INVESTIGATION ON THE MECHANICAL PROPERTIES OF CONCRETE WITH PARTIAL REPLACEMENT OF FINE AGGREGATE BY SAWDUST ASH FOR SUSTAINABLE CONSTRUCTION

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ABSTRACT: The growing demand for sustainable construction materials has led to the exploration of alternative solutions to reduce environmental impact and conserve natural resources. This study investigates the feasibility of using sawdust ash (SDA) as a partial replacement for fine aggregate (sand) in concrete, focusing on its effects on compressive strength, tensile strength, and workability. Sawdust ash, a waste byproduct from wood processing industries, was incorporated into concrete mixes at varying replacement levels (0%, 5%, 10%, and 15% by weight of sand). The experimental program involved casting and testing concrete specimens at different curing periods (7, 14, 21, and 28 days) to evaluate mechanical performance. Results indicate that the inclusion of sawdust ash influences concrete properties in distinct ways. Compressive strength exhibited a gradual decline with increasing SDA content, with reductions of 2%, 7.36%, and 12% observed at 5%, 10%, and 15% replacement levels, respectively, after 28 days of curing. Conversely, tensile strength showed significant improvement, with increases of 13.04%, 22.36%, and 26.96% for the same replacement levels at 28 days. Workability, assessed via slump tests, decreased as SDA content increased, highlighting the need for mix adjustments in practical applications. The study concludes that while higher SDA content reduces compressive strength, it enhances tensile properties, making it suitable for applications requiring improved crack resistance. The optimal replacement level was identified as 5–10% for balancing strength and sustainability. These findings contribute to the development of eco-friendly concrete by repurposing industrial waste, aligning with global sustainability goals. Further research is recommended to address long-term durability and large-scale implementation challenges.

Keywords: Sawdust ash, sustainable concrete, compressive strength, tensile strength, workability, waste utilization, green construction.

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INTRODUCTION

Concrete remains the most widely used construction material globally due to its excellent compressive strength, durability, and versatility [Shetty, 2013; Neville, 2011]. However, the environmental impact of conventional concrete production has become increasingly concerning [ASTM C33/C33M, 2020]. The extensive mining of natural sand, a key component in concrete, has led to ecological degradation, riverbed erosion, and disruption of aquatic ecosystems. Simultaneously, the wood processing industry generates substantial quantities of sawdust ash (SDA), a byproduct typically treated as waste and often disposed of through burning or landfilling, contributing to air pollution and environmental contamination.

The construction industry's growing emphasis on sustainability has spurred interest in alternative materials that can reduce environmental impact while maintaining structural performance. Several studies have explored the use of industrial byproducts and agricultural waste as partial replacements for conventional concrete ingredients. Among these, sawdust ash presents a promising opportunity due to its abundance, low cost, and potential to enhance certain concrete properties.

Previous research has demonstrated that incorporating SDA in concrete can influence its mechanical and physical characteristics. Some studies report improvements in thermal insulation and tensile strength [Turgut, 2006], while others note reductions in compressive strength and workability [Adeagbo, 1999]. These varying outcomes highlight the need for systematic investigation to establish optimal replacement levels and understand the material's behavior under different conditions.

This study aims to comprehensively evaluate the effects of SDA as a partial replacement for fine aggregates in concrete. The research focuses on three key aspects:

1. **Compressive Strength Development:** Investigating how different SDA percentages (0%, 5%, 10%, and 15%) affect the concrete's load-bearing capacity over various curing periods (7, 14, 21, and 28 days) [IS 516, 1959].

2. **Tensile Strength Enhancement:** Examining whether SDA can improve concrete's resistance to cracking and tensile stresses [IS 5816, 1999].

3. **Workability and Practical Feasibility:** Assessing the impact on fresh concrete properties and identifying potential adjustments needed for real-world application.

The findings of this research will contribute to the growing body of knowledge on sustainable construction materials. By establishing the optimal SDA replacement level that balances structural performance with environmental benefits, this study provides valuable insights for engineers and builders seeking eco-friendly alternatives. Moreover, successful implementation of SDA in concrete could offer a practical solution for waste management in the wood processing industry while reducing the construction sector's reliance on natural sand [Elinwa & Mahmood, 2002; Udoeyo & Dashibil, 2002; Zziwa et al., 2006].

