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Laboratory Investigation Partial Replacement of Coarse Aggregate with Coconut Shell in Concrete Mixture

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Abstract

The growing demand for construction materials due to population growth and urbanization has increased the cost of traditional concrete materials in Malaysia, leading researchers to explore sustainable and low-cost alternatives like coconut shells as a substitute for coarse aggregates in concrete. This study aimed to examine the effects of using coconut shells in concrete to partially replace coarse aggregates by analyzing the properties of coconut shell aggregates (CSA), measuring the compressive strength of concrete with CSA, and evaluating its effectiveness as a replacement. Coconut shells were added to concrete mixes at 0%, 5%, 10%, and 15% and tested for compressive strength according to ASTM E9-19 standards. Results showed that after 7 days, compressive strength decreased with higher percentages of coconut shells, with 0% replacement showing an average strength of 26.55 MPa and 15% replacement showing 7.20 MPa. After 14 days, 0% and 15% replacements had average strengths of 22.19 MPa and 5.00 MPa, respectively. The study concluded that using coconut shells as aggregates could reduce environmental impact and construction costs, especially in coconut farming regions where shells are abundant and inexpensive, while also evaluating the mechanical properties, workability, and durability of the concrete.

1. Introduction

The global construction industry plays a pivotal role in fostering economic growth by providing essential infrastructure and housing for the expanding global population. However, the environmental impact of traditional concrete production, characterized by high carbon emissions and resource depletion, poses significant sustainability challenges [1]. As a response, there is a growing interest in exploring alternative construction materials to mitigate these environmental costs. Among the potential alternatives, coconut shells have emerged as a promising candidate for incorporation as a lightweight aggregate in concrete [2]. As agricultural by-products, coconut shells offer a sustainable substitute for conventional coarse aggregates, presenting an opportunity to reduce the environmental footprint of concrete production.

However, it's important to acknowledge that coconut shells possess distinct properties, such as higher water absorption capacity, elongation index, and flakiness index, which may impact their performance in construction applications [3]. Previous research has investigated the potential of coconut shells as a replacement for traditional coarse aggregates in concrete, focusing on aspects such as workability and various mechanical properties. This research aims to contribute to the understanding of the effects of incorporating coconut shells as coarse aggregate in concrete mixtures. The objectives of this study are to characterize the physical and mechanical properties of coconut shell aggregate (CSA) used in this study, evaluate the mechanical properties of concrete mixtures incorporating CSA, and assess the effectiveness of CSA in replacing traditional coarse aggregates in concrete mixtures. By addressing these objectives, this research seeks to provide valuable insights into the potential applications, limitations, and optimization strategies for utilizing coconut shell aggregate in sustainable concrete production.

2. Materials & Methods

In this study, locally sourced coconut shells from Muar, Johor, were prepared through cleaning and drying, alongside Type 1 Portland cement, fine aggregates from Bukit Pasir quarries, and crushed stone aggregate. Following a 1:2:4 ratio, the concrete mix design produced 100mm x 100mm x 100mm cubes for compressive strength testing at 7 and 14 days. Coconut shell concrete mixes replaced coarse aggregate at 0%, 5%, 10%, and 15%. The compressive strength test compared mixtures with and without coconut shells, aiding in determining the optimal replacement level. This comprehensive procedure facilitated the assessment of concrete mix properties and performance, ensuring compliance with relevant standards and guidelines, ultimately enhancing understanding and optimization of concrete properties.

2.1 Materials

The materials for this study were prepared to ensure the best experimental results. Coconut shells from Muar, Johor, were cleaned, sun-dried, and pre-treated to remove impurities and moisture. Type 1 Portland cement, following ASTM C150 standards, was used for consistency. Fine aggregates from Bukit Pasir, Johor, meeting ASTM C33 criteria, and crushed stone aggregate, properly sized for structural integrity, were utilized. The preparation and testing of cement and aggregate were conducted at the Bengkel Teknologi Konkrit, UTHM, while the experiments on aggregates were conducted at the Highway and Traffic Laboratory, UTHM.

