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EXPERIMENTAL STUDY OF ENHANCING SELF-COMPACTING CONCRETE PERFORMANCE THROUGH FIBER REINFORCEMENT

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ABSTRACT

The construction industry has evolved to include diverse projects that enhance communities both aesthetically and functionally. Concrete remains the fundamental building material due to its strength, durability, and adaptability. Self-compacting concrete (SCC) can consolidate without external compaction, offering significant construction advantages. Fiber-reinforced concrete (FRC) improves structural integrity by incorporating fibres. This thesis examines the impact of fibre inclusion on SCC's flowability, workability, and compressive strength.

The study formulates SCC blends without fibres and then introduces steel and glass fibres at varying concentrations. Flowability and workability are measured using slump and V-funnel tests, while compressive strength is assessed through compression tests. The methodology includes a literature review, SCC mix formulation, flow and strength testing, and result analysis. Findings show that fibre addition reduces slump values and increases T50 times, indicating decreased flowability and workability. Fiber-reinforced SCC demonstrates notable early-age strength development, with steel fibres showing superior strength gains compared to glass fibres. The 0.5% steel fibre SCC achieves the highest strength after 28 days of curing, highlighting the importance of optimizing fibre content.

In conclusion, fibre-reinforced SCC enhances compressive strength and structural integrity, with fibre concentration playing a critical role in achieving desired characteristics. This research highlights the benefits of fibre reinforcement in SCC for diverse structural applications.

Keywords: Self-compacting concrete, Fiber reinforced concrete, Steel fibers, Glass fibers, Concrete slump test, V-funnel test, Compression test.

1. INTRODUCTION

1.1 GENERAL

The construction industry has evolved beyond merely erecting massive towers, encompassing a wide array of structures from towering skyscrapers to intricate road networks that connect communities. These projects not only serve functional purposes but also enhance the visual and cultural landscape of our surroundings. Concrete, celebrated for its unparalleled strength, durability, and versatility, remains the cornerstone of construction. Composed of cement, fine aggregate (usually sand), coarse aggregate, and water, concrete undergoes a transformative hardening process, resulting in a robust material that allows architects and builders to create enduring and aesthetically pleasing structures.

1.1.1 Composition of Concrete

Concrete's composition includes:

- Cement: A grey binding agent essential for cohesion and adhesion of materials. Upon contact with water, cement initiates a setting and hardening process, imparting structural integrity.

- Water: Facilitates the chemical reaction with cement, forming a cohesive paste that binds aggregates, crucial for achieving the desired concrete consistency and properties.

- Aggregates: Comprising coarse (larger than 4.75mm) and fine (smaller than 4.75mm) particles, aggregates add bulk and compressive strength to concrete. They must be clean, hard, and free from substances that could compromise the mix.

- Admixtures: Additives that enhance properties such as setting time, workability, and resistance to environmental conditions.

Fig.: Cement and Aggregates

1.1.2 Types of Concrete

The construction industry uses various types of concrete to meet specific needs:

- Plain Cement Concrete (PCC): A simple, durable mix of cement, water, and aggregates used in a wide range of projects.

- Reinforced Cement Concrete (RCC): Includes reinforcement bars to enhance tensile strength and prevent cracking.

- Prestressed Concrete: Uses tensioned elements to improve load-bearing capacity.

- Lightweight Concrete: Made with lightweight aggregates for reduced density and improved thermal insulation.

- High-Density Concrete: Uses heavy aggregates for applications requiring radiation shielding.

- Ready-Mix Concrete: Pre-mixed at a plant and transported to the site, offering high precision and convenience.

- Self-Compacting Concrete (SCC): Flows and consolidates under its own weight, ideal for complex formworks.

- Fiber-Reinforced Concrete (FRC): Incorporates fibres to improve crack resistance and durability.

1.2 SELF-COMPACTING CONCRETE

Self-compacting concrete (SCC) addresses the challenges of densely packed formworks and complex reinforcement by flowing and consolidating without external vibration. Originating in Japan in the 1980s, SCC, developed by Professor H. Okamura, ensures uniformity and fills formwork through its own weight, enhancing construction efficiency and structural integrity.

