of RHA on lightweight concrete and its environmental benefits. However, most of these studies primarily focus on mechanical properties or partial physical characteristics [16], [17], [18], and only a limited number of studies have systematically evaluated the effect of RHA particle size on concrete strength [19], [20]. In addition, comparative analyses among different particle sizes and their influence on sound absorption behavior remain insufficiently discussed in the literature.

Therefore, the research question of this study is: *How does the variation in rice husk ash particle size affect the physical (density and porosity) and acoustic (sound absorption) properties of concrete blocks?*

The results of this research are expected to provide insights into the potential utilization of rice husk ash as an additive in concrete block production and contribute to the development of more environmentally friendly construction materials.

Research Methods

This study used a quantitative, descriptive analysis to evaluate the effect of incorporating rice husk ash on the physical properties of concrete blocks, including porosity, density, and sound absorption. In this study, the specimens were classified into four types: a control specimen without rice husk ash and three specimens incorporating rice husk ash with sieve sizes of 0.1 cm, 0.2 cm, and 0.3 cm. Each specimen was tested in duplicate for each test type.

Rice Husk Ash Preparation

The initial stage of the study involved preparing rice husk ash. The rice husks were first cleaned and washed to remove impurities. They were then dried in the sunlight until completely dry. The dried rice husks were subsequently burned until they turned into black charcoal. The next step was controlled ashing using a furnace at approximately 500°C for around 30 minutes to obtain rice husk ash ready for use in the research.

Following this, the mineral content of the rice husk ash was analyzed using the X-Ray Fluorescence (XRF) method. The ash was placed into the XRF sample holder, and the instrument was used to determine the mineral composition. The results were obtained as printed output, which was recorded and presented in observation tables as the mineral content data for rice husk ash [21].

Concrete Block Preparation

The next stage involved preparing concrete block samples. The process began by mixing cement and sand at a 1:7 ratio in a small container with a capacity of approximately 4.90 kg. The mixture was thoroughly stirred, and sufficient water was added to form a moldable concrete mixture. The mixture was then poured into the steel mould and compacted using a tamping tool until fully dense. An additional mixture was added to completely fill the mould, and it was compacted again. The mould was then levelled by tapping until the surface was even. After a few minutes, the mould was carefully removed. The cast concrete block samples were placed in a shaded area, protected from direct sunlight and rain, and left to dry for 7 to 20 days. The same procedure was applied to samples containing rice husk ash with varying sieve sizes, where rice husk ash replaced approximately 10% of the cement content. After drying, the concrete block samples were tested to determine their physical characteristics, namely porosity, density and sound absorption.

Porosity Testing

Porosity testing was performed by first ensuring that the samples were completely dry. If the samples were still damp, they were dried in an oven at approximately 150°C. The dried samples were then cooled to room temperature (around 25°C) and weighed to obtain the dry mass (md). The samples were then placed in a vacuum container for 24 hours, followed by immersion in water under vacuum for another 24 hours to ensure complete water penetration into the pores. After immersion, the samples were removed, surface water was wiped off, and the samples were weighed again to obtain the wet mass (mw). The data were recorded in observation tables and used to calculate porosity according to the specified equations.

$$\text{Porositas} = \frac{m_k - m_b}{V_b} \times \frac{1}{\rho_{air}} \times 100\% \quad (1)$$

where :
P = Porosity (%)
m_k = Dry mass of the sample (gr)
m_b = Wet mass of the sample (gr)
V_b = Volume of the specimen (m^3)[22]

Density

Density testing was also conducted to determine the mass per unit volume of the concrete blocks. The samples were first dried and weighed to obtain the dry mass. They were then immersed in a water container, and the mass of the sample in water was measured based on Archimedes' principle. The dry and submerged masses were recorded and used to calculate density following the predetermined formula.

$$\text{Density} = \frac{m_k}{m_k + m_b} \times \rho_{air} \quad (2)$$

where:
D = Density (%)
m_k = The mass of the specimen in air (gr)
m_{bdl} = the apparent mass of the specimen in water (gr)
ρ_{air}= The density of water, assumed to be 1 g/cm^3[22]

Sound Absorption

In addition to porosity and density testing, sound-absorption tests were conducted to evaluate the concrete blocks' ability to attenuate sound. The testing procedure began with preparing a concrete block box measuring approximately 24 × 24 × 24 cm³ and the required equipment. A computer was used as the sound source, running the Test Tone Generator application to produce sound at various frequencies. An active speaker was connected to the computer and set at maximum volume.

The sound intensity of the source produced by the speaker was first measured using an Android Sound Meter application, with the sensor placed 2 meters from the speaker to obtain the initial intensity values. Measurements were conducted at 200 Hz, 600 Hz, 1000 Hz, 1400 Hz, and 1800 Hz.

Next, the sound intensity transmitted through the concrete block material was measured. The active speaker was placed inside the concrete block box, and the sound level meter was positioned 2 meters from the box to measure the transmitted sound intensity. Measurements were repeated at the same frequencies: 200 Hz, 600 Hz, 1000 Hz, 1400 Hz, and 1800 Hz.

