Mechanical Behavior of Sand-Replaced Self-Compacting Concrete With Granite Stone Dust

P. Ravi Prasad[1], Dr. C. Sashidhar[2]*, Dr. B. Ramesh Babu[1]

1 Research Scholar, Department of Civil Engineering, JNTUA, 515002, Andhra Pradesh.
2 Professor, Department of Civil Engineering, JNTUA College of Engineering, 515002, Andhra Pradesh.
3 Principal, PVKK Institute of Technology, 515002, Andhra Pradesh.

ABSTRACT

In response to growing environmental concerns and the depletion of natural sand resources, there is a necessity to explore alternative materials for concrete production. One promising avenue is the utilization of industrial quarry by-products like granite stone dust (GSD) as a replacement for natural river sand. This study delves into the optimization of self-compacting concrete mixes by incorporating GSD, aiming to assess its impact on mechanical properties and sustainability in concrete construction. GSD offers a sustainable alternative to river sand, reducing the environmental impact of sand mining and conserving natural resources. The study discussed focuses on optimizing self-compacting concrete mixes by incorporating GSD as a replacement for fine aggregates. Various concrete mixes were prepared with different percentages (0-30%) of GSD by weight of fine aggregates, and mechanical properties such as compressive strength, split-tensile strength, and flexural strength were evaluated according to Indian Standard protocols at curing periods ranging from 7 to 90 days. Results indicated that while GSD adversely affected early strength, dosages up to 15% improved strength for concrete cured over 28 and 90 days, attributed to microstructural changes enhancing cement hydration products. However, beyond 15%, increased porosity and reduced strength were observed. The study recommends an optimum dosage of 15% GSD to achieve the target mean strength corresponding to M30 grade concrete.

1. Introduction

The waste material stone dust is obtained from the screening of coarse aggregates obtained after blasting of rocks, causing a severe problem for its disposal. The fast depletion of river sand and aggregates has forced the researchers to identify alternative materials. Self-compacting concrete (SCC) is an innovative concrete characterized by its ability to flow under its own weight without segregation or blocking and to achieve full compaction without vibration. Thus, SCC can be cast without honeycombing where it is difficult to mechanically compact fresh concrete, such as underwater concreting, cast in-situ piles, and columns or walls with congested reinforcement. In addition, it can be pumped to great heights in high-rise buildings without segregation.

Celik and Marar (1996) [1] conducted an experimental study to examine the impact of varying proportions of crusher dust, a fine material generated during the crushing process of rocks, on the properties of both fresh and hardened concrete. Their findings revealed that as the percentage of dust content increased, the slump and air content of fresh concrete decreased. However, up to 10% dust content led to improvements in compressive strength and flexural strength, beyond which both strengths gradually declined. Impact resistance improved with up to 5% dust content but decreased significantly thereafter. The absorption of concrete was minimized at 15% dust content, while water permeability decreased with increasing dust content due to blocked water passages. Drying shrinkage increased up to 10% dust content, but beyond this threshold, the shrinkage strain decreased, correlating with compressive strength.

Topçu et al. (2008) [2] investigated the incorporation of waste marble dust as filler material in SCC, finding that while fresh SCC workability remained unaffected up to a certain marble dust content, mechanical properties of hardened SCC declined beyond a certain threshold.

Singh et al. (2015) [3] explored the use of stone dust as a partial replacement for natural river sand in concrete, aiming to improve concrete quality while conserving natural resources. Their experimental program investigated the workability and compressive strength of concrete with stone dust replacing fine aggregate in varying proportions from 10% to 100%. Using M25 grade concrete with Portland pozzolana cement (PPC) as a reference, the study determined the optimum replacement level based on compressive strength. Results indicated that replacing 60% of fine aggregate with stone dust yielded concrete with maximum compressive strength compared to other replacement levels.

Sadek et al. (2016) [4] explored the feasibility of utilizing waste powders from marble and granite industries as mineral additives in SCC, concluding that high volumes of waste powders could be successfully incorporated, with mixed powder performing best followed by granite powder, while silica fume enhanced marble powder performance.

Rajput (2018) [5] conducted an experimental study investigating the use of crushed stone dust as a substitute for natural sand in cement concrete. The study evaluated various proportions of crushed stone dust in M-20 and M-30 grade concrete mixes, demonstrating comparable strength properties to conventional concrete. Results suggest that crushed stone dust can effectively replace natural sand in construction, offering potential cost savings and environmental benefits.

