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ANALYSIS OF MECHANICAL PROPERTIES OF CONCRETE PARTIALLY REPLACED BY QUARRY DUST AND GROUND GRANULATED BLAST FURNACE SLAG

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Abstract
The research examined how natural sand replacement with sandstone quarry dust affected the mechanical properties and durability of M30 grade concrete. The study assessed different replacement levels which involved replacing natural sand with sandstone quarry dust at 10% 20% 30% 40% and 50% replacement levels. The researchers used BIS 10262 (2009) mix design guidelines to create concrete mixtures which they then tested for fresh properties through slump tests. The researchers conducted tests on hardened concrete to measure its density and compressive strength and splitting tensile strength and water absorption and sorptivity and rapid chloride permeability at three testing intervals of 7 days and 28 days and 90 days. The research team used X-ray diffraction (XRD) and scanning electron microscopy (SEM) to study microstructural features which included phase composition and morphological characteristics. The study results showed that quarry dust added to concrete increased its density and compressive strength which reached optimal performance levels at 40% sand replacement. The researchers found that splitting tensile strength reached its highest value at 40% substitution which demonstrated that quarry dust contributes to concrete strength improvement.
The durability tests showed that higher replacement percentages resulted in decreased water absorption and decreased sorptivity and decreased chloride permeability, which showed better environmental protection against degradation. The SEM analysis showed that quarry dust's smaller angular particles filled the concrete's empty spaces and created better concrete microstructure, which resulted in stronger cement pasteto-aggregate bonding. The XRD results showed that all replacement levels produced identical cement hydration products, which confirmed that quarry dust physically contributed to the concrete structure while it did not chemically react during hydration. The study found that replacing natural sand with up to 40% quarry dust produced sustainable concrete mixes, which improved both mechanical strength and durability of the material.

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Keywords: Quarry dust, Concrete, Compressive strength, Splitting tensile strength, Durability, Microstructure, X-ray diffraction, SEM

1. INTRODUCTION

The increasing environmental challenges which industrial and agricultural waste create have led to sustainable development becoming an essential requirement for contemporary construction methods. Every year, the world produces more than 300 million tons of industrial by-products which create problems for disposal and present health risks and lead to environmental damage. The civil engineering field requires professionals to create building materials which support both structural integrity and waste management solutions.

Concrete stands as the primary construction material which enables construction projects because of its fundamental properties of strength and enduring nature and its ability to serve multiple functions. Traditional concrete production requires substantial natural resources because it depends on the extraction of river sand and Portland cement. The use of quarry dust and Ground Granulated Blast Furnace Slag (GGBS) as partial replacements from industrial by-products creates a technoeconomic solution which solves both material shortages and waste disposal problems. GGBS which comes from steel manufacturing operations serves as an eco-friendly material since it produces minimal carbon emissions. The material enables sustainable concrete production because it decreases CO2 emissions when used in concrete compared to standard Portland cement. GGBS serves as a green construction material because it can be used in ready-mix concrete, precast elements, and soil stabilization, and other cement-based applications.

GGBS provides advantages that extend beyond its environmental benefits. The material improves concrete durability because it decreases thermal cracking and alkali-silica reaction and sulphate and chloride chemical attack resistance. Concrete that contains GGBS performs better and lasts longer in extreme environments, which makes it suitable for use in long-lasting infrastructure projects.

GGBS provides architectural benefits because it produces a lighter surface finish which enhances building safety through increased light reflectivity. The substance prevents crystalline buildup on concrete surfaces, which results in permanent concrete protection and lower upkeep needs. The use of GGBS in construction projects provides an environmentally friendly option that performs better than Portland cement.

GGBS exists as a pozzolanic substance which results from the quick solidification process that transforms molten blast furnace slag into its final form through grinding. The glassy structure of the material contains high silica and calcium and magnesium and aluminum content which activates cementitious reactions when it interacts with

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Portland cement and other activators. The combination of these properties creates a dependable mineral additive which improves the strength and workability and durability of concrete used in contemporary construction methods.

