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A CRITICAL REVIEW ON EFFECTS OF REPLACEMENT OF NATURAL SAND WITH MANUFACTURED SAND ON STRENGTH PARAMETERS OF CONCRETE

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ABSTRACT

The global construction industry is currently grappling with a critical shortage of natural river sand, a crisis compounded by the severe environmental degradation resulting from unregulated riverbed mining. As the industry seeks sustainable alternatives, Manufactured Sand (M-sand) has emerged as a frontrunner. This paper provides a comprehensive evaluation of M-sand produced through the systematic crushing of hard stone as a functional replacement for fine aggregates in concrete. Unlike the rounded grains of river sand, the angular geometry and micro-surface roughness of M-sand facilitate a superior mechanical interlocking within the cementitious matrix, potentially enhancing both durability and structural integrity. Through a comparative analysis of M20 and M22 concrete grades, this study investigates the performance shifts associated with incremental replacement levels (25%, 50%, 75%, and 100%). The synthesised data suggests that a 50% substitution ratio represents a "sweet spot," consistently achieving optimal compressive strengths, specifically 19.2 N/mm² for M20 and 21.2 N/mm² for M22 mixes over a 28day curing period. Additionally, the study explores the synergistic effects of incorporating silica fume as a mineral admixture to further refine the concrete's pore structure.

The findings conclude that transitioning to Msand not only mitigates the ecological footprint of sand extraction but also offers a technically robust and economically viable solution for the future of sustainable infrastructure.

Keywords: Manufactured Sand (M-sand), Sustainable Concrete, Compressive Strength, Fine Aggregate Replacement, Construction Materials

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1. INTRODUCTION

Concrete is the most widely used construction material, and fine aggregate significantly influences its quality and strength. Natural river sand, though traditionally used, is becoming scarce, costly, and environmentally harmful due to over-extraction. To address this, Manufactured Sand (M-sand) has emerged as a sustainable alternative. It is produced by crushing hard stones to achieve a consistent quality free from silt and clay.

M-sand ensures better availability, supports cost optimisation by reducing transportation and material expenses, and promotes waste reduction by utilising quarry by-products. Unlike natural sand's smooth particles, Msand's angular and rough texture improves bonding with the cement paste, leading to comparable or higher strength parameters such as compressive, tensile, and flexural strength. Thus, replacing natural sand with M-sand is an effective solution for sustainable and durable concrete.

2. MATERIAL

Cement:

The binder used in this study was Ordinary Portland Cement (OPC). Cement acts as the chemically active constituent, which, upon hydration, forms the calcium-silicate-hydrate (C-S-H) gel responsible for the structural integrity of the matrix.

The cement was stored in an airtight environment to prevent pre-hydration due to atmospheric moisture. Its physical properties were evaluated as per IS 4031-1988. The specific gravity, a critical parameter for mix design calculations, was determined to be 3.15. The bulk density was recorded at 1440 kg/m³. These values indicate a high-quality mineral composition consistent with standard construction-grade cement.

Fine Aggregates:

This research focuses on the transition from traditional Natural River Sand (N-Sand) to Manufactured Sand (M-Sand). Fine aggregates are defined as those particles passing through a 4.75 mm IS sieve.

Natural River Sand (N-Sand)

The N-Sand utilised was sourced from local riverbeds and complied with IS 383-1970 Zone II. Geologically, river sand particles are rounded or cubical due to natural weathering and water attrition, which generally aids workability but may limit the mechanical interlock.

- Specific Gravity: 2.46
- Water Absorption: 6.5% (The relatively higher absorption suggests the presence of porous silica or organic impurities).
- Void Ratio: 36.70%, indicating a moderately packed skeletal structure.

Manufactured Sand (M-Sand)

M-Sand is produced by crushing hard granite rocks using Three-Stage VSI (Vertical Shaft Impactor) technology. This process results in particles that are angular and have a rougher surface texture compared to N-Sand.

- Specific Gravity: 2.87 (The higher density suggests a more robust mineral structure).
- Water Absorption: 5.5% (Lower than N-Sand, indicating a denser, less permeable particle).
- Void Ratio: 87.97%. The significantly higher void ratio in M-Sand is attributed to its angularity and flaky particles, which prevent tight nesting unless combined with a well-graded paste. This property necessitates careful proportioning to ensure a dense concrete matrix.

Coarse Aggregates

Coarse aggregates provide the "skeleton" of the concrete, contributing to its volumetric stability and compressive strength. For this study, crushed angular granite was used.

- Size: A maximum nominal size of 20 mm was maintained to ensure a balanced grading and to prevent honeycombing within the 150mm cube specimens.

- Bulk Density: Ranging from 1650 kg/m³ to 1800 kg/m³, reflecting the high mass-to-volume ratio of the crushed stone.
- Specific Gravity: 2.85.
- Shape and Texture: The angular shape provides superior mechanical interlocking between the aggregate and the mortar phase, which is vital for enhancing the Interfacial Transition Zone (ITZ).

