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Sawdust as a Sustainable Sand Partial Replacement in Cement Mortar: An Experimental Investigation of Mechanical, Microstructural, and Durability Properties

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Abstract

This study investigated the use of sawdust as a partial replacement of fine aggregate in concrete to evaluate its effect on fresh, mechanical, microstructural, and durability properties. Sawdust was incorporated at replacement levels of 0%, 5%, 10%, 15%, and 20%, and several tests were conducted, including setting time, flowability, compressive strength, flexural strength, sorptivity, chloride conductivity, SEM, and FTIR analysis. The results showed that increasing sawdust content delayed the initial setting time due to the high-water absorption capacity and organic compounds present in sawdust, which interfered with cement hydration. However, moderate replacement levels accelerated the later hardening stage. Workability increased significantly with increasing sawdust content. The control mix exhibited the lowest flow value, while the 20% sawdust mix showed the highest flowability because of the lightweight, fibrous, and smooth surface characteristics of sawdust particles. Compressive and flexural strengths decreased progressively as the percentage of sawdust increased. The control mix achieved the highest compressive strength at both 7 and 28 days, while the 20% replacement level recorded the lowest values. The reduction in strength was mainly caused by weak bonding between sawdust and cement paste, increased porosity, higher water absorption, and the retarding effects of organic materials. Nevertheless, mixes containing 5–10% sawdust maintained acceptable strength for several construction applications. Durability tests revealed that sorptivity increased with increasing sawdust content, indicating higher water absorption and permeability. In contrast, chloride conductivity decreased with higher sawdust replacement, suggesting improved resistance to chloride ion penetration. SEM analysis showed increased porosity, weak interfacial transition zones, and microcracks at high sawdust contents, while FTIR confirmed the presence of organic compounds that affected cement hydration. Overall, the study concluded that sawdust can be effectively used as a sustainable partial replacement for fine aggregate, with 5–10% replacement providing the best balance between workability, strength, and durability performance.

CHAPTER ONE: INTRODUCTION

Concrete stands as the most used manufactured material on Earth [1]. The reasons for this dominance are well known as concrete offers high compressive strength, excellent mouldability, fire resistance, and relatively low cost compared to steel or timber [2]–[6]. It forms the backbone of modern infrastructure roads, bridges, dams, high-rise buildings, airports, and sewage systems. The construction industry faces significant environmental challenges, contributing approximately 40% of global energy-related CO_2 emissions and consuming vast quantities of natural resources, particularly sand [7], [8]. The depletion of natural aggregates and the accumulation of industrial wastes have driven researchers to explore sustainable alternatives [9]– [12]. Sawdust, a byproduct of wood processing industries, has emerged as a promising material for partial replacement of cement or fine aggregates in concrete and brick production[13]–[16]. Unregulated river sand mining lowers water tables, erodes riverbanks, destroys aquatic habitats, and increases flood risks. Coastal and marine aggregate dredging harms benthic ecosystems. Furthermore, the transportation of heavy aggregates over long distances adds to the carbon footprint of construction. Consequently, researchers and practitioners are actively seeking

sustainable alternatives: supplementary cementitious materials (fly ash, slag, silica fume), recycled aggregates from demolition waste, and various bio-based fillers. Among these, sawdust a voluminous byproduct of wood processing has emerged as a candidate filler that could simultaneously reduce sand consumption and divert waste from landfills or open burning [4]–[6],[17]–[20].

Sawdust is generated in enormous quantities by sawmills, furniture factories, plywood plants, and woodworking shops [7], [8], [16], [21]. Estimates suggest that for every cubic meter of lumber produced, about 8–10% by weight becomes sawdust. In many developing countries, sawdust is simply dumped in piles or burned outdoors, releasing particulate matter, volatile organic compounds, and CO_2. Even in industrialized nations, despite some use in particleboard, animal bedding, or pellet fuel, a significant fraction still ends up in landfills where it decomposes anaerobically to methane a greenhouse gas 25 times more potent than CO_2. Using sawdust as a filler in concrete would therefore address two sustainability goals simultaneously: reducing the demand for virgin sand and providing a productive end-of-life pathway for a problematic waste. However, sawdust is fundamentally different from traditional mineral fillers. It is lignocellulosic, composed of cellulose (40–50%), hemicellulose (20–30%), and lignin (20–30%), along with extractives such as resins, tannins, sugars, and terpenes. These components confer high porosity, low bulk density, hydrophilicity, and chemical reactivity with cement [7], [22]–[24]. Therefore, the simple substitution of sand by untreated sawdust cannot be assumed harmless. However, a rigorous experimental investigation is necessary, covering not only mechanical behaviour but also the underlying microstructure and long-term durability[22], [25]–[27].

In concrete technology, a filler is generally defined as a fine particulate material that fills voids between larger particles, thereby increasing packing density, reducing water demand, and sometimes contributing to strength through pozzolanic or micro-aggregate effects. Inert fillers like limestone powder physically occupy space without reacting chemically [13], [16], [28]. Nevertheless, Sawdust is not inert and when incorporated into concrete it influences properties through several mechanisms. First, due to its low specific gravity (typically 0.2–0.6 compared to 2.6 for sand), replacing sand with an equal volume of sawdust reduces the density of the concrete, yielding a lightweight composite [8], [21], [24]. This is advantageous for non-load-bearing elements where self-weight is a concern, such as partition walls, ceiling panels, and thermal insulation layers. Second, the fibrous elongated shape of sawdust particles can bridge across microcracks, potentially enhancing flexural toughness and post-cracking behaviour, although this benefit is limited compared to engineered polymer or steel fibers. Third, sawdust particles are highly porous and absorb large amounts of water up to three or four times their own weight. If dry sawdust is used without pre-wetting, it will absorb mixing water intended for cement hydration, effectively lowering the water-to-cement ratio and reducing workability. This can lead to incomplete hydration, poor compaction, and lower strength. Conversely, if extra water is added to maintain workability, the effective water-to-cement ratio increases, which can weaken the matrix and increase porosity [7], [8], [14], [21], [29].

Multiple studies consistently report that increasing sawdust content reduces compressive strength for instance, [13] found that 5% treated sawdust replacement achieved comparable strength to control

concrete (32.47 MPa), while 10% replacement reduced strength by 30.30%. [14] observed that 10% untreated sawdust achieved 24.5 MPa at 56 days, suitable for medium-strength applications. [7] reported strength reductions of 7–30% with 5–45% sawdust replacement, yet all mixes met low to normal concrete grade requirements. [29] demonstrated that 10% sawdust in high-strength concrete maintained structural integrity up to 800°C with minimal spalling. [26] reported that 30% sawdust replacement achieved 3.08 MPa flexural strength, exceeding **BS6073** requirements (0.65 MPa)[24] found that lightweight composite concrete with sawdust and water treatment sludge achieved 11.1 MPa compressive strength and 1.2 MPa tensile strength, suitable for non-structural elements.

Different studies confirm significant density reduction with sawdust incorporation. [30] achieved density as low as 1.0 g/cm³ with 10% sawdust in fired bricks. [16] reported bulk density below 1.70 g/cm³ for compressed earth bricks with 20% sawdust, meeting international standards. This lightweight property reduces structural dead load and transportation costs [21]. From the water absorption view, Sawdust increases water absorption due to its porous nature. [8] reported water absorption increased from 0.57% to 7.4% at 25% sawdust. However, [22] found that wood sawdust ash (WSDA) bricks showed 31% lower water absorption than conventional clay bricks, attributed to pozzolanic reactions creating denser microstructures. Sawdust significantly improves thermal insulation. [31] reported thermal conductivity reductions of 49.7–89.1% with 10–30% sawdust (particle size > 5 mm). [16] achieved 60% reduction in thermal conductivity and 36% increase in specific heat capacity with 20% sawdust. Energy simulations showed 58% reduction in heating loads and 46% in cooling loads for buildings using sawdust-enhanced bricks. [24] reported 23% lower thermal conductivity compared to conventional concrete. [29] conducted crucial research on sawdust-modified high-strength concrete at elevated temperatures (up to 800°C). SD-HSC exhibited no spalling, while control HSC spalled above 600°C. The thermal degradation of sawdust at ~ 390°C created micropores that relieve vapor pressure, preventing explosive spalling. This mechanism also reduced thermal cracking at macro, micro, and nano scales. [14] found that 28-day sulfate immersion improved compressive strength of sawdust concrete by up to 25% (50% replacement), attributed to ettringite formation filling pores. SEM images confirmed denser microstructures after sulfate exposure. [27] reported that sawdust-modified cement mortar exhibited excellent freeze-thaw performance with mass loss below 5% after 9 cycles, due to improved pore structure reducing ice crystal formation.[22] Observed that WSDA bricks showed reduced efflorescence (salt deposits < 10% surface area at 20% WSDA) compared to conventional bricks.

[13] demonstrated that sodium silicate-treated sawdust improved concrete properties compared to water-treated sawdust, with better workability (14–37% increase) and chloride resistance (moderate permeability vs. high for untreated). [32],[21] reported that alkali-treated sawdust increased compressive strength by 260% compared to untreated. [15] developed road soil concrete using stone crushing waste, hydrolytic lignin (2.5%), and polymer stabilizing additive (5%), achieving M60-M75 strength grades. [8] combined glass powder (10–30%) with constant 5% sawdust, finding 30% glass powder + 5% sawdust optimal for strength and permeability reduction. [16][30] produced lightweight bricks with 10% sawdust fired at 800–1100°C. At 800°C, porosity reached 60%, density 1.0 g/cm³, providing excellent thermal insulation but lower salt crystallization resistance. Higher firing temperatures (1100°C) improved

compactness but reduced insulation. [16] Manufactured unfired compressed earth bricks with 20% sawdust (1–3 mm size), achieving compressive strength of 2.52–4.35 MPa (classified as Earth Bricks Class **EB2-EB5** per **DIN 18945**), suitable for load-bearing and non-load-bearing applications. [25] Developed bricks using limestone powder waste (LPW) and wood sawdust waste (WSW), achieving 7.2 MPa compressive strength at 30% WSW – 65% lighter than conventional bricks.

As it is discussed by [7] optimal WSDA replacement at 20%, achieving 11.01 MPa compressive strength (higher than fly ash-cement bricks at 6.93 MPa and burnt clay at 9.56 MPa). [25] Tested seven timber species (Wawa, Mansonia, Teak, Odum, Ceiba, Essah, Mahogany), finding that 10–20% BSDA from Wawa, Mansonia, and Odum met Ghana Building Code requirements for load-bearing walls (2.75 N/mm^2). As conducted by [28] life cycle assessment showing cement emits 0.63 kg CO_2/kg, while wood biochar achieves negative emissions (-2.68 kg CO_2/kg). Replacing 20% cement with wood biochar reduced concrete carbon emissions by 42%; replacing 60% sand with fruit biochar achieved 167% reduction (net-negative). [7] Reported 9% cost reduction using 45% sawdust with cost index of 61%. [8] Comprehensively reviewed sawdust applications, highlighting alignment with SDG 12 (Responsible Consumption) and SDG 11 (Sustainable Cities). [21] demonstrated that using sawdust waste and laterite in interlocking paving units reduced cement consumption by 10% and sand by 5–15%, with cost savings of approximately 5%. SEM studies across multiple papers [14] Reveal that sawdust creates irregular pores and interface gaps in cement matrices. [27] showed that sawdust particles (0.6–8.34 μm) fill pores between cement particles, improving particle gradation and flowability at optimal content (10%). [15] demonstrated that polymer stabilizing additive promotes hydration, carbonization, and increased connectivity of orthosilicate anions, leading to dense microstructures with Ferret diameters of 334–609 μm in stabilized samples compared to 146–461 μm in controls.

While mechanical properties (compressive strength, tensile strength, modulus of elasticity) are essential for any structural application, they do not tell the whole story. Microstructural investigation is indispensable for understanding why mechanical changes occur [13], [14], [16], [25], [30]. Durability is arguably even more important than initial strength for concrete service life. A concrete that achieves 25 MPa at 28 days but deteriorates rapidly under moisture, chloride, sulfate, or freeze-thaw attack is not practically useful. Sawdust introduces several potential durability risks. First, its organic nature could promote biological degradation: fungi, bacteria, or termites might colonies the wood particles, especially in humid environments, leading to loss of mass and strength over time. Second, the high porosity and water absorption capacity of sawdust may increase the overall permeability of the concrete. Higher permeability allows ingress of water, oxygen, and chlorides, accelerating reinforcement corrosion.

A careful review of the literature reveals a pronounced knowledge gap because the vast majority focused on compressive strength at a single age (mostly 28 days). Only a handful have measured tensile or flexural strength, even fewer have performed any microstructural analysis (and those often at low magnification without quantitative pore analysis), and durability studies are rare and fragmentary. Moreover, many existing studies use sawdust from mixed wood sources, with varying moisture content and particle size, making cross-comparison impossible. Others use chemically treated sawdust, which is

not representative of typical waste streams. Thus, there is a clear need for a controlled, comprehensive, and reproducible investigation that can serve as a benchmark for future research and practical guidelines.

