Improving Self-Compacting Concrete Performance with Manufactured Sand: An Experimental Investigation of Workability and Mechanical Properties

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A structural concrete mix with a target compressive strength of M40 was developed using a binder composed of 65% Ordinary Portland Cement (OPC) and 35% fly ash. Manufactured sand (M-sand) was employed as a partial replacement for river sand at various levels: 20%, 40%, 60%, 80%, and 100%. To maintain consistent workability, the amount of super-plasticizer was adjusted according to the level of M-sand replacement. The workability of the self-consolidating concrete (SCC) was evaluated through T50 flow time, V-Funnel time, and V-Funnel T5 time measurements. Additionally, the compressive strength, split tensile strength, and flexural strength of SCC were tested for each M-sand replacement level. Performance comparisons were made between SCCs made with M-sand and those with river sand. The results indicate that M-sand can be effectively used in SCC production, showing comparable or even superior workability and strength properties compared to river sand. This suggests that M-sand is a viable alternative to river sand in SCC, offering benefits such as increased sustainability and reduced dependence on natural river sand. However, further studies are needed to confirm the long-term effectiveness and durability of SCC made with M-sand.

Keywords: I Self-Compacting Concrete (SCC), Manufactured Sand (M-sand), Compressive Strength Workability, Super-Plasticizer.

1. Introduction

Concrete is widely used in construction due to its versatility and strength. However, due to, poor construction practices and inadequate mix constituents can lead to various problems, such as inadequate compaction and honeycomb formations. Honeycomb formations occur when concrete is not properly compacted during construction, leaving voids or gaps in the material. This can weaken the structure and compromise its durability [1]. Self-Compacting Concrete (SCC) addresses this issue by eliminating the need for external compaction or vibration. SCC is a special type of concrete that is designed to flow easily into place, filling all spaces and voids without the need for mechanical compaction [2]. This is achieved through careful selection and proportioning of materials, including the use of specialized admixtures. The development of SCC minimizes the labor required for compaction and ensures more consistent and uniform concrete placement. By allowing the concrete to compact itself under its own weight, SCC reduces the risk of honeycomb formations, as well as issues such as bleeding and segregation. Overall, SCC offers significant advantages in terms of construction efficiency, quality, and durability, making it a valuable solution for various applications in the construction industry.

The generation of industrial waste is indeed a significant concern due to its potential impact on human health and the environment. Industrial activities produce a wide variety of wastes with diverse properties and chemical compositions, which can pose challenges for safe management and disposal. The cement industry, in particular, is known for its high consumption of natural resources and its contribution to atmospheric pollution, primarily through the emission of carbon dioxide (CO2) during the cement production process. To address these issues, there has been increasing interest in utilizing industrial waste materials, especially those with pozzolanic properties, as supplementary cementitious materials (SCMs) in concrete production. Pozzolanic materials, such as fly ash, slag, silica fume, and certain types of industrial by-products, have the ability to react with calcium hydroxide in the presence of moisture to form additional cementitious compounds. By incorporating these waste materials into concrete mixes, the cement content can be partially replaced, reducing both the consumption of natural resources and the carbon footprint associated with cement production. Additionally, the shortage of river sand and natural aggregates in countries like India has prompted the construction sector to explore alternative materials for use in concrete production. Industrial by-products, [3] such as crushed glass, recycled concrete aggregates, and bottom ash, can be utilized as substitutes for traditional aggregates, helping to alleviate the demand for natural resources and reduce environmental impact [4].

Overall, the utilization of industrial waste materials in concrete production not only offers environmental benefits by reducing waste generation and conserving natural resources but also helps to improve the performance and sustainability of concrete structures. However, it's essential to ensure that proper testing and quality control measures are implemented to assess the suitability and performance of these alternative materials in concrete mixes.

2. Objectives of Research

The objective of the present study is to investigate the properties of self-compacting concrete

(SCC) prepared using river sand (natural sand, NS) as fine aggregates, and to assess the impact of replacing river sand with manufactured sand (M-sand) at various replacement levels. The study aims to compare the properties of SCC made with river sand and M-sand, in order to understand how the replacement affects the concrete characteristics.