Mineral Admixture: Silica Fume

To optimise the micro-structural density of the M-Sand concrete, Silica Fume (also known as Micro-silica) was incorporated. Silica fume is a byproduct of the production of silicon metal or ferrosilicon alloys. 4

Mechanism of Action:

1. Pozzolanic Effect: During the hydration of cement, Calcium Hydroxide, Ca (OH)₂ is released as a byproduct. While Ca (OH)₂ contributes little to the strength of concrete and can be susceptible to leaching, the high reactive silica content in Silica Fume undergoes a secondary chemical reaction with it. This pozzolanic reaction produces additional Calcium-Silicate-Hydrate (C-S-H) gel, which is the primary mineral phase responsible for the strength and binding properties of the cement paste. This process not only densifies the matrix but also strengthens the bond at the Interfacial Transition Zone (ITZ).

2. Filler Effect: In addition to its chemical reactivity, Silica Fume acts as an ultra-fine physical filler. The individual particles of Silica

Fume are approximately 100 times smaller than the average cement grain. Because of this extreme fineness, the particles are able to infiltrate and occupy the microscopic voids between cement particles that would otherwise remain as capillary pores. This "microfiller" action significantly reduces the permeability of the concrete and increases its packing density. By filling these interstitial spaces, Silica Fume creates a more homogenous and less porous structure, which is particularly effective in compensating for the higher void ratio observed in Manufactured Sand (M-Sand) mixes. 1

3. METHODOLOGY

The research follows a systematic process including material collection, testing of physical properties, mix design, and cube testing.

1. IS Codes Referred: The study referred to IS 456:2000 for target strength and cement content calculations, and IS 10262:2009 for water-cement ratio and aggregate proportions.

2. Mix Design: Grade M20: Used a standard ratio of 1:1.5:3.

- Grade M22: Designed with a water-cement ratio of 0.47, resulting in a calculated mix ratio of 1 : 1.61: 2.91 (Cement: Fine Aggregate: Coarse Aggregate).

3. Replacement Levels: Natural sand was replaced by M-sand at levels of 25%, 50%, 75%, and 100%. 6

4. Sampling and Casting: Materials were weighed, sieved, and mixed thoroughly.

- Concrete was filled into cube moulds in layers and compacted using a tamping rod.



Cubes were demoulded and marked for identification.

Fig.1 Materials were weighed



Fig.2 cube compacted using a tamping rod



Fig.3 Cubes were demoulded and marked for identification

4. Curing and Testing:

- Specimens underwent a curing process to ensure strength development
- Compressive strength tests were performed at intervals of 7, 14, and 28 days to analyse the effect of different replacement levels.



Fig.4 Curing Process of Cubes



Fig.5 Compressive strength tests were performed at intervals of 7, 14, and 28 days

4. RESULTS AND DISCUSSIONS

All experimental procedures were carried out in accordance with standard protocols. The results for compressive strength, obtained across different replacement levels and curing periods, are detailed in the following sections.

4.1 Compressive Strength Analysis

The mechanical performance of the concrete mixes was primarily evaluated through compressive strength testing, conducted in accordance with IS 516-1959 standards. Cubical specimens measuring 150 mm × 150 mm × 150 mm were cast and subjected to a standardised curing regime. The testing was performed using a calibrated Compression Testing Machine (CTM) with a capacity of 2000 KN. To monitor the kinetic development of strength, the specimens were tested at chronological intervals of 7, 14, and 28 days post-casting.

Table 1: Compressive Strength Results for M20 Grade Concrete (N/mm²)

Sr. No.	Replacement Level (N-Sand : M-Sand)	7 Days	14 Days	28 Days
1.	25% N-Sand: 75% M-Sand	8.4	14.4	18.3
2.	50% N-Sand: 50% M-Sand	9.2	13.4	19.2
3.	0% N-Sand: 100% M-Sand	6.7	13.9	16.4
4.	100% N-Sand : 0% M-Sand (Control)	7.9	16.4	19.9

Table 2: Compressive Strength Results for M22 Grade Concrete (N/mm²)

This mix included Silica Fume as an admixture to enhance performance. The calculated mix ratio was 1 : 1.61 : 2.91.

Sr. No.	Replacement Level (N-Sand: M-Sand)	7 Days	14 Days	28 Days
1.	25% N-Sand: 75% M-Sand	10.2	16.1	19.8
2.	50% N-Sand: 50% M-Sand	11.3	14.2	21.2
3.	0% N-Sand: 100% M-Sand	8.9	12.9	20.6
4.	100% N-Sand : 0% M-Sand (Control)	12.6	16.9	21.8

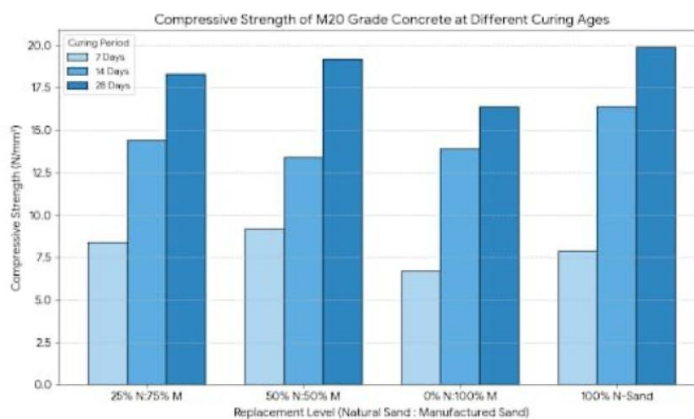


Figure 1: Compressive Strength of M20 Grade Concrete at 7, 14, and 28 Days for Various Sand 5 Replacement Levels