1.2.1 Materials Used

Key components of SCC include:

- Cement: Ordinary Portland cement (43-grade or 53-grade).

- Aggregates: Typically, up to 20mm in size, with smaller sizes used in densely reinforced structures.

- Water: Adheres to quality standards used in reinforced and prestressed concrete.

- Mineral Admixtures: Such as silica fume and fly ash, improve fresh and hardened properties.

- Chemical Admixtures: Superplasticizers enhance flow-ability, while air-entraining agents and retarders improve durability and workability.

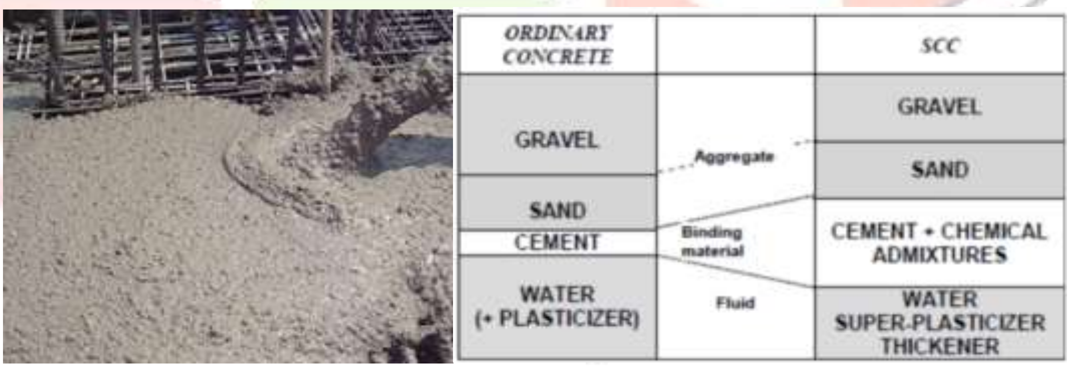


Fig.: Self-compacting concrete and their composition

1.2.2 Description of Self-Compacted Concrete

SCC's success hinges on its filling ability, passing ability, and segregation resistance. Achieving these properties requires a precise mix design to balance fluidity and stability. SCC's high flow properties enable it to fill complex and heavily reinforced sections without segregation, offering advantages such as enhanced strength, rapid placement, and superior finishes.

1.3 FIBER-REINFORCED CONCRETE

Fiber-reinforced concrete (FRC) integrates fibrous materials to enhance structural integrity. Fibers, such as steel, glass, synthetic, and natural types, are uniformly distributed to improve impact resistance and reduce permeability. FRC's properties depend on factors like fibre type, geometry, and distribution.

Fig.: Fiber reinforced concrete

1.3.1 Types of Fiber-Reinforced Concrete

Various fibres used in FRC include:

- Steel Fibers: Enhance crack resistance and structural reinforcement.

- Polypropylene Fibers: Improve toughness and impact strength.

- Glass Fibers: Offer high tensile strength and durability.

- Polyester Fibers: Used in industrial applications for enhanced crack resistance.

- Carbon Fibers: Provide high stiffness and tensile strength.

- Macro and Micro Synthetic Fibers: Substitute for steel fibres in corrosion-prone environments and improve crack resistance.

- Natural Fibers: Locally available and used historically for reinforcement.

- Cellulose Fibers: Derived from plant materials, offering similar benefits to engineered fibres.

1.4 OBJECTIVE

This study aims to enhance concrete durability and strength by incorporating high-strength fibres. Objectives include:

- Formulating SCC blends without fibres, then adding steel (0.3% and 0.5%) and glass fibres (0.3% and 0.5%).

- Assessing flowability and workability using slump and V-funnel tests.

- Measuring compressive strength with and without fibres.

- Investigating the impact of fibre inclusion on SCC's properties.

This research seeks to improve concrete strength with high-strength fibres and evaluate the resulting structural characteristics using traditional testing methods.

