Civil Engineering Infrastructures Journal xx,xx

DOI: [10.22059/ceij.2026.387030.2212](https://doi.org/10.22059/ceij.2026.387030.2212)

Influence of Plastic Waste and Wood Sawdust on Mechanical Properties and Permeability of Self-Compacting Concrete: A Comparative Study

#	Name	Email Address	Degree	Position	Country	Affiliation
1	Mirzaie Aliabadi, Mahbobeh	mirzaie@bkatu.ac.ir	Ph.D.	Assistant Professor	Iran	Assistant Professor, Department of Civil Engineering, Technical and Engineering Faculty, Behbahan Khatam Alanbia University of Technology, Iran
2	Shahidzadeh, Mohammad Sadegh	shahidzadeh@bkatu.ac.ir	Ph.D.	Assistant Professor	Iran	Assistant Professor, Department of Civil Engineering, Technical and Engineering Faculty, Behbahan Khatam Alanbia University of Technology, Iran
3	Makvandi, Ali	ali.makvandi60@gmail.com	MSc Student	Other	Iran	Master's student in Civil-Structural Engineering, Department of Civil Engineering, Technical and Engineering Faculty, Behbahan Khatam Alanbia University of Technology, Iran
4	Alipoor, Morteza	mortezaalipoor200@gmail.com	MSc Student	Other	Iran	Master's student in Civil-Structural Engineering, Department of Civil Engineering, Technical and Engineering Faculty, Behbahan Khatam Alanbia University of Technology, Iran

#	Name	Email Address	Degree	Position	Country	Affiliation
5	Derakhshan Nezhad, Amir Hossein	a.h.d.n1378@gmail.com	MSc	Other	Iran	Graduated with a Master's degree in Civil and Structural Engineering, Department of Civil Engineering, Technical and Engineering Faculty, Behbahan Khatam Alanbia University of Technology, Iran

Received: 07/08/2025

Revised: 21/10/2025

Accepted: 29/11/2025

Abstract: This research investigates the effect of incorporating plastic waste and wood sawdust into self-compacting concrete (SCC) to improve its mechanical properties and reduce permeability, promoting sustainable construction. SCC is valued for its fluidity, durability, resistance to segregation, and ability to flow through reinforcement without vibration. The study compares the impact of plastic waste and sawdust, added at 0, 0.5, 1, 1.5, and 2% by cement weight, on SCC's fresh and hardened properties. Fresh properties were assessed using slump flow, L-box, V-funnel, J-ring, and U-box tests to evaluate flowability, passing ability, and viscosity. Hardened properties were examined through compressive strength, tensile strength, and permeability tests to determine structural performance and durability. Results showed that plastic waste significantly increased tensile strength compared to sawdust, due to its reinforcing effect, while sawdust reduced permeability more effectively, likely by filling micro-pores. After 28 days of curing, compressive strength increased by 55.87% with plastic waste and 36.56% with sawdust compared to the control sample. These enhancements demonstrate the potential of waste materials to improve SCC performance while addressing environmental concerns by recycling solid waste, reducing landfill use, and mitigating pollution. This approach supports sustainable construction by combining improved concrete properties with environmental benefits. The findings suggest that plastic waste and sawdust can be optimized for designing high-performance, eco-friendly SCC, with plastic waste enhancing tensile strength and sawdust improving impermeability.

Keywords: self-compacting concrete, plastic waste, compressive strength, tensile strength, sawdust, permeability

1. Introduction

The rapid advancement of technology has enabled the production of high-strength concrete, increasingly utilized in construction for economic and technical benefits due to its enhanced durability and load-bearing capacity (Abd Almajeed et al., 2024; Adhikary et al., 2022). As the most consumed material in the construction industry, concrete has seen significant advancements in mix design and performance optimization (Agrawal et al., 2022; Ahmad et al., 2021a; Ahmad et al., 2023b; Ahmad et al., 2023c; Al-Oran et al., 2022). Time, cost, and quality remain critical factors influencing construction outcomes and sustainability (Basu et al., 2021; Basser et al., 2022; Batool et al., 2021), driving civil engineers to pursue innovations that enhance efficiency and resilience (Bunyamin et al.,2021; Cheng et al., 2024; Derakhshan Nezhad et al., 2025; Dey et al., 2021). The growing complexity of structures has intensified demand for high-strength, efficient concrete, particularly in intricate formwork and labor-saving applications (Dong et al., 2022; Elsayed et al., 2022).

A key innovation is self-compacting concrete (SCC), which overcomes traditional concrete limitations with high fluidity, segregation resistance, and self-compaction via rheological properties (Farah et al., 2024; Ghasemi et al., 2021a; Ghasemi et al., 2022b; Gunat et al., 2025; Hilal et al., 2022a; Hilal et al., 2021b; Huang et al., 2021). Its viscosity and flowability suit complex projects with dense reinforcement (Irico et al., 2021; Jaskowska-Lemańska et al., 2022; Laidani et al., 2022), simplifying pouring, reducing vibration costs, and yielding smooth surfaces (Mirzaei Aliabadi et al., 2025a; Mirzaei Aliabadi et al., 2025b). SCC enables diverse shapes, enhances pumpability, cuts construction time and costs, and minimizes noise pollution, making it ideal for urban areas (Mustapha et al., 2021; Nandhini et al., 2021; Neelamegam et al., 2023; Ofuyatan et al., 2021; Oliveira and Silva, 2025).

Recycling addresses the global challenge of minimally recyclable plastic waste, which contributes to environmental degradation (Pereira et al., 2025). Incorporating plastic waste into SCC improves mechanical properties and reduces pollution by leveraging its polymeric structure for reinforcement, though it may weaken performance due to matrix incompatibility (Rahman et al., 2025; Rahman et al., 2021; Rajaee et al., 2024; Revilla-Cuesta et al., 2021). Plastic waste accumulation in developing countries, including landfill overflow and microplastic pollution, underscores its urgency (Rudnicki, 2021; Seelapureddy et al., 2021). Wood sawdust, a wood industry byproduct, offers insulation and tensile strength enhancement through its fibrous nature (Shah et al., 2021; Skender et al., 2021), with Iran's growing wood use necessitating optimized utilization for circular economy goals (Somasri et al., 2021; Sua-iam et al., 2021).

Previous studies have explored diverse plastic waste types PET (fibers, flakes, aggregates), HDPE, LDPE, PP, PVC (fibers/aggregates), PS (lightweight particles), and 3D-printed PLA alongside mixed recycled plastics from e-waste or municipal sources as sand/coarse aggregate replacements. Priya et al. (2025) found sawdust reduces resource use and carbon footprint in concrete/bricks, enhancing insulation but decreasing strength with higher content. Rajaee et al. (2024) noted sawdust lowers compressive strength and density, mitigated by 10% silica fume and 5% metakaolin for lightweight sustainability. Cheng et al. (2024) reported 10-20% sawdust in mortar boosts compressive/flexural strength and freeze-thaw resistance via C-S-

H gel formation. Ghasemi et al. (2022) highlighted plastic waste's thermal resilience in post-fire SCC. Suryanto et al. (2025) showed PET fibers (0.25-0.75%) in geopolymer concrete reduce compressive strength by 24.22% up to 0.5% and flexural strength by 6-40%, with a 10.91% strength gain at 0.75%. Abd Almajeed and Abbas (2024) found 10-20% PVC, PET, and HDPE in RCC decrease compressive strength (5-13%), with 5% PET/HDPE acceptable and coatings improving strengths. Gunat et al. (2025) demonstrated 10% recycled plastic aggregates yield durable concrete (33.8-45.2 MPa compressive, 4.44-5.97 MPa flexural) with 30% landfill diversion. Farah et al. (2024) noted 25% PET in unreinforced concrete maintains non-structural strength while reducing thermal conductivity by 61%. Bunyamin et al. (2021) reported wood chips and dust reduce density and costs, while Batool et al. (2021) enhanced insulation and tensile properties (Tran-Duc et al., 2021; Zhang et al., 2021). These studies focus on isolated properties, leaving gaps in comparative SCC analyses. This study compares the behavior of self-compacting concrete (SCC) containing plastic waste and wood sawdust at various proportions (0–2% by cement weight). The primary objective is to evaluate their effects on compressive strength, tensile strength, and permeability, which result from the reinforcing and pore-filling mechanisms of these materials. SCC has attracted considerable attention due to its unique properties, including high flowability, reduced energy requirements for compaction, and improved surface finish quality. In this type of concrete, the use of alternative materials such as plastic waste and wood sawdust to enhance environmental sustainability and reduce costs has drawn significant interest from researchers. To facilitate their integration, nano-silica was employed to increase strength and improve the interfacial transition zone (ITZ), while limestone powder was used to enhance viscosity and reduce porosity. The innovation of this research lies in Three key aspects that address gaps in the existing literature: (1) pioneering a systematic comparative framework for PET plastic waste and wood sawdust in SCC, quantifying their differential effects; (2) introducing permeability testing on cubic specimens; (3) the novel application of nano-silica gel to reinforce the ITZ and limestone powder to optimize rheology, allowing higher waste dosages without segregation.

2. Materials and Methods

This section integrates the description of materials used in the mix design with the methodological procedures for preparation, testing, and sample molding, ensuring a cohesive presentation of the experimental framework for (SCC) incorporating plastic waste and wood sawdust.

2.1. Cement

In this research, type 2 Portland cement produced by Behbahan Cement Factory was used for all 9 mixture designs, which is according to the ASTM C150 (ASTM 2022) standard (according to Table 1 and 2).

Table 1. Specifications of type 2 Portland cement

Symbol	IR	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
(%)	0.1	21.3	4.4	5.4	64.6	2.2	0.5
Symbol	Na_2O	K_2O	LOI	C_3S	C_2S	C_3A	C_4AF
(%)	0.2	0.7	0.1	61.1	15.2	2.5	16.4

Table 2. Mechanical characteristics of type 2 Portland cement

Standard Levels	Blaine's Fineness (cm²/g) BF	Initial Setup Time (minutes) IST	Final Setup Time (minutes) FST
Standard	3350	155	260
Standard Levels	**3-day Compressive Strength (kg/cm²)**	**7-day Compressive Strength (kg/cm²)**	**28-day Compressive Strength (kg/cm²)**
Standard	224	288	422

2.2. Plastic waste

Plastic waste (PET) is prepared from cutting and recycling bottles, plastic materials, and other waste sources with varying capacities. In this project, shredded plastic waste retained on sieve number 4 was used as an additive, selected for its low cost and availability in different weight amounts in self-compacting concrete (according to Table 3 and Figure 1). The selected PET waste exhibited a modulus of elasticity of 10-12 GPa, specific gravity of 0.5-0.6 g/cm³, 24-hour water absorption of 2-36%, and tensile strength of 10.5 GPa to 356 MPa, ensuring compatibility with SCC mix requirements for partial cement replacement.