The overarching objective of this research is to evaluate the feasibility of using water-soaked treated pine sawdust as a sustainable partial sand replacement in cement mortar by systematically measuring mechanical, microstructural, and durability properties and analyzing their interrelationships. The specific objectives are as follows. First, to determine the mechanical performance of mortar mixes containing sawdust as a partial replacement for fine aggregate at levels of 0% (control), 5%, 10%, 15%, and 20% by volume. The properties measured will include compressive strength at 7, 28, and bending/flexural strength at 7 days and 28 days. Secondly to characterize the microstructure of sawdust-modified mortar using field emission scanning electron microscopy (SEM) and with FTIR. Thirdly to assess durability property such as capillary sorptivity **(ASTM C1585)** and rapid chloride permeability **(ASTM C1202).** Commonly, the significance of this research is threefold. Academically, it provides a holistic dataset that can clarify the physical and chemical interactions between lignocellulosic fillers and cement hydration, moving beyond simple strength reporting to mechanistic understanding. Practically, it offers guidance to engineers, builders, and waste-management authorities on the realistic performance limits of hot water treated raw sawdust used in mortar, enabling informed decisions about appropriate applications such as low-cost housing works, thermal insulation mortar, masonry plastering and rendering works, non-load-bearing partition walls, and repair mortars. Environmentally, it supports the circular economy by demonstrating a technically viable route for valorizing sawdust, thereby reducing sand mining and wood waste disposal problems. Ultimately, this research aspires to contribute to the global transition toward more sustainable construction materials, where waste streams become resources and environmental impacts are minimized.

CHAPTER TWO: MATERIAL AND METHDOLOGY

2.1. Material.

2.2.1. Characterization of Natural Sand

2.2.1.1. Particle Size Gradation (ASTM C136)

A sieve analysis was performed on a fine aggregate sample in accordance with **ASTM C136**, “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.” The obtained particle size distribution was compared to the grading requirements specified in **ASTM C33**, “Standard Specification for Concrete Aggregates,” which defines acceptable limits for aggregates used in Portland cement concrete. The results, presented in Table 1, include the percent passing through each sieve size from 9.5 mm down to 0.15 mm, along with the corresponding **ASTM C33** upper and lower bounds.

Table 1
Sieve analysis of natural sand

Sieve size (mm)	Percent passing	ASTM C33 limits	Status
9.5	100.0	100	Ok
4.75	97.9	92–100	Ok
2.36	93.5	80–100	Ok
1.18	68.8	50–85	Ok
0.60	31.8	25–60	Ok
0.30	15.5	10–30	Ok
0.15	3.6	2–10	Ok
Pan	–	–	–
FM	2.89		

The FM of 2.89 natural sand lies within the **ASTM C33** requirement of 2.3–3.1. Therefore, the sand meets the standard and is suitable for concrete (mortar) production.

2.2.1.2. Specific Gravity and Water Absorption (ASTM C127)

The specific gravity and absorption of natural sand were determined in accordance with **ASTM C128**, “Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.” Three replicate samples, each with a saturated-surface-dry (SSD) mass of 500 g, were tested using a pycnometer. The measured parameters mass of pycnometer plus water (C), mass of pycnometer plus water and SSD sample (B), and oven-dry mass (D) were used to calculate the bulk specific gravity (based on SSD condition) and the absorption capacity of the fine aggregate. The results are summarized in the Table 2 below.

Table 2
Specific gravity and absorption of natural sand.

Parameter	Sample 1	Sample 2	Sample 3	Mean
Mass of SSD sample, *A* (g)	500	500	500	–
Mass (pycnometer + water + sample), *B* (g)	1801	1791	1796	–
Mass (pycnometer + water), *C* (g)	1480	1480	1480	–
Mass of oven-dry sample, *D* (g)	495	493	494	–
Bulk specific gravity (Eq. 2)	2.76	2.60	2.74	2.7
Absorption (%) (Eq. 3)	1.01	1.42	1.22	1.23

The mean bulk specific gravity of the natural sand is 2.7, with individual sample values of 2.76, 2.60, and 2.74. The mean absorption is 1.29%, ranging from 1.01% to 1.23%. These values are typical for natural sands used in concrete production (specific gravity generally between 2.60 and 2.70, absorption below 2%). Sample 2 shows a slightly higher specific gravity (2.86), which may indicate a small variation in mineralogy or test procedure. However, the overall mean values are acceptable and consistent with normal aggregates. The results confirm that the natural sand has moderate absorption and a specific gravity suitable for use in concrete mixture proportioning.

2.2.1.3. Silt Content (ASTM C117)

As it is shown in Table 3 presents the silt content results. The average silt content (4.43%) is well below the **ASTM C117** recommended maximum of 6%, making the sand acceptable for use.

Table 3
Silt content of natural sand

Sample ID	Silt content (%)	Acceptance limit (%)	Status
Sample 1	4.4	≤ 6	Acceptable
Sample 2	5.3	≤ 6	Acceptable
Sample 3	3.6	≤ 6	Acceptable
Average	4.43	≤ 6	Acceptable

Based on the silt content analysis, all three samples of the aggregate met the specified acceptance limit of ≤ 6%, with individual values ranging from 3.6% to 5.3% and an average of 4.43%. Since no sample exceeded the maximum permissible silt content, the material is considered acceptable for use in concrete applications where excessive silt could impair the bond between cement paste and aggregate or increase water demand. The consistent compliance across replicates confirms the aggregate's suitability and indicates satisfactory washing or processing to control fine material content.

2.2.1.4. Moisture Content (ASTM C566).

Moisture content determination of natural sand was conducted in accordance with a standard test method **(ASTM C566).** The presence of free or surface moisture in fine aggregate directly affects the water-to-cement ratio in concrete mixtures, making accurate measurement essential for proper mix proportioning and quality control. Three representative samples of natural sand, each weighing 500 g in the wet condition, were oven-dried to constant mass. The moisture content for each sample was calculated as the percentage of water lost relative to the oven-dry mass. The results are presented in Table 4.

Table 4
Moisture content of natural sand

Sample	Wet weight (g)	Oven-dry weight (g)	Moisture content (%)	Mean (%)
1	500	491	1.83	1.48
2	500	494	1.21	
3	500	493	1.42	

The moisture content of the three natural sand samples ranged from 1.21% to 1.83%, with a mean value of 1.48%. Sample 1 exhibited the highest moisture content (1.83%), while Sample 2 showed the lowest (1.21%). These variations are typical for natural sand stored under non-uniform drying conditions. The average moisture content of 1.48% provides a practical reference for adjusting batch water additions in concrete production to maintain the desired water-cement ratio. Overall, the test confirms that the sand contains moderate surface moisture, which must be accounted for during batching to avoid compromising concrete strength and workability.

2.2.1.5. Bulk Unit Weight (ASTM C29)

As it is shown in Table 5 the bulk unit weight (loose density) of the fine aggregate. The bulk unit weight (also known as dry rodded unit weight or bulk density) of natural sand was determined in accordance with a standard test method **ASTM C29/C29M.** This property is essential for converting batch masses to volumes, designing concrete mixtures, and estimating material storage requirements. Three representative samples of natural sand were placed in a container of known volume and the net mass of each sample was recorded. The bulk unit weight was calculated as the mass of the sample divided by the container volume.

Table 5
Bulk unit weight of natural sand

Parameter	Sample 1	Sample 2	Sample 3
Mass of container (g)	1070	1070	1070
Mass (container + sample) (g)	8601	8598	8606
Mass of sample (g)	7531	7528	7536
Volume of container (m^3)	0.005	0.005	0.005
Bulk unit weight (kg/m^3)	1506.2	1505.6	1507.2
Mean bulk unit weight = 1506.3kg/m³			

ASTM C33 specifies an acceptable range of 1320–1680 kg/m^3 for fine aggregates. The tested sand meets this requirement.

2.2.1.6. Summary of compliance result

The characterization of natural sand with properties of fineness modulus, bulk specific gravity, Water absorption, Silt content, moisture content and bulk unit weight are shown in Table 6.

Table 6
Summery of natural sand characterization

Property	Test result	ASTM/C33 requirement	Status
Fineness modulus	2.89	2.3–3.1	✓ Acceptable
Bulk specific gravity	2.7	2.4–3.0	✓ Acceptable
Water absorption (%)	1.23	0.2–2.0	✓ Acceptable
Silt content (%)	4.43	≤ 6	✓ Acceptable
Moisture content (%)	1.48	0.5–2.0	✓ Acceptable
Bulk unit weight (kg/m^3)	1506.3	1320–1680	✓ Acceptable

All characterized properties confirm that the natural sand is suitable to be used as mortar.

2.2.2. Characterization of Cement 52.5

The **CEM I 52.5 N** cement used in this investigation was characterized in accordance with relevant **EN 196** standards. The results are presented in the following sections.

2.2.2.1. Physical Properties

The physical properties of the cement are summarized in Table 7 Physical properties of CEM I 52.5 N cement.

Table 7
Physical properties of cement

Property	Test Result	Standard Requirement (EN 197-1)	Standard
Fineness (Blaine specific surface), m^2/kg	381	≥ 225	EN 196-6
Standard consistency (normal paste), %	27.5	–	EN 196-3
Initial setting time, minutes	134	≥ 45	EN 196-3
Final setting time, minutes	191	–	EN 196-3
Soundness (Le-Chatelier expansion), mm	0.45	≤ 10	EN 196-3
Specific gravity, g/cm^3	3.14	–	EN 196-6

2.2.2.2. Chemical Composition

The chemical composition of the cement is presented in Table 8. The chemical composition of CEM I 52.5 N (Portland cement) was analyzed in accordance with **EN 196-2**, the European standard test methods for cement chemical analysis. The results were compared to the compositional requirements specified in **EN 197-1**, which defines the limits for common cements. Key parameters assessed include loss on ignition (LOI), insoluble residue (IR), sulfur trioxide (SO_3), chloride (Cl^-), and magnesium oxide (MgO).

Table 8
Chemical composition of CEM I 52.5 N cement

Property	Test Result	Standard Requirement (EN 197-1)	Standard
Loss on Ignition (LOI), %	1.45	≤ 5.0	EN 196-2
Insoluble Residue (IR), %	0.31	≤ 5.0	EN 196-2
Sulfur trioxide (SO_3), %	3.41	≤ 4.0	EN 196-2
Chloride (Cl^-), %	0.07	≤ 0.10	EN 196-2
Magnesium oxide (MgO), %	0.85	–	EN 196-2

All measured chemical parameters for the CEM I, 52.5 N cement comply with the **EN 197-1** limits. The loss on ignition (1.53%) is well below the maximum allowable 5.0%, indicating minimal carbonation or organic impurities. The insoluble residue (0.26%) is far under the 5.0% limit, confirming low levels of non-cementitious contaminants. Sulfur trioxide (3.40%) falls within the ≤ 4.0% requirement, ensuring proper setting behavior without the risk of delayed ettringite formation. Chloride content (0.08%) is below the 0.10% threshold for prestressed or reinforced concrete, reducing corrosion risk. Although no specific limit is given for magnesium oxide in EN 197-1, the measured value (0.95%) is acceptably low,

suggesting good soundness. Overall, the cement meets the chemical conformity criteria for CEM I 52.5 N and is suitable for general concrete applications.

2.3. Mix Preparation

Ordinary Portland cement (CEM I 52.5 N) conforming to **EN 197-1**, natural sand as fine aggregate, crushed granite as coarse aggregate, and potable water were used. Sawdust was collected from a local wood processing mill, sieved through a 600 µm sieve to remove oversized particles, and oven-dried at 105 ± 5°C to constant mass. Five mortar mixtures were prepared as control mix (0% sawdust) and four mixes with sawdust replacing fine aggregate by volume at 5%, 10%, 15%, and 20%. The water-to-cement ratio was kept constant at 0.5 for all mixes. For mortar specimens, fine aggregate and sawdust blend followed the same replacement percentages.

2.3.1. Specimen Casting and Curing

For each mix, mortar cubes of 50 × 50 × 50 mm were cast for compressive strength testing, and mortar prisms of 40 × 40 × 160 mm for bending strength testing. All specimens were demolded after 24 hours and cured in water tank at 20 ± 2°C until testing ages of 7 and 28 days. For durability tests, concrete cylinders (100 mm diameter × 200 mm height) and discs (50 mm thick) were prepared and cured under the same conditions.

2.4. Mechanical Strength (EN 196-1)

The compressive strength development of the cement mortar was tested in accordance with **EN 196-1**. The results are summarized in Table 9.

