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An Investigation into Sustainable Concrete Production Using Glass Powder and Sawdust as Fine Aggregate Substitutes

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Abstract

The construction industry faces significant environmental challenges due to the over-extraction of natural sand and the accumulation of industrial waste. To address this, this study investigates the partial replacement of fine aggregates in concrete with two industrial byproducts: glass powder (GP) and sawdust (SD). The research aims to mitigate ecological damage by diverting these materials from landfills, with a specific focus on replacing 35% of the natural sand volume in its optimal mix. The experimental program involved creating four concrete mixes with a constant 5% SD replacement and varying GP contents of 10%, 20%, and 30% by volume of fine aggregates. These were compared to a conventional control mix. Results demonstrated that the combination of 30% GP and 5% SD yielded the most favorable balance, achieving 85% of the control's compressive strength (25.7 MPa) while improving workability and reducing density by 7%. The increased GP content enhanced the matrix density through pozzolanic reactions, counteracting the porosity introduced by the sawdust. In conclusion, the integration of 30% glass powder and 5% sawdust as a replacement for fine aggregates is technically viable for producing sustainable concrete. This optimal mix not only delivers adequate mechanical properties for non-structural applications but also offers substantial environmental and economic benefits, including reduced raw material consumption and lower CO_2 emissions. Thus, this approach presents a promising pathway towards a more circular economy in the construction sector.

Keywords

Sustainable concrete; Glass powder; Sawdust; Fine aggregate; Compressive strength

1. Introduction

Concrete is the most widely used construction material globally, serving as the foundation of modern infrastructure, including high-rise buildings, transportation systems, bridges, and residential developments. Its unmatched dominance in the construction industry can be attributed to its high compressive strength, durability, adaptability, and cost-effectiveness. Global production of concrete now exceeds 30 billion tons annually— A volume that has more than doubled over the past two decades (Monteiro, Miller, & Horvath, 2017) [1]. This surge is primarily driven by rapid urban expansion, growing populations, and infrastructure development across emerging and developed economies.

However, the growing demand for concrete exerts immense pressure on natural resources, particularly fine aggregates such as sand, which typically comprise around 30% of the total concrete volume. The construction sector consumes tens of billions of tons of sand and gravel each year, making sand the second-most exploited natural resource after water. Conventional sand extraction from riverbeds, lakes, and coastal zones is causing significant environmental degradation, including riverbank erosion, aquifer depletion, habitat destruction, and a reduction in biodiversity. In some regions, unsustainable and even illegal sand mining practices have severely disrupted local ecosystems, altered watercourses, and posed risks to nearby communities and agriculture. The intensifying ecological and social consequences of this “sand crisis” underscore the urgent need for sustainable alternatives in concrete production.

Given the dual crises of raw material scarcity and escalating waste accumulation, the construction sector is increasingly looking toward integrated, sustainable solutions based on circular economy principles. One promising approach involves the use of industrial byproducts such as finely ground glass powder and sawdust as partial replacements for natural sand in concrete. When glass is milled to fine particles below certain thresholds, it develops pozzolanic properties. The silica content in glass powder can react with calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H), which improves the density and mechanical strength of the concrete matrix (Islam, Rahman, & Kazi, 2017) [2]. Moreover, when properly processed to a fine size, glass powder can reduce the risk of alkali-silica reaction, a potentially harmful expansion process in concrete. On the other hand, sawdust contributes value by significantly reducing the weight of concrete, making it attractive for applications where low density is beneficial. Its fibrous, porous nature also improves thermal insulation, which can enhance energy efficiency in buildings.

However, while glass powder strengthens the concrete matrix, sawdust introduces challenges, particularly due to its high water absorption and potential to weaken early-age strength. The addition of sawdust tends to reduce concrete's workability and mechanical strength if not carefully controlled. As such, combining these two materials—glass powder and sawdust—presents both opportunities and challenges. The theoretical basis for their synergy is compelling: the pozzolanic behavior of glass powder may offset the strength loss introduced by sawdust, while the lightweight nature of sawdust could reduce the density increase typically associated with glass powder. Moreover, glass powder's relatively low water absorption may help compensate for the high hygroscopicity of sawdust, potentially improving fresh-state properties like slump and setting time.

Despite individual studies (Schwarz, Cam, & Neithalath , 2008; Aigbomian & Fan, 2013) [3,4] exploring either glass powder or sawdust as partial sand replacements in concrete, the combined application of both materials remains largely unexamined. Their interactions, performance across varying replacement levels, and long-term durability effects have not been systematically investigated. This gap in research limits the development of optimized mix designs and constrains broader adoption of these sustainable alternatives in practice.

This study addresses these shortcomings through a structured investigation into the synergistic use of glass powder and sawdust in concrete production. Three key innovations guide this work. First, it presents the first comprehensive analysis of how glass powder and sawdust interact within concrete mixtures, particularly focusing on their complementary physical and chemical behaviors. Second, it evaluates the performance of these mixtures over an extended period—up to 90 days—thereby providing insights into both early-age and long-term strength and durability metrics. Third, the study emphasizes practical optimization by seeking the ideal balance between environmental benefit and structural viability, especially for non-load-bearing applications.