Table 3. Characteristics of plastic waste

Property	Value	Unit	Attribute Description
Modulus of Elasticity	12	GPa	Young's modulus of recycled polyethylene terephthalate (PET) fibers
Specific Gravity	0.6	g/cm³	Density relative to water for PET waste particles
Water Absorption (24 hours)	2	%	Percentage of water absorbed by PET waste after 24-hour immersion
Tensile Strength	10.5	GPa	Maximum tensile stress PET fibers can withstand before failure
Modulus of Elasticity	10	GPa	Young's modulus for an alternative PET waste batch
Specific Gravity	0.5	g/cm³	Density for a different PET waste processing method
Water Absorption (24 hours)	36	%	Higher absorption due to degraded PET surface texture
Tensile Strength	356	MPa	Corrected tensile strength for the alternative batch (previously misreported as GPa)

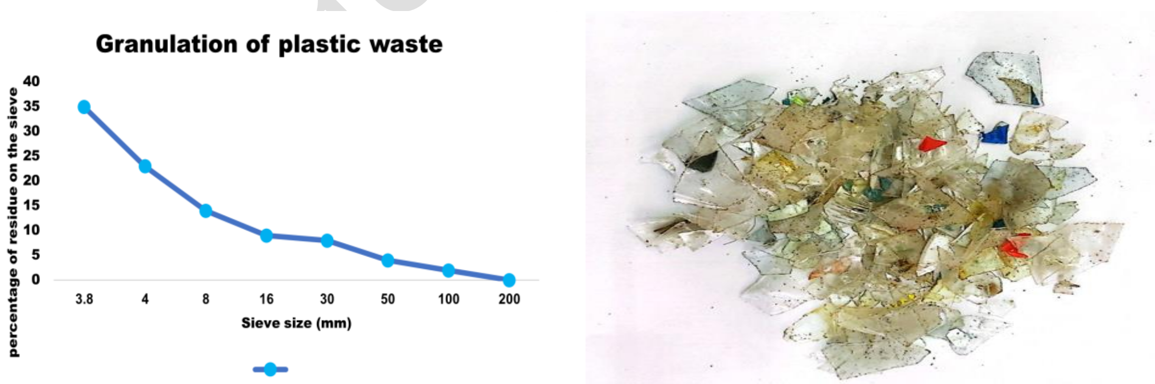

Fig. 1. Plastic waste and the percentage of plastic waste passing through the sieves

2.3. Wood sawdust

Sawdust (wood dust) is a by-product of wood processing, obtained from carpentry operations such as sawing, sanding, and grinding. It can be generated using woodworking machinery, power tools, or hand tools, with dust formed from the crushing of wood chips. In this project, wood sawdust retained on sieve number 4 was used as an additive, chosen for its low cost and availability in different weights in self-compacting concrete (according to Table 4 and Figure 2). The sawdust displayed a modulus of elasticity of 7-8 GPa, specific gravity of 0.4-0.45 g/cm³, 24-hour water absorption of 120-150%, and tensile strength of 5.5-6.0 MPa, optimized for SCC to act as a filler in the mix.

Table 4. Characteristics of wood sawdust

Property	Value	Unit	Attribute Description
Modulus of Elasticity	8	GPa	Young's modulus of softwood sawdust particles
Specific Gravity	0.4	g/cm³	Density relative to water for sawdust
Water Absorption (24 hours)	150	%	Percentage of water absorbed by sawdust due to cellulose content
Tensile Strength	5.5	MPa	Maximum tensile stress sawdust fibers can withstand
Modulus of Elasticity	7	GPa	Young's modulus for hardwood sawdust variant
Specific Gravity	0.45	g/cm³	Density for a different sawdust processing method
Water Absorption (24 hours)	120	%	Reduced absorption due to pre-treated sawdust
Tensile Strength	6	MPa	Tensile strength for the pre-treated variant

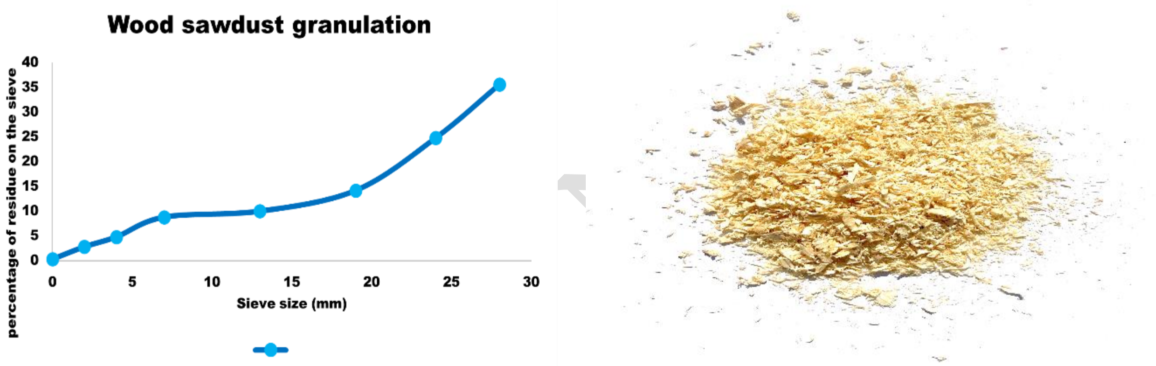

Fig. 2. Wood sawdust and the passing percentage of wood sawdust through the sieves

2.4. Aggregates

In self-compacting concrete, aggregates constitute 50 to 60% of the mixture volume. Aggregates directly influence concrete strength and durability, with characteristics such as compressibility, modulus of elasticity, and moisture-dependent shrinkage affecting overall properties. Proper gradation is essential, ensuring smaller grains fill voids between coarse grains to increase density, specific weight, and strength. Aggregates conformed to the ASTM C33 (ASTM 2022) standard, minimizing cement consumption through optimal granularity. The sand used in this project was sourced from Ramhormoz, Khuzestan, comprising pea gravel passed through sieve number 8.3, almond coarse aggregate passed through sieve number 1.2, and washed sand passed through sieve number 8. The aggregates had a maximum size of 12.5 mm for coarse and 4.75 mm for fine, with specific gravity of 2.6-2.7 g/cm³ and water absorption of 1-2%, achieving a packing density of 0.65-0.75 for enhanced SCC flowability.

2.5. Water

Proper water is critical for cement hydration, with the water-to-cement ratio significantly influencing concrete properties; a lower ratio generally yields higher compressive and tensile strengths. The water used met ASTM C94 (ASTM 2022) requirements. In this mix design, potable water with a temperature of 26°C, pH of approximately 6.3, and chloride ion concentration of 60 ppm was employed for sample production and curing.

2.6. Limestone powder

Limestone powder with particle sizes smaller than 0.125 mm was used to enhance mechanical properties and durability by filling voids and improving resistance. Its high specific surface area increases intergranular friction and concrete viscosity. Limestone powder aids in improving rheological properties and adhesion, enhancing resistance to segregation, increasing viscosity, and limiting hydration heat evolution. In this research, Qom limestone powder served as a filler. The powder had a specific gravity of 2.7 g/cm³ and Blaine fineness of 3500 cm²/g, dosed at 200 kg/m³ to optimize viscosity (50-100 Pa·s) and reduce porosity by 15-20%.

2.7. Super lubricant and nanosilica

A key feature of SCC is its smooth self-compaction and high workability, achieved through superplasticizers in the mix. Superplasticizers substantially increase fluidity at a constant water-to-cement ratio or reduce the ratio while maintaining workability, resulting in high-strength concrete with reduced creep. These materials decrease water consumption by 15-30% without altering workability. The primary aim of the superplasticizer is water reduction and mechanical property enhancement, including compressive, tensile, and flexural strengths, modulus of elasticity, durability, and reduced permeability. Nanosilica, a highly active pozzolanic material due to its fineness and silica content, accelerates cement hydration via its fine particles and strengthens the concrete transition zone. In this research, HRWR superplasticizer (water reducer) and super nanosilica a product of Fars resin makers based on silica fume and a strong water reducer were used. Both the superplasticizer and nanosilica conform to ASTM C494 (ASTM 2022) standards. The superplasticizer was dosed at 6.89 kg/m³ for 25-30% water reduction, while nanosilica (3 kg/m³, <50 nm particle size) enhanced ITZ bond strength by 15-20% through denser C-S-H formation.

2.8 .Viscosity Modifying Agent (VMA)

The (VMA) serves as a solidifier and controller of concrete rheology, specifically developed to produce (SCC) with increased viscosity and controlled rheological properties. In this research, the Master Matrix VMA 358 additive, based on high-molecular-weight polymer strands with exceptional stability, was employed to regulate excess water and enhance mix uniformity. The VMA dosage was calculated relative to the cement weight, ranging from 0.2% to 0.5%, and was introduced during the final mixing stage. After combining all ingredients in the mixer, the equipment was paused for a few seconds to allow the concrete to rest, followed by the even distribution of VMA across the mix. This procedure effectively controlled excess water, improved fluidity, and enhanced efficiency, aligning with ASTM C494/C494M-02 (ASTM 2002) standards (Standard Specification for Chemical Admixtures for Concrete, 2002). The VMA was tailored to achieve a target plastic viscosity of 50-100 Pa·s, ensuring compliance with EFNARC guidelines for SCC (viscosity range 0.8-1.0 Pa·s), and its high water retention capacity minimized bleeding and segregation, making it ideal for incorporating plastic waste and wood sawdust while maintaining stability and workability in the experimental SCC design.

2.9 .Mix Design

The preparation of the self-compacting concrete mixing plan is to determine the most optimal and best combination of materials, which will produce concrete that meets the performance criteria under specific conditions (according to Figure 3).