2.2 Methods

The study involved several tests to evaluate the properties and suitability of the materials used. Sieve analysis determined particle size distribution, crucial for assessing aggregate suitability in concrete production. Flakiness and elongation index tests evaluated the shape characteristics of aggregate particles, impacting concrete workability and strength. Additionally, the Aggregate Impact Value (AIV) test assessed aggregate durability under the sudden impact, crucial for construction applications. These methodologies are detailed in Fig 1, summarizing the comprehensive approach taken to characterize coconut shell aggregate. Furthermore, ASTM standards were used to evaluate the compressive strength of concrete mixtures with coconut shell aggregate substitutions, providing insights into their performance compared to conventional concrete. These tests collectively enhance our understanding of coconut shell's potential as a sustainable alternative in concrete production.

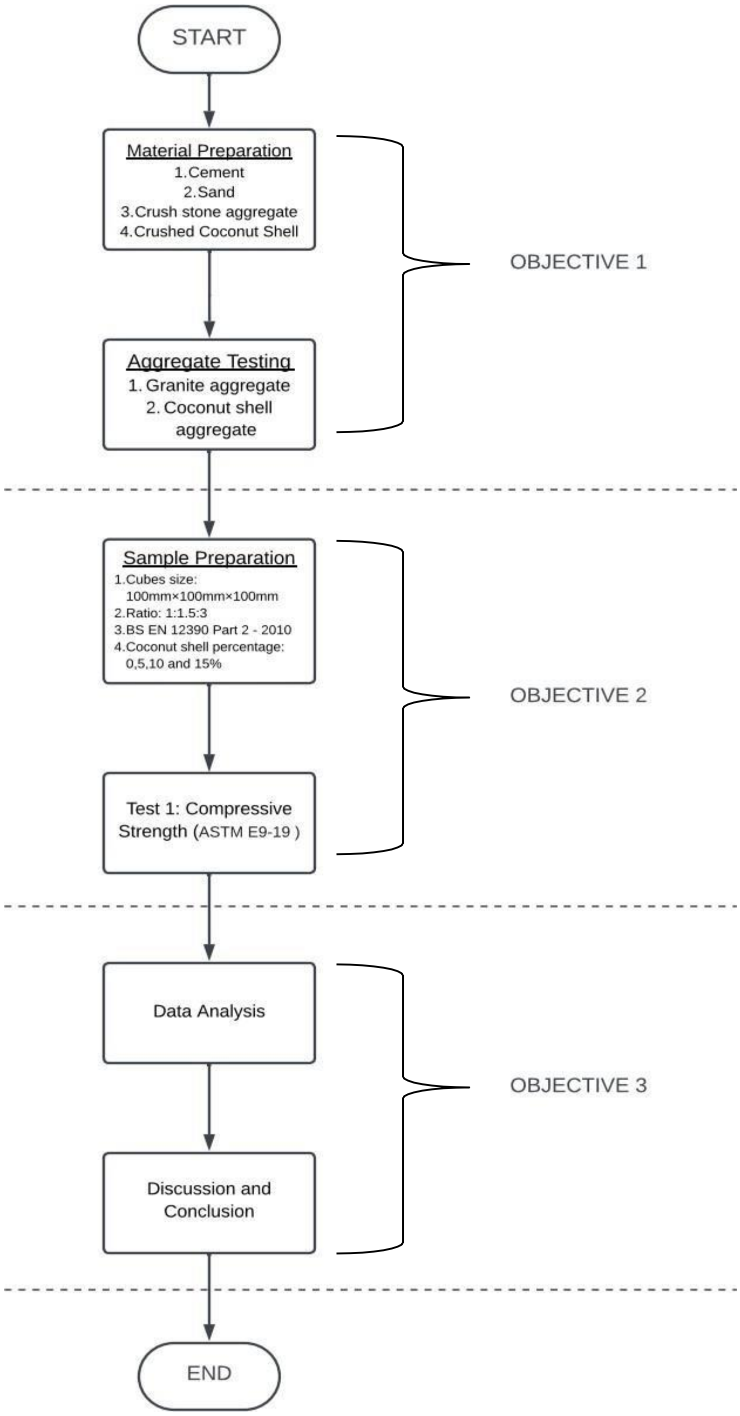

Fig. 1 *Research Methodology Chart*

2.2.1 Sieve Analysis

Sieve analysis is a method used to assess the particle size distribution of aggregates according to ASTM C136. This process involves passing a sample of aggregate through a series of sieves with progressively smaller openings, stacked from coarsest to finest. After shaking the sieves, the retained material on each sieve is measured to create a gradation curve. The results of sieve analysis, illustrated in Fig 2, provide critical insights into the particle size distribution within the aggregate. This data is essential for ensuring the concrete mix achieves desired properties such as workability and strength.

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Fig. 2 *Sieve Analysis Test*

2.2.2 Flakiness and Elongation Index

Flakiness and elongation index parameters assess the shape of individual particles in an aggregate sample, as per ASTM D4791 standards. Excessive flakiness can impact concrete workability and durability by measuring the percentage of thin, flat particles in the aggregate sample. Similarly, the elongation index measures the percentage of elongated particles that can affect concrete properties. Flaky particles are thin in one dimension compared to their other dimensions, while elongated particles are long and narrow. Both indices are calculated based on particle dimensions to ensure concrete achieves the desired properties. These assessments are detailed in Fig 3, illustrating the methodology used to evaluate particle shapes and their influence on concrete performance.