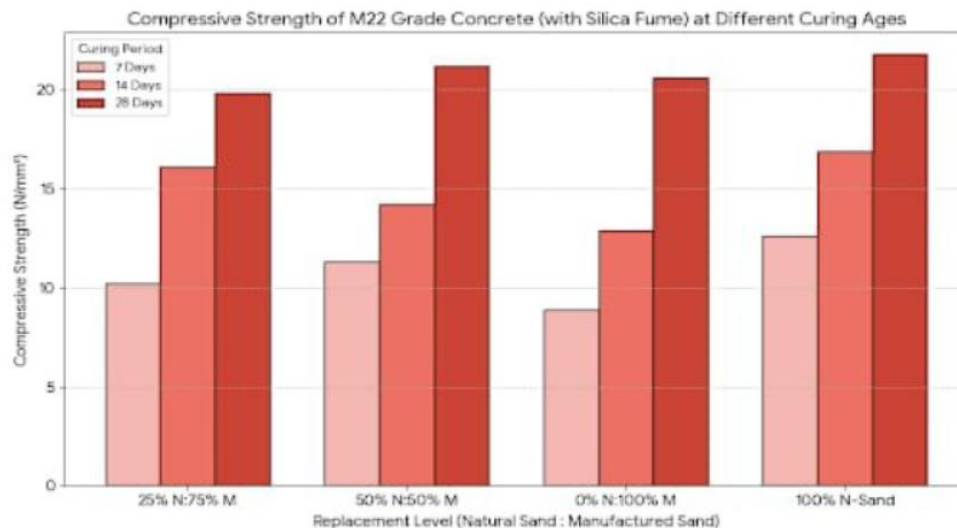


Figure 2: Compressive Strength of M22 Grade Concrete with Silica Fume across Different Curing Ages and Sand Ratios.

4.2. Discussion of Strength Development

The experimental data indicate that the strength of concrete progressively increases with age across all replacement levels.

- **Optimal Replacement:** For the standard M20 concrete, the results show that replacing half of the natural sand with M-sand (50% replacement) is the best choice. This 50/50 mix reached a strength of 19.2 N/mm², which is almost the same as the 100% natural sand mix (19.9 N/mm²). This proves that we can use M-sand to save natural resources without losing the strength needed for construction.
- **Influence of Admixtures:** In our study, the M22 grade mixes performed better than the standard M20 mixes because we added Silica Fume (a special mineral powder). This additive acts like a "super-filler" that makes the concrete much stronger. For example, when we replaced 50% of the sand with M-Sand in the M22 mix, the strength reached 21.2 N/mm² after 28 days. This shows that adding Silica Fume helps the concrete handle more weight and stay more durable.
- **Performance of 100% M-Sand:** While the 100% M-Sand replacement initially showed lower early-age strength (7 days), it demonstrated significant gain by 28 days, reaching 20.6 N/mm² in the M22 design. This suggests that the angular texture of M-Sand provides a strong mechanical bond that matures over time.

4.3. Observations

The inclusion of M-Sand, especially when balanced with natural sand or enhanced with silica fume, maintains the structural requirements of the concrete. The rough surface and angularity of the M-Sand particles improve the Interfacial Transition Zone (ITZ) bonding, contributing to the overall durability and strength parameters observed in the 28-day results.

5. CONCLUSION

The extensive experimental analysis conducted throughout this study underscores a pivotal shift in modern concrete technology, positioning Manufactured Sand (M-sand) not merely as a substitute but as a superior engineering asset. The empirical evidence demonstrates that a 50% replacement threshold acts as a definitive "optimum equilibrium." At this specific concentration, the structural integrity of both M20 and M22 concrete grades is effectively maintained, achieving 28-day compressive strengths of 19.2 N/mm² and 21.2 N/mm², respectively. These results are fundamentally rooted in the distinctive physical morphology of M-sand; unlike the smooth, hydro-eroded grains of river sand, the angular geometry and micro-surface asperities of crushed rock facilitate a robust mechanical interlocking within the cementitious matrix.

Beyond the immediate mechanical advantages, the transition toward Msand represents a critical response to the global ecological crisis. By adopting a controlled manufacturing process that yields particles free from deleterious organic impurities like silt and clay, the construction industry can actively mitigate the environmental devastation caused by unregulated riverbed extraction. While traditional natural sand remains a benchmark for strength, the 50% M-sand blend, particularly when reinforced with silica fume, delivers a nearly identical performance profile with a significantly reduced carbon and economic footprint. Ultimately, this research concludes that M-sand is a technically sound, reliable, and sustainable fine aggregate that adheres to the rigorous standards of IS 456:2000, offering a viable path forward for the future of green infrastructure.

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