2. Literature Review: Sustainable Concrete with Glass Powder and Sawdust as Fine Aggregate Replacements

Concrete remains the world's most consumed construction material due to its structural integrity, durability, and versatility. However, its widespread use raises environmental concerns, especially due to the extraction of natural aggregates and accumulation of construction and industrial waste. These challenges have prompted increased interest in sustainable concrete production, with focus on integrating industrial by-products like glass powder (GP) and sawdust (SD) as partial replacements for fine aggregates.

2.1. Environmental Impacts of Sand Extraction and Waste Accumulation

The global demand for natural sand—primarily used as a fine aggregate in concrete—has soared dramatically, with estimated annual extraction exceeding 40–50 billion tons (Villioth, 2014) [5]. This demand outpaces the natural replenishment of sand in rivers, lakes, and coastal zones. As a result, uncontrolled sand mining has triggered numerous environmental issues, including riverbed degradation, flooding, habitat destruction, and water table depletion. Villioth (2014) [1] further argues that some regions now face an acute sand shortage, destabilizing local construction economies and inflating raw material costs.

At the same time, industrial and post-consumer waste continues to grow. According to Glass Alliance Europe (2020) [6], approximately 209 million tons of glass waste are produced globally each year, predominantly from beverage containers, flat glass, and packaging. Borzecka (2018) [7] notes that in Europe alone, sawdust generation from wood processing reaches around 55 million tons per year, most of which ends up in landfills or is incinerated—contributing to air and soil pollution. Idir, Cyr, and Tagnit-Hamou (2015) [8] highlight inefficiencies in glass recycling processes: more than 80% of glass waste remains unrecycled due to logistical barriers, contamination issues, and limited infrastructure.

2.2. Waste Valorization in Concrete: Glass Powder as Fine Aggregate Replacement

The valorization of glass powder (GP) in concrete has been widely explored due to its pozzolanic potential. When ground finely (typically <100 μm), glass powder contains a high content of amorphous silica, which reacts with calcium hydroxide from cement hydration to form additional calcium silicate hydrate (C-S-H)—enhancing the concrete matrix (Du & Tan, 2014) [9]. Adaway and Wang (2015) [10] found that replacing 20–30% of natural sand with GP improved compressive strength by 4–9%, while simultaneously reducing permeability by up to 50%. Such improvements stem from refined particle packing and reduced capillary porosity.

Meddah (2019) [11] also demonstrated that using glass particles below 2 mm mitigates the alkali–silica reaction (ASR)—a significant durability concern in glass-containing concrete. Additionally, these mixes exhibited enhanced resistance to freeze-thaw cycles, making them more suitable for infrastructure in cold climates.

However, the use of GP is not without limitations. Serelis and Ngobeni (2025) [12] caution that excessive replacement levels (beyond 40%) may negatively affect mechanical properties and consistency due to variability in glass source, particle morphology, and color. The heterogeneity in recycled glass introduces challenges in mix design control, necessitating standardization in preprocessing techniques.

2.3. Sawdust as an Organic Fine Aggregate Substitute

Sawdust, a lightweight and porous material, introduces a different set of mechanical and durability considerations. Its incorporation in concrete primarily reduces density, making it useful for lightweight applications. Narayanan, Hemnath, and Sampaul (2017) [13] reported that substituting 5–15% of fine aggregate with sawdust led to density reductions of 4–19%. This makes sawdust concrete attractive for non-structural or thermally insulating applications where lower dead load is beneficial.

However, its high water absorption capacity (200–250%) poses a major issue. James and Daniel (2018) [14] observed that untreated sawdust leads to excessive slump loss and impaired strength development, with compressive strength losses ranging from 13–50%, depending on replacement ratio. Ganiron (2014) [15] similarly found that permeability increased by 60–80% due to poor particle bonding and internal voids. Nevertheless, soaking sawdust prior to mixing was found to reduce water absorption by up to 40%, partially mitigating these effects.

Farahinia et al. (2024) [16] explored further enhancements by incorporating pozzolanic additives such as silica fume and metakaolin. They found that a mix containing 10% silica fume or 5% metakaolin improved interfacial bonding and compressive strength by up to 20% compared to untreated sawdust mixes, particularly at early curing ages.

2.4. Combined Use of Glass Powder and Sawdust: Synergistic Approaches

Recent studies have explored the combined use of GP and SD, leveraging their complementary properties—GP’s pozzolanic reactivity and SD’s lightweight characteristics. Animasaun et al. (2025) [17] evaluated concrete mixes containing 20% GP and 10% SD, reporting a modest increase in compressive strength (2.65%) and flexural strength (1.68%) compared to control samples. The combination reduced the overall unit weight while preserving mechanical integrity within acceptable limits for non-load-bearing applications.

Farahinia et al. (2025) [18] expanded on this by testing high-volume substitutions (30% GP + 25% SD), but observed significant declines in compressive and tensile strengths. These results indicate a performance threshold beyond which durability and structural reliability cannot be maintained. Thus, optimal replacement levels must be carefully determined based on intended application and exposure conditions.

Presbitero et al. (2025) [19] applied GP–SD composites in flooring tile production. They used 50% GP and 25% SD in a cementitious matrix and achieved density reductions of 18% while still satisfying European standards for water absorption and flexural resistance. Their work underscores the potential of such mixes in circular construction, especially for cost-effective, sustainable housing solutions.

