Assessing The Viability of Sawdust as A Sustainable Partial Sand Replacement in Concrete Mix Design

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Abstract

As the demand for sustainable construction materials grows, this study investigates sawdust as a viable partial sand replacement in concrete mix designs, addressing significant environmental and economic concerns. This study fills a critical gap in sustainable material use for construction by assessing the mechanical and cost effects of sawdust incorporation. Six concrete mixes were prepared with varying ratios of natural sand and sawdust (0–25%) in a C-25 grade mix, maintaining a 0.49 water-cement ratio. Experimental findings indicate that a 10% sawdust substitution maintains a compressive strength comparable to that of standard concrete, achieving C-25 grade, while a 15% replacement optimizes workability. Additionally, the treated sawdust reduced water absorption by 31.8%, promoting enhanced internal curing and long-term durability. A cost comparison of river sand from Hiwane, Aby-Adi, and Wukro revealed a reduction of 750 ETB/m³ with sawdust inclusion, making it a financially advantageous alternative, especially in regions with limited or costly natural sand supplies. These results emphasize the potential of sawdust as an eco-friendly, cost-effective material, advancing circular economy practices, and supporting sustainable and resource-efficient construction.

Keywords: aggregate, compressive strength, concrete, raw sawdust, workability

DOI: 10.7176/CER/17-1-03

Publication date: January 31st 2025

Introduction

The global demand for concrete has surged in recent years, driven by rapid urbanization and infrastructure development, which places significant pressure on natural resources, particularly sand, which is essential for concrete production. Current estimates suggest that between 32 billion and 50 billion tons of sand are extracted annually, with projections indicating that the world could face a sand shortage by 2050 if unsustainable extraction practices continue. The United Nations Environment Programme (UNEP) warns that the unregulated extraction of sand from rivers, lakes, and marine environments poses severe environmental risks, including habitat destruction and biodiversity loss. As urban populations are projected to increase significantly, the demand for construction-grade sand will only intensify, exacerbating these challenges (1) (2)(3).

Excessive sand extraction can have significant environmental consequences. This disrupts aquatic ecosystems, leading to reduced biodiversity and altered sediment dynamics, which can destabilize waterways. The removal of sand from riverbeds and coastal areas contributes to erosion, increased vulnerability to flooding, and the degradation of water quality. Furthermore, the ecological impacts extend to changes in fish populations and the overall health of marine environments, as evidenced by recent studies highlighting the destructive effects of large-scale sand mining operations (2)(3). Without immediate regulatory measures and sustainable practices in place, the ecological impacts of sand depletion will escalate, posing significant challenges for both the environment and future generations (2)(3).

Sawdust, a readily available byproduct of the timber industry, offers a promising solution for reducing the environmental footprint of concrete production.(4)(5)(6)(7) (8) The abundance of sawdust, coupled with its potential for waste management, makes it a valuable resource for sustainable construction. (4)(5)(6)(7) (8) Using sawdust as a partial replacement for sand can reduce the overall weight of concrete, potentially leading to cost savings in transportation and construction. (4)(5)(6).

Sawdust holds potential as a sustainable partial sand substitute in concrete production, offering benefits in terms of thermal and acoustic insulation, reduced carbon footprint, and cost-effectiveness. (9)(5)(10)(5) However, challenges related to its organic composition, potential impact on strength and durability, and compatibility with other concrete components require further research and development. (9)(11)(12) Continued research and development efforts are crucial to optimize sawdust utilization in concrete, overcome existing challenges, and promote the adoption of this sustainable construction material. Further research is necessary to fully understand the long-term performance of sawdust concrete, develop optimized mix designs, and explore innovative pre-treatment methods to enhance its properties. (13)(12)(12) By addressing these challenges and promoting the use of sawdust as a sustainable construction material, the construction industry can contribute to a greener and more sustainable future. (13)(12)(12).