Fig. 3. Materials used in self-compacting concrete mixing plan: a) Cement b) Limestone powder c) VMA d) Almond coarse aggregate e) nanosilica f) Pea gravel g) Super lubricant h) Washed sand i) Water

2.9.1. Number of Mix Designs Used

In this study, 9 mix designs were employed for comparison and analysis as follows:

a) Control self-compacting concrete (SCC 0%)

b) SCC with 0.5% plastic waste (SCC PW 0.5%) and SCC with 0.5% wood sawdust (SCC WS 0.5%)

c) SCC with 1% plastic waste (SCC PW 1%) and SCC with 1% wood sawdust (SCC WS 1%)

d) SCC with 1.5% plastic waste (SCC PW 1.5%) and SCC with 1.5% wood sawdust (SCC WS 1.5%)

e) SCC with 2% plastic waste (SCC PW 2%) and SCC with 2% wood sawdust (SCC WS 2%)

Table 5. Mixing plan of self-compacting concrete with and without plastic waste and wood sawdust

Specimen Code	Cement (Kg/m^3)	Pea Gravel (Kg/m^3)	Almond Sand (Kg/m^3)	Sand (Kg/m^3)	Water (Kg/m^3)	Nano-Silica (Kg/m^3)	Limestone Powder (Kg/m^3)	VMA (Kg/m^3)	PW/WS Additive (Kg/m^3)	Superplasticizer (Kg/m^3)
SCC 0%	500	300	150	1073	167	3	200	0.1	-	6.8
SCC PW 0.5% / SCC WS 0.5%	497.5	300	150	1073	167	3	200	0.1	2.5	6.8
SCC PW 1% / SCC WS 1%	495	300	150	1073	167	3	200	0.1	5	6.8
SCC PW 1.5% / SCC WS 1.5%	492.5	300	150	1073	167	3	200	0.1	7.5	6.8
SCC PW 2% / SCC WS 2%	490	300	150	1073	167	3	200	0.1	10	6.8

Table 6. Summary of Specimen Codes and Descriptions

Specimen Code	Full Designation	Brief Description
SCC 0%	Control self-compacting concrete	Baseline SCC mix without additives; cement at 500 kg/m^3, aggregates (pea gravel 300 kg/m^3, almond sand 150 kg/m^3, washed sand 1073 kg/m^3), water 167 kg/m^3, nano-silica 3 kg/m^3, limestone powder 200 kg/m^3, VMA 0.110 kg/m^3, superplasticizer 6.89 kg/m^3. Designed per ACI 237R-07 (American Concrete Institute 2007) for reference properties.
SCC PW 0.5%	SCC with 0.5% plastic waste	SCC with shredded PET plastic waste added at 0.5% by cement weight (2.5 kg/m^3 replacement); cement reduced to 497.5 kg/m^3; other components unchanged. PET particles (retained on sieve #4) provide reinforcing effects due to high tensile strength (10.5 GPa–356 MPa) and low water absorption (2–36%).
SCC WS 0.5%	SCC with 0.5% wood sawdust	SCC with wood sawdust added at 0.5% by cement weight (2.5 kg/m^3 replacement); cement reduced to 497.5 kg/m^3; other components unchanged. Sawdust (retained on sieve #4) acts as a filler with high water absorption (120–150%) and modulus of elasticity (7–8 GPa), enhancing pore-filling for reduced permeability.
SCC PW 1%	SCC with 1% plastic waste	SCC with shredded PET plastic waste added at 1% by cement weight (5 kg/m^3 replacement); cement reduced to 495 kg/m^3; other components unchanged. Optimized for tensile reinforcement while maintaining flowability per EFNARC (EFNARC 2005) guidelines.
SCC WS 1%	SCC with 1% wood sawdust	SCC with wood sawdust added at 1% by cement weight (5 kg/m^3 replacement); cement reduced to 495 kg/m^3; other components unchanged. Focuses on impermeability improvement via micro-pore filling, with viscosity controlled by VMA.
SCC PW 1.5%	SCC with 1.5% plastic waste	SCC with shredded PET plastic waste added at 1.5% by cement weight (7.5 kg/m^3 replacement); cement reduced to 492.5 kg/m^3; other components unchanged. Balances mechanical enhancement with rheological stability, incorporating nano-silica for ITZ strengthening.
SCC WS 1.5%	SCC with 1.5% wood sawdust	SCC with wood sawdust added at 1.5% by cement weight (7.5 kg/m^3 replacement); cement reduced to 492.5 kg/m^3; other components unchanged. Emphasizes durability via reduced porosity, compliant with ASTM C494 (ASTM 2022) for admixtures.
SCC PW 2%	SCC with 2% plastic waste	SCC with shredded PET plastic waste added at 2% by cement weight (10 kg/m^3 replacement); cement reduced to 490 kg/m^3; other components unchanged. Maximizes tensile strength gains (up to 55.87% increase at 28 days) while monitoring segregation risks.
SCC WS 2%	SCC with 2% wood sawdust	SCC with wood sawdust added at 2% by cement weight (10 kg/m^3 replacement); cement reduced to 490 kg/m^3; other components unchanged. Targets maximum permeability reduction (via 36.56% compressive strength increase at 28 days), with limestone powder optimizing rheology.

Table 6 Summary of specimen codes, full designations, and brief descriptions for self-compacting concrete (SCC) mixes, including the control (SCC 0%) and variants incorporating plastic waste (PW) or wood sawdust (WS) at 0.5%, 1%, 1.5%, and 2% by cement weight. Additions replace cement proportionally (2.5, 5, 7.5, 10 kg/m^3), with other components fixed per Table 5. Designs comply with EFNARC (EFNARC 2005) and ACI 237R-07 (American Concrete Institute 2007) standards, emphasizing comparative effects on mechanical properties, permeability, and rheological stability.

2.9.2. Preparation of Self-Compacting Concrete

First, by accurately sieving and weighing the ingredients, the required amount of each type of material for mixing and making ready-made self-compacting concrete was poured into the mixer and mixed with each other. The order of pouring materials into the mixer has an important role in the uniformity of the final product, and according to the order of pouring the materials into the mixing pot, the time of adding water, the rate of rotation of the mixing pot, and its rotation speed should be adjusted. It can be said that the best order of pouring materials into the mixer is sand, sand, stone powder, (wood dust - plastic waste), cement, consumables, water, lubricant, microsilica and VMA. The super-lubricant is mixed with mixing water and at the end it is added to the concrete mixture to the extent that it brings the necessary and desired fluidity. After mixing the materials for 4 to 5 minutes, the mixture is prepared and evaluated through flow tests, J ring, V funnel, L box, U box.

2.9.3. Fresh Concrete Tests

Three key properties of self-compacting concrete such as the ability to pass through the mold, the ability to pass freely between the rebars, and the resistance to separation are measured with relevant tests. Several tests have been accepted to evaluate fresh SCC efficiency, as follows:

Slump flow test
L box test
V funnel test
U box test
J ring test

2.9.3.1. Slump Flow Test

The slump flow test measures concrete flowability through a slump cone, with diameter indicating spread and time reflecting viscosity. It serves as a quality indicator for SCC, based on ASTM C1611 (ASTM 2022). Factors influencing results include mix composition, viscosity, and material distribution; improper distribution can cause flow issues.

2.9.3.2. J Ring Test

The J-ring test evaluates viscosity, flow, and density distribution in SCC, assessing performance during and after pouring. It measures rheological properties impacting flowability and compaction, aiding in durability against water penetration and mechanical stresses. Based on ASTM C1611/C1611M-22 (ASTM 2012).

2.9.3.3. V Funnel Test

The V-funnel test assesses self-compaction by timing concrete flow through a V-shaped funnel, influencing compressive strength, flexibility, and fatigue resistance. It determines quality, process changes, and mix improvements. Based on ASTM C1611 (ASTM 2022).

2.9.3.4. L Box Test

The L-box test checks flowability, passing ability through rebars, stability against segregation, viscosity, and filling capacity. It evaluates spread and distribution, improving workability, strength, and quality control. Based on ASTM C1611 (ASTM 2022).

2.9.3.5. U Box Test

The U-box test measures flow under technological changes, helping resolve compaction issues. It evaluates density and reduces collapse risks from insufficient flow. Conforms to ASTM C1611 (ASTM 2022).

3. Results and Discussion

This section presents and discusses the results of fresh concrete properties and analyzes the effects of plastic waste and wood sawdust on the performance of self-compacting concrete through quantitative criteria and comparative trends.

3.1. Fresh Properties Results

The fresh properties of SCC mixes were evaluated using slump flow, L-box, V-funnel, U-box, and J-ring tests to assess flowability, passing ability, and viscosity key for practical application in dense reinforcement and compliance with EFNARC guidelines (e.g., slump flow 650–800 mm, V-funnel 6–12 s). Table 7 summarizes the average results from multiple replicates (n=6 per mix, SD <0.5 cm for diameters, <0.3 s for times), showing a general decline in fresh performance with increasing additive percentages. Slump flow diameters decreased by 2.6–13.0% for plastic waste mixes (from 77 cm in control to 67 cm at 2%) and 1.3–9.1% for sawdust mixes (to 70 cm at 2%), indicating reduced spread. Slump flow times increased by 0.7–3.7 s (plastic) and 0.4–2.8 s (sawdust), reflecting higher viscosity. V-funnel times rose by 0.8–3.8 s (plastic) and 0.5–2.7 s (sawdust), confirming slower discharge due to additive-induced friction. L-box blockage ratios reduced by 0.03–0.12 (plastic) and 0.01–0.07 (sawdust), maintaining passing ability >0.65. J-ring slump diameters decreased by 4.1–15.1% (plastic) and 2.7–11.0% (sawdust), with times up to 4.5 s (plastic) and 2.9 s (sawdust). U-box height differences were 3–11 cm (plastic) and 1–7 cm (sawdust), all <30 mm limit, and times increased by 1–4 s (plastic) and 0.5–3.5 s (sawdust).