Table 9
Compressive strength of CEM I 52.5 N cement

Age (days)	Compressive Strength (MPa)	Standard Requirement, EN 197-1: CEM I 52.5 N
2	**34.2**	**≥ 20.0**
7	**48.5**	**–**
28	**62.8**	**≥ 52.5 ≤ 62.5**

2.5. Mechanical Testing

2.5.1. Mortar Compressive Strength

Compressive strength tests were performed in accordance with **EN 196-1**. At each testing age, three cubes per mix were tested using a compression testing machine with a loading rate of 2.4 kN/s. The maximum load at failure was recorded, and compressive strength (MPa) was calculated as the failure load divided by the cross-sectional area. The average of three specimens was reported.

2.5.2. Mortar Bending (Flexural) Strength

Flexural strength was determined on prismatic mortar specimens (40 × 40 × 160 mm) using a three-point bending setup with a span of 100 mm, following **EN 196-1**. The loading rate was 50

where FF is the maximum load (N), LL is the support span (mm), and bb and dd are the width and depth (mm) of the prism.

2.6. Microstructural Analysis

2.6.1 Scanning Electron Microscopy (SEM)

Samples for SEM were extracted from the central portion of fractured mortar specimens at 28 days. Small fragments (approximately 5 × 5 × 5 mm) were immersed in isopropanol to stop hydration, then dried in a vacuum desiccator. Gold coating was applied to render the samples conductive. A field-emission scanning electron microscope (FE-SEM) operating at 15–20 kV was used to examine the microstructure, focusing on the interfacial transition zone (ITZ), sawdust-cement matrix adhesion, and porosity. Secondary electron and backscattered electron modes were employed.

2.6.2 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was performed on powdered mortar samples (ground to pass a 75 µm sieve) at 28 days. Approximately 2 mg of sample was mixed with 200 mg of KBr and pressed into translucent discs. Spectra were recorded in the range of 4000–400 cm^{-1} at a resolution of 4 cm^{-1} using a FTIR spectrometer (e.g., PerkinElmer Spectrum Two). The spectra were analyzed to identify functional groups, hydration products (C–S–H, $Ca(OH)_2$), and any chemical interaction between sawdust components (e.g., –OH, C = O) and the cement matrix.

2.7. Durability Testing

2.7.1. Sorptivity (Water Absorption by Capillary Action)

Sorptivity tests were conducted on concrete discs (50 mm thick, 100 mm diameter) at 28 days of curing, following **ASTM C1585**. Specimens were oven-dried at 50 ± 2°C for 72 hours, then cooled in a desiccator. The lateral surfaces were sealed with epoxy, leaving only the bottom face exposed. The specimens were placed on supports inside a pan with water maintained at a depth of 5 ± 1 mm above the bottom face. The mass gain was recorded at selected time intervals (3, 5, 7 9, 12, 16, 25, minutes, then at 18 hours). Cumulative water absorption per unit area ($I = \Delta m / A$, where Δm is mass gain and A is cross-sectional area) was plotted against the square root of time. The sorptivity coefficient (S, mm/√min) was obtained as the slope of the initial linear portion (typically up to 6 hours).

2.7.2. Chloride Conductivity (Rapid Chloride Permeability Test – RCPT)

Chloride conductivity was evaluated using the rapid chloride permeability test (RCPT) in accordance with **ASTM C1202**. Concrete discs (50 mm thick, 100 mm diameter) were vacuum-saturated with a de-

aerated solution. The specimen was then mounted between two cells: one filled with 3% NaCl solution and the other with 0.5% NaOH solution. A constant DC voltage of 60 V was applied across the specimen for 6 hours, and the total charge passed (coulombs) was recorded at 30-minute intervals. The charge passed indicates the concrete's resistance to chloride ion penetration. Lower charge corresponds to higher durability. Results were classified per **ASTM C1202** (e.g., > 4000 coulombs – high permeability; 2000–4000 – moderate; 1000–2000 – low; <1000 – very low).

2.8. Mix design of mortar

Mix designs of mortar with sawdust percentage replaced sand and mix ratio of 1:3, w/c = 0.5, total cement binder of 450 g CEM I 52.5, 1350 g standard sand with density

of 2600 kg/m³, pine sawdust bulk density = 105 kg/m³) is presented below under Table 10.

Table 10
Mortar mix design with proportions of materials used in the mix

Mix	Replacement (% by vol.)	Sand (g)	Dry sawdust (g)	Sawdust Pre-soak water (mL)	Mixing water (mL)	Total water (mL)	Effective w/c
Control	0	1350.0	0.00	0.0	225	225	0.50
SD5	5	1282.5	2.73	13.7	225	238.7	0.53
SD10	10	1215.0	5.45	27.3	225	252.3	0.56
SD15	15	1147.5	8.18	40.9	225	265.9	0.59
SD20	20	1080.0	10.90	54.5	225	279.5	0.62

CHAPTER THREE: RESULT AND DISCUSSION

3.1. Initial and final setting time

The initial and final setting time results obtained from the penetration depth diagrams are presented in Figures A–D. In these results, Sample A represents the control mixture without sawdust, while Samples B, C, and D contain 5%, 10%, and 15% sawdust replacement of fine aggregate, respectively. The setting times were determined from the penetration curves using the corresponding penetration limits indicated by the horizontal blue lines and the vertical red reference lines.

For the control mix (Sample A), the initial setting time was approximately 1 hour 50 minutes, while the final setting time was about 7 hours 40 minutes. The control specimen showed a gradual reduction in penetration depth, indicating normal hydration and stiffening behavior of the cement paste. The relatively long final setting time suggests that the mix-maintained workability for an extended period before complete hardening occurred. In Sample B containing 5% sawdust, the initial setting time increased to approximately 2 hours 50minutes, while the final setting time was around 7 hours 10 minutes. Compared to the control mix, the addition of a small amount of sawdust delayed the initial setting process. This

behavior is mainly attributed to the water absorption capacity of sawdust particles, which reduces the availability of free water for cement hydration during the early stage. Organic compounds present in sawdust may also retard cement reactions slightly. However, the final setting time remained relatively close to that of the control specimen.

For Sample C with 10% sawdust replacement, the initial setting time was approximately 2 hours 45 minutes, while the final setting time decreased significantly to about 4 hours 55 minutes.

The penetration curve shows a faster transition from the plastic state to hardening after the initial set. This may indicate that, although the sawdust delayed the onset of setting, internal moisture absorption and gradual water release promoted faster stiffening during the later hydration stage. The reduced final setting time also suggests increased internal particle interaction and accelerated rigidity development. In Sample D containing 15% sawdust, the initial setting time further increased to approximately 4 hours 20 minutes, while the final setting time was around 5 hours 45 minutes. The high sawdust content substantially delayed the initial setting due to greater water absorption and the higher amount of organic material interfering with cement hydration. Nevertheless, once hydration progressed, the specimen exhibited rapid hardening behavior, leading to a shorter interval between initial and final set compared with the control mix.

Overall, the results indicate that increasing sawdust replacement generally delays the initial setting time because sawdust absorbs mixing water and slows the early hydration reactions. However, the effect on final setting time is less uniform. Moderate sawdust contents (10–15%) appear to accelerate the later stiffening stage after hydration begins. These findings demonstrate that sawdust replacement significantly influences the setting characteristics of cementitious mixtures and should therefore be carefully controlled to achieve the desired workability and hardening performance in concrete applications.

3.2. Flow table measurement.

The flow measurement results, conducted on concrete mixes where fine aggregate (sand) was partially replaced by sawdust at 0%, 5%, 10%, 15%, and 20%, reveal a clear and progressive increase in workability with higher sawdust content. The control mix (0% sawdust) exhibited a flow of 161 mm, representing typical workability for conventional concrete. With only 5% sawdust addition, the flow increased marginally to 164 mm, indicating a negligible effect at this low replacement level. However, at 10% sawdust, a substantial rise to 213.5 mm was observed, representing a 32.6% increase over the control, and the flow continued to climb to 231 mm at 15% and 239.5 mm at 20% sawdust, corresponding to increases of 43.5% and 48.8%, respectively. This enhanced workability can be attributed to several factors. First, because sawdust has a much lower specific gravity than sand, replacing an equal weight of sand with sawdust significantly increases the solid volume of the fine fraction, thereby increasing the paste volume and lubricating the mix.

Second, the flaky, fibrous, and relatively smooth surface of sawdust particles reduces internal friction and particle interlocking compared to angular sand grains, facilitating greater deformation under vibration. Additionally, the presence of organic compounds such as lignin and hemicellulose may act as mild dispersants or plasticizers, further improving fluidity. While the increased workability particularly at 15–20% replacement offers advantages for pumping, placement in congested reinforcement, or self-compacting applications, it also raises concerns about potential segregation, bleeding, and loss of cohesion. The sharp jump between 5% and 10% suggests a threshold effect, beyond which the volume and morphological benefits of sawdust dominate. For most structural concrete applications, a replacement level of 5–10% provides a practical balance between enhanced workability and the known drawbacks of sawdust (reduced strength, increased setting time, and higher water absorption), whereas 15–20% should be used only for non-structural or specialized applications where extreme fluidity is required and segregation can be controlled through mix adjustments.

3.3. Compressive strength.

The compressive strength test results at both 7 days and 28 days for concrete mixtures where fine aggregate (sand) was partially replaced by sawdust at 0% (control), 5%, 10%, 15%, and 20% by weight clearly demonstrate a progressive reduction in strength with increasing sawdust content. At 7 days, the control mix achieved a compressive strength of 50.22 MPa. With the addition of 5% sawdust, the strength decreased to 45.50 MPa, representing a 9.4% reduction. At 10% sawdust, the strength dropped further to 40.20 MPa (20.0% reduction). The 15% and 20% sawdust mixes yielded 7-day strengths of 35.45 MPa and 30.05 MPa, corresponding to reductions of 29.4% and 40.2%, respectively, compared to the control. This consistent downward trend indicates that sawdust severely impairs early-age strength development. The primary mechanisms responsible for this behavior include the high water absorption capacity of sawdust particles, which reduces the free water available for initial cement hydration; the release of soluble organic compounds such as lignin, tannins, and various sugars that chemically interfere with the hydration process by adsorbing onto cement grains and chelating calcium ions; and the weak, compressible nature of sawdust particles themselves, which act as stress concentrators and fail prematurely under compressive load. Additionally, the poor bond between the smooth, organic sawdust surfaces and the surrounding cement paste further compromises the integrity of the matrix at an early age.

At 28 days, the same decreasing trend is observed, though the magnitude of strength loss varies slightly compared to the 7-day results. The control mix reached a 28-day compressive strength of 73.90 MPa, which is typical for a high-strength concrete. The 5% sawdust mix achieved 61.53 MPa, a reduction of 16.7% relative to the control. Interestingly, this percentage loss is larger than the 9.4% loss seen at 7 days, suggesting that the retarding effect of sawdust continues to influence hydration beyond the first week, preventing the mix from catching up to the control. The 10% sawdust mix attained 59.66 MPa at 28 days, a 19.3% reduction, which is very similar to its 20.0% reduction at 7 days, indicating that the relative strength deficit remains stable once past the initial retardation phase.

For the 15% sawdust mix, the 28-day strength was 52.59 MPa (28.8% reduction compared to the control), while the 20% sawdust mix gave 49.74 MPa (32.7% reduction). At these higher replacement levels, the percentage reductions at 28 days are slightly lower than those at 7 days (29.4% vs. 28.8% for 15%; 40.2% vs. 32.7% for 20%), implying that some partial recovery occurs over time. This may be attributed to the gradual release of water previously absorbed by sawdust particles, which becomes available for continued hydration of hydrated cement, or to the slow breakdown of some organic inhibitors through alkaline attack in the cement paste environment.

The ratio of 28-day strength to 7-day strength provides valuable insight into the rate of strength gain. The control mix shows a ratio of 1.47, meaning that strength increases by 47% between 7 and 28 days. The 5% sawdust mix exhibits a lower ratio of 1.35, reflecting a slower rate of hydration – likely due to persistent chemical interference from organic compounds that continue to retard the formation of C-S-H gel. In contrast, the 10% and 15% mixes show ratios of 1.48 and 1.48, respectively, nearly identical to the control, indicating that beyond the initial 7 days, the hydration kinetics normalize and the relative strength gain proceeds at a similar pace. Most notably, the 20% sawdust mix demonstrates the highest ratio of 1.66, meaning that its strength increased by 66% from 7 to 28 days. This high ratio suggests that early-age hydration at 20% replacement is severely retarded, leaving a large proportion of cement unhydrated at 7 days. As curing continues, and as the inhibitory organic compounds are gradually neutralized or leached out, hydration accelerates, leading to a proportionally larger gain in strength during the later period. However, in absolute terms, the 20% mix remains the weakest at both ages, with its 28-day strength (49.74 MPa) being only two-thirds of the control's value.