Verma et al. (2020) [6] investigated the utilization of stone dust in concrete production to address disposal issues. By incorporating stone dust and silica fume into binary and ternary concrete mixes, they aimed to enhance durability. Through various replacement percentages, they identified an optimal combination—30% stone dust replacing fine aggregate and 10% silica fume replacing cement—for producing sustainable and durable concrete, offering a solution to both disposal challenges and the creation of resilient structures.

Rashwan et al. (2021) [7] examined the use of natural stone wastes as cement replacements in SCC, observing improvements in workability with increasing waste proportions and insignificant drops in mechanical properties at lower replacement levels.

Based on the literature [8-14], several conclusions emerge regarding the use of industrial wastes in concrete production. Optimal incorporation of these wastes promises sustainable development in construction and effective waste management. They can partially replace conventional materials without compromising strength and durability. Notably, Construction demolition waste, Steel slag, Ladle furnace slag, Copper slag, Granite sawing waste, Iron slag, Marble Powder, Volcanic powder, and Foundry Sand exhibit excellent mechanical and durability properties for concrete production. For high-strength self-compacting concrete, materials like steel slag, copper slag, granite sawing waste, and marble powder are recommended, while copper slag, foundry sand, granite powder, and steel slag are advised for durable self-compacting concrete. Incorporating recycled fines, copper slag, marble powder, and granite powder improves microstructure in self-compacting concrete [15- 21].

2. Materials

The research investigated the impact of substituting natural river sand with granite stone-dust, ranging from 0% to 30% of the total fine aggregates by weight, on the mechanical properties of concrete. In addition, viscosity modifying agent and poly carboxylic ether based admixture were used preparation of self-compacting concrete. The study utilizes two stocks of coarse aggregates, each with a distinct particle distribution, as illustrated in figure 1.

The basic properties of aggregates such as specific gravity, water-absorption, flakiness and elongation indices and evaluated for coarse aggregates. In this study, zone-1 grade natural sand was utilized and partially replaced with granite stone dust. The details of physical properties are illustrated in Tables 1-3. Further, the gradation details are depicted in figure 1.

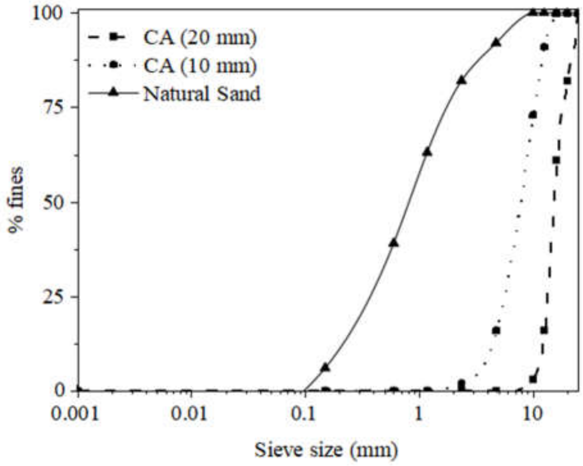

Fig. 1 *Particle distribution curves for aggregates*

Table 1 *Basic properties of aggregates*

Basic Property	Coarse aggregates		Fine aggregates	IS-Code
	10 mm	20 mm		
Specific Gravity	2.74	2.71	2.68	2386-IV
Water absorption	0.91	0.82	0.78	2386-IV
Class of FA	-	-	Zone-II	383-2016
Impact Value	13.8	11.6	-	2386-IV
Crushing Value	18.6	12.7	-	2386-IV
Los-Angeles Abrasion Value	12.1	12.4	-	2386-IV
Fineness modulus	-	-	2.71	383-2016
Combined Flakiness and Elongation Index	21.6	12.1	-	2386-IV

Table 2 *Various characteristics of 53 grade OPC*

Characteristic		Test value	Specifications as per IS: 12269-1987
Compressive strength	3-days	28	27
	7-days	39	37
	28-days	55	53
Normal consistency		36%	---
Initial setting time (min)		37	≥ 30 minutes
Final setting time (min)		471	≤ 600 minutes
Soundness		1.5	≤ 10 mm
Specific gravity		3.17	≥ 3.15