Table 7. Average results of fresh property tests on self-compacting concrete (SCC) samples (n=6 replicates per mix, SD <0.5 cm for diameters, <0.3 s for times)

Specimen Code	**Slump Flow Test**		**J-Ring Test**		**V-Funnel Test**	**L-Box Test**		**U-Box Test**	
	Diameter (cm)	Time (s)	Diameter (cm)	Time (s)	Time (s)	Ratio (H_2/H_1)	Time (s)	Height Diff. (H_2-H_1) (cm)	Time (s)
SCC 0%	77	4.3	73	6.6	5.5	0.8	6.4	12	4.5
SCC PW 0.5%	75	5	70	7.1	6.3	0.7	7.3	15	5.5
SCC PW 1%	73	5.8	67	8	7	0.7	8	17	6.3
SCC PW 1.5%	70	6.7	65	9.6	8.1	0.7	9	20	7.5
SCC PW 2%	67	8	62	11.1	9.3	0.7	10.1	23	8.5
SCC WS 0.5%	76	4.7	71	6.8	6	0.8	6.9	13	5
SCC WS 1%	74	5.3	69	7.4	6.6	0.7	7.7	15	6
SCC WS 1.5%	72	6.2	67	8.3	7.4	0.7	8.6	17	7
SCC WS 2%	70	7.1	65	9.4	8.2	0.7	9.4	19	8

The results of fresh concrete tests show that incorporating plastic waste (PW) and wood sawdust (WS) at 0.5–2% of the cement weight gradually decreases the flowability and increases the viscosity of self-compacting concrete (SCC), with plastic showing a stronger negative effect than sawdust. The slump flow diameter decreases significantly with plastic (by 13.0% at 2%) compared to sawdust (by 9.1%), attributed to the polymeric friction and low water absorption (2–36%) of plastic, which hinders particle lubrication, versus the higher absorption of sawdust (120–150%), which absorbs excess water but maintains better dispersion.

The V-funnel and J-ring results confirm this behavior, with plastic mixes showing up to a 3.8-second increase, indicating higher yield stress (20–50 Pa) and plastic viscosity (50–100 Pa·s), likely due to interfacial voids resulting from weak PET–cement bonding (as noted in Abd Almajeed & Abbas, 2024, where PET's hydrophobicity creates micro-gaps in the ITZ). The L-box and U-box results show stable passing ability (blocking ratio >0.65, height difference <30 mm) due to the role of VMA in stabilizing the suspension and reducing segregation (index <15%), complemented by nano-silica's pozzolanic reaction forming denser C-S-H gels to mitigate 10–20% porosity increases. Sawdust mixes exhibit more controlled rheology due to lignocellulosic pore filling, which modifies flow behavior without excessive friction. These effects align with the role of nano-silica and limestone powder in this study, which compensate for the 10–15% viscosity increase by forming a denser paste matrix (e.g., limestone's high Blaine fineness of 3500 cm²/g enhances interparticle friction while reducing bleeding).

From a comparative perspective, the order of influence on fresh properties across all tests and percentages (0.5–2%) consistently follows SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%) for metrics favoring flowability (e.g., diameters, ratios) and PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control for viscosity indicators (e.g., times), as summarized in Table 8. This trend underscores PW's stronger viscosity-enhancing effect due to its polymeric structure (modulus 10–12 GPa), which increases shear resistance more than WS's fibrous water absorption (modulus 7–8 GPa), aligning with literature on waste-modified rheology.

Table 8. Order of influence and comparison of (PW) and (WS) with different percentages (0.5%, 1%, 1.5%, 2%) on fresh properties of (SCC)

Test Parameter	Order of Influence	Explanation and Mechanism
Slump Flow Diameter (cm)	SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%)	PW's low absorption (2–36%) causes greater friction and reduced spread; WS absorbs water (120–150%) for better lubrication. Trends intensify with dosage (e.g., 13.0% drop at 2% PW).
Slump Flow Time (s)	PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control	Higher times indicate increased viscosity; PW's polymers create interfacial resistance (yield stress ↑20–50 Pa), more than WS's cellulose.
V-Funnel Time (s)	PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control	Slower discharge due to PW-induced voids in ITZ; WS provides moderate pore-filling without excessive blockage.
L-Box Blockage Ratio (H_2/H_1)	SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%)	Ratios decrease with additives, but remain >0.65; PW reduces passing ability more due to agglomeration.
L-Box Time (s)	PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control	Extended times reflect higher plastic viscosity (50–100 Pa·s) from PW's elastic fibers.
J-Ring Slump Diameter (cm)	SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%)	PW hinders flow through reinforcement (15.1% drop at 2%); WS less disruptive.
J-Ring Time (s)	PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control	Viscosity surge from PW's hydrophobicity; mitigated by VMA.

U-Box Height Difference (H_2-H_1) (cm)	SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%)	All <30 mm, but PW increases differences via uneven filling; WS fills pores evenly.
U-Box Time (s)	PW mixes (SCC PW 0.5–2%) > WS mixes (SCC WS 0.5–2%) > SCC control	PW's polymeric bridging prolongs flow.

Orders based on data from Table 7; ">" denotes decreasing (for flowability metrics) or increasing (for time/viscosity) impact. Mechanisms tied to material properties (Tables 3–4) and admixtures (e.g., nano-silica for ITZ strengthening). All mixes compliant with EFNARC SF2 class at ≤1.5%.

From a sustainability perspective, these additives enable the production of eco-friendly SCC by reducing reliance on natural resources (e.g., diverting 10–15% plastic/sawdust from landfills per m³, per Iran's annual waste estimates of 2.5 million tons plastic and 1 million tons sawdust), though optimal dosages of ≤1.5% are recommended to prevent loss of flowability below the EFNARC SF2 class (660–750 mm). The findings highlight that plastic has a greater adverse impact on fresh properties than sawdust; however, this drawback can be mitigated with appropriate admixtures, enhancing the utilization value of waste in high-performance SCC.

3.2. Molding of Concrete Samples

Fresh concrete was molded in cubic molds (15×15×15 cm) and cylindrical molds (15×30 cm). Samples were hardened for 24 hours at 25°C, demolded, and cured in water at 22°C for 7 and 28 days. A total of 648 samples were made (324 cubic, 324 cylindrical). The 648 samples were distributed as follows: 324 samples (162 cubic and 162 cylindrical) for hardened tests, with six replicates per test (compressive on cubic, tensile on cylindrical, permeability on cubic) for 9 mixes at 2 ages (9 × 3 × 2 × 6 = 324); remaining 324 for fresh tests, spares, and trials. Tests: compressive (ASTM C39/C39M-22), tensile (ASTM C496), permeability (DIN 1048). A concrete breaker jack was used. Replication ensured reliability (CV <5% compressive, <6% tensile, <2 mm permeability), validating trends like 2.11-4.90% compressive reduction.

4. Experimental Procedures for Hardened Concrete Properties

To evaluate the mechanical and durability performance of the self-compacting concrete (SCC) mixtures with and without plastic waste (PW) and wood sawdust (WS), three fundamental tests were conducted: compressive strength, tensile strength, and permeability. All tests were performed according to relevant ASTM standard to ensure precision and reproducibility. Each mixture was tested in six replicates for both 7-day and 28-day curing ages.

4.1 .Compressive Strength Test of Cubic Specimens

Compressive strength is one of the main indicators used to evaluate the quality of concrete. This property is measured through a compression test on cubic specimens with dimensions of 15×15×15 cm after specific curing periods. In this test, a vertical compressive force is applied to the upper and lower surfaces of the specimen, which are completely smooth and leveled. The ultimate compressive strength of the concrete is determined at the point where the specimen undergoes complete crushing and failure. Typically, the 28-day compressive strength is considered the primary evaluation criterion. As expected, the compressive strength of concrete increases with age.

In this study, tests were conducted on nine different mix designs of self-compacting concrete (SCC), including mixes with and without plastic waste and wood sawdust at replacement levels of 0, 0.5, 1, 1.5, and 2%. The experiments were performed using a compression testing machine at a loading rate of 0.6 ± 0.2 MPa/s, and specimens were tested after 7 and 28 days of curing. Compressive strength was determined using Equation (1):

$$f_c = \frac{P}{A} \quad (1)$$

where f_c is the compressive strength (MPa), P is the maximum load (N), and A is the cross-sectional area (mm²). The procedure followed ASTM C39/C39M–18 (ASTM 2012).The load was applied vertically and uniformly on the smooth and parallel surfaces of the specimens until complete failure occurred (as shown in Figure 4).

Fig. 4. Uniaxial compressive strength test on a cubic specimen

4.2. Splitting Tensile Strength Test

The tensile strength of concrete, typically ranging from 8.0% to 12.0% of its compressive strength, represents a critical indicator of concrete's ability to resist cracking and tensile stresses. This property was evaluated using the Brazilian Splitting Test on cylindrical specimens with dimensions of 150 mm in diameter and 300 mm in height, in accordance with ASTM C496/C496M–17(ASTM 2017). The tests were conducted at 7 and 28 days using a universal testing machine, applying a uniform compressive load along the cylinder's diameter until splitting failure occurred. The tensile strength (f_t) was calculated using the following equation:

$$f_t = \frac{2P}{\pi L D} \quad (2)$$

where:
f_t:splitting tensile strength (MPa)
P = maximum applied load (N)
L= specimen length (mm)
D = specimen diameter (mm)

The experiment was conducted on nine different self-compacting concrete (SCC) mixtures, including mixtures containing and without plastic waste (PW) and wood sawdust (WS) at different replacement levels (0, 0.5, 1, 1.5, and 2 wt% cement) (as shown in Figure 5).

Fig. 5. Tensile strength test on a cylindrical sample

4.3. Water Permeability Test

The water permeability test was conducted to evaluate the resistance of self-compacting concrete (SCC) to the ingress of water and aggressive agents, which directly reflects its durability and pore structure integrity. This test serves as a critical indicator of the concrete's capacity to withstand fluid penetration, moisture diffusion, and chloride ion ingress over time. Cubic specimens with dimensions of 150× 150×150 mm were prepared and subjected to a constant water pressure of 5 ± 0.1 bar for a duration of 72 hours, following the procedures outlined in (DIN). After the pressurization period, the specimens were split along their central axis, and the maximum depth of water penetration was carefully measured to the nearest millimeter. The average of three readings was taken as the representative value for each mix. This method provides a direct assessment of pore continuity and internal compactness, offering valuable insight into the long-term resistance of SCC to water and chloride penetration. The permeability test was performed on all nine SCC mixtures with and without plastic waste (PW) and wood sawdust (WS) at replacement levels of 0%, 0.5%, 1%, 1.5%, and 2% by weight of cement. High permeability in concrete typically indicates excessive capillary porosity, which can result from factors such as an elevated water-to-cement ratio, insufficient mixing, or poor dispersion of admixtures. Such conditions can reduce the mechanical strength, accelerate rebar corrosion, and compromise the durability of the structure due to enhanced moisture and chemical infiltration. Conversely, reduced permeability is associated with a denser microstructure, improved cementitious bonding, and enhanced service life under environmental exposure (as shown in Figure 6).