2.5. Optimization and Modeling Approaches

To determine the ideal mix proportions, several researchers have applied optimization techniques. Chakravarty, Sen, and Khiangte (2023) [20] employed Response Surface Methodology (RSM) to optimize the replacement ratios of GP and SD. Their findings suggested that 30% GP and 5% SD yielded the best compromise between strength, workability, and weight reduction. Statistical modeling helped identify key interaction terms, allowing for predictive formulation without extensive trial batches.

Machine learning tools are also gaining popularity in sustainable concrete research. Gebremichael, Jadidi, and Karakouzian (2023) [21] developed an artificial neural network (ANN) model trained on laboratory data to predict compressive strength of

GP–SD concrete mixes. Their model achieved a high R^2 value of 0.945, proving effective in capturing nonlinear interactions between constituents and enabling efficient mix design iteration.

2.6. Practical Applications and Environmental Benefits

From an application standpoint, GP and SD-based concrete mixes are being tested in various building elements. Depan, Raval, and Pitroda (2022) [22] successfully developed foamed concrete bricks using GP–SD blends, achieving low thermal conductivity (0.25–0.35 W/mK) ideal for passive cooling strategies in hot climates. Alabduljabbar et al. (2020) [23] demonstrated the suitability of sawdust geopolymer concrete in non-structural applications, achieving compressive strengths of ~28 MPa with good thermal insulation.

Sustainability assessments further reinforce the value of GP–SD integration. Folagbade and Olatunji (2020) [24] conducted a life cycle assessment (LCA) and found that incorporating recycled materials reduced CO_2 emissions by 18–25% compared to conventional concrete. These reductions primarily stemmed from lower cement content and elimination of virgin aggregate use.

However, despite these advantages, long-term durability remains a concern. Batool et al. (2021) [25] emphasize the need for standardized testing for acid resistance, sulfate attack, and freeze–thaw durability to ensure the structural reliability of GP–SD-based concretes over their service life. Without such data, adoption in critical structural elements remains limited.

3. Materials and Methodology

3.1. Experimental Framework

This study adopted a systematic and comprehensive experimental approach to evaluate the performance of concrete with partial replacement of fine aggregates using glass powder (GP) and sawdust (SD). Four distinct mix designs were developed, incorporating 0%, 10%, 20%, and 30% GP while maintaining a fixed 5% SD replacement level across all variants. The objective was to achieve C20 concrete strength (20 MPa) with a workability range targeted within a 50–80 mm slump. The experimental workflow was carefully sequenced, beginning with material characterization and mixture proportioning, followed by specimen preparation and curing, and concluding with mechanical and durability testing at specified curing periods (7, 28, 56, and 90 days). Quality control was maintained rigorously at all stages to ensure consistency, reliability, and reproducibility of the experimental results.

3.2. Material Specifications and Preparation

3.2.1. Cement

The cement used in this study was CEM III/A 42.5 N, which complies with the EN

197-1:2011 standard. This blended cement includes 37.5% ground granulated blast-furnace slag (GGBFS), contributing to enhanced sulfate resistance and low heat of hydration. Key physical properties include a Blaine fineness of 3,593 cm^2/g and a moisture content of 0.04%. The chemical composition, verified using X-ray fluorescence (XRF), revealed significant proportions of silica (SiO_2 – 25.38%), alumina (Al_2O_3 – 7.65%), lime (CaO – 55.29%), and other oxides. The cement demonstrated good early strength development and durability characteristics suitable for use in modified concrete formulations.

3.2.2. Aggregates

Coarse aggregates used were sourced from quarries and divided into two size fractions: 12.5–19 mm (40%) and 4.75–12.5 mm (60%). Fine aggregates consisted of natural river sand passing through a 4.75 mm sieve. Physical properties such as specific gravity, water absorption, and bulk density were thoroughly assessed. The aggregate materials met the required standards for strength, durability, and gradation to ensure compatibility with the GP and SD blends.

Figure 3.1. Sample of Coarse Aggregates Used (Size Range: 12.5 mm - 19 mm)

3.2.3. Glass Powder (GP)

Figure 3.2. Sample of the glass powder used

The glass powder was produced from post-consumer green glass bottles. The preparation process included label and contaminant removal using pressurized water, primary crushing via a jaw crusher to reduce bottle fragments to 10–15 mm, and subsequent milling in a Los Angeles abrasion machine for finer particle breakdown. The ground material was sieved using a 2 mm mesh to ensure uniform particle size, with particles retained on the sieve discarded. The GP was stored in airtight containers to prevent moisture absorption. The processed material exhibited a specific gravity of 2.65 and water absorption of just 0.04%, with 92% of the particles measuring less than 1 mm in diameter. The sample is shown on Figure 3.2.

3.2.4. Sawdust (SD)

Sawdust was obtained from local pinewood sources and processed to ensure uniformity and moisture stability. The raw material was sun-dried for 48 hours at 30±5°C, followed by sieving through a 2 mm mesh to eliminate large particles. To simulate saturated surface dry (SSD) conditions, the sieved SD was immersed in water for 12 hours, then surface-dried using absorbent cloths. The final material had a specific gravity of 0.35, with a high untreated water absorption rate of 200%, and a bulk density of 229 kg/m^3. Sieving of the sawdust shown in Figure 3.3

Figure 3.3. Sieving of the sawdust

3.2.5. Chemical Admixtures

A polycarboxylate-based superplasticizer (Glenium 51) was used at 1.5% of the cement weight, equivalent to 5.4 kg/m^3. This admixture meets ASTM C494 Type F standards and is characterized by a pH of 6.5±1 and a chloride content of less than 0.1%. Its purpose was to enhance workability and ensure target slump levels were achieved, particularly in mixes containing high GP content which may otherwise reduce fluidity.