2. Literature Review

To ensure the thoroughness of this study, a comprehensive review of previous research on the effects of SCC, additives, and fibres is essential. This chapter summarizes findings on SCC, mineral and chemical additives, fibre-reinforced concrete (FRC), and hollow compression members under axial loads.

Ahmad, S., et al. (2017) This study compares the properties of normal concrete (NC) and self-compacting concrete (SCC), examining the influence of glass fibres. Findings show that glass fibres slightly reduce SCC's workability but enhance splitting tensile strength and modulus of rupture.

Akcay, B., & Tasdemir, M. A. (2012) Investigates hybrid steel fibre-reinforced SCC (HSFRSCC), focusing on workability, fibre dispersion, and mechanical properties. Results indicate reduced workability and improved toughness and ductility with high-strength, long steel fibres.

Alsubari, B., et al. (2018) Explores palm oil fuel ash (POFA) as a cement substitute in SCC. The study shows that while early compressive strength decreases with higher POFA content, extended curing significantly improves strength and durability.

Aslani, F., et al. (2018) Develops self-compacting rubberized concrete (SCRC) using waste rubber aggregates. Findings indicate that SCRC exhibits promising properties, with potential for improved performance and sustainability in concrete production.

Aslani, F., & Samali, B. (2014) Examines the flexural toughness of fibre-reinforced SCC (FRSCC). Results show that steel fibre-reinforced SCC has superior toughness, highlighting the effectiveness of steel fibres in enhancing SCC's mechanical properties.

Asteris, P. G., et al. (2016) Applies artificial neural networks (ANNs) to predict SCC's compressive strength. The study concludes that ANNs, particularly multi-layer feed-forward networks, offer accurate and efficient predictions of SCC properties.

Beigi, M.H., et al. (2013) Assesses the impact of nanosilica and various fibres on SCC. Results indicate that the optimal combination of nanosilica and fibres enhances SCC's mechanical properties and durability but adversely affects its rheology.

Campos, R. S., et al. (2018) Analyses the impact of recycled aggregates on SCC. Despite reduced fluidity, mechanical properties remain comparable to natural aggregates, suggesting viable use of recycled aggregates in SCC within certain replacement ratios.

Carro-López, D., et al. (2017) Investigates the use of recycled sand in SCC. Findings show that up to 20% substitution maintains workability and mechanical performance, while higher ratios significantly reduce these properties.

Carro-López, D., et al. (2015) Explores the rheological behaviour of SCC with recycled sand. Results indicate that higher replacement ratios compromise workability and compressive strength, with 20% being the most feasible substitution level.

Corinaldesi, V., & Moriconi, G. (2004) Prepares SCC for thin precast elements using steel fibres. The study finds that fibres improve drying shrinkage resistance and durability, making SCC suitable for non-structural applications.

Djelal, C., et al. (2004) Develops a tribometer to measure friction between SCC and metal surfaces. The study emphasizes understanding friction mechanisms to optimize SCC placement and formwork pressure.

González-Taboada, I., et al. (2017) Examines SCRC with varying recycled aggregate content. Rheological tests show that adding extra water compensates for recycled aggregate absorption, maintaining self-compacting behaviour up to 45 minutes.

González-Taboada, I., et al. (2017) Studies the workability and rheology of SCRC. Results suggest that empirical limits for SCC apply to SCRC, with adjustments needed for higher recycled aggregate content.

Mansoor, J., et al. (2018) Utilizes industrial by-products as partial cement replacements in SCC. ANN analysis shows that silica fume optimally enhances mechanical properties, promoting sustainable construction practices.

Pajak, M., et al. (2019) Inspects the impact of hybrid fibres on SCC under various strain rates. Findings reveal minimal influence on compressive strength under static conditions, but reduced strain rate sensitivity under dynamic loading.

Siddique, R., et al. (2011) Compares ANN models for predicting SCC compressive strength. Results show that models incorporating bottom ash data outperform others, emphasizing the significance of input parameters.

Iqbal, S., et al. (2015) Investigates micro steel fibre content in SHLSCC. Findings indicate improved tensile and flexural strengths with higher fibre content, while workability and compressive strength slightly decline.

