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SELF-COMPACTING CONCRETE USING ULTRAFINE NATURAL STEATITE POWDER REPLACEMENT OF CEMENT

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Abstract
An experimental investigation was conducted to study the flow properties and compressive strength of self-compacting concrete (SCC) incorporating ultrafine natural steatite powder (UFNSP) as a partial replacement for cement. Specimens were prepared with UFNSP replacing cement at 5%, 10%, 15%, 20%, and 25% by weight, and their performance was compared with control specimens. The flow properties of all specimens were tested and evaluated against existing guidelines. Compressive strength tests were performed at 7, 14, 28, and 56 days. Hardened samples were analyzed for their microstructural behavior, and elemental mapping of Mg, Ca, and Si was performed. The formation of magnesium silicate hydrate (M-S-H) along with calcium silicate hydrate (C-S-H) was observed through microstructural analysis. Results indicate that UFNSP addition reduces the flow properties but improves compressive strength up to 20% replacement. Further, UFNSP increases the microstructural denseness of the specimens, leading to enhanced strength.

Keywords: Self-compacting concrete, Ultrafine natural steatite powder, Flow properties, Silica fume, Fly ash

1. Introduction

Self-compacting concrete (SCC), also referred to as self-consolidating concrete, has been a focal point in the construction industry over the past two decades. SCC is a type of concrete that can flow and compact itself into every corner of formwork solely under its self-weight, eliminating the need for external vibration. Cement mortars containing steatite particles have been studied for applications in sculpture restoration and electrotechnics. The stabilization of protoenstatite in the steatite body is achievable through the development of small crystals. However, improper selection of parameters can lead to undesired outcomes, such as separation of the powder-binder mixture, collapses, and cracks in the structure of molded parts.

The main objective of this study is to investigate the properties of SCC, focusing on strength and durability through various test methods, including its application in reinforced concrete (RC) slab elements. The SCC mix design corresponds to an M70 grade of concrete, which is especially suited for heavily reinforced sections where high reinforcement congestion poses challenges for proper compaction. Such scenarios often result in honeycombing due to incomplete compaction. SCC

Volume 13, Issue 3 | May 2023 Pages 13-25

addresses these issues by flowing into every corner of the formwork and around steel reinforcements purely by its own weight, eliminating the need for mechanical vibration.

In this project, UFNSP is utilized as a partial replacement for cement to enhance the properties of SCC. UFNSP, along with materials such as red mud and foundry waste, offers potential benefits as these materials are abundant solid waste byproducts. Their incorporation into concrete aligns with sustainable construction practices. While extensive research on SCC has been conducted globally, limited work has been reported from India, where SCC holds significant promise due to the scarcity of skilled labor and the limited mechanization of the construction industry.

This study aims to bridge this gap by evaluating the performance of SCC with UFNSP and advancing its application in modern construction.

Therefore, it can be said that SCC is still relatively unfamiliar to many researchers, builders, ready-mix concrete producers, and academics. Self-compacting concrete is essentially a concrete that flows into formwork without segregation, uniformly filling every corner solely by its own weight, without the need for vibration or other external energy during placement. Since there is no standard SCC, each mix must be tailored to the specific structure being constructed. Due to its superior flowability and resistance to segregation, SCC can be designed for nearly any type of concrete structure.

In the present research, the effect of ultrafine natural steatite powder (UFNSP) on the setting time and strength development of cement was investigated. The experimental study was further supported by scanning electron microscope (SEM) analysis. As the replacement level increased, micro-cracks were arrested, resulting in an improved microstructure with minimal voids. The SEM images also revealed the formation of magnesium silicate hydrate (M-S-H) gels, which contributed significantly to the enhancement of durability properties.