3. Materials

The information about the materials used in the preparation of self-compacting concrete (SCC) are as follows:

3.1 Cement

The selection of Ordinary Portland Cement (OPC) 43 Grade for the self-compacting concrete (SCC) formulation is based on meeting specific requirements tailored to the concrete's intended use. The properties of the cement used in the SCC mix are evaluated according to IS: 4031 - 1988 and IS 4032 – 1988 standards. These standards ensure that the cement meets quality benchmarks necessary for concrete production. The results obtained from the testing process are typically presented in a Table 1, detailing various characteristics such as fineness, setting time, compressive strength, and chemical composition. These results play a crucial role in the proportioning of SCC, as they provide essential data for determining the optimal mix design and ensuring the desired performance of the concrete.

Table 1 Cement Properties

zq	Obtained Value	Code Recommendations
Specific Gravity	3.15	3.10-3.15
Consistency	29 %	25-35
Initial setting time	45 minutes	Not less than 30 minutes
Final setting time	6 hours and 30 minutes	Not greater than10hours
Fineness	3 %	Not greater than10%
Soundness	1	Maximum 10

3.2 Fly ash

Fly ash is a commonly used supplementary cementitious material in the production of self-compacting concrete (SCC). When properly incorporated Class F fly ash into the mix, it can improve various properties of SCC, such as workability, durability, and long-term strength. In SCC mixtures, fly ash is typically used as a partial replacement for cement, reducing the overall cement content while maintaining or enhancing the performance of the concrete. Class F fly ash typically contains finer particles that can fill in the gaps between cement particles, reducing the water demand of the concrete mixture. This leads to improved cohesiveness and reduced bleeding and segregation tendencies, contributing to the stability and homogeneity of the SCC.

Table 2 Properties of Fly Ash

Property	Obtained Value	Code Recommendations
Specific Gravity	2.15	2.1 to 2.5
Consistency	29 %	25-35
Initial setting time	45 minutes	Not less than 30 minutes

Final setting time	6 hours and 30 minutes	Not greater than10hours
Fineness	3 %	Not greater than10%
Soundness	1	Maximum 10

3.3 Fine aggregate

3.3.1 River Sand

The river sand utilized in this study was sourced locally, adhering to the specifications outlined in IS 383-1987, which categorizes it under Zone-II. IS 383-1987 is an Indian standard that provides guidelines for the quality of natural coarse aggregates, including river sand, based on their particle size distribution. Zone-II signifies that the river sand meets the requirements for use in construction applications, including concrete production.

3.3.2 Manufactured Sand

M-sand, also known as manufactured sand was employed as a replacement for river sand in the preparation of self-compacting concrete (SCC) specimens. The decision to use M-sand as a replacement for river sand was motivated by several factors, including environmental concerns, sustainability, and availability. M-sand offers a viable alternative to river sand, mitigating the environmental impact associated with excessive sand mining from riverbeds and promoting sustainable construction practices. Prior to use, the properties of the M-sand were evaluated to ensure conformity with relevant standards and specifications, including particle size distribution, fineness modulus, silt content, and moisture content. This ensured consistency and reliability in the experimental results obtained during the investigation of SCC properties with varying levels of M-sand replacement [10].

Table 3 Properties of M-Sand and River Sand

Property	Obtained Value	Code Recommendations
Specific Gravity	2.15	2.1 to 2.5
Consistency	29 %	25-35
Initial setting time	45 minutes	Not less than 30 minutes
Final setting time	6 hours and 30 minutes	Not greater than10hours
Fineness	3 %	Not greater than10%
Soundness	1	Maximum 10

3.4 Coarse aggregate

Coarse aggregate with a nominal size of 12.5 mm was utilized in the preparation of self-compacting concrete (SCC) specimens. Coarse aggregate, also known as stone or gravel, plays a crucial role in providing strength and stability to concrete structures. The 12.5 mm size designation refers to the nominal maximum size of the coarse aggregate particles, indicating that the majority of particles pass through a sieve with apertures of 12.5 mm but are retained on a sieve with smaller openings.

