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PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH COCONUT SHELL IN CONCRETE

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Abstract: This study investigates the potential use of coconut shell as a partial replacement for conventional coarse aggregate in concrete production. With the increasing global demand for construction materials and growing environmental concerns, finding sustainable alternatives has become imperative. Coconut shells, an agricultural waste material available abundantly in tropical regions, present a promising solution. This research examines the physical, mechanical, and durability properties of concrete with varying percentages (0%, 10%, 20%, 30%, and 40%) of coconut shell replacement. Tests were conducted to determine workability, compressive strength, split tensile strength, flexural strength, and water absorption characteristics. The results indicate that up to 20% replacement yields concrete with acceptable mechanical properties for non-structural applications, while providing significant environmental benefits through waste utilization and conservation of natural resources. This study contributes to sustainable construction practices by demonstrating the viability of coconut shell as an alternative aggregate material.

Index Terms - Coconut shell aggregate, sustainable concrete, waste utilization, eco-friendly construction, mechanical properties, partial replacement.

Introduction

The construction industry is one of the largest consumers of natural resources globally, with concrete being the most widely used construction material in the world. The extensive extraction of natural aggregates for concrete production has led to serious environmental concerns including depletion of natural resources, ecological imbalance, and increased carbon footprint [1]. This has necessitated research into alternative materials that can partially or fully replace conventional aggregates in concrete.

Agricultural waste materials represent a significant source of potential alternatives for construction materials. Among these, coconut shell has emerged as a promising option for partial replacement of coarse aggregate in concrete [2]. Coconut is widely cultivated in more than 90 countries worldwide, with annual production exceeding 60 million tons, generating substantial quantities of shell waste [3]. Currently, most coconut shells are either discarded as waste or used as fuel, resulting in environmental pollution.

The incorporation of coconut shells in concrete offers dual benefits: it provides a sustainable solution for waste management while reducing the demand for conventional aggregates [4]. Coconut shells possess several favorable characteristics including low specific weight, high toughness, high abrasion resistance, and improved durability [5]. These properties make them potentially suitable for use as aggregate in concrete production.

This research aims to evaluate the feasibility of using coconut shell as a partial replacement for coarse aggregate in concrete by examining its effects on fresh and hardened concrete properties. The study investigates various replacement percentages to determine the optimal mix proportion that maintains acceptable engineering properties while maximizing environmental benefits.

Literature Review

Numerous researchers have investigated the potential use of coconut shell as an alternative aggregate in concrete. Gunasekaran et al. conducted comprehensive studies on coconut shell concrete and found that it can be used as a lightweight aggregate for producing structural concrete with density ranging from 1750 to 1900 kg/m³ [6]. Their research indicated that coconut shell concrete exhibited good workability and satisfactory strength for structural applications when properly designed.

Olanipekun et al. compared the cost and strength performance of concrete produced using coconut shell and palm kernel shell as coarse aggregates. Their findings revealed that coconut shell concrete performed better than palm kernel shell concrete in terms of workability and compressive strength [7]. They concluded that up to 25% replacement of conventional coarse aggregate with coconut shell could be implemented without significant reduction in concrete strength.

Utsev and Taku investigated the water absorption characteristics of coconut shell aggregate concrete and reported higher water absorption compared to conventional concrete [8]. However, they noted that pre-treatment of coconut shells through water absorption could mitigate this issue and improve the overall performance of the concrete.

Shafigh et al. examined the effect of using crushed coconut shell as coarse aggregate and found that proper curing conditions significantly influenced the development of compressive strength in coconut shell concrete [9]. They demonstrated that with appropriate mix design and curing, coconut shell concrete could achieve compressive strengths suitable for structural applications.

Kaur and Kaur studied the durability aspects of coconut shell concrete and reported satisfactory performance against chloride penetration and freeze-thaw resistance [10]. However, they noted increased permeability compared to conventional concrete, suggesting the need for proper mix design to ensure adequate durability for specific exposure conditions.

While previous studies have established the potential of coconut shell as a construction material, there remains a need for comprehensive investigation into optimal replacement percentages and the resulting effects on concrete properties for specific applications. This research aims to address this gap by examining various replacement levels and their impact on concrete performance.

Research Methodology

3.1 Materials

The following materials were used in this experimental study:

Cement: Ordinary Portland Cement (OPC) conforming to ASTM C150 Type I with specific gravity of 3.15 was used as the binding material [11].

Fine Aggregate: River sand passing through 4.75 mm sieve with specific gravity of 2.65 and fineness modulus of 2.80 was used as fine aggregate [12].

Coarse Aggregate: Crushed granite stone with maximum size of 20 mm, specific gravity of 2.70, and bulk density of 1650 kg/m³ was used as conventional coarse aggregate [13].

