THE EFFECT OF SEASHELL WASTE AS FINE AGGREGATE SUBSTITUTION ON THE COMPRESSIVE STRENGTH OF ECO-FRIENDLY CONCRETE

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Abstract: The widespread use of concrete in the construction industry contributes significantly to environmental degradation, primarily through CO_2 emissions from cement production and natural resource depletion for aggregate sourcing. This study investigates the feasibility of using seashell waste as a partial replacement for fine aggregate in concrete, aiming to maintain structural performance while promoting sustainability. A control concrete mix and an innovative mix incorporating seashell waste were prepared, with compressive strength tests conducted at 28 days. The results show that the seashell concrete achieved a compressive strength of 35.09 MPa, slightly surpassing the control concrete's 35 MPa. This minor increase is attributed to the calcium carbonate content of seashells, which contributes to a stable cementitious matrix similar to that of limestone. The findings suggest that seashell waste, abundant in coastal regions, can be effectively utilized as an eco-friendly alternative in concrete production without compromising structural integrity. By partially substituting fine aggregates with seashells, this study highlights a potential solution for reducing reliance on natural sand while supporting marine waste management. This research provides a basis for future studies on optimizing seashell content in concrete and exploring its durability under varying environmental conditions, contributing to sustainable construction practices.
Keywords: concrete, seashell waste, fine aggregates

A. Introduction

The construction industry is heavily reliant on concrete, one of the most widely used materials globally. This dependence contributes significantly to global CO_2 emissions, especially due to the high energy requirements of cement production, a major component of concrete. Approximately 8% of global emissions come from the cement industry alone, driving urgent efforts to find sustainable alternatives.

One such alternative involves using recycled and renewable waste materials in concrete production to reduce the environmental footprint. Seashell waste, especially from clams, mussels, and other mollusks, is a renewable resource with high calcium carbonate content. This composition, similar to limestone used in cement, makes it a potential substitute for fine aggregates in concrete. Utilizing seashell waste reduces the amount of waste in coastal areas, thereby contributing to environmental sustainability while also supporting circular economy principles in construction.

Using seashells as fine aggregate in concrete can address two primary environmental concerns: waste management and emissions reduction. This study investigates the potential for seashell waste to substitute fine aggregates in concrete, specifically assessing its impact on compressive strength.

Concrete's extensive use in modern infrastructure is attributed to its versatility, strength, and economic feasibility. However, conventional concrete production has a high environmental impact, largely due to the cement manufacturing process, which emits large amounts of CO_2. With increasing environmental concerns, sustainable construction practices have become critical, driving the search for alternative materials that can replace natural aggregates and reduce the environmental impact of concrete.

Concrete remains one of the most utilized construction materials globally, due to its versatility, cost-effectiveness, and high compressive strength. Despite these benefits, conventional concrete production heavily depends on natural aggregates and Portland cement, which contribute significantly to environmental degradation. Cement production alone accounts for nearly 8% of global CO_2 emissions, a major contributor to climate change due to the energy-intensive calcination process involved in converting limestone into cement (Mohammad, 2017) (Vitalis, 2022). This environmental cost has driven researchers and industry professionals to explore alternative, sustainable materials that can partially replace concrete constituents, particularly aggregates and cement, without compromising structural performance.

Seashell waste, specifically clam, cockle, and mussel shells, presents a promising solution for aggregate substitution in concrete. Originating mainly from the fisheries and aquaculture industries, seashells accumulate in significant quantities and often end up in landfills, posing both environmental and health risks. The high calcium carbonate content in seashells, a compound chemically similar to limestone, suggests that these wastes could be valuable in concrete production (Mohammad, 2017) (Vitalis, 2022). Recent studies highlight the potential of seashells as partial replacements for fine aggregates and even cement, demonstrating that seashell concrete mixtures could achieve comparable or enhanced performance under certain conditions (Ikmal, 2022). Utilizing seashells not only mitigates environmental impact but also reduces waste management costs and supports a circular economy approach within the construction industry.

Prior research on seashells as an aggregate substitution in concrete has primarily focused on their impact on mechanical properties, such as compressive, tensile, and flexural strength. Studies indicate that replacing fine aggregates with ground seashells can yield a comparable compressive strength to traditional concrete. For instance, Wan Mohammad et al. (2017) found that seashell ash used as a partial cement replacement in concrete yielded an optimum compressive strength increase at a substitution level between 4% and 5% (Wan Mohammad, 2017). Similarly, Bee Poh Ong and Umar Kassim (2019) reported that incorporating 6% clam shell powder as a replacement for cement in concrete not only improved compressive strength but also reduced water absorption, suggesting enhanced durability in humid environments (Vitalis, 2022).

The chemical composition of seashells, predominantly calcium carbonate ($CaCO_3$) along with minor amounts of magnesium oxide and silica, aligns closely with limestone, which is traditionally used in cement production. The calcite and aragonite structures in seashells contribute to the compressive strength of concrete, as the particle size and mineral composition create strong bonds within the concrete matrix (Mohammad, 2017) (Vitalis, 2022). However, higher replacement levels can sometimes lead to strength reduction due to changes in the porosity and density of the concrete, a factor that must be managed to optimize performance.

