

Experimental Study on Concrete Performance with Manufactured Sand as Fine Aggregate Replacement

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ABSTRACT: The depletion of natural river sand and increasing environmental concerns have accelerated the need for sustainable alternatives in concrete production. This study evaluates the performance of concrete using manufactured sand (M-sand) as a partial and full replacement for natural fine aggregate. Experimental investigations are carried out to assess the mechanical and durability properties of concrete at varying replacement levels. Key parameters such as compressive strength, tensile strength, workability, and durability characteristics are analyzed through standard tests. The results indicate that concrete with manufactured sand exhibits comparable or improved strength properties compared to conventional concrete, particularly at optimum replacement levels. The angular shape and better grading of M-sand contribute to enhanced bonding between cement paste and aggregates, resulting in improved mechanical performance. However, a slight reduction in workability is observed due to the rough texture of M-sand, which can be mitigated by the use of admixtures. Durability aspects such as water absorption and resistance to environmental effects also show satisfactory performance.

The study concludes that manufactured sand is a viable and sustainable alternative to natural sand in concrete, offering both environmental and technical benefits for modern construction practices.

KEYWORDS: Manufactured sand, Fine aggregate replacement, Concrete performance, Compressive strength, Workability, Sustainable construction etc.

I. INTRODUCTION

Concrete is one of the most widely used construction materials and plays a vital role in the sustainable development of infrastructure. The rapid growth of urbanization and industrialization has significantly increased the demand for concrete, leading to a corresponding rise in the consumption of fine aggregates. Traditionally, natural river sand has been used as fine aggregate; however, its excessive extraction has resulted in depletion of resources, increased costs, and serious environmental concerns such as riverbed degradation and lowering of groundwater levels.

The scarcity and rising cost of natural sand have encouraged researchers and engineers to explore alternative materials. Manufactured sand (M-sand), produced by crushing hard granite rocks and processing them into fine aggregates of size less than 4.75 mm, has emerged as a viable substitute. M-sand offers advantages such as controlled gradation, improved particle shape, and reduced environmental impact compared to river sand.

In this study, concrete mixes are designed using manufactured sand as a replacement for natural fine aggregate for both medium and high-strength grades. The performance of concrete is evaluated in terms of mechanical and durability properties to assess the suitability of M-sand as a sustainable alternative in modern construction practices.

II. LITERATURE SURVEY

The increasing scarcity of natural river sand and the growing demand for sustainable construction materials have led to extensive research on the use of manufactured sand (M-sand) as a fine aggregate in concrete. Several studies have investigated its effects on mechanical properties, durability, and overall performance of concrete.

Ding et al. (2016) studied the long-term compressive strength of concrete with manufactured sand and concluded that properly graded M-sand can achieve comparable or improved strength compared to natural sand concrete. Similarly, Li et al. (2017) and Zhao et al. (2014) highlighted that the characteristics of manufactured sand, particularly particle shape and stone powder content, significantly influence concrete strength and performance. Shen et al. (2018) and Ilangovana et al. (2008) reported that concrete with M-sand exhibits satisfactory strength and durability when properly designed.

Recent studies have focused on optimization and advanced analysis techniques. Gao et al. (2024) and Ma et al. (2022) applied response surface methodology to optimize mix proportions and demonstrated that M-sand concrete can achieve high compressive strength with proper mix design. Bardhan et al. (2024) and Zhang et al. (2023) utilized machine learning approaches to predict compressive strength, indicating the growing role of data-driven methods in concrete research.

Durability and sustainability aspects have also been widely explored. Yu and Zhuang (2024) examined resistance to freeze-thaw and corrosion, while Rao et al. (2019) confirmed good durability performance of M-sand concrete. Kumar et al. (2020) and Akhtar et al. (2024) emphasized the environmental benefits of using manufactured sand, highlighting reduced dependence on natural resources and lower ecological impact.

Experimental investigations by Raj and Prajapati (2024), Patel et al. (2021), and Singh et al. (2022) demonstrated that M-sand concrete provides adequate workability and strength, although minor reductions in workability may occur due to angular particle shape. Advanced applications such as 3D printed concrete (2023) and the inclusion of supplementary materials like fly ash (Sathvik et al., 2025) further indicate the versatility of manufactured sand in modern construction.

Overall, the literature indicates that manufactured sand is a viable and sustainable alternative to natural sand, offering comparable strength, satisfactory durability, and environmental advantages. However, proper mix design and quality control are essential to fully utilize its benefits in concrete production.

III. METHODOLOGY

The current section deals with the materials and methods used in this research work. All the materials and methods used in the study consoled with the specification of Indian Standards (IS), Indian Road Congress (IRC), and American Standards of Testing Material (ASTM) standards where ever possible.

