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# UTILIZATION OF SANDSTONE QUARRY DUST AS A PARTIAL REPLACEMENT FOR NATURAL SAND IN CONCRETE: EFFECTS ON WORKABILITY, STRENGTH, AND DURABILITY

**Anandita*[1], SatyaPal Singh*[2], Panshul Jamwal*[3], Rohit Sharma*[4]**

*[1]M.Tech Student, Department Of Civil Engineering, Baddi University, Baddi, Solan (HP), India.

*[2,3]Assistant Professor, Department Of Civil Engineering, Baddi University, Baddi, Solan (HP), India.

*[4]HOD & Assistant Professor, Department Of Civil Engineering, Baddi University, Baddi, Solan (HP), India.

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## ABSTRACT

"A Study on Sandstone Quarry Dust" is a study focused on investigating the use of sandstone quarry dust as a partial replacement for natural sand in concrete. The study aims to address issues related to excessive sand mining and environmental impacts, while exploring quarry dust as a sustainable alternative for natural sand in construction.

The research tests concrete mixes with different substitution rates of sandstone quarry dust (10%, 20%, 30%, 40%, and 50%) and evaluates various properties, including workability, compressive strength, tensile strength, water absorption, chloride-ion permeability, and durability. The study also conducts X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses to observe changes in cement phases and microstructure.

Key findings highlight that quarry dust can improve concrete properties under specific conditions. This concludes with recommendations for optimal substitution rates to balance strength, durability, and workability, presenting sandstone quarry dust as a viable partial replacement for natural sand in concrete production. The study investigates the potential of using sandstone quarry dust as a sustainable partial replacement for natural sand in concrete. This research aims to mitigate the environmental impacts of excessive sand mining by exploring alternative materials.

Results indicate that replacing natural sand with quarry dust can improve certain properties of concrete, especially with an optimal replacement level around 40%. The study concludes that sandstone quarry dust is a viable, environmentally friendly alternative for partial sand replacement in concrete, with minimal impact on workability and significant improvements in density, strength, and durability under specific conditions.

**Keywords:** Stone Dust, Concrete Mix, Sand Replacement, Compressive Strength, Workability, Portland Composite Cement (PCC), River Sand, Waste Management, Slump Test, Sustainable Concrete Materials.

## I. INTRODUCTION

Sustainable development refers to growth that satisfies the needs of the current generation without jeopardizing the ability of future generations to fulfill their own needs. The goal of sustainable development is to enhance the quality of life while supporting energy and resource use that ensures the long-term survival of humanity [1-6].

Today, concrete is one of the most widely used construction materials globally, including in Indonesia. As infrastructure projects increase, so does the demand for concrete. The primary component of concrete is aggregate, typically sourced from natural materials. Sand, often extracted from rivers, is the second-most used material in concrete after coarse aggregate. Consequently, the construction industry must explore alternative materials to replace natural sand to promote sustainable development. Utilizing industrial by-products like stone dust as a replacement for natural sand in concrete offers advantages, including lower production costs [7] and reduced environmental issues from stone dust waste [8].

At PT Mega Beton Jaya, a stone crushing company, three stone crusher machines produce an average of 150 $m^3$ of stone dust per day per machine. The company faces challenges in securing enough land to store this stone dust, as shown in Figure 1 below. Additionally, the stone dust generated causes air pollution, affecting the surrounding community. Thus, incorporating this stone dust into concrete could alleviate local environmental concerns related to air quality around the stone crusher facility. Stone dust waste from the crushed stone industry poses challenges for both the industry and nearby communities. PT Mega Beton Jaya faces difficulties in securing adequate land to accommodate the waste generated by their stone crushing operations. The facility's three crushers produce approximately 150 $m^3$ of stone dust per day per machine, as shown in Figure 1 above.

The demand for concrete in India is growing rapidly. Consequently, the need for key concrete materials, such as sand, is also rising. To prevent depletion of these natural resources, efforts must be made to partially replace them, supporting sustainable development initiatives.

## II. METHODOLOGY

Numerous studies have explored the impact of using stone dust as a partial sand replacement in concrete mixtures. Sankh et al. examined various alternative materials—such as copper slag, ground granulated blast furnace slag (GGBS), washed bottom ash, quarry dust, and foundry sand—as potential replacements for natural sand in concrete. Their findings revealed that replacing sand with quarry dust could enhance the compressive strength of concrete. However, quarry dust also tends to reduce the workability of the mix due to its water absorption properties. Based on their results, they recommended using quarry dust at a replacement level between 55% and 75%. For full replacement (100%), they suggested combining fly ash with quarry or stone dust to replace a portion of the cement along with sand.

