Correlation Between Workability Characteristics and Compressive Strength of SCC with Fly Ash Blends

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Abstract : This research investigates the relationship between workability and compressive strength of Self-Compacting Concrete (SCC), which can flow and compact under its own weight without segregation. Four SCC mixes with varying water/powder ratios (0.35 to 0.50) and superplasticizer dosages (7, 8.5, and 10 L/m³) were studied, with 15% cement replaced by fly ash. Workability was assessed using slump flow, V-funnel, and L-box tests, and compressive strength was measured.Results indicate that increasing superplasticizer dosage improves both workability and compressive strength. The SCC4 mix with the lowest W/P ratio (0.35) showed the highest compressive strength, while the SCC3 mix (W/P 0.50) had the best workability. The SCC2 mix achieved optimal balance between strength and workability. The study concludes that the relationship between workability and compressive strength in SCC is nonlinear.

IndexTerms- Self-Compacting Concrete, Workability, Superplasticizer Dosage, Fly Ash, Concrete Flowability, Nonlinear Relationship

1. INTRODUCTION

Self-Compacting Concrete (SCC) is a high-performance concrete that flows under its own weight and achieves full compaction without the need for vibration. Its high deformability and resistance to segregation make it ideal for complex structures and areas with dense reinforcement. The development of SCC has been made possible with the introduction of advanced superplasticizers and improved mix designs involving fine materials like fly ash and silica fume. SCC offers numerous benefits including faster construction, reduced labor, better surface finishes, improved durability, and reduced noise from construction activities. Its fresh-state properties—high flowability, viscosity, and segregation resistance—enhance structural integrity by minimizing defects like honeycombing.Despite its advantages, SCC poses challenges such as higher material costs, increased creep and shrinkage, and complex mix design requirements. Careful quality control is essential, especially when producing SCC on-site.Historically, SCC was developed in Japan in the 1980s to address poor compaction in conventional concrete. Researchers like Okamura and Ozawa played a key role in its evolution, leading to widespread industrial use under various trade names.In India, SCC use is growing, with notable applications in projects like the Delhi Metro, Tarapur Atomic Power Project, and Bandra-Worli Sea Link. Research institutions such as SERC Chennai and IITs have conducted extensive trials, confirming SCC's comparable structural performance to conventional vibrated concrete, especially in highly reinforced or inaccessible areas.

2. LITERATURE REVIEW

The development and study of Self-Compacting Concrete (SCC) have garnered significant attention globally due to its enhanced workability, mechanical properties, and suitability for complex formwork and congested reinforcement. The foundational work of **Okamura and Ouchi (2003)** introduced the concept of SCC and outlined its necessity, mix design, and future direction, setting the stage for extensive global research. Building on this, **Krieg (2003)** and **Bartos (2003)** emphasized the importance of proper testing methods and mix evaluation to ensure performance, especially in varied construction environments.Several studies have investigated the fresh and hardened properties of SCC. **Anant Patel et al. (2011)** and **Patel (2010)** highlighted the compressive strength and modulus of elasticity, establishing that SCC can achieve comparable or even superior strength to conventional concrete. **Gaywala and Raijiwala (2011)** termed SCC as the concrete of the next decade due to its self-compacting ability and reduced labor requirement. **Soni et al. (2011-12)** supported this view by presenting SCC as a solution for modern construction challenges, including durability and faster placement.**Selvamony et al. (2010)** and **Ahmadi et al. (2007)** studied the incorporation of supplementary cementitious materials such as limestone powder and rice husk ash, respectively, showing that these materials improve the sustainability and performance of SCC. **Aggrawal et al. (2005, 2008)** and **Subhramanian & Chattopadhyay (2002)** proposed mix design procedures suitable for Indian conditions, while **Murali and Kandasamy (2009)** applied statistical tools like Response Surface Methodology (RSM) to optimize mix proportions.Investigations into the influence of additives have been central to improving SCC. **Grdic et al. (2008)** explored different chemical and mineral admixtures and their impact on flowability and strength. **Bouzoubaa and Lachemi (2001, 2003)** presented evidence on the use of high volumes of fly ash, especially Class F, significantly enhancing workability while maintaining adequate strength. Similarly, **Ahmad et al. (2008)** showed that SCC can be effectively made using marginal aggregates, expanding its applicability to regions with limited material availability.The European Guidelines (2005) and IS 456:2000 (Amendment 2007) provided standardized frameworks for SCC production and application, facilitating consistent quality. **Assad et al. (2004)** and **Shen et al.** discussed stability issues such as segregation and bleeding, emphasizing the role of viscosity-modifying agents (VMAs), as also highlighted by **Umar and Al-Tamimi (2005)**. **Ravindrarajah et al. (2003)** stressed the importance of high-performance superplasticizers in achieving desirable flow without compromising strength.Comprehensive evaluations by researchers like **Brouwers and Radix (2005)** and **Khayat et al. (2004)** addressed both theoretical and practical perspectives on SCC behavior, including static stability and rheological properties. Field-oriented insights by **Barots (2000)** and **GAB Suresh et al.** underscored SCC's practical applications, especially in precast, repair, and heavily reinforced elements.In conclusion, the literature collectively illustrates that SCC, when properly proportioned and tested, offers significant advantages over conventional concrete in terms of workability, strength, and adaptability. Its compatibility with industrial by-products like fly ash and rice husk ash further enhances its sustainability credentials, making it an ideal material for future concrete innovations.