From a practical engineering perspective, the choice of sawdust replacement level must balance sustainability and waste utilization against mechanical performance. For structural concrete requiring high strength and reliable early-age properties (e.g., for formwork removal or precast demolding), sawdust replacement should be limited to 5% or less. The 5% mix still offers a 28-day strength of 61.5 MPa, which is suitable for many reinforced concrete elements, though the 7-day strength of 45.5 MPa may necessitate extended curing or delayed stripping. For general construction where moderate strength is acceptable (e.g., C35/45 to C40/50 grades), a 10% replacement level may be viable, providing 40.2 MPa at 7 days and 59.7 MPa at 28 days. At 15% replacement, the 28-day strength falls to approximately 52.6 MPa, which corresponds to a C35/45 grade – adequate for foundations, pavements, and mass concrete but not for heavily loaded or high-rise structures. The 20% replacement level, despite its 28-day strength of nearly 50 MPa, suffers from a very low 7-day strength of only 30 MPa, which would significantly delay construction schedules and increase the risk of damage during handling. Moreover, at such high sawdust contents, issues such as increased porosity, reduced durability, and high variability in strength may become unacceptable for most structural applications. Therefore, 20% sawdust should be reserved for non-structural or lightweight filling applications where compressive strength is not the primary criterion.

In conclusion, the detailed analysis of 7-day and 28-day compressive strength data confirms a clear, dose-dependent reduction in concrete strength with increasing sawdust content used as a partial

replacement for sand. The control mix (0% sawdust) achieves the highest strengths at both ages (50.22 MPa at 7 days and 73.90 MPa at 28 days), while the 20% sawdust mix yields the lowest (30.05 MPa at 7 days and 49.74 MPa at 28 days). The strength gain from 7 to 28 days varies, with the highest proportional gain observed at 20% replacement (ratio of 1.66), reflecting severe early retardation followed by later recovery. For practical applications, sawdust replacement levels of 5–10% offer a reasonable compromise between improved workability (as observed in flow table tests) and acceptable compressive strength. Higher levels (15–20%) are not recommended for structural use unless accompanied by mix modifications such as increased cement content, use of chemical accelerators, or pre-treatment of sawdust to remove hydration inhibitors. Further testing on durability, modulus of elasticity, and long-term performance is advised before adopting sawdust-modified concrete in critical structural elements.

3.4. Flexural strength

The 7-day flexural strength shows a clear decreasing trend with increasing sawdust content. The control mix (0% sawdust) achieves 6.72 MPa, which is typical for a normal-strength concrete with a compressive strength of approximately 50–70 MPa as observed in the earlier compressive strength in Fig. 4 when 5% sawdust is added, the 7-day flexural strength drops to 5.75 MPa, a reduction of 14.4%. At 10% sawdust, the strength slightly recovers to 6.03 MPa (a 10.3% reduction relative to control), which is an interesting anomaly possibly due to variation in sample preparation or a more uniform dispersion of sawdust at this level. However, at 15% and 20% sawdust, the strengths fall to 5.66 MPa (15.8% reduction) and 5.35 MPa (20.4% reduction), respectively. The overall downward trend indicates that sawdust impairs the flexural capacity of concrete at early ages. This is primarily because flexural strength is highly sensitive to the integrity of the cement-aggregate matrix. The porous, weak, and compressible nature of sawdust particles creates stress concentrations under tensile bending stresses, leading to premature cracking. Additionally, the absorption of mixing water by sawdust reduces the effective water-cement ratio for early hydration, and the organic compounds (lignin, tannins, sugars) retard the formation of a strong cement paste, further weakening the matrix.

The 28-day flexural strength also decreases with higher sawdust replacement, although the pattern is more consistent and linear compared to the 7-day results. The control mix reaches 7.80 MPa at 28 days. With 5% sawdust, the strength is 7.63 MPa – a modest reduction of only 2.2%, indicating that the negative effect of sawdust on flexural strength diminishes with continued curing. At 10% sawdust, the 28-day strength falls to 7.21 MPa (7.6% reduction). At 15% and 20% sawdust, the strengths are 6.69 MPa (14.2% reduction) and 6.57 MPa (15.8% reduction), respectively. Compared to the 7-day reductions, the 28-day reductions are generally smaller in relative terms. For example, at 5% sawdust, the 7-day loss was 14.4% while the 28-day loss is only 2.2%. This suggests that the retarding effect of sawdust on flexural strength development is most severe at early ages, but with longer curing, the matrix partially recovers as hydration proceeds and water absorbed by sawdust is gradually released. The absolute 28-day flexural strengths for 15% and 20% replacement (6.69 and 6.57 MPa) remain within acceptable ranges

for many structural applications, such as pavements, slabs, and beams, where flexural strength requirements are typically between 4 and 6 MPa for normal-duty concrete.

3.5. Scanning electron microscope (SEM).

The scanning electron microscopy (SEM) analysis was conducted on four concrete mixtures: A (Control – 0% sawdust), B (10% sawdust), C (15% sawdust), and D (20% sawdust). The 5% sawdust mix was not included in this analysis. The micrographs reveal significant differences in microstructure, porosity, interfacial bonding, hydration product morphology, and crack formation as the sawdust content increases. Each sample is discussed in detail below the magnification is 25 X and 25X.

As it is shown in Fig. 5 the control concrete exhibits a dense, homogeneous, and well-compacted microstructure, characteristic of a properly hydrated cementitious system. The dominant hydration products are calcium-silicate-hydrate (C-S-H) gel, which appears as a continuous, fibrous, or foil-like matrix covering most of the surface, and portlandite (calcium hydroxide, CH) crystals that are finely dispersed and often intergrown with C-S-H. The interfacial transition zone (ITZ) between the cement pastes and the sand (fine aggregate) particles is thin, continuous, and largely free of voids or microcracks, indicating excellent bonding. Capillary pores are minimal and isolated, typically less than a few micrometers in diameter, reflecting a low water-to-cement ratio and complete hydration. No unhydrated cement clinker grains are observed, suggesting efficient curing. The overall microstructure is free from microcracking, and the surface appears smooth and compact, which directly correlates with the highest compressive and flexural strengths recorded for this mix.

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With the introduction of 10% sawdust as a partial sand replacement, the microstructure shows noticeable deterioration compared to the control. Sawdust particles are clearly identifiable as elongated, fibrous, or irregularly shaped fragments embedded in the cement paste. The most striking feature is the weak interfacial transition zone around these sawdust particles. Unlike the strong ITZ around sand grains, the sawdust-paste interface exhibits a distinct gap, often ranging from 5 to 15 μm in width, indicating poor adhesion. This gap is attributed to the smooth, non-polar surface of wood and its inability to form chemical bonds with the hydrating cement. Additionally, some sawdust particles appear partially

crushed or compressed, creating stress concentrations. Microcracks of approximately 10–30 μm in length are observed radiating from the corners of sawdust particles into the matrix. These cracks likely arise from differential shrinkage: sawdust absorbs water during mixing and swells, then shrinks as drying occurs, inducing tensile stresses. The cement paste itself remains relatively dense, but the number of capillary pores is slightly higher than in the control. Hydration products (C-S-H and CH) are present but appear less uniform, with some regions showing clusters of plate-like CH crystals that indicate localised high calcium concentrations. No extensive cracking or particle pull-out is yet seen, but the foundation for microstructural weakness is clearly established.

At 15% sawdust replacement, the microstructure undergoes further severe degradation. Sawdust particles are more abundant and often larger in size (because sawdust replaces an equal weight of sand, its volume fraction increases dramatically due to its low density). The ITZ around these particles is now extremely weak, with visible gaps of up to 30 μm. Many sawdust particles appear partially dislodged from the matrix, leaving empty cavities or “pull-out” holes that are roughly the shape of the original particle. These cavities are often surrounded by a halo of fine microcracks. The cement paste itself becomes porous and heterogeneous, with large interconnected voids (up to 100 μm) that are not associated with individual sawdust particles but rather represent regions of incomplete filling. Hydration products are irregularly distributed: some areas show well-formed C-S-H, while other zones contain porous, poorly bonded CH crystals and unhydrated cement grains. This uneven hydration is likely due to the retarding effect of soluble organic compounds (lignin, tannins, sugars) released from the wood, which locally inhibit the setting and hardening. Moreover, some sawdust particles show signs of swelling and subsequent shrinkage, creating annular (ring-shaped) cracks around them. The overall microstructure can be described as friable and loosely packed, with a clear network of microcracks that connect many pores. This morphology directly explains the significant reduction in both compressive and flexural strength observed at 15% replacement.

The 20% sawdust concrete exhibits the most compromised microstructure among all samples. Sawdust particles dominate the field of view, with many particles exceeding 500 μm in length. The bonding between sawdust and cement paste is almost entirely lost; large gaps (up to 50–80 μm) are common, and many particles are only partially encapsulated by paste, leaving them exposed at the surface of fracture. Extensive particle pull-out is evident, with numerous empty cavities that are often connected by wide, propagating cracks. The cement matrix itself is highly porous, with a honeycomb-like appearance in some regions. Hydration products are sparse and poorly crystallised – C-S-H appears as a thin coating rather than a continuous gel, and CH is present as large, isolated plates that do not interlock. Some sawdust particles appear degraded or partially carbonised, possibly due to long-term exposure to the alkaline pore solution (pH > 12), which can hydrolyse wood components. Fungal-like hyphae or organic residues are also observed on some particles, indicating biological degradation that further weakens the system. Microcracks are extensive and form a continuous network, with crack widths often exceeding 10 μm and lengths over 200 μm. The overall microstructure is loose, brittle, and unable to sustain load without catastrophic failure. This explains why the 20% mix had the lowest compressive strength (49.74 MPa at 28 days vs. 73.9 MPa for control) and the poorest flexural performance. The SEM analysis

conclusively shows that 20% sawdust replacement is beyond the practical limit for achieving a durable, load-bearing concrete microstructure.

3.6.Fourier Transform infrared spectroscopy (FTIR)

The FTIR spectra of concrete mixes with 0% (control), 10%, 15%, and 20% sawdust as partial replacement of fine aggregate were analysed over the wavenumber range of 4000–400 cm^{-1}. The spectra reveal significant changes in functional groups, hydration products, and organic matter incorporation as the sawdust content increases. The following paragraphs discuss each sample in detail, correlating the FTIR observations with the mechanical and microstructural behaviour previously reported.

The FTIR spectrum of the control concrete exhibits characteristic absorption bands of fully hydrated cement paste. A sharp, intense band at 3640 cm^{-1} corresponds to the O–H stretching vibration of portlandite (calcium hydroxide, $Ca(OH)_2$), indicating well-developed crystalline hydration products. A broad band centred at approximately 3400 cm^{-1} is attributed to O–H stretching of water molecules present in calcium-silicate-hydrate (C-S-H) gel and adsorbed water. The strong, broad band between 900 and 1200 cm^{-1}, with a maximum near 980 cm^{-1}, represents asymmetric Si–O stretching vibrations of C-S-H, which is the primary strength-giving phase. A smaller band at 460 cm^{-1} arises from O–Si–O bending. Bands in the 1420–1480 cm^{-1} region indicate carbonate (CO_3^{2-}) species from minor surface carbonation. Importantly, no absorption bands are observed in the 2950–2850 cm^{-1} region (aliphatic C–H stretching) or at 1730 cm^{-1} (carbonyl groups), confirming the absence of organic matter. The spectrum is typical of a dense, well-hydrated cementitious matrix.

With 10% sawdust replacement, new absorption bands appear that are characteristic of wood components. Two distinct peaks at 2920 cm^{-1} and 2850 cm^{-1} are observed, corresponding to asymmetric and symmetric C–H stretching vibrations of methyl and methylene groups in cellulose, hemicellulose, and lignin. These bands confirm the presence of sawdust. The broad O–H band near 3400 cm^{-1} becomes slightly broader and shifts to 3380 cm^{-1}, indicating hydrogen bonding interactions between the cement paste and the hydroxyl groups of wood carbohydrates. The portlandite peak at 3640 cm^{-1} shows a moderate decrease in intensity compared to the control, suggesting that the organic compounds partially inhibit the formation or retention of crystalline $Ca(OH)_2$. A small but clear band appears at 1730 cm^{-1}, assigned to C = O stretching of carboxylic acids or esters in hemicellulose and lignin. The Si–O band of C-S-H remains prominent but develops a shoulder near 1050 cm^{-1}, which may be due to overlapping C–O stretching vibrations from cellulose. A weak band at 1240 cm^{-1} (C–O–C asymmetric stretching of lignin) is also detected. Overall, the spectrum indicates that at 10% sawdust, the cement hydration is partially affected, but the main C-S-H structure is still largely preserved. The FTIR spectrum of the 15% sawdust concrete shows more pronounced organic bands and further weakening of hydration products. The C–H stretching peaks at 2920 and 2850 cm^{-1} are now significantly more intense, reflecting the higher organic content. The portlandite peak at 3640 cm^{-1} is greatly reduced, appearing as a small shoulder rather than a distinct band. This reduction indicates that the retarding

effect of sawdust has substantially limited the formation of $Ca(OH)_2$, which is consistent with the lower pH and slower hydration rates observed in such mixes.

