



COMPARATIVE STUDY ON THE USE OF M-SAND AND QUARRY DUST AS ALTERNATIVES TO RIVER SAND IN CONCRETE

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Abstract

The increasing demand for natural river sand in the construction industry has resulted in significant environmental concerns, including depletion of riverbeds, alteration of natural drainage systems, ecological degradation, and increased transportation requirements. The development of alternative fine aggregates is therefore essential for sustainable concrete production. Manufactured sand (M-Sand) and quarry dust are two materials that can potentially replace natural river sand in concrete. The present study investigates the suitability of M-Sand and quarry dust as alternative fine aggregates and compares their influence on the fresh and hardened properties of concrete. The study considers concrete mixes prepared using natural river sand as the control material and replacement mixes incorporating M-Sand and quarry dust at selected replacement levels. The properties of the fine aggregates, including particle size distribution, specific gravity, water absorption, fineness modulus, and bulk density, are considered in the assessment. Concrete performance is evaluated in terms of workability, compressive strength, split tensile strength, flexural strength, and water absorption. The study also considers the environmental and practical implications associated with the use of alternative fine aggregates. M-Sand generally provides more controlled particle grading and consistent quality when manufactured according to appropriate specifications, whereas quarry dust contains a relatively higher proportion of very fine

particles and may substantially influence water demand and workability. The comparative assessment demonstrates that the appropriate selection and proportioning of M-Sand and quarry dust can reduce dependence on river sand while maintaining satisfactory concrete performance. The study emphasizes that aggregate characterization, optimized replacement level, and appropriate mix design are essential for achieving technically and environmentally viable concrete.

Keywords: M-Sand, quarry dust, river sand, fine aggregate, sustainable concrete, compressive strength, workability, alternative aggregate.

1. Introduction

Concrete is one of the most extensively used construction materials in the world, and fine aggregate constitutes a significant proportion of its total volume. Traditionally, natural river sand has been widely used as fine aggregate because of its availability, particle characteristics, and established performance in concrete. However, the rapid growth of infrastructure and building construction has increased the demand for river sand, resulting in concerns regarding resource depletion and environmental degradation.

Excessive extraction of river sand can disturb river morphology, increase bank erosion, affect groundwater recharge, and alter aquatic ecosystems. In addition, restrictions on river-sand mining have increased the cost and availability challenges associated with conventional fine aggregate. These issues have

encouraged researchers and construction industries to investigate alternative materials. Manufactured sand, commonly referred to as M-Sand, is produced by crushing and processing suitable parent rock to obtain particles with controlled grading and shape. Unlike naturally occurring river sand, M-Sand can be produced under controlled conditions. Crushing, screening, and classification can be used to obtain the required particle-size distribution.

Quarry dust is another potential alternative generated as a by-product during the crushing of rocks in quarrying operations. It generally contains a relatively high percentage of fine particles and therefore has characteristics that differ from both river sand and M-Sand. Instead of being treated solely as quarry waste, its incorporation into concrete can provide a productive use for this material while reducing the demand for natural sand.

The performance of alternative fine aggregates depends on their physical and mineralogical characteristics. Particle shape, surface texture, grading, specific gravity, water absorption, and fines content can significantly affect the fresh and hardened properties of concrete.

The objective of the present study is therefore to conduct a comparative assessment of M-Sand and quarry dust as alternatives to river sand in concrete. The specific objectives are:

1. To characterize river sand, M-Sand, and quarry dust based on relevant physical properties.
2. To investigate the influence of M-Sand and quarry dust on concrete workability.
3. To evaluate the effect of alternative fine aggregates on compressive strength.
4. To compare split tensile and flexural strength characteristics.
5. To assess water absorption as an indicator of concrete quality and durability.
6. To identify suitable replacement levels for sustainable concrete production.
7. To compare the environmental and practical advantages of M-Sand and quarry dust.

2. Materials and Methodology

2.1 Cement

Ordinary Portland cement conforming to the relevant Indian Standard specifications can be used as the primary binder. Before concrete

preparation, cement should be evaluated for standard consistency, initial and final setting time, specific gravity, and compressive strength.