Suman concluded that the optimal replacement level for sand with stone dust is 60%, which provides the maximum compressive strength for concrete. They also recommended using a superplasticizer dosage of 1–1.5% by the weight of cementitious materials to achieve this strength. Similar findings were reported by Srivastava, who observed that substituting 8–100% of natural sand with stone dust could increase the compressive strength of concrete by 8–27%. The impact of stone dust on concrete durability was examined by Shanmugapriya. They found that increasing stone dust content in concrete mixtures reduced electric current permeability at 28 and 90 days, indicating lower chloride ion permeability and thus greater concrete durability.

## III. MODELING AND ANALYSIS

**Cement**

- Ordinary Portland Cement Grade 43 (OPC 43) manufactured by UltraTech Cement Limited
- Physical properties tested according to Bureau of Indian Standard specifications:
- Fineness (BIS 4031-Part 1:1996)
- Soundness (BIS 4031-Part 3:1988)
- Standard consistency (BIS 4031-Part 4:1988)
- Initial and final setting time (BIS 4031-Part 5:1988)
- Compressive strength (BIS 4031-Part 6:1988)
- Specific gravity (BIS 4031-Part 11:1988)

**Aggregates**

1. Coarse Aggregates
- Combination of 20mm and 10mm nominal size aggregates
- Physical properties tested:
- Sieve analysis (BIS 2386-Part 1:1988)
- Specific gravity (water basket method)
- Water absorption
- Bulk density (BIS 2386-Part 3:1963)

2. Fine Aggregates
- Natural sand and sandstone quarry dust
- Physical properties tested for both materials:
- Sieve analysis (BIS 2386-Part 1:1988)
- Specific gravity (pycnometer method)
- Water absorption
- Bulk density (BIS 2386-Part 3:1963)

**Mix Design**

- Grade of concrete: M30
- Target slump: 100mm
- Exposure conditions: Moderate
- Mix design procedure followed as per IS 10262:2009
- Concrete mixes prepared with varying percentages of sandstone quarry dust:
- Control mix (100% natural sand)
- QD10 (10% quarry dust replacement)
- QD20 (20% quarry dust replacement)
- QD30 (30% quarry dust replacement)
- QD40 (40% quarry dust replacement)
- QD50 (50% quarry dust replacement)

**Specimen Preparation**

**Mixing Procedure**

- Laboratory drum mixer used
- Dry mixing of aggregates followed by cement addition
- Water added carefully to achieve uniform consistency
- Water corrections applied based on aggregate moisture content

**Casting and Curing**

- Steel moulds used, properly cleaned and oiled
- Two-layer casting with vibrating table compaction
- 24-hour mould removal
- Water curing as per test requirements

**Test Specimens**

1. Compressive Strength: 150mm × 150mm × 150mm cubes
2. Splitting Tensile Strength: 150mm diameter × 300mm height cylinders
3. Water Absorption: 70.6mm × 70.6mm × 70.6mm cubes
4. Sorptivity: 100mm diameter × 50mm height cylinders
5. Rapid Chloride-Ion Permeability: 100mm diameter × 50mm height cylinders

**Testing Methods**

**Fresh Properties**

- Workability tested using slump test (BIS 1199:1959)
- Measurements taken immediately after mixing

**Hardened Properties**

1. Compressive Strength (BIS 516:1959)
- Testing ages: 7, 28, and 90 days
- Loading rate: 140 kg/cm$^2$/min
- Average of 3 specimens reported
2. Splitting Tensile Strength (BIS 5816:1999)
- Testing ages: 7, 28, and 90 days
- Loading rate: 1.2-2.4 N/mm$^2$/min
- Average of 3 specimens reported
3. Density
- Measured at 1 day
- Average of 3 specimens reported

**Durability Properties**

1. Water Absorption (ASTM C642-13)
- Testing ages: 7 and 28 days after initial 28-day curing
- Average of 3 specimens reported

2. Sorptivity (ASTM C1585-04)
- Testing ages: 7 and 28 days after initial 28-day curing
- Measurements taken at 5, 10, 20, 30, 60, 120, 180, 240, and 360 minutes
- Average of 2 specimens reported

3. Rapid Chloride-Ion Permeability (ASTM C1202-97)
- Testing age: 28 days
- 6-hour test duration
- 60V potential difference applied
- Average of 2 specimens reported

**Microstructural Analysis**

1. X-Ray Diffraction (XRD)
- Testing ages: 28 and 90 days
- Cement paste analyzed using CuKα radiation
- Diffraction angle 2θ: 10° to 80°
- Step size: 2θ=0.013°

2. Scanning Electron Microscopy (SEM)
- Testing ages: 28 and 90 days
- Core samples analyzed at various magnifications

## IV. RESULTS AND DISCUSSION

### 4.1 General

This chapter presents the findings from the experimental tests conducted to evaluate the performance of concrete mixes incorporating sandstone quarry dust as a partial replacement for natural sand. The study assessed the fresh properties (workability), hardened properties (compressive strength, density, and splitting tensile strength), durability characteristics (chloride-ion permeability, water absorption, and sorptivity), and microstructural changes (using X-ray diffraction and Scanning Electron Microscopy).