Quarry dust which comes from stone crushing operations serves as an affordable and eco-friendly replacement for natural sand. The low-cost availability of quarry dust enables waste material to be diverted from landfills while decreasing the need for river sand extraction. The use of quarry dust as fine aggregate in concrete enables resource conservation while maintaining the structural strength of the material.

2: REVIEW OF LITERATURE

2.1 Workability of Quarry Dust

Concrete workability declines when river sand gets replaced with quarry dust because the angular shape and rough texture of quarry particles with their increased surface area needs additional water for suitable mixing. Control concrete maintained a 60 mm slump but 100% quarry dust concrete showed a 30 mm slump reduction according to Shi-Cong 2009 study. Vijaya Lakshmi 2014 and Singh et al. 2016 observed that workability decreases when substitute materials increase which leads to higher superplasticizer requirements for successful handling and placement operations. The overall trend shows that while quarry dust functions as fine aggregate it decreases fluidity which requires modifications to the mix design.

2.2 Compressive Strength

Several studies report that moderate replacement of sand with quarry dust enhances compressive strength, whereas excessive replacement decreases it. Chi-Sun (2010) and Raman et al. (2011) found that 50% replacement optimized strength, while higher levels reduced compressive capacity. Vijayalakshmi (2014) observed that 15% strength increase occurred during early-age testing when 15% of material was replaced, while Rai et al. (2014) and Singh et al. (2016) discovered that 20% quarry dust provides optimal reactivity and filling capacity. The partial replacement of fine aggregate in concrete shows potential to enhance its compressive strength when replacement amounts stay within optimal limits.

2.3 Flexural Strength

The flexural strength of concrete shows dependency on quarry dust replacement, which produces no changes at low substitution levels, while higher substitution levels create strength reductions. Vijaya Lakshmi (2014) observed comparable flexural strength to control concrete at 5–15% replacement, while significant drops occurred beyond 20% due to reduced workability and poor compaction. Singh et al. (2017) discovered that optimum flexural strength occurred at 20% replacement because the initial strength increase resulted from the filler effect and rough texture of quarry

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particles, but higher replacement levels caused negative effects on bond strength and mix cohesion.

2.4 Splitting Tensile Strength

Artificially replacing sand with quarry dust creates better splitting tensile strength results up to a specific point because this process enhances both particle distribution and bonding between materials. Ghannam et al. (2016) reported 4%, 15%, and 29% improvements at 5%, 10%, and 15% replacement rates, respectively, after 28 days, which showed that angular particles of quarry dust created better mechanical interlock between aggregates and cement paste, resulting in higher tensile strength.

2.5 Elasticity Module

Cordeiro et al. (2017) showed that quarry dust replacement does not change the modulus of elasticity for concrete. The Young's modulus of concrete mixes with 10% 30% and 50% replacement showed similar values to the control mix, which indicates that different workability and strength characteristics of the concrete maintain its overall stiffness, thus proving quarry dust functions as an effective structural alternative.

2.6 Penetration of Chloride-ion

Chloride ion penetration increases when more materials are used because this practice creates less workable concrete which results in higher microstructural porosity. ChiSun (2010) reported a moderate increase in chloride permeability at 25% replacement while Vijaya Lakshmi (2014) found low permeability results which remained below 1500 Coulombs up to 15% replacement. The study demonstrated that concrete density decreases when more than optimal substitution levels are used, which creates a need to use quarry dust at specific levels that will protect against chloride corrosion damage.

2.7 Permeability

The permeability of concrete depends on quarry dust content because the fines in the material either obstructing pathway blocks or forming small voids depends on the specific proportions used in the mixture. Omar (2011) found that limestone fines decreased hydraulic conductivity because they filled empty spaces in the material while Vijaya Lakshmi (2014) discovered that permeability reached its highest level between 20 and 25 percent granite powder substitution. The study found that low to moderate quarry dust levels enhance impermeability, while excessive dust replacement leads to water tightness loss which results in durability problems.