Materials mixed in concrete Cement

Current investigation, the cement used is OPC of grade 53, confirmation of IS:12269 (1987) and cement is tested in accordance with standard procedure. The physical and chemical compositions of the cement used were performed and described in Tables.

Physical Properties of Cement

Sr.No	Name of the property	Value	As per IS: 12269-1987
1	Specific Gravity	3.15	3.10 - 3.15
2	Standard Consistency. (%)	30	30 -35
3	Initial setting time(min.)	33	30 (Min.)
4	Final Setting Time(min.)	385	600 (Max.)
5	Compressive strength (7 days in MPa)	43.50	43 MPa
6	Compressie strength-28 days (MPa)	57.50	53 MPa

7	Fineness m ² /kg	270.80	225
8	Soundness (mm)	1.00	10

Chemical composition of 53 grade cement

Sr.No.	Composition	Value in (%)	Asper IS:12269-1987
1	CaO	62.55	-
2	SiO ₂	19.85	-
3	Na ₂ O	0.28	-
4	K ₂ O	0.40	-
5	MgO	0.91	6 (Max)
6	Al ₂ O ₃	5.65	-
7	Fe ₂ O ₃	5.20	-
8	SO ₃	1.95	-
9	Ignition loss	0.65	5 (Max)
10	Residue	0.31	2 (Max)

Coarse Aggregates

As a coarse aggregate, solid broken natural granite stone of 20 mm graded metal was used. The gradation to be satisfied to 20 mm metal as per IS:383(2002). The percentage of materials are selected for aggregate by blending and finally arrived as 20 mm (50%) and 12.50 mm (50%) and the gradation satisfied to IS:383 (2002). The material collected from the crusher at Panamarathupatty, Salem, Tamil Nadu, India and stacked at Laboratory for Research work. The physical properties of coarse aggregate are calculated and is presented in Table.

Analysis of Sieve was conducted to assess the particle size or gradation of coarse aggregates in the materials obtained. In addition, sieve analysis is used to obtain the gross average of less than 20 mm in length.

Fine aggregates

As a fine aggregate is the material size varies from 4.75 mm to 150 microns. Sieve analysis was conducted with set of sieves of sizes 4.75, 2.36, 1.18 mm and 600,300- and 150-microns sieves on conventional sand and M-sand to understand the particle size distribution and to find out the fineness modulus and also to classify the zone to which they belong to. More details about the sieve analysis are included in the following subsections.

Properties of Coarse Aggregate

Sr.No.	Name of the property	Value
1	Specific Gravity	2.70
2	Bulk density, Kg/m ³	15.10
3	Water absorption (%)	0.45
4	Elongation Index and Flakiness	14.80
5	Surface moisture (%)	0.09
6	Impact Value	12.50
7	Crushing value	21.67
8	Fineness modulus	6.67

Natural river sand

In the current investigation, natural river sand endorsing criteria IS: 383 (2002) was used. For the present work, the Natural River sand obtained from Cauvery River near Karur, which is Tamil Nadu's sand center, is used. Table 3.4 and 3.5 respectively tabulate the physical properties and chemical composition of natural river sand. Hence forth the natural sand to be termed as conventional sand in this entire experimental works. The sieves were arranged in descending order with the largest size sieve on top. The sand was poured in the top sieve and then closed it with sieve plate. The machine was switched on and the shaking of the sieves was done for 5 minutes. After sieving, weights retained on each sieve were recorded. Cumulative weight retained was computed. Finally, the cumulative passing percentage retained on each sieves was determined. It was discovered from the study that the natural sand belongs to zone II.

Physical Properties of conventional Sand

Sr.No	Name of the Property	Value
1	Bulk Density, Kg/m ³	1460
2	Specific Gravity	2.60
3	Fineness particles less than 150microns (%)	4.14
4	Fineness Modulus	3.44
5	Moisture content (%)	1.10
6	Water absorption (%)	1.15

Table 3.5 Chemical composition of conventional sand

Sl. No	Constituent	Value (%)
1	SiO ₂	95.06
2	MgO	0.34
3	CaO	1.05
4	Al ₂ O ₃	1.54
5	Fe ₂ O ₃	0.80
6	Na ₂ O	0.35
7	K ₂ O	0.56
8	TiO ₂	-
9	Loss of ignition	0.30