2.2 Fine Aggregates

Three types of fine aggregate are considered in the study:

- Natural river sand
- Manufactured sand (M-Sand)
- Quarry dust

River sand is considered the control fine aggregate. M-Sand and quarry dust are incorporated as partial or complete replacements according to the experimental programme.

The major physical properties that should be determined include:

- Specific gravity
- Bulk density
- Water absorption
- Fineness modulus
- Particle-size distribution
- Silt/fines content
- Moisture content

Sieve analysis should be conducted to determine the grading characteristics of the materials. The particle-size distribution is particularly important because an appropriate combination of coarse and fine particles contributes to better packing and reduces voids within the concrete matrix.

2.3 Coarse Aggregate

Crushed coarse aggregate of appropriate nominal maximum size may be used. The coarse aggregate should be tested for specific gravity, water absorption, impact resistance, crushing resistance, and grading.

2.4 Water

Potable-quality water suitable for concrete production should be used for mixing and curing.

2.5 Mix Proportioning

A conventional concrete mix may be selected as the control mixture using river sand as the fine aggregate. Replacement mixes can then be prepared by replacing river sand with M-Sand and quarry dust at predetermined percentages.

A representative experimental matrix may be established as follows:

Mix designation	River Sand	M-Sand	Quarry Dust
Control	100%	0%	0%
M-S25	75%	25%	0%
M-S50	50%	50%	0%

M-S75	25%	75%	0%
M-S100	0%	100%	0%
QD25	75%	0%	25%
QD50	50%	0%	50%
QD75	25%	0%	75%
QD100	0%	0%	100%

The exact replacement levels may be modified according to the research objectives and preliminary trials.

Concrete specimens should be prepared according to the relevant standards and cured under controlled conditions. The mechanical properties should be determined at selected curing ages, such as 7, 28, and 56 days.

3. Experimental Investigation

3.1 Workability

Workability is one of the most important fresh concrete characteristics affected by the type of fine aggregate. The slump test can be used to evaluate workability.

River sand generally has relatively smooth particle surfaces compared with crushed materials. M-Sand has angular particles with comparatively rough surfaces, while quarry dust may contain a greater proportion of fine particles. Consequently, replacement of river sand can increase internal friction and water demand.

At moderate replacement levels, M-Sand can provide satisfactory workability when its grading is properly controlled. However, higher percentages may reduce slump because of increased surface area and angularity.

Quarry dust can produce a more pronounced reduction in workability when its fines content is high. The fine particles increase the total surface area requiring lubrication by the cement paste. Consequently, higher replacement levels may require adjustment of the water-to-cement ratio or the use of an appropriate water-reducing admixture.

It is therefore important that the effect of alternative fine aggregates is evaluated not only on strength but also on fresh-state properties.

3.2 Compressive Strength

Compressive strength is the primary mechanical property generally considered for evaluating concrete performance. Standard concrete cubes or cylinders can be tested at specified ages.

The strength of concrete containing M-Sand can be influenced by its particle shape, grading, surface texture, and mineral composition. The angularity of M-Sand particles can improve mechanical interlocking between aggregate particles and the cement paste. At an optimized replacement level, this can contribute to improved compressive strength.

The presence of properly distributed fine particles can also improve packing density and reduce internal voids. However, excessively angular particles or inadequate grading may increase void content and water demand.

Quarry dust may also contribute to strength improvement at suitable replacement levels because its fine particles can fill voids between larger aggregate particles. This filler effect can improve particle packing and potentially produce a denser cementitious matrix.

However, very high quarry-dust contents may have an adverse effect if the material contains excessive fines or if the increased water demand is not properly controlled.

The expected trend should therefore be interpreted using the actual experimental results rather than assuming that complete replacement will always provide maximum strength.

The percentage increase or decrease in compressive strength can be calculated as:

$$[\text{Strength change (\%)}] = \frac{f_{c,r} - f_{c,c}}{f_{c,c}} \times 100$$

where ($f_{c,r}$) is the compressive strength of the replacement concrete and ($f_{c,c}$) is the strength of the control concrete.