2.8 Water Absorption

The increase in quarry dust content leads to reduced water absorption because the material fills empty spaces and creates a more compact structure. Cordeiro et al. (2017) reported reductions from 5.1% for control concrete to 3.4% for 50%

replacement which indicates improved resistance to water ingress. The densification effect decreases porosity which results in improved concrete durability and extended service life when used at optimal replacement levels.

2.9 Shrinkage

The study found that using quarry dust as a substitute for natural sand reduced drying shrinkage because crushed stone has bigger particles and smaller surface area compared to river sand. The fine quarry particles create a filling effect that makes the mixture denser which results in reduced water loss and volume changes during the curing process. The study shows that using moderate replacement levels helps to enhance dimensional stability while decreasing the risk of cracks in hardened concrete.

2.10 Resistance of Abrasion

The particles of quarry dust which have their hard texture and sharp edges create an increased resistance to concrete abrasion when they are added to concrete. Singh et al. (2017) reported that concrete with up to 40% quarry dust exhibited lower wear depth compared to the control mix, except at the highest replacement level where workability issues slightly reduced performance. The research shows that quarry dust enhances concrete surface durability which makes it appropriate for use in pavements and other areas that experience high wear.

2.11 Carbonation Depth

The carbonation depth of concrete rises when more quarry dust is used because the material becomes less compactable and harder to work with, which creates pathways for carbon dioxide to enter the concrete. Vijayalakshmi (2014) discovered that carbonation depth reached 8.9 to 10.2 millimeters after 365 days at 20 to 25 percent replacement, which brought it near rebar cover and increased the corrosion danger. Singh et al. (2016) demonstrated that better microstructure development at intermediate replacement levels establishes a link between quarry dust content optimization and sustainable durability outcomes.

2.12 Optimization Study of GGBS

Ground Granulated Blast Furnace Slag (GGBS) improves both strength and durability of concrete when used as a partial cement replacement. Saranya et al. (2017) reported optimum performance at 40% GGBS for compressive strength and 50% for tensile strength, while Anushai et al. (2018) found that SCC mixes with 40% GGBS and 20% fly ash exhibited enhanced mechanical properties. The studies show that GGBS functions as a practical mineral additive which supports sustainable concrete production when combined with quarry dust at optimized levels.

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3: METHODOLOGY

3.1 Overview

The primary objective of this study is to evaluate the mechanical and durability properties of concrete when partially replaced with quarry dust as fine aggregate and Ground Granulated Blast Furnace Slag (GGBS) as a partial cement replacement. The methodology uses systematic experimental investigations to measure strength and microstructural properties and corrosion resistance in the modified concrete mixes. The researchers used traditional mechanical testing methods together with advanced analytical approaches to assess the performance of sustainable concrete mixtures.

3.2 Materials

The study utilizes Portland cement as its primary material which combines with river sand as fine aggregate and with coarse aggregate and quarry dust and GGBS and water and required superplasticizer admixtures. Quarry dust serves as a partial replacement for natural sand, while GGBS is used as a partial replacement for cement. The selection of replacement percentages is based on previous studies highlighting optimal performance ranges for mechanical and durability properties.

3.3 Concrete Mix Design

Concrete mixes are prepared using different ratios of quarry dust and GGBS while maintaining a constant water-cement ratio to achieve workability. The mix design follows standard guidelines for concrete preparation to achieve proper compaction and uniformity. Superplasticizers are added to maintain the desired slump and facilitate placement, especially in mixes with higher percentages of quarry dust. The control mix uses conventional river sand and Portland cement as its basis for comparison.

3.4 Mechanical Tests

The structural performance of the concrete is assessed through these mechanical tests:

- The Compressive Strength Test measures the maximum load-bearing capacity of concrete through standard cube testing.
- The Split Tensile Strength Test measures tensile strength and cracking resistance of materials through testing on cylinders.
- The Flexural Strength Test evaluates the bending resistance of concrete beams through testing on prism samples.
- The Bond Strength Test evaluates how reinforcement interacts with concrete because this interaction is essential for understanding structural performance.