Umar, A., et al. (2016) Compares the effects of glass and PVA fibres on SCC. Results show that PVA fibres more significantly improve hardened properties, despite slightly reducing workability.

Yaman, M. A., et al. (2017) Compares two ANN methodologies for predicting SCC mix ingredients. Results indicate that multiple single-output ANNs outperform multi-output models, enhancing prediction accuracy and mix proportioning efficiency.

Literature Gap

- **Focus of Current Research**: Primarily on reinforcing concrete with steel and glass fibres.
- **Evaluation Method**: Predominantly through compression tests.
- **Gap in Studies**: Limited research on compression tests for steel and glass fibres in self-compacting concrete (SCC).
- **Issue with SCC**:
  - Often suffers from inadequate compaction.
  - Results in reduced compressive strength.
- **Proposed Solution**:
  - Enhance strength through high-strength fibres (e.g., steel and glass).
  - Improve structural integrity and durability by incorporating these fibres.
  - Address challenges related to compaction and strength in SCC.

3. Methodology

This study involves an experimental investigation of self-compacting concrete (SCC) using destructive testing methods. It focuses on evaluating the effects of steel and glass fibres on the performance of SCC. The findings are intended to provide insights into the effectiveness of fibre reinforcement in enhancing SCC properties, informing future construction and material engineering practices.

Methodology Steps:

1. **Literature Review**:
   - Conducted an extensive review of existing research on SCC.
   - Identified gaps in current studies.
2. **Preparation of SCC Mixes**:
   - Prepared various SCC mixes, including:
     - Control mix without fibres.
     - Mixes with 0.3% and 0.5% steel fibres.
     - Mixes with 0.3% and 0.5% glass fibres.
   - Used materials and proportions adhering to M20 grade specifications.

3. **Assessment of Flow Characteristics and Workability**:
   - Conducted concrete slump test to measure consistency.
   - Conducted V-funnel flow test to assess flow rate and workability.
4. **Molding and Curing of Specimens**:
   - Formed cube specimens (150mm × 150mm × 150mm).
   - Cured the cubes in a humid environment for 24 hours.
   - Submerged cubes in clean fresh water until testing.
5. **Compressive Strength Testing**:
   - Performed tests on specimens at intervals of 3, 7, and 28 days.
   - Applied load gradually using a compression testing machine.
   - Recorded the load at failure and calculated compressive strength.
6. **Analysis and Discussion**:
   - Analysed test results to evaluate the impact of fibre reinforcement.
   - Discussed findings in relation to the structural integrity and durability of SCC.
7. **Conclusions**:
   - Drew conclusions based on the analysis of test results.
   - Highlighted the benefits of incorporating high-strength fibres in SCC.

Specific Tests and Procedures:

- **Concrete Slump Test**:
  - Gathered necessary equipment (slump cone, base plate, tamping rod, measuring tape).
  - Moistened and positioned the slump cone, filled it with concrete, and measured slump after cone removal.
- **V-Funnel Flow Test**:
  - Prepared 12 litters of concrete, moistened the V-funnel, and filled it.
  - Measured flow time immediately after opening the trap door and again after 5 minutes.
- **Compressive Strength Test**:
  - Prepared specimens by mixing cement and aggregates, poured into moulds, and cured.
  - Tested specimens by applying load in a compression testing machine until failure.
  - Calculated compressive strength from the load at failure divided by the cross-sectional area.

Fig.: V- Funnel Test Equipment and SCC

Fig.: Casting Cubes and Curing

Fig.: Testing of Cubes and Cracks

Results and Discussion

General Overview

This chapter presents a detailed analysis of the compressive strength of five different SCC mixtures: one without fibers, two with 0.3% and 0.5% steel fibers, and two with 0.3% and 0.5% glass fibers. The goal is to assess how different types and concentrations of fibers influence the compressive strength and workability of SCC.