3. METHODOLOGY

The experimental investigation was carried out to study the relationship between the workability and compressive strength of Self-Compacting Concrete (SCC) incorporating fly ash as a partial replacement of cement. The work included detailed material characterization, mix design, workability testing using standard methods, and compressive strength evaluation of hardened concrete

3.1 Materials Used

Cement

Ordinary Portland Cement of 43 Grade (Binani brand) conforming to IS standards was used. The physical and mechanical properties of the cement were tested and are summarized in Table 4.1. Cement exhibited good strength and fineness characteristics suitable for SCC applications.

Fine Aggregate

Locally available river sand conforming to IS: 383-1970 was used as fine aggregate. It was clean, sieved, and belonged to Zone III. The physical and grading characteristics were determined and are presented in Tables 4.2 and 4.3.

Coarse Aggregate

Crushed angular coarse aggregates with a maximum nominal size of 10 mm were used. The aggregates were cleaned and surface dried before use. The relevant properties and gradation are listed in Tables 4.4 and 4.5.

Water

Potable water, free from harmful impurities and suitable for mixing and curing, was used throughout the experimental work.

Fly Ash

Class F fly ash procured from the Vanakbori Thermal Power Station (Gujarat) was used as a supplementary cementitious material. It was used at a constant replacement level of 15% by weight of cement in all mixes.

Superplasticizer

A high-range water reducer "Hypo Supersizer," an organic polymer-based superplasticizer, was employed to achieve desired flowability. Dosages of 7, 8.5, and 10 L/m³ of binder were studied.

3.2 Mix Design

The mix design was carried out as per IS 456:2000 (Amendment, 2007). Four mix proportions were prepared with varying water-to-powder (W/P) ratios of 0.35, 0.40, 0.45, and 0.50. All mixes included 15% fly ash replacement. Superplasticizer dosages were adjusted to ensure the self-compactability of the mixes.

3.3. Workability Tests

To assess the workability characteristics of SCC, the following tests were performed as per EFNARC (2005):

1. Slump Flow & T50 for Filling Ability
2. V-Funnel for Flowability and Segregation Resistance
3. L-Box for Passing Ability

Acceptance criteria and test procedures were strictly followed as per EFNARC and related literature. Each mix was evaluated using all three tests to assess filling, passing, and segregation resistance.

3.4. Compressive Strength Testing

Compressive strength tests were conducted in accordance with IS: 516-1959. For each mix, three cubes were tested at 7 and 28 days using a calibrated compression testing machine (CTM). The average compressive strength was calculated and reported. Results deviating more than ±15% from the average were discarded and retested.

3.5. Summary

The entire methodology was structured to ensure a controlled environment for evaluating the influence of varying water/powder ratios and superplasticizer dosages on the workability and strength characteristics of SCC containing fly ash. The adoption of EFNARC workability guidelines and IS compressive strength standards ensured reliability and reproducibility of test results.