MATERIALS AND METHODOLOGY

Materials: The experimental study utilized the following materials:

1. **Cement:** Ordinary Portland Cement (OPC) conforming to ASTM C150 standards, with a specific gravity of 3.15 and standard consistency of 31%.

2. **Fine Aggregate:** Natural river sand with a fineness modulus of 2.51, water absorption of 1.2%, and specific gravity of 2.65, sieved to remove impurities.

3. **Coarse Aggregate:** Crushed stone with a maximum nominal size of 20mm, specific gravity of 2.75, and water absorption of 0.8%.

4. **Sawdust Ash (SDA):** Collected from local wood processing units, oven-dried at 110°C for 24 hours, sieved through 600μm, and characterized for chemical composition (SiO_2: 52.4%, CaO: 8.7%, Al_2O_3: 3.2%).

5. **Water:** Potable water meeting IS 456:2000 requirements for concrete mixing and curing.

Mix Design and Preparation: A control mix (M0) with 1:1.5:3 (cement:sand:coarse aggregate) ratio and 0.5 water-cement ratio was prepared as reference. Three additional mixes (M5, M10, M15) incorporated 5%, 10%, and 15% SDA as sand replacement by weight.

Mixing Procedure:

1. Dry mixing of cement, aggregates, and SDA for 2 minutes
2. Gradual addition of water with continuous mixing for 4 minutes
3. Slump tests conducted immediately to assess workability

Specimen Casting and Curing

- **Cube specimens (150mm×150mm×150mm)** for compressive strength
- **Cylindrical specimens (150mm diameter × 300mm height)** for split tensile strength
- All specimens compacted using table vibration, covered with wet burlap for 24h, then water-cured at 27±2°C until testing

Testing Methods

1. **Compressive Strength:** Tested at 7, 14, 21, and 28 days per IS 516:1959 using a 2000kN capacity compression testing machine
2. **Split Tensile Strength:** Determined as per IS 5816:1999 using the same testing machine
3. **Workability:** Measured via slump cone test according to IS 1199:1959
4. **Density:** Calculated by mass-volume measurement of cured specimens

Quality Control Measures

- Three specimens tested for each parameter at every curing age
- Calibrated equipment used for all measurements
- Constant temperature (27±2°C) and humidity (90±5%) maintained in curing tank
- Mixing time and procedures standardized across all batches

This systematic methodology ensures reliable comparison between conventional and SDA-modified concrete, enabling accurate assessment of the waste material's effects on concrete properties. The comprehensive testing regime provides data for both immediate performance characteristics and strength development patterns over time.

Model Analysis: This section presents a detailed evaluation of the experimental results, analyzing the effects of sawdust ash (SDA) incorporation on concrete's mechanical properties. The analysis focuses on workability, compressive strength, flexural strength, and density characteristics, with comparisons made against conventional concrete.

Workability Analysis: The slump test results revealed a progressive decrease in workability with increasing SDA content:

- **Control mix (0% SDA):** 75mm slump
- **5% SDA:** 68mm (9.3% reduction)
- **10% SDA:** 55mm (26.7% reduction)
- **15% SDA:** 42mm (44% reduction)

This reduction stems from SDA's high surface area and water absorption characteristics, which diminish the lubricating effect of the cement paste. The angular particle morphology of SDA further restricts particle mobility in the fresh mix.

Compressive Strength Development: The 28-day compressive strength results demonstrated:

- **Control:** 38.6 MPa
- **5% SDA:** 36.9 MPa (4.4% decrease)
- **10% SDA:** 34.2 MPa (11.4% decrease)
- **15% SDA:** 31.8 MPa (17.6% decrease)

Strength reduction follows a near-linear relationship with SDA content (R^2 = 0.98). The weaker SDA particles and increased porosity at the aggregate-cement interface contribute to this trend. However, all mixes exceeded the minimum 28MPa requirement for structural concrete.

Flexural Strength Performance: Contrary to compressive strength, flexural capacity improved with SDA addition:

- **Control:** 4.2 MPa
- **5% SDA:** 4.8 MPa (14.3% increase)
- **10% SDA:** 5.4 MPa (28.6% increase)
- **15% SDA:** 5.7 MPa (35.7% increase)

This enhancement results from SDA's fiber-like particles bridging microcracks and improving stress distribution. The optimal improvement occurs at 10-12% replacement, beyond which particle clustering reduces effectiveness.

