

Improving the Performance of Self-compacting Concrete Using Optimized Admixture Combinations

Ashish Singh^{1,*}, Harsh Rathore²

Abstract

This study explores the influence of various admixture combinations on the performance of Self-Compacting Concrete (SCC), with an emphasis on its flow behavior, compressive strength, tensile strength, flexural strength, and resistance to impact. Various admixtures, including Air-Entraining Agent (AEA), Water-Reducing Plasticizer (WPC), Retarder (RET), and Accelerator (ACC), were incorporated into the SCC reference mix (SP + VMA) to evaluate their impact on SCC performance. A series of tests—such as slump flow, Orimet, V-funnel, L-box, and U-box tests—were conducted to assess flow characteristics. Strength properties were examined through compressive, tensile, flexural, and impact strength tests. The results indicate that SCC with AEA, WPC, and RET generally exhibited improved flow characteristics compared to the reference mix, attributed to the ball-bearing effect of air bubbles and reduced friction among particles. The addition of ACC decreased flowability but accelerated strength gain. Strength tests showed modest increases in compressive, tensile, and flexural strengths with AEA, WPC, and ACC, while RET led to a slight reduction in strength. These findings highlight the potential of tailored admixture combinations to optimize SCC properties, suggesting that AEA and WPC enhance both flowability and strength, while ACC accelerates setting for early-strength applications.

Keywords: Self-Compacting Concrete (SCC), admixtures, flow characteristics, compressive strength, tensile strength, flexural strength, impact strength, air-entraining agent, water-reducing plasticizer, retarder, accelerator.

INTRODUCTION

Today's concrete structures demand higher performance standards, requiring concrete with qualities such as high fluidity, self-compacting ability, enhanced strength, durability, improved serviceability, and extended service life. Self-Compacting Concrete (SCC) was first introduced in Japan during the 1980s to meet the need for a highly fluid concrete mixture capable of filling intricate formwork and achieving full compaction solely under its own weight, eliminating the need for external vibration.

Despite its high flowability, SCC resists segregation of coarse aggregate, eliminated for external or internal vibration while still achieving the desired engineering properties.

Modern concrete is no longer just a simple mix of cement, aggregate, water, and admixtures. It has evolved into a sophisticated material, engineered

*Author for Correspondence

Ashish Singh
Email: ashishsingh700@gmail.com

¹Research Scholar, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, Madhya Pradesh, India

²Associate Professor, Department of Civil Engineering, Sanjeev Agarwal Global Educational University, Bhopal, Madhya Pradesh, India

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with various new ingredients to meet specific performance demands under diverse exposure conditions. EFNARC has provisions and guidelines for SCC, which were published in 2002 [1-7].

SCC can be defined as cat flows freely within formwork, passing through reinforcement and filling the mold naturally, consolidating solely under its own weight. In its fresh state, SCC is characterized by its ability to fill formwork, pass through congested reinforcement, and maintain stability without segregation. Ensuring high-quality compaction typically requires skilled labor. However, Japan's construction industry has seen a decline in skilled workers, affecting construction quality. SCC offers a solution by achieving durability without manual compaction.

True to its name, SCC should selwithout additional vibration, achieving full compaction by gravity alone. It should adapt to complex formwork shapes without leaving voids or trapping air, fully encapsulating reinforcement and ensuring thorough integration of aggregates into the concrete matrix. SCC is generally categorized into three types to meet performance requirements: powder type, viscosity-agent type, and combination type [8-17].

Various test methods have been developed erize SCC properties. However, no single test or combination of tests has gained universal acceptance for assessing all workability aspects. Therefore, each SCC mix design should be evaluated using multiple test methods to verify different workability parameters. During initial mix design, key workability parameters—filling ability, passing ability, and stability—should be thoroughly assessed to ensure the mix meets all criteria. To ensure quality control on-site, two testing methods are generally adequate for monitoring the production process.

