Mechanical properties of self-compacting concrete produced by using various admixtures

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***Abstract*—The advancement of Self-Compacting Concrete (SCC), alternatively known as 'Self-Consolidating Concrete' and 'High-Performance Concrete', stands out as a significant stride in the construction sector. This specialized type of concrete effortlessly flows into reinforcement gaps and mold corners, eliminating the necessity for vibration and compaction during pouring. Its versatility extends to both pre-cast applications and on-site concrete placement. Utilizing SCC yields durable structures while streamlining labor efforts and minimizing consolidation noise. SCC represents an innovative evolution from traditionally vibrated concrete (NVC), distinguished by its remarkable ability to seamlessly flow and spread even within thinner and densely reinforced sections, all achieved without requiring supplementary vibration. This paper presents the influence of admixtures on the properties of self-compacting concrete. In this paper, both the fresh state properties and hardened state properties were studied.**

***Index Terms*—Admixtures; cement; self-compacting concrete; fresh properties; hardened properties**

I. INTRODUCTION

Researchers, driven by the burgeoning demands of the construction sector, persistently dedicate themselves to the development of diverse concrete formulations. Through their tireless efforts, a spectrum of concrete variations has emerged, ranging from high-strength concrete to self-healing concrete, high-performance concrete, and groundbreaking self-compacting concrete (SCC). The pivotal juncture arrived in 1988 when Japanese researchers unveiled SCC, heralding a transformative shift in construction methodologies [1]. Distinguished as an evolved iteration of normally vibrated concrete (NVC), SCC possesses the unique ability to effortlessly flow and distribute evenly, even within slender and densely reinforced sections, obviating the need for additional vibration [2]. Its superiority over NVC extends across multiple dimensions, offering advantages such as reduced casting durations, diminished labor expenditures, seamless placement in inaccessible locations, mitigation of noise pollution, attainment of superior surface finishes, and heightened adaptability in sculpting intricate geometries. As the construction landscape evolves, the adoption of SCC accelerates, propelling the demand for conventional materials like cement and sand. Nonetheless, this amplified reliance on traditional resources raises pertinent sustainability concerns. An urgent imperative emerges for the development of alternative materials, poised to alleviate the construction industry's dependency on conventional resources, thereby fostering sustainability and resilience in construction practices [3,4].

Since its inception into the construction industry during the early 1990s, the advent of SCC has ignited a flurry of research and development endeavors. These efforts have predominantly centered on comprehending and appraising its fresh properties, crucial for initial handling and placement. However, while fresh properties are pivotal during the pouring phase, it is the hardened properties that assume paramount significance for structural designers and end-users alike [5-7]. Consequently, a substantial portion of research has been directed towards meticulously gathering data on all facets of these enduring characteristics.

Within the realm of mix development studies, routine collection of compressive and other strength data has been a staple practice. This data serves as a cornerstone for assessing the structural integrity and load-bearing capacity of SCC compositions. Moreover, an array of ancillary properties, spanning from elastic modulus and creep to shrinkage, bond to steel, and overall durability, have undergone exhaustive scrutiny through studies of varying magnitudes and depths [8,9]. This comprehensive exploration ensures a nuanced understanding of SCC's performance across diverse environmental and structural contexts, thus facilitating informed decision-making and optimized utilization in construction projects. Numerous investigations within this realm have often constrained themselves to a modest selection of mixes, characterized by a narrow spectrum of properties. While the data derived from these studies are undeniably valuable, there exists a significant opportunity for enhancement through comparative analysis, correlation, and critical evaluation. Thus far, such endeavors have predominantly manifested in the form of summarized sections found within overarching specification and guidance documents crafted by national and international committees and working groups [10-12].