3.3. Mixture Proportioning and Design

3.3.1. Design Philosophy

The mix design followed the ACI 211.1 method, with specific adaptations to accommodate the inclusion of GP and SD. A constant water-cement ratio of 0.62 was maintained for the control mix, while a higher ratio of 0.75 was adopted for mixes with GP and SD to account for the increased absorption and surface area of these materials. Coarse aggregate content was fixed at 1024 kg/m^3, while natural river sand was partially replaced by varying proportions of GP (10%, 20%, 30%)

combined with a consistent 5% SD. Adjustments to the superplasticizer dosage were made to ensure target workability, and the full mix proportions are detailed in Table 3.1 with units of numbers in kilograms per cubic meter (kg/m^3).

3.4. Specimen Fabrication Protocol

3.4.1. Batching and Mixing

Prior to mixing, all materials were conditioned at 23±2°C for 24 hours. Materials were batched using precision electronic scales (accuracy ±0.1%). Dry mixing of cement, coarse and fine aggregates, GP, and SD was performed for two minutes, followed by the addition of water and superplasticizer, with continued mixing for one minute. A final mixing sequence involved three minutes of wet mixing, a one-minute rest, and a final two-minute mix to ensure homogeneity. Visual inspection was used to verify mix consistency.

Table 3.1. Detailed Concrete Mix Proportions (kg/m^3)

Component	Mix 1 (Control)	Mix 2 (10% GP)	Mix 3 (20% GP)	Mix 4 (30% GP)
Cement	361	361	361	361
Water	224	271	271	271
Coarse Agg. (12.5-19mm)	410	410	410	410
Coarse Agg. (4.75-12.5mm)	614	614	614	614
Natural Sand	746	634	560	485
Glass Powder (GP)	0	74.4	149	224
Sawdust (SD)	0	37.3	37.3	37.3
Superplasticizer	0	5.4	5.4	5.4
Replacement Rate	0%	15% (10% GP+5% SD)	25% (20% GP+5% SD)	35% (30% GP+5% SD)

3.4.2. Casting Procedure

Steel molds of dimensions 150 mm (cubes) and Ø150×300 mm (cylinders) were prepared using a release agent. Concrete was cast in three layers with each layer compacted using 25 strokes of a tamping rod, followed by external vibration for 10 seconds. Finishing was done using a steel trowel to create smooth surfaces. Each specimen was labeled with engraved identification codes indicating the mix number and casting date.

3.4.3. Curing Regime

Specimens underwent initial curing under wet burlap at 23±2°C for 24 hours. After demolding, they were immersed in lime-saturated water at the same temperature. Specimens were removed for testing at 7, 28, 56, and 90-day intervals in accordance with standard procedures.

3.5. Testing Methods and Instrumentation

3.5.1. Fresh Concrete Tests

Workability was assessed using the slump test as per ASTM C143, employing the standard Abrams cone. Setting times were measured using an automated Vicat apparatus following ASTM C403, with specific criteria for initial and final setting based on needle penetration resistance.

3.5.2. Hardened Concrete Tests

Compressive strength was tested following EN 12390-3 using 150 mm cubes, with a loading rate of 0.6 MPa/sec. Splitting tensile strength was measured according to EN 12390-6 on Ø150×300 mm cylinders with a loading rate of 0.04 MPa/sec. Water permeability was evaluated under EN 12390-8, applying 5-bar pressure over 72 hours and measuring the maximum penetration depth after specimen splitting. Density and water absorption were determined using ASTM C642 by oven-drying the specimens at 110°C to constant mass followed by vacuum saturation.

3.6. Quality Assurance Framework

To ensure the reliability of results, several quality assurance measures were adopted. Aggregate moisture was monitored daily, and consistency of cement batches was validated through early compressive strength testing. Load frames were calibrated quarterly in accordance with ISO 7500-1, and measuring instruments were verified weekly. Each test condition included three specimens, and outliers were identified using Grubbs' test at a 5% significance level. The laboratory environment was controlled at a temperature of 23±2°C and relative humidity of 50±10%. Data acquisition was conducted electronically with backup manual logs to ensure traceability.

4. Results and Discussions

4.1. Overview of Material Characterization

Comprehensive material characterization formed the foundation for interpreting concrete performance. The grain size distribution analysis (Table 4.1) revealed that 82% of natural sand passed the 2 mm sieve, establishing compatibility with processed glass powder (GP) and sawdust (SD) particles. The absorption characteristics showed significant variation: coarse aggregates exhibited low absorption (0.5-0.7%), while sawdust demonstrated exceptionally high absorption capacity (200% in untreated state). Moisture content analysis (Table 4.2) confirmed minimal water content in aggregates (<0.04%) but notable levels in cement (1.07%), necessitating precise batching control. Bulk density measurements (Table 4.3) highlighted the substantial density differential between conventional materials (sand: 1845 kg/m^3) and sawdust (229 kg/m^3), foreshadowing significant impacts on concrete density.