A key challenge in the widespread adoption of Self-Compacting Concrete (SCC) in India is the absence of reliable mixture proportioning methods. SCC typically requires higher paste content, ranging from 38% to 45% for mixes with a maximum aggregate size of 16 to 20mm, consisting of cement, fillers, and water. The proportions of coarse and fine aggregates are usually similar, or fine aggregates may even exceed coarse aggregates. To prevent issues like bleeding or segregation—common at construction sites due to varying aggregate moisture levels—Viscosity Modifying Agents (VMAs) are essential in all SCC mixes [18-25].

Objectives

The primary aim of this study is to investigate how different admixture combinations affect the properties of Self-Compacting Concrete (SCC). Specifically, the objectives are:

- i. To evaluate the flow behavior of SCC when using various admixture combinations.
- ii. To examine the impact of different admixture combinations on the compressive strength of SCC.
- iii. To analyze the effects on tensile and flexural strength of SCC with various admixture blends.
- iv. To assess the impact resistance of SCC formulated with different admixture combinations.
- v. To determine the most effective admixture combinations for improving SCC performance across multiple properties.

The admixture combinations investigated in this study include:

- Superplasticizer + Viscosity Modifying Agent (SP + VMA) [Reference Mix]
- Superplasticizer + Viscosity Modifying Agent + Air-Entraining Agent (SP + VMA + AEA)
- Superplasticizer + Viscosity Modifying Agent + Water-Proofing Compound (SP + VMA + WPC)
- Superplasticizer + Viscosity Modifying Agent + Retarder (SP + VMA + RET)
- Superplasticizer + Viscosity Modifying Agent + Accelerator (SP + VMA + ACC)

Material

The materials used in the experimentation were as follows:

Cement: 53-grade Ordinary Portland Cement (OPC) with a specific gravity of 3.15, conforming to the specifications of IS: 8112–1989.

Fine Aggregate: Sand sourced locally, with a specific gravity of 2.63, categorized under Zone II as per the guidelines of IS: 383-1970.

Coarse Aggregate: Locally procured coarse aggregate with a specific gravity of 2.88, meeting the requirements outlined in IS: 383-1970.

Fly Ash: Sourced from the Thermal Power Station, Mandideep.

Viscosity Modifying Admixture: Structuro 485, used at a rate of 0.30% by the weight of binder (cement + fly ash), was employed to enhance flow without causing segregation.

Superplasticizer: Structuro 100, a high-performance concrete superplasticizer based on modified polycarboxylic ether, was used at a rate of 0.40% by weight of binder (cement + fly ash).

Air Entraining Admixture: Conplast PA21(S), used at a rate of 0.30% by weight of cement, was added to improve the air entrainment properties of the concrete.

Waterproofing Compound: Conplast X421 IC, used at a rate of 0.30% by weight of cement, was utilized as an integral waterproofing admixture.

Retarder: Conplast RP264, applied at 0.4% by weight of cement, was used to delay the setting time of the concrete.

Accelerator: Conplast NC was incorporated at a dosage of 2% by the weight of cement to enhance the setting process and promote early strength development in the concrete.

Mix Design

The mix design for the M20 grade concrete was carried out using the Nan-Su method. The concrete was prepared with a mix ratio of 1:3:6:5, comprising cement, fly ash, sand, and coarse aggregate, with a water-to-binder ratio of 0.38. The materials were weighed according to the specified proportions and then dry-mixed on a non-absorbent platform. Once mixed, the required amount of water was added, and the mixture was thoroughly blended.

Following this, the admixtures were incorporated in the designated quantities and mixed thoroughly to ensure uniformity. At this point, the concrete was in a flowable state, and flowability tests were conducted to assess its properties. The prepared mix was then poured into molds to form specimens for strength testing. No compaction was applied using a vibrator, as the concrete did not require such treatment, and it also did not need any finishing procedures.

After casting, the specimens were immediately covered with moist gunny bags to preserve moisture. The molds were removed after 24 hours, and the specimens were placed in a curing tank for the specified curing duration [26-31].

RESULTS

Test Results

The results of various tests on Self-Compacting Concrete (SCC) with different admixture combinations are presented in the following tables:

- *Table 1:* This table details the flow characteristics of SCC, showcasing the results of flow tests for mixtures with various admixture combinations.
- *Table 2:* Compressive strength test results of SCC with different admixture combinations are presented here, including the percentage increase or decrease in strength compared to the reference mix. Figure 1 illustrates the variations in compressive strength in graph form.