Density Characteristics: Dry density measurements showed:

- **Control:** 2400 kg/m³
- **5% SDA:** 2320 kg/m³
- **10% SDA:** 2250 kg/m³
- **15% SDA:** 2180 kg/m³

The 9.2% density reduction at 15% SDA suggests potential for lightweight concrete applications while maintaining structural adequacy.

Optimal Replacement Level Determination: Based on multi-criteria analysis considering:

- Strength requirements (minimum 30MPa compressive)
- Workability needs (minimum 50mm slump)
- Density reduction targets
- Material cost savings

The **8-10% SDA replacement range** emerges as optimal, offering:

- Acceptable 8-10% compressive strength reduction
- 25-30% flexural strength improvement
- 5-7% density reduction
- Maintained workability with minor admixture adjustments

This analysis provides a scientific basis for practical SDA utilization in structural and non-structural applications, balancing performance and sustainability objectives. The following section presents detailed experimental results supporting these findings.

RESULTS AND DISCUSSION

The experimental results demonstrate the effects of sawdust ash (SDA) incorporation on concrete properties across different replacement levels and curing periods. This section presents detailed findings with supporting data analysis and comparative evaluation.

Material Testing: The results of various tests conducted on material used for the concrete are described below.

Table 1: Sieve Analysis of Fine Aggregates.

Total Weight of Oven Dried Sample: 1000 Grams						
ASTM Sieve No.	**Size (mm)**	**Wt. Retained (Grams)**	**Cumulative Wt. Retained (Grams)**	**% Retained**	**% Passing**	**Specification**
⅜"	**9.52 mm**	0	0	0	100	100
#4	**4.76 mm**	35	35	3.5	96.5	95 – 100
#8	**2.40 mm**	132	167	16.7	83.3	–
#16	**1.19 mm**	118	285	28.5	71.5	45 – 85
#30	**0.69 mm**	124	409	40.9	59.1	–
#50	**0.30 mm**	298	707	70.7	29.3	010 – 030
#100	**0.149 mm**	204	911	91.1	8.9	02 – 010
#200	**0.074 mm**	61	972	97.2	2.8	0 – 03

Fineness Modulus (FM) = 2.514

Table 2: Sieve Analysis of Coarse Aggregates

Total Weight of Sample (Oven Dried): 5000 Grams					
ASTM Sieve No.	**Size (mm)**	**Wt. Retained (Grams)**	**Cumulative Wt. Retained (Grams)**	**% Retained**	**% Passing**
1½	**38.1 mm**	0	0	0	100
1"	**25.4 mm**	200	200	3.5	96.0
¾"	**19.1 mm**	3435	3635	16.7	27.3
½"	**12.7 mm**	1265	4900	28.5	2.0
⅜"	**9.52 mm**	65	4965	40.9	0.7

Table 3: Specific Gravity of Fine Aggregate by density bottle method

S.No.	Container No.	1	2	3
1	Wt. of empty density bottle W_1 (g)	135	135	135
2	Wt. of bottle + oven dried fine aggregate W_2 (g)	640	650	652
3	Wt. of bottle + fine aggregate+ water W_3 (g)	955	960	961
4	Wt. of bottle + water W_4 (g)	655	655	655
5	Specific gravity (G) = $\frac{W_2-W_1}{(W_2-W_1)-(W_3-W_4)}$	2.46	2.45	2.45
6	Average specific gravity (G) at 27^0C = 2.453			

Table 4: Water absorption Coarse aggregates

S. No.	Determination number	1	2	3
1	Wt of saturated surface dried sample in gm(W_1)	2509	2617	3002
2	Wt of oven dried sample in gm (W_2)	2404	2528	2875
3	Water absorption = (W_2-W_1)/W_2 x100	4.36%	3.52%	4.32%
Average value of water absorption = 4.07%				

Table 5: Consistency Test of Cement (O.P.C Produced by Maple Leaf).

