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Experimental Investigation of Sawdust as a Sustainable Partial Replacement Material in Concrete Composites

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Abstract

This study experimentally investigated sawdust as a sustainable partial replacement material in C-25 concrete, addressing global concerns over natural sand depletion and environmental degradation. Treated sawdust, derived from lignocellulosic biomass rich in cellulose, hemicellulose, and lignin, plays a dual role in concrete composites: its porous structure lowers density, while its fibrous morphology can enhance internal bonding. However, untreated lignocellulose absorbs significant water, potentially weakening the cement matrix; therefore, the sawdust in this study was pre-treated with waste engine oil and lime water, reducing absorption from 34.98% to 10.79% in line with ASTM C330. Concrete mixes incorporating 0%, 5%, and 10% sawdust were evaluated for mechanical, physical, and economic performance. At the optimal 10% replacement, 28-day compressive strength reached 30.25 MPa, only 3.51% below the 31.35 MPa control, while splitting tensile strength decreased marginally by 2.53% (3.08 MPa vs. 3.16 MPa). Workability remained acceptable, with slump values of 37 mm compared to 45 mm for the control. Density dropped from 2512.99 kg/m³ to 2360.27 kg/m³, achieving a 6.08% reduction, beneficial for lightweight applications. Water absorption decreased by 31.8%, indicating improved durability, and production costs were reduced by up to 341.62 ETB/m³ (about 6.4% savings) when substituting 10% of sand with sawdust. Nonetheless, higher replacement levels (15–25%) caused strength losses exceeding 30%, confirming their unsuitability for structural use. Key limitations include the short-term scope of mechanical testing, exclusion of long-term durability assessments such as shrinkage, carbonation, and sulfate attack, and insufficient microstructural analysis to fully explain hydration–lignocellulose interactions. Additionally, the study focused on a single wood-waste source and treatment method, limiting generalizability. Despite these boundaries, the findings highlight the potential of treated sawdust to support circular-economy construction practices, reduce reliance on river sand, and promote environmentally responsible material innovation.

Keywords: Cost Efficiency, Compressive Strength, Circular Economy, Sawdust, Sustainable Concrete.

1. Introduction

Rapid global infrastructure growth and accelerated urbanization have substantially increased concrete consumption, intensifying pressure on natural resources—particularly river sand, a critical component in concrete production. Current estimates indicate that 32–50 billion tons of sand are extracted annually. A rate that exceeds natural replenishment and raises the possibility of global sand scarcity by 2050 if unsustainable practices continue. The United Nations Environment Program warns that excessive extraction from fluvial and coastal systems disrupts sediment balance, accelerates erosion, and contributes to habitat degradation and biodiversity loss. Empirical studies further report that indiscriminate sand mining destabilizes waterways, alters hydrological cycles, and reduces aquatic species diversity. Large-scale extraction has been associated with measurable declines in fish populations and deterioration of marine ecosystem health, underscoring the urgent need for sustainable alternatives. (Koehnken et al., 2020; Pandey, Kumar, Kumari, & Pandey, 2023; Rentier & Cammeraat, 2022).

Sawdust, an abundant lignocellulosic by-product of the wood-processing industry, offers a promising pathway to mitigate the environmental burden of sand mining. Its cellulose–hemicellulose–lignin composition contributes to lightweight characteristics, enhanced thermal performance, and potential internal micro-reinforcement within cementitious systems. Previous studies have shown that partial sand replacement with sawdust can reduce concrete density by 5–20% and improve thermal insulation by up to 35%. Economically, sawdust contributes to cost reduction due to its widespread availability and low processing requirements. Such attributes align with circular-economy principles by diverting wood waste from landfills and reducing demand for finite mineral resources (Asabonga, Cecilia, Mpundu, & Vincent, 2017; Rentier & Cammeraat, 2022).

Furthermore, A review of current literature reveals a persistent knowledge gap concerning the complex relationships among workability, strength development, durability, and cost in sawdust-modified concrete. While several studies highlight potential benefits, limited research quantifies the strength-to-cost trade-off or identifies optimal replacement ratios for practical construction use. Furthermore, most existing studies lack comprehensive assessments of microstructural evolution and long-term performance, including shrinkage, carbonation, and moisture-related degradation. (Deng, Li, Li, Lai, & Pan, 2022; Han et al., 2023).