Slump Tests

The slump test measures the final flow diameter of the concrete, indicating its workability and consistency. A minimum slump value of 650 mm is required for adequate flowability in SCC. The results are as follows:

- **No Fiber**: Slump value 685 mm, T50 time 3.5 sec.
- **0.3% Steel Fiber**: Slump value 676 mm, T50 time 3.9 sec.
- **0.5% Steel Fiber**: Slump value 670 mm, T50 time 4.1 sec.
- **0.3% Glass Fiber**: Slump value 674 mm, T50 time 4.0 sec.
- **0.5% Glass Fiber**: Slump value 667 mm, T50 time 4.2 sec.

The addition of fibers decreases slump values and increases T50 times, indicating reduced flowability and enhanced stability.

V-Funnel Flow Tests

This test evaluates the flowability of SCC, with shorter times indicating higher flowability. Suitable ranges are 6-12 sec for T0 and 6-15 sec for T5. The results show:

- **No Fiber**: T0 8.7 sec, T5 10.0 sec, T5-T0 1.3 sec.
- **0.3% Steel Fiber**: T0 9.8 sec, T5 11.3 sec, T5-T0 1.5 sec.
- **0.5% Steel Fiber**: T0 10.5 sec, T5 12.1 sec, T5-T0 1.6 sec.
- **0.3% Glass Fiber**: T0 10.2 sec, T5 11.8 sec, T5-T0 1.6 sec.
- **0.5% Glass Fiber**: T0 10.9 sec, T5 12.6 sec, T5-T0 1.7 sec.

The addition of fibers increases T0 and T5 times, indicating improved stability but reduced flowability.

Compression Test Results

Without Fiber:

- 3 days: 10.13 N/mm²
- 7 days: 14.53 N/mm²
- 28 days: 21.33 N/mm²

0.3% Steel Fiber:

- 3 days: 12.57 N/mm²
- 7 days: 15.24 N/mm²
- 28 days: 23.24 N/mm²

0.5% Steel Fiber:

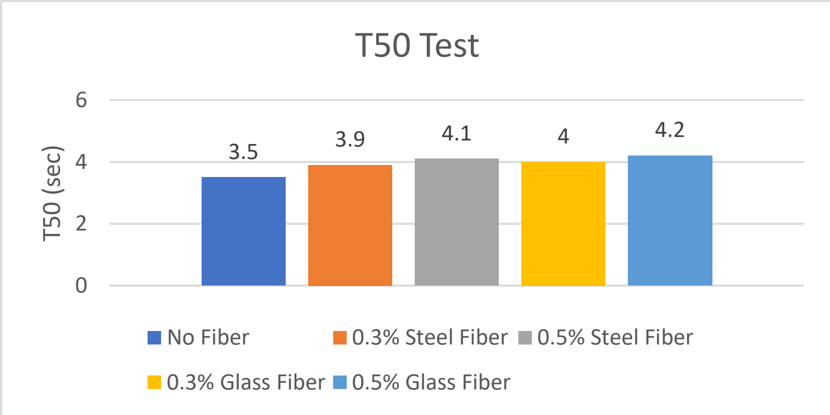
- 3 days: 13.33 N/mm²
- 7 days: 16.57 N/mm²
- 28 days: 24.31 N/mm²

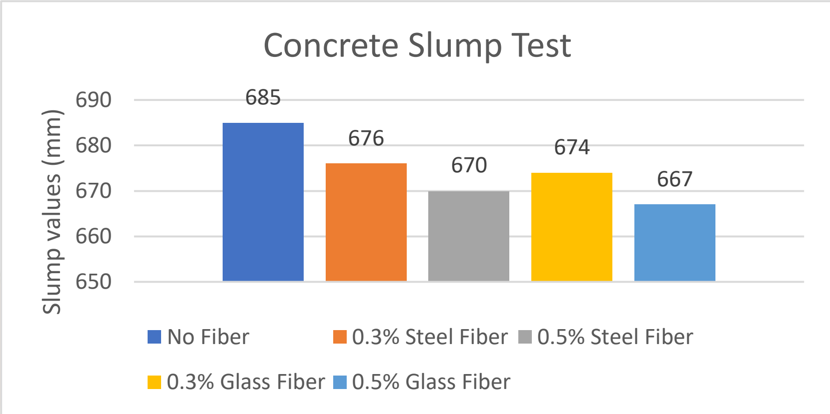
0.3% Glass Fiber:

