

# Fresh Properties of Self-Compacted Engineering Cementitious Composites

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Received: 23 January 2025 | Revised: 9 February 2025 | Accepted: 28 February 2025

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## ABSTRACT

**Self-Compacting Engineered Cementitious Composites (SC-ECC) integrate the workability and flowability of Self-Compacting Concrete (SCC) with the exquisite ductility of Engineered Cementitious Composites (ECCs). This study investigates the optimization of the clean and hardened properties of SC-ECC by studying the results of PVA fibers, superplasticizer dosage, and fly ash-to-cement ratios. 18 trial mixes were produced and evaluated based on the recommendations of EFNARC (2005). The slump flow ranged from 240 mm to 280 mm, meeting self-compacting requirements, as the compressive strength at 7 days varied between 39 MPa and 59 MPa. The findings underscore the role of these variables in enhancing the overall performance of SC-ECC, making it suitable for modern construction.**

**Keywords-SC-ECC; self-compacting concrete; PVA fibers; fly ash-to-cement ratio**

## I. INTRODUCTION

Self-Compacting Concrete (SCC) does not require vibration to settle and cure, as it can move and flow under its own weight, completely filling the formwork and providing stability, stiffness, and uniformity even in the presence of reinforcement [1, 2]. Key features include flow, shear strength, and crack resistance. Flowability ensures that the mixture can flow in all areas of the formwork, and the resistance to cracks remains constant throughout installation, helping to prevent material cracking [3]. Recent studies have examined strategies to improve its properties. For example, the addition of metakaolin as a partial cement replacement has been shown to improve the properties of SCC [4], as 5-20% metakaolin can be used to replace cement, offering better flowability and viscosity. In [5], increasing the content of fly ash led to better flowability and viscosity.

Fly ash, a byproduct of coal combustion in power plants, plays a significant role in improving the properties of concrete due to its pozzolanic activity. Incorporation of fly ash into concrete mixtures improves workability, reduces water demand, and contributes to strength development through the formation of calcium silicate hydrate (C-S-H), creating a dense microstructure with low porosity [6]. Incorporating large volumes of fly ash into Engineered Cementitious Composites (ECCs) has been shown to improve ductility and durability, while also mitigating the environmental and economic impacts associated with high cement consumption [7]. ECC, often called bendable or flexible concrete, is a class of fiber-

strengthened cementitious materials designed to achieve substantial ductility and durability compared to standard concrete. Unlike traditional concrete, which is brittle and prone to cracking under strain, ECC can undergo a large deformation while preserving its structural integrity. This behavior is generally due to the absence of coarse aggregates and the inclusion of discontinuous fibers, such as Polyvinyl Alcohol (PVA) fibers, bridging microcracks and allowing controlled crack propagation [7]. Furthermore, supplementary cementitious materials and fibers have been proven to influence the fresh properties of SCC. A review of diverse studies shows that materials such as furnace slag and herbal zeolite can affect flow, shrinkage, and compressive energy, with the most suitable dosages improving performance in both fresh and hardened states [8]. Traditional concrete is almost unbendable, displaying about 0.1% strain potential, which renders it brittle and stiff. This lack of flexibility is a major cause of pressure failure. ECC can achieve dramatically multiplied flexibility, deforming without breaking, unlike traditional concrete [9].

## II. EXPERIMENTAL SETUP

### A. Cement

This study used ordinary cement (CEM I) that complies with the Iraqi Standard No. 5 of 2019 [10]. Table I details its physical and chemical properties.

TABLE I. CHEMICAL AND PHYSICAL PROPERTIES OF ORDINARY PORTLAND CEMENT [10]

Oxides	Specification according to [10]	OPC
SiO <sub>2</sub>	-	18,68
Al <sub>2</sub> O <sub>3</sub>	-	7.70
Fe <sub>2</sub> O <sub>3</sub>	-	1,95
CaO	-	63.01
MgO	≥5.0%	4.32
SO <sub>3</sub>	≥2.8%	2.32
L.O.I	≥4.0%	0.95
Specific gravity	-	3.15
Blaine fineness, cm <sup>2</sup> /gm	≤3000	4324

### B. Fly Ash

This study used fly ash obtained from the EUROBUILD-UAE power plant, which is characterized as a fine, glass-like powder produced by coal combustion. Table II details the chemical composition of this fly ash, which is consistent with the ASTM C618 [11] standard.