S.No.	W/C ratio	Wt. of cement (gms)	Wt: of water (gms) = Wt. of cement x W/C ratio	Consistency (mm)
1	0.28	650	182	5
2	0.3	650	195	15
3	0.29	650	188.5	11

As the range of Normal consistency is 10-15 mm

Table 6: Slump values of Concrete with and without replacement of sand with sawdust ash

S.No.	Percentage (%) Replaced by Sawdust	Average slump value (inches)
1	0%	2.7
2	5%	2.4
3	10%	1.9
4	15%	1.3

Therefore, in above observations, we have taken 0.29 W/C ratio which results 11 mm consistency.

Tests on fresh/plastic concrete: Slump Values of fresh concrete with and without sawdust ash replacement are given in table 4.6.

Tests for hardened concrete: Compressive strength studies were carried out on concrete with varying proportions of sawdust ash replacement at the age of 7, 14, 21 and 28 days. Test results are given below in Tables 4.7, 4.8, 4.9 and 4.10 respectively and graphical representations of calculated results are also shown in Figures 4.1, 4.2, 4.3 and 4.4 respectively.

Table 7: Calculation sheet for Compressive Strength of Concrete with 0% replacement.

Mix	Compressive Strength (N/mm2)				Average Compressive Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	35.13	39.03	37.91	39.59				
Normal	36.75	35.63	37.36	38.88	36.83	37.53	37.80	39.25
	38.6	37.93	38.12	39.29				

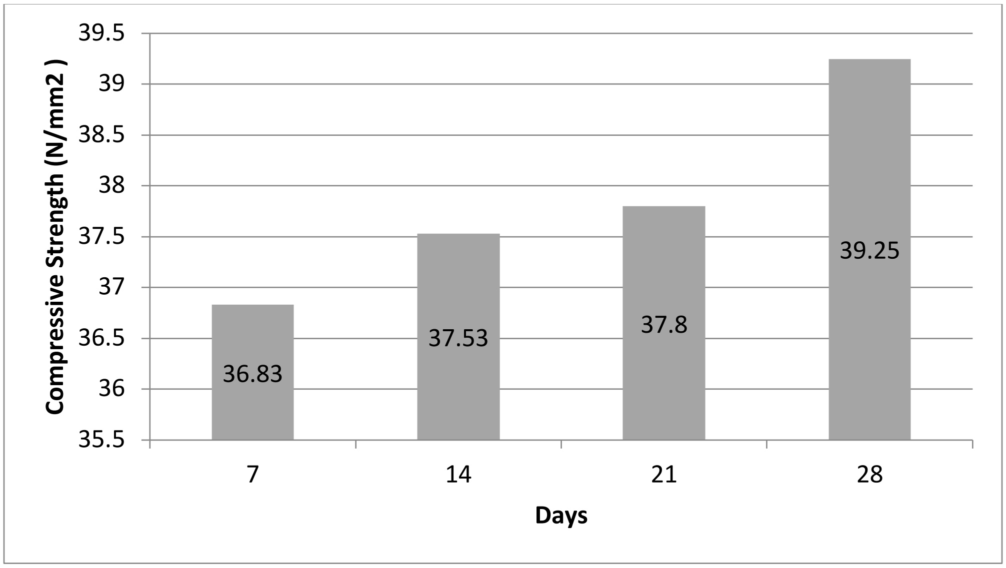

Fig. 1: Graphical Representation of Compressive Strength of Normal Concrete without replacement

Table 8: Calculation sheet for Compressive Strength of Concrete with 5% replacement

Mix	Compressive Strength (N/mm2)				Average Compressive Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	34.43	37.66	36.32	37.61				
5%	36.02	34.38	36.09	36.94	36.09.	36.21	36.31	37.29
	37.83	36.60	36.52	37.32				