This review highlights the potential of sawdust as a sustainable and cost-effective alternative to traditional sand for concrete production. (14) (15)(16)(17) However, a significant gap exists in our understanding of the complex interplay between strength, workability, and cost when sawdust is used as a partial sand replacement. (14) (15)(16)(17) Future research should focus on developing a comprehensive understanding of the factors influencing sawdust concrete performance, leading to practical guidelines for its use in sustainable construction. (14) (15)(16)(17).

The primary objective of this study is to assess the feasibility of using sawdust as a partial replacement for sand in concrete, focusing on its mechanical and economic impacts. Specifically, it aims to evaluate concrete workability and compressive and tensile strengths, identify the optimal sawdust replacement ratio, and compare the strength-to-cost ratio between sawdust-replaced and conventional concrete mixes.

This study was confined to C-25 grade concrete, which is commonly used in building construction. By exploring sawdust as a sand substitute, this study aims to produce lightweight low-cost concrete that can be applied to non-load-bearing elements, such as partitions and residential slabs, while maintaining essential concrete properties.

The significance of this study lies in its potential to reduce reliance on natural sand, which is becoming increasingly scarce and expensive. Sawdust, a widely available by-product, is an eco-friendly solution that supports a circular economy by repurposing waste. If successful, this approach can lead to more sustainable and cost-effective construction practices, particularly in areas with limited or expensive traditional sand resources.

2.Materials and test methods

2.1. Materials

This study, conducted at the Concrete Laboratory at the School of Civil Engineering, Ethiopian Institute of Technology, Mekelle University, employed a systematic approach to evaluate the potential of sawdust as a partial sand replacement for concrete. Four primary materials—cement, sawdust, fine aggregate (river sand), and coarse aggregate—were characterized and utilized to develop a concrete mix design. This methodology comprised material characterization, mix design formulation, concrete production, and comprehensive testing of physical and mechanical properties, aimed at assessing sawdust's effects on workability, compressive strength, tensile strength, and cost efficiency Materials

1. Cement: Messebo Ordinary Portland Cement (OPC) conforming to the Ethiopian (ES-1177-1-2005) and European (EN-197-1-2000) standards were used. A high calcium oxide (CaO) content of 63.94% and balanced composition of silica (SiO_2), iron oxide (Fe_2O_3), and alumina (Al_2O_3) ensure optimal strength development and durability, which are found in the concrete mix.

2. Fine Aggregate (River Sand): River sand, sourced from Hiwane in Tigray, underwent rigorous cleaning and grading. Characterized as coarse sand with a fineness modulus of 2.93, it met ASTM C33 and Ethiopian standards with a compacted unit weight of 1758 kg/m³ and a bulk specific gravity of 2.62, providing suitable cohesion and stability within the concrete matrix.

3. Coarse Aggregate: Locally sourced basaltic crushed rock with a nominal size of 37.5 mm, was selected owing to its high stability and density. The aggregate compacted unit weight of 1651.89 kg/m³ and specific gravity of 2.62 complement the concrete's structural requirements and contributes to the mix's compressive strength.

4. Sawdust: Sawdust from local wood-processing enterprises was treated with engine oil to reduce its absorption capacity from 34.98% to 10.79%, aligning it within lightweight aggregate standards with a bulk specific gravity of 0.92 and unit weight of 213 kg/m³. The treated sawdust was evaluated for its effectiveness as a partial replacement for sand, providing a sustainable alternative for concrete applications.

2.2. Mix Design

The concrete mix was designed using the American Concrete Institute (ACI) 211 method to achieve a C-25 concrete grade, with a target compressive strength of 31 MPa and a water-to-cement ratio of 0.491. Six mix proportions were prepared by substituting sawdust with sand at 0, 5, 10, 15, 20, and 25%. The calculated quantities of each component ensured consistent and reproducible concrete mixes across the samples, enabling an accurate comparison of the strength and workability at varying levels of sawdust replacement.