The tests deliver numerical data which assesses the strength and stiffness properties of the concrete mixtures.

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3.5 Microstructural Characterization

Microstructural properties of concrete are assessed to understand its durability and porosity:

- The Water Absorption Test measures concrete water absorption capacity which establishes its porosity and density characteristics.
- The Bulk Density Test calculates mass per unit volume which enables assessment of material compactness and empty space volume.
- Percentage of Permeable Voids: Evaluated to assess the potential for fluid ingress, which affects long-term durability.

The tests create a connection between mix composition and the material's ability to resist deterioration while exposed to environmental conditions.

3.6 Corrosion Resistance Evaluation

Corrosion performance of embedded steel reinforcement is studied using multiple methods:

- **Chloride Ion Penetration**: Measured by impressed voltage technique in a saline medium to simulate aggressive environments.
- **Weight Loss Method**: Determines the mass loss of steel specimens due to corrosion over time.
- **AC Impedance Spectroscopy**: Confirms the electrochemical behavior and corrosion resistance of steel in concrete.

These tests collectively provide a detailed understanding of the protective ability of concrete against steel corrosion.

3.7 Surface Analysis

The corrosion assessment uses Scanning Electron Microscope (SEM) testing to examine both concrete and embedded steel materials. SEM demonstrates its capability to deliver high-resolution images which scientists use to study microstructural elements and pore patterns and the degradation status of reinforcement surfaces. The system enables scientists to link their observed corrosion patterns with the specific concrete mix properties of the material.

3.8 Experimental Procedure

The experimental procedure requires researchers to prepare concrete mixes and cast test specimens before performing controlled curing and conducting mechanical and microstructural testing at planned time intervals. The research conducts corrosion studies by using reinforced specimens that researchers immerse into saline solutions. The tests comply with all applicable standards and guidelines which ensure both test accuracy and reproducible results.

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3.9 Data Analysis

The research team conducts statistical analysis on the test results which include mechanical performance testing and microstructural assessment and corrosion testing to determine existing patterns and the best replacement percentages. The assessment between standard control mixes and modified mixes demonstrates how quarry dust and GGBS improve concrete properties while achieving environmental sustainability. The study uses graphical representations and correlation analysis to show how mix design affects both mechanical performance and durability characteristics.

4. RESEARCH GAP

The research evaluated the performance of fresh concrete and strength properties when using quarry dust and GGBS as complete replacements for natural sand and cement. The research examined how different mineral admixtures and corrosion inhibitors functioned to improve the corrosion resistance of standard concrete. The technical literature contains limited research about how various percentages of mineral admixtures and GGBS work with quarry dust to create concrete that exhibits corrosion resistance.

5. OBJECTIVE OF RESEARCH

Objectives of the present work are given below:

- To study the strength and corrosion resistive properties of concrete containing quarry dust as fine aggregate and to compare with the conventional concrete having river sand as fine aggregate and to find out the elements present in the quarry dust by EDAX
- To investigate the influence of partial replacement of cement by fly ash in enhancing strength and durability properties of concrete containing quarry dust as fine aggregate.

6. ANALYSIS AND RESULTS

6.1 Overview

The chapter provides experimental results which analyze the mechanical and durability and microstructural characteristics of concrete that uses sandstone quarry dust (QD) as a replacement for natural sand at various levels from 0% to 50% in increments of 10%. The research investigates the workability of fresh concrete and the physical properties of hardened concrete which include density and compressive strength and splitting tensile strength and the water absorption and sorptivity and chloride-ion permeability and the microstructural analysis which used X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques.

6.2 Workability of Concrete

The slump test showed that concrete workability decreased when more quarry dust was added because the dust particles had an angular shape and rough surface which required more water for mixed with the concrete.