Moreover, an easily available byproduct of the forestry industry, sawdust, is a viable way to lessen the environmental impact of producing concrete. Sawdust is an important resource for sustainable building because of its availability and waste management possibilities. Concrete's overall weight can be decreased by partially substituting sawdust for sand, which could result in construction and shipping cost reductions. (Malik et al., 2015; Omar, Abdullah, Rashid, & Rani, 2020; Raheem, Olasunkanmi, Folorunso, & journal, 2012). With advantages in terms of cost-effectiveness, decreased carbon footprint, and thermal and acoustic insulation, sawdust has the potential to be a sustainable partial sand substitute in the manufacturing of concrete (Ahmed et al., 2018; Batool, Islam, Cakiroglu, & Shahriar, 2021; Garg & Sharma, 2022).

However, more research and development are needed to address issues with its organic makeup, possible effects on strength and durability, and compatibility with other concrete components. Sustained research and development are essential to maximizing sawdust use in concrete, resolving current issues, and encouraging

the use of this environmentally friendly building material. To completely comprehend sawdust concrete's long-term performance, create mix designs that are optimal, and investigate cutting-edge pre-treatment techniques to improve its qualities, more research is required. 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 (Abdulhameed et al., 2023; Dadzie, Dokyi, Niakoh, & Research, 2018; Elahi, Shahriar, Alam, Abedin, & Materials, 2020; Ikponmwosa et al., 2020).

This assessment emphasizes sawdust's potential as an economical and environmentally friendly substitute for conventional sand in the manufacturing of concrete. However, when sawdust is utilized as a partial substitute for sand, there is a substantial knowledge gap regarding the intricate relationship between strength, workability, and cost. Future studies should concentrate on gaining a thorough grasp of the variables affecting sawdust concrete performance to provide useful recommendations for its application in environmentally friendly buildings. (Kotey et al., 2023; Majeed, 2024; Oluchiri, 2022; Oyedepo, Oluwajana, Akande, & Research, 2014; Siddique, Singh, Mehta, & Belarbi, 2020; Suliman, Razak, Mansor, Alisibramulisi, & Amin, 2019).

Given these gaps, the present study aims to evaluate the mechanical and economic viability of partially substituting sand with sawdust in C-25 structural concrete, a widely used grade in contemporary construction. The specific objectives are to assess compressive and tensile strength variations, analyze workability and density changes, determine the optimal sawdust replacement proportion, and evaluate overall cost efficiency. This research particularly targets lightweight, low-cost concrete suitable for non-load-bearing components such as residential slabs, partitions, and infill elements. The significance of this study lies in its potential to reduce dependence on natural sand, an increasingly scarce and expensive resource, while advancing eco-friendly construction solutions. By valorizing sawdust as a viable fine-aggregate substitute, this research supports sustainable material innovation, promotes resource conservation, and contributes to global efforts toward environmentally responsible infrastructure development.

2. Materials and Methodology

2.1. Materials

This study employed a systematic approach to evaluate the potential of sawdust as a partial sand replacement in concrete. Four primary components, cement, sawdust, fine aggregate (river sand), and coarse aggregate, were identified and incorporated into the mix design. The methodology encompassed material characterization, mix design development, concrete production, and comprehensive testing of physical and mechanical properties. These procedures aimed to assess the effects of sawdust on workability, compressive strength, tensile strength, and overall cost efficiency. The materials used are described as follows.

2.1.1. Cement

Messebo Ordinary Portland Cement (OPC), conforming to ES-1177-1:2005 and EN-197-1:2000 standards, was used for all concrete mixes. Its chemical and mineralogical composition promotes early strength development and ensures reliable hydration performance, as shown in Table 1.

Table 1. Messebo OPC Properties

Oxide (%)	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
Value	20.05	3.70	4.75	63.94	1.31	2.41

2.1.2 Fine Aggregate (River Sand)

River sand from the Hiwane area, located approximately 40 km from Mekelle, was used in this study. The sand initially contained 13% silt, which was reduced to 2.39% through thorough washing. The particle-size distribution and overall grading were then verified according to ES C.D3.201 and ASTM C330 standards. Results confirmed that the sand exhibited well-graded particle sizes, falling within the recommended limits for concrete production, as shown in Table 2.