The selection of coarse aggregate with a nominal size of 12.5 mm was based on standard construction practices and considerations for achieving the desired workability and strength characteristics of SCC. Prior to incorporation into the concrete mix, the coarse aggregate was subjected to grading analysis to ensure compliance with relevant standards and specifications. The properties of the coarse aggregate, including particle shape, surface texture, and grading, directly influence the workability, strength, and durability of SCC. Therefore, careful attention was given to the selection and quality control of coarse aggregate to optimize the performance of the concrete mixture.

3.5 Superplasticizer

Conplast, a high-performance superplasticizer, was utilized in the preparation of self-compacting concrete (SCC) specimens. Superplasticizers are chemical admixtures that are added to concrete mixes to enhance workability and flowability without compromising strength or durability. Conplast is a widely recognized brand of superplasticizer known for its effectiveness in improving the rheological properties of concrete. Prior to use, the dosage of Conplast was carefully optimized through trial mixes to achieve the target slump flow and viscosity parameters specified for SCC. Quality control measures were implemented to ensure consistency in the dosage and performance of Conplast throughout the experimental testing.

3.6 Water

Tap water was utilized as the mixing agent in the preparation of self-compacting concrete (SCC) specimens. Water is a critical component of concrete mixtures, serving as a medium for hydration reactions and facilitating the workability and flowability of the concrete mix.

4. Methodology

The preparation and evaluation of self-compacting concrete (SCC) involved several crucial steps and assessments. Initially, SCC was prepared using river sand as the fine aggregate to achieve a slump flow of 650mm, with the superplasticizer dosage adjusted accordingly. Subsequently, M-sand was introduced to replace river sand at varying levels, ranging from 20% to 100%. This substitution aimed to explore the impact of M-sand replacement on SCC properties. The fillability, flowability, and segregation resistance of the SCC were then evaluated according to EFNARK 2005 standards, ensuring that the mix could effectively fill complex shapes, flow uniformly without segregation, and resist separation during handling and casting processes [6]. Following the preparation and evaluation stages, concrete specimens including cubes, cylinders, and beams were cast and cured for 28 days under standard curing conditions. Finally, the compressive strength, split tensile strength, and flexural strength of the SCC were determined in accordance with IS 516:1959, providing a comprehensive assessment of the concrete's performance across various M-sand replacement levels [7]. Adjustments to the superplasticizer dosage ensured consistent workability throughout the testing process, facilitating accurate comparisons of strength and other key properties.

5. Experimental Results

5.1 Fresh State Properties

The fibre material used here is pineapple leaf fibre. The fibre diameter was 0.5 mm, the length was 60 mm, and the aspect ratio was 100. Fibre materials are commonly used to stop small cracks in concrete. It accelerates the concrete's Tensile Strength. To be considered an SCC, concrete must have a satisfactory filling ability, passing ability, and segregation resistance in the plastic state. Slump flow, L-box, V-funnel, and J-Ring tests were performed on the freshly mixed concrete. Six sets of concrete mixes were made by varying the percentage of fibre in the SCC. These mixes were then tested in their fresh state to see how they behaved, and the results are shown in Table 4.

Table 4 Mix Proportion of replacement of materials on SCC

Material/ Mix	Powder content		Fine Aggregate		Coarse Aggregate
	Cement	Fly ash	River Sand	M-Sand	
Conventional	25%		42%		33%
	75%	25%	100%	0%	100%
	435.44 kg	99.60 kg	922.9 kg	0 kg	707 kg
SCC-1	25%		42%		33%
	75%	25%	80%	20%	100%
	435.44 kg	99.60 kg	738.33 kg	182.41 kg	707 kg
SCC-2	25%		42%		33%
	75%	25%	60%	40%	100%
	435.44 kg	99.60 kg	553.73 kg	364.82 kg	707 kg
SCC-3	25%		42%		33%
	75%	25%	40%	60%	100%
	435.44 kg	99.60 kg	369.15 kg	547.24 kg	707 kg

5.2 Hardened State Properties

5.2.1 Compression Test

The variation of compressive strength of self-compacting concrete with various replacement of M- sand after 7 and 28 days curing is presented in Table 3. From the Fig. 2, it was observed that the compressive strength decreases with increase in amount of replacement of M-sand at both 7 and 28 days testing. For 60% replacement by M-sand, the compressive strength was 20% lower than that of SCC with river sand.