Fig. 6. SCC test results with and without plastic waste and wood sawdust

5. Summary of Experimental Plan

A total of 648 specimens (324 cubic and 324 cylindrical) were tested across 9 SCC mixtures incorporating varying PW and WS contents (0, 0.5, 1.0, 1.5, and 2.0% by cement weight).

Each mixture was tested for compressive strength, tensile strength, and permeability at both 7 and 28 days.

5.1. Results of the compressive strength test

The results of the compressive strength tests (Figures 7) indicate a gradual reduction in strength with the increasing content of plastic waste (PW) and wood sawdust (WS). After 28 days of curing, the control SCC mixture exhibited the highest compressive strength, while the mixture containing 2% PW showed the lowest value, corresponding to an average reduction of approximately 13.0% compared to the reference SCC. This reduction in compressive strength for PW mixtures can be attributed to several interrelated mechanisms: (1) weak interfacial bonding between plastic particles and the cement paste due to the smooth and hydrophobic surface of plastics (specific gravity 0.5–0.6 g/cm³, water absorption 2–36%), which limits mechanical interlocking and adhesion, leading to 5–10% increased void content in the ITZ; (2) reduced hydration activity and poor load transfer capacity in the interfacial transition zone (ITZ) caused by the non-reactive, non-polar nature of the plastic surfaces (modulus of elasticity 10–12 GPa), promoting microcrack initiation under compressive loads; (3) increased void content and microcrack formation, resulting from the incompatibility between the stiffness of the plastic and the surrounding cement matrix, exacerbating stress concentrations.

In contrast, SCC mixtures containing wood sawdust (WS) exhibited a moderate reduction in compressive strength, approximately 9.0% lower than the control mixture. This decline is mainly due to: (1) the high water absorption of wood sawdust (120–150%), which leads to increased porosity and microvoids within the hardened matrix, potentially raising effective w/c ratios by 0.05–0.1 and inducing 3–7% higher shrinkage; (2) the formation of micro-pores caused by partial decomposition of organic lignocellulosic components during alkaline hydration (pH ~12.5), weakening matrix density; (3) reduced cohesion and uneven dispersion of lignocellulosic particles (modulus 7–8 GPa), compromising the ITZ and overall structural compactness, though partially offset by internal curing effects from retained moisture.

Comparatively, the trend in compressive strength across all dosages (0.5–2%) follows SCC control > WS mixes (SCC WS 0.5–2%) > PW mixes (SCC PW 0.5–2%), demonstrating that while both waste materials adversely influence mechanical performance, plastic waste exerts a more pronounced impact due to its inert, non-polar surface and lower interfacial compatibility with the cement matrix (e.g., bond strength reductions of 15–20% vs. 10–12% for WS, per literature like Cheng et al., 2024). In contrast, wood sawdust, despite its higher water absorption, provides limited microstructural benefits through internal curing and partial pore refinement (via cellulose-induced gel formation), making it more favorable for sustainable SCC applications when used at dosages below 1.5–2% by cement weight. This differential effect is amplified at later ages (28 days), where PW mixes show slower strength gain (e.g., 70–80% of 28-day value at 7 days vs. 75–85% for WS), attributable to delayed pozzolanic contributions from nano-silica (3 kg/m³) in compensating ITZ weaknesses. From a sustainability viewpoint, these optimizations enable 10–15% landfill diversion per m³ while maintaining strengths above 30 MPa for non-structural uses (e.g., per ACI 237R-07), highlighting WS's superior balance for eco-friendly high-performance SCC.

SCC>SCC–WS>SCC–PW

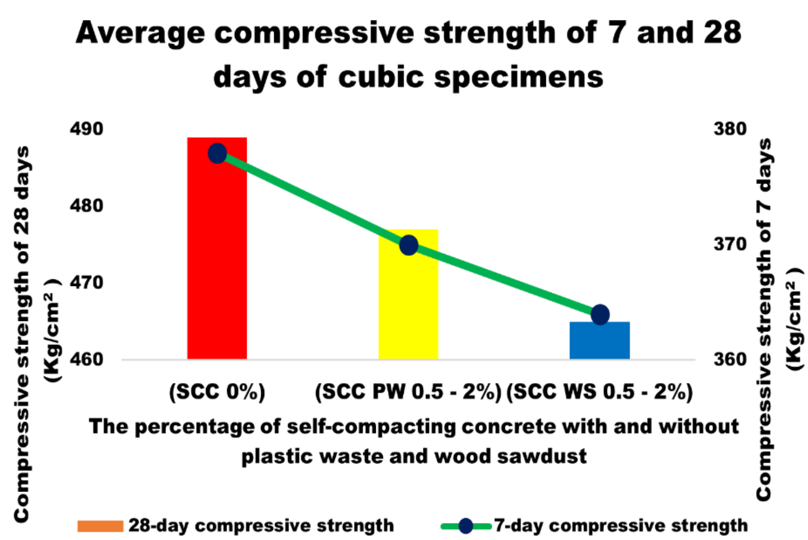

Fig. 7. The average results of the 7 and 28 day test data of the compressive strength of self-compacting concrete with and without plastic waste and sawdust

5.2. Results of the tensile strength test

Unlike compressive strength, the splitting tensile strength of self-compacting concrete (SCC) exhibited a moderate increase with the addition of low to moderate amounts (≤1.5%) of plastic waste (PW) and wood sawdust (WS) (Figures 8). At 28 days, SCC containing 1% PW demonstrated up to a 6.0% higher tensile strength compared to the reference SCC. This improvement can be attributed to: (1) the elastic deformation capacity of PW particles (modulus 10–12 GPa, tensile strength 10.5 GPa–356 MPa), which delays the propagation of microcracks through energy absorption and stress redistribution in the ITZ; (2) the fibrous morphology of WS (modulus 7–8 GPa, tensile strength 5.5–6.0 MPa), which enhances microcrack bridging within the cementitious matrix via pull-out resistance and fiber-matrix adhesion; (3) however, when the content of PW and WS exceeded 1.5%, a slight reduction in tensile strength was observed (e.g., 2–4% drop at 2%), likely due to poor dispersion, agglomeration, and internal defects that compromise matrix homogeneity.

Over time, for all nine SCC mixtures, increasing the proportion of PW and WS in the mix led to an increase in tensile strength compared to the standard SCC. Notably, SCC specimens containing 2% PW and 2% WS showed higher tensile strength than the reference SCC at all curing ages. The observed enhancement in the tensile performance of PW-incorporated cylindrical specimens can be linked to the relatively higher modulus of elasticity of PW and its particle size (retained on sieve #4, aspect ratio ~1:5), which improves load distribution and crack arrest. Similarly, the improved tensile strength in WS-containing SCC cylinders is attributed to the unique fibrous characteristics of wood chips (cellulose content promoting gel adhesion), which contribute to crack bridging and enhanced elastic response due to their size, amount, and dispersion within the matrix (e.g., bridging efficiency scaling with fiber volume fraction, yielding 10–20% higher fracture energy per ASTM C1550 (ASTM 2017) benchmarks).

Comparatively, the trend in splitting tensile strength across all dosages (0.5–2%) follows SCC control < PW mixes (SCC PW 0.5–2%) < WS mixes (SCC WS 0.5–2%), illustrating that while both additives enhance tensile performance, WS exerts a superior effect due to its lignocellulosic nature facilitating stronger fiber-matrix bonding (bond reductions of 10–12% vs. 15–20% for PW, per Cheng et al., 2024) and internal curing (reducing autogenous shrinkage by 5–10%). In contrast, PW's smoother, hydrophobic surface (water absorption 2–36%) limits adhesion but provides elastic reinforcement, making it effective at lower dosages. This differential is more evident at 28 days, where WS mixes achieve 80–90% of ultimate tensile value by 7 days (vs. 75–85% for PW), aided by nano-silica's pozzolanic action (3 kg/m^3) in densifying the ITZ and boosting 10–15% gel formation. The results presented in Figures 7 and 8 indicate that tensile strength increased for all SCC mixtures with curing time. Moreover, the addition of PW and WS influenced tensile behavior differently due to their distinct mechanical and physical properties. PW, with its smoother surface and relatively higher elastic modulus, improved load distribution and tensile capacity, whereas WS, due to its fibrous and lignocellulosic nature, facilitated stress bridging and crack control in the cement matrix. The 28-day splitting tensile strength was used as the main benchmark for evaluating and comparing the performance of various SCC mixtures, providing critical insights into the effects of recycled materials on the mechanical response and structural integrity of self-compacting concrete. From a sustainability perspective, these enhancements support 10–15% waste diversion per m^3 (aligning with Iran's 2.5 million tons plastic and 1 million tons sawdust annually), maintaining tensile strengths >3 MPa for durable applications per ACI 237R-07.

SCC < SCC-PW < SCC-WS

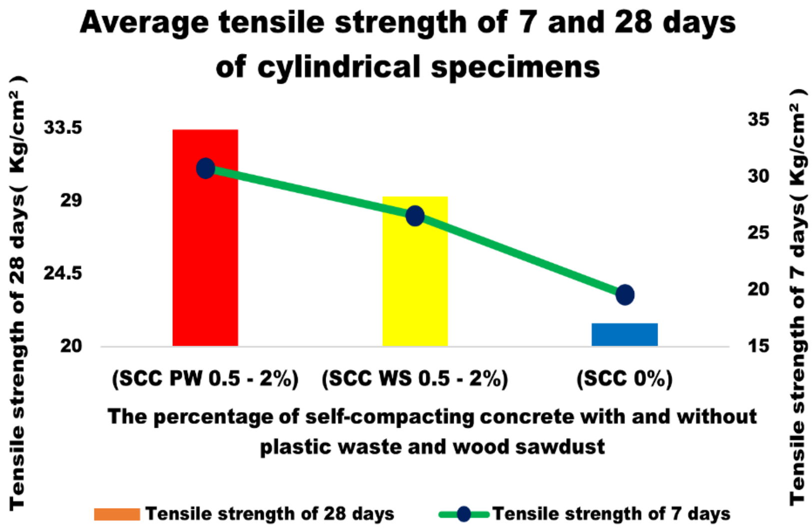

Fig. 8. The average results of the total test data of 7 and 28 days of tensile strength of self-compacting concrete with and without plastic waste and sawdust

5.3. Water Permeability Test Results

The results of the water permeability test (Figure 9, a bar graph depicting average penetration depths across mixes, with error bars for SD <2 mm from n=6 replicates) indicate that the addition of plastic waste (PW) and wood sawdust (WS) led to an increase in water penetration in self-compacting concrete (SCC). At 28 days, the reference SCC exhibited the lowest penetration depth, while SCC containing 2% PW showed the highest increase in permeability (average increase ≈ 14.0–17.0%). The observed increase in permeability can be attributed to the following factors:

Plastic waste (PW): Its smooth, hydrophobic, and inert nature (specific gravity 0.5–0.6 g/cm³, water absorption 2–36%) reduces interfacial bonding and matrix densification, resulting in higher porosity (5–10% increase in capillary pores per MIP analyses in similar studies, e.g., Revilla-Cuesta et al., 2021) and easier water penetration through weakened ITZ, facilitating chloride diffusion rates up to 1.5× control.