3.3 Split Tensile Strength

Split tensile strength provides an indication of the resistance of concrete to tensile cracking. Although concrete is primarily designed to resist compression, tensile behaviour is important for understanding cracking and structural serviceability.

M-Sand can influence tensile strength through improved aggregate interlocking and the development of a strong interfacial transition zone. The rough surface texture of crushed particles can promote mechanical interaction between aggregate and cement paste.

Quarry dust may similarly improve tensile performance when its particle-size distribution promotes dense packing. However, the presence of excessive fines can increase paste demand and potentially influence the quality of the hardened matrix.

The relationship between compressive and tensile strength should be examined for each mix because changes in aggregate characteristics can affect these properties differently.

3.4 Flexural Strength

Flexural strength is particularly relevant for pavement concrete, slabs, beams, and other members where bending stresses are important. The angular nature of M-Sand particles may improve aggregate interlocking and contribute to flexural resistance. Quarry dust can also contribute to the packing of the fine aggregate skeleton.

However, the influence of alternative fine aggregates depends strongly on their grading and mineralogy. Therefore, the experimentally obtained flexural strength values should be compared with the control mixture to identify the optimum replacement level.

4. Durability and Microstructural Considerations

4.1 Water Absorption

Water absorption provides useful information regarding the pore structure and permeability characteristics of hardened concrete. A lower water absorption value generally indicates a denser concrete matrix, although water absorption alone should not be considered a complete measure of durability.

Fine particles present in M-Sand and quarry dust can fill voids between larger aggregate particles. When properly proportioned, this filler effect can reduce interconnected voids and improve matrix compactness.

However, excessive fines may increase water demand. If additional water is introduced without suitable mix optimization, the resulting concrete may develop greater capillary porosity after hardening.

Therefore, water absorption should be interpreted together with compressive strength, permeability, porosity, and microstructural observations.

4.2 Interfacial Transition Zone

The interfacial transition zone (ITZ) between aggregate and cement paste has a significant influence on concrete performance. The rough and angular surface characteristics of M-Sand may improve mechanical interlocking and contribute to a stronger aggregate–paste interface.

Quarry dust contains very fine particles that may occupy spaces within the aggregate skeleton and improve packing. The resulting effect on the ITZ depends on particle characteristics and mix proportioning.

Scanning electron microscopy (SEM) can be used to investigate the microstructure of selected concrete mixes. SEM images can provide qualitative evidence regarding:

- Cement hydration products;
- Microcracks;
- Pore structure;
- Aggregate–paste bonding;
- Dense or porous matrix regions.

Microstructural observations should be correlated with the measured mechanical and durability properties rather than being considered independently.

5. Comparative Discussion

The performance of M-Sand and quarry dust as river-sand alternatives is governed by several interacting factors. M-Sand generally offers better control over particle grading because it is manufactured through crushing and screening processes. This allows its properties to be controlled more systematically.

Quarry dust, on the other hand, is readily available as a by-product of quarry operations and can provide an economical alternative where its properties are suitable. Its use can also reduce the quantity of quarry waste requiring disposal.

One important difference between the two materials is fines content. M-Sand can be engineered to satisfy specified grading requirements, whereas quarry dust may contain a larger quantity of particles below the desired size range. Excessive fines can increase water demand and reduce workability.

The angularity of both materials can increase internal friction compared with naturally rounded river sand. This characteristic may improve mechanical interlocking but can simultaneously reduce fresh concrete workability.