2.2.1. Concrete Production Process

1. Mixing Procedure: Each batch was carefully measured, with the coarse aggregate added first, followed sequentially by cement, sand, sawdust, and water to ensure thorough mixing. Given its high absorptive capacity, sawdust was carefully mixed to achieve a uniform blend and an optimal water distribution. A slump test was conducted immediately after mixing to assess workability, which was adjusted as necessary to maintain the target consistency across all sample variations.

2. Molding and Curing: Concrete cubes (150 mm × 150 mm × 150 mm) were cast for compressive strength testing, whereas cylinders (150 mm diameter, 300 mm height) were used for tensile strength testing. The molds were pre-treated with a releasing agent to facilitate demolding. After 24 h, the samples were demolded and cured in water for the designated testing days at 3, 7, and 28 d, ensuring controlled hydration and strength gain for comprehensive analysis.

2.2.2. Testing and Analysis

Physical and Mechanical Testing: Workability was assessed through slump tests, providing insight into how sawdust affects concrete flow and compaction. Compressive and tensile strength tests were conducted according to ASTM standards to evaluate the mechanical performance of each mix. The performance of the sawdust-modified concrete was benchmarked against that of conventional concrete to determine the optimal sawdust replacement ratio for balancing workability, durability, and strength.

Economic Analysis: A cost analysis was conducted to evaluate the economic benefits of sawdust substitution. River sand samples from Hiwane, Aby-Adi, and Wukro were assessed, which revealed cost reductions of approximately 750 ETB/m^3 when 10% sawdust was used instead of sand. This analysis highlights the cost-effectiveness of sawdust, particularly in regions that face high sand costs or scarcity.

This methodical approach to material analysis, mix formulation, and testing has established a foundation for assessing sawdust as a sustainable and economically viable replacement for sand. The findings underscore the potential to contribute to circular economy practices in construction, promoting resource efficiency, and environmental responsibility in the concrete industry.

3.Results and Discussion

This study examined the impact of raw sawdust as a partial sand replacement for concrete, focusing on workability, compressive strength, density, and tensile strength. The experiments were conducted in three phases at replacement levels of 0, 5, 10, 15, 20, and 25%. Phase I evaluated the workability and compressive strength with a fixed water-to-cement (W/C) ratio, whereas Phase II analyzed the weight and density of hardened concrete, leveraging the lightweight properties of sawdust. Finally, Phase III assesses the split tensile strength for resilience under stress.

The results indicate that optimal sawdust replacement balances the structural performance and environmental benefits of positioning sawdust as a viable and eco-friendly alternative for concrete production. Standard slump tests confirmed workability, and the compressive strength was measured at 3, 7, and 28 d, adhering to civil engineering standards.

3.1. Effect of Sawdust Replacement as Fine Aggregate on Concrete Workability

The study demonstrated a clear inverse relationship between sawdust replacement percentage and workability, as indicated by the slump test results. The concrete mix without sawdust exhibited a slump of 45 mm, which declined progressively with increasing sawdust content: 42 mm at 5%, 37 mm at 10%, and significantly lower values of 15 mm and 10 mm at 20% and 25% replacements, respectively.