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- Control concrete (CM): 90 mm
- QD10: 85 mm • QD20: 80 mm •
  QD30: 70 mm • QD40: 60 mm •
  QD50: 50 mm

The observation showed that all mixes maintained medium workability which fell between 50 and 100 mm and this range matched the requirements for casting reinforced concrete structures.

6.3 Hardened Concrete Properties

6.3.1 Density

The density of concrete increased with quarry dust substitution up to 40%, then slightly decreased at 50%.

- CM: 2411.16 kg/m³
- QD10: 2430.28 kg/m³ • QD20: 2455.64 kg/m³
- QD30: 2480.12 kg/m³
- QD40: 2508.64 kg/m³ (maximum)
- QD50: 2495.33 kg/m³

The filling effect of fine quarry dust particles produces increased density because they decrease voids present in the concrete matrix.

6.3.2 Compressive Strength (MPa)

The substitution of quarry dust for aggregate materials increased compressive strength measurements which reached their peak value at 40% substitution before showing a small decrease at 50% substitution.

- The 7day testing results showed CM 29.77 QD10 31.24 QD20 32.78 QD30 34.22 QD40 35.44 QD50 33.91.
- The 28day testing results showed CM 36.13 QD10 37.67 QD20 39.73 QD30 40.80 QD40 41.83 QD50 40.55.
- The 90day testing results showed CM 38.49 QD10 39.73 QD20 41.38 QD30 42.80 QD40 44.21 QD50 42.95.

The study found that sand replacement at 40% showed maximum strength because it enhanced particle packing and densification in the material.

6.3.3 Splitting Tensile Strength (MPa)

The testing process assessed the results at three distinct time points which were seven days and twenty-eight days and ninety days.

- Seven days testing showed these results: CM 2.41 and QD10 2.47 and QD20 2.59 and QD30 2.87 and QD40 3.02 and QD50 2.84.
- The results of the twenty-eight days testing showed these values: CM 2.78 and QD10 2.82 and QD20 2.96 and QD30 3.25 and QD40 3.39 and QD50 3.22.

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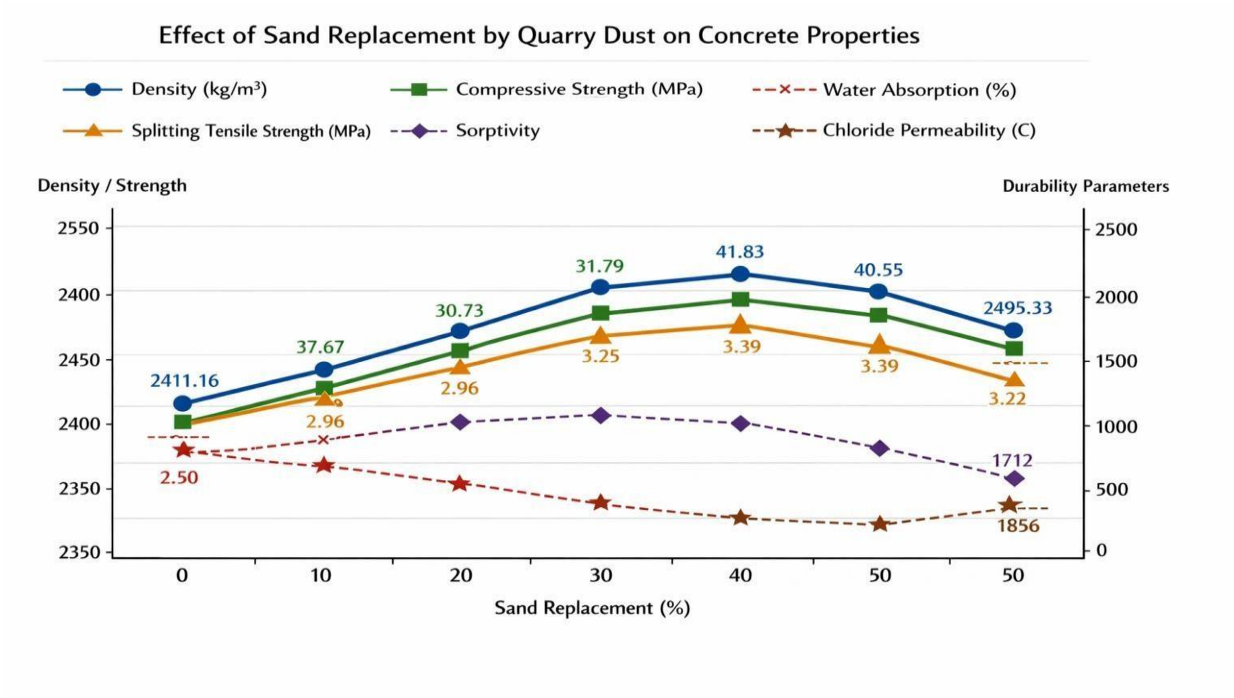
- The results of the ninety days testing showed these values: CM 2.92 and QD10 3.01 and QD20 3.23 and QD30 3.49 and QD40 3.68 and QD50 3.50.