Table 2. Summary of Fine Aggregate Properties

Test	Result	Test	Result
Fineness Modulus	2.93	Moisture Content	1.32%
Unit Weight (Compacted)	1758 kg/m³	Unit Weight (Loose)	1644 kg/m³
Bulk Specific Gravity	2.62	SSD Bulk Specific Gravity	2.71
Apparent Specific Gravity	2.79	Absorption Capacity	3.10%
Silt Content (pre-wash)	13%	Silt Content (post-wash)	2.39%

2.1.3 Coarse Aggregate

The coarse aggregate used in this study was basaltic crushed rock obtained from May-Weyni, Mekelle, with sizes of 10 mm, 20 mm, and a nominal maximum of 37.5 mm. Prior to use, the aggregates were sieved, thoroughly washed, and air-dried to ensure cleanliness and proper grading. The aggregate grading was verified in accordance with ASTM C330 and the standards ES-1177-1:2005 and EN-197-1:2000, ensuring structural consistency and appropriate workability within the concrete matrix, as shown in Table 3.

Table 3. Summary of Coarse Aggregate Properties

Test	Result	Test	Result
Unit Weight (Compacted)	1651.89 kg/m³	Unit Weight (Loose)	1435.22 kg/m³
Bulk Specific Gravity	2.62	SSD Bulk Specific Gravity	2.70
Apparent Specific Gravity	2.85	Absorption Capacity	3.09%
Moisture Content	0.08%	—	—

2.2. Properties of Raw Sawdust

The raw sawdust used in this study was collected from micro- and small-scale woodworking enterprises in Mekelle city, where it is typically discarded or sold at approximately ETB 10 per 100 kg. The sawdust, primarily derived from eucalyptus and acacia species, was evaluated using standard procedures for fine aggregates to assess its suitability for concrete production, as shown in Figure 1.



Figure 1. Sawdust waste around Mekelle Kebele 03

2.2.1 Particle Size Distribution

Sieve analysis of the raw sawdust was performed in accordance with ES C.D3.201 to evaluate its particle-size distribution and suitability as a concrete ingredient. The results demonstrated a well-graded distribution, with particle sizes adequately spanning the required range for fine aggregates. Comparison with ASTM C330 standards confirmed that the sawdust met the necessary specifications for use in concrete, including proper grading and uniformity, which are critical for achieving consistent workability and mechanical performance. These findings indicate that the sawdust possesses appropriate physical characteristics to function effectively as a partial replacement for natural sand in concrete mixes, supporting its potential use in sustainable construction applications, as shown in Table 4.

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Table 4. Particle Size Distribution of Raw Sawdust

Sieve (mm)	9.5	4.75	2.36	1.18	600µm	300µm	150µm	Pan
% Retained	0.89	8.89	11.93	25.62	27.77	15.81	6.68	2.42
% Passing	99.11	90.22	78.29	52.67	24.90	9.09	2.42	0.00

2.2.2 Unit Weight and Specific Gravity

Sawdust was found to have significantly lower densities compared to conventional mineral aggregates, classifying it as a lightweight material suitable for partial replacement in concrete. This characteristic can contribute to the production of lighter structural elements, potentially reducing overall dead loads and associated construction costs. Specific gravity tests conducted on the sawdust yielded values typical for organic materials, confirming its lower mass and porosity. These properties highlight the potential of sawdust to improve thermal insulation, handling, and sustainability in concrete applications without severely compromising performance, as shown in Table 5.

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Table 5. Physical Properties of Treated Sawdust

Property	Value	Property	Value
Fineness Modulus	3.4	Absorption Capacity	10.79%
Unit Weight (Compacted)	213 kg/m³	Bulk Specific Gravity	0.92
Unit Weight (Loose)	149 kg/m³	Bulk Specific Gravity (SSD)	1.01
Moisture Content	2.75%	Apparent Specific Gravity	1.02

2.2.3 Absorption Treatment

The sawdust, with a naturally high water absorption of 34.98%, was treated with waste engine oil at a rate of 10 g per 250 g of sawdust, reducing absorption to 10.79% and rendering it suitable for use as a lightweight aggregate according to ASTM C330 standards. This treatment also enhanced its fire resistance and dimensional stability. Subsequently, the sawdust was sun-dried, sieved to remove impurities and reduce moisture content, and pre-soaked in lime water to neutralize reactive organic compounds, thereby improving durability. Before incorporation, its physical and chemical properties were carefully characterized to minimize reactivity and optimize performance as a partial fine aggregate in concrete mixes, as shown in Table 6.