- *Table 3:* This table displays the tensile strength results for SCC containing varied admixture combinations. It also includes the percentage change in tensile strength relative to the reference mix, with graphical representation of the variations shown in Figure 2.
- *Table 4:* Flexural strength test results for SCC with different admixture combinations are provided here, along with percentage changes in strength compared to the reference mix. These flexural strength variations are depicted graphically in Figure 3.
- *Table 5:* The impact strength test results for SCC with various admixture combinations are shown, along with percentage differences in impact strength relative to the reference mix. Figure 4 presents these variations in a graphical format.

Table 1. Includes the results of the flow test for self-compacting concrete (SCC) with various combinations of admixtures.

Combination of Admixtures	Slump Flow (J-Ring) (mm)	Slump Flow (mm)	Orimet Test Flow Time (sec)	V-Funnel Test Flow Time (sec)	L-Box Test Results	U-Box Test (Filling Height H1-H2) (mm)
SP + VMA (Reference Mix)	360	482	24	30	H2/H1 Ratio: 0	418
SP + VMA + AEA	390	512	15	12	H2/H1 Ratio: 0.12	204
SP + VMA + WPC	380	502	14	16	H2/H1 Ratio: 0.16	285
SP + VMA + RET	370	485	19	21	H2/H1 Ratio: 0.19	351
SP + VMA + ACC	340	458	36	48	H2/H1 Ratio: 0.08	484

Table 2. Presents the compressive strength test results for SCC with different admixture combinations.

Admixture Combination	Specimen ID	Specimen Weight (N)	Density (kN/m ³)	Avg. Density (kN/m ³)	Failure Load (kN)	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	% Change in Compressive Strength (w.r.t Ref. Mix)	Std. Dev.
SP + VMA (Reference Mix)	A1	73.9	23.65	23.98	623	27.86	28.03	-	0.904
	A2	72.45	23.78		652	28.9			
	A3	73.65	23.92		615	27.32			
SP + VMA + AEA	B1	70.65	23.74	23.72	656	29.23	29.2	+ 0.45	0.455
	B2	71.65	23.54		674	29.87			
	B3	71.25	23.69		664	29.54			
SP + VMA + WPC	C1	71.98	23.4	23.66	692	30.71	30.1	+ 5.9	0.52
	C2	72	23.68		676	30.17			
	C3	72.35	23.45		662	29.76			
SP + VMA + RET	D1	71.25	23.49	23.56	614	27.02	27.33	-3.8	1.114
	D2	72.15	23.58		590	26.32			
	D3	71.65	23.61		604	26.89			
SP + VMA + ACC	E1	72.4	23.78	23.99	631	28.63	29.52	+4.9	0.624
	E2	72.55	23.84		670	30.12			
	E3	71.98	23.65		649	29.8			