The measured sound intensity values were recorded in observation tables containing the incident intensity (Ii) and transmitted intensity (It) for each frequency variation for all samples, including concrete blocks without rice husk ash and concrete blocks with rice husk ash additions at sieve sizes of 0.1 cm, 0.2 cm, and 0.3 cm. The collected data were then analyzed to calculate the sound absorption coefficient (α) of the concrete blocks using the specified formula.

$$\alpha = \frac{I_\alpha}{I_i}$$

Where,
α = Sound absorption coefficient
I_α= The absorbed sound intensity (dB)
I_i = The incident sound intensity (dB) [23]

Results and Discussion

Concrete blocks (batako) made from a mixture of cement, sand, and rice husk ash were naturally dried for 7–20 days. The rice husk ash used in the mixture had been combusted under controlled conditions at 500 °C. The concrete block samples were subsequently tested for porosity, density, and sound absorption. The results obtained for each of these parameters are as follows:

Porosity

Porosity testing is one of the physical parameters used to evaluate the characteristics of concrete blocks. This test aims to determine the total volume of pores present within the concrete block material.

Table 2. Porosity

No.	Type	Porosity (%)	Average (%)
1	Control sample	12.50 25.00	18.75
2	Sieve size 0.1	6.25 12.50	9.38
3	Sieve size 0.2	6.25 18.75	12.50
4	Sieve size 0.3	18.75 12.50	15.63

In this test, four types of concrete blocks were prepared: concrete blocks without rice husk ash, and concrete blocks with rice husk ash using sieves of 0.1 cm, 0.2 cm, and 0.3 cm. All samples were naturally dried for 15 days. The principle of the porosity test is to determine the volume of voids within the concrete block that can be occupied by a fluid, as shown in Figure 1. The porosity of the concrete blocks without rice husk ash (TS) was 18.75%. For concrete blocks with rice husk ash, the porosity values using 0.1 cm, 0.2 cm, and 0.3 cm sieves were 9.38%, 12.50%, and 15.63%, respectively. These results clearly demonstrate the effect of adding rice husk ash, as its fine particles can fill the small pores within the concrete blocks. Furthermore, the variation in rice husk ash particle size indicates that the 0.1 cm sieve produced the lowest porosity among the samples.

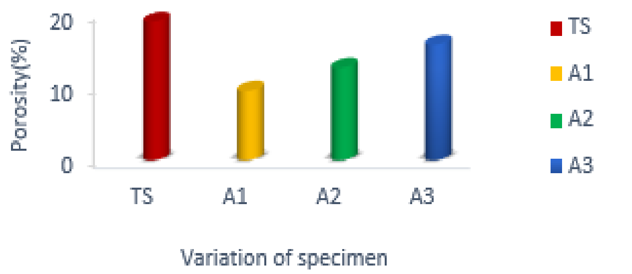

Figure 1. Porosity as a Function of Sieve Size Variation

This effect occurs because the particle size of rice husk ash significantly influences the characteristics of the concrete blocks. Rice husk ash with larger particles tends to have irregular shapes and higher internal porosity. Sieving the ash into finer particles breaks down its internal structure, resulting in more uniform particle shapes and reduced internal porosity. Additionally, rice husk ash particles that are smaller than the cement can act as a microfiller, improving the overall density of the cement composite [24].

Density

Density testing is one of the physical parameters used to evaluate the characteristics of concrete blocks. This test aims to determine the compactness or mass per unit volume of the concrete block composition.

Table 2. Density

No	Type	Density (Kg/m³)	Average (Kg/m³)
1	Control sample	653.85 660.00	656.92
2	Sieve size 0.1	660.00 660.00	660.00
3	Sieve size 0.2	660.00 666.67	663.33
4	Sieve size 0.3	660.00 653.85	656.92

In this test, four types of concrete blocks were prepared: concrete blocks without rice husk ash, and concrete blocks with rice husk ash using sieves of 0.1 cm, 0.2 cm, and 0.3 cm. All samples were naturally dried for 15 days. The principle of the density test is to determine the compactness of particles within the concrete block.

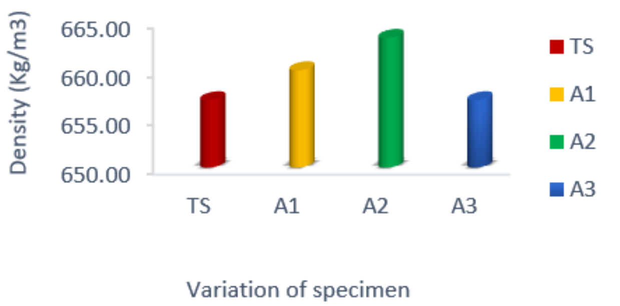

Figure 2. Density as a Function of Sieve Size Variation

As shown in Figure 4.2, there is a noticeable difference between the pre- and post-addition of rice husk ash. Among all treatments, the highest density value was observed in the 0.2 cm sieve treatment. Theoretically, changes in density are driven by factors such as particle size, porosity, and the material's composition. Aggregate particles may be less strong for two reasons: either they are composed of weak materials, or they consist of strong particles that are not well bonded [25].

