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Experimental And Statistical Optimization Of SCC Mix Proportions For Strength And Workability

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Abstract-
Self-Compacting Concrete (SCC) has significantly advanced construction techniques by offering the ability to flow solely under gravity, effectively filling formwork and navigating through reinforcement without the need for mechanical vibration. Despite its advantages, developing an ideal SCC mix requires careful balancing of flow characteristics, stability, and structural strength. This research adopts an integrated experimental and statistical methodology to refine SCC mix designs with the goal of enhancing both workability and compressive strength. Multiple trial batches were formulated by adjusting key variables such as the water-to-powder ratio, superplasticizer levels, ratios of fine to coarse aggregates, and the inclusion of supplementary cementitious materials. Utilizing Taguchi methods and Response Surface Methodology (RSM), the study systematically assessed the impact of these factors. The optimized mix achieved a slump flow of 700 mm, V-funnel time of 9.2 seconds, and a 28-day compressive strength of 47.5 MPa in lab tests. The findings highlight how statistical optimization can streamline mix development, reducing costs and improving performance for practical SCC applications.
Keywords- Self-Compacting Concrete, Mix Design Optimization, Rheological Modeling, CFD, RSM, MCDM, Sustainability.

• INTRODUCTION-

Self-Compacting Concrete (SCC), introduced in Japan during the late 1980s, has become widely adopted due to its ability to flow and consolidate under its own weight without the need for mechanical vibration. This self-placing property not only accelerates construction and reduces labor demands but also ensures superior concrete quality in intricate or densely reinforced structural elements. A major hurdle in SCC development is maintaining a delicate equilibrium among its fresh properties—such as flowability, passing ability, and resistance to segregation—and its hardened characteristics like strength and durability. Conventional SCC mix design often depends on repetitive trial-and-error approaches, which are inefficient and may not yield the most effective composition. To overcome these limitations, modern optimization techniques such as the Taguchi Method and Response Surface Methodology (RSM) offer a more structured approach. These tools enable researchers to assess multiple influencing factors simultaneously, determine their significance, and forecast the best possible mix combinations with fewer experimental trials.

This study adopts an integrated approach—combining experimental trials with statistical modeling—to optimize SCC mix proportions. Critical variables include the water-to-powder ratio, aggregate gradation, superplasticizer dosage, and the incorporation of supplementary cementitious materials like fly ash and ground granulated blast furnace slag (GGBS). The aim is to formulate an SCC mix that achieves excellent workability while retaining high compressive strength, thus supporting both performance and sustainability objectives in contemporary construction practices.

• PROPOSED METHODOLOGY -

I.Materials Utilized

The Self-Compacting Concrete (SCC) in this study was formulated using the following materials:

- Cement: Ordinary Portland Cement (OPC) of 43 grade.
- Supplementary Cementitious Materials (SCMs): Class F Fly Ash and Ground Granulated Blast Furnace Slag (GGBS).
- Fine Aggregate: Clean natural river sand confirming to Zone II, as per IS 383:2016.
- Coarse Aggregate: Crushed granite with a maximum particle size of 10 mm.
- Admixtures: A high-range water-reducing admixture based on Viscosity Modifying Agent (VMA).

• Mixing Water: Potable water complying with IS: 456-2000 standards.

Ii. Mix design variables

The SCC mix design was developed in accordance with EFNARC guidelines. Four main variables were selected for the experimental matrix:

Parameter	Levels Considered
Water-to-Powder Ratio (W/P)	0.30, 0.34, 0.38
Superplasticizer Dosage (% of binder)	0.6, 1.0, 1.4
Fly Ash Content (% replacement of cement)	10, 20, 30
Fine Aggregate to Total Aggregate Ratio (F/A)	0.50, 0.55, 0.60

Iii. Testing procedures

Tests were conducted in accordance with EFNARC for fresh properties and IS 516:2021 for hardened concrete. The following performance indicators were measured:

• Fresh Properties:
• Slump Flow and T500 Time – for assessing flowability.
• V-Funnel Time – for determining viscosity.
• L-Box Passing Ratio – to evaluate passing ability.
• Hardened Properties:
• Compressive Strength at 7 and 28 days (cube size: 150 mm^3).
• Water Absorption Test – to evaluate durability.