In addition to providing comprehensive insights into the selection of component materials, mixture proportions, and subsequent concrete properties, many of these case studies delve into meticulous details. As highlighted by researcher, exercising caution is imperative when directly comparing data from individual mixes. This necessity arises from the fact that the components and proportions therein are contingent upon local mix design parameters, production processes, and specific application requirements. However, with a growing repository of such case studies, there emerges an opportunity for a systematic evaluation of the diverse spectrum of mix parameters and properties in statistical terms, thereby rendering it both valid and beneficial [12].

The surge in publications across scholarly journals and prestigious international conferences in recent years underscores the burgeoning research activity surrounding this dynamic new technology, now gaining traction on a global scale. Amidst this surge, a noticeable influx of papers has emerged, shedding light on practical applications through detailed case studies. These case studies serve as invaluable resources, delving deep into the rationale behind the adoption of SCC for specific scenarios. They meticulously analyze its advantages and limitations, evaluate its impact on construction costs, project timelines, and overall efficiency, and consider its effects on various facets including working conditions, the well-being of construction personnel, and the ecological footprint, both locally and globally [12,13]. However, despite the undeniable importance and intrigue of these considerations, they are intricately intertwined with the idiosyncrasies of each individual application and the unique context of the locale. Consequently, conducting rigorous quantitative comparisons across different scenarios poses a formidable challenge.

II. RESEARCH SIGNIFICANCE

The main aim of this paper is to explore the influence of the dosage of mineral admixtures on the characteristics of self-compacting concrete. On the other hand, the fresh properties of self-compacting concrete are presented by using workability tests immediately after the preparation of concrete. Furthermore, the hardened properties were investigated by conducting a compressive strength test after 7 and 28 days of water curing.

III. MATERIALS AND METHODS

In this paper 43 grade cement is used, a type of Portland cement that is commonly used in construction projects. It is characterized by its compressive strength, which is designated as 43 MPa (megapascals) after 28 days of curing. This strength grade makes it suitable for a wide range of applications, including residential, commercial, and industrial construction. In the manufacturing process, 43 grade cement is produced by grinding clinker, gypsum, and other additives to a fine powder. It typically contains a higher percentage of C_3S (tricalcium silicate) and C_3A (tricalcium aluminate) compared to lower-grade cements, which contributes to its higher early strength development. The use of 43 grade cement is prevalent in situations where moderate strength concrete is required, such as in the construction of residential buildings, foundations, beams, columns, and plastering works. It offers a balance between cost-effectiveness and performance, making it a popular choice for various construction applications.

Fly ash is a fine powder residue generated from the combustion of pulverized coal in thermal power plants. It is carried away by the exhaust gases and collected by electrostatic precipitators or bag filters before being dispersed into the atmosphere. Due to its pozzolanic properties, fly ash is commonly utilized as a supplementary cementitious material in concrete production. When mixed with cement and water, it undergoes a chemical reaction, contributing to improved workability, durability, and strength characteristics of concrete. Additionally, the utilization of fly ash in concrete offers environmental benefits by reducing the demand for cement, thus lowering greenhouse gas emissions and conserving natural resources. Class-F fly ash is used in this study.