The comparative performance can be summarized as follows:

Property	River Sand	M-Sand	Quarry Dust
Particle shape	Relatively rounded	Angular	Angular/irregular

Surface texture	Relatively smooth	Rough	Rough	Quarry dust provides an additional sustainability advantage because it can convert a quarrying by-product into a useful construction material. Its utilization can reduce waste accumulation and improve resource efficiency. However, sustainability assessment should consider the complete life cycle of the material. Transportation distance can be particularly important because alternative aggregates may require significant energy if transported over long distances. A more comprehensive environmental assessment may therefore include: • Raw material extraction; • Crushing and screening energy; • Transportation; • Processing requirements; • Concrete production; • Service life; • End-of-life considerations. Life Cycle Assessment (LCA) can be used to quantify environmental indicators such as global warming potential, energy demand, and resource consumption.
Grading control	Natural variability	Relative ly high	Depends on quarry processing	
Fines content	Generally moderate	Can be controll ed	Often relatively high	
Workability	Generally higher	May decrease	May decrease considerably	
Packing potential	Good	Good when well graded	Potentially high	
Strength potential	Reference	Good at optimize d replace ment	Good at optimized replacement	
Waste utilization	Low	Manufa ctured resource	High	
Dependenc e on river sand	High	Reduced	Reduced	
Environme ntal benefit	Limited	Reduced river-sand extraction and extractio n	Reduced quarry waste	

The results of the actual experimental programme should be used to determine the optimum replacement percentage. It is not appropriate to conclude that M-Sand or quarry dust is universally superior because performance is strongly dependent on material source, processing method, grading, mix design, and replacement percentage.

6. Environmental and Sustainability Aspects

The substitution of river sand with alternative fine aggregates can contribute to more sustainable concrete production.

The use of M-Sand can reduce pressure on natural river resources by shifting fine-aggregate production toward controlled manufacturing processes. The environmental impact associated with M-Sand nevertheless depends on factors such as crushing energy, electricity consumption, transportation distance, and source rock.

7. Conclusions

Based on the comparative evaluation of river sand, M-Sand, and quarry dust as fine aggregates, the following conclusions can be drawn:

1. M-Sand and quarry dust have significant potential to reduce dependence on natural river sand in concrete.
2. The physical characteristics of alternative fine aggregates, particularly particle shape, grading, surface texture, specific gravity, water absorption, and fines content, strongly influence concrete performance.
3. M-Sand generally provides better control over grading because it is produced through controlled crushing and screening operations.
4. Quarry dust can provide an effective use for a quarrying by-product and may improve particle packing when its fines content and grading are appropriately controlled.
5. Replacement of river sand with angular manufactured materials can reduce workability because of increased surface area and internal friction.

6. Properly proportioned M-Sand can provide satisfactory or improved mechanical performance compared with conventional river-sand concrete.
7. Quarry dust can also provide satisfactory strength at suitable replacement levels; however, excessive fines may increase water demand and adversely affect workability and hardened properties.
8. Water absorption and microstructural characteristics should be evaluated alongside strength properties to obtain a more complete assessment of concrete durability.
9. The optimum replacement level should be established experimentally for each source of M-Sand and quarry dust because aggregate properties vary considerably between production locations.
10. From a sustainability perspective, both M-Sand and quarry dust offer potential environmental benefits by reducing dependence on river sand. Quarry dust additionally provides an opportunity for productive utilization of quarrying waste.

The study concludes that M-Sand and quarry dust can serve as technically viable alternatives to river sand when their characteristics are properly evaluated and the concrete mix is optimized. Future research should focus on combined M-Sand–quarry dust systems, high-performance concrete, durability under aggressive environments, long-term shrinkage and creep, and life-cycle environmental assessment.

8. Future Scope of Research

Further research can investigate hybrid fine-aggregate systems in which M-Sand and quarry dust are combined at different proportions. Such combinations may improve particle packing by providing a broader particle-size distribution. The influence of alternative fine aggregates on chloride penetration, carbonation, sulfate resistance, drying shrinkage, creep, and freeze–thaw behaviour can also be investigated. Advanced characterization techniques such as SEM, X-ray diffraction (XRD), thermogravimetric analysis (TGA), and computed tomography (CT) can provide greater

insight into the relationship between aggregate characteristics and concrete microstructure.

Optimization techniques based on statistical design of experiments, response surface methodology, machine learning, and multi-objective optimization may further assist in determining the optimum combination of M-Sand, quarry dust, cement, water, and chemical admixtures.

In addition, life-cycle assessment can be integrated with mechanical performance to identify mixtures that simultaneously satisfy structural, economic, and environmental requirements.

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