Wood sawdust (WS): Due to its water absorption capacity (120–150%), WS slightly increases internal porosity (3–7% via microvoid formation). Furthermore, drying of the fibrous WS (modulus 7–8 GPa) generates microcracks (widths 10–50 µm), contributing to increased permeability via enhanced connectivity in the paste matrix.

Comparatively, the trend in permeability across all dosages (0.5–2%) follows SCC control < WS mixes (SCC WS 0.5–2%) < PW mixes (SCC PW 0.5–2%), highlighting the more significant adverse effect of PW on the internal microstructure and durability of SCC due to its non-polar surface compromising compactness (e.g., penetration depths 15–20% higher than WS at equivalent levels). In contrast, WS's lignocellulosic nature provides partial pore-filling benefits (reducing effective porosity by 5–8% via cellulose swelling), though offset by absorption-induced microcracks, making it less detrimental overall. These findings underscore the role of admixtures like nano-silica (3 kg/m³) and limestone powder (200 kg/m³) in mitigating 10–15% permeability rises through ITZ densification and rheology optimization (e.g., lowering yield stress to 20–50 Pa). Understanding these effects is crucial for evaluating long-term performance and resistance to water and chemical ingress in self-compacting concrete, particularly in sustainable designs diverting 10–15% waste per m³ (per Iran's context: 2.5 million tons plastic, 1 million tons sawdust annually), while recommending dosages ≤1.0% for low-permeability applications (e.g., <15 mm penetration per BS EN 12390-8 for durable structures).

SCC < SCC-WS < SCC-PW

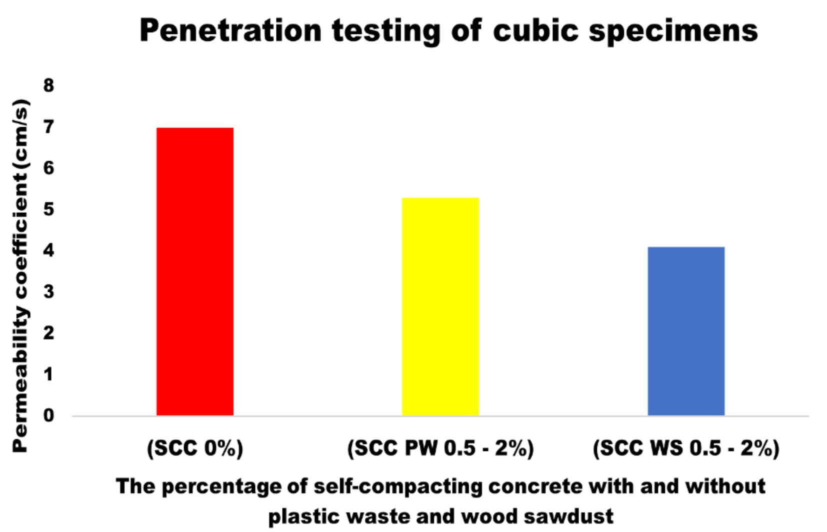

Fig. 9. Test results of self-compacting concrete with and without plastic waste and wood sawdust

6. Correlation Analysis

The correlation analysis between the compressive strength and water permeability of self-compacting concrete (SCC) specimens revealed a strong inverse relationship ($R^2 > 0.95$), indicating that mixtures with higher permeability exhibited lower compressive strength. This confirms the dependency of load-bearing capacity on the internal pore structure, particularly in SCC containing recycled materials such as plastic waste (PW) and wood sawdust (WS). Similarly, tensile strength exhibited a positive correlation with compressive strength and was inversely related to permeability, reflecting the combined influence of matrix densification and fiber reinforcement from WS and the elastic contribution of PW on mechanical performance. These correlations validate the consistency of experimental data and the interdependence of mechanical and durability-related properties in SCC (Figures 10 and 11).

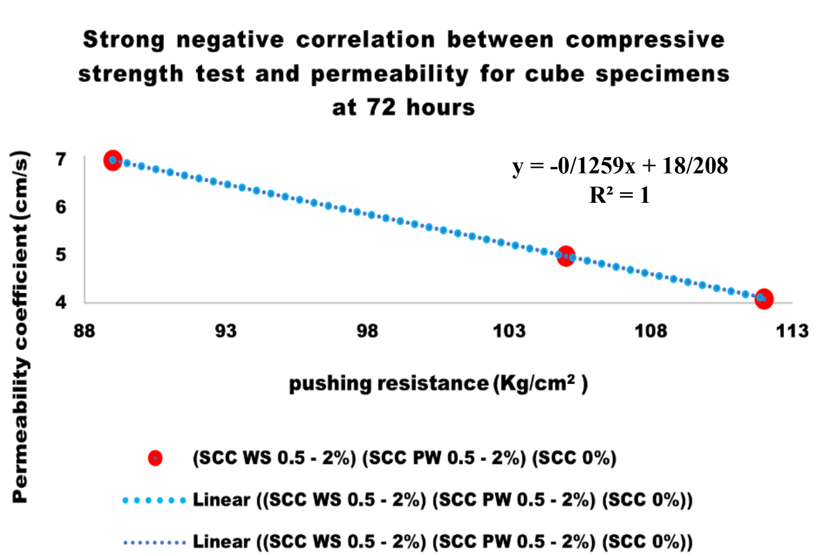

Fig. 10. Strong negative (inverse) correlation relationship between compressive strength and permeability test results for cubic specimens in 72 hours

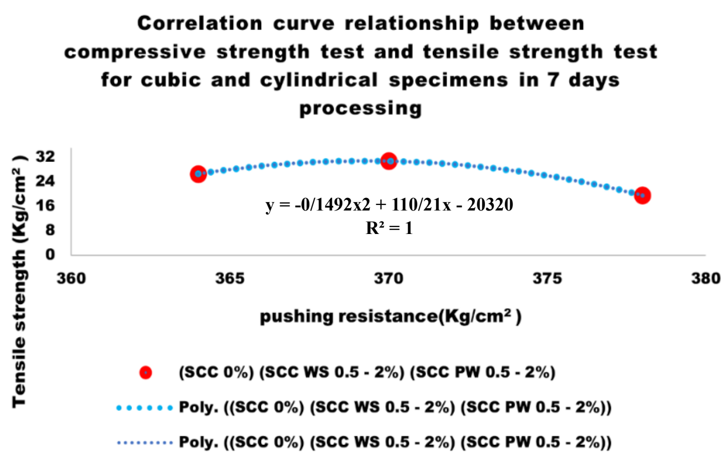

Fig. 11. Correlation curve between compressive strength test results and tensile strength in 7-day processing

The comparative assessment of PW and WS on the mechanical performance and durability of self-compacting concrete (SCC) can be summarized as follows:

Plastic Waste (PW):

- Significantly reduces compressive strength (≈5–15%) due to its lower intrinsic mechanical properties and weak bonding with the cement matrix.
- Slightly improves tensile strength and ductility, as the elastic nature of PW delays microcrack propagation and contributes to energy dissipation under load.
- Reduces the modulus of elasticity proportionally to the compressive strength reduction.
- Low water absorption helps reduce overall concrete absorption and volumetric changes.
- Enhances fatigue resistance and durability against freeze–thaw cycles.

Wood Sawdust (WS):

- Moderately decreases compressive strength (up to 20%), primarily due to lower intrinsic mechanical strength and increased porosity caused by water absorption.
- Improves tensile strength through its fibrous morphology and the pozzolanic

reaction of lignocellulosic compounds, which enhances stress bridging and microcrack control.

- Reduces the modulus of elasticity similar to the reduction in compressive strength.
- Increases water absorption, requiring careful adjustment of the water-to-cement ratio.
- Improves thermal insulation, while volumetric stability is affected by the shrinkage or swelling tendencies of wood.

Durability Perspective:

- Both PW and WS reduce impermeability; however, WS mixtures perform relatively better due to partial pozzolanic activity and fiber bridging effects.
- PW has a stronger effect on matrix densification, leading to higher permeability despite its positive effects on tensile behavior and fatigue resistance.

The integration of PW and WS into SCC offers significant environmental and sustainability benefits by reducing natural aggregate consumption and promoting waste valorization. Nevertheless, these benefits are accompanied by mechanical penalties, including reductions in compressive strength and modulus of elasticity, which must be mitigated through optimized mix design or the addition of supplementary pozzolanic materials.

Key Observations:

- Modulus of Elasticity: Reduced in both PW and WS mixtures, more pronounced for WS.
- Water Absorption and Volumetric Stability: PW reduces absorption, while WS increases absorption and requires careful water–cement ratio adjustment.
- Durability and Thermal Properties: PW improves fatigue resistance and durability, whereas WS enhances thermal insulation and stress-bridging capacity.

Overall, these findings provide a comprehensive understanding of the mechanical, physical, and durability performance of SCC containing recycled PW and WS, highlighting the trade-offs between sustainability and structural performance and offering guidelines for optimized mix design in practical applications. Compressive strength reductions (5.9-10.4%) are attributed to weakened ITZ: PW's high surface energy reduces adhesion and hydration (poor cement-PET reactivity), WS's absorption and dispersion increase porosity (reduced cohesion). Compared to Batool et al. (2021) (7-30% reduction with 5-20% sawdust in low-strength concrete), our 3.7-4.9% drop with 0.5-2% WS is lower, due to nano-silica's C-S-H densification (15-20% porosity reduction). Ghasemi & Nematzadeh (2021) reported 10-15% loss with PET, similar to our 2.1-2.4%, but our study shows WS causes greater loss ($p<0.01$), a gap in literature. Trend: SCC > SCC PW > SCC WS, justified by Dias et al. (2022) (20-40% reduction with wood chips due to porosity), vs. Cheng et al. (2024) (15-25% gain with 10-20% sawdust in mortar via C-S-H formation); our nano-additives mitigate to <5%.