2. Literature Review

Self-Compacting Concrete Using Steatite Powder

The use of steatite powder as a partial replacement for cement in SCC has been the focus of numerous studies. Below are some key works:

1. **"Behaviour of Concrete Partially Replacing Cement with Steatite and Polypropylene Fiber"**
   Dr. T. Bhagavathi Pushpa and S. Rajesh Kumar (2016)
   The study highlighted the growing interest in fiber-reinforced composites for concrete reinforcement. The incorporation of polypropylene fibers showed significant improvement in tensile properties, reduced shrinkage, and minimized cracks. Steatite powder was used as a partial cement replacement (30%, 25%, 20%, and 15%), combined with 0.5% polypropylene fiber by weight of concrete. Ordinary Portland Cement (OPC) of 53 grade was used, and M30 grade concrete was tested for compressive, tensile, and pozzolanic properties over curing periods of 7, 14, and 28 days. Results were compared with conventional concrete, showing notable strength improvements.
2. **"Mechanical Properties of Self-Compacting Concrete Containing Silica Fume and Steatite**

Volume 13, Issue 3 | May 2023 Pages 13-25

Powder"
Padmanapam and N. Sakthieswaren (2015)
This study investigated the mechanical properties of SCC made with silica fume and natural steatite powder as cement replacements. M30 grade SCC was prepared using the Nansu method with 0–15% steatite powder by weight of cement and 1.8% conplast 430 as a superplasticizer. Compressive strength, split tensile strength, and flexural strength were evaluated. The research demonstrated that steatite powder significantly enhanced the mechanical properties of SCC, especially in high-performance applications.

3. **"Properties of Green Concrete Containing Quarry Rock Dust and Marble Sludge Powder as Fine Aggregate"**
   M. Shahul Hameed and A. S. S. Sekar (2009)
   This study explored the use of industrial waste materials, such as marble sludge powder and quarry rock dust, as fine aggregates in green concrete. These materials not only reduced the consumption of natural resources but also enhanced concrete durability. Marble sludge powder acted as a filler, reducing voids, while quarry rock dust met the desired grading and fineness. Durability studies showed that concrete made with quarry rock dust exhibited 14% higher compressive and tensile strength than conventional concrete. Additionally, resistance to sulfate attack was greatly improved, showcasing green concrete as a sustainable and durable construction material.
4. **"Self-Compaction High Performance Green Concrete for Sustainable Development"**
   M. Shahul Hameed and A. S. S. Sekar (2010)
   Self-Compacting Concrete (SCC), as the name implies, requires little to no vibration to fill the formwork uniformly. SCC is characterized by two primary properties: its ability to flow and deform under its own weight, and its capacity to remain homogeneous while adjusting the use of environmental resources. The development of sustainable industrial growth will influence the cement and concrete industry, which has significant environmental impacts due to its high energy consumption and resource use. The concept of "green concrete" is crucial for enabling global infrastructure growth while minimizing environmental harm. This study discusses the potential environmental benefits of using green concrete, as it can reduce the environmental costs of concrete production through advancements in concrete technology. The research emphasizes the fresh properties and basic strength characteristics, such as compressive strength and splitting tensile strength, of SCC when incorporating crusher rock and marble slurry dusts.
5. **"Development of Self-Compacting Concrete"**
   L V A Seshasayi et al., 33rd Conference on Our World in Concrete & Structures, Singapore, 2008
   This paper outlines the history of SCC, from its origins in Japan in the late 1980s to its widespread development across Europe. Initially developed for underwater concretes requiring additional cohesiveness, SCC became a major innovation in concrete technology. The paper discusses the challenges faced in the UK and Europe, such as the lack of experience and the

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN
Volume 13, Issue 3 | May 2023 Pages 13-25

absence of published guidance, codes, and specifications. Despite these challenges, the paper highlights the growing use and potential of SCC for concrete construction worldwide.