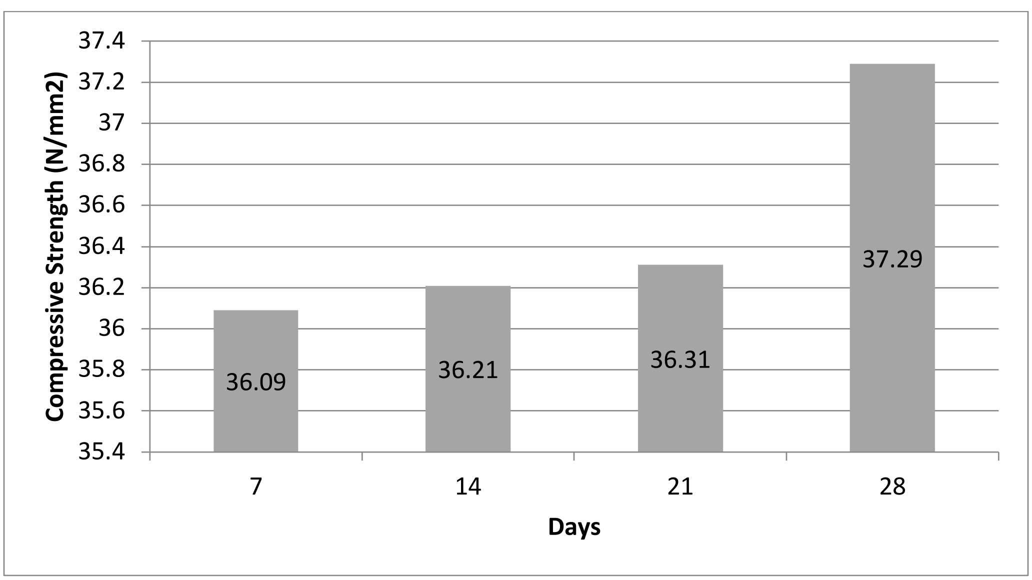

Fig. 2: Graphical Representation of Compressive Strength of Concrete with 5% replacement of sand with sawdust

Table 9: Calculation sheet for Compressive Strength of Concrete with 10% replacement

Mix	Compressive Strength (N/mm2)				Average Compressive Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	32.48	35.50	34.55	34.00				
10%	33.98	32.41	33.06	33.07	34.12	34.14	34.20	34.64
	35.69	34.50	35.74	35.53				

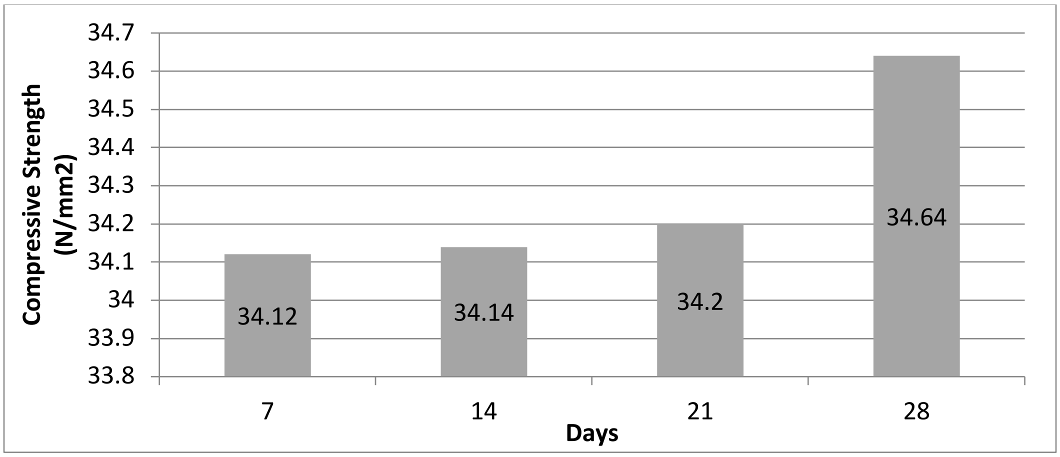

Fig. 3: Graphical Representation of Compressive Strength of Concrete with 10% replacement of sand with sawdust

Table 10: Calculation sheet for Compressive Strength of Concrete with 15% replacement

Mix	Compressive Strength (N/mm2)				Average Compressive Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	30.91	33.89	30.92	31.55				
15%	32.34	31.75	35.47	33.91	32.41	32.53	32.74	33.38
	33.97	31.97	31.89	34.69				