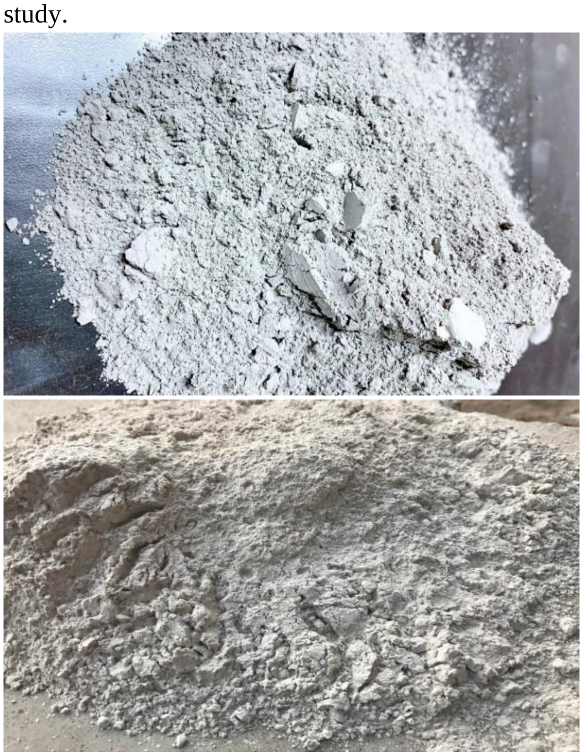

Figure 1: Raw cement sample and fly ash sample

Aggregates are categorized as either 'coarse' or 'fine'. Coarse aggregates consist of particles larger than 4.75mm, typically falling within the range of 9.5mm to 37.5mm in diameter. Fine aggregates, on the other hand, generally comprise sand or crushed stone with a diameter less than 9.55mm. Locally available fine and coarse aggregates used in the production of self-compacting concrete. Table 1 illustrates the chemical composition of cement and fly ash used in this study.

Table 1: Chemical composition of fly ash and cement

Compound (%)	Cement	Fly ash
SiO_2	18.34	45.67
CaO	64.25	12.56
MgO	2.6	4.57
Al_2O_3	4.72	28.19
Fe_2O_3	0.4	6.35
LOI	3-5	2-4

In general, minimizing free water content to improve stability can lead to self-compacting concrete mixtures characterized by a low yield stress and moderate-to-high viscosity levels. Achieving the desired deformability, particularly with lower binder contents, necessitates a relatively high dosage of high-range water reducers. A new generation polycarboxylic ether was utilized, offering superior effectiveness compared to other bases, and it operates effectively at lower dosages than alternative superplasticizers. The pH of the superplasticizer exceeded 6.

A series of experimental mixes were conducted to evaluate the properties of self-compacting concrete, comprising one control mix and five alternative formulations with varying levels of mineral admixture replacements. The compositions of these mixes, detailed in Table 2, feature replacements spanning from 30% to 50% by mass. After multiple trial iterations, a water-to-powder mass ratio of 0.35 was chosen. Initially, the total powder content was subjected to variations, ranging between 400 kg/m3, 450 kg/m3, and 500 kg/m3, before ultimately settling at 500 kg/m3. Additionally, each mix, including the control, was augmented with a polycarboxylate-based high-range water-reducing admixture. Subsequently, specific design guidelines were formulated based on the results obtained from standardized test methods.

Table 2: Mix proportions of self-compacting concrete

Mix Id	Binder		Aggregate		W/C ratio
	Cement	Fly ash	Coarse	Fine	
OPC	400	-	1217	610	0.35
SCC1	320	80	1217	610	0.35
SCC2	280	120	1217	610	0.35
SCC3	240	160	1217	610	0.35
SCC4	200	200	1217	610	0.35

The investigation into compressive strength involved the use of cube moulds sized at 150 mm × 150 mm × 150 mm, which were subjected to testing within a compression testing machine. Preceding these strength evaluations, a comprehensive array of workability tests, including slump flow, L-box, and V-funnel tests, were conducted. These tests were employed to thoroughly assess the workability characteristics of self-compacting concrete, particularly focusing on its ability to fill molds smoothly and pass through congested reinforcement. Notably, the slump flow test was specifically employed to quantify the flowability of self-compacting concrete by measuring the average spread diameter. It was established that for fresh self-compacting concrete, the spread diameter should ideally range between a minimum of 650 mm and a maximum of 800 mm to meet acceptable standards.