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Table 6. Treatment Ratio – Engine Oil to Sawdust

Material	Unit Wt. (kg/m³)	Ratio Used	Volume (m³)	Oil/Sawdust (L/m³)
Engine Oil Waste	840	0.01 kg	0.000012	10.16
Sawdust	213	0.25 kg	0.0012	—

2.2.4 Chemical Composition

Chemical analysis conducted at Messebo Cement Factory showed that the cement contains high levels of silica (41.38%) and calcium (32.28%). These components support potential pozzolanic reactions and contribute to internal curing, enhancing hydration, strength development, and durability in concrete mixes, as shown in Table 7.

Table 7. Chemical Composition of Raw Sawdust

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
41.38 %	5.33%	5.03 %	32.28 %	2.90 %

2.2.5 Mix Design

Concrete mixes were prepared using a water–cement ratio of 0.49 and cement content of 360 kg/m³, as per C25-grade requirements. The mix followed the absolute volume method and included sawdust at replacement levels of 0%, 5%, 10%, 15%, 20%, and 25% by weight of sand. However, only 0%, 5%, and 10% are reported in this journal manuscript for their optimal performance in mechanical tests. To evaluate the mechanical and physical performance of sawdust-replaced concrete, a comprehensive experimental program was implemented. Standardized tests were conducted on all mixes to assess their structural behavior and material characteristics. These included the slump test (ASTM C143) for workability, compressive strength testing (ASTM C39) at 7, 14, and 28 days, and split tensile strength testing (ASTM C496) at 28 days. Additionally, density and weight analyses were performed to determine the lightweight properties of the concrete, alongside water absorption tests to assess potential durability implications, and the concrete specimens were cured in water at a temperature of 23 ± 2°C, in accordance with standard laboratory curing conditions recommended by ASTM C511.

Moreover, this study adopted C25-grade concrete as the baseline to examine the practical viability of sawdust as a partial sand replacement. Unlike higher-strength concrete grades (C30–C40) used in modern structural applications, C25 was selected due to its relevance in lightly-loaded and non-load-bearing components such as partition walls and floor slabs. The selected grade also allowed for a controlled evaluation of the material's performance under moderate loading conditions. Initial results revealed a trade-off between sustainability and strength performance. Owing to its high organic content and elevated absorption rate, untreated or excessive sawdust replacement was found to reduce compressive strength significantly. Specifically, a 10% replacement level led to a reduction of approximately 34% in 28-day compressive strength. These findings underscore the need for optimal replacement thresholds and material treatment to balance structural integrity with eco-efficiency.

Furthermore, an economic assessment was performed to evaluate the cost-effectiveness of partially replacing river sand with sawdust in C25-grade concrete production. The analysis considered direct material costs per cubic meter at substitution levels of 0%, 2.5%, 5%, and

10%. Sawdust, sourced locally from woodworking enterprises at 10 ETB per 100 kg (approximately 21.30 ETB/m³), provides a highly cost-effective and environmentally favorable alternative to conventional sand. Three common sand sources in the Tigray region—Aby Adi (55,000 ETB/truck), Hiwane (29,000 ETB/truck), and Wukro (36,000 ETB/truck), with truck capacities of 16 m³—correspond to unit costs of 3,437.50 ETB/m³, 1,812.50 ETB/m³, and 2,250.00 ETB/m³, respectively. At 10% sawdust replacement, fine aggregate costs per cubic meter decrease to 3,095.88 ETB (Aby Adi), 1,633.38 ETB (Hiwane), and 2,027.13 ETB (Wukro), yielding savings of 341.62 ETB, 179.12 ETB, and 222.87 ETB per cubic meter. Even lower replacement levels of 2.5% and 5% produce measurable cost reductions. For example, scaling production to 100 m³ of concrete could save over 34,000 ETB using Aby Adi sand. Beyond financial benefits, the partial replacement approach reduces river sand extraction, valorizes wood waste, and supports sustainable, circular construction practices.