Manufactured sand

Vertical shaft crusher mass produced sand (VSI) was collected from nearby quarry in Panamarathupatty, Salem. A foreseen engineered sand is used as a replacement for sand to replace natural river sand with fine aggregates. It has bulk density 1556 kg / m³, a general gravity of 2.45 and a fineness unit of 3.54. Tables, demonstrate the physical characteristics and chemical composition of the treated soil. The sample of M-sand used in the study can be seen in Fig. The characterization of manufactured sand is studied and the general properties of manufactured sand used in this study are evaluated and presented as follows. The Particle size distribution and analysis for manufactured sand is found and it shows that confirms to zone II. The properties of the manufactured sand are as follows:

Physical characteristics of manufactured sand

Sl. No	Name of the Property	Value
1	Specific Gravity	2.45
2	Bulk Density Kg/m ³	1556

3	Water absorption (%)	1.00
4	Fineness Modulus	3.54
5	Moisture content (%)	1.15
6	Fineness particles less than 150 microns (%)	5.30

Chemical composition of manufactured sand

Sl. No	Constituent	Value (%)
1	SiO ₂	91.80
2	Al ₂ O ₃	3.48
3	Fe ₂ O ₃	2.65
4	CaO	0.40
5	MgO	0.50
6	Na ₂ O	-
7	K ₂ O	0.15
8	TiO ₂	0.25
9	Loss of Ignition	0.77

Water

Water is a vital concrete element that actually interacts with cement. Water should be free from oil, vinegar, alkalis, clay and loam or any other vegetable matter and used to be very good for concrete preparation and water quality with a pH value of 7.0, fresh potable acid-free water, organic material is used in all scientific investigations for mixing concrete and curing. Water's physical properties are analyzed and the findings are described in table 3.8.

Properties of Potable Water

Sr.No	Name of the Property	Value	Limit (IS: 456:2000)
1	pH Value	7.00	Not less than 6.00
2	Dissolved Solids(organic), mg/lit	10	Nottoexceed200
3	Dissolved Solids (in-organic), mg/lit	1084	Not to exceed 3000
4	Suspended solids mg / lit	30	Not to exceed 2000
5	Chlorides as Cl mg / lit	36	Not to exceed 2000for PC and 500 for RCC
6	Sulphates as SO ₄ , mg / lit	64	400
7	Alkalinity as CaCO ₃ , mg / lit	52	250

Admixture

Super Plasticizer (SP) used as water reducing and strength improvement agent for concrete. A naphthalene sulphonate based SP was used in this work and it conforms to IS:9103 (1999). The dosage of super plasticizer used is arrived from marsh cone test. Used to improve the workability of high-performance concrete, a Super plasticizer is an easily dispersible brown substance in air with a specific gravity of 1.18. The super plasticizer is used in concrete grades M30, M40 and M50. The super plasticizer specification is illustrated in Table.

Specification of Super plasticizer

Sl. No	Name of the Property	Value
1	Physical state	Brown in color
2	Specific gravity	1.18
3	pH	6.50
4	Relative density	1.10
5	Chloride content	0.002

Compressive Strength Test

According to compressive strength, concrete mixing strength is generally measured. Therefore, the compressive strength is a subjective indicator of the hardened concrete's properties. The compressive strength of the concrete is measured according to IS:516 (2006) specification. Cast the cubes of 150 mm x 150 mm x 150 mm. After 24 hours, the specimens were demolished and then fully healed in the healing tank at room temperature for the required number of days before the test. For each mix combination at the age of 7, 28 and 90 days, the concrete, compressive strength of concrete cubes is measured using 200-300 T power compression testing machines is shown in Fig. 3.7. The compressive strength was then measured using equation below as specified in Eqn. Split tensile strength

This is the indirect way to measure concrete's tensile strength. The cylindrical concrete sample of 150 mm x 300 mm height is used to estimate the split tensile strength. This experiment is carried out by positioning the cylindrical sample between the compression testing machine's charging layer horizontally. The load is applied together with the vertical diameter until concrete's cylindrical specimen has collapsed. To minimize the intensity of high strength near the loading point, between the sample and the loading plate of the device, two plywood strips of 300 mm long and 12 mm wide are used. This experiment is carried out in compliance with IS:516 (2006). Figure 3.8 demonstrates the Split Tensile Experiment test. The magnitude of the tensile stress acting in a direction perpendicular.

IV. EXPERIMENTAL RESULTS

Materials considered for the investigation proved the efficacy in achieving the desired strength and durability. Fresh concrete properties such as working capacity, mechanical properties, i.e. compressive strength, tensile strength splitting, flexural strength and MOE have been performed and results are discussed in detail in this section. Furthermore, results pertain to drop-weight test; durability studies and the microscopic studies are presented and discussed in detail. Results reported related all the tested properties using correlated equations and microstructure analysis in this investigation.