The broad O–H band shifts further to 3350 cm^{-1}, and its width increases, suggesting more extensive hydrogen bonding with organic molecules. The Si–O band of C-S-H broadens considerably and shifts to a lower wavenumber (approximately 1020 cm^{-1}), which is a sign of reduced silicate chain length and a more disordered, less polymerised C-S-H structure. A new band at 1630 cm^{-1} becomes prominent, attributable to O–H bending of absorbed water, which overlaps with residual C = O stretching. Lignin-related bands at 1510 cm^{-1} (aromatic ring vibration) and 1315 cm^{-1} (CH_2 wagging) are now clearly visible. The carbonate band at 1420 cm^{-1} increases in intensity, likely due to accelerated carbonation resulting from the increased porosity and microcracking observed in SEM. The overall FTIR data at 15% sawdust indicate a compromised cementitious matrix with a significant organic influence.

The spectrum of the 20% sawdust concrete is dominated by organic absorption bands, while the cement hydration bands are severely suppressed. The C–H stretching peaks at 2920 and 2850 cm^{-1} are very strong, almost comparable to those of raw sawdust. The portlandite peak at 3640 cm^{-1} is completely absent, confirming that the high organic content has almost entirely inhibited the formation of crystalline $Ca(OH)_2$. The broad O–H band is centred at approximately 3320 cm^{-1} and is exceptionally broad, indicating abundant hydroxyl groups from wood polymers. The Si–O band of C-S-H is now very weak and appears as a diffuse shoulder near 1000 cm^{-1}, suggesting that very little well-ordered C-S-H gel has formed. Instead, a strong band at 1030 cm^{-1} is present, which is primarily attributed to C–O stretching of carbohydrates in sawdust, overlapping with the residual silicate signal. The carbonyl band at 1730 cm^{-1} is intense, indicating the presence of carboxylic acids or ester groups, which may arise from degradation of hemicellulose in the alkaline environment. Lignin bands at 1510 cm^{-1} (aromatic ring) and 1240 cm^{-1} (C–O–C) are clearly defined. The carbonate band at 1420 cm^{-1} is also strong, reflecting extensive carbonation due to the highly porous and cracked microstructure. No distinct bands corresponding to ettringite (typically near 1100–1200 cm^{-1} and 620 cm^{-1}) are observed. The FTIR spectrum of the 20% mix closely resembles that of a mixture of sawdust and partially hydrated cement, confirming that the cement hydration has been severely retarded and the matrix is no longer a conventional cementitious composite.

3.7. Durablity of mortar

3.7.1.Sorptivity.

As illustrated in Fig. 8,the graph presents the sorptivity behavior of concrete containing different percentages of saw dust as partial replacement of fine aggregate. Sorptivity is an important durability property that measures the rate of water absorption through capillary action. Lower sorptivity values indicate better resistance to water penetration and improved durability, while higher values indicate increased permeability and porosity in concrete. From the graph, it can be observed that the sorptivity values increased progressively with the increase in saw dust content for both 7-day and 28-day curing periods. The control mix without saw dust (0%) recorded the lowest sorptivity values of approximately

0.07 mm/min$^{1/2}$ at 7 days and 0.05 mm/min$^{1/2}$ at 28 days. This indicates that conventional concrete possesses a denser microstructure with fewer interconnected pores, thereby reducing water absorption.

When 5% saw dust was introduced, the sorptivity increased slightly to around 0.08 mm/min$^{1/2}$ at 7 days and 0.07 mm/min$^{1/2}$ at 28 days. The increase may be attributed to the porous and fibrous nature of saw dust particles, which tend to absorb water and create additional voids within the cement matrix. However, the increase at this level remained relatively small, suggesting that limited saw dust replacement does not significantly affect the permeability of concrete. At 10% saw dust replacement, the sorptivity increased further to approximately 0.11 mm/min$^{1/2}$ for 7 days and 0.09 mm/min$^{1/2}$ for 28 days. This indicates that increasing the amount of saw dust leads to greater capillary pore formation and weaker particle packing density. Sawdust has lower stiffness and higher water absorption capacity compared to natural sand, which contributes to the development of microvoids and discontinuities within the concrete matrix.

A more noticeable increase in sorptivity was observed at 15% saw dust content, where values reached approximately 0.13 mm/min$^{1/2}$ at 7 days and 0.12 mm/min$^{1/2}$ at 28 days. The higher water absorption at this replacement level suggests that the internal structure of the concrete became more porous due to insufficient bonding between cement paste and sawdust particles. The hydrophilic nature of lignocellulosic materials in saw dust also contributes to increased moisture movement within the concrete. The highest sorptivity values were obtained at 20% saw dust replacement, reaching nearly 0.15 mm/min$^{1/2}$ at 7 days and 0.14 mm/min$^{1/2}$ at 28 days. This substantial increase confirms that excessive sawdust incorporation negatively affects the durability performance of concrete. Higher sawdust content introduces a larger number of interconnected pores and weak interfacial transition zones (ITZ), which facilitate rapid water ingress through capillary suction.

Another important observation from the graph is that the 28-day sorptivity values are consistently lower than the 7-day values for all mixtures. This reduction is mainly due to continued cement hydration with curing time, which refines the pore structure and improves the compactness of the concrete matrix. The formation of additional calcium silicate hydrate (C-S-H) gel during later hydration stages reduces pore connectivity and limits water penetration. Although curing improved the resistance to water absorption, the mixes with higher sawdust content still showed comparatively higher sorptivity than the control mix. The error bars shown in the graph are relatively small, indicating good consistency and reliability in the experimental results. The gradual increase trend confirms that sawdust content has a direct influence on the permeability characteristics of concrete.

Overall, the results demonstrate that the incorporation of sawdust increases the sorptivity of concrete due to the porous structure and water absorption nature of the material. Lower replacement levels such as 5% may still provide acceptable durability performance, whereas higher replacement levels above 10–15% significantly increase water absorption and may reduce long-term durability. Therefore, the optimum use of sawdust should be carefully controlled to balance sustainability benefits and durability requirements in concrete production.

3.7.2.Chloride conductivity.

Chloride conductivity is a significant durability parameter used to evaluate the resistance of concrete against chloride ion penetration. Lower charge passed values indicate lower permeability and better resistance to chloride ingress, while higher values indicate greater ionic movement through the concrete pores, which may increase the risk of reinforcement corrosion in reinforced concrete structures. Figure 9 illustrates the chloride conductivity behavior of concrete containing different percentages of sawdust as partial replacement of fine aggregate. From the graph, it is evident that the charge passed decreases continuously with increasing sawdust content for both 7-day and 28-day curing periods. The control mix without sawdust (0%) recorded the highest charge passed values of approximately 580 coulombs at 7 days and 850 coulombs at 28 days. These values indicate comparatively higher chloride ion movement through the concrete matrix in the absence of sawdust.

At 5% sawdust replacement, the chloride conductivity slightly decreased to around 565 coulombs at 7 days and 780 coulombs at 28 days. This reduction suggests that the incorporation of a small amount of sawdust may contribute to partial pore refinement within the concrete structure. Fine sawdust particles can act as fillers, reducing the continuity of capillary pores and limiting chloride ion transport. When the sawdust content increased to 10%, the charge passed reduced further to approximately 520 coulombs at 7 days and 770 coulombs at 28 days. This improvement in chloride resistance may be associated with enhanced particle packing and the possible formation of a denser internal microstructure. The finer organic particles may help block interconnected pores, thereby reducing ionic conductivity through the concrete.

A significant reduction in chloride conductivity was observed at 15% saw dust replacement, where the charge passed values decreased to nearly 425 coulombs at 7 days and 740 coulombs at 28 days. This indicates improved resistance against chloride penetration compared to the control mix. The reduction in permeability may result from improved pore discontinuity and reduced movement of chloride bearing water through the concrete matrix.The lowest chloride conductivity values were obtained at 20% saw dust replacement, with approximately 320 coulombs at 7 days and 685 coulombs at 28 days. These results indicate that higher sawdust incorporation substantially reduced chloride ion penetration. The reduction may be due to the increased tortuosity of pore channels and reduced connectivity of capillary pores within the concrete. The fibrous and lightweight characteristics of sawdust may also contribute to restricting ionic movement through the matrix.

Based on the **ASTM C1202** classification for rapid chloride permeability, the recorded charge passed values generally fall within the “very low” chloride ion penetrability range, especially at higher sawdust replacement levels. This indicates that sawdust concrete possesses good resistance against chloride attack and may offer improved durability in chloride rich environments such as marine structures, coastal regions, and deicing salt exposure conditions. Another notable observation is that the 28-day charge passed values are consistently higher than the 7-day values in the presented graph. Although concrete typically shows reduced permeability with longer curing due to continued hydration, the

observed trend may be related to the moisture condition of the samples, variability in pore solution conductivity, or the influence of organic constituents present in sawdust. The organic compounds and absorbed moisture in sawdust may increase ionic conductivity during prolonged curing periods. Nevertheless, the overall decreasing trend with increasing sawdust content clearly demonstrates the beneficial effect of sawdust in reducing chloride ion penetration.

The error bars shown in the graph are relatively small, indicating good consistency and repeatability of the experimental results. The gradual reduction trend confirms that the addition of sawdust significantly influences the chloride transport properties of concrete. Overall, the results suggest that incorporating sawdust as partial fine aggregate replacement can improve the chloride resistance of concrete by reducing charge passed values and limiting chloride ion penetration. Lower to moderate replacement levels provide a balance between durability enhancement and structural integrity, while higher replacement levels show greater resistance to chloride ingress. Therefore, sawdust has potential as a sustainable supplementary material for improving the durability performance of concrete exposed to aggressive chloride environments

CONCLUSION

5.1. Conclusion

This study investigated the effect of sawdust as a partial replacement of fine aggregate on the fresh, mechanical, microstructural, and durability properties of mortar. Sawdust was incorporated at replacement levels of 0%, 5%, 10%, 15%, and 20%, and a comprehensive experimental program was conducted including setting time, flowability, compressive strength, flexural strength, SEM, FTIR, sorptivity, and chloride conductivity analyses. Based on the experimental findings, the following conclusions can be drawn.

The incorporation of sawdust significantly influenced the setting characteristics of cementitious mixtures. Increasing sawdust content generally delayed the initial setting time because of the high water absorption capacity and organic compounds present in sawdust, which interfered with early cement hydration. However, at moderate replacement levels, the final setting time was comparatively reduced, indicating accelerated stiffening after the onset of hydration. The workability of concrete increased progressively with increasing sawdust replacement. The flow table results showed that the control mix recorded the lowest flow value, while mixtures containing higher percentages of sawdust exhibited substantially improved flowability. This improvement was mainly attributed to the low density, fibrous texture, and smooth surface characteristics of sawdust particles, which reduced internal friction and increased paste volume within the mix.

Compressive strength decreased continuously with increasing sawdust content at both 7 and 28 days. The control mix achieved the highest compressive strength, whereas the 20% sawdust mixture recorded the lowest values. The reduction in strength was mainly associated with the porous structure of

sawdust, weak interfacial bonding between sawdust and cement paste, higher water absorption, and the retarding effect of organic substances on cement hydration. Nevertheless, mixtures containing 5–10% sawdust still maintained acceptable compressive strength suitable for several structural and non-structural applications. Flexural strength also showed a decreasing trend with increasing sawdust replacement, although the reduction was less severe than that observed for compressive strength. The 28-day flexural strength results demonstrated that moderate sawdust contents retained reasonable bending performance due to continued hydration and gradual densification of the matrix over time.

SEM analysis revealed substantial microstructural changes as sawdust content increased. The control concrete exhibited a dense and compact microstructure with strong aggregate paste bonding and minimal pores. In contrast, sawdust-modified concretes displayed weak interfacial transition zones (ITZ), increased porosity, microcracking, particle pull-out, and discontinuities within the cement matrix. The severity of these defects increased significantly at 15% and 20% replacement levels. FTIR analysis confirmed the presence of organic functional groups associated with sawdust, including cellulose, hemicellulose, and lignin compounds. Increasing sawdust content reduced the intensity of hydration-related peaks such as portlandite and calcium silicate hydrate (C-S-H), indicating suppression of cement hydration. At high replacement levels, the spectra were dominated by organic absorption bands, confirming the strong influence of sawdust on the chemical structure of the concrete matrix.

Sorptivity results showed that water absorption increased with increasing sawdust content. Higher sawdust replacement produced more interconnected pores and capillary channels which facilitated moisture penetration into the concrete. Although 28-day curing reduced sorptivity compared to 7-day values due to continued hydration, mixtures with high sawdust content still exhibited relatively high permeability. Chloride conductivity results demonstrated a reduction in charge passed values with increasing sawdust content, indicating improved resistance to chloride ion penetration. The fibrous structure and pore discontinuity created by sawdust appeared to restrict chloride ion movement through the concrete matrix. According to **ASTM C1202** classification, most mixtures fell within the low to very low chloride penetrability range.