Fig. 3 *Flakiness and Elongation Test*

2.2.3 Aggregate Impact Value

The Aggregate Impact Value (AIV) test is conducted using the Aggregate Impact Testing Machine, where a prepared aggregate sample, sieved to specified size ranges (10 mm to 14 mm), undergoes testing. The dried aggregate is placed in the machine's cylindrical cup, and a standard steel hammer is released to fall freely onto the aggregate surface. The resulting fines, measured as a percentage of the total sample weight, determine the Aggregate Impact Value per ASTM C131. A higher value indicates a weaker aggregate, suggesting greater vulnerability to sudden impacts, whereas lower values are preferable, indicating higher resistance and overall toughness of the aggregate. This test is crucial for evaluating aggregate durability and suitability for construction applications, as shown in Fig 4.

Fig. 4 *Aggregate Impact Value Test*

2.2.4 Concrete Mix Design

The Dry Loose Bulk Density method is used to determine material quantities for concrete mix design based on a 1:2:4 (cement: sand: gravel) ratio. This involves calculating the dry loose bulk densities of materials. Next, materials are prepared to cast four concrete cubes, each measuring 100 mm by 100 mm by 100 mm, both controlled and modified. To ensure a homogeneous mixture, batching and mixing follow BS 1881: Part 125: 1983 standards. The workability of the designed mix is then assessed using a slump test per BS 1881: Part 102: 1983 guidelines. Finally, the compressive strength of 24 concrete cubes was tested as outlined in Fig 5.

Fig. 5 *Procedure Test*

2.2.5 Compressive Strength

There are multiple processes involved in testing the compressive strength of concrete that has coconut shells substituted for coarse aggregate. First, various percentage replacements of coconut shell aggregate, such as 0, 5, 10, and 15%, are used to make the concrete mixtures. After that, test specimens in cubes are cast using these mixes. A testing machine is used to provide a compressive force to the specimens until failure by applicable standards, such as ASTM C31, during the compressive strength test.