6. **"Experimental Methods on Glass Fiber Reinforced Self-Compacting Concrete"**
   Deepak Raj A et al., IOSR Journal of Mechanical and Civil Engineering, 2012
   This study investigates the workability and mechanical properties of plain SCC and Glass Fiber Reinforced SCC (GFRSCC). Various laboratory tests were conducted, including slump flow, L-box, sieve segregation resistance, density, ultrasonic pulse velocity, compressive strength, splitting tensile strength, and flexural strength. The results indicated that the addition of glass fibers (up to 1% by volume) did not negatively affect the filling ability, passing ability, or segregation resistance of SCC. The addition of glass fibers helped enhance the mechanical properties of the concrete, making it a suitable choice for applications requiring higher durability and strength.
7. **"Effect of Polypropylene Fibers on Fresh and Hardened Properties of SCC at Elevated Temperatures"**
   Arabic Nawwaf Saoud AL Qudi et al., Australian Journal of Basic and Applied Sciences, 2012
   This research presents an experimental study on the optimal amount of Polypropylene (PP) fibers to be used in SCC to prevent spalling when exposed to elevated temperatures. The study focused on the fresh and hardened properties of SCC at high temperatures, showing that incorporating the right amount of PP fibers can improve the thermal resistance and prevent cracking, making SCC a viable option for fire-resistant concrete applications.
8. **"Rapid Chloride Permeability Test on Self-Compacting High Performance Green Concrete"**
   M. Shahul Hameed, V. Saraswathi, and A. S. S. Sekar, 2011
   SCC has been a significant advancement in concrete technology, developed to ensure adequate compaction and facilitate placement in areas with congested reinforcement. This paper investigates the combined effects of Marble Sludge Powder (MSP) and Crusher Rock Dust (CRD) on the durability of Self-Compacting High Performance Green Concrete (SCHPGC). The study focuses on chloride permeability, a critical factor affecting the durability of concrete. The results showed that the use of MSP and CRD not only reduced the total void content but also enhanced the concrete's resistance to chloride penetration, thereby improving its durability and making it suitable for use in aggressive environments.

Properties of Self-Compacting Concrete (SCC)

1. **Glass Fibers in SCC:**
   Studies have shown that the addition of glass fibers, up to a maximum of 1% by volume, does not adversely affect the filling ability, passing ability, or segregation resistance of SCC. This makes glass fiber a viable reinforcement material for SCC without compromising its workability or flow characteristics (*Deepak Raj A et al., IOSR Journal of Mechanical and Civil Engineering* [6]).
2. **Polypropylene Fibers in SCC:**

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN
Volume 13, Issue 3 | May 2023 Pages 13-25

Research on polypropylene (PP) fibers in SCC has demonstrated their effectiveness in preventing spalling at elevated temperatures. The optimal amount of PP fibers improves thermal resistance without compromising the fresh or hardened properties of SCC (*Arabic Nawwaf Saoud AL Qudi et al., Australian Journal of Basic and Applied Science, 2012* [7]).

3. **Durability with Marble Sludge Powder and Crusher Rock Dust:**
   The use of Marble Sludge Powder (MSP) and Crusher Rock Dust (CRD) as fillers reduces void content in SCC, enhances compressive strength, and improves resistance to chloride permeability. This combination significantly contributes to the durability of Self-Compacting High-Performance Green Concrete (SCHPGC) (*M. Shahul Hameed et al., 2011* [8]).

3. Design Methodology

The primary objective of this project is to investigate the properties of self-compacting concrete (SCC), specifically focusing on its strength and durability, using various test methods. The study also explores the application of SCC in reinforced concrete (RC) slab elements.

Mix Design for SCC

The mix design corresponds to M70 grade concrete, which is specifically suited for heavily reinforced sections where traditional compaction methods fail due to high reinforcement congestion. SCC, with its ability to flow into every corner of the formwork and fill gaps between steel reinforcements under its own weight, addresses issues like honeycombing and incomplete compaction.

Use of Alternative Materials

This project incorporates red mud and foundry waste as partial replacements for cement. These materials, being solid industrial wastes, align with sustainable construction practices by reducing environmental impact and waste disposal issues.

Challenges Addressed by SCC

- **Congested Reinforcement:** SCC overcomes the limitations of traditional concrete in heavily reinforced structures by eliminating the need for external vibration.
- **Workability and Strength:** The replacement materials improve the workability and strength of SCC while promoting eco-friendly construction practices.

Scope in India

Despite the potential of SCC, limited research has been conducted in India, where the future of concrete is promising. Challenges like the scarcity of skilled manpower and the lack of mechanization in the construction industry make SCC an ideal solution for addressing these gaps and advancing sustainable infrastructure development.