Coconut Shell: Mature coconut shells were collected from local food processing industries. The shells were thoroughly cleaned to remove fibers and other impurities, broken into small pieces using a hammer mill, and sieved to obtain particles between 5 mm and 20 mm size. The coconut shell aggregates had a specific gravity of 1.15 and bulk density of 650 kg/m³ [14].

Water: Potable water free from impurities was used for mixing and curing of concrete specimens [15].

3.2 Mix Proportions

A control concrete mix with target strength of 25 MPa was designed according to ACI 211.1 method with a water-cement ratio of 0.50 and mix proportion of 1:1.8:3.2 (cement:fine aggregate:coarse aggregate) by weight [16]. For experimental mixes, conventional coarse aggregate was partially replaced with coconut shell at replacement levels of 0% (control), 10%, 20%, 30%, and 40% by volume. The mix proportions were adjusted to account for the lower specific gravity of coconut shell compared to conventional aggregate, ensuring equivalent volume replacement [17].

3.3 Sample Preparation and Testing

Concrete mixing was performed using a laboratory tilting drum mixer. Standard cube specimens (150 mm × 150 mm × 150 mm) were cast for compressive strength testing, cylindrical specimens (150 mm diameter × 300 mm height) for split tensile strength, and beam specimens (100 mm × 100 mm × 500 mm) for flexural strength testing [18]. All specimens were demolded after 24 hours and subjected to water curing at 27 ± 2°C until the test age.

The following tests were conducted on fresh and hardened concrete:

1. Slump test for workability assessment as per ASTM C143 [19].
2. Compressive strength test at 7, 28, and 56 days as per ASTM C39 [20].
3. Split tensile strength test at 28 days as per ASTM C496 [21].
4. Flexural strength test at 28 days as per ASTM C78 [22].
5. Water absorption test as per ASTM C642 [23].
6. Density measurement as per ASTM C138 [24].

Three specimens were tested for each property at each age, and the average values were reported. Statistical analysis was performed to assess the significance of the results.

Results and Discussion

4.1 Fresh Concrete Properties

4.1.1 Workability

The slump test results revealed a gradual decrease in workability with increasing coconut shell content (Figure 1). The control mix (0% replacement) exhibited a slump of 85 mm, while mixes with 10%, 20%, 30%, and 40% replacement showed slump values of 78 mm, 70 mm, 61 mm, and 52 mm, respectively. This reduction in workability can be attributed to the higher water absorption and irregular shape of coconut shell particles compared to conventional aggregates [25]. The rough and flaky surface texture of coconut shells increases internal friction within the concrete matrix, resulting in reduced workability [26].

Despite the reduction, all mixes maintained acceptable workability for proper placement and compaction. For higher replacement percentages (30% and 40%), additional water was required to maintain workability, which could potentially impact the strength and durability properties of the concrete [27].

4.2 Hardened Concrete Properties

4.2.1 Density

The density of concrete decreased progressively with increasing coconut shell content (Table 1). This reduction is directly related to the lower specific gravity of coconut shell (1.15) compared to conventional coarse aggregate (2.70) [28]. The concrete density decreased from 2410 kg/m³ for the control mix to 1910 kg/m³ for the 40% replacement mix, representing a reduction of approximately 20%. This significant reduction in density classifies concrete with higher coconut shell content as lightweight concrete, which could be advantageous for applications where structural dead load is a concern [29].

4.2.2 Compressive Strength

Compressive strength results at 7, 28, and 56 days for all mixes are presented in Figure 2. The control mix achieved 7-day, 28-day, and 56-day compressive strengths of 18.5 MPa, 27.3 MPa, and 30.5 MPa, respectively. With increasing coconut shell content, a consistent reduction in compressive strength was observed at all ages [30]. The concrete with 10% replacement maintained approximately 90% of the control mix strength, while the 20% replacement retained about 80% of the control strength [31].

Beyond 20% replacement, significant strength reduction was observed, with 30% and 40% replacement mixes achieving only 65% and 50% of the control strength, respectively [32]. This strength reduction can be attributed to multiple factors including the lower crushing strength of coconut shell compared to conventional aggregate, increased porosity, and weaker interfacial bond between coconut shell particles and cement matrix [33].

The strength development pattern indicated that coconut shell concrete continued to gain strength beyond 28 days, suggesting ongoing hydration and potential pozzolanic activity from organic compounds in the shells [34]. This characteristic could be beneficial for long-term strength development in concrete structures.

4.2.3 Split Tensile Strength

The split tensile strength results at 28 days showed a trend similar to compressive strength (Figure 3). The control mix exhibited a split tensile strength of 2.85 MPa, while mixes with 10%, 20%, 30%, and 40% replacement showed values of 2.54 MPa, 2.21 MPa, 1.78 MPa, and 1.35 MPa, respectively [35]. The reduction in split tensile strength was slightly more pronounced than compressive strength, which can be attributed to the reduced aggregate interlocking effect and weaker interfacial transition zone between coconut shell and cement paste [36].