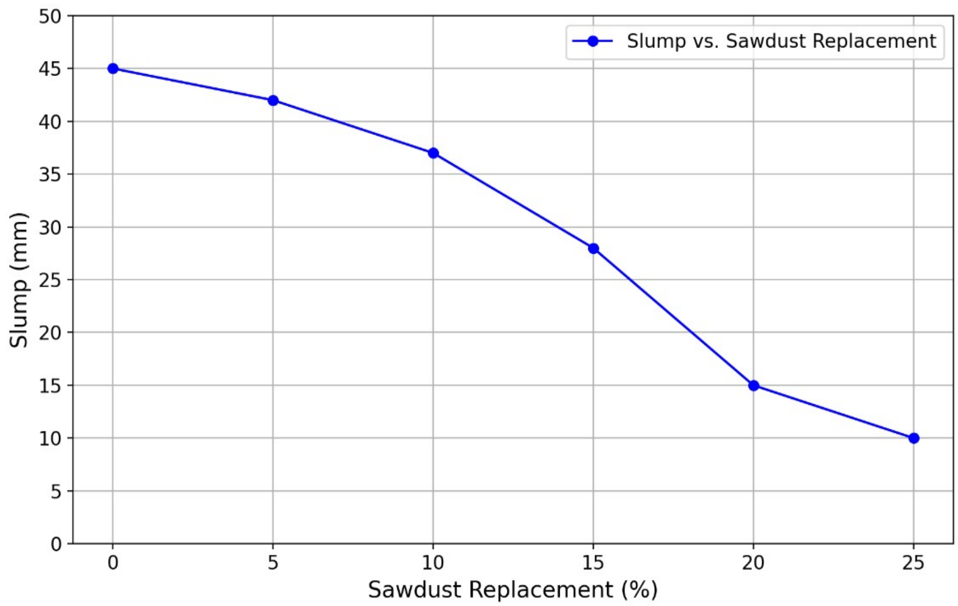

Figure 6: Effect of Sawdust Replacement as Fine Aggregate on Concrete Workability

The ASTM C143 standard outlines an acceptable slump variability of approximately 2 mm; thus, the reductions observed at 5% and 10% sawdust replacements are statistically insignificant, suggesting that these levels maintain an adequate workability for practical applications. However, the notable drop in the slump at higher replacement levels indicates a reduction in fluidity and compact ability owing to the high absorption and fibrous nature of sawdust, which could complicate concrete placement. Therefore, although sawdust can enhance sustainability, its use should be limited to 10% for applications where high workability is essential or combined with admixtures to mitigate its effects.

3.2. Influence of Curing Period and Sawdust Replacement on Compressive Strength of Concrete

The compressive strength tests revealed that the performance of the concrete improved significantly over time but varied markedly with the sawdust content. At 0% replacement, compressive strengths were 10.85 MPa at 3 days, 17.79 MPa at 7 days, and 31.35 MPa at 28 days, which align with the expected characteristics of C-25 concrete.

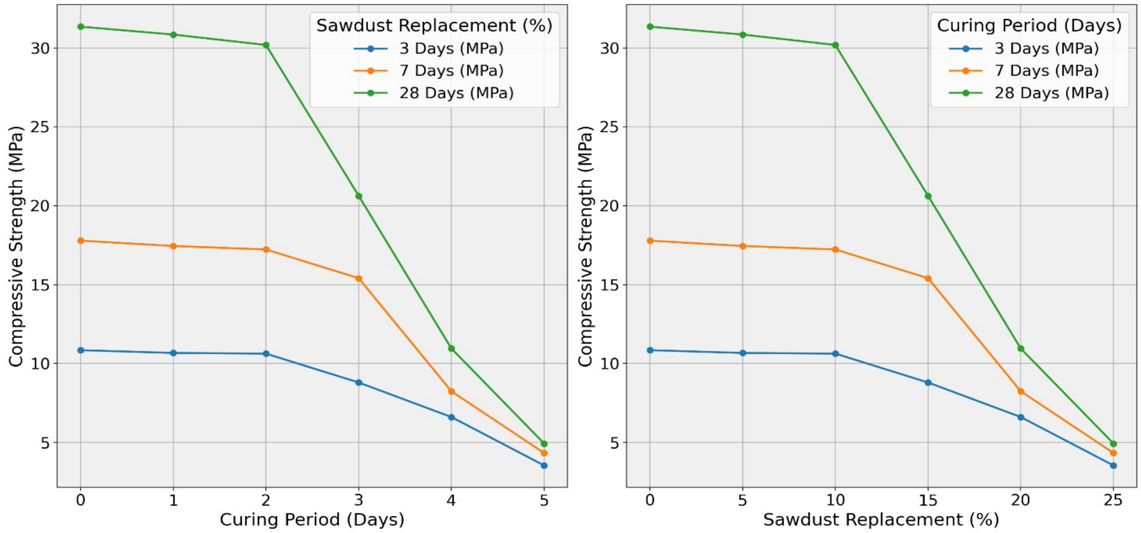

Figure 7: Influence of Curing Period and Sawdust Replacement on Compressive Strength of Concrete