Overall, the study demonstrated that sawdust can be successfully utilized as a sustainable supplementary material in concrete production, particularly at low to moderate replacement levels. Replacement levels between 5% and 10% provided the best balance between workability, mechanical performance, and durability characteristics. However, higher replacement levels above 15% significantly reduced strength and increased porosity, making them unsuitable for structural applications requiring high durability and load bearing capacity. The use of sawdust in mortar offers important environmental and economic benefits by reducing wood waste disposal problems, conserving natural sand resources, and promoting sustainable construction practices. Nevertheless, proper mix design optimization and material treatment are necessary to overcome the negative effects associated with high organic content and water absorption.

5.2. Recommendations

Based on the findings obtained from this study, the following recommendations are proposed for future research and practical applications of sawdust replacement in mortar should preferably be limited to 5–10% of fine aggregate for structural applications, as this range provides acceptable strength, improved workability, and satisfactory durability performance.

Higher replacement levels above 15% should only be considered for non-structural applications such as lightweight blocks, partition walls, insulation materials, and low-load concrete elements where high compressive strength is not critical. Pre-treatment methods such as washing, alkali treatment, heat treatment, or chemical stabilization of sawdust should be investigated to reduce water absorption and remove soluble organic compounds that retard cement hydration. The use of supplementary cementitious materials such as fly ash, silica fume, rice husk ash, or slag in combination with sawdust should be explored to improve the microstructure, reduce porosity, and enhance long-term durability performance.

Chemical admixtures such as superplasticizers and accelerators should be incorporated in future studies to compensate for the delayed setting time and strength reduction caused by sawdust addition. Further investigations should be conducted on long-term durability properties including sulfate resistance, carbonation resistance, freeze-thaw behavior, shrinkage, creep, abrasion resistance, and thermal conductivity of sawdust-modified concrete. Future research should include detailed interfacial transition zone (ITZ) characterization using advanced techniques such as EDX, XRD, TGA, and nanoindentation analysis to better understand the interaction between sawdust particles and cement hydration products.

The influence of particle size, moisture condition, and source type of sawdust on concrete performance should be systematically studied, since different wood species may exhibit different chemical and physical behaviors. Optimization studies using statistical and numerical modeling techniques should be carried out to identify the optimum combination of sawdust content, water-cement ratio, and admixture dosage for achieving sustainable high-performance concrete. Field-scale studies and practical implementation trials are recommended to evaluate the real-life performance of sawdust concrete under varying environmental and loading conditions before widespread commercial application.

Standards and guidelines should be developed for the safe and effective use of sawdust as a construction material in concrete production to ensure consistency, durability, and structural reliability. Sustainable waste management policies should encourage the utilization of sawdust in concrete manufacturing as an environmentally friendly alternative to landfill disposal and uncontrolled burning of wood waste.

DECLARATIONS

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Data Availability Statement

All experimental results, raw data, and processed datasets generated and analyzed in this study on the use of coffee husk ash in sustainable concrete, which provide insights into its microstructure and mechanical properties, have been retained by the authors. These data are available from the corresponding author upon reasonable request.

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Consent to participate

Dawit Beza: participate Conceptualization, Data Curation, Formal analysis, Writing- original draft.

Opeoluwa Rotimi Dada: Conceptualization, Data Curation, Writing- original draft, Supervision.

Abdulkerim Kedir Tesi: lab work, Conceptualization, Supervision, Writing- review and editing**.**

Akeem Ayinde Raheem and Bolanle Deborah Ikotun: Analysis and editing. All authors have willingly participated and approved the final version of the paper.

Consent to Publish Declaration

The author confirms that they consent to the publication of this manuscript titled ***Sawdust as a sustainable sand partial replacement in cement mortar: an Experimental Investigation of mechanical, microstructural, and durability properties***