The researchers found that the highest splitting tensile strength occurred when they replaced 40% of the material which matched the observed compressive strength pattern.



6.4 Data Table – Mechanical & Durability Properties

Mix	Sand Replacement (%)	Slump (mm)	Density (kg/m³)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Water Absorption (%)	Sorptivity (mm³/mm²/min$^{0.5}$)	Chloride Permeability ©
CM	0	90	22411.16	9.77 / 36.13 / 38.49	41 / 2.78 / 2.92	.01 / 2.50	1777 / 0.1638	2150
QD10	10	85	32430.28	1.24 / 37.67 / 39.73	47 / 2.82 / 3.01	.74 / 2.30	1441 / 0.1472	2042
QD20	20	80	3455.64	2.78 / 39.73 / 41.38	59 / 2.96 / 3.23	.24 / 2.10	1037 / 0.1304	1928

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QD30	30	70	2480.12	4.22 / 40.80 / 42.80	87 / 3.25 / 3.49	91 / 1.85	0840 / 0.1107	1825
QD40	40	60	2508.64	35.44 / 41.83 / 44.21	02 / 3.39 / 3.68	73 / 1.68	0721 / 0.0956	1712
QD50	50	50	2495.33	3.91 / 40.55 / 42.95	84 / 3.22 / 3.50	44 / 1.50	0619 / 0.0812	1856

Note: Values in compressive strength and splitting tensile strength are shown as **7 days / 28 days / 90 days**. Similarly, water absorption and sorptivity are shown as **7 days / 28 days**.

7. CONCLUSION

The researchers examined whether pulverized sandstone powder (quarry dust) could serve as a partial substitute for natural sand in concrete production. The researchers measured various concrete properties which included workability and compressive strength and splitting tensile strength and water absorption and sorptivity and rapid chloride ion permeability while testing different levels of sand substitution. The researchers conducted microstructural analysis through X-ray diffraction (XRD) and scanning electron microscopy (SEM) to study how cement phases and concrete structure changed. The study found that quarry dust which is produced as a mechanical by-product can replace natural sand in concrete production while delivering better mechanical strength and durability.

The study showed that workability decreased when sand replacement increased because of the fine and angular particles present in quarry dust. All concrete mixes remained suitable for structural applications up to 50% sand replacement. The concrete properties of density and compressive strength and splitting tensile strength showed improvement with increased quarry dust content until reaching the maximum 40% replacement level. The study results showed that water absorption and sorptivity decreased while the material showed improved resistance against chloride ion penetration which indicated better durability. The XRD analysis showed that quarry dust maintained its original form as an inert filler because it did not change cement hydration products while the SEM images demonstrated that 40-50% sand replacement mixes developed a more compact microstructure with fewer voids. The study demonstrated that quarry dust serves as a sustainable and effective partial replacement for natural sand in concrete.

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