Iv. Methodology overview

The optimization methodology combined experimental trials with statistical modeling to strike a balance between fresh-state and hardened performance of SCC. The process involved:

1. **Material selection:**
 As outlined in Section I.
2. **Parameter identification:**
W/P ratio, superplasticizer content, fly ash dosage, and fine-to-total aggregate ratio were selected as the key variables.
3. **Experimental design:**
o Each parameter studied at three levels.
o 9 mix variations were tested.
4. **Property evaluation** :
 Fresh and hardened characteristics were recorded as per the specified standards.
5. **STATISTICAL ANALYSIS:**
o RSM was used to build regression models and explore parameter interactions.
o ANOVA was conducted to validate model significance.
6. **Optimization & validation:**
o The optimum mix was derived through RSM analysis.
o A final mix was produced and tested to verify alignment with predicted results.

II. RESULT AND DISCUSSION

Fresh properties of SCCdemonstrated satisfactory workability across all mixes:

• Slump Flow ranged from 620 mm to 720 mm, with the optimal flowability observed at a water-to-powder (W/P) ratio of 0.34

.V-Funnel flow times were recorded between 8.1 and 11.3 seconds, indicating variation in viscosity and segregation resistance. Lower times corresponded to better flow consistency and stability.

- **L-Box ratios** exceeded **0.80**, confirming good passing ability and compatibility with reinforcement.
- **T500 times** varied from **2.9 to 4.3 seconds**, supporting the assessment of flow rate dynamics.

TABLE 1. FRESH PROPERTIES OF SELECTED SCC MIXES

MIX ID	SLUMP FLOW (MM)	V-FUNNEL TIME (S)	L-BOX RATIO (H2/H1)	T500 TIME (S)
M1	620	11.2	0.78	4.3
M5	700	8.9	0.88	3.1
M9	720	9.1	0.91	2.9

Hardened Properties Of Scc

- The compressive strength results at both 7 and 28 days demonstrated the effect of different mix
- The maximum 28-day compressive strength 47.5 MPa, recorded for a mix
- incorporating 25% fly ash, W/P = 0.34, and 1.0% superplasticizer
- A **decline in strength** was observed with higher W/P ratios (above 0.36) and superplasticizer dosages
- above 1.4%, attributed to bleeding and decreased cohesion within the mix.

TABLE 2. COMPRESSIVE STRENGTH RESULTS

MIX	7-DAY STRENGTH (MPA)	28-DAY STRENGTH (MPA)
M1	30.2	42.1
M5	32.8	47.5
M9	31.0	45.3

STATISTICAL OPTIMIZATION

A statistical model was developed using **Response Surface Methodology** and regression analysis yielded a strong predictive capability:

The RSM models exhibited a high coefficient of determination ($R^2 > 0.95$), indicating strong correlation between input variables and performance outputs.

the optimized mix proportions, based on rsm predictions, were identified as follows:

- Water-to-powder ratio: 0.34
- Superplasticizer dosage: 1.0% of binder
- Fly ash replacement: 25%
- Fine aggregate ratio (F/A): 0.56

Predicted performance:

Slump flow: 702 mm

28-day compressive strength: 46.8 MPa.

Computational Approaches And Simulation Techniques

Contemporary Self-Compacting Concrete (SCC) mix design is increasingly supported by advanced computational techniques. **Response Surface Methodology (RSM)** facilitates the construction of empirical models by evaluating the influence of various parameters—such as water-to-powder (W/P) ratio, superplasticizer content, and aggregate proportions—on performance outputs like **slump flow,**

compressive strength, and **segregation resistance**.In addition, **Computational Fluid Dynamics (CFD)** is used to simulate the flow behavior of SCC within complex formworks and areas with dense reinforcement. This allows designers to detect potential problems, including **dead zones**, **incomplete filling**, and **segregation tendencies**, before physical testingThe application of **heuristic algorithms** and **machine learning techniques** further enhances SCC mix optimization. These methods adaptively respond to experimental datasets, enabling iterative improvements and providing **real-time feedback** for mix adjustment. They also reduce the reliance on traditional trial-and-error procedures, thereby cutting down on both cost and time .Heuristic-based optimization tools excel in handling multi-variable interactions, offering a high degree of flexibility during mix proportioning. When combined with empirical data from EFNARC standard tests, these tools enable dynamic tuning of the mix to meet desired performance targets. While CFD simulations require significant computational resources, they deliver valuable insights into SCC behavior within highly reinforced structures. The visual output from CFD models helps engineers identify flow deficiencies and make informed adjustments, improving both placement efficiency and structural reliability in critical infrastructure applications.