Ethics declaration

not applicable

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Figures

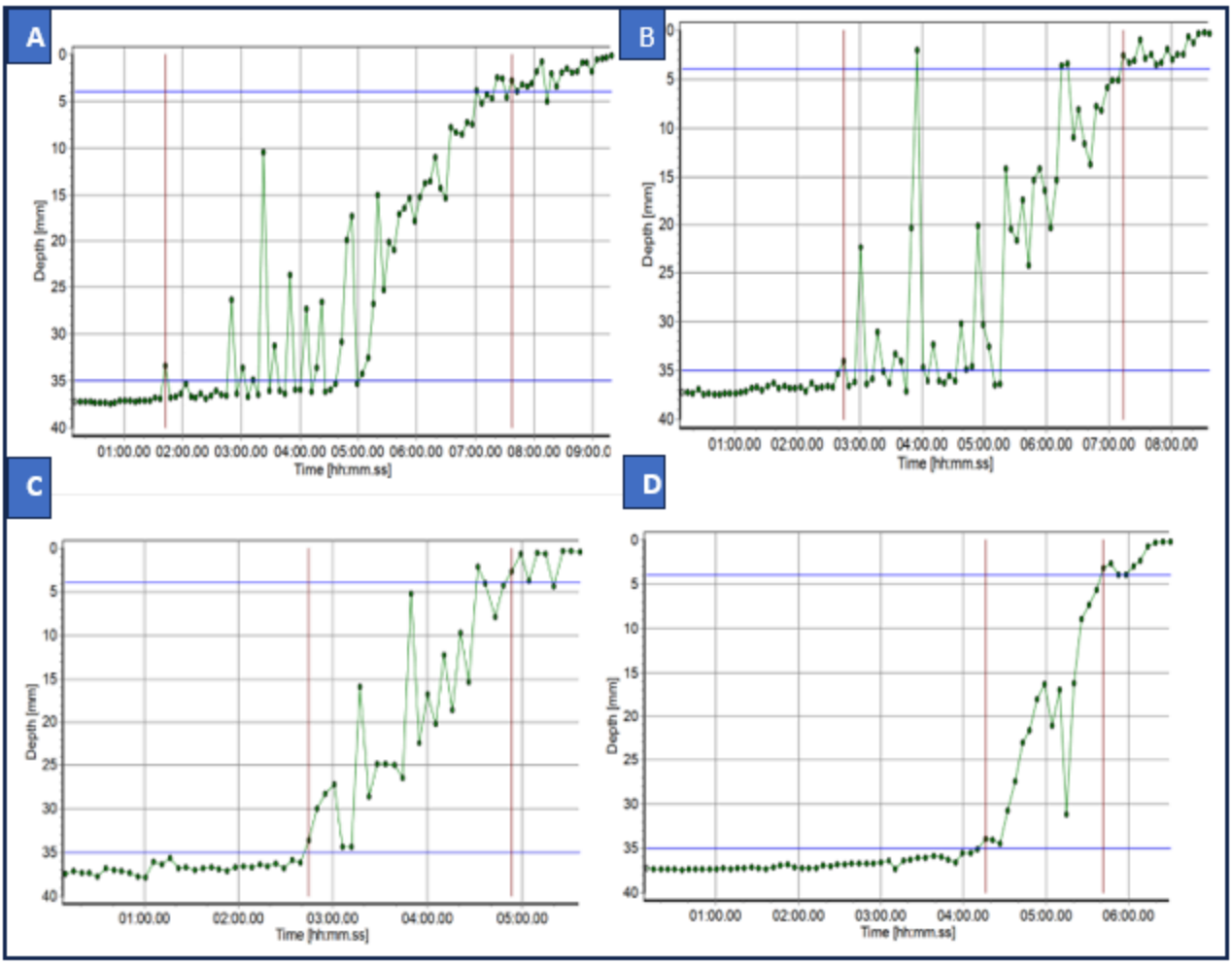


Figure 1

Initial and final setting time of cement

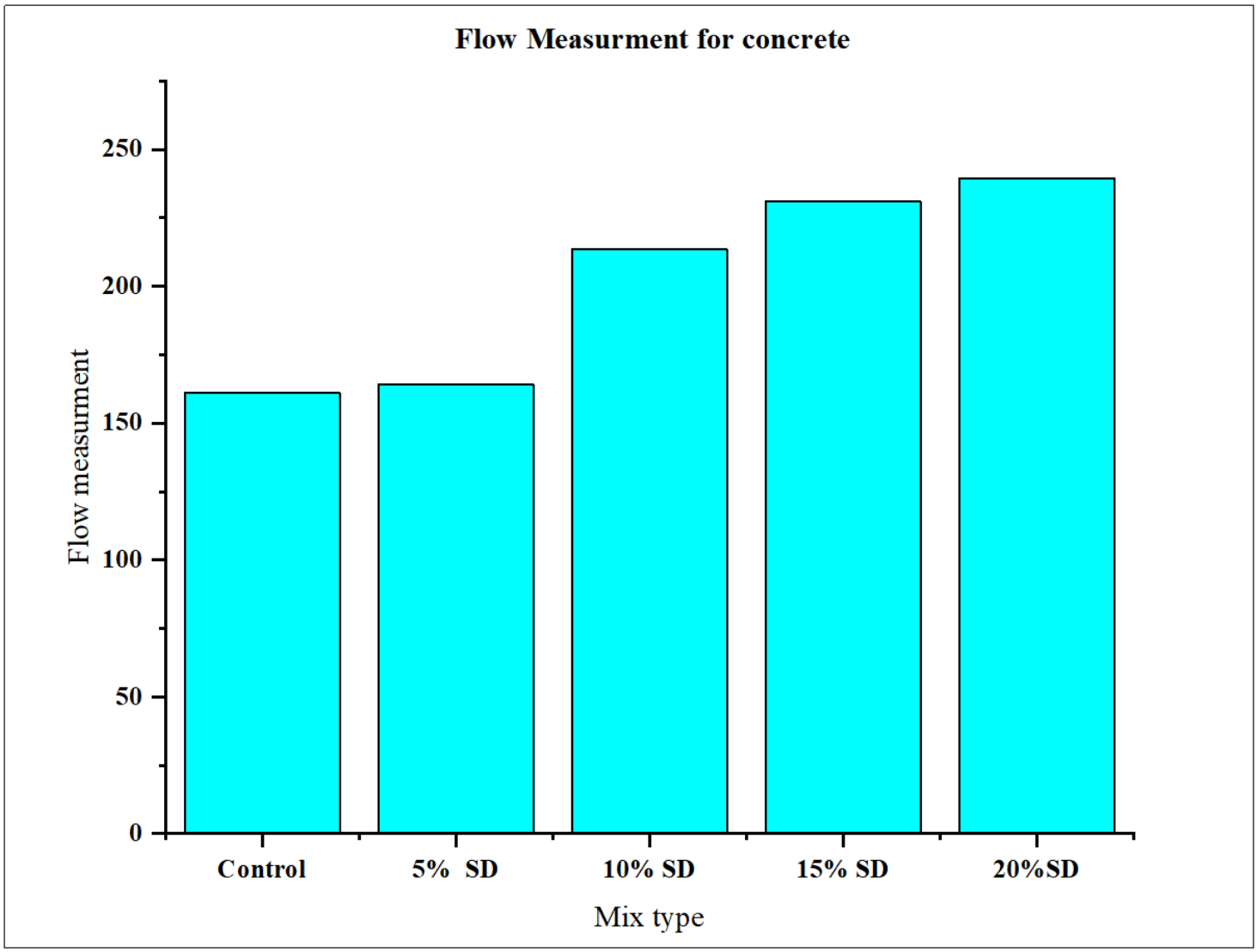


Figure 2

Flow measurement of mortar

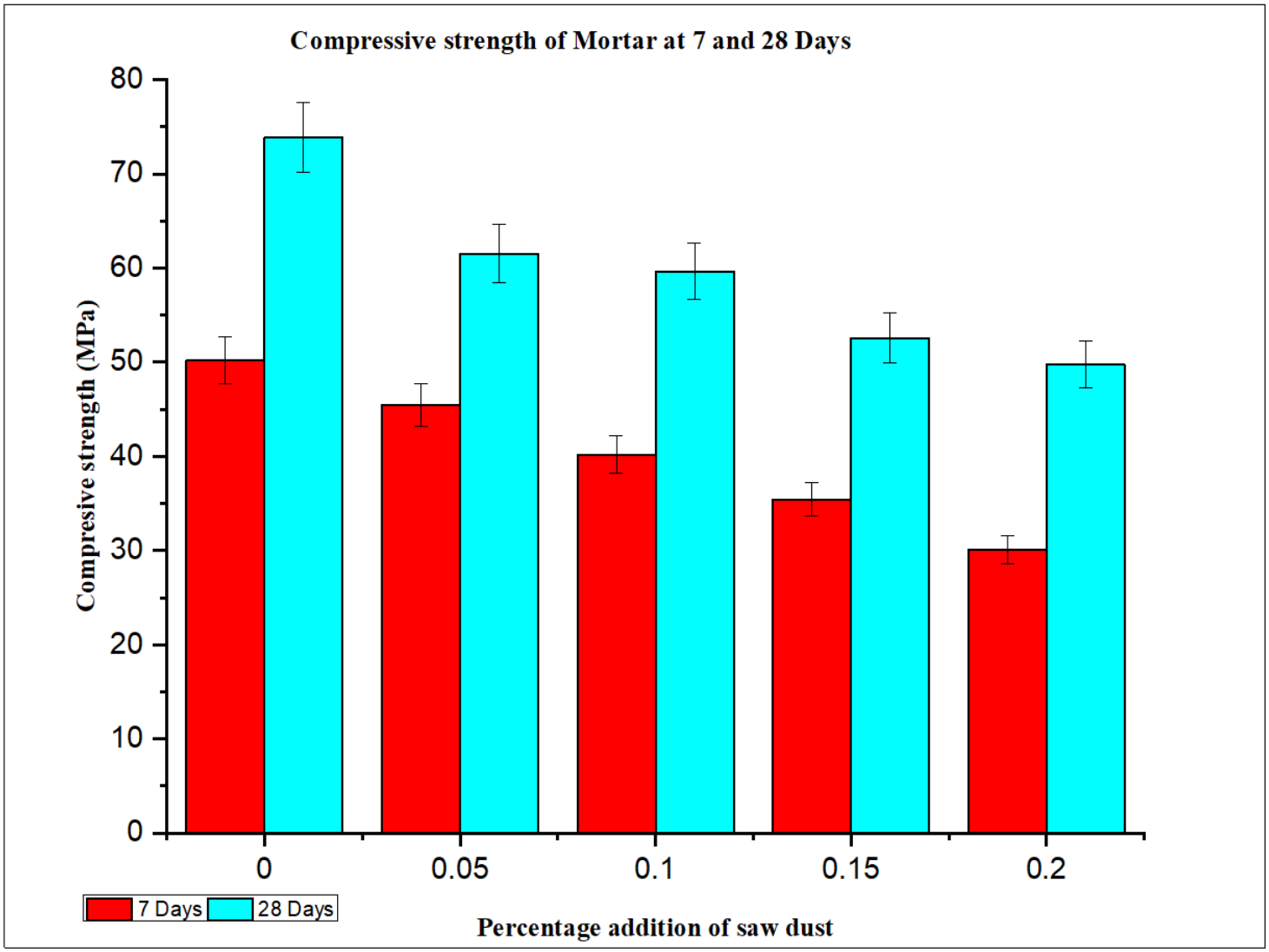


Figure 3

Compressive strength of mortar

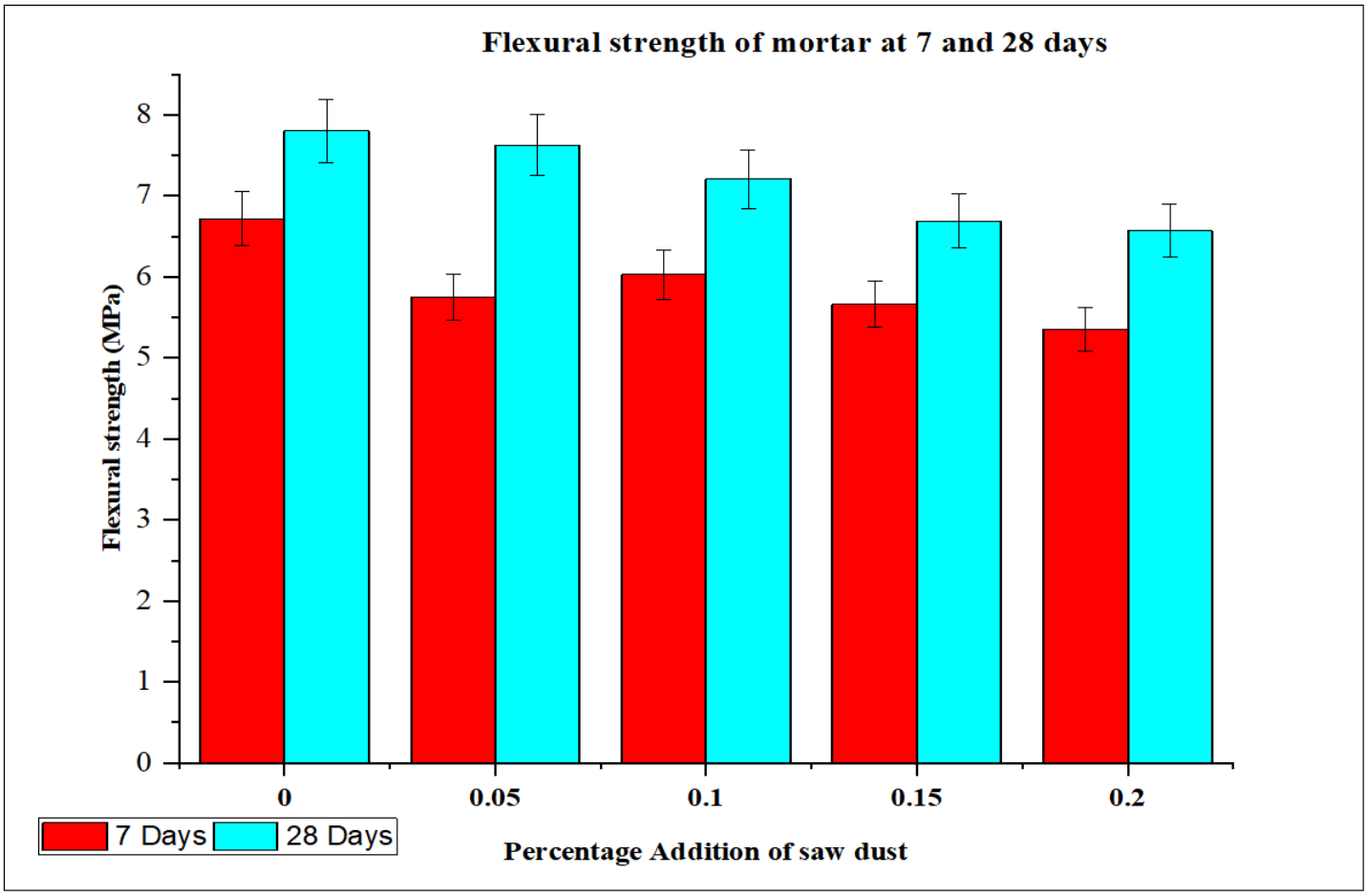


Figure 4

Flexural strength of mortar