### 4.2 Properties of Raw Materials

#### 4.2.1 Cement

The Ordinary Portland Cement (OPC) Grade 43 used in this study was tested for various properties, such as fineness, soundness, setting times, compressive strength, and specific gravity, following Bureau of Indian Standards (BIS). The results confirmed that the cement conformed to the necessary standards, making it suitable for concrete preparation.

#### 4.2.2 Coarse Aggregate

Coarse aggregate consisting of a blend of 20mm and 10mm nominal sizes was used. Tests on the aggregates included sieve analysis, specific gravity, water absorption, and bulk density as per BIS 2386 (Parts 1 and 3):1963. The properties of the aggregates were found to comply with the standards for use in concrete.

#### 4.2.3 Fine Aggregate

Natural sand sourced locally was evaluated for its physical properties, including sieve analysis, specific gravity, water absorption, and bulk density, in accordance with BIS 2386 (Parts 1 and 3):1963. The sand used complied with the IS 383:1970 standards, confirming its suitability as fine aggregate in concrete.

#### 4.2.4 Sandstone Quarry Dust

Sandstone quarry dust was obtained from a local crushing plant in Mansa, Punjab. The dust was analyzed for particle size distribution, specific gravity, and water absorption. X-ray diffraction (XRD) was employed to determine the mineral content, while Scanning Electron Microscopy (SEM) was used to study particle shape and texture.

### 4.3 Fresh Properties of Concrete

#### 4.3.1 Workability

The workability of concrete was evaluated using the slump test. Results showed that increasing the replacement of natural sand with sandstone quarry dust led to a decrease in slump, thereby reducing workability. This reduction can be attributed to the angular shape and higher fines content of quarry dust, which increases the water demand of the concrete mix.

### 4.4 Hardened Properties of Concrete

#### 4.4.1 Compressive Strength

Compressive strength tests were performed on concrete cube specimens at 7, 28, and 90 days. The results indicated that replacing natural sand with sandstone quarry dust up to a level of 40% improved the compressive strength. At this replacement level, the concrete exhibited a strength increase of approximately 15% compared to the control mix. However, further increasing the replacement percentage beyond 40% resulted in a decline in compressive strength due to reduced workability and increased brittleness.

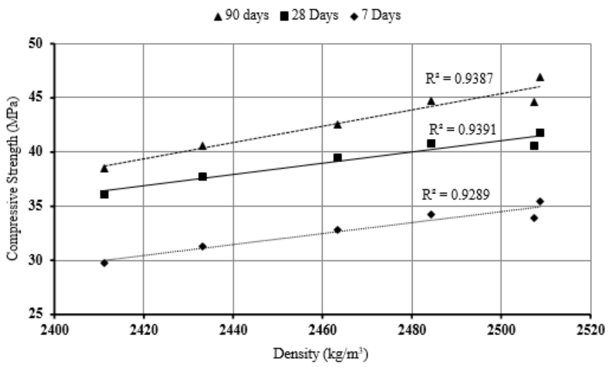


**Fig. 1** Relation between 1-day Density and Compressive Strength of Concrete at all Ages

#### 4.4.2 Splitting Tensile Strength

The splitting tensile strength of concrete was tested on cylindrical specimens at 7, 28, and 90 days. The results indicated that concrete mixes containing up to 40% quarry dust as sand replacement showed an improvement in tensile strength compared to the control mix. Beyond this replacement level, the tensile strength gradually decreased.