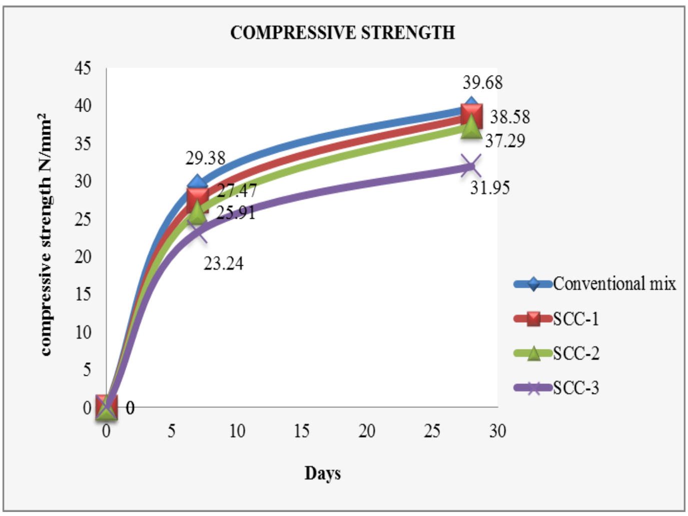

Figure 1. Compressive strength of the specimens

5.2.2 Spilt Tensile Strength Test

The desired no. of cylinders were cast and tested in the laboratory after the curing period of 28 days for split tensile strength. From the Fig. 3, it was observed that the split tensile strength of mix SCC-1 and SCC-2 are more when compared to conventional mix. Maximum split tensile strength was observed in concrete with 80 % river sand and 20% M-sand, which is 9.5 % higher compared to concrete with natural sand. The increase in strength of concrete with M-sand may be due to the rough surface texture of M-sand when compared to natural sand.

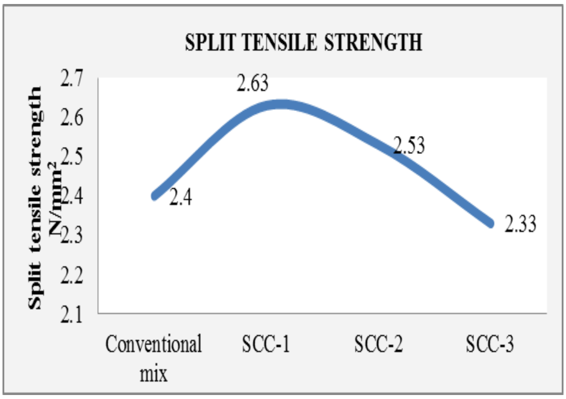

Figure 2. Split tensile strength of the tested specimens

5.2.3 Flexural Strength Test

For the flexural strength test, the specimen before and after loading in testing machine is shown in Fig. 4. The results of flexural strength tests for the M-Sand in concrete mixtures SCC-1, SCC- 2, and SCC- 3 are illustrated in Fig. 5. These results show that the flexural strength of concrete mixtures at 28days curing age is become to decrease with the increase of the M-Sand ratio in these mixtures. The flexural strengths of the SCC-1, SCC- 2, and SCC- 3 are compared to conventional is high. The variation of flexural strength with various replacement levels of M-sand when compared to concrete with natural sand is marginal. Hence M-sand can be used for pre casting concrete pavement slabs.