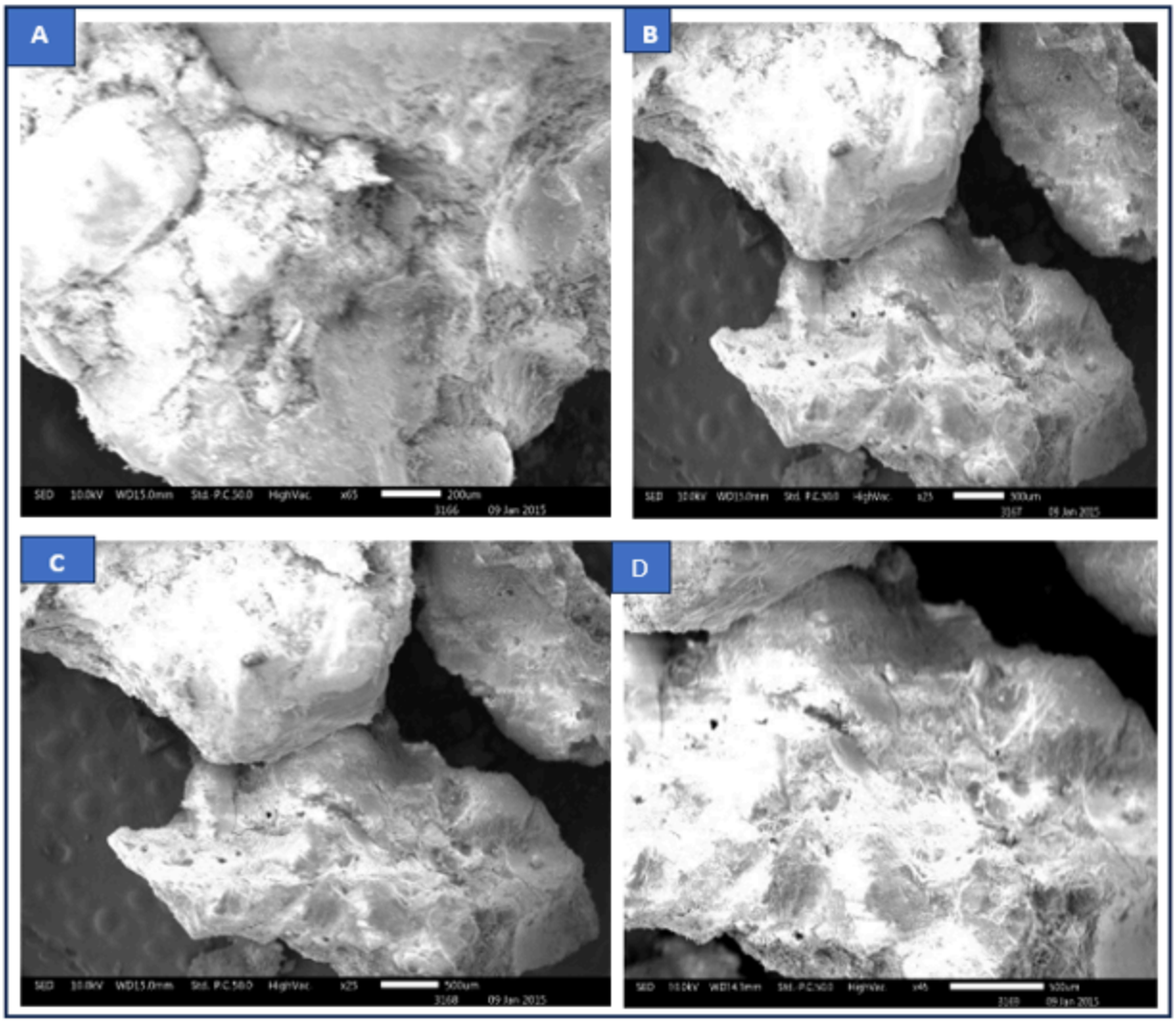


Figure 5

SEM Analysis for the mortar

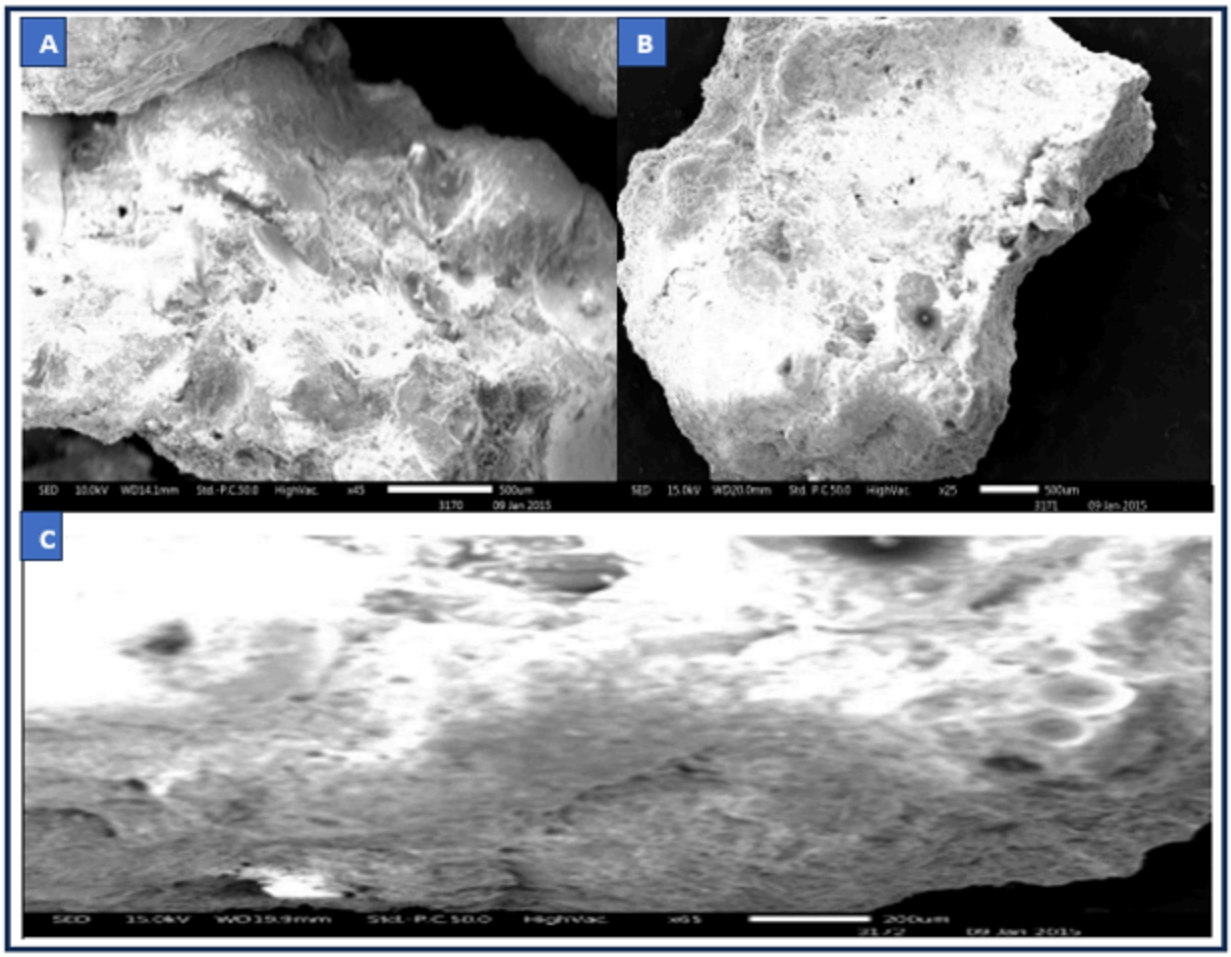


Figure 6

SEM Image of mortar containing wood ash

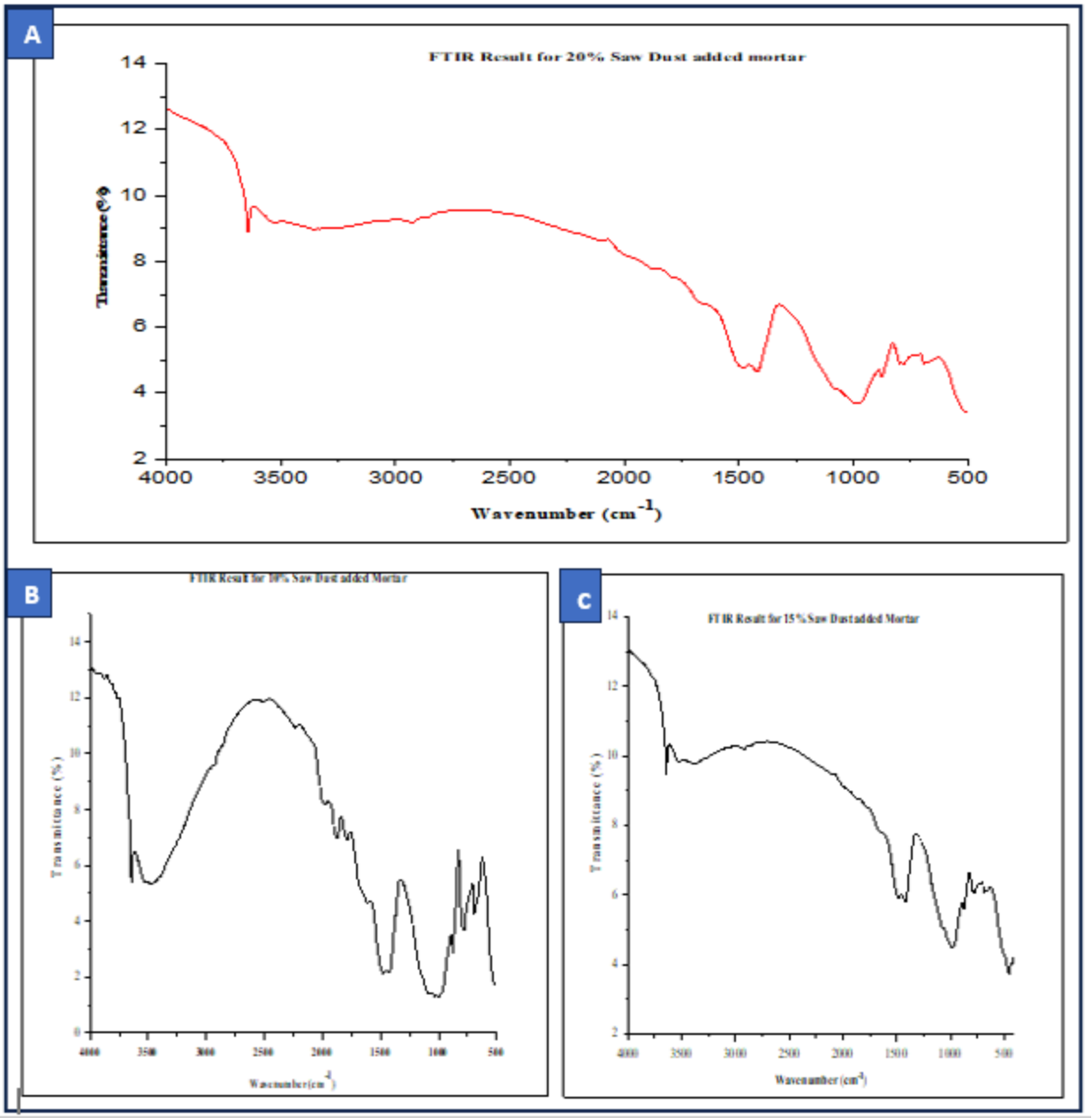


Figure 7

FTIR Result for concrete containing mortar

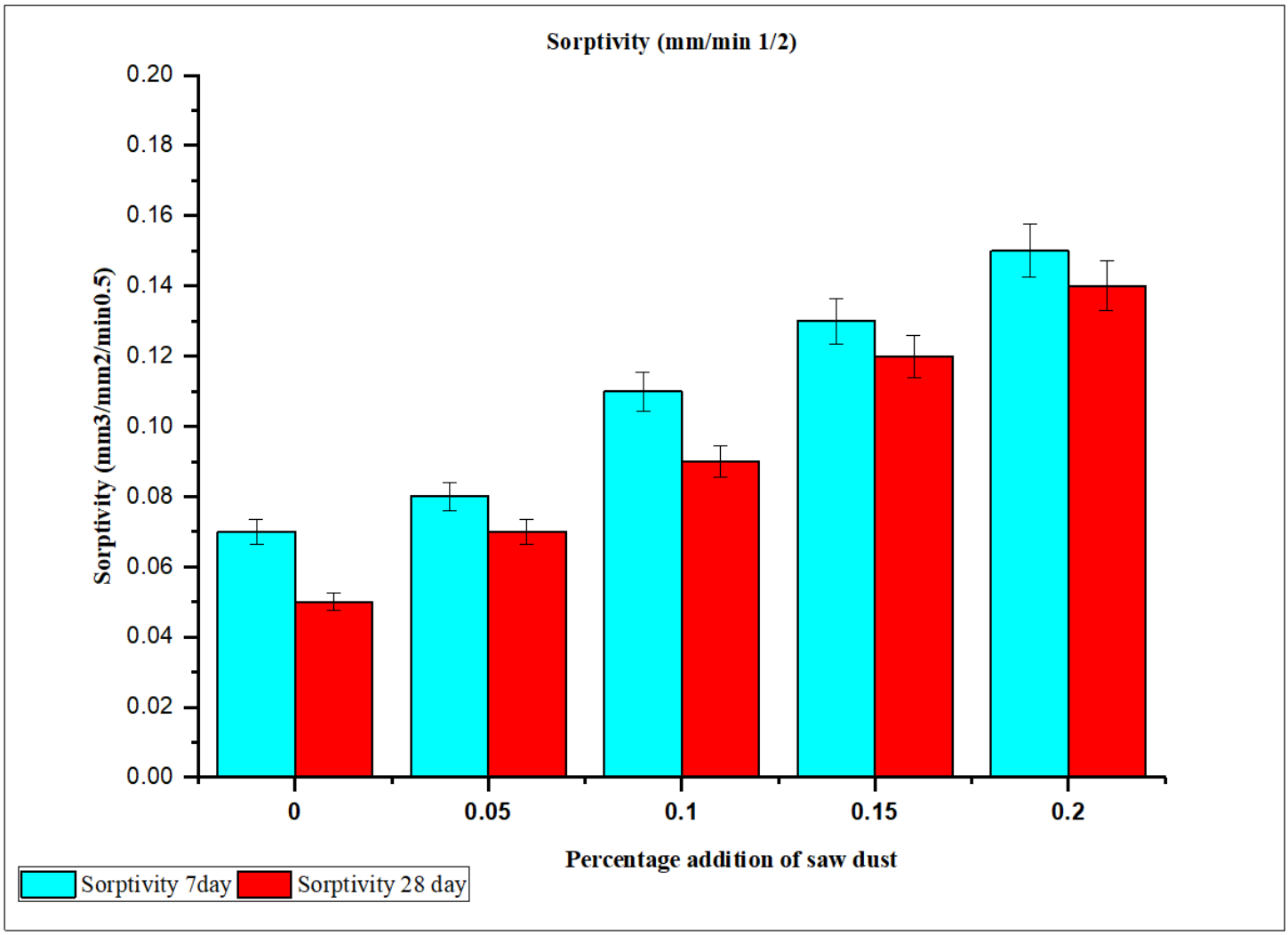


Figure 8

Sorptivity result of mortar containing saw dust

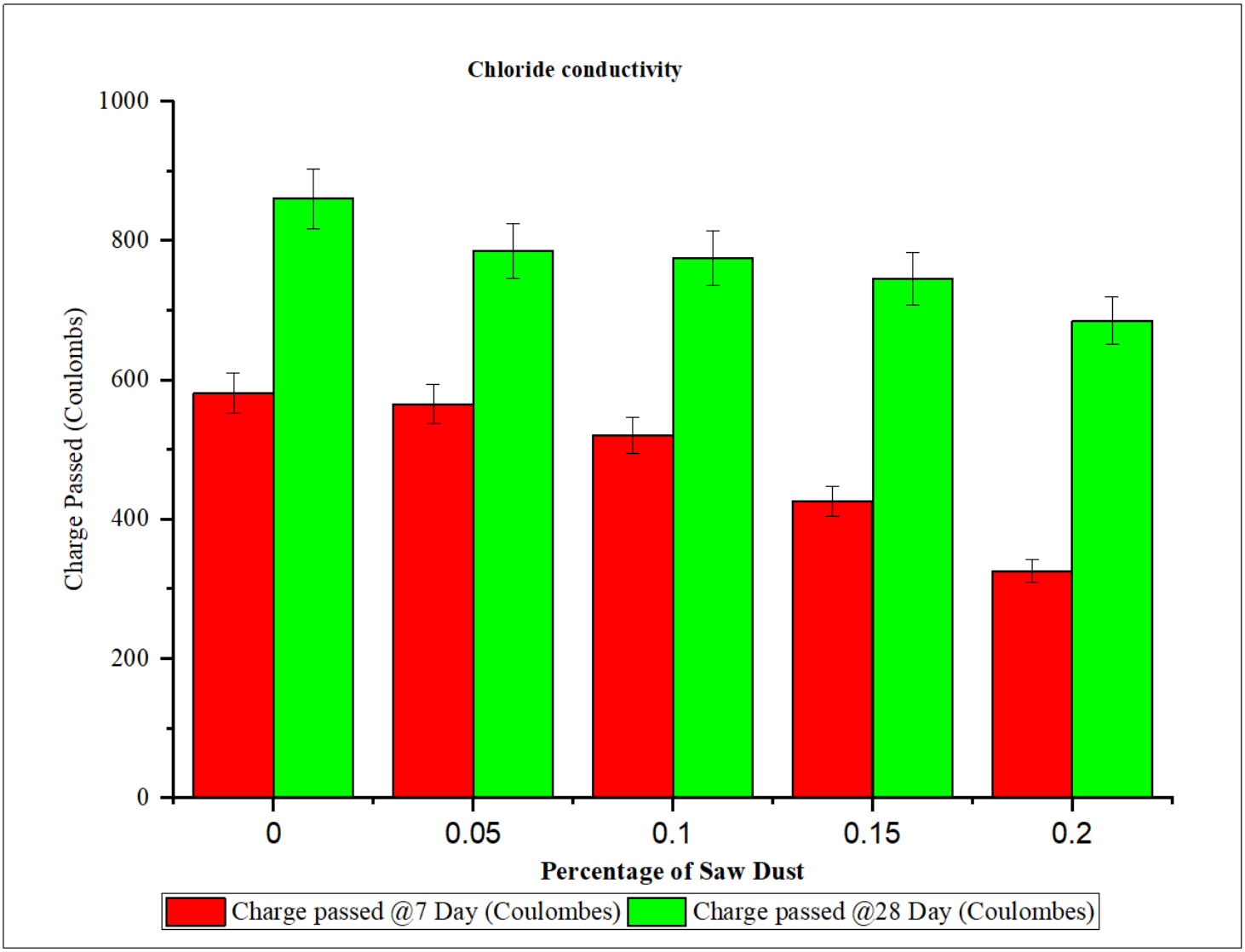


Figure 9

Chloride conductivity of mortar containing saw dust