However, as sawdust replacement increased, particularly beyond 10%, there was a pronounced decline in compressive strength: 3.54 MPa at 3 days, 4.33 MPa at 7 days, and 4.93 MPa at 28 days for the 25% replacement. The organic nature of sawdust likely interferes with the ability of the concrete matrix to densify and bond effectively, leading to weaker structures. Optimal compressive strength retention was observed at 5% and 10% replacement, where the strengths remained relatively close to the conventional levels, suggesting that incorporating sawdust up to these limits can produce sustainable concrete without significantly compromising structural integrity.

The analysis indicated a critical threshold for sawdust replacement in C-25 concrete with an optimal dosage of 10%. At this level, the compressive strength losses were minimal, with reductions of only 1.05% and 1.93% at 3 and 7 d, respectively. In contrast, exceeding 10% led to substantial declines in strength, culminating in a 34.19% decrease in compressive strength at 28 d for the 15% replacement compared with the control mix. This reduction is significant, as it falls below the acceptable thresholds for structural applications, indicating that a higher sawdust content not only diminishes the load-bearing capacity of concrete but also affects its long-term durability. The findings underscore the importance of adhering to established design standards, which suggest limiting organic replacements to a maximum of 10% to ensure structural safety and performance.

3.3. Impact of Partial Replacement of Raw Sawdust on Weight and Density of Hardened Concrete

In the investigation of sawdust as a partial sand replacement, the data in Table 4.2 highlights the impact of increasing sawdust content on the unit weight of concrete. As the sand replacement percentage rises from 0% to 25%, there is a clear reduction in unit weight, dropping from 2512.99 kg/m³ for the control mix to 1603.26 kg/m³ at the 25% replacement level. This reduction represents a 9.10% decrease in density compared to the control mix, with each 5% increase in sawdust content yielding a progressive reduction in unit weight. This trend indicates that sawdust contributes to lighter concrete mixtures, potentially benefiting applications requiring reduced dead loads, such as lightweight concrete structures or nonload-bearing elements.

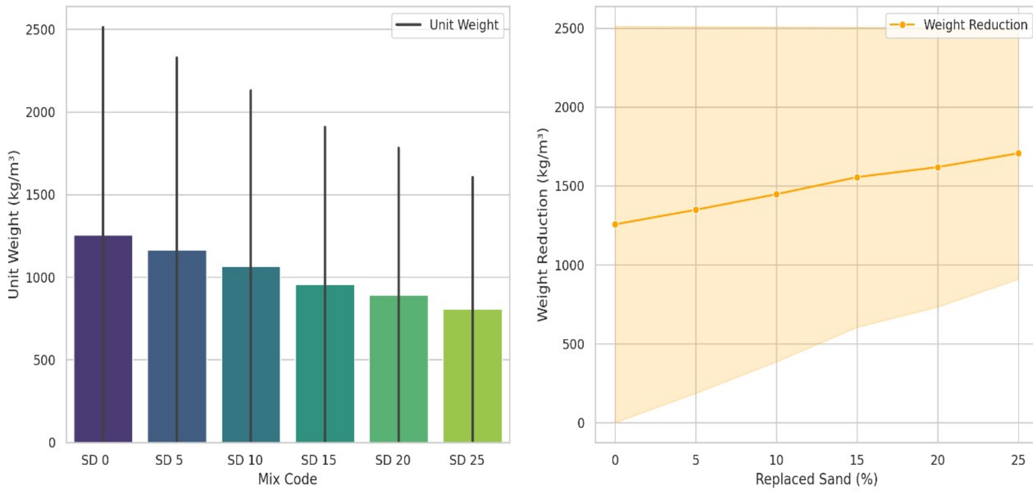

Figure 8: Impact of Partial Replacement of Raw Sawdust on Weight and Density of Hardened Concret