3. Results and Discussion

This study experimentally investigated sawdust as a sustainable partial replacement for sand in concrete composites. Experiments were conducted in three phases across replacement levels of 0%, 5%, 10%, 15%, 20%, and 25%. Phase I evaluated workability and compressive strength using a fixed water-to-cement (W/C) ratio. Phase II examined the weight and density of hardened concrete, highlighting the lightweight properties of sawdust. Phase III assessed split tensile strength to determine concrete resilience under stress. Results indicate that an optimal sawdust replacement achieves a balance between structural performance and environmental benefits, supporting its potential as an eco-friendly concrete alternative. Workability was assessed using standard slump tests, and compressive strength measurements were taken at 3, 7, and 28 days in accordance with established civil engineering standards.

3.1 Impact of Sawdust Substitution as a Fine Aggregate on Concrete Workability

The study revealed an inverse relationship between sawdust content and concrete workability, as measured by slump tests. The control mix without sawdust had a slump of 45 mm, which decreased progressively with higher sawdust replacement: 42 mm at 5%, 37 mm at 10%, and sharply reduced to 15 mm and 10 mm at 20% and 25% replacement levels, respectively.

According to ASTM C143, an acceptable slump variation is approximately 2 mm; therefore, the reductions observed at 5% and 10% sawdust replacement are statistically negligible, indicating that workability remains suitable for practical use. In contrast, the substantial slump decline at 20% and 25% replacement reflects reduced fluidity and compatibility, caused by sawdust's high absorption and fibrous texture, which may hinder concrete placement. Consequently, while sawdust contributes to sustainability, its use should be limited to 10% for applications requiring high workability or supplemented with admixtures to offset these effects, as shown in Figure 2.

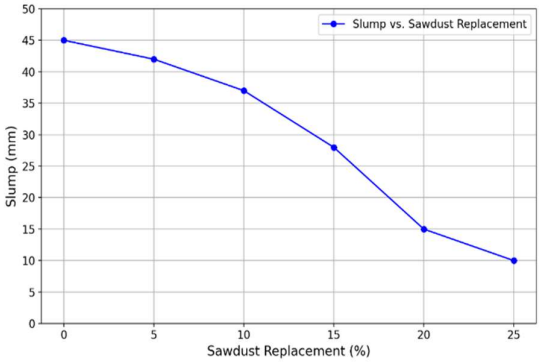


Figure 2. Impact of Sawdust Substitution as a Fine Aggregate on Concrete Workability

3.2 Impact of Curing Time and Sawdust Substitution on Compressive Strength

Compressive strength tests showed that concrete performance increased significantly over time, with values varying according to sawdust content. For the control mix (0% sawdust), strengths were 10.85 MPa at 3 days, 17.79 MPa at 7 days, and 31.35 MPa at 28 days, consistent with the expected properties of C-25 grade concrete.

As sawdust replacement increased beyond 10%, compressive strength declined sharply. For the 25% replacement mix, strengths were 3.54 MPa at 3 days, 4.33 MPa at 7 days, and 4.93 MPa at 28 days. This reduction is attributed to the organic nature of sawdust, which interferes with matrix densification and bonding, resulting in weaker concrete. Optimal strength retention occurred at 5% and 10% replacement, where compressive values remained close to conventional levels, indicating that these dosages can produce sustainable concrete without significantly compromising structural integrity.

Analysis identified 10% sawdust as the critical threshold for C-25 concrete. At this level, compressive strength losses were minimal only 1.05% at 3 days and 1.93% at 7 days, demonstrating a negligible impact on performance. Exceeding 10% caused substantial reductions, with a 34.19% decrease at 28 days for the 15% replacement compared to the control, falling below acceptable thresholds for structural applications. These findings highlight that higher sawdust content not only diminishes load-bearing capacity but may also compromise long-term durability. Therefore, adhering to established design standards and limiting organic replacements to 10% is essential to ensure structural safety and performance, as shown in Figure 3.