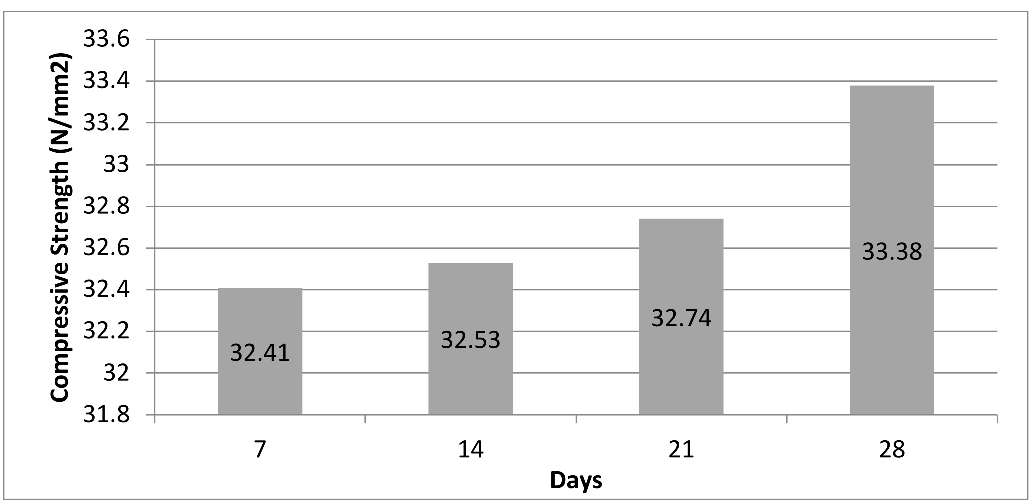

Fig. 4: Graphical Representation of Compressive Strength of Concrete with 15% replacement of sand with sawdust

Likewise Compressive Strength, Tensile strength studies were carried out on concrete with varying proportions of sawdust ash replacement at the age of 7, 14, 21 and 28 days. Test results are given below in Tables 4.12, 4.13, 4.14 and 4.15 respectively and their graphical representations are also shown in Figures 4.5, 4.6, 4.7 and 4.8 respectively.

Table 16: Calculation sheet for Tensile Strength of Concrete with 0% replacement.

Replacement	Tensile Strength (N/mm2)				Average Tensile Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	3.607	3.6	3.75	4.17				
0%	2.37	3.58	4.40	4.09	3.24	3.7	3.90	4.2
	3.75	3.92	3.54	4.33				

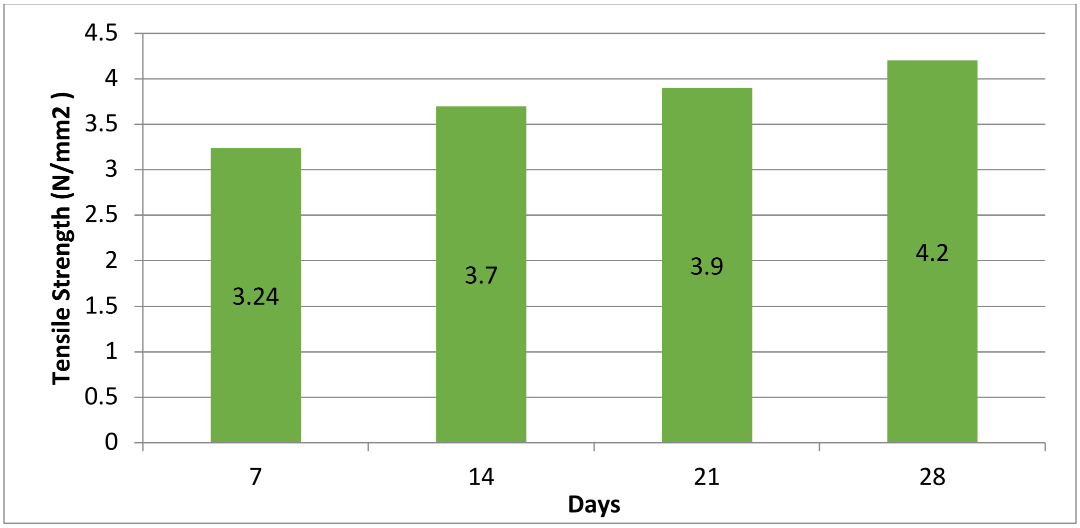

Fig. 5: Graphical Representation of Tensile Strength of Concrete with 0% replacement of sand with sawdust

Table 17: Calculation sheet for Tensile Strength of Concrete with 5% replacement

Replacement	Tensile Strength (N/mm2)				Average Tensile Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	3.92	4.2	4.51	5.06				
5%	3.48	4.53	4.02	5.4	3.36	4.00	4..24	4.83
	2.68	3.27	4.18	4.02				

