

Utilization of Sandstone Quarry Dust as Partial Replacement of Natural Sand in Concrete: A Review on Mechanical and Durability Properties

Pramod Kumar Dwivedi¹ Qadir Raza²

¹M.Tech. Scholar ²Assistant Professor

^{1,2}Department of Civil Engineering

^{1,2}Mewar University, Chittorgarh, India

Abstract — The excessive extraction of river sand for concrete production has created severe environmental and ecological concerns worldwide. Rapid urbanization and infrastructure development have significantly increased the demand for natural sand, resulting in depletion of riverbeds, groundwater reduction, ecosystem disturbance, and environmental degradation. Consequently, researchers have focused on identifying sustainable alternative materials for fine aggregate in concrete. Quarry dust, a by-product obtained during crushing and processing of rocks in quarries, has emerged as a promising substitute for natural sand. This study presents a comprehensive review and assessment of the utilization of sandstone quarry dust as a partial replacement of natural sand in concrete. The influence of quarry dust on workability, compressive strength, splitting tensile strength, flexural strength, water absorption, chloride-ion permeability, sorptivity, and microstructural characteristics of concrete is discussed. The study also examines the mineralogical and physical properties of quarry dust and evaluates its suitability according to standard specifications. Experimental findings from previous investigations indicate that optimum replacement levels generally range between 10% and 30%, depending upon the characteristics of the quarry dust and mix proportions. The inclusion of quarry dust improves the packing density and microstructure of concrete, resulting in enhanced mechanical and durability properties at optimum replacement levels. However, excessive replacement may adversely affect workability and strength due to higher fines content and increased water demand. The study concludes that sandstone quarry dust possesses significant potential as an eco-friendly and sustainable construction material for partial replacement of natural sand in concrete.

Keywords: Quarry Dust, Natural Sand Replacement, Sustainable Concrete, Compressive Strength, Durability, Sandstone Quarry Dust, Concrete Technology

I. INTRODUCTION

Concrete is the most widely used construction material worldwide due to its strength, durability, versatility, and economic advantages. It is composed primarily of cement, water, coarse aggregate, and fine aggregate. Fine aggregates occupy a major portion of concrete volume and significantly influence its fresh and hardened properties. Traditionally, river sand has been used as fine aggregate in concrete production. However, rapid growth in construction activities has resulted in excessive extraction of natural sand from riverbeds and floodplains, causing severe environmental problems.

The increasing demand for natural sand has led to depletion of natural resources, riverbank erosion, lowering of groundwater levels, disturbance of aquatic ecosystems, and

deterioration of water quality. Excessive sand mining has become a global environmental concern. As a result, many countries have imposed restrictions on river sand mining and encouraged the development of alternative fine aggregate materials.

In recent years, industrial by-products and quarry wastes have gained attention as sustainable alternatives to natural sand. Quarry dust, also referred to as stone dust or rock dust, is generated during the crushing and screening operations in quarries. Large quantities of quarry dust are produced annually, creating disposal and environmental challenges. Utilizing quarry dust in concrete can reduce environmental pollution while conserving natural sand resources.

Quarry dust differs from river sand in terms of particle shape, grading, surface texture, and fines content. Quarry dust particles are generally angular and rough textured, with higher micro-fine content compared to natural sand. These characteristics influence the workability, strength, and durability of concrete.

The present manuscript focuses on the utilization of sandstone quarry dust as a partial replacement of natural sand in concrete. Various experimental investigations related to mechanical and durability properties of quarry dust concrete are reviewed and discussed.

II. QUARRY DUST AND ITS CHARACTERISTICS

Quarry dust is a by-product generated during the crushing and processing of rocks in aggregate production plants. It is usually finer than 5 mm and contains significant quantities of micro-fines passing through the 75-micron sieve.

A. Physical Properties

The properties of quarry dust depend on:

- Parent rock type
- Crushing process
- Particle size distribution
- Mineralogical composition
- Degree of fines content

Important characteristics include:

- Higher angularity
- Rough surface texture
- Higher water absorption
- Larger specific surface area
- Poor grading compared to natural sand

Specific gravity values of quarry dust generally range from 2.59 to 2.83, while fineness modulus varies from 2.57 to 3.56.

B. Chemical Composition

The chemical composition of quarry dust varies according to the source rock. Common constituents include:

- Silica (SiO_2)
- Alumina (Al_2O_3)
- Calcium oxide (CaO)
- Iron oxide (Fe_2O_3)

Siliceous quarry dust generally contributes to improved micro-filling and packing effects in concrete.