The compressive strength test results offer important information about how the material performs under compression, allowing a comparison of the strengths of concrete mixtures with and without coconut shells as a coarse aggregate replacement. The results of the test can be used to determine the ideal percentage replacement level of coconut shell aggregate in concrete, providing the desired strength characteristics of the finished product. Additionally, the compressive strength test can be combined with other tests, such as split tensile strength and flexural strength tests, to provide a comprehensive understanding of the material's behavior under various loading conditions.

Overall, the compressive strength test on concrete that has coconut shell replaced with coarse aggregate is a crucial step in assessing the material's behavior under compression and figuring out the ideal proportion of coconut shell aggregate replacement in concrete mixtures. Through this experiment, scientists and engineers will be able to better understand the behavior of the material and create concrete structures with stronger properties.

3. Result and Discussion

The tests were carried out to determine the following properties of the aggregates and concrete samples which are sieve analysis, flakiness and elongation index tests, aggregate impact value (AIV) test, and Compressive strength tests were conducted on concrete samples at 7 days, and 14 days.

3.1 Aggregate Properties

Sieve analysis, aggregate impact value, flakiness, and elongation index measurements were carried out to obtain comprehensive aggregate characteristics according to ASTM standards, and further analysis is shown in subsequent sections.

3.1.1 Sieve Analysis

The gradation of both coarse aggregates and crushed coconut shells used in concrete mixtures is critical for achieving desired strength, durability, and performance characteristics [4].This gradation test, also known as sieve analysis, involves passing aggregates through progressively smaller sieves, measuring the retained mass on each sieve, and calculating the cumulative percentage passing. The sieve analysis determines particle size distribution to ensure compliance with design, production control, and verification specifications. Fig 6 Grading Curve of Aggregates and Crushed Coconut Shells illustrates the resulting gradation curve, compared against specified limits such as those in JKR (Jabatan Kerja Raya) specifications, to verify compliance. Proper aggregate gradation is crucial in pavement construction for optimizing workability, stability, and binder-aggregate bonding, ensuring strong, durable surfaces [5].