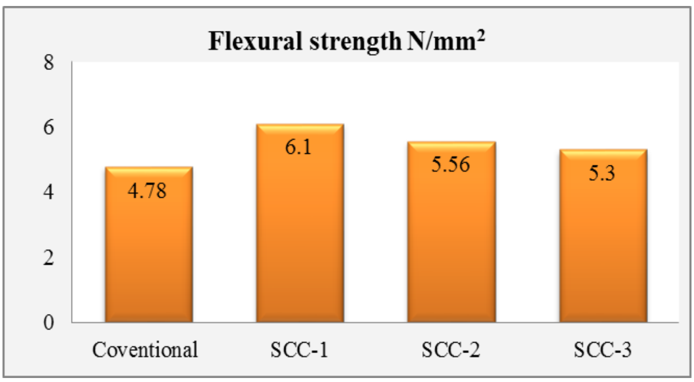

Figure 3. Flexural strength of specimens

6. Discussions

The experimental results of this study demonstrate that Self-Compacting Concrete (SCC) with varying levels of M-sand as a replacement for river sand exhibits notable performance characteristics in both fresh and hardened states. Fresh state workability metrics, including T50 flow time, V Funnel time, and V-funnel T5 time, indicated that SCC mixes incorporating M-sand maintained or enhanced workability compared to SCC mixes using river sand. This can be attributed to the angular and rough texture of M-sand particles, which likely contribute to better cohesiveness and reduced segregation. Compressive strength tests conducted at 7 and 28 days revealed a decreasing trend in strength with increasing M-sand content, with a 60% M-sand replacement showing a 20% reduction compared to SCC with river sand. However, up to a 40% replacement level, the compressive strength remained within acceptable limits for structural applications, corroborating findings by previous studies on the use of alternative fine aggregates in concrete.

The split tensile strength results were particularly significant, with the SCC mix containing 20% M-sand exhibiting a 9.5% higher tensile strength than the conventional mix. This enhancement is likely due to the improved interfacial transition zone (ITZ) provided by the rough surface of M-sand, which enhances mechanical interlock and bond strength [11-14]. Flexural strength tests revealed a marginal increase in strength at a 20% M-sand replacement level, followed by a decline at higher replacement levels. Despite this, the flexural strength of all SCC mixes with M-sand surpassed that of the SCC using river sand, indicating the potential of M-sand to contribute positively to the flexural performance of SCC.

These findings suggest that M-sand can effectively substitute river sand in SCC formulations, providing comparable or superior workability and mechanical properties at certain replacement levels [15-19]. The incorporation of M-sand not only addresses the environmental concerns associated with river sand mining but also promotes the utilization of industrial by-products, aligning with sustainable construction practices. The study underscores the potential of M-sand as a sustainable alternative, capable of enhancing the performance of SCC while contributing to resource conservation and environmental sustainability. Future research should focus on long-term durability studies and the microstructural analysis of SCC with M-sand to further validate these findings and expand their applicability [20-24].

7. Conclusion

Based on the findings from the study on Self-Compacting Concrete (SCC), the following conclusions have been drawn:

- Workability: SCC mixes with M-sand maintained or improved workability compared to those with river sand, demonstrating effective flow and filling properties.
- Compressive Strength: Up to 40% M-sand replacement maintained compressive strength within acceptable limits, making it a viable alternative for structural applications.
- Split Tensile Strength: The highest tensile strength was observed at 20% M-sand

replacement, showing a 9.5% increase over conventional SCC due to improved interfacial bonding.

- Flexural Strength: Slight improvements were noted at lower M-sand replacement levels, with all SCC mixes surpassing the flexural strength of conventional SCC.

- Sustainability: M-sand offers a sustainable alternative to river sand, reducing environmental impact and promoting resource conservation.

Future Scope: Further studies on long-term durability and microstructural analysis are recommended to validate the extended-term performance of SCC with M-sand. Overall, the flexural strength of all SCC mixes surpasses that of SCC using river sand, indicating the viability of using M-Sand for precasting concrete pavement slabs.

Conflict of interest

There is no conflict of interest in the submission of this work and has been agreed by all the authors for the publication of the manuscript.

Credit Author Statement

Yesudhas Abisha - Conceptualization, Methodology, Experimentation and Original drafting (corresponding author)

Natarajen Nalanth - Validation, Analysis, Data Curation, Supervision, Review& Editing

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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