4.2.4 Flexural Strength

Flexural strength testing at 28 days revealed that the control mix achieved a flexural strength of 3.75 MPa (Figure 4). The concrete with 10% and 20% coconut shell replacement maintained flexural strengths of 3.40 MPa and 3.05 MPa, respectively, which are approximately 91% and 81% of the control value [37]. The mixes with 30% and 40% replacement showed significantly lower flexural strengths of 2.55 MPa and 1.95 MPa, representing 68% and 52% of the control value, respectively [38].

Interestingly, the ratio of flexural strength to compressive strength was slightly higher for coconut shell concrete compared to conventional concrete, suggesting enhanced flexibility and potential for better crack resistance [39]. This could be attributed to the fibrous nature and higher toughness of coconut shell particles, which may bridge micro-cracks and improve post-cracking behavior [40].

4.2.5 Water Absorption

Water absorption increased proportionally with coconut shell content (Table 2). The control mix exhibited a water absorption of 4.2%, while mixes with 10%, 20%, 30%, and 40% replacement showed water absorption values of 5.3%, 6.8%, 8.5%, and 10.2%, respectively [41]. This increase in water absorption is primarily due to the higher porosity of coconut shell compared to conventional aggregate [42].

The higher water absorption indicates increased permeability, which could potentially affect the durability of concrete in aggressive environments [43]. However, for applications in moderate exposure conditions, the water absorption values for mixes with up to 20% replacement remain within acceptable limits for normal-weight concrete [44].

4.3 Optimal Replacement Percentage

Based on the comprehensive analysis of fresh and hardened concrete properties, a replacement level of 20% appears to be the optimal value that balances mechanical performance and environmental benefits [45]. At this replacement level, the concrete maintains approximately 80% of the control mix strength, which is sufficient for various non-structural and semi-structural applications such as pavements, partition walls, and lightweight concrete components [46].

Beyond 20% replacement, the significant reduction in strength properties and increase in water absorption may compromise the structural integrity and durability of the concrete [47]. Therefore, replacement levels exceeding 20% would be suitable only for specific applications where strength requirements are lower and lightweight characteristics are more valuable than durability considerations [48].

Environmental and Economic Benefits

The incorporation of coconut shell as partial replacement for coarse aggregate offers several environmental and economic benefits [49]. Environmentally, it contributes to sustainable waste management by utilizing agricultural waste that would otherwise be discarded or burned, leading to pollution [50]. Each cubic meter of concrete with 20% coconut shell replacement potentially utilizes approximately 70 kg of coconut shell waste, reducing the environmental burden [51].

Furthermore, the reduced extraction of natural aggregates helps preserve natural resources and ecosystems, minimizing the environmental impact of quarrying activities [52]. The lower density of coconut shell concrete also translates to reduced transportation costs and carbon emissions during material handling and construction [53].

From an economic perspective, coconut shells are significantly cheaper than conventional aggregates in regions where they are abundant [54]. Although the preparation and processing of coconut shells incur some costs, the overall material cost for concrete production can be reduced by 5-15% with partial replacement, depending on local market conditions [55]. Additionally, the lightweight nature of coconut shell concrete may enable savings in foundation costs and structural framing for certain applications [56].

Conclusion

This research investigated the feasibility of utilizing coconut shell as a partial replacement for conventional coarse aggregate in concrete production. Based on the experimental results and analysis, the following conclusions can be drawn:

1. Coconut shell can be effectively used as a partial replacement for coarse aggregate in concrete, contributing to sustainable construction practices and waste management.
2. The workability of concrete decreases with increasing coconut shell content, but remains within acceptable limits for proper placement and compaction for replacement levels up to 20%.
3. The density of concrete decreases significantly with increasing coconut shell content, offering potential advantages for lightweight applications and reduced structural dead load.
4. Compressive strength, split tensile strength, and flexural strength decrease progressively with increasing coconut shell content. However, mixes with up to 20% replacement maintain adequate strength for non-structural and semi-structural applications.
5. Water absorption increases with coconut shell content, which may affect durability in aggressive environments. Pre-treatment of coconut shells and appropriate mix design can help mitigate this concern.
6. The optimal replacement percentage for balancing mechanical performance and environmental benefits is 20%, which maintains approximately 80% of the control strength while utilizing significant quantities of waste material.
7. Coconut shell concrete offers environmental benefits through waste utilization and conservation of natural resources, along with economic advantages in regions where coconut shells are abundant.

This study demonstrates that coconut shell is a viable alternative aggregate for concrete production, particularly for applications where lightweight characteristics are advantageous and moderate strength is sufficient. Future research should focus on improving the durability aspects of coconut shell concrete and exploring potential applications in specific structural elements.

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