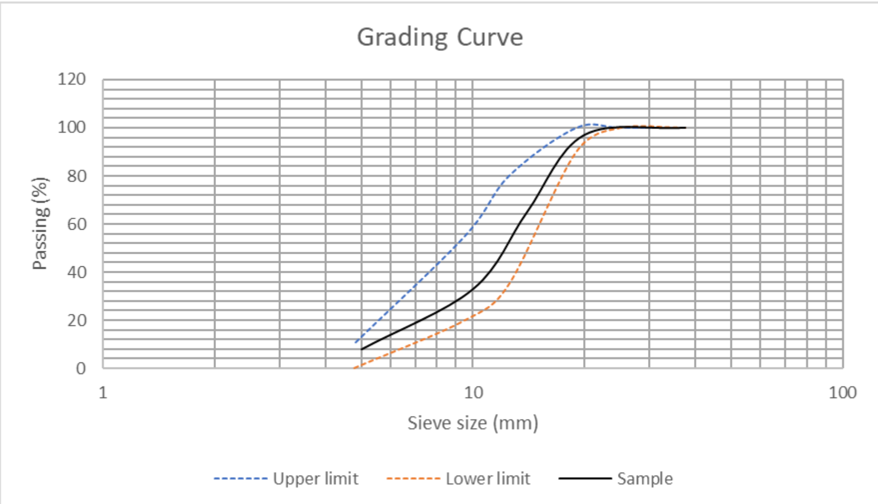

Fig. 6 *Grading Curve of Aggregates and Crushed Coconut Shells*

3.1.2 Flakiness and Elongation Test

The increase in elongated and flaky grain percentages significantly impacts the compressive strength of concrete and the load capacity of road and pavement layers [6]. The flakiness test assesses the percentage of flat or elongated particles in the sample, while the elongation test specifically measures the percentage of elongated particles. For granite aggregate, the elongation index value is 33.22%, and the flakiness index is 8.85%, exceeding the permitted 30% upper limit for elongation. Coconut shells, which naturally have a flat and elongated shape, are expected to exhibit higher flakiness and elongation indices. For coconut shell aggregate, the elongation and flakiness indices are 55.87% and 92.09%, respectively. The presence of numerous flaky and elongated particles in concrete reduces workability, strength, and durability. However, these particles can interlock within concrete, as illustrated in Fig 7 Flakiness and Elongation Index for Granite Aggregate and Coconut Shell Aggregate, which increases internal friction, restricts micro-movements, and enhances crack resistance, resulting in higher tensile and flexural strengths, increased load-carrying capacity, durability, and service life [7].

Table 1 *Flakiness and Elongation Index for Granite Aggregate and Coconut Shell Aggregate*

Sample	Granite aggregate		Coconut Shell aggregate	
Test	**Flakiness**	**Elongation**	**Flakiness**	**Elongation**
Value	33.22%	8.85%	92.09%	55.87%
JKR Specification (Flakiness ≤ 25%, Elongation ≤ 30%)	NO	PASS	NO	NO

3.1.3 Aggregate Impact Value

Aggregate impact value (AIV) tests were conducted on both untreated and treated aggregates to assess the impact of treatments on enhancing their properties [8]. The aggregate impact value for granite is 29.76%, while for coconut shell it is 29.34%. These values classify both aggregates within the 20 to 30% range, which is considered satisfactory for road surfacing according to JKR specifications. This indicates that coconut shell can effectively serve as a partial replacement for coarse aggregate based on its aggregate impact value [9]. Lower aggregate impact values correlate with stronger concrete, as aggregates with low impact values are more resistant to breaking and crushing, contributing to overall concrete strength and durability under heavy loads and impacts. Refer to Fig 8 for a visual representation of the aggregate impact values.

3.2 Compressive Strength

Compressive strength measurements were conducted to assess aggregate characteristics according to ASTM standards, with further analysis presented in subsequent sections.

3.2.1 Sample Test

The compressive strength test results for 7 days provide insights into the strength development of coconut shell aggregate concrete over an extended curing period. This test is crucial for assessing the concrete's ability to withstand compressive forces after a longer duration of curing, reflecting its durability and long-term performance. According to the JKR standard for M15 grade concrete at 7 days, which ranges from 12.75 MPa to 13.5 MPa, the mixes with 0% and 5% coconut shell aggregate replacement meet the required strength criteria. The highest average compressive strength observed at 0% replacement was 22.19 MPa, significantly exceeding the M15 standard. However, the compressive strength decreases as the percentage of coconut shell aggregate replacement increases, attributed to bond failure between the cement mortar and coconut shell aggregate, weakening the overall structure [3]. Refer to Fig 9 for a visual representation of the compressive strength results for 7 days.