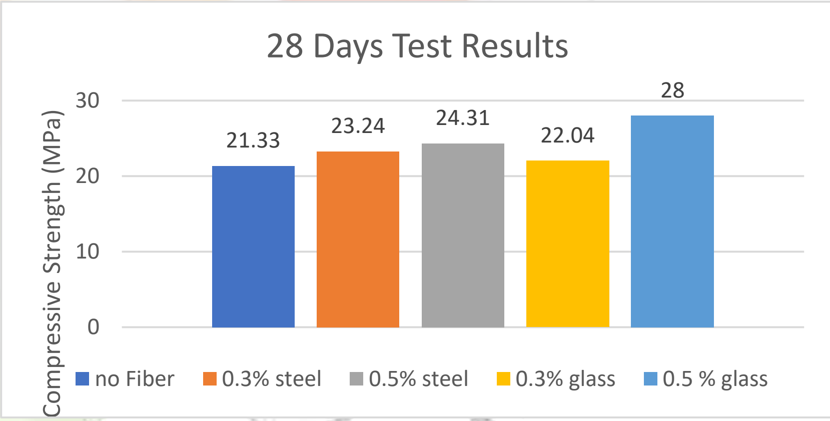
- 3 days: 8.35 N/mm²
- 7 days: 12.35 N/mm²
- 28 days: 22.04 N/mm²

0.5% Glass Fiber:

- 3 days: 10.08 N/mm²
- 7 days: 16.4 N/mm²
- 28 days: 28.00 N/mm²







Analysis

3-Day Results: 0.5% steel fiber SCC exhibits the highest strength; 0.3% glass fiber SCC the lowest.

7-Day Results: Similar to 3-day results.

28-Day Results: 0.5% glass fiber SCC shows the highest strength; fiber-less SCC the lowest.

These findings demonstrate that fibre addition, particularly steel and higher concentrations, significantly improves early and long-term compressive strength of SCC. Fiber type and concentration are crucial in optimizing SCC formulations for desired performance.

5. Conclusion

This research analyses SCC samples with and without fibres, focusing on steel and glass fibres' impact on compressive strength, workability, and flowability. Key findings are:

- **Workability and Flowability**:
  - Addition of fibres reduces slump flow values, indicating improved stability but reduced flowability.
  - Both steel and glass fibres increase T50 time, enhancing segregation resistance and stability.

- **Setting Time**:
  - Fibres significantly increase initial setting time (T0), indicating better early strength development.
  - Disparity between T0 and T5 values grows with fibre addition, showing enhanced early setting, especially with higher fibre content.
- **Compressive Strength**:
  - SCC with 0.3% and 0.5% steel fibres show significant early-age strength gains, with 0.5% concentration slightly outperforming 0.3%.
  - Glass fibres also improve strength but less than steel fibres in early stages. After 28 days, 0.5% glass fibre SCC shows the best performance.
  - All fibre-reinforced SCC mixtures exhibit notable early-age strength development, with significant gains at three and seven days.
  - At 28 days, 0.5% steel fibre SCC demonstrates the highest strength, followed by 0.5% glass fibre SCC. The 0.3% steel fibre SCC shows moderate strength, while 0.3% glass fibre SCC has the lowest ultimate strengths.
- **Overall Performance**:
  - Fibre-reinforced SCC demonstrates superior strength after 28 days compared to fibre-less SCC, indicating enhanced structural integrity and resistance.
  - The choice of fibre type and concentration should be based on project-specific strength and performance requirements.

In summary, incorporating steel or glass fibres into SCC formulations effectively enhances compressive strength, with steel fibres generally providing higher gains. Optimizing fibre content is crucial to achieving the desired strength characteristics, making fibre-reinforced SCC a valuable option for applications requiring high strength and durability.

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