4. EXPERIMENTAL SETUP

4.1. Concrete Mix Proportions

Mixture ID	Cement (Kg/Cum)	Fly Ash (Kg/Cum)	Sand (Kg/Cum)	Coarse Aggregate (Kg/Cum)
SCC1	382.5	67.5	800	850
SCC2	425	75	670	870
SCC3	446	79	850	850
SCC4	468	83	850	850

Table I *Mix Proportions*

Water/Powder ratios- 0.35, 0.40, 0.45 and 0.50 L/cum

Super plasticizer Dosages – 7, 8.5 and 10 L/cum of binder

5. RESULTS AND DISCUSSION

5.1. Result Table – Workability and Compressive Strength of SCC Mixes

Mix ID	W/P Ratio	SP Dosage (L/m^3)	Slump Flow (mm)	V-Funnel Time (sec)	L-Box Ratio (H_2/H_1)	7-Day Strength (MPa)	28-Day Strength (MPa)
SCC1	0.50	7.0	695	12.4	0.81	28	38
SCC2	0.40	8.5	725	10.6	0.88	32	43
SCC3	0.45	10.0	755	9.2	0.92	30	42
SCC4	0.35	10.0	715	10.1	0.86	36	48

Table II Result of Workability and Compressive Strength of SCC Mixes

5.2. Summary of Test Results

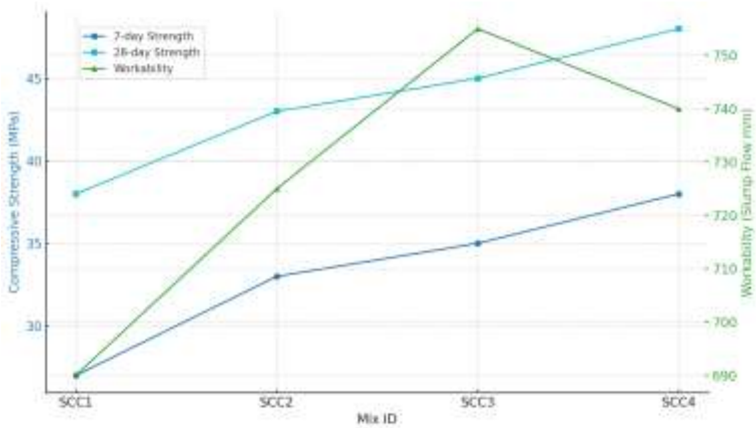

Fig. 1. Comparison of SCC mixes: Workability and Compressive strength

The research evaluated four different Self-Compacting Concrete (SCC) mixes—SCC1, SCC2, SCC3, and SCC4—varying by water/powder ratios and superplasticizer dosages. Key observations from the results:

Compressive Strength:

Strength increased with reduction in water/powder (W/P) ratio.

SCC4 (W/P = 0.35, SP = 10 L/m^3) exhibited the **highest compressive strength** of 48 MPa at 28 days.

SCC2 (W/P = 0.40, SP = 8.5 L/m^3) provided **optimum strength** of 43 MPa, balancing both strength and workability.

Workability

SCC3 (W/P = 0.45, SP = 10 L/m^3) achieved the **highest workability** with a slump flow of 755 mm.

SCC1 (W/P = 0.50, SP = 7 L/m^3) showed the lowest performance in both workability and strength.

6. CONCLUSION

The experimental investigation successfully established the relationship between workability and compressive strength of Self-Compacting Concrete (SCC) incorporating fly ash as a partial replacement of cement (15% by weight). Four mix designs (SCC1 to SCC4) were prepared with varying **water-to-powder (W/P) ratios** and **superplasticizer (SP) dosages**.

- **Workability**: It was observed that workability increased with higher superplasticizer dosages. Among all, **SCC3 (W/P 0.45, SP 10 L/m^3)** achieved the highest workability with a **slump flow of 755 mm**, **V-funnel time of 9.2 sec**, and **L-box ratio of 0.92**, indicating excellent flow and passing ability.
- **Compressive Strength**: The compressive strength was highest for **SCC4 (W/P 0.35, SP 10 L/m^3)** with **28-day strength of 48 MPa**, due to its lower W/P ratio and higher cementitious content. This mix also maintained acceptable workability.
- **Optimum Mix**: **SCC2 (W/P 0.40, SP 8.5 L/m^3)** exhibited a balanced performance, delivering good workability and strength (**28-day strength of 43 MPa**) with efficient use of materials.
- **Relationship**: The study revealed a **nonlinear relationship** between workability and compressive strength. While higher SP dosages improved both parameters up to a limit, excessively high W/P ratios reduced strength despite better workability.

Overall, the results highlight that **optimizing the W/P ratio and SP dosage is essential** to achieving a balance between flowability and strength in SCC. The findings support the feasibility of using SCC with fly ash for high-performance and complex structural applications.

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