Workability is evaluating the unset concrete's strength. Slump cone test is a readily available method for testing the concrete strength at the work site. Slump is the difference in height between the slump cone and the height of concrete after removal from the slump cone. Accordingly, the slump cone test method is used in this analysis to assess the workability of M30, M40 grades of concrete are tested for the specific M-sand mix ratios ranging from 0 percent -100 percent for the incremental 10 percent increase for M1 to M11 mixes. Table 5.1 shows the results of slump test for all mixes of concrete grades M30, M40.

Fig. shows the performance of all mix proportion in the workability aspect. It is revealed that the outcomes of slump test for various grades of concrete such as M30, M40, at various levels of replacements of manufactured sand from 0% to 100% at the incremental increase of 10% for the test conducted for the concrete with super plasticizer the workability increases.

Compressive Strength

The compressive strength of concrete was measured after 7 days, 28 days and 90 days. The effects of processed sand on the compressive strength of concrete mixtures of grades M30, M40 were experimentally tested for the mix ratios of grades M1, M2, M3, M4, M5, M6, M7, M8, M9, M10 and M11 at 7 days, 28 days, and 90 days. Such findings are compared with results of 28 days of traditional sand compressive strength and the results are addressed as follows in detail. The concrete mix of 1 m³ built with the IS requirements for traditional sand concrete mix M1 (0 percent manufactured sand) is 390 kg of cement, 544 kg of fine aggregates and 1277 kg of coarse aggregates with a water binder ratio of 0.40 and 1.00% by weight admixture of cement is used for a target strength of 38.25 MPa at 28 days of age. For M30 concrete, Table reviews and tabulates the results of concrete with manufactured sand. Evaluation of findings shown at the age of 7 days, the maximum compressive strength shown for (M8) is 37.80 MPa and for full level of replacement (M11) is 35.80 MPa compared to conventional sand concrete, M1 is 33.50 MPa, for concrete with manufactured sand shows 12.84% and 6.87% more strength than conventional sand concrete.

Split Tensile Strength:

The split tensile strength of concrete grades M30, M40 and M50 is experimentally tested with cylindrical concrete specimens of 150 mm diameter x 300 mm height with super plasticizer for 7, 28 and 90 days at specific replacement rates of treated sand varying from 0 to 100% with incremental 10% rise. Table 5.5 shows the results of the concrete grade M30 split tensile strength test. The split tensile strength of the concrete grade M30 is shown in Fig. 5.8. That's it. From the figure it was observed that the split tensile strength for concrete grade M30 increases from 0 percent to 70 percent of the replacement level of manufactured sand and gradually decreases to a replacement level of 100 percent for concrete. The Split concrete tensile strength with super plasticizer for optimum replacement level rises by 16.19 percent, 21.55 percent and 6.50 percent respectively, compared to conventional sand concrete with super plasticizer at age 7, 28 and 90 days. Concrete split tensile strength increases up to 70% of investigation replacements and decreases slightly from 70% to 10% of replacements, but this is also more than conventional sand concrete.

The split tensile strength rises by 15.65%, 10.61% and 9.40% respectively at 7, 28 and 90 days of concrete for maximum concrete replacement level compared to conventional sand concrete for M40 grade Concrete. And the split tensile strength increases by 10.98 percent, 7.27 percent, and 1.99 percent for 7, 28, and 90 days respectively with standard concrete sand concrete with total sand replacement. From the above studies, concrete split tensile strength increases to a replacement level of 70 percent (M8) and decreases slightly above 70 percent to a replacement level of 100 percent (M11), which is also higher than standard sand concrete (M1). Current study yielded more split tensile strength up to a replacement level of 70 percent, and increased concrete tensile strength as compressive strength decreases.

V. CONCLUSION

This study demonstrates that manufactured sand (M-sand) can effectively replace natural river sand in concrete across various grades (M30, M40). The experimental results indicate that both partial and full replacement of natural sand with M-sand improves mechanical properties, including compressive, tensile, and flexural strength, due to enhanced particle packing and better interfacial bonding. Durability performance is also significantly improved, with reduced water absorption, lower sorptivity, and higher resistance to acid and chloride attacks. Microstructural analysis confirms that the angular shape and rough texture of M-sand contribute to a denser concrete matrix and stronger bond with cement paste. Although workability variations are observed, overall performance improves at higher replacement levels. The findings suggest that M-sand not only enhances strength and durability but also offers a sustainable and environmentally friendly alternative to natural sand. Therefore, M-sand can be confidently recommended as a full or partial replacement of fine aggregate in concrete for durable and high-performance construction applications.

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