From a theoretical perspective, the 0.1 cm sieve should have resulted in a higher density compared to the other treatments because of its smaller particle size. However, factors such as non-uniform mixing during preparation or inadequate compaction during molding can reduce particle bonding, resulting in slightly lower density than expected.

The particle size distribution theory indicates that particle size significantly influences the packing density and void volume within the concrete matrix. As reported in the literature, particle size distribution affects the packing efficiency of the aggregate skeleton, which determines the volume of voids that must be filled by the cement paste. An increase in packing density generally reduces void content; however, this relationship is also influenced by the particles' specific surface area. An increase in specific surface area can reduce the effective thickness of the cement paste film and alter the compaction behavior, which may result in non-linear or inconsistent variations in density [26].

Sound Absorption

Sound absorption testing is one of the physical parameters used to evaluate the characteristics of concrete blocks. This test aims to determine the magnitude of the sound absorption coefficient of the concrete block material. The table below presents the results of the sound absorption tests for each concrete block sample.

Table 3. sound absorption coefficient in various frequencies

Specimen	Koefisien Absorbsi (α)				
	200 Hz	600 Hz	1000 Hz	1400 Hz	1800 Hz
Control sample	0.03	0.17	0.08	0.09	0.07
Sieve size 0.1 cm	0.26	0.40	0.28	0.28	0.25
Sieve size 0.2	0.11	0.31	0.25	0.22	0.18
Sieve size 0.3	0.06	0.25	0.13	0.15	0.15

In this test, four types of concrete blocks were prepared: concrete blocks without rice husk ash, and concrete blocks with rice husk ash using sieves of 0.1 cm, 0.2 cm, and 0.3 cm. All samples were naturally dried for 20 days. The principle of the sound absorption test is to determine the magnitude of the material's ability to absorb sound, indicated by the sound absorption coefficient.

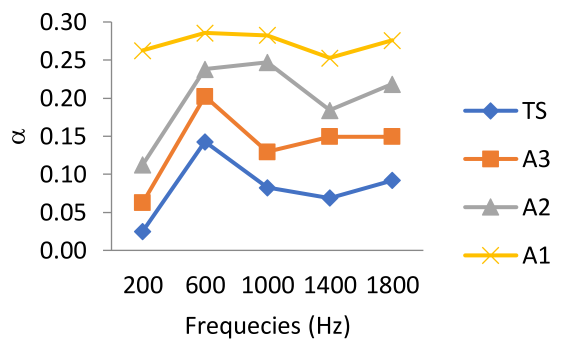

Figure 3. Sound Absorption Coefficient as a Function of Sieve Size Variation

When a sound wave travels from medium I (air) through medium II (concrete block), there are three possible outcomes: the wave may be completely reflected, completely transmitted to medium III (air), or partially reflected to medium I and partially transmitted to medium III. The amount of sound energy reflected and transmitted depends on the absorption coefficient of medium II and the frequency of the incident sound wave.

The absorption coefficient (α) ranges from 0 to 1. A value of α = 0 indicates that no sound is absorbed, whereas α = 1 means that 100% of the incident sound is absorbed by the material [27]. As shown in Figure 3, there is a noticeable difference in sound absorption before and after the addition of rice husk ash. The 0.1 cm sieve treatment exhibited the highest sound absorption among the treatments. This is because fine rice husk ash particles can fill the small pores within the concrete blocks, reducing the likelihood of sound diffraction and, consequently, decreasing the amount of transmitted sound, thereby increasing the absorption coefficient.

A material can be considered a good sound absorber if its absorption coefficient is greater than 0.2. [28]. The 0.1 cm sieve treatment provided good sound absorption, with coefficients exceeding 0.2 across all tested frequencies. Particle size influences the pore structure of the material, with finer particles contributing to a microfiller effect that reduces pore size and modifies pore distribution. In addition, the role of pore connectivity has been further elaborated. A more interconnected pore structure facilitates multiple reflections and frictional losses of sound waves within the material, thereby enhancing sound absorption performance. Conversely, changes in particle size affect the continuity and distribution of pores, which directly influence the dissipation of acoustic energy [29].

Conclusion

Based on this study's results, it can be concluded that adding rice husk ash (RHA) to concrete block materials significantly influences the properties of the resulting concrete blocks. Rice husk ash contains very fine particles capable of filling the micro-pores within the concrete block structure. This pore-filling mechanism contributes to the formation of a denser, more compact material, increasing density and reducing porosity. Furthermore, modifications to the pore structure also affect the acoustic performance of the concrete blocks. A more controlled pore distribution and a more homogeneous particle dispersion can enhance the material's ability to absorb and dissipate sound waves. Consequently, the addition of rice husk ash not only improves the physical properties of concrete blocks, such as density and structural compactness, but also enhances their potential for sound absorption compared to conventional concrete blocks without rice husk ash.

Author's Contribution

N.A.Ridha: The author was responsible for carrying out the research, processing and analyzing the data, collecting the data, and drafting the manuscript. R. Rahmaniah: contributed to the study's conceptualization, overall supervision, and final preparation of the manuscript. All authors have read, reviewed, and approved the final version of the manuscript.

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