Table 3 *Basic physical properties of granite stone dust*

Basic Property	Granite Stone Dust	IS-Code
Specific Gravity	2.31	2386-IV
Water absorption	1.21	2386-IV
Fineness modulus	2.71	383-2016
% fines < 40 microns	9.2	-

3. Methodology

The compressive strength of concrete is assessed according to IS 516 standards, utilizing 150 mm x 150 mm x 150 mm cube molds. Concrete is compacted in three layers, cured for 24 hours, and then tested for compression. The split tensile strength is evaluated using cylindrical specimens (150 mm diameter, 300 mm height), following IS 5816 guidelines, with curing periods ranging from 7 to 90 days. Flexural strength testing is conducted in accordance with IS 516 standards, employing 150 mm x 150 mm x 750 mm beam molds. After compaction and curing, the specimens undergo a 4-point loading test setup to determine the modulus of rupture (flexural strength).

4. Results and discussions

Figure 2 provides a comprehensive view of the average compressive strength of Self-Compacting Concrete (SCC) with varying Granite Stone Dust (GSD) percentages at different curing periods, ranging 7, 14, 28, and 90 days. Commencing with 0% GSD, the 7-day compressive strength is 22.57 MPa, steadily increasing to 29.91 MPa at 14 days, 39.30 MPa at 28 days, and peaking at 43.11 MPa at 90 days (figure 4.22). This pattern of progressive strength development is consistent with the influence of GSD over an extended curing period. A similar trend is observed for GSD percentages up to 15%, where the 90-day compressive strength reaches

48.31 MPa. Notably, the highest compressive strength occurs at 15% GSD, indicating potential advantages of GSD up to this dosage and longer curing periods. From the results corresponding to long term compressive strength (28 and 90-days), an optimum dosage of 15% is recommended for the further study to optimize the dosages of SPD and SF replacing OPC in SCC.

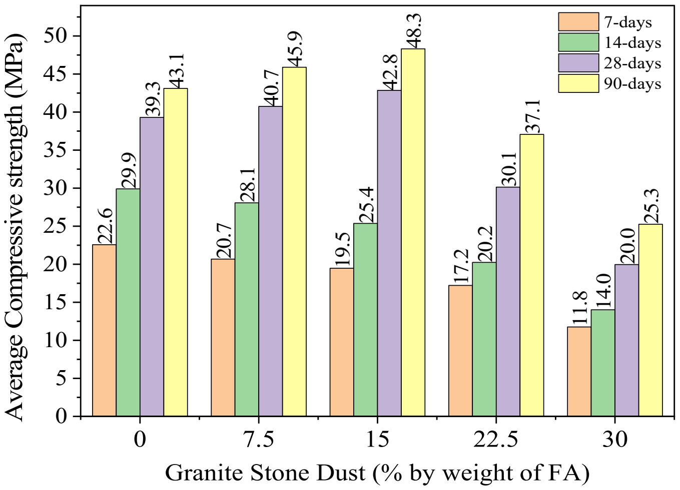

Fig 2 Average compressive strength of SCC with GSD at different curing periods

Figure 3 provides a comprehensive view of the average split tensile strength of Self-Compacting Concrete (SCC) with varying Granite Stone Dust (GSD) percentages at different curing periods, ranging 7, 14, 28, and 90 days. Results showed an increasing trend in tensile strength from 7 to 90 days of curing for all GSD levels (figure 3). At the 7-day mark, SCC without GSD exhibited a split-tensile strength of 2.47 MPa, while SCC with 30% GSD displayed 1.61 MPa. This pattern persisted at 14, 28, and 90 days, where strengths progressively improved across all GSD percentages. Notably, strengths ranged from 2.92 MPa to 1.85 MPa at 14 days, 3.30 MPa to 2.31 MPa at 28 days, and 3.44 MPa to 2.45 MPa at 90 days, for 0% GSD and 30% GSD, respectively. The findings suggest a positive influence of GSD on split-tensile strength, particularly within the 90-day curing period. However, beyond this timeframe, there may be indications of diminishing returns or saturation, underscoring the necessity of optimizing GSD content in SCC mixtures for sustained mechanical properties over time.