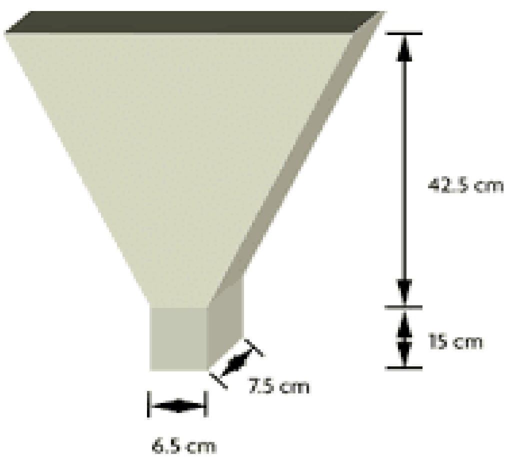

Figure 2: V-funnel test on fresh SCC

Figure 3: L-box test on fresh SCC

Figure 4: Compression testing machine

IV. RESULT AND DISCUSSIONS

4.1 Slump flow

The slump flow values for self-compacting concrete (SCC) containing fly ash, measured immediately after the mixing process, are presented in Figure 5. These values provide a crucial insight into the workability and fluidity of the SCC mixtures. In terms of slump flow, all SCC mixtures demonstrated satisfactory results, with measurements ranging from 640 to 690 mm. This range is well within the acceptable limits, indicating that the SCC has good deformability, which is essential for ensuring the concrete can fill formwork and encapsulate reinforcement without the need for mechanical vibration.

Notably, mixtures with a higher percentage of fly ash replacement exhibited even better flowability. This finding underscores the positive impact of fly ash on the fresh properties of SCC. Fly ash, being a finer material than cement, contributes to improved particle packing and reduces the water demand of the concrete mix. Additionally, the spherical shape of fly ash particles helps to decrease the internal friction within the mix, facilitating easier flow and spread. As a result, SCC with higher fly ash content not only meets but often exceeds the flowability requirements, making it highly suitable for complex formworks and heavily reinforced sections. This enhanced flowability also translates to improved surface finish and reduced risk of defects such as honeycombing, ultimately leading to better overall quality of the finished concrete structure.

Compared to conventional concrete, the inclusion of fly ash significantly enhanced the flowability of the SCC samples, making them more workable and easier to handle during construction. This improvement in flowability is attributed to several factors. Firstly, the spherical shape of fly ash particles acts like tiny ball bearings within the concrete mix, reducing internal friction and allowing the mixture to flow more freely. This characteristic helps the concrete to spread more easily and uniformly, which is particularly beneficial when filling intricate formwork or around dense reinforcement.

Additionally, the finer particles of fly ash contribute to a denser packing of materials within the mix, which in turn reduces the void spaces that typically require water to fill. With fewer voids, the water content can be optimized to enhance fluidity without compromising the strength and stability of the concrete. This finer particle size also means that fly ash can partially replace the cement in the mix, leading to a reduction in heat of hydration and less potential for cracking and shrinkage, further improving the overall workability and durability of the concrete.

Moreover, the chemical properties of fly ash contribute to improved concrete performance. Fly ash contains pozzolanic materials that react with calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H), which enhances the bonding and overall matrix of the concrete. This results in a more cohesive and fluid mix that can achieve a high level of compaction and surface finish with minimal effort.

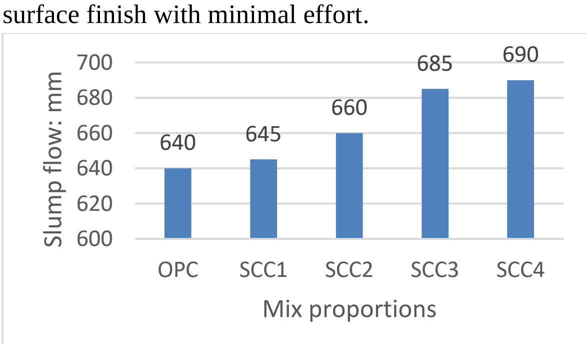

Figure 6: Slump flow values of SCC in mm

4.2 L-box test

In the L-Box test, the procedure began by simultaneously removing the control gate to permit the flow of self-compacting concrete (SCC) through the horizontal obstruction within the box. This setup mimics the real-world conditions where concrete must navigate through various obstacles. The flow of SCC was observed, and the ratio of h2/h1 (the height of concrete at the end of the flow to the height at the start) was determined. Ideally, if the concrete flows as freely as water, it will settle horizontally, resulting in a ratio equal to unity. This indicates that the concrete has excellent filling and passing ability, essential for ensuring proper placement without segregation or blockages. The observed values for the L-Box test fell within the standard limits, demonstrating that the SCC mixtures had adequate flow characteristics. The L-box ratio, which measures the relative heights, indicates the filling and passing ability of each mixture. This test is particularly sensitive to the risk of blocking, as it simulates the conditions under which the concrete must pass through tight spaces and around reinforcements without losing its homogeneity.