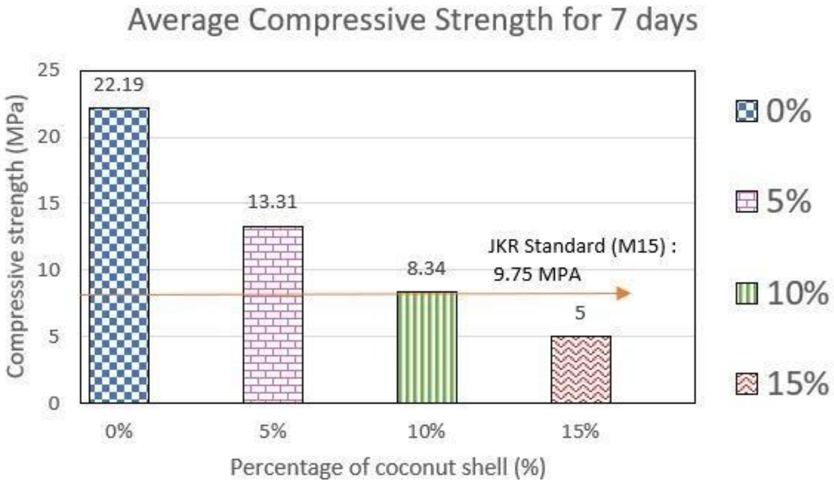

Fig. 9 *Compressive Strength for 7 Days*

The compressive strength results for 14-day coconut shell aggregate concrete reveal a noticeable decrease in strength as the percentage of coconut shell replacement increases. At 0% replacement, the average compressive strength was 26.55 MPa, demonstrating the highest strength among the tested mixes. However, as the replacement level increased to 5%, 10%, and 15%, the average compressive strength decreased to 15.89 MPa, 11.65 MPa, and 7.20 MPa, respectively. The water absorption properties of coconut shell aggregates influence concrete strength negatively, as higher coconut shell percentages correlate with increased water absorption. This inverse relationship between coconut shell replacement and compressive strength underscores the importance of selecting an optimal replacement level to balance sustainability and structural performance. Refer to Fig 10 for a visual representation of the compressive strength results for 14 days. [3].

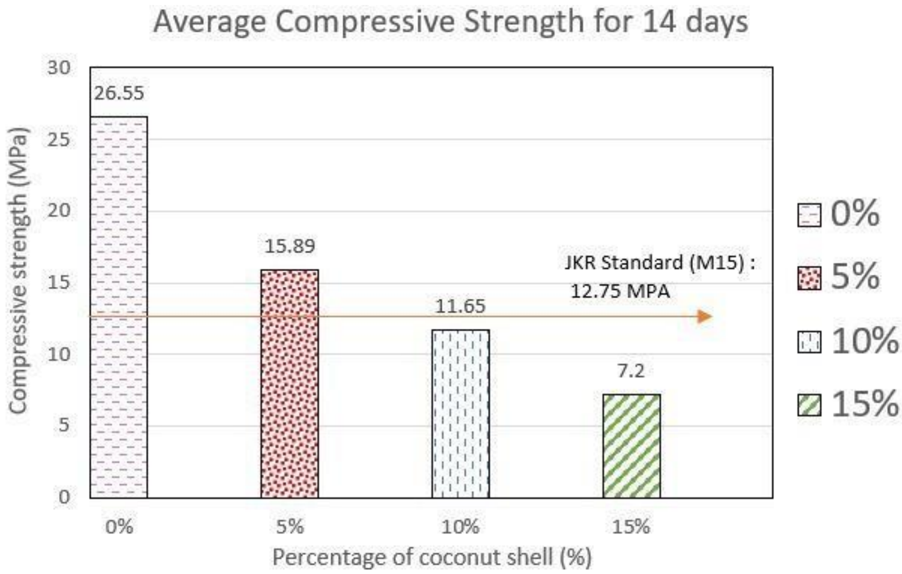

Fig. 10 *Compressive Strength for 14 Days*

Conclusion

This laboratory study focused on evaluating the feasibility of using coconut shell as a partial replacement for coarse aggregate in concrete mixtures, conducted according to ASTM standards ASTM C127/C127M for sieve analysis, ASTM C131/C131M for aggregate impact value, ASTM C136/D75 for flakiness index and elongation index, and ASTM C39/C39M for compressive strength testing. Coconut shell is a lightweight material, thus producing lightweight concrete. The investigation compared the properties of concrete containing coconut shell aggregate with those containing traditional granite aggregate. Results demonstrated that all samples met the standards specified by JKR (Jabatan Kerja Raya), indicating their compliance with regulatory requirements under dry, wet, and greasy conditions. This study underscores the potential of coconut shell as a sustainable alternative in concrete production, showing promising mechanical properties suitable for various construction applications. Further research should focus on optimizing mixture proportions and assessing long-term durability to fully exploit the benefits of coconut shell aggregate in practical engineering scenarios.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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