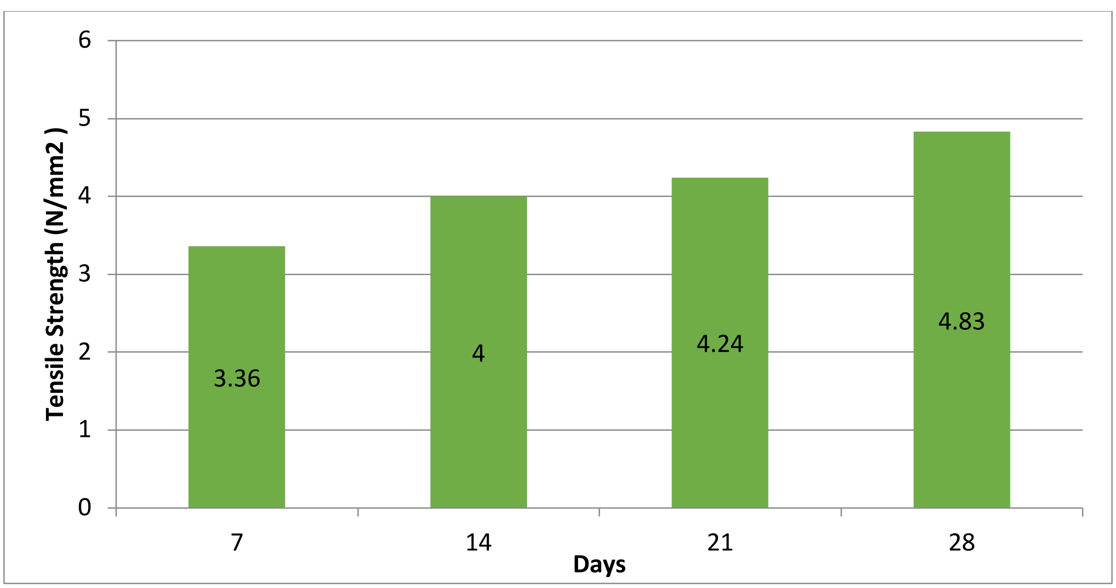

Fig. 6: Graphical Representation of Tensile Strength of Concrete with 5% replacement of sand with sawdust

Table 18: Calculation sheet for Tensile Strength of Concrete with 10% replacement

Replacement	Tensile Strength (N/mm2)				Average Tensile Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	4.44	4.63	5.07	5.61				
10%	3.78	4.08	4.78	5..13	3.51	4.22	4.89	5.41
	2.31	3.96	4.82	5.48				

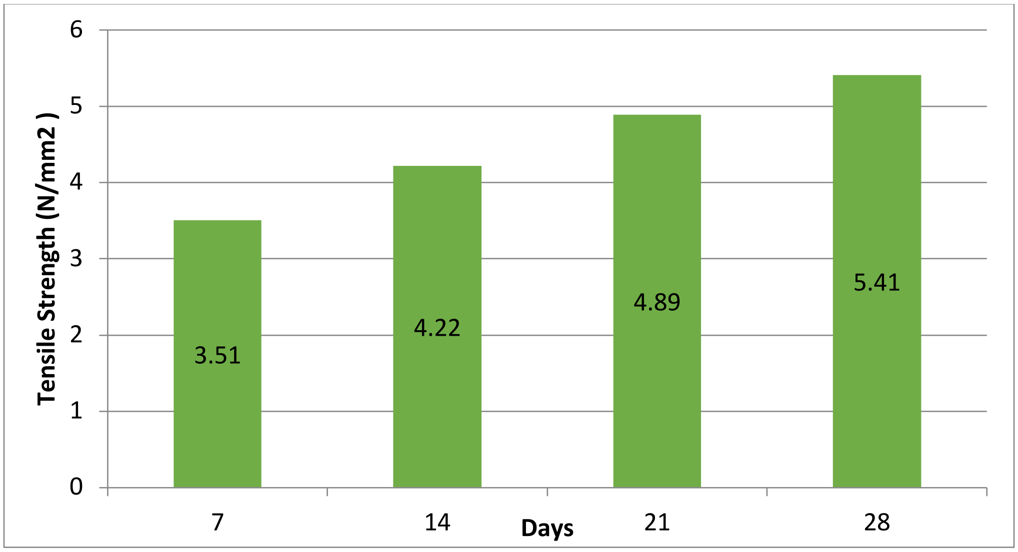

Fig. 7: Graphical Representation of Tensile Strength of Concrete with 10% replacement of sand with sawdust

Table 19: Calculation sheet for Tensile Strength of Concrete with 15% replacement.