TABLE II. CHEMICAL PROPERTIES OF FLY ASH FOLLOWING ASTM C618 [11]

Oxide	Contents %	Requirements [11]
Fe <sub>2</sub> O <sub>3</sub>	5.33	Sum of more than 70%
Al <sub>2</sub> O <sub>3</sub>	17.57	
SiO <sub>2</sub>	65.52	
SO <sub>3</sub>	0.83	Max. 5%
MgO	0.83	--
CaO	0.96	--
L.O. I	2.79	Max. 6%
K <sub>2</sub> O	2.35	--
Na <sub>2</sub> O	1.34	--

### C. Water

Tap water was used in the mixture, according to IQS 1703 [12].

### D. Fine Aggregate

The fine aggregate used was sourced from northern Iraq. Classified as Zone 2, it adhered to the physical and chemical property requirements outlined in IQS No. 45/1984 [13]. Table III presents details on the properties of the sand.

TABLE III. PHYSICAL CHARACTERISTICS OF THE FINE AGGREGATES [13]

Size of the Sieve, mm	Cumulative percentage pass	IQS (45-1984), zone2
10	100	100
4.750	93	90-100
2.360	85	75-100
1.180	76	55-90
0.60	54	35-59
0.30	24	8-30
0.150	8	0-10

### E. PVA Fiber

Table IV presents the PVA fibers used in this study, along with their properties.

TABLE IV. PVA PROPERTIES- ACCORDING TO THE MANUFACTURER

Item	Content	Unit	Standard
1	Melting point	°C	217
2	Tensile strength	MPa	1789
3	Modulus of Elasticity	GPa	57
4	Ultimate elongation	%	<30
5	Length	mm	8mm
6	Diameter equivalent	μm	42
7	Alkali resistance	%	≥95
8	Safety		Non-toxic
9	Elongation at break	%	7
10	Hot water resistance	° C	≥98
11	Density	g/cm <sup>3</sup>	1.28



Fig. 1. PVA fibers.

### F. Superplasticizer

Sika® Viscocrete®-180 GS is a high-performance admixture designed for concrete and mortar. It functions as a set retarder, a high-range water reducer, and a superplasticizer (SP), utilizing Sika's advanced third-generation polycarboxylate polymer technology known as Viscocrete®. ECC workability was improved to ASTM C494 [14] standards.

## III. MANUFACTURING SC-ECC

A total of 18 trial mixes were prepared to optimize the material's fresh and hardened properties. Each mix was designed with specific proportions of cement, fly ash, SP, and fiber, as shown in Table V. The following key details summarize the method.

### A. Materials and Mix Proportions

- Cement: The cement content varied between 650 and 715 kg/m<sup>3</sup>, depending on the mix design.
- Fly Ash: Two levels of fly ash replacement (20% and 30%) were used, resulting in a fly ash content of 130-195 kg/m<sup>3</sup>.
- Sand: A fixed sand content of 570 kg/m<sup>3</sup> was maintained for all mixes.
- Water: The water content was kept constant at 270 kg/m<sup>3</sup> for all trials.
- Superplasticizer (SP) dosages ranged between 1.5% and 2.0% of the cement weight.
- Fibers: PVA fibers were included at levels between 1.5% and 2.0% by volume.

TABLE V. TRAIL MIXES OF SC-ECC

Mix No.	Cement Kg/m <sup>3</sup>	Fly ash (%)	Fly ash Kg/m <sup>3</sup>	SP (%)	Fiber (%)	Slump flow (mm)	V-funnel time (s)
R1	650	30	195	1.5	1.5	240–260	10–12
R2	650	30	195	1.75	1.5	260–280	9–11
R3	650	30	195	2.0	1.5	280–300	8–10
R4	650	30	195	1.5	1.75	220–240	11–13
R5	650	30	195	1.5	2.0	200–220	12–14
R6	650	30	195	1.75	1.75	240–260	10–12
R7	650	30	195	2.0	1.75	260–280	9–11
R8	650	30	195	1.75	2.0	220–240	11–13
R9	650	30	195	2.0	2.0	240–260	10–12
R11	715	20	130	1.75	1.5	240–260	10–12
R12	715	20	130	2.0	1.5	260–280	9–11
R13	715	20	130	1.5	1.75	200–220	12–14
R14	715	20	130	1.75	1.75	220–240	11–13
R15	715	20	130	2.0	1.75	240–260	10–12
R16	715	20	130	1.5	2.0	180–200	13–15
R17	715	20	130	1.75	2.0	200–220	12–14
R18	715	20	130	2.0	2.0	220–240	11–13