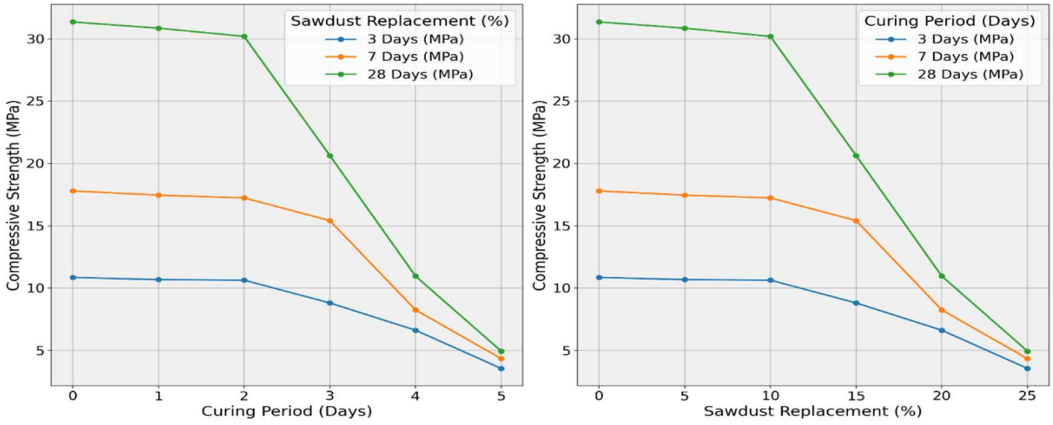


Figure 3. Impact of Curing Time and Sawdust Substitution on Compressive Strength

3.3 Impact of Partial Sawdust Replacement on Concrete Weight and Density

The effect of sawdust as a partial sand replacement on concrete unit weight was investigated. As the replacement level increased from 0% to 25%, unit weight decreased from 2,512.99 kg/m³ for the control mix to 1,603.26 kg/m³ at 25% replacement. This represents a 9.10% reduction in density, with each 5% increment in sawdust content producing a progressive decrease in unit weight. The results demonstrate that sawdust effectively reduces concrete density, making it suitable for applications where lower dead loads are advantageous, such as lightweight structural elements or non-load-bearing components.

The analysis further showed that incremental increases in sawdust content result in predictable reductions in concrete density, confirming its suitability as a partial sand replacement while allowing controlled weight reduction. Lightweight concrete is commonly employed in applications prioritizing reduced dead load over compressive strength, such as thermal or acoustic insulation layers. Moreover, using sawdust promotes sustainable construction, as it is an abundant, low-cost, and environmentally friendly resource. These findings indicate that sawdust can serve as an effective partial replacement for sand, particularly in projects targeting lightweight, cost-effective, and sustainable concrete solutions, as shown in Figure 4.

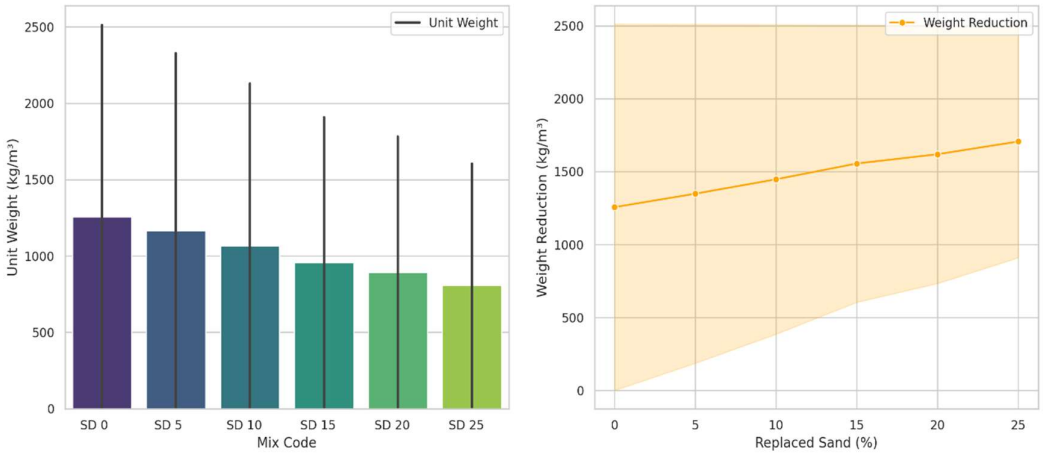


Figure 4. Effects of Partially Replacing Raw Sawdust on Concrete's Density and Weight.