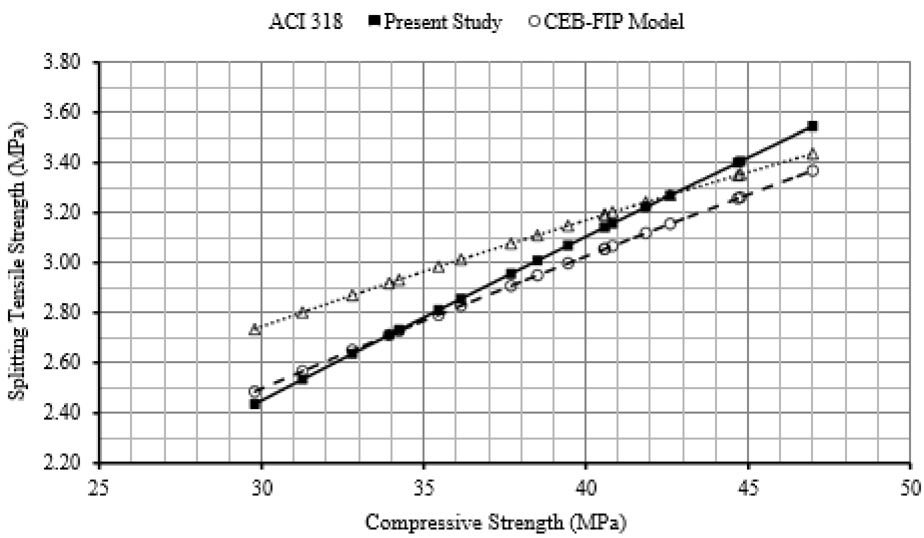


**Fig. 2** Comparison between Equation Proposed by Present Study and Relations given in OtherStandard Literatures

### 4.5 Durability Properties of Concrete

#### 4.5.1 Water Absorption

Water absorption tests were conducted to evaluate the permeability of concrete. The results demonstrated that increasing the replacement of natural sand with quarry dust reduced water absorption, indicating a denser microstructure. The mix containing 40% quarry dust replacement showed the lowest water absorption values.

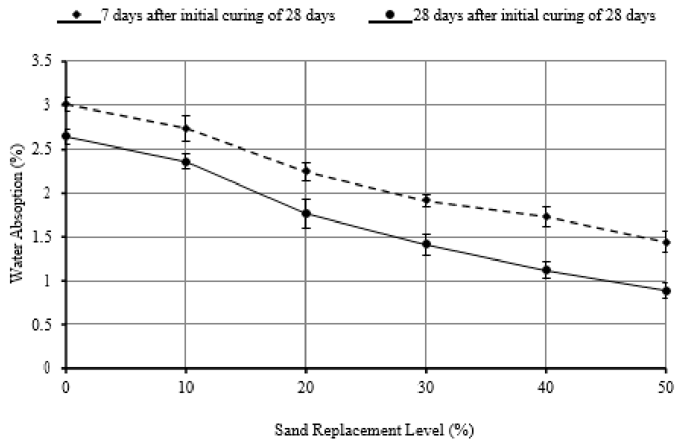


**Fig. 3** Effect of Replacement of Natural Sand with Sandstone Quarry Dust on Water Absorptionof Concrete

### 4.5.2 Sorptivity

Sorptivity tests, which measure the rate of water absorption through capillary action, revealed that concrete containing up to 40% quarry dust had lower sorptivity values, thus enhancing its durability.

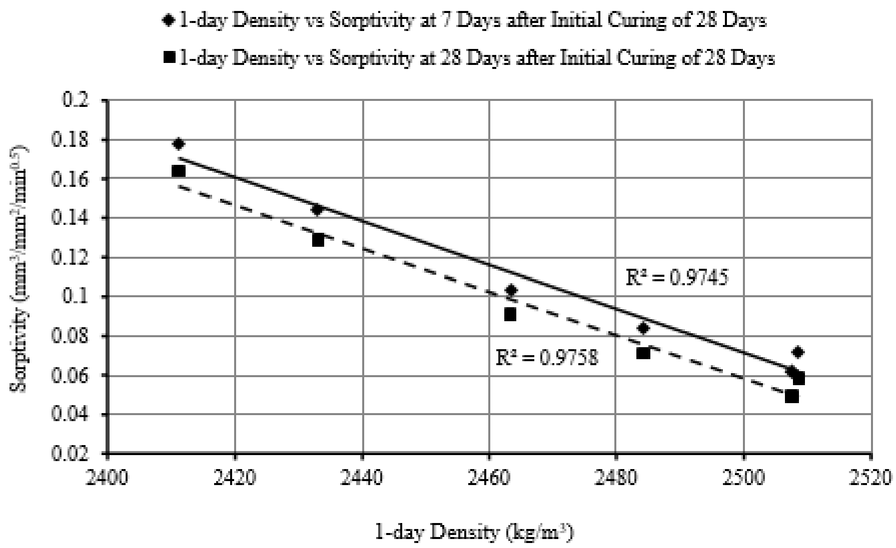


**Fig.4** Relation between 1-day Density and Sorptivity of Concrete Mixes

### 4.5.3 Rapid Chloride-Ion Permeability

Rapid chloride-ion permeability tests were conducted to assess the concrete's resistance to chloride ingress. Results showed that concrete mixes with up to 40% quarry dust exhibited significantly lower chloride permeability, indicating enhanced durability and reduced risk of steel reinforcement corrosion.