This study aims to bridge these gaps by evaluating SCC's properties and its potential for modern construction, especially in the Indian context.

4. Materials and Experiment

To produce self-compacting concrete (SCC), a trial-and-error approach based on European guidelines

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN

Volume 13, Issue 3 | May 2023 Pages 13-25

(EFNARC) was employed. The initial trials yielded unsatisfactory results; however, by the fourth trial, SCC was successfully produced, and appropriate mix proportions were established. The control SCC mix contained a total cement content of 525 kg/m³, with a final mix ratio of 1:1.8:1.9 and a water-powder ratio of 0.46.

For the experimental specimens, fly ash replaced cement at levels of 10% and 20%. Additionally, ultrafine natural steatite powder (UFNSP) was incorporated in varying percentages (0%, 5%, 10%, 15%, 20%, and 25% by the weight of cement). Compressive strength tests were conducted on hardened cubes measuring 150 mm × 150 mm × 150 mm, conforming to IS 10086:1982 standards. The testing followed the guidelines of IS 516:1959 (reaffirmed 2004) using a 2000 kN hydraulic compression testing machine.

Microstructural analysis was performed using scanning electron microscopy (SEM). Samples for SEM analysis were taken near the surface (0–1 mm depth) and prepared as 10 mm cubes, coated with evaporated copper. The SEM (ZEISS) was equipped with an EDAX analyzer for elemental observations. The analysis was conducted at a maximum magnification of 1000x with energy settings of 20 keV and a high resolution of 3.5 nm.

5. Production of SCC

The production process for SCC followed a systematic batching and mixing sequence to ensure homogeneity and consistency:

1. **Preparation of Materials:**
   - All materials were prepared and stored in the laboratory a day before casting.
   - Fine aggregates were tested for moisture content, and adjustments were made to the water-powder ratio to account for variations.
2. **Temperature Control:**
   - Concrete mixing was carried out in the early morning to minimize temperature effects.
3. **Mixing Sequence and Duration:**
   Based on the recommendations of Khayat et al., the following mixing sequence was adopted:
   - Aggregates were mixed in a pan mixer for 0.5 minutes.
   - 50% of the water content was added and mixed for 1 minute.
   - The mix was left undisturbed for 1 minute to allow aggregates to absorb water.
   - Powder content was added and mixed for 1 minute.
   - The remaining 50% of water, along with superplasticizer and viscosity-modifying agents, was added and mixed for 3 minutes.
   - The mix was left undisturbed for 2 minutes, followed by a final mixing for 2 minutes.

This procedure produced a highly workable mix with no bleeding or segregation. The cement paste blended effectively with the coarse aggregate, resulting in a homogeneous SCC mix.

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN
Volume 13, Issue 3 | May 2023 Pages 13-25

6. Sampling

Standard steel molds were used to cast test specimens for the durability study. For each test, three samples per mix were prepared, cured, and tested, with the average value of the three specimens recorded.

- **Cube Specimens:**
  - Size: 100 mm × 100 mm
  - Used for sorptivity and water absorption tests.
- **Disk Specimens:**
  - Diameter: 100 mm
  - Height: 50 mm
  - Used for rapid chloride penetration tests.
- **Cylindrical Specimens:**
  - Height: 200 mm
  - Diameter: 100 mm
  - Used for bulk diffusion tests.

Fig 1 Preparation of specimen Tester

Fig 2 Steatite Powder

Fig 3 Steatite Powder flow

Manufacturing of Recycled Concrete Blocks

Material Properties

- Specific Gravity of Cement: 3.14
- Specific Gravity of Fine Aggregate: 2.64
- Specific Gravity of Coarse Aggregate: 2.74

Manufacturing Process

The manufacturing of recycled concrete blocks involved the following steps, adhering to the practices of professional concrete block producers:

1. **Compaction:**
   - The prepared mixture was subjected to a mechanical compaction machine to enhance its load-bearing capacity and improve aesthetics.
2. **Initial Setting:**
   - The newly compacted blocks were covered with a plastic sheet for 24 hours to prevent rapid hardening.
3. **Curing:**
   - After the initial setting period, the blocks were cured by immersion in water for 26 days to ensure proper hydration.
4. **Surface Drying:**
   - Following curing, the blocks were left to air dry for one day to ensure surface readiness before laboratory testing.