3.4 Sawdust's Effect on Concrete's Splitting Tensile Strength

Splitting tensile strength tests were performed to assess the influence of raw sawdust on concrete's tensile behavior. Cylindrical specimens (150 mm × 300 mm) were cast with sawdust replacing fine aggregates at 0%, 5%, 10%, and 15%, then cured for 7 and 28 days. At 7 days, the control mix (0% sawdust) exhibited a tensile strength of 1.42 MPa, which slightly increased to 1.46 MPa (a 2.81% gain) at 5% replacement. However, higher sawdust contents led to reductions of 5.97% and 21.27% at 10% and 15% replacement, respectively, indicating diminished tensile performance at elevated dosages, as shown in Figure 5. The split tensile strength is a test to determine the tensile strength of concrete indirectly using concrete cylinder specimens. Simply use compressive strength with a loading and alter the longitudinal location of the specimen to perform the split tensile strength test. The formula in the equation was used to determine the maximum tensile stress, as shown in the equation. (1).

$$fst = \frac{2P}{\pi ld} \quad (1)$$

Where is the load applied to the cylinder in Newtons fst Is the split tensile stress in N/mm² l Is the length of the cylinder in mm, and d Is the diameter of the cylinder in mm.

The reduction in tensile performance observed with increasing sawdust content is consistent with previous studies that attribute strength losses to a weakened interfacial transition zone (ITZ) between aggregates and cement paste. Sawdust, being a porous and organic material, negatively impacts the ITZ due to its rough surface texture, irregular particle shapes, and limited mineral compatibility, which collectively reduce the bond strength with the surrounding cement matrix. While small

quantities of sawdust may improve internal packing and slightly enhance tensile performance, higher replacement levels disrupt the structural continuity necessary to resist tensile stresses effectively. Moreover, the inherently low tensile strength and high flexibility of sawdust limit its capacity to transfer loads within the concrete matrix.

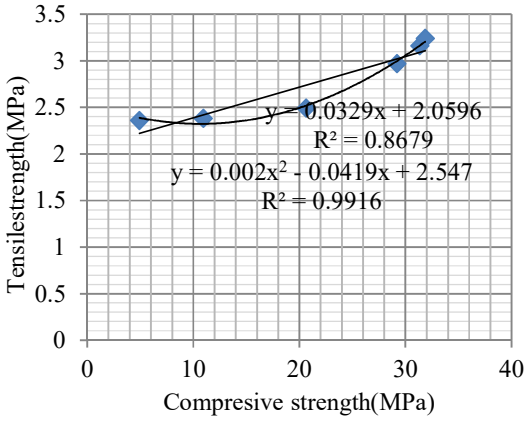


Figure 5. Sawdust's Effect on Concrete Splitting Tensile Strength

Microstructural analyses, including SEM and XRD, confirm that the fibrous nature of sawdust introduces voids and microcracks at the ITZ, which facilitate early crack initiation under stress. Therefore, while minimal incorporation of sawdust may be beneficial, higher percentages compromise tensile integrity and should be carefully limited in sustainable concrete mix designs.

At 28 days, the control concrete sample without sawdust exhibited a tensile strength of 3.16 MPa. Incorporating 5% sawdust as a partial sand replacement slightly increased tensile strength by 2.44%, suggesting a minor improvement due to enhanced internal packing. However, higher sawdust replacement levels led to significant reductions in tensile performance. For instance, the 15% replacement mix experienced a 34.19% decrease compared with the control, highlighting that excessive sawdust compromises the concrete's ability to resist tensile stresses due to its limited structural capacity and low tensile strength. To further understand this relationship, linear and quadratic models were fitted to correlate tensile and compressive strengths, yielding R^2 values of 0.8679 and 0.9916, respectively. These high correlation coefficients indicate strong predictive reliability of the models for assessing tensile behavior in sawdust-modified concrete, as shown in Figure 6.