Table 4.1. Sieve Analysis of Fine Aggregates

Sieve size (mm)	Retained%	Passed%

4.75	0	100
2.36	90	90
2	75	82
1.18	150	65
0.6	225	40
0.3	225	15
0.15	135	0

Table 4.2. Material Moisture Content

Material	Normal State (**gr**)	Oven Dry State (**gr**)	Moisture Content (%)
Coarse	500	499.9	0.02
Aggregate Fine	500	499.8	0.04
Aggregate Cement	500	494.8	1.07
Glass Powder	500	499.8	0.04

Table 4.3. Bulk Density of Constituent Materials

	Bulk Density (g/cm^3)
Coarse Aggregate	1.412
Fine Aggregate	1.845
Glass Powder	1.737
Sawdust	0.229

4.2. Fresh Concrete Properties

4.2.1. Workability Characteristics

The slump test results (Table 4.4) demonstrated complex interactions between waste materials and workability. The control mix (Mix 1) achieved the target slump of 6 cm at w/c 0.62. Mix 2 (10% GP + 5% SD) exhibited a 50% slump reduction (3 cm) despite increased water content (w/c 0.75) and superplasticizer addition. This phenomenon is attributed to sawdust's hygroscopic nature, where its microporous structure absorbed mixing water, reducing lubricating paste volume. As GP content increased to 20% (Mix 3) and 30% (Mix 4), slump values recovered to 4 cm and 7 cm respectively. This recovery stems from two mechanisms: 1) GP's smooth, non-absorbent particles improved particle mobility; 2) Reduced sand content lowered overall surface area requiring water coating.

Table 4.4. Concrete Workability Parameters

Mix Designation	w/c Ratio	Superplasticizer (% cement)	Slump (cm)
Mix 1 (Control)	0.62	0	6

Mix 2 (10% GP)	0.75	1.5% of cement content (5.4 kg/m^3)	3
Mix 3 (20% GP)	0.75	1.5% of cement content (5.4 kg/m^3)	4
Mix 4 (30% GP)	0.75	1.5% of cement content (5.4 kg/m^3)	7

4.2.2. Setting Behavior

Setting time measurements (Table 4.5) revealed significant retardation in waste-modified mixes. The control mix set rapidly (initial: 155 min; final: 320 min), consistent with CEM III cement properties. Incorporation of 10% GP + 5% SD (Mix 2) extended initial setting to 445 min and final setting to 565 min. This retardation is attributed to: 1) Sugar compounds in sawdust interfering with hydration nucleation; 2) Zinc ions from glass inhibiting C_3A reaction. As GP content increased to 30% (Mix 4), setting times reduced progressively (initial: 262 min; final: 528 min) due to GP's pozzolanic activity consuming $Ca(OH)_2$ and accelerating reaction kinetics. All values remained within ASTM C191 limits (initial ≤600 min, final ≤720 min).

Table 4.5. Concrete Setting Times

Mix Designation	Initial Setting (min)	Final Setting (min)
Mix 1 (Control)	155	320
Mix 2 (10% GP)	445	565
Mix 3 (20% GP)	323	546
Mix 4 (30% GP)	262	528

As presented in Table 4.5 and graphically illustrated in Figure 4.1, the partial replacement of fine aggregate with glass powder markedly altered the concrete's setting behavior. The results demonstrate a substantial delay in setting times for all GP-containing mixes compared to the control. A key observation from the bar chart is the peak in setting times at 10% GP replacement, with a gradual reduction observed at higher GP percentages (20% and 30%), suggesting a complex interaction between the pozzolanic activity and the dilution effect.

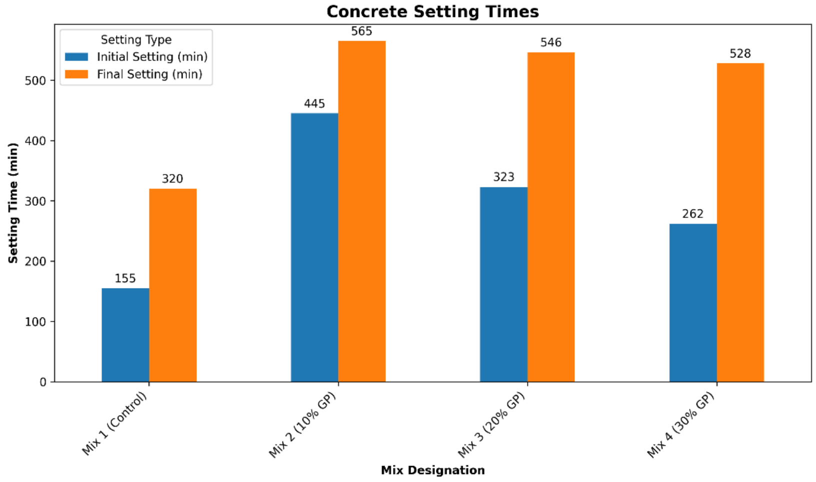

Figure 4.1. Concrete Setting Times

4.3. Hardened Concrete Properties

4.3.1. Compressive Strength Development

The compressive strength development showed clear trends across curing periods. At 7 days, Mix 2 (10% GP) experienced a 77.9% reduction in strength compared to the control, due to sawdust hindering early hydration. In contrast, Mix 4 (30% GP) performed better, reaching 74.3% of control strength, benefiting from GP's nucleation effect that accelerated C-S-H formation. By 28 days, Mix 4 showed significant strength recovery, achieving 80.5% of control strength, with a 15.8% gain from 7 to 28 days, indicating the onset of pozzolanic reactions. Meanwhile, Mix 2 remained weak at 47.6%. At 90 days, Mix 4 continued to improve, reaching 69.5% of control strength with a 15.3% gain from 28 to 90 days, confirming ongoing reactivity. In contrast, Mix 2 dropped further to 17.2%, highlighting the long-term weakening effect of sawdust versus the sustained pozzolanic contribution of GP.