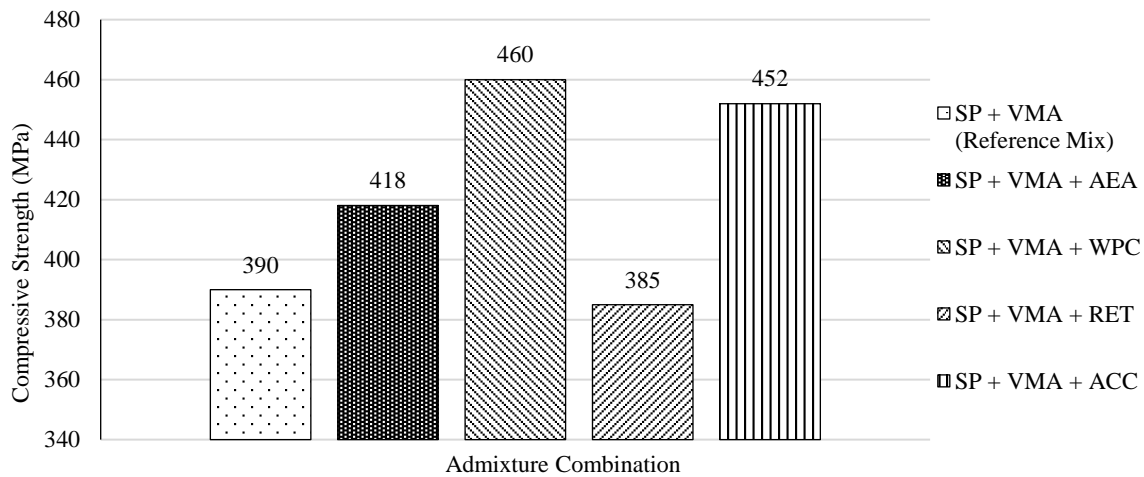


Figure 1. Illustrates the variation in compressive strength of SCC for various admixture combinations.

Table 3. Provides the tensile strength test results of SCC for different admixture combinations.

Admixture Combination	Specimen ID	Failure Load (kN)	Tensile Strength (MPa)	Average Tensile Strength (MPa)	% Change in Tensile Strength from Ref Mix
SP + VMA (Reference Mix)	A1	140	6.19	5.9	-
	A2	131	5.83		
	A3	128	5.42		
SP + VMA + AEA	B1	133	5.92	6.38	+0.62
	B2	141	6.28		
	B3	156	6.93		
SP + VMA + WPC	C1	131	5.83	6.31	+7.2
	C2	148	6.58		
	C3	147	6.52		
SP + VMA + RET	D1	117	5.19	5.39	-8.2
	D2	117	4.95		
	D3	124	5.24		
SP + VMA + ACC	E1	148	6.56	5.96	+1.1
	E2	131	5.83		
	E3	123	5.19		

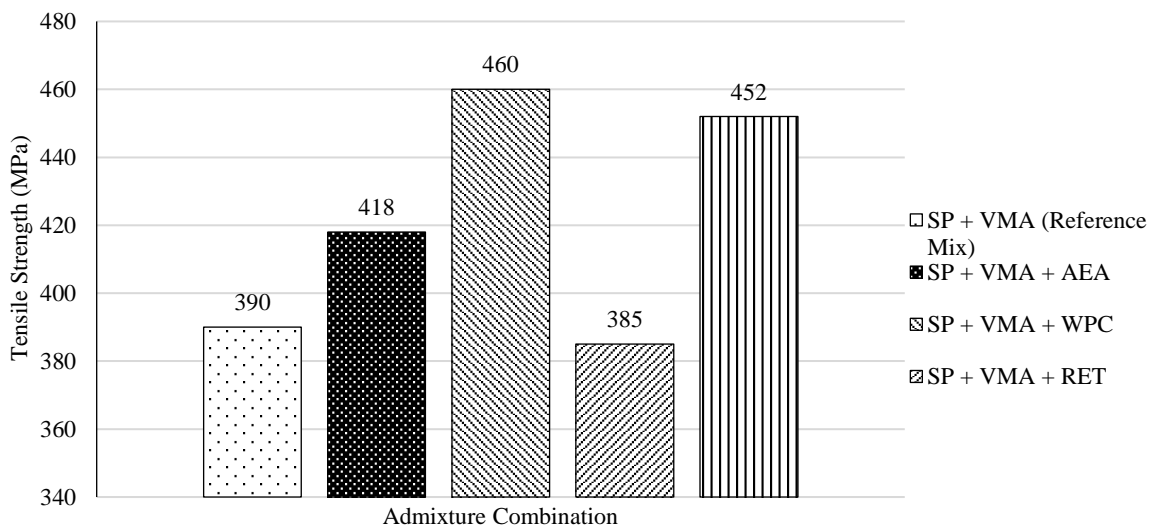


Figure 2. Shows the variation in tensile strength of SCC for the same combinations.

Table 4. Presents the flexural strength test results of SCC with varying admixture combinations.