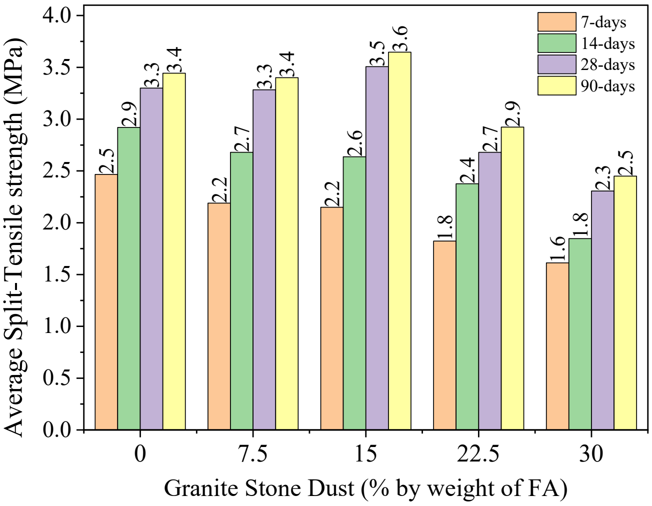

Fig 3 Average split-tensile strength of SCC with GSD

Figure 4 provides a comprehensive view of the average flexural strength of Self-Compacting Concrete (SCC) with varying Granite Stone Dust (GSD) percentages at different curing periods, ranging 7, 14, 28, and 90 days. The influence of varying percentages of Granite Stone Dust (GSD) on the flexural strengths of Self-Compacting Concrete (SCC) over different curing periods is presented in figure 4. At 7 days of curing, SCC without GSD exhibited a flexural strength of 3.08 MPa, whereas SCC with 30% GSD displayed a lower strength of 2.03 MPa. With extended curing to 14 days, the flexural strengths improved across all GSD levels, with values ranging from 3.64 MPa to 2.25 MPa. Subsequent progression to 28 days and 90 days of curing saw continued enhancements in flexural strengths for all GSD percentages. This underscores the notable influence of GSD content on mechanical properties of SCC throughout the curing process, particularly evident at higher GSD levels.

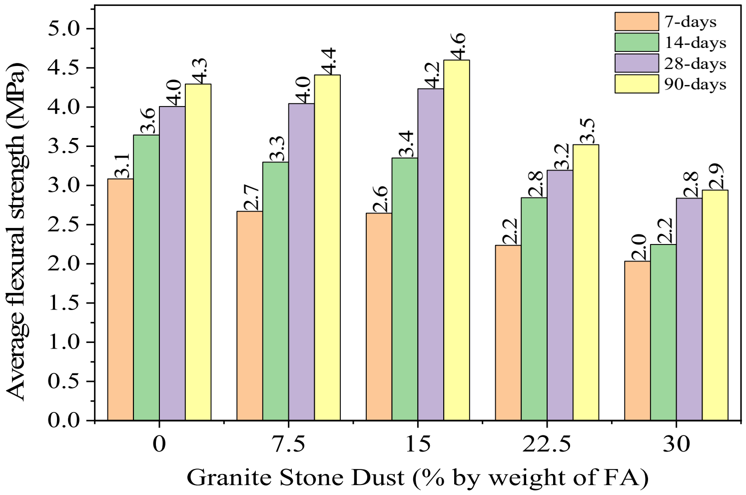

Fig 4 Average flexural strengths of SCC with GSD at different curing periods

5. Conclusions

This study focuses on optimizing self-compacting concrete (SCC) mixes by incorporating Granite Stone Dust (GSD) as a partial replacement for fine aggregates. Various mixes were prepared with GSD replacing 0-30% of the total fine aggregates to determine the optimal dosage. Mechanical properties, including compressive strength, split-tensile strength, and flexural strength, were evaluated following Indian Standard protocols, with curing periods ranging from 7 to 90 days.

The addition of GSD adversely affected the early strength of SCC across all dosages. However, replacement dosages of up to 15% showed improved SCC strength when cured for 28 and 90 days. Microstructural analysis confirmed the involvement of GSD in cement hydration products up to a 15% dosage, contributing to enhanced strength. Conversely, higher GSD quantities led to increased porosity and decreased strength.

In overall, the study recommends an optimal dosage of 15% GSD in self-compacting concrete to achieve a target mean strength corresponding to M30 grade as per IS-10262-2019. Additionally, future research aims to explore replacing Ordinary Portland Cement (OPC) with Supplementary Cementitious Materials (SCMs) such as Silica Fume (SF) and Fly Ash (SF) in SCC formulations containing 15% GSD.

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