### B. Workability and Fresh Properties

- The mixes were tested for slump flow, ranging from 180 to 300 mm, to assess flowability.
- V-funnel time tests were conducted, with results varying between 8 and 15 seconds, indicating the mixes' passing ability and viscosity.

### C. Target Performance

These trials aimed to achieve a balance between high workability in the fresh state and optimal strength and ductility in the hardened state. The results indicated that adjustments in fly ash, SP, and fiber content significantly impacted the material's performance.

## IV. RESULTS AND DISCUSSION

The results of the study are discussed in terms of the fresh and hardened properties of SC-ECC mixes, evaluated using the EFNARC 2005 guidelines [1]. The tests focused on the flowability and compressive strength of selected mixes (R6, R7, R9, R11, and R12) that achieved slump flow between 240–280 mm.

### A. Fresh Properties Evaluation

The workability of the SC-ECC mixes was assessed using the Mini V-funnel test and a slump flow test. According to [1], slump flow values between 240 and 280 mm are considered acceptable for ensuring adequate flowability without segregation. The fresh density of the mixtures was also measured, with an average value of 1712 kg/m<sup>3</sup>, which aligns with typical ranges for SCC composites.

- Slump Flow: These mixes achieved slump flow values within the target range of 240–280 mm, indicating their compliance with EFNARC requirements for self-compacting behavior.
- V-funnel time: The measured times ranged between 9 and 12 seconds, signifying sufficient viscosity, and aligning with recommendations in [1] for maintaining mix stability during placement. The combined results from these tests

suggest that the selected mixes exhibited excellent fresh properties, suitable for SCC applications. Figure 4 shows the results.



Fig. 2. Slump flow for mix R6.



Fig. 3. Slump flow for mix R7.

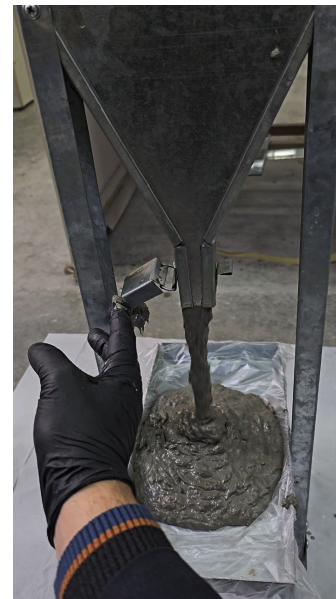


Fig. 4. V-funnel test.

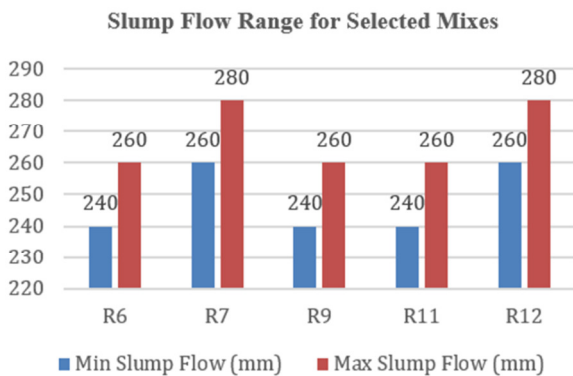


Fig. 5. Results of V-funnel tests.

**B. •Compressive Strength at 7 Days**

The compressive strength of the SC-ECC mixes was evaluated at 7 days using 50×50×50 mm cube specimens following the ASTM C109-2 [15] standard. Table VI and Figure 6 shows the results for the selected mixes (R6, R7, R9, R11, R12).