Processing of Demolished Concrete Waste

1. **Collection and Preparation:**
   - Concrete waste was procured from demolition sites, transported, crushed, and segregated.
2. **Testing of Segregated Concrete:**
   - Laboratory tests conducted on the segregated concrete included:
     - Water Absorption Test
     - Sieve Analysis
     - Crushing Value Test
     - Impact Value Test
     - Abrasion Test
     - Workability Assessment
     - Crushing Strength Test
3. **Sieve Analysis:**
   - The demolished concrete waste was sieved using IS sieves to achieve the required fineness for replacing fine aggregate.

Experimental Investigation

To study the effect of partial replacement of demolished waste in fresh concrete, more than 180 concrete cubes of size **150 mm × 150 mm × 150 mm** were cast in the laboratory using two nominal mixes:

- M15 (1:2:4)
- M20 (1:1.5:3)

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN

Volume 13, Issue 3 | May 2023 Pages 13-25

The replacement of fresh coarse aggregate with demolished waste aggregate was performed at five levels: **0%, 25%, 50%, 75%, and 100%**.

Materials Used

1. **Cement:** Ordinary Portland Cement (53 Grade) was used in all mixes.
2. **Fine Aggregate:** Locally available coarse sand was utilized.
3. **Coarse Aggregate:** Crushed stone aggregates of size ranging from **4.75 mm to 20 mm** were employed throughout the study.
4. **Water:** Potable water was used for mixing and curing.
5. **Water-Cement Ratios:**
   - Three water-cement ratios were adopted: **0.60**, **0.625**, and **0.65**.

Testing

1. **Compressive Strength Tests:**
   - The compressive strength of the cubes was measured after **7 days** and **28 days** of curing.
   - Both mixes (M15 and M20) were tested to observe the effects of demolished waste aggregate replacement.

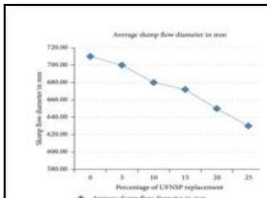

Fig 4 Result of slumpcone

Fig 5 Testing of slumpcone

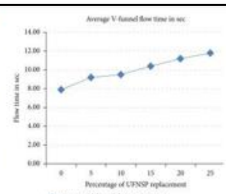

Fig 6 Result of V funnel

Fig 7 Testing of V funnel

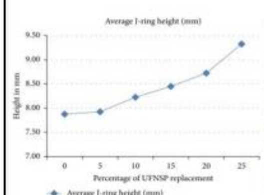

Fig 8 Result of JRing Test

Fig 9 Testing of JRing

Fig 10 Casting samples

Fig 11 Compression Testing

S.NO	Mix Details	Replacement of UFNSP %	Average Slump Flow Diammeter in MM	Average Vfunnel Flow Time in (sec)	Average J-Ring Height (mm)
1	SCC	0	710	7.90	7.88
2	SCC5	5	700	9.20	7.93
3	SCC10	10	680	9.50	8.23
4	SCC15	15	672	10.40	8.45
5	SCC20	20	650	11.20	8.73
6	SCC25	25	630	11.80	9.33

Table 1 Result of Flow Table

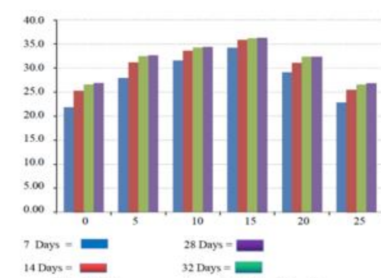

Fig 12 Compression Test On Hard Concrete Test At Different Age

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN

Volume 13, Issue 3 | May 2023 Pages 13-25

7. Compression Test on Hardened Concrete at Different Ages

The compressive strength of hardened concrete was tested at different ages for SCCCS (control specimen), SCC5, SCC10, SCC15, SCC20, and SCC25. The results show significant variations in strength attainment at 7, 14, 28, and 56 days:

7 Days Compressive Strength

- Strength attainment for SCCCS, SCC5, SCC10, SCC15, SCC20, and SCC25 was 82%, 86%, 92%, 94%, 90%, and 86% of the designed strength, respectively.
- SCC5 and SCC10 achieved over 90% of the designed strength, indicating rapid early-age strength development.
- The strength increments compared to SCCCS were:
    - **SCC5:** 28.21%
    - **SCC10:** 44.50%
    - **SCC15:** 56.88%
    - **SCC20:** 33.35%
    - **SCC25:** 4.59%

14 Days Compressive Strength

- Strength increments compared to SCCCS were:
    - **SCC5:** 23.47%
    - **SCC10:** 33.30%
    - **SCC15:** 42.07%
    - **SCC20:** 22.71%
    - **SCC25:** 0.67%

28 Days Compressive Strength

- Strength increments for SCC5, SCC10, SCC15, and SCC20 were:
    - **SCC5:** 22.18%
    - **SCC10:** 28.95%
    - **SCC15:** 36.09%
    - **SCC20:** 21.43%
- **SCC25:** Strength was reduced by 0.38% compared to SCCCS.

56 Days Compressive Strength

- Strength increments for SCC5, SCC10, SCC15, and SCC20 were:
    - **SCC5:** 21.38%
    - **SCC10:** 27.88%
    - **SCC15:** 34.94%
    - **SCC20:** 20.33%

NATIONAL JOURNAL ON INFORMATION AND COMMUNICATION ENGINEERING
ISSN: 2231-2099 | NJICE - WWW.NJICE.IN

Volume 13, Issue 3 | May 2023 Pages 13-25

- **SCC25:** Strength was reduced by 0.37% compared to SCCCS.

Observations

- Strength enhancement was evident for all replacement levels up to 20%.
- SCC25 exhibited similar or slightly lower strength than SCCCS at 28 and 56 days, marking the practical limit for UFNSP replacement.
- Early-age strength attainment was attributed to the presence of Mg and reduced particle size of UFNSP, which facilitated particle intrusion into the cement matrix, enhancing hydration rates.
- Maximum strength was achieved with SCC15 specimens, and denser microstructures were observed in SCC10, SCC15, and SCC20 specimens due to the formation of magnesium hydroxide and silicate phases.

Conclusion

The present study demonstrates that incorporating ultrafine natural steatite powder (UFNSP) as a partial replacement for cement significantly influences the workability, flow properties, compressive strength, and microstructural characteristics of self-compacting concrete (SCC). It was observed that the flow properties decreased with increasing UFNSP content. Although all replacement percentages remained within acceptable limits, SCC with 25% UFNSP replacement reached the threshold, indicating that further addition could compromise the flowability of the mix.

The study highlights the early-age strength development in SCC5, SCC10, SCC15, and SCC20 specimens, where strength attainment exceeded the target at 7 days. Maximum compressive strength was observed in SCC15 specimens, indicating that this replacement percentage optimally balances strength and workability. Strength improvements were consistently noted up to 20% UFNSP replacement, with a slight decline in the SCC25 specimens at 28 and 56 days due to higher magnesium content.

Microstructural analysis revealed that SCC10, SCC15, and SCC20 exhibited denser structures, with well-distributed magnesium hydroxide and silicate phases, which contributed to strength enhancement. However, the SCC25 specimens showed an excess of magnesium, leading to minor reductions in strength. These findings confirm that the hydration process and the presence of Mg in the UFNSP play a vital role in early-age strength attainment and durability.

Based on the experimental results, it is concluded that the optimal replacement level of UFNSP in SCC is up to 20%. Beyond this limit, the strength parameters and flow properties are adversely affected. The study underscores the potential of UFNSP as an additive for enhancing SCC performance, making it a viable option for sustainable and high-strength concrete applications.

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