The analysis also revealed that each incremental increase in sawdust leads to predictable decreases in density, demonstrating the suitability of the material as a partial replacement while maintaining control over concrete weight reduction. According to civil engineering standards, lightweight concrete is often selected for applications that prioritize weight reduction over compressive strength, such as thermal or acoustic insulation layers in construction. Additionally, incorporating sawdust supports eco-friendly construction because it is an abundant, low-cost, and sustainable resource. These data suggest that sawdust could serve as an effective partial sand replacement in concrete, particularly in projects aimed at lightweight and sustainable design solutions.

3.4. Influence of Raw Sawdust on the Splitting Tensile Strength of Concrete

A splitting tensile strength test for the sawdust-sand-cement composite was conducted to evaluate the effect of raw sawdust on the tensile strength of hardened concrete. Cylinder samples (150 mm × 300 mm) were cured in water for 7 and 28 days, after which they were subjected to a gradually applied load until failure. The results showed that the 0% sawdust replacement had a 7-day tensile strength of 1.42 MPa, while the 5% sawdust replacement increased it slightly to 1.46 MPa, indicating a 2.81% increase. However, as the sawdust replacement increased to 10% and 15%, the tensile strength dropped by 5.97% and 21.27%, respectively.

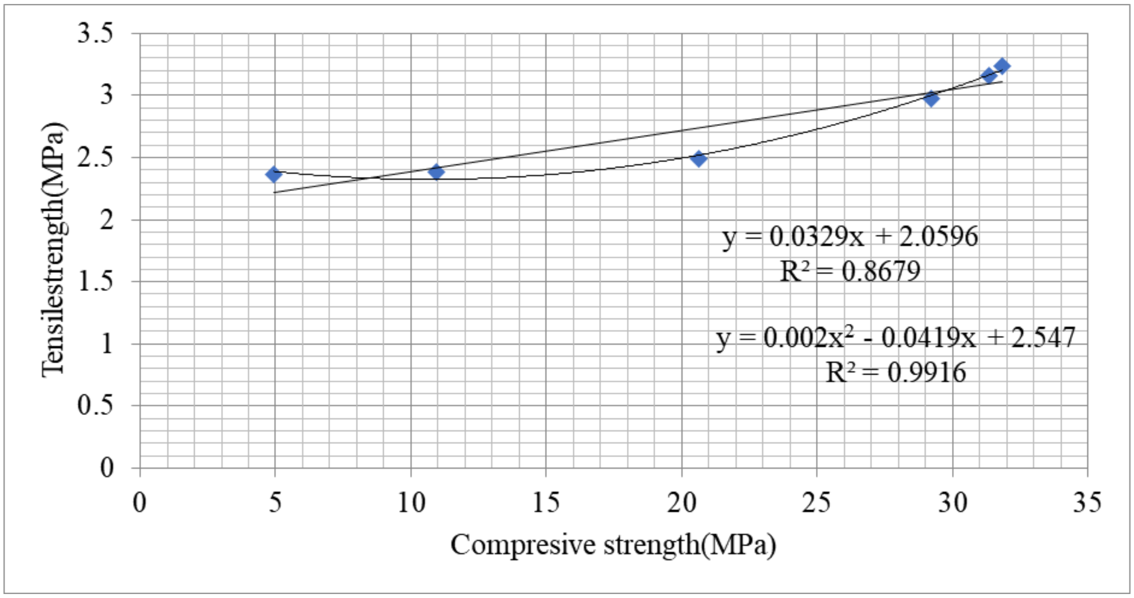

Figure 9: Influence of Raw Sawdust on the Splitting Tensile Strength of Concrete

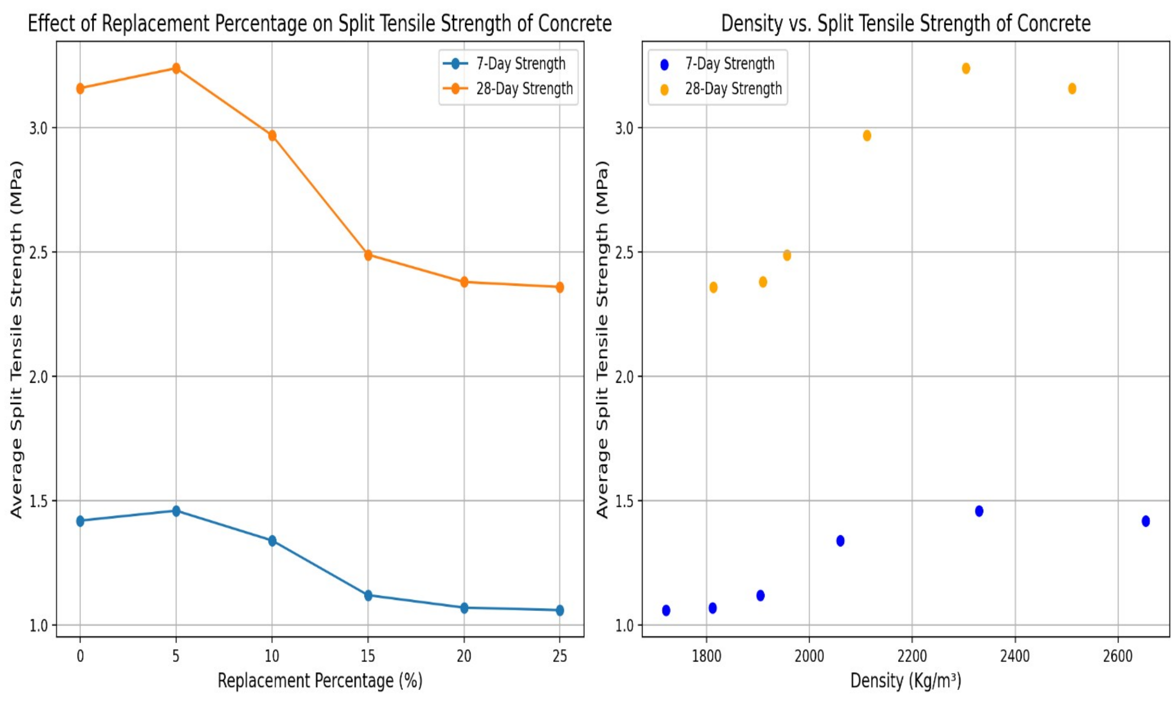

Figure 10: Impact of Replacement Percentage on Split Tensile Strength and Density-Tensile Strength Relationship in Concrete

At 28 days, the 0% sawdust sample achieved a tensile strength of 3.16 MPa. For the 5% replacement, the strength increased slightly by 2.44%; however, at higher sawdust levels, the tensile strength notably decreased. The 15% replacement sample showed a 34.19% reduction compared with the 0% replacement sample. This trend suggests that while a small amount of sawdust may enhance the tensile strength, higher percentages weaken it, likely owing to the structural limitations of the sawdust content in supporting tensile stress.

The observed relationships between the tensile and compressive strengths were modeled linearly and quadratically, with R^2 values of 0.8679 and 0.9916, respectively. These high R^2 values indicate a strong correlation, supporting the adequacy of these models for predicting the tensile behavior of sawdust-replaced concrete.