A critical value in this test is the blocking ratio, with a threshold of 0.8. If the L-Box blocking ratio falls below this value, there is a significant risk that the mixture will experience blocking, meaning it may not flow adequately through confined spaces or around dense reinforcement without segregating. Fortunately, the obtained L-Box values for the SCC mixtures tested were above this critical threshold, ensuring that the mixtures possessed good passing ability and minimized the risk of blocking. These results, which are detailed and tabulated in Figure 7, confirm that the SCC mixtures tested are capable of flowing through complex geometries and around obstacles while maintaining their integrity and uniformity. This highlights their suitability for applications where ease of placement and reliability in filling are crucial.

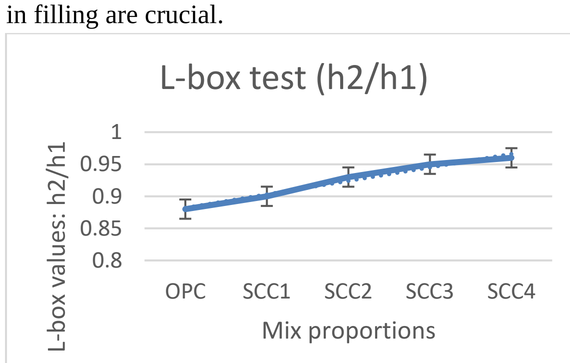

Figure 7: L-box test results on SCC

4.3 V-funnel test

The V-funnel test was conducted to evaluate both the flowability and stability of the self-compacting concrete (SCC). This test is essential for understanding how the concrete behaves under conditions where it must pass through narrow spaces, simulating real-world scenarios of flowing through formwork and around reinforcement bars. For self-compacting concrete, a flow time of approximately 10 seconds is considered ideal. This flow time indicates that the concrete possesses sufficient fluidity to fill molds and encapsulate reinforcement without requiring vibration, which is a key characteristic of SCC. The test involves pouring the SCC into a V-shaped funnel and measuring the time it takes for the concrete to flow through the narrow opening at the bottom and completely exit the funnel. The inverted cone shape of the V-funnel inherently restricts the flow of concrete, making this test particularly sensitive to the mixture's viscosity and cohesiveness. A prolonged flow time, longer than the standard 10 seconds, can provide valuable information about the mixture's characteristics. Specifically, it may indicate the concrete's susceptibility to blocking, where the mixture could become obstructed within formwork or around reinforcements, leading to poor filling and potential defects in the hardened concrete.

By monitoring the flow time in the V-funnel test, engineers can assess whether the SCC mixture needs adjustments to improve its performance. A mixture that flows too quickly might be prone to segregation, where the coarse aggregate separates from the cement paste, while a mixture that flows too slowly might indicate excessive viscosity or lack of adequate flowability, leading to potential blockages. Thus, the V-funnel test not only assesses the immediate flowability of SCC but also provides insights into its stability and potential challenges during placement. The results from this test are critical for ensuring that the SCC mixture used in construction will perform as expected, achieving the desired balance between fluidity and stability to ensure high-quality concrete structures.