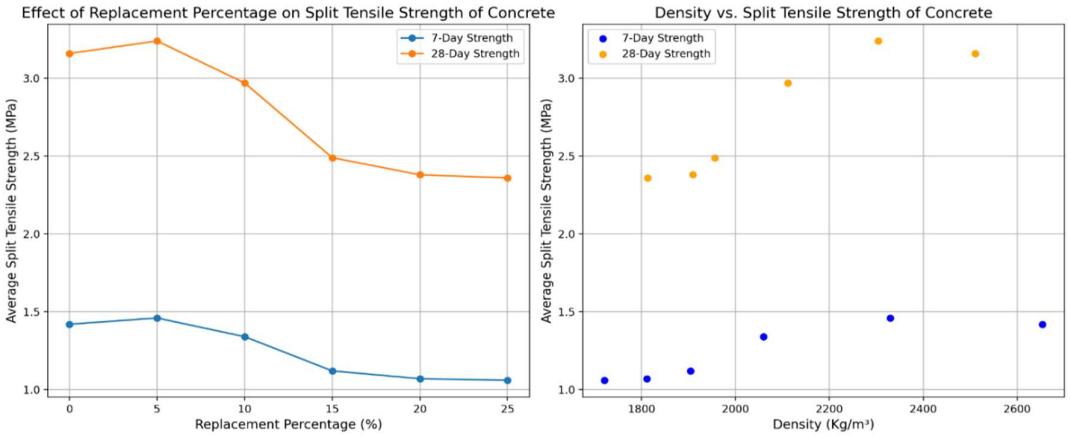


Figure 6. Impact of Replacement Percentage on the Relationship between Density and Tensile Strength and Split in Concrete Strength in Tensile

Furthermore, an economic assessment was conducted to evaluate the cost-effectiveness of partially replacing river sand with sawdust in C25-grade concrete. The analysis examined direct material costs per cubic meter at replacement levels of 0%, 2.5%, 5%, and 10%. Locally sourced sawdust, obtained from

woodworking enterprises at 10 ETB per 100 kg (approximately 21.30 ETB/m³), offers a highly cost-effective and environmentally sustainable alternative to conventional sand. Three commonly used sand sources in the Tigray region, Aby Adi (55,000 ETB/truck), Hiwane (29,000 ETB/truck), and Wukro (36,000 ETB/truck), with truck capacities of 16 m³—translate to unit costs of 3,437.50 ETB/m³, 1,812.50 ETB/m³, and 2,250.00 ETB/m³, respectively. At 10% sawdust replacement, fine aggregate costs per cubic meter decreased to 3,095.88 ETB (Aby Adi), 1,633.38 ETB (Hiwane), and 2,027.13 ETB (Wukro), yielding savings of 341.62 ETB, 179.12 ETB, and 222.87 ETB per cubic meter. Even lower replacement levels of 2.5% and 5% provided measurable cost reductions. For example, scaling production to 100 m³ of concrete could save over 34,000 ETB using Aby Adi sand. Beyond financial benefits, this approach reduces river sand extraction, valorizes wood waste, and promotes sustainable, circular construction practices.

Moreover, the use of sawdust as a partial replacement for sand in concrete not only reduces reliance on finite natural resources but also contributes to environmental sustainability. Life Cycle Assessment (LCA) studies indicate that incorporating sawdust can significantly lower the embodied energy and carbon footprint of concrete production. By diverting wood waste from landfills and reducing river sand extraction, sawdust incorporation minimizes ecological degradation, including habitat destruction, erosion, and biodiversity loss associated with conventional sand mining. For example, substituting 10% of fine aggregate with sawdust can reduce material-related CO_2 emissions and energy consumption by approximately 5–8%, depending on local sourcing and processing methods. These environmental benefits, combined with cost savings and lightweight properties, demonstrate that sawdust-replaced concrete aligns with circular economy principles and supports the development of more sustainable construction practices.

4. Conclusion

This experimental study investigated the use of sawdust as a sustainable partial replacement for sand in concrete composites. The findings demonstrate that incorporating sawdust up to 10% can produce lightweight, cost-effective concrete with mechanical properties comparable to conventional C-25-grade concrete. The study highlights both practical and environmental implications of sawdust use, providing insights for sustainable construction and circular economy practices. Key conclusions and broader impacts are summarized as follows:

- Concrete with up to 10% sawdust replacement achieved 28-day compressive and tensile strengths comparable to conventional concrete; higher replacements reduced strength and increased water demand, complicating workability and mix control.
- Treatment of sawdust with waste automobile oil reduced water absorption by 31.8% without affecting workability or strength, enhancing durability; however, the environmental implications of using engine oil require careful management or alternative eco-friendly treatments.
- A 10% replacement was identified as the optimal limit, meeting C-25 strength standards, reducing concrete weight, and achieving approximately 6% production cost savings, making it suitable for budget-conscious and lightweight construction projects.
- Sawdust incorporation supports circular economy principles by valorizing wood waste, reducing

dependence on river sand, and promoting sustainable construction practices.

- Policy relevance includes providing guidance for industry adoption of eco-friendly concrete materials and encouraging regulations that support sustainable material use.
- Future research directions include long-term durability testing, comprehensive life cycle assessments (LCA), optimization of sawdust treatment methods, and pilot-scale implementation trials to validate practical performance and scalability of sawdust-modified concrete.

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