Admixture Combination	Specimen ID	Failure Load (kN)	Flexural Strength (MPa)	Average Flexural Strength (MPa)	% Change in Flexural Strength from Ref Mix
SP + VMA (Reference Mix)	A1	14.35	6.38	6.23	-
	A2	13.56	6.28		
	A3	13.57	6.03		
SP + VMA + AEA	B1	15.79	7.04	7.01	+13.2
	B2	15.91	7.06		
	B3	16.1	7.11		
SP + VMA + WPC	C1	13.39	6.28	6.27	+1
	C2	13.91	6.43		
	C3	14.05	6.56		
SP + VMA + RET	D1	10.23	4.53	4.47	-26.4
	D2	9.99	4.64		
	D3	9.52	4.55		
SP + VMA + ACC	E1	15.19	6.65	6.53	+4.6
	E2	14.25	6.66		
	E3	14	6.56		

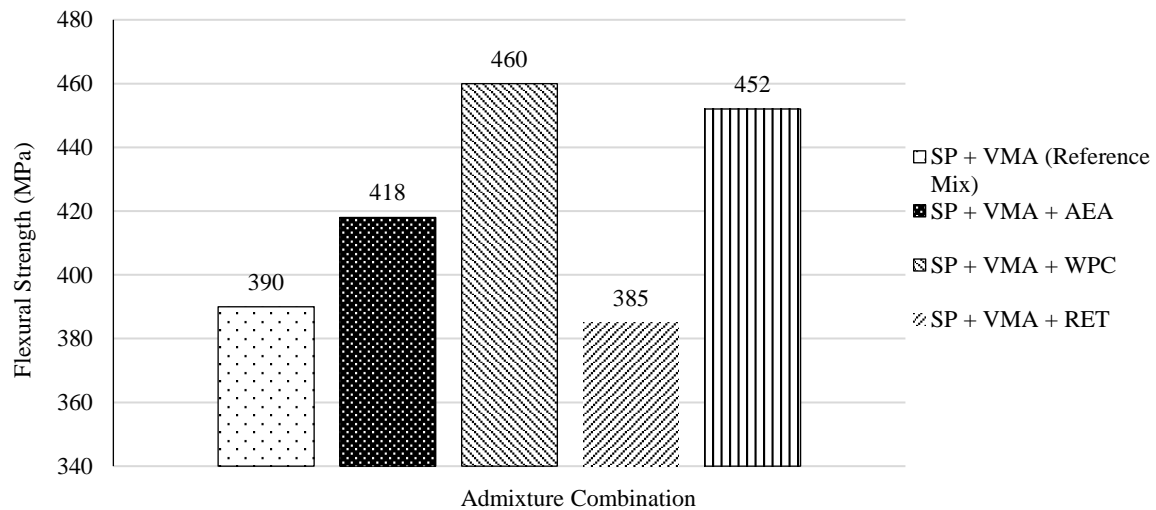


Figure 3. Displays the changes in flexural strength of SCC for different combinations of admixtures.

Table 5. Summarizes the impact strength test results for SCC with different admixture combinations

Admixture Combination	Specimen ID	Blows Required to Cause		Average Blows Required to Cause		Impact Energy Required to Cause		% Change in Impact Energy from Ref Mix	
		First Crack	Final Failure	First Crack	Final Failure	First Crack	Final Failure	First Crack	Final Failure
SP + VMA (Reference Mix)	A1	17	18	17.33	18.67	362	390	-	-
	A2	17	19						
	A3	18	19						
SP + VMA + AEA	B1	20	22	18.66	21	390	418	+9	+8
	B2	18	20						

	B3	18	21						
SP + VMA + WPC	C1	20	22	20.6	21.67	425	460	+18	+19
	C2	21	22						
	C3	21	21						
SP + VMA + RET	D1	16	17	16.67	17.66	348	385	-5	-2.8
	D2	17	18						
	D3	17	18						
SP + VMA + ACC	E1	19	22	19	22.33	398	452	+11	+17
	E2	19	22						
	E3	19	23						