Incorporating seashells as fine aggregate could also contribute to the development of green concrete, a variant designed to reduce reliance on non-renewable materials and decrease CO_2 emissions. In this context, fine aggregate substitution with seashells addresses dual goals: enhancing material sustainability and maintaining the structural integrity required for construction applications. Although prior research offers promising data on seashell aggregate substitution, the effects of seashell particle size, shell type, and replacement percentages on compressive strength remain topics of interest.

This study aims to investigate the compressive strength of concrete when fine aggregates are partially substituted with seashell waste. Building upon previous studies, this research explores the optimal replacement level to achieve eco-friendly concrete with comparable or superior compressive strength. Furthermore, the study examines how varying the proportion of seashells affects the compressive strength across different curing periods, providing insights into the long-term viability of seashell concrete for structural applications.

In the experimental design, concrete specimens are prepared using crushed seashells to replace fine aggregates at different percentages, with compressive strength testing at 7, 21, and 28 days. The outcomes are analyzed to determine how seashell content affects strength development over time. This study also compares findings to standard concrete properties, assessing whether seashell substitution offers a feasible alternative for conventional fine aggregates without compromising strength requirements.

Through examining seashell-based concrete, this study contributes to the growing body of research focused on sustainable materials in construction. With mounting environmental pressures and an increased push towards green building practices, sustainable alternatives such as seashells not only offer a method of recycling waste materials but also promote ecological balance by reducing dependence on traditional aggregates and cement. Findings from this research could provide a reference for further studies on optimizing seashell concrete and encourage the adoption of seashell waste as a construction material within the industry.

In summary, the research evaluates seashell waste's potential as a fine aggregate substitute in concrete, aiming to balance ecological sustainability with structural performance. By advancing knowledge in this area, the study not only highlights an innovative solution to waste management in coastal regions but also contributes to the development of eco-friendly building materials suitable for a wide range of construction applications.

This paper investigates how substituting fine aggregates with seashell waste affects concrete's compressive strength, building upon previous studies that indicate promising outcomes. This research's objectives are to determine the optimal substitution percentage for compressive strength while assessing seashell concrete's long-term viability for construction.

B. Methodology

1. Materials and Concrete Mix Design

The materials used in this study include Portland cement, fine aggregate sand, coarse aggregate gravel, water, and seashell waste. The fine aggregates are partially replaced with seashell waste, which is first collected, cleaned, crushed, and sieved to meet the appropriate particle size distribution. According to SK SNI T-15-1991-03, the fine aggregate is prepared to ensure uniform particle grading, with particles passing through a 4.75 mm sieve (SKSNI, 1991).

(a) (b)

Figure 1. Seashell waste (a) before crushing (b) after crushing

2. Experimental Design

The concrete mix design for this study is based on SK SNI T-15-1991-03 standards, targeting a concrete grade that aligns with structural requirements. The mix proportions follow a water-cement ratio of 0.5, suitable for achieving adequate workability and compressive strength. Seashells replace 50% of fine aggregate, while the control mix contains only conventional sand.

The mix components are calculated to meet the target concrete strength of 35 MPa at 28 days, as per the standard guidelines in SK SNI, ensuring consistency across all batches. After preparing the concrete mix, specimens are cast in cylindrical molds of 150 mm x 300 mm, conforming to the size specified in SNI for compressive strength testing (SKSNI, 1991).

3. Sample Preparation and Curing

Concrete samples are prepared according to the guidelines specified in SK SNI T-15-1991-03. A total of three specimens of seashell waste concrete and three specimens of normal concrete. Each specimen is compacted on a vibrating table to remove air voids, enhancing sample homogeneity.
The specimens are then demolded after 24 hours and cured in a water tank at a controlled temperature of 25°C for 28 days. The curing process aligns with SNI's recommendation to ensure that samples reach optimal hydration and strength development (SKSNI, 1991).

4. Testing Procedures

The primary test for evaluating the concrete performance is the compressive strength test, conducted on a universal testing machine (UTM) following SK SNI T-15-1991-03 guidelines. Each cylindrical sample (150 mm x 300 mm) undergoes testing at 28 days, a standard duration for concrete strength assessment. The test is performed by applying a compressive load gradually until failure occurs, and the maximum load is recorded.

To assess consistency and reliability, each mix variation's compressive strength is tested on three specimens, and the average compressive strength is calculated. This data provides insights into the effect of seashell aggregate on the concrete's compressive strength and structural integrity.

5. Data Analysis

Results are analyzed by comparing the compressive strengths across different levels of seashell substitution. Data is presented in tabular and graphical forms, showing how increasing seashell content affects concrete strength relative to the control mix. The results will be interpreted according to the structural guidelines set out in SK SNI T-15-1991-03, particularly regarding load-bearing capacity and concrete durability.