Table 4.6. Compressive Strength Evolution (MPa)

Mix Designation	7 days	28 days	56 days	90 days
Mix 1 (Control)	14.0	26.5	32.3	37.0
Mix 2 (10% GP)	3.1	12.6	9.2	6.4
Mix 3 (20% GP)	3.0	14.2	11.8	13.3
Mix 4 (30% GP)	10.4	21.3	22.1	25.7

The compressive strength development of all concrete mixes over a 90-day curing period is detailed in Table 4.6 and graphically depicted in Figure 4.2. The control mix (Mix 1) demonstrated a consistent and significant strength gain over time.

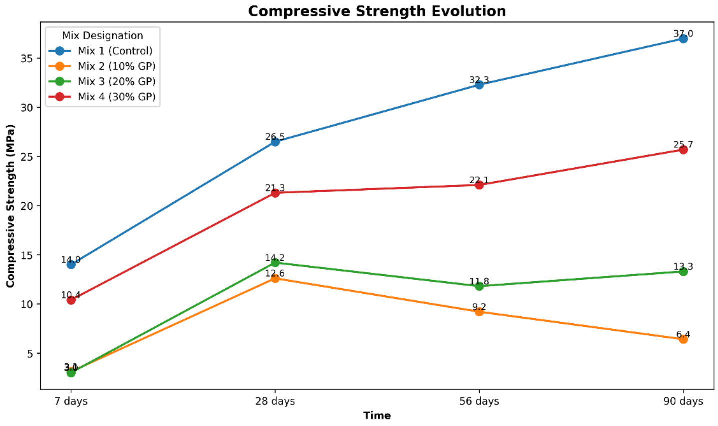

Figure 4.2. Compressive Strength Evolution (MPa)

In contrast, the experimental mixes exhibited distinct behaviors: Mix 2 (10% GP) and Mix 3 (20% GP) showed low early strength and a concerning decline in performance after 28 days. However, Mix 4 (30% GP) displayed a more promising trajectory, with substantial early strength compared to other GP mixes and a continuous, positive strength gain, ultimately achieving 69% of the control's 90-day strength. This indicates that a 30% glass powder replacement is necessary to initiate a sufficient pozzolanic reaction for sustained strength development.

4.3.2. Tensile Strength Characteristics

Splitting tensile tests at 56 days (Table 4.7) confirmed that all waste-modified mixes maintained tensile capacity comparable to the control (2.0-2.2 MPa). This performance is attributed to the equilibrium of two opposing mechanisms: 1) GP's angular particles enhanced interlocking and its pozzolanic activity densified the matrix, and 2) Sawdust introduced weak planes perpendicular to the tensile stress. The 10% strength increase in Mix 2 (10% GP) is attributed to improved particle packing, where the GP fines effectively filled voids between the sawdust and cement paste. For the 20% and 30% GP mixes, the sustained pozzolanic reaction at these higher replacement levels provided sufficient matrix densification to fully counterbalance the weakening effect of the sawdust, resulting in tensile strength equivalent to the conventional concrete

Table 4.7. Splitting Tensile Strength at 56 Days

Mix Designation	Tensile Strength (MPa)	Change vs Control (%)
Mix 1 (Control)	2.0	-
Mix 2 (10% GP)	2.2	+10.0
Mix 3 (20% GP)	2.0	0.0
Mix 4 (30% GP)	2.0	0.0

The 56-day testing period was selected to capture the mature strength properties, allowing sufficient time for the slow pozzolanic reaction of the glass powder to contribute significantly to the concrete's tensile strength development. This age provides a more complete representation of the long-term performance of mixes containing supplementary cementitious materials.

4.3.3. Permeability Resistance

Water penetration depth results revealed a strong relationship with mix composition. At 28 days, the control mix had a penetration depth of 42 mm, while Mix 2 (10% GP) exhibited a significantly higher depth of 83 mm—an increase of 97.6%—attributed to the sawdust's capillary network formation and the increased water-to-cement ratio. In contrast, Mix 4 (30% GP) performed better, showing a penetration of 64 mm, which is a 52.4% increase compared to the control, primarily due to the pore-filling effect of glass powder. By 90 days, Mix 4 showed further improvement, reducing penetration depth to 54 mm—a 28.6% decrease from its 28-day value—indicating continued pozzolanic activity leading to pore refinement. Mix 2, however, showed minimal change, with penetration decreasing only slightly to 77 mm, suggesting limited self-healing capacity in sawdust-containing concrete.