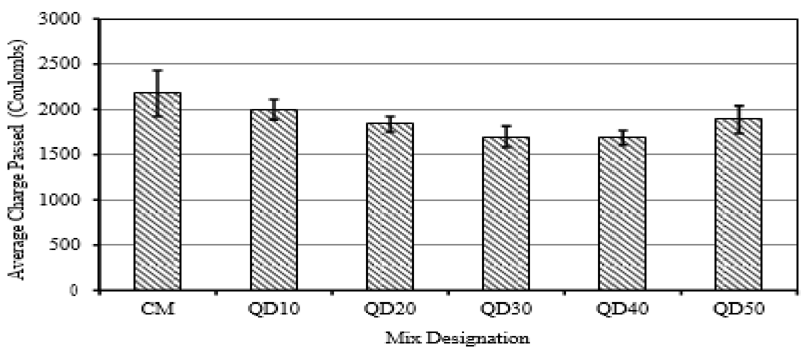


**Fig.5** Rapid Chloride-ion Permeability Test Results for Concrete Mixes at 28 Days

## V. CONCLUSION

- Workability of concrete was decreased as the percentage replacement of natural sand with sandstone quarry dust was increased. The increase in specific surface area of fine aggregate due to the micro-fines present in quarry dust and the angular shape of quarry dust particles increased the water demand of concrete and consequently resulted in decrease in workability. However, workability of all concrete mixes up to 50% sand replacement was suitable in structural uses.
- Density of concrete was increased with increase in replacement of natural sand with sandstone quarry dust. Density of concrete mix with 40% sand replacement level was maximum, which recorded a 4% increase in density as compared to control mix. Filling effect of quarry dust micro-fines to produce a dense microstructure and the higher specific gravity of quarry dust as compared to natural sand was the reason behind the increase in density of concrete.
- Compressive strength of concrete was increased with inclusion of sandstone quarry dust as partial replacement of natural sand. Concrete mix with 40% sand replacement level had maximum compressive strength at all ages. The increase in compressive strength of concrete was mainly attributed to increase in density of concrete with the inclusion of quarry dust and better conditions for hydration of cement in the presence of quarry dust micro-fines.
- Splitting tensile strength of concrete was increased with inclusion of sandstone quarry dust as partial replacement of natural sand. Concrete mix with 40% sand replacement level had maximum splitting tensile strength at all ages. The increase in splitting tensile strength of concrete was mainly attributed to increase in density of concrete with the inclusion of quarry dust and better conditions for hydration of cement in the presence of quarry dust micro-fines, same as in case of compressive strength.
- Water absorption of concrete was decreased with increase in replacement of natural sand with sandstone quarry dust at all ages. Concrete mix with 50% sand replacement level had lowest water absorption among all mixes. The filling effect of quarry dust micro-fines reduced voids, which consequently decreased water absorption of concrete.
- Sorptivity of concrete was decreased with increase in replacement of natural sand with sandstone quarry dust at all ages. Concrete mix with 50% sand replacement level had lowest sorptivity among all mixes. The reason behind the decrease in sorptivity was that the filling effect of quarry dust micro-fines not only reduced the size of the voids, but also modified the internal pore structure of concrete by blocking interconnecting capillary pores.
- Chloride-ion penetration resistance was increased with inclusion of sandstone quarry dust as partial replacement of natural sand. Concrete mix with 40% sand replacement level had minimum charge passed among all concrete mixes. The increase in chloride- ion penetration resistance can be mainly attributed to increase in density of concrete with replacement of natural sand with sandstone quarry dust.
- X-ray diffraction analysis showed that there is no qualitative change in various phases of cement in concrete mixes containing sandstone quarry dust as partial replacement of natural sand as compared to control concrete. Various phases present in all concrete mixes were identified as quartz, portlandite, calcium silicate hydrate, calcium silicate, calcium aluminium silicate hydrate and calcite. Thus, quarry dust can be considered as an inert material.
- SEM analysis of concrete mixes clearly demonstrated the filling effect of sandstone quarry dust micro-fines in concrete. Control mix had maximum voids at all ages, which decreased continuously as the replacement of natural sand with quarry dust was increased. Concrete mixes with 40% and 50% sand replacement seemed to have minimum voids and most dense microstructure among all mixes.

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