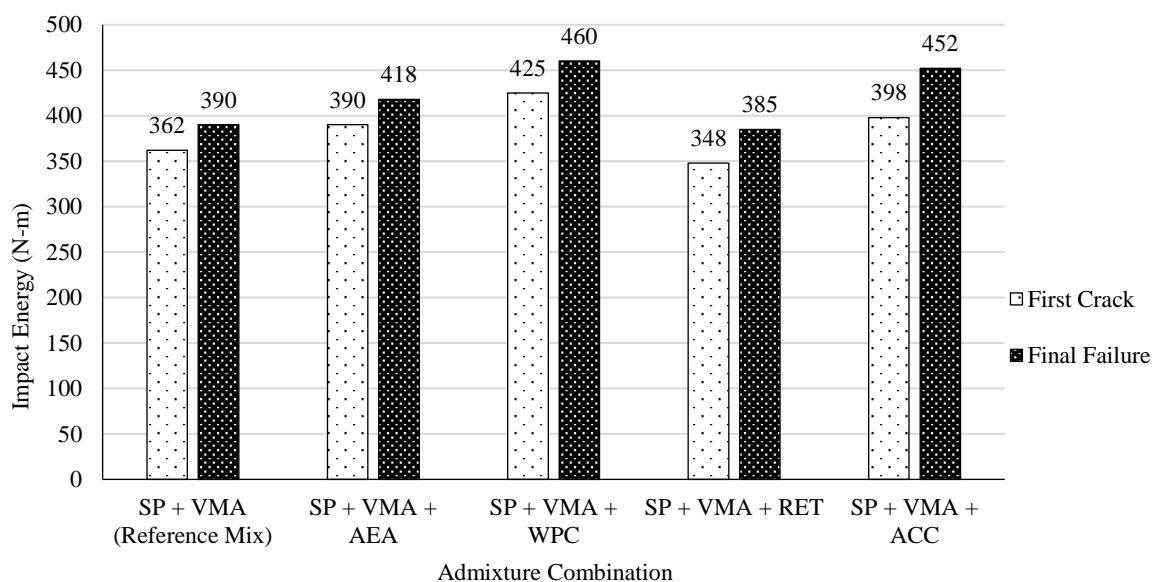


Figure 4. illustrates the variation in impact energy of SCC for the various admixture combinations.

CONCLUSIONS

The study of Self-Compacting Concrete (SCC) with different admixture combinations highlights several key insights into its performance based on flow characteristics and strength properties. The addition of specific admixtures to the base mix (SP + VMA) has varied impacts:

Flow Characteristics

- Admixture combinations with (SP + VMA + AEA), (SP + VMA + WPC), and (SP + VMA + RET) exhibited improved flow properties compared to the reference mix, (SP + VMA), as evidenced by higher slump flows, lower Orimet and V-funnel flow times, and higher filling ratios in L-box and U-box tests.
- The combination with (SP + VMA + ACC) showed reduced flow performance due to the accelerator causing early setting, thus limiting the flow.

Compressive Strength

- Mixtures with (SP + VMA + AEA), (SP + VMA + WPC), and (SP + VMA + ACC) achieved a modest increase in compressive strength relative to the reference mix. The maximum increase of 5.9% was observed in the (SP + VMA + WPC) mix, likely due to better internal cohesion and improved compaction.
- The (SP + VMA + RET) mix, however, showed a decrease in compressive strength, possibly due to delayed setting from the retarder, affecting the hydration process.

Tensile and Flexural Strength

- Combinations such as (SP + VMA + AEA), (SP + VMA + WPC), and (SP + VMA + ACC) showed slight increases in tensile and flexural strength, with the (SP + VMA + AEA) mix achieving a notable 13.2% improvement in flexural strength.
- The (SP + VMA + RET) mix demonstrated lower tensile and flexural strengths, indicating that the retarder might compromise these properties by delaying the concrete's initial setting and strength gain.

Impact Strength

- The impact strength of SCC mixes with (SP + VMA + AEA), (SP + VMA + WPC), and (SP + VMA + ACC) also improved, with (SP + VMA + WPC) showing the highest increase in impact energy, both for the first crack and final failure.
- The (SP + VMA + RET) combination had a slight decrease in impact strength, likely due to reduced early-age strength caused by the retarder.

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