TABLE VI. COMPRESSIVE STRENGTH RESULTS

Mix	Compressive strength (MPa)
R6	47.2
R7	39.6
R9	46.4
R11	52.8
R12	58.4

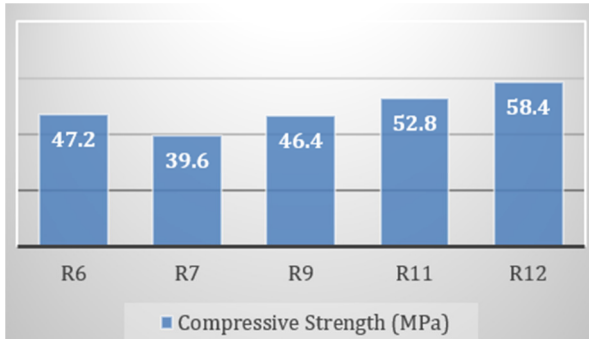


Fig. 6. Results on compressive strength at 7 days.



Fig. 7. Testing ECC cubes.



Fig. 8. ECC cubes.

The results demonstrated that SC-ECC achieved satisfactory fresh and hardened properties, aligning with the EFNARC (2005) guidelines [1]. The slump flow values (240-280 mm) and V-funnel times (9-12 s) indicate that the mixtures maintained high workability without segregation, similar to previous studies on SCC incorporating supplementary cementitious materials, such as fly ash [5].

The results also demonstrated that increasing the PVA fiber content enhanced crack resistance and improved stress distribution. However, a higher fiber content slightly reduced workability, as seen in the slump flow values. Among the tested mixtures, the optimal PVA fiber content was determined to be 1.5%, providing the best balance between workability (slump flow 260-280 mm) and mechanical performance (compressive strength up to 58.4 MPa at 7 days). These findings are consistent with previous research on ECC materials, which also showed that excessive fiber content can hinder flowability while improving ductility.

The compressive strength results at 7 days (ranging from 39.6 MPa to 58.4 MPa) confirm that the higher content of fly ash (30%) contributed to strength enhancement, which is consistent with the findings of [7] that reported that high volume fly ash in ECC improves compressive strength due to its pozzolanic reaction and dense microstructure formation. However, the mix containing 20% fly ash exhibited lower strength (39.6 MPa), indicating that a higher fly ash replacement might require an optimized balance of superplasticizer dosage and fiber content.

In terms of fresh properties, this study aligns with [5], where increasing fly ash replacement improved slump flow and reduced viscosity, ensuring better flowability in self-compacting mixtures. The results also support the work in [7], where optimized ECC formulations with a controlled fiber content maintained both workability and mechanical performance.

Despite these similarities, this study extends previous research by specifically analyzing the combined effects of fly ash percentage, PVA fiber volume, and superplasticizer dosage on SC-ECC. Unlike conventional ECC research that focuses primarily on mechanical performance, these findings highlight the importance of balancing fresh and hardened properties to ensure optimal workability while maintaining strength development.

## V. CONCLUSIONS

This study investigated the effects of PVA fibers, superplasticizer dosage, and fly ash-to-cement ratio on the fresh and hardened properties of SC-ECC. Based on the findings and observations, the following can be concluded.

### A. Effect of PVA Fibers

The results demonstrated that increasing the superplasticizer dosage from 1.5% to 2.0% significantly improved the workability of SC-ECC, achieving optimal slump flow values between 260 and 280 mm while maintaining the stability of the mix. Furthermore, the inclusion of PVA fibers improved crack resistance and contributed to better stress distribution, although further testing is required to quantify improvements in tensile strength.

### B. Effect of Fly Ash-to-Cement Ratio

The impact of fly ash replacement at 20% and 30% was also examined. The mix containing 30% fly ash (R12) exhibited the highest compressive strength of 58.4 MPa at 7 days, suggesting an optimal balance between pozzolanic activity and particle packing. On the contrary, the 20% fly ash mixture (R7) showed a lower compressive strength of 39.6 MPa, highlighting the importance of mix design adjustments when varying the fly ash content.

### C. General Observations

The results align with the EFNARC (2005) guidelines, confirming that SC-ECC mixes exhibit excellent self-compacting behavior and early-age performance. The combination of optimized fiber content, SP dose, and fly ash-to-cement ratio ensures a balance between workability and mechanical properties.

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