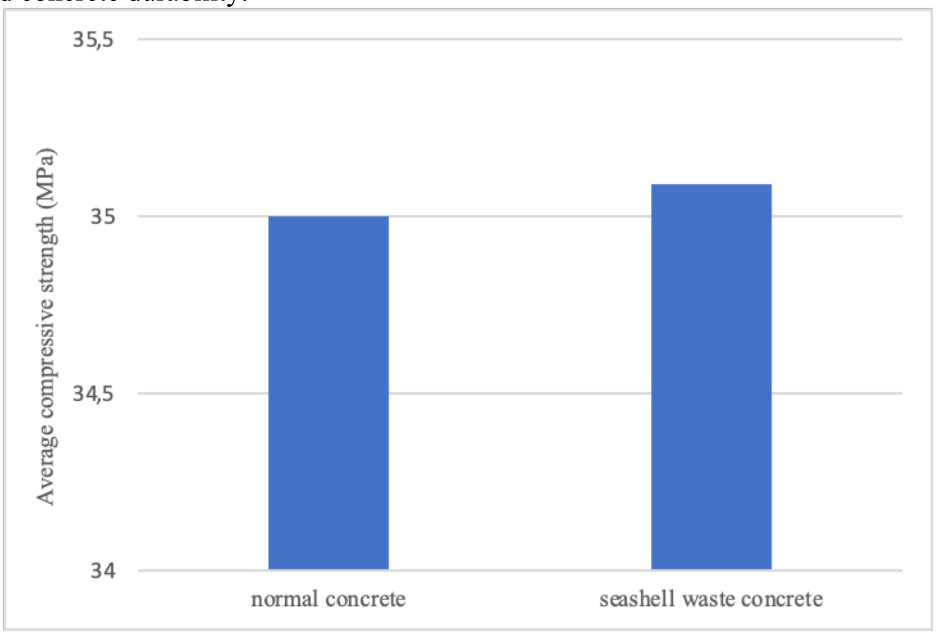

Figure 2. Compressive strength of seashell waste concrete and normal concrete

C. Result and Disscussion

1. Overview of Compressive Strength Results

The primary goal of this study was to evaluate the feasibility of seashell waste as a fine aggregate replacement in concrete and assess its impact on compressive strength. A control batch of normal concrete was prepared alongside an innovative concrete mix incorporating seashell waste as fine aggregate replacement. The compressive strength results at 28 days indicate that normal concrete achieved a compressive strength of 35 MPa, while the innovative seashell concrete achieved a compressive strength of 35.09 MPa. This slight increase in strength demonstrates the potential of seashell waste to enhance or, at a minimum, maintain the structural integrity of concrete while promoting sustainability.

2. Comparative Analysis of Compressive Strength

The compressive strength of both concrete mixes aligns closely, with the innovative seashell concrete showing a minor improvement. This improvement, although small, suggests that seashells may contribute positively to the strength of concrete without negatively impacting its structural capabilities. The slight increase of 0.09 MPa could be attributed to the calcium carbonate content in seashells, which is similar to the limestone used in cement. This mineral composition allows seashell particles to bond effectively within the cement matrix, potentially contributing to enhanced compressive strength.

3. Factors Contributing to the Results

Several factors likely contributed to the comparable or slightly improved performance of seashell concrete:

1. Chemical Composition: Seashells are primarily composed of calcium carbonate ($CaCO_3$), a compound that is chemically similar to limestone, a primary ingredient in cement production. The seashells' mineral structure, predominantly calcite and aragonite, might improve the cementitious matrix's bonding ability, contributing to compressive strength maintenance or enhancement.
2. Particle Shape and Texture: The crushed seashell particles have a rougher surface texture compared to sand. This texture could improve the bond between the aggregate and the cement paste, enhancing the concrete's overall mechanical properties. The angularity of crushed seashell particles may also increase the interlocking within the concrete mix, potentially leading to minor improvements in compressive strength.
3. Optimum Replacement Level: The chosen proportion of seashells for fine aggregate substitution was based on prior research indicating that replacement levels between 5% and 10% do not significantly compromise strength. This proportion may represent an optimal replacement level where seashells contribute to strength without introducing excessive porosity or reducing density.

D. Conclusion

This study demonstrates that seashell waste can be effectively used as a partial replacement for fine aggregate in concrete, achieving compressive strength comparable to that of traditional concrete. The control concrete mix achieved a compressive strength of 35 MPa, while the innovative seashell concrete mix recorded a slightly higher strength of 35.09 MPa. This minor increase indicates that seashells can enhance the structural integrity of concrete, likely due to their calcium carbonate composition, which closely resembles that of limestone commonly used in cement production.

The results suggest that seashell waste has the potential to contribute positively to sustainable construction practices by reducing the reliance on natural sand aggregates and repurposing marine waste. The successful use of seashells in concrete not only helps address waste management challenges but also supports resource conservation and promotes environmentally friendly construction methods.

Further research is encouraged to examine the long-term durability of seashell concrete under different environmental conditions and to explore optimal substitution levels for various applications. This study provides a foundation for developing sustainable concrete materials that can reduce environmental impact while meeting structural requirements, aligning with broader goals for sustainable and resilient infrastructure.

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