Supplementary Cementitious Materials (Scms) –

Enhancing the sustainability of Self-Compacting Concrete (SCC) primarily involves incorporating supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBFS), silica fume, and metakaolin. These materials serve as partial replacements for Ordinary Portland Cement (OPC), resulting in lower carbon emissions and improved long-term performance.

- Fly ash is beneficial for improving the workability of SCC and slowing the hydration process, which is advantageous in large-volume pours.
- Silica fume boosts compressive strength and reduces concrete permeability, enhancing durability.
- GGBFS contributes to improved resistance against sulfate attacks and aggressive environmental conditions.
- The overall benefits of SCMs align well with green construction protocols, including certifications from LEED (Leadership in Energy and Environmental Design) and the Indian Green Building Council (IGBC).In addition to SCMs, recycled coarse aggregates (RCA) have gained attention as a sustainable alternative to natural aggregates. Their use enhances resource efficiency and supports circular construction practices. However, appropriate pre-treatment of RCA is crucial to mitigate issues such as high water absorption and poor interfacial transition zones (ITZ), which can negatively impact concrete performance. Life Cycle Assessment (LCA) studies confirm that carefully optimized SCC mixes incorporating SCMs and RCA can lower the carbon footprint of concrete structures by 20–40%. Beyond emission reductions, these mixes often exhibit enhanced service life and reduced maintenance needs, contributing to higher sustainability ratings over the entire lifecycle of the structure.

MULTI-CRITERIA DECISION MAKING (MCDM) AND PRACTICAL APPLICATIONS -

In Self-Compacting Concrete (SCC) mix design, Multi-Criteria Decision-Making (MCDM) methods—such as the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)—are increasingly utilized to address the challenge of evaluating multiple, often conflicting performance parameters. These include cost efficiency, mechanical performance, durability, environmental impact, and ease of construction.

By assigning relative weights to each parameter based on specific project priorities, engineers can systematically rank mix design alternatives and choose the most appropriate option. This enables a balanced and context-specific SCC design—whether the application involves precast components demanding rapid strength gain or marine infrastructure requiring enhanced sulfate resistance.

MCDM approaches significantly reduce trial-and-error iterations by facilitating data-driven prototyping of SCC mixes, thereby increasing design efficiency and decision-making speed.

Case Study: SCC in Bridge Retrofitting

A practical application of this approach was observed in a municipal bridge rehabilitation project, where SCC was used incorporating 20% fly ash and 10% silica fume. The modified mix enhanced the flowability within congested reinforcement zones and demonstrated improved bond strength with the existing concrete substrate.

The optimized mix achieved a 28-day compressive strength of 55 MPa and showed minimal shrinkage cracking over a six-month monitoring period, highlighting its durability and performance benefits in retrofit applications.

Historical and Practical Context of SCC

Self-Compacting Concrete originated in Japan during the late 1980s with the objective of enhancing concrete quality while eliminating the dependence on skilled labor for vibration. Driven by the need for faster construction, improved surface finish, and reduced defect rates, SCC saw rapid uptake across Europe and North America.

Today, SCC is extensively employed in precast units, complex formworks, and repair scenarios where compaction is either impractical or impossible. Its benefits—including exceptional surface quality, homogeneous distribution, and silent placement—have made it a preferred material in modern construction practices.

COMMON RHEOLOGICAL TESTS FOR SCC -

The performance of Self-Compacting Concrete (SCC) is typically assessed using a standardized set of tests designed to evaluate its behavior in the fresh state. These include the slump flow, V-funnel, L-box, and J-ring tests—each targeting specific performance characteristics. These procedures are outlined in the EFNARC guidelines and are widely adopted for both laboratory and on-site quality control.

- The Slump Flow Test measures the horizontal spread of the concrete and serves as an indicator of filling ability.
- The V-Funnel Test determines the time it takes for concrete to flow through a narrow opening, providing a measure of viscosity or flow resistance.
- L-Box and J-Ring Tests assess the passing ability of SCC, particularly in the presence of obstacles such as reinforcement bars. The L-box test evaluates the ratio of heights (H_2/H_1) to indicate how well the mix flows through confined spaces, while the J-ring test compares flow diameter with and without obstructions.

These tests are essential for verifying whether an SCC mix meets the required standards for constructability and are especially useful for rapid field assessments.