Table 4.8. Water Penetration Depth Under Pressure

Mix Designation	28 days (mm)	90 days (mm)	Reduction (%)
Mix 1 (Control)	42	30	28.6

Mix 2 (10% GP)	83	77	7.2
Mix 3 (20% GP)	79	71	10.1
Mix 4 (30% GP)	64	54	15.6

The water penetration depths under pressure for all mixes at 28 and 90 days are summarized in Table 4.8 and illustrated in Figure 4.3. The results demonstrate that permeability is significantly influenced by the glass powder (GP) content. As the GP replacement level increased from 10% to 30%, a clear trend of reduced penetration depth emerged at both test ages, with the 30% GP mix (Mix 4) showing the lowest values (64 mm at 28 days and 54 mm at 90 days). This improvement is attributed to the progressive pozzolanic reaction of the finer GP particles, which densifies the concrete microstructure over time by forming additional C-S-H gel and reducing pore connectivity. Consequently, while all modified mixes were more permeable than the control, the data confirms that higher GP content enhances the concrete's resistance to water penetration.

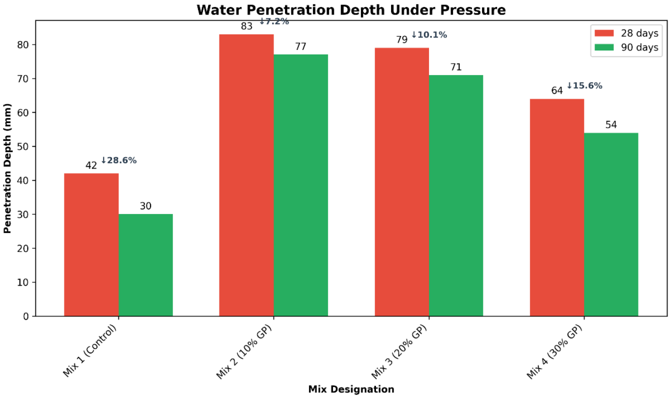

Figure 4.3. Water Penetration Depth Under Pressure

4.4. Density and Mass-Volume Relationships

Concrete density results highlighted the light weighting effect of incorporating waste materials. Mix 2 (10% GP) achieved a 7.1% reduction in density, measuring 2300 kg/m^3 compared to the control's 2480 kg/m^3, mainly due to the low specific gravity of sawdust. Mix 4 (30% GP) exhibited a smaller density reduction of 3.2% (2400 kg/m^3), as the higher-density glass powder partially compensated for the sawdust's influence. Additionally, mass-volume analysis showed a 2.8% increase in absolute volume for Mix 4, attributed to the slightly lower specific gravity of glass powder compared to sand (2.64 vs 2.65), which likely contributed to improved workability.

Table 4.9. Concrete Density at 28 Days

Mix Designation	Density (kg/m^3)	Change vs Control (%)
Mix 1 (Control)	2480	-

Mix 2 (10% GP)	2300	-7.1
Mix 3 (20% GP)	2350	-5.2
Mix 4 (30% GP)	2400	-3.2

4.5. Performance Optimization Mechanisms

The combination of 30% glass powder (GP) and 5% sawdust (SD) in Mix 4 exhibited an optimal balance through synergistic effects. The pozzolanic activity of GP contributed to the consumption of calcium hydroxide, leading to the formation of secondary calcium-silicate-hydrate (C-S-H), which strengthened the matrix surrounding sawdust particles and reduced permeability by 15.6% between 28 and 90 days. Additionally, the fine GP particles (less than 0.3 mm) enhanced particle packing by filling voids between sawdust and aggregates, while sawdust's ability to retain internal moisture promoted continued hydration. In contrast, mixes with 20% or less GP showed a progressive decline in strength. This was primarily due to the dominant influence of sawdust, where cellulose fibers introduced weak zones in the cement matrix. Furthermore, the low GP content provided insufficient pozzolanic reaction to generate enough C-S-H to mitigate capillary porosity, and the water absorbed by sawdust remained largely unavailable for hydration, limiting overall performance.

4.6. Comparative Performance Assessment

This integrated assessment confirms Mix 4 (30% GP + 5% SD) as the optimal sustainable solution, balancing 69.5% strength retention with 3.2% density reduction while utilizing 35% waste materials. For non-structural applications prioritizing weight reduction, Mix 2 offers superior lightweighting but requires strength enhancement strategies. See Table 4.10. The evaluation criteria for the performance matrix are derived from standardized test results and comparative analysis against the control mix (Mix 1). Workability was assessed via slump tests (ASTM C143), with higher slump values rated better. Early and Long-term Strength were evaluated based on 7-day and 90-day compressive strength tests (EN 12390-3), respectively, with ratings corresponding to the percentage of the control's strength achieved. Permeability was ranked according to water penetration depth (EN 12390-8), where lower penetration indicates better performance. Weight Reduction was calculated based on the measured density (ASTM C29) compared to the control. Finally, Sustainability was evaluated on the proportion of natural sand replaced by industrial waste, with higher replacement levels and associated reduction in landfill material rated more favorably.