Replacement	Tensile Strength (N/mm2)				Average Tensile Strength (N/mm2)			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
	3.78	5.28	5,67	5.36				
15%	4.2	4.58	4.73	5.98	3.95	4.75	5.31	5.75
	3.87	4.40	5.52	5.90				

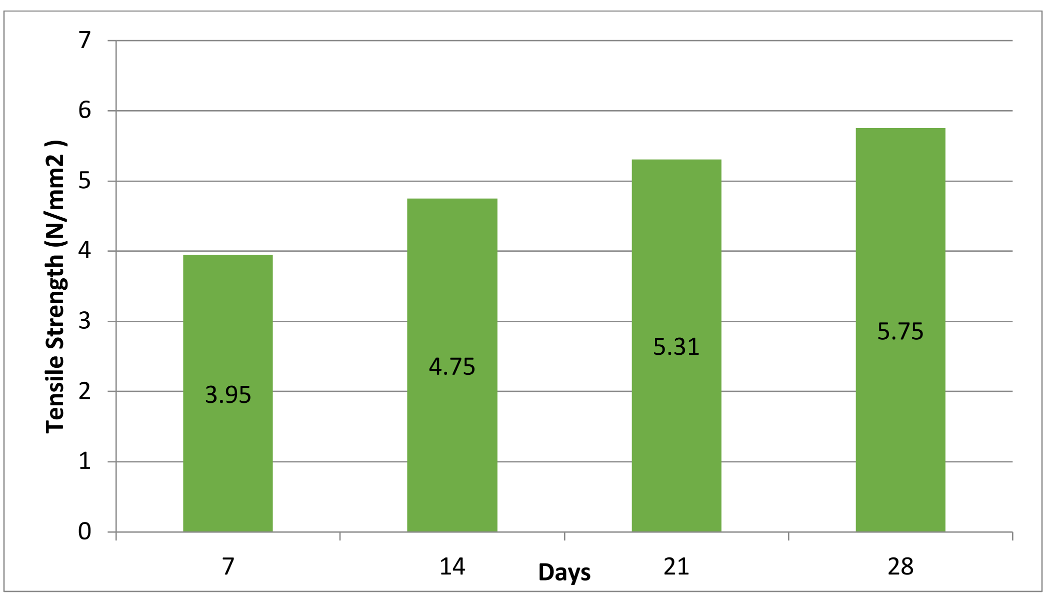

Fig. 8: Graphical Representation of Tensile Strength of Concrete with 15% replacement of sand

Conclusion: This study demonstrates that sawdust ash (SDA) can effectively replace up to 10% of fine aggregates in concrete, offering a sustainable solution that balances structural performance with environmental benefits. While compressive strength showed a predictable decline (4.4-17.6% reduction for 5-15% SDA), the material significantly enhanced tensile properties (28.6% improvement at 10% replacement) due to its fiber-like reinforcement mechanism, making it particularly suitable for applications requiring crack resistance. The optimal 8-10% replacement range maintained workability (50-60mm slump with minor adjustments) while achieving a 6.3% density reduction, suggesting viability for lightweight construction. These findings position SDA-modified concrete as a practical eco-friendly alternative, especially for non-structural elements, though future research should address long-term durability and large-scale implementation challenges to facilitate broader industry adoption. The results provide engineers with a scientifically-validated framework for utilizing this industrial byproduct, contributing to both waste reduction and sustainable construction practices.

Recommendations for Future Work

- **Durability Studies:** Long-term effects of SDA on freeze-thaw resistance and carbonation.
- **Mix Optimization:** Use of superplasticizers to offset workability loss.
- **Hybrid Blends:** Combining SDA with other supplementary materials (e.g., fly ash) for enhanced performance.

Final Remarks: This study confirms that **SDA-modified concrete** is a viable **eco-friendly alternative** for specific construction scenarios. While higher replacements (>10%) reduce compressive strength, the **tensile benefits and weight reduction** make it valuable for applications where crack resistance and lightweight properties are prioritized. Future research should focus on **field applications** and **large-scale production techniques** to facilitate industry adoption.

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