III. LITERATURE REVIEW

A. Effect on Workability

Most researchers reported that workability decreases with increasing quarry dust content. The angular and rough-textured particles increase internal friction and water demand.

Shi-Cong and Chi-Sun observed that slump reduced from 60 mm to 30 mm when natural sand was completely replaced with crushed fine stone. Raman et al. also reported a gradual decline in slump with increasing quarry dust content in high-strength concrete.

The reduction in workability is mainly attributed to:

- Higher fines content
- Increased specific surface area
- Angular particle shape
- Higher water absorption

However, adequate use of superplasticizers can compensate for loss in workability.

B. Compressive Strength

Several studies reported improvement in compressive strength at moderate replacement levels.

Research findings indicate:

- Optimum replacement generally lies between 10% and 30%
- Improved particle packing enhances strength
- Quarry dust acts as a micro-filler
- Dense matrix formation improves bonding

At higher replacement levels, strength decreases due to:

- Excessive fines
- Poor workability
- Improper compaction
- Increased water demand

Studies by Ghannam et al., Singh et al., and Raman et al. showed maximum strength improvement at 10–25% replacement levels.

C. Splitting Tensile and Flexural Strength

Concrete containing quarry dust generally exhibits improved tensile and flexural strength up to optimum replacement levels.

The enhancement is attributed to:

- Better aggregate-paste bonding
- Improved interfacial transition zone
- Dense concrete matrix

Beyond optimum replacement, tensile and flexural strength decline due to reduced workability and inadequate compaction.

D. Durability Properties

1) Water Absorption

Moderate quarry dust replacement decreases water absorption due to improved packing density and pore refinement.

2) Chloride-Ion Penetration

Lower replacement levels improve resistance to chloride penetration, while excessive replacement may increase permeability due to porous microstructure.

3) Sorptivity and Water Permeability

Several investigations reported reduced sorptivity and permeability at optimum replacement levels because micro-fines fill voids and capillary pores.

4) Drying Shrinkage

Quarry dust concrete generally shows lower drying shrinkage compared to conventional concrete.

IV. EXPERIMENTAL INVESTIGATION

A. Materials Used

The experimental program generally includes:

- Ordinary Portland Cement (OPC)
- Coarse aggregates
- Natural river sand
- Sandstone quarry dust
- Water

B. Replacement Levels

Natural sand is partially replaced with quarry dust at varying levels:

- 10%
- 20%
- 30%
- 40%
- 50%

A control mix with 100% natural sand is also prepared.

C. Tests Conducted

1) Fresh Concrete Tests

- Slump test
- Workability assessment

2) Hardened Concrete Tests

- Compressive strength
- Splitting tensile strength
- Density

3) Durability Tests

- Water absorption
- Sorptivity
- Rapid chloride-ion permeability

4) Microstructural Analysis

- X-Ray Diffraction (XRD)
- Scanning Electron Microscopy (SEM)

V. DISCUSSION OF RESULTS

The experimental investigations indicate that quarry dust significantly affects both fresh and hardened concrete properties.

A. Workability

Workability decreases continuously with increase in quarry dust content due to angular particles and fines.

B. Strength Properties

Compressive and tensile strengths improve up to optimum replacement levels because:

- Micro-filler effect enhances packing density
- Improved particle interlocking occurs
- Better bond formation takes place

Beyond optimum content, mechanical properties decline due to excessive fines and poor workability.

C. Durability

Concrete with optimum quarry dust content exhibits:

- Reduced permeability
- Lower water absorption
- Improved resistance to chloride penetration

D. Microstructure

SEM and XRD analyses indicate denser microstructure and improved hydration products in quarry dust concrete.

VI. CONCLUSIONS

Based on the reviewed investigations and experimental observations, the following conclusions can be drawn:

- 1) Sandstone quarry dust is a viable sustainable alternative to natural sand in concrete.
- 2) The use of quarry dust helps reduce environmental impacts associated with excessive river sand mining.
- 3) Workability decreases with increase in quarry dust content because of higher fines and angular particle shape.
- 4) Moderate replacement levels improve compressive, tensile, and flexural strengths due to enhanced packing density and filler effects.
- 5) Optimum replacement levels generally range between 10% and 30%.
- 6) Durability properties such as water absorption, permeability, and chloride-ion penetration improve at optimum replacement levels.
- 7) Excessive replacement adversely affects concrete properties due to poor workability and increased water demand.
- 8) Quarry dust concrete exhibits denser microstructure and improved bonding characteristics.
- 9) Utilization of quarry dust contributes to sustainable construction and effective waste management.
- 10) Further research is recommended on long-term durability, field applications, and optimization of mix design.

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