Table 4.10. Overall Performance Matrix

Parameter	Mix 1	Mix 2	Mix 3	Mix 4	Optimal
Workability	Excellent	Poor	Fair	Good	Mix 1
Early Strength	Excellent	Poor	Poor	Good	Mix 1

Long-term Strength	Excellent	Poor	Fair	Good	Mix 4
Permeability	Excellent	Poor	Fair	Good	Mix 1
Weight Reduction	-	Excellent	Very Good	Good	Mix 2
Sustainability	Poor	Good	Very Good	Excellent	Mix 4

5. Conclusions and Recommendations

This study examined the use of glass powder and sawdust as fine aggregate replacements in concrete, testing four mixes with glass powder ranging from 0% to 30% and a fixed 5% sawdust content. Results showed that incorporating these waste materials reduces the concrete's density and cost, with minimal impact on split tensile strength. The combination of 30% glass powder and 5% sawdust produced the best compressive strength and lowest water penetration among the modified mixes, though still below the control. Increasing glass powder content improved workability and counteracted the water absorption of sawdust. However, due to lower compressive strength overall, these mixes are not suitable for structural elements like beams or columns. The study concludes that 30% glass powder and 5% sawdust is the most effective replacement ratio for non-structural applications.

Based on these findings, the study recommends replicating the experiments for validation, exploring higher ratios of both materials, conducting long-term durability and fire resistance testing, evaluating the effects of various curing conditions, and assessing additional mechanical properties such as flexural strength and shrinkage. These steps will provide a broader understanding of the practical applications and limitations of using glass powder and sawdust in sustainable concrete production.

References

[1] Monteiro, P. J. M., Miller, S. A., & Horvath, A. (2017). Towards sustainable concrete. Nature Materials, 16*(7), 698–699. https://doi.org/10.1038/nmat4930

[2] Islam, G. M. S., Rahman, M. H., & Kazi, N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. International Journal of Sustainable Built Environment, 6*(1), 37–44. https://doi.org/10.1016/j.ijsbe.2016.10.005

[3] Schwarz, N., Cam, H., & Neithalath, N. (2008). Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash. Cement and Concrete Composites, 30*(6), 486–496. https://doi.org/10.1016/j.cemconcomp.2008.02.001

[4] Aigbomian, E. P., & Fan, M. (2013). Development of wood-crete building materials from sawdust and waste paper. Construction and Building Materials, 40*, 361–366. https://doi.org/10.1016/j.conbuildmat.2012.11.018

[5] Villioth, J. (2014). *Sand scarcity: Building an economy on quicksand*. EJOLT Report No. 14.

[6] Glass Alliance Europe. (2020). Glass production statistics 2019-2020.

[7] Borzecka, M. (2018). *European wood waste statistics report*. BIOREG Consortium.

[8] Idir, R., Cyr, M., & Tagnit-Hamou, A. (2015). Use of waste glass in cement-based

materials. *Déchets Sciences et Techniques, 57*, 1–10.

[9] Du, H., & Tan, K. H. (2014). Concrete with recycled glass as fine aggregates. *ACI Materials Journal, 111*(1), 47–58.

[10] Adaway, M., & Wang, Y. (2015). Recycled glass as partial sand replacement in structural concrete. *Electronic Journal of Structural Engineering, 14*(1), 116–122.

[11] Meddah, M. S. (2019). Waste window glass as natural sand substitute in concrete. *IOP Conference Series: Materials Science and Engineering, 603*(3), 032011.

[12] Serelis, E., & Ngobeni, S. P. (2025). Particle size effects on glass powder concrete performance. *Construction and Building Materials, 318*, 125932.

[13] Narayanan, A., Hemnath, G., & Sampaul, K. (2017). Density reduction in sawdust concrete. *International Journal of Advanced Research, 3*(1), 206–210.

[14] James, G. A., & Daniel, Y. T. (2018). Solignum-treated sawdust in concrete production. *International Journal of Civil Engineering, 9*(12), 252–260.

[15] Ganiron, T. U. (2014). Sawdust as fine aggregate in concrete mixtures. *International Journal of Advanced Science and Technology, 63*, 73–82.

[16] Farahinia, E., et al. (2024). Mechanical enhancement of sawdust concrete with mineral additives. *Preprints*, 2024110746.

[17] Animasaun, A. B., et al. (2025). Synergistic effects of glass powder and sawdust in concrete. *Mechanical Technology and Engineering, 3*(1), 17–26.

[18] Farahinia, E., et al. (2025). Performance limits of high-volume GP-SD concrete. *SSRN Electronic Journal*. https://dx.doi.org/10.2139/ssrn.5013064

[19] Presbitero, J., et al. (2025). Sustainable floor tiles with glass-sawdust composites. *Engineering and Technology Journal, 10*(6), 5361–5366.

[20] Chakravarty, S., Sen, M., & Khiangte, L. (2023). Optimization of GP-SD concrete ratios. *Asian Journal of Civil Engineering, 24*(7), 2415–2425.

[21] Gebremichael, N. N., Jadidi, K., & Karakouzian, M. (2023). Machine learning for waste-glass concrete design. *Construction and Building Materials, 392*, 132044.

[22] Depan, R., Raval, A., & Pitroda, J. (2022). Foamed concrete bricks with GP-SD. *International Research Journal of Engineering, 9*(4), 819–824.

[23] Alabduljabbar, H., et al. (2020). Sawdust geopolymer concrete. *Materials, 13*(23), 5490.

[24] Folagbade, S. O., & Olatunji, A. S. (2020). Environmental impacts of GP-SD concrete. *Civil and Environmental Research, 12*(4), 36–48.

[25] Batool, F., et al. (2021). Durability challenges in sawdust concrete. *Journal of Building Engineering, 44*, 103237.