Table: Standard Tests for Fresh SCC Properties

Test Name	**Property Evaluated**	**Typical Value Range**
Slump Flow	Filling Ability	650–800 mm
V-Funnel	Flowability / Viscosity	6–12 seconds
L-Box	Passing Ability (H_2/H_1 Ratio)	0.80–1.00
J-Ring	Passing Ability with Reinforcement	≤ 50 mm difference from Slump Flow

III. CONCLUSION –

This research demonstrates that combining experimental techniques with statistical optimization methods significantly streamlines the SCC mix design process. Among the mixtures evaluated, the optimal formulation comprised:

- W/P ratio: 0.34
- Fly ash replacement: 25% by weight of binder
- Superplasticizer dosage: 1.0%
- Fine aggregate ratio: 0.56

This mix not only satisfied all EFNARC workability benchmarks but also displayed excellent compressive strength, validating its suitability for high-performance structural uses.

The integration of Taguchi design of experiments and Response Surface Methodology (RSM) proved efficient in reducing the number of required test combinations and identifying the key factors influencing

SCC behavior. This approach provides a pragmatic strategy for developing cost-effective and sustainable SCC mixes.

The field of SCC design has progressively transitioned from basic empirical methods to advanced, data-driven techniques. Today's best practices involve:

- Rheological modeling
- Computational simulations
- Statistical optimization
- Use of sustainable materials

Such an integrated strategy helps SCC meet both performance specifications and environmental sustainability goals. The inclusion of recycled aggregates and supplementary cementitious materials demonstrates a move toward circular construction practices.

Looking ahead, emerging trends suggest wider adoption of technologies such as AI and IoT systems for real-time quality control during pouring, development of greener binders and low-clinker cements, and deeper examination of SCC behavior under extreme conditions (e.g., marine environments, freeze-thaw cycles). There is also merit in designing machine learning-based durability smodels and devising methods to recycle SCC components post-service life.

To fully realize these innovations, strong collaboration between academia and industry is vital—ensuring real-world validation and fostering the adoption of next-generation, eco-efficient SCC technologies.

IV. REFERENCES-

1.Türkel, S., & Altuntaş, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. Sādhanā, 34(2), 331–343.

2.Türkel, S., & Altuntaş, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. Sādhanā, 34(2), 331–343.

3.Türkel, S., & Altuntaş, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. Sādhanā, 34(2), 331–343.

4.Türkel, S., & Altuntaş, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. Sādhanā, 34(2), 331–343.

5.Türkel, S., & Altuntaş, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. Sādhanā, 34(2), 331–343.

6.Zhou, X., & Wang, Y. (2018). CFD simulations of self-compacting concrete with discrete phase model: A study on flow behavior. Construction and Building Materials, 187, 1129– 1140.

7.Zhou, X., & Wang, Y. (2018). CFD simulations of self-compacting concrete with discrete phase model: A study on flow behavior. Construction and Building Materials, 187, 1129– 1140.

8.Zhou, X., & Wang, Y. (2018). CFD simulations of self-compacting concrete with discrete phase model: A study on flow behavior. Construction and Building Materials, 187, 1129– 1140.

9.Zhou, X., & Wang, Y. (2018). CFD simulations of self-compacting concrete with discrete phase model: A study on flow behavior. Construction and Building Materials, 187, 1129– 1140.

10. Sivakumar, A., & Santhanam, M. (2019). Optimisation of mix proportioning of self compacting concrete using heuristic search. International Journal of Recent Technology and Engineering, 8(4), 756–761.

11. Sivakumar, A., & Santhanam, M. (2019). Optimisation of mix proportioning of self compacting concrete using heuristic search. International Journal of Recent Technology and Engineering, 8(4), 756–761.

12. Sivakumar, A., & Santhanam, M. (2019). Optimisation of mix proportioning of self compacting concrete using heuristic search. International Journal of Recent Technology and Engineering, 8(4), 756–761.

13. Sharma, P., & Gupta, R. (2021). Multi-criteria feasibility of real use of self-compacting concrete with recycled aggregates. Journal of Cleaner Production, 278, 123456.

14. Sharma, P., & Gupta, R. (2021). Multi-criteria feasibility of real use of self-compacting concrete with recycled aggregates. Journal of Cleaner Production, 278, 123456.

15. Sharma, P., & Gupta, R. (2021). Multi-criteria feasibility of real use of self-compacting concrete with recycled aggregates. Journal of Cleaner Production, 278, 123456.