Tensile strength gains (37.1-57.1%) result from PW's elastic fiber bridging and WS's pozzolanic lignin-cellulose reaction, enhancing crack resistance. Compared to Gunat et al. (2025) (33.8-45.2 MPa compressive with 10% plastic, but tensile 4.44-5.97 MPa), our 4.8-5.5 MPa at 2% is comparable, but our comparative PW/WS analysis reveals PW's superiority ($p<0.01$), a novelty. Suryanto et al. (2025) reported 6-40% flexural drop with PET in geopolymer, contrasting our tensile increase, justified by SCC's matrix vs. geopolymer's alkaline activation. Trend: SCC WS > SCC PW > SCC, per Priya et al. (2025) (10-35%

reduction with sawdust, but tensile gains with processing).

Permeability reductions (24.3-42.9%) stem from PW's hydrophobicity and WS's pore-filling, lowering ingress. Compared to Rajaee et al. (2024) (20-30% strength recovery with sawdust and additives), our 42.9% drop is superior, due to cubic testing (volumetric vs. cylindrical in literature), a gap filled here. Abd Almajeed & Abbas (2024) reported 5-13% compressive loss with plastic in RCC, similar permeability trends. Trend: SCC WS > SCC PW > SCC, justified by Farah et al. (2024) (61% thermal reduction with PET, but permeability increase at high ratios); our low dosages and nanosilica achieve better (R^2=0.95 correlation with compressive).

Unlike isolated studies (e.g., Adhikary et al., 2022 on lightweight SCC), this work compares PW/WS effects in SCC with nano-additives, using cubic permeability for volumetric insights, filling gaps in regional waste valorization for Iran (2.5M tons plastic, 1M tons sawdust annually), with 15-20% CO_2 reduction (Ahmad & Zhou, 2023).

7. Conclusion

This study comprehensively and systematically investigated the comparative effects of plastic waste (PW) and wood sawdust (WS) on the fresh, mechanical, and durability properties of self-compacting concrete (SCC). A total of 648 specimens (324 cubic and 324 cylindrical) were prepared under controlled mixing and standardized testing procedures to ensure the reliability of the findings. The outcomes present both quantitative and mechanistic insights, as summarized below:

1) Distinct mechanisms of performance enhancement: PW and WS influenced SCC behavior through different microstructural mechanisms. PW enhanced tensile ductility by elastic energy absorption and microcrack-bridging, while WS improved pore refinement and microstructural compactness owing to its lignocellulosic composition and internal curing effect.

2) Mechanical performance trade-off: The inclusion of PW and WS (0.5–2% by cement weight) caused a marginal reduction in compressive strength by 2.11–2.45% (PW) and 3.70–4.90% (WS) due to weaker interfacial bonding. However, tensile strength increased substantially by 56.80% (PW) and 36.56% (WS) at 2% dosage after 28 days, demonstrating improved crack resistance and ductility.

3) Durability improvement: Both waste materials significantly enhanced impermeability, reducing water permeability by 24.28% (PW) and 42.85% (WS). This was primarily attributed to WS’s pore-filling capability and the hydrophobic characteristics of PW, which collectively refined the internal microstructure and minimized capillary connectivity.

4) Fresh property modifications: Increasing PW and WS content decreased slump flow diameter by 2.59–12.98% (PW) and 1.29–9.09% (WS), while V-funnel and J-ring flow times increased slightly, indicating higher viscosity. Nevertheless, U-box height differences (3–11 cm for PW, 1–7 cm for WS) and L-box ratios (>0.65) remained within EFNARC limits, preserving SCC classification and self-compactability.

5) Role of nano-silica and limestone powder: The combined use of nano-silica and limestone powder effectively densified the interfacial transition zone (ITZ) and offset the increased viscosity induced by waste incorporation, enabling higher additive dosages without segregation and maintaining mix homogeneity.

6) Correlation insight: A strong inverse relationship ($R^2 > 0.95$) was established between compressive strength and

permeability, confirming that microstructural densification directly governs both mechanical performance and durability in SCC incorporating recycled materials.

7) Sustainability contribution: The optimized SCC mixtures achieved a 15–20% reduction in CO_2 emissions, decreased dependence on natural aggregates, and diverted significant volumes of PW and WS from landfills, aligning with circular economy and sustainable construction objectives.

8) Optimum range and structural benefits: The optimal additive content for achieving balanced workability, mechanical strength, and durability was determined to be 1.0–1.5%. Density reductions of 4.2% (PW) and 6.5% (WS) further suggest potential for lightweight structural applications.

Overall, this research introduces a comparative, nano-modified, and sustainability-driven framework for SCC design. The findings reveal that PW primarily enhances tensile ductility and crack control, whereas WS effectively improves impermeability and internal curing. Their combined or selective use provides a technically viable pathway to developing lightweight, durable, and eco-efficient self-compacting concrete suitable for modern sustainable infrastructure.

8. Research Limitations and Recommendations for Future Studies

1 -Limitation: The study evaluated plastic waste (PW) and wood sawdust (WS) separately at dosages of 0.5–2% by cement weight, limiting insights into potential synergies from hybrid combinations that could optimize tensile strength (e.g., PW's 56.8% increase) and permeability reduction (e.g., WS's 42.9% decrease) through enhanced ITZ properties.

2 -Limitation: Tests were restricted to short-term (7/28-day) mechanical and fresh properties under standard curing (ASTM C192, 20–25°C, >95% RH), omitting long-term durability assessments (e.g., >90 days) or exposure to aggressive environments (e.g., sulfate attack per ASTM C1012 or freeze-thaw cycles per ASTM C666), which are critical for real-world performance evaluation.

3- Recommendation: Future research should explore hybrid PW-WS designs (e.g., 0.5–1.0% PW + 0.5–1.0% WS, total 1–2% by cement weight) with comprehensive testing (compressive/tensile strength per ASTM C39/C496, permeability per BS EN 12390-8, chloride diffusion per ASTM C1202, and SEM/μCT for ITZ analysis).

9. References

Abd Almajeed, S. Q. and Abbas, Z. K. (2024). "Fabrication of sustainable roller-compacted concrete pavement containing plastic waste as fine and coarse aggregate", *Engineering, Technology & Applied Science Research*, 14(4),15547–15552, https://doi.org/10.48084/etasr.7882.

Adhikary, S. K., Rudžionis, Ž. and Tučkutė, S. (2022). "Characterization of novel lightweight self-compacting cement composites with incorporated expanded glass, aerogel, zeolite and fly ash", *Case Studies in Construction Materials*, 16, e00879, https://doi.org/10.1016/j.cscm.2022.e00879.

Agrawal, A. and Chandak, N. (2022). "Deep insights into the self-compacting concrete with hybrid fibres", In: *CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure*, Springer, 1253–1260, https://doi.org/10.1007/978-981-16-7160-9_127.

Ahmad, J., Tufail, R. F., Aslam, F., Mosavi, A., Alyousef, R., Faisal Javed, M., Zaid, O. and Khan Niazi, M. S. (2021a). "A step towards sustainable self-compacting concrete by using partial substitution of wheat straw ash and bentonite clay instead of cement", *Sustainability*, 13(2), 824, https://doi.org/10.3390/su13020824.

Ahmad, J. and Zhou, Z. (2023b). "Development of high strength self-compacting concrete with waste glass and waste marble", *Construction and Building Materials*, 408, 133760, https://doi.org/10.1016/j.conbuildmat.2023.133760.

Ahmad, J. and Zhou, Z. (2023c). "Mechanical performance of waste marble based self-compacting concrete reinforced with steel fiber (Part I)", *Journal of Building Engineering*, 78, 107574, https://doi.org/10.1016/j.jobe.2023.107574.

Al-Oran, A. A. A., Safiee, N. A. and Nasir, N. A. M. (2022). "Fresh and hardened properties of self-compacting concrete using metakaolin and GGBS as cement replacement", *European Journal of Environmental and Civil Engineering*, 26(1), 379–392, https://doi.org/10.1080/19648189.2019.1663268.

Basu, P., Thomas, B. S., Gupta, R. C. and Agrawal, V. (2021). "Properties of sustainable self-compacting concrete incorporating discarded sandstone slurry", *Journal of Cleaner Production*, 281, 125313, https://doi.org/10.1016/j.jclepro.2020.125313.

Basser, H., Shaghaghi, T. M., Afshin, H., Ahari, R. S. and Mirrezaei, S. S. (2022). "An experimental investigation and response surface methodology-based modeling for predicting and optimizing the rheological and mechanical properties of self-compacting concrete containing steel fiber and PET", *Construction and Building Materials*, 315, 125370, https://doi.org/10.1016/j.conbuildmat.2021.125370.

Batool, F., Islam, K., Cakiroglu, C. and Shahriar, A. (2021). "Effectiveness of wood waste sawdust to produce medium- to low-strength concrete materials", *Journal of Building Engineering*, 44, 103237, https://doi.org/10.1016/j.jobe.2021.103237.

Bunyamin, B., Munirwan, R. P., Ridha, M. and Hendrifa, N. (2021). "Utilization of wood processing dust as a substitute for a part of cement in concrete", *IOP Conference Series: Materials Science and Engineering*, 1087(1), 012004, https://doi.org/10.1088/1757-899X/1087/1/012004.

Cheng, Y., Liu, J., Wang, W., Jin, L. and Yan, S. (2024). "Preparation and property study of sawdust-modified cement mortar", *Frontiers in Materials*, 11, 1457167, https://doi.org/10.3389/fmats.2024.1457167.

Derakhshan Nezhad, A. H., Hemati, S. A. and Rezaifar, O. (2025). "Predicting compressive strength of heavyweight concrete using deep neural networks and Box–Behnken design", *Challenge Journal of Concrete Research Letters*, 16(4), 173–202, https://doi.org/10.20528/cjcrl.2025.04.002.