4.Economic and Cost Analysis

The economic analysis of using sawdust as a partial replacement for sand in concrete mix design revealed both cost savings and environmental benefits. With sawdust sourced locally and available at minimal or no cost, significant savings can be achieved, particularly when compared to the cost of traditional river sand, which varies with location. River sand costs, including transport costs, were evaluated from three sources Hiwane, Aby-Adi, and Wukro,

4.2. Breakdown of Cost Savings

The economic advantage primarily stems from the reduced demand for river sand, which, unlike sawdust, requires extensive processing and transportation and incurs significant costs. By reducing the sand content and substituting it with readily available sawdust, the material costs of concrete production are minimized.

Additionally, the reduction in sand consumption lowers the environmental impact associated with sand quarrying and transportation, aligning with sustainability goals, while offering cost-effective solutions for construction.

4.3. Environmental and Material Savings

Using sawdust, a recycled byproduct, not only reduces costs, but also reduces the environmental burden of waste disposal. The analysis showed that using 5% and 10% sawdust replacement could save 1.55% and 3.10% of the fine aggregate materials, respectively.

This practice further aligns with the circular economy principles by repurposing sawdust, reducing reliance on natural sand, and decreasing the overall carbon footprint of concrete production.

In summary, substituting sand with sawdust at the 5% and 10% levels presents a cost-effective and sustainable option for concrete production, with potential savings of up to 750 ETB/m^3 and significant environmental benefits. This approach not only reduces production costs, but also supports eco-friendly construction practices in regions where sand resources are scarce or costly.

Conclusion

This study assessed the viability of raw sawdust as a sustainable partial replacement for fine aggregates in concrete, primarily for normal-strength applications. Key findings include:

1. Strength Characteristics: Concrete with up to 10% sawdust replacement achieved 28-day compressive and tensile strengths comparable to those of conventional concrete. Although higher replacement levels did not increase the strength, sawdust-modified concrete satisfied the requirements for standard-grade concrete applications.

2. Workability and Water Demand: Increasing the sawdust content resulted in more pronounced mixing difficulties, mainly owing to the high water absorption of sawdust. Higher water-cement ratios are necessary for workability, which can complicate mix control.

3. Optimal Replacement Level: A 10% replacement level was optimal, achieving the C-25 concrete grade strength requirements. Replacement levels above 10% lead to noticeable strength reductions, making 10% the practical upper limit for sawdust use in concrete.

4. Economic and Weight Reduction Benefits: Sawdust-modified concrete offers a reduction in structural self-weight and an estimated 6% reduction in production costs at a 10% replacement. This cost-saving potential makes sawdust concrete attractive for projects with budget constraints.

5. Water Repellent Treatment: Treating sawdust with car oil waste successfully reduced water absorption by 31.8% without negatively affecting the strength or workability. This treatment is vital for improving the long-term durability of sawdust concretes.

6. Limitations at High Replacement Levels: Replacement levels beyond 10% were associated with strength reduction and handling issues, making them unsuitable for higher-strength applications.

7. Potential Structural Applications: The reduced weight and production cost of sawdust concrete make it suitable for non-load-bearing elements or structures in which a lower self-weight is advantageous.

Recommendations

1. Incorporation of Admixtures: For applications requiring higher sawdust percentages, the use of compatible admixtures, particularly water reducers and workability enhancers, is recommended. This can help maintain concrete performance and ease mixing challenges.

2. Consistent Sawdust Sourcing: Given sawdust variability, selecting sawdust with consistent properties—preferably sourced from stable, uniform wood types—is critical for ensuring strength and mix uniformity.

3. Curing Techniques: To mitigate the water absorption of sawdust and ensure proper hydration, adopting a sprinkling curing method instead of the traditional pond curing is advised. This approach minimizes the risk of excessive water absorption by sawdust, while promoting adequate hydration.

4. Enhanced Quality Control for Sawdust: Collecting sawdust free of impurities, such as soil or debris, is essential. The implementation of supplier-based quality controls can reduce the need for additional processing, improve consistency, and lower costs.

These recommendations can support the practical application of sawdust-modified concrete, advancing its sustainable potential in the construction industry while optimizing workability, strength, and economic viability.

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