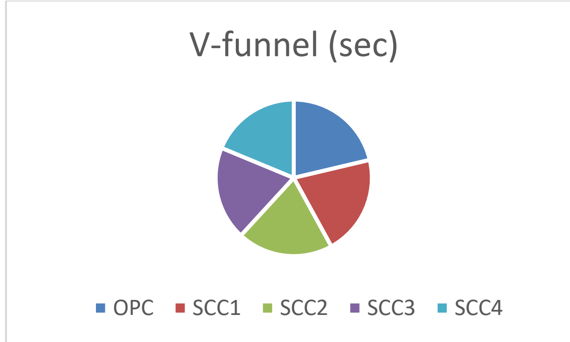

Figure 8: V-funnel for self-compacting concrete

4.4 Compressive strength

The mechanical properties of the self-compacting concrete (SCC) were assessed through a series of compression tests conducted at two curing periods: 7 days and 28 days. These tests are crucial for determining the concrete's ability to withstand loads without failing, which is a fundamental requirement for structural applications. The results indicated a clear trend related to the fly ash content in the SCC mixtures. Specifically, as the fly ash content increased, the compressive strength of the SCC also increased. This suggests that fly ash contributes positively to the development of compressive strength over time, likely due to its pozzolanic properties, which enhance the binding and densification of the concrete matrix.

The minimum compressive strength was observed in samples with a 20% fly ash replacement. Although these samples met the necessary standards, their strength was lower compared to those with higher fly ash content. In contrast, the highest compressive strength was observed in samples with a 50% fly ash replacement. These samples demonstrated superior strength characteristics, making them particularly suitable for applications requiring high strength and durability. The improvement in compressive strength with higher fly ash content can be attributed to several factors. Fly ash, as a pozzolanic material, reacts with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate (C-S-H), which is the primary strength-giving compound in concrete. This reaction not only enhances the strength but also improves the density and durability of the concrete.

Furthermore, the fine particles of fly ash contribute to a better packing density of the mix, reducing the porosity and increasing the overall compactness of the concrete. This results in a stronger and more durable concrete structure. The findings from the compression tests underscore the beneficial role of fly ash in enhancing the mechanical properties of SCC, particularly when used at higher replacement levels.

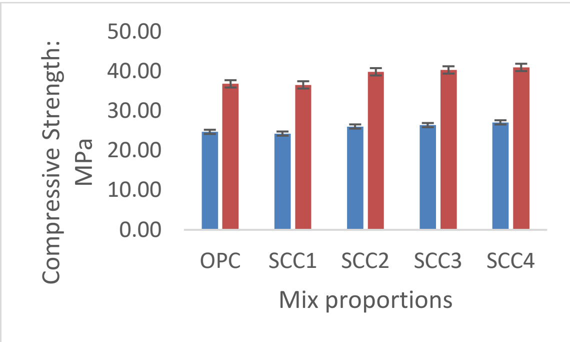

Figure 9: Compressive strength of SCC for 7 and 28 days

V. CONCLUSIONS

The tests were conducted to evaluate both the fresh and mechanical properties of self-compacting concrete (SCC) mixtures. The results of these tests are as follows:

•All the self-compacting concrete mixes exhibited satisfactory performance in their fresh state. The replacement of 50% fly ash-based samples was shown better fresh properties.

•In general, the incorporation of mineral admixtures significantly improved the performance of self-compacting concrete (SCC) in its fresh state. The improved performance in the fresh state ensured that the concrete could flow effortlessly into intricate formwork and around dense reinforcement, achieving full compaction and a smooth finish with minimal effort.

•fly ash acts as a pozzolan, reacting with calcium hydroxide produced during the hydration of cement to form additional calcium silicate hydrate (C-S-H). This reaction not only consumes a by-product that could be detrimental to concrete durability but also generates more of the binding C-S-H gel, which significantly improves the strength and durability of the concrete.

•The fly ash-based self-compacting concrete (SCC) samples exhibited enhanced compressive strength compared to the conventional SCC samples. This increase in compressive strength is attributed to several beneficial properties of fly ash. Fly ash particles, being finer and spherical in shape, contribute to better packing density within the concrete matrix, reducing void spaces and leading to a denser, stronger material.

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