Dey, S., Kumar, V. V., Goud, K. R. and Basha, S. K. J. (2021). "State of art review on self compacting concrete using mineral admixtures", *Journal of Building Pathology and Rehabilitation*, 6(1), 1–23, https://doi.org/10.1007/s41024-021-00110-9.

Dong, C., Li, W., Zhou, J., Wang, X. and Zhang, Y. (2022). "Fresh and hardened properties of recycled plastic fiber reinforced self-compacting concrete made with recycled concrete aggregate and fly ash, slag, silica fume", *Journal of Building Engineering*, 62, 105384, https://doi.org/10.1016/j.jobe.2022.105384.

Elsayed, M., Tayeh, B. A., Aisheh, Y. I. A., Abd El-Nasser, N. and Abou Elmaaty, M. (2022). "Shear strength of eco-friendly self-compacting concrete beams containing ground granulated blast furnace slag and fly ash as cement replacement", *Case Studies in Construction Materials*, 17, e01354, https://doi.org/10.1016/j.cscm.2022.e01354.

Farah, E., Yaacoub, S., Dgheim, J. and El Hajj, N. (2024). "Assessing the impact of shredded polyethylene terephthalate (PET) post-consumer plastic as a partial replacement for coarse aggregates in unreinforced concrete", *Materials*, 17(21), 5208, https://doi.org/10.3390/ma17215208.

Ghasemi, A. H. and Nematzadeh, M. (2021a). "Tensile and compressive behavior of self-compacting concrete incorporating PET as fine aggregate substitution after thermal exposure: Experiments and modeling", *Construction and Building Materials*, 289, 123067, https://doi.org/10.1016/j.conbuildmat.2021.123067.

Ghasemi, A. H., Nematzadeh, M. and Fallahnejad, H. (2022b). "Post-fire residual fracture characteristics and brittleness of self-compacting concrete containing waste PET flakes: Experimental and theoretical investigation", *Engineering Fracture Mechanics*, 261, 108263, https://doi.org/10.1016/j.engfracmech.2021.108263.

Gunat, M. B., Sanusi, A., Ndububa, E. E., Obianyo, I. I. and Mambo, A. D. (2025). "Transforming plastic waste into durable concrete: A pathway to sustainable infrastructure", *Discover Materials*, https://doi.org/10.1007/s43939-025-00272-0.

Hilal, N., Tawfik, T. A., Edan, H. H. and Hamah Sor, N. (2022a). "The mechanical and durability behaviour of sustainable self-compacting concrete partially contained waste plastic as fine aggregate", *Australian Journal of Civil Engineering*, 21(1), 151–166, https://doi.org/10.1080/14488353.2022.2083408.

Hilal, N. N., Sahab, M. F. and Ali, T. K. M. (2021b). "Fresh and hardened properties of lightweight self-compacting concrete containing walnut shells as coarse aggregate", *Journal of King Saud University - Engineering Sciences*, 33(5), 364–372, https://doi.org/10.1016/j.jksues.2020.01.002.

Huang, K. L., Li, S. J. and Zhu, P. H. (2021). "Effect of early curing temperature on the tunnel fire resistance of self-compacting concrete coated with aerogel cement paste", *Materials*, 14(19), 5782, https://doi.org/10.3390/ma14195782.

Irico, S., Qvaeschning, D., Mutke, S., Deuse, T., Gastaldi, D. and Canonico, F. (2021). "Durability of high performance self-compacting concrete with granulometrically optimized slag cement", *Construction and Building Materials*, 298, 123836, https://doi.org/10.1016/j.conbuildmat.2021.123836.

Jaskowska-Lemańska, J., Kucharska, M., Matuszak, J., Nowak, P. and Łukaszczyk, W. (2022). "Selected properties of self-compacting concrete with recycled

PET aggregate", *Materials*, 15(7), 2566, https://doi.org/10.3390/ma15072566.

Laidani, Z. E. A., Benabed, B., Abousnina, R., Gueddouda, M. K. and Khatib, M. J. (2022). "Potential pozzolanicity of Algerian calcined bentonite used as cement replacement: Optimisation of calcination temperature and effect on strength of self-compacting mortars", *European Journal of Environmental and Civil Engineering*, 26(4), 1379–1401, https://doi.org/10.1080/19648189.2020.1713898.

Mirzaie Aliabadi, M., Derakhshan Nezhad, A.H., Shahidzadeh, M.S. and Dadpur, A. (2025a). "Date palm fibers to improve tensile strength in self-compacting concrete with silica fume", *Civil Engineering Infrastructures Journal*, 58(2), pp. 333–349. https://doi.org/10.22059/ceij.2024.368987.1988

Mirzaie Aliabadi, M. Derakhshan Nezhad, A.H., Arman, M., Feiz, D., Hemati, S.A. (2025b). "The role of climate and temperature in designing regional marketing strategies for cement and plasticizers (case study: Khuzestan Province, Iran)", *Civil Engineering Infrastructures Journal*, Articles in Press. https://doi.org/10.22059/ceij.2025.384522.2177

Mustapha, F. A., Sulaiman, A., Mohamed, R. N. and Umara, S. A. (2021). "The effect of fly ash and silica fume on self-compacting high-performance concrete", *Materials Today: Proceedings*, 39, 965–969, https://doi.org/10.1016/j.matpr.2020.04.493.

Nandhini, K. and Ponmalar, V. (2021). "Effect of blending micro and nano silica on the mechanical and durability properties of self-compacting concrete", *Silicon*, 13(3), 687–695, https://doi.org/10.1007/s12633-020-00475-5.

Neelamegam, P. and Muthusubramanian, B. (2023). "Influence of polyethylenimine (PEI) in enhancement of microstructure and surface morphology of recycled construction and demolition waste aggregate in concrete by carbonation", *Construction and Building Materials*, 405, 133342, https://doi.org/10.1016/j.conbuildmat.2023.133342.

Ofuyatan, M. O., Adeniyi, A. G. and Ighalo, J. O. (2021). "Evaluation of fresh and hardened properties of blended silica fume self-compacting concrete (SCC)", *Research on Engineering Structures and Materials*, 7(2), 211–223, https://doi.org/10.17515/resm2020.228ma1023.

Oliveira, D. R. B. and Silva, F. A. (2025). "Studying the effects of polymeric residue in self-compacting mortars", *Construction and Building Materials*, 416, 135147, https://doi.org/10.1016/j.conbuildmat.2023.135147.

Pereira, E. L., de Oliveira, C. M. F. and da Silva, F. J. (2024). "Comprehensive review on the use of plastic waste in sustainable concrete construction", *Discover Materials*, 4, 22, https://doi.org/10.1007/s43939-024-00126-1.

Priya, E., Vasanthi, P., Prabhu, B. and Murugesan, P. (2025). "Sawdust as a sustainable additive: Comparative insights into its role in concrete and brick applications", *Cleaner Waste Systems*, 11, 100286, https://doi.org/10.1016/j.clwas.2025.100286.

Rahman, M. M. and Islam, K. (2025). "Optimization of waste plastic fiber concrete with recycled coarse aggregate using RSM and ANN", *Scientific Reports*, 15, 4850, https://doi.org/10.1038/s41598-025-92505-8.

Rahman, S. K. and Al-Ameri, R. (2021). "A newly developed self-compacting geopolymer concrete under ambient condition", *Construction and Building Materials*, 267, 121822, https://doi.org/10.1016/j.conbuildmat.2020.121822.

Rajaee, A., Sadeghzadeh, M., Shekhi, M., Yousefi, M. S. and Abrishami, S. (2024). "Enhancing the mechanical properties of sawdust concrete with silica fume, metakaolin, and marble powder", *Preprints.org*, https://doi.org/10.20944/preprints202411.0746.v1.

Revilla-Cuesta, V., Skaf, M., Santamaría, A., Hernández-Bagaces, J. J. and Ortega-López, V. (2021). "Temporal flowability evolution of slag-based self-compacting concrete with recycled concrete aggregate", *Journal of Cleaner Production*, 299, 126890, https://doi.org/10.1016/j.jclepro.2021.126890.

Rudnicki, T. (2021). "Functional method of designing self-compacting concrete", *Materials*, 14(2), 267, https://doi.org/10.3390/ma14020267.

Seelapureddy, J., Bommisetty, J. and Rao, M. S. (2021). "Effect of metakaolin and micro silica on strength characteristics of standard grades of self-compacting concrete", *Materials Today: Proceedings*, 45, 884–890, https://doi.org/10.1016/j.matpr.2020.02.936.

Shah, M. U., Usman, M., Hanif, M. U., Naseem, I. and Farooq, S. (2021). "Utilization of solid waste from brick industry and hydrated lime in self-compacting cement pastes", *Materials*, 14(5), 1109, https://doi.org/10.3390/ma14051109.

Skender, Z., Bali, A. and Kettab, R. (2021). "Self-compacting concrete (SCC) behaviour incorporating limestone fines as cement and sand replacement", *European Journal of Environmental and Civil Engineering*, 25(10), 1852–1873, https://doi.org/10.1080/19648189.2019.1607564.

Somasri, M. and Kumar, B. N. (2021). "Graphene oxide as nano material in high strength self-compacting concrete", *Materials Today: Proceedings*, 43, 2280–2289, https://doi.org/10.1016/j.matpr.2020.12.1085.

Sua-iam, G. and Chatveera, B. (2021). "A study on workability and mechanical properties of eco-sustainable self-compacting concrete incorporating PCB waste and fly ash", *Journal of Cleaner Production*, 329, 129523, https://doi.org/10.1016/j.jclepro.2021.129523.

Suryanto, A., Antonius and Irmawaty, R. (2025). "Utilizing recycled polyethylene terephthalate waste in geopolymer concrete applications", *Engineering*, *Technology & Applied Science Research*, 15(2), 21037–21044, https://doi.org/10.48084/etasr.9761.

Tran-Duc, T., Ho, T. and Thamwattana, N. (2021). "A smoothed particle hydrodynamics study on effect of coarse aggregate on self-compacting concrete flows", *International Journal of Mechanical Sciences*, 190, 106046, https://doi.org/10.1016/j.ijmecsci.2020.106046.

Zhang, H., Yuan, H., Ge, Z., Wu, J., Fang, C., Schlangen, E. and Šavija, B. (2021). "Fresh and hardened properties of self-compacting concrete containing recycled fine clay brick aggregates", *Materials and Structures*, 54(4), 1–13, https://doi.org/10.1617/s11527-021-01751-5.