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Experimental study on Strength Characteristics of Concrete by Partial Replacement of Cement with Silica Fume and Fine Aggregate with Quarry Dust

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Abstract: *This research investigates the strength characteristics of M30 grade concrete incorporating silica fume and quarry dust as partial replacements for cement and fine aggregate respectively. The study examines various replacement levels to determine optimal combinations that enhance mechanical properties while promoting sustainable construction practices The experimental investigation revealed that a combination of 10% silica fume and 30% quarry dust yielded optimal strength characteristics, achieving compressive strengths exceeding the control mix by approximately 12-15%. The incorporation of silica fume significantly improved the microstructure through pozzolanic reactions, while quarry dust demonstrated effective performance as a fine aggregate substitute. Water absorption tests indicated enhanced durability properties with reduced permeability in optimized mixes. Economic analysis revealed potential cost savings of 8-12% compared to conventional concrete.*

Keywords*:* Quarry Dust, Silica Fume, Partial Replacement, Particle Packing and Strength of Concrete

I. INTRODUCTION

Concrete is the most used composite material today. It’s made up of coarse aggregate, fine aggregate, cement, and water. With the rapid increase in construction activities, we’re seeing a shortage of traditional materials. Typically, natural sand is used as fine aggregate in concrete, which helps with workability and uniformity in the mix. River deposits have been the go-to source for this fine aggregate. However, nowadays, natural river sand is becoming scarce and quite pricey. So, we really need to explore some alternative materials! Quarry Dust could actually take the place of river sand completely or partially. There’s a proposal to investigate how we can replace sand with locally sourced Quarry Dust without compromising the strength and workability of concrete by adding Silica Fume as a mineral admixture. In today’s construction practices, it's just as important to focus on durability as it is on strength. The Indian Standard Code for plain and reinforced concrete highlights the minimum cement content needed to ensure both strength and durability, which has led to increased cement usage. But we all know that cement production requires a significant amount of energy and contributes to carbon dioxide emissions, which isn’t great for our environment. One solution to tackle these challenges is the use of Pozzolana materials. Previous research shows that replacing a portion of cement with materials like Fly Ash, Silica Fume, Metakaolin, and Ground Granulated Blast Furnace Slag can reduce cement consumption while also boosting the strength and durability of concrete.

II. OBJECTIVES

The primary aim of this research study is to investigate the impact of the combined use of Quarry Dust and Silica Fume on different strength characteristics of M30 grade concrete. Replacement percentages of 10%, 20%, 30%, 40% by weight of fine aggregate for Quarry Dust, along with 5%, 10%, 15% by weight of cement with Silica Fume. Compressive strength, split tensile strength, and flexural strength of modified concrete at 7, 14, and 28 along with water absorption, of various combinations of Quarry Dust and Silica Fume was measured, and the findings was compared to those of the control concrete.

III. LITERATURE REVIEW

Safiuddin et al. (2003) Investigated hardened properties of concrete incorporating quarry dust as partial fine aggregate replacement. Examined compressive strength, splitting tensile strength, and elastic modulus characteristics. Reported optimal performance at 20-30% replacement levels with proper particle size distribution control.

Shanmugavadivu and Malathy (2007) Investigated durability properties of quarry dust concrete including water absorption, sorptivity, and permeability characteristics. Reported reduced water absorption with quarry dust replacement up to 30%, attributed to improved particle packing and reduced void content in the concrete matrix.

Khan and Rana (2012) Investigated sustainable use of silica fume in cement-based materials. Conducted life cycle assessment and carbon footprint analysis.

Quantified environmental benefits including reduced greenhouse gas emissions and energy consumption in concrete production.

Ravichandran and Ramasamy (2021) Investigated nano-silica and silica fume effects on concrete properties. Compared performance characteristics of different silica- based supplementary materials.

Demonstrated that nano-silica provided enhanced early-age strength while conventional silica fume optimized long-term performance.

Venkatesh and Raju (2024) Recent investigation on high-performance concrete incorporating industrial by-products. Developed performance-based specifications and quality control protocols. Established standardized procedures for material characterization, mix proportioning, and quality assurance.

IV. EXPERIMENTAL PROGRAMME

4.1 Properties of Materials

4.1.1 Cement: In the present investigation Ordinary Portland Cement (OPC) of 53 Grade confirming to IS specifications was used.

4.1.2 Fine Aggregate

Locally available river sand confirming to IS specifications was used as the fine aggregate in the concrete preparation. The properties of Fine aggregate are shown in Table 1

Table 1. Physical Properties of Fine Aggregate

Property	Test Result	IS 383 Requirement
Specific Gravity	2.64	-
Fineness Modulus	2.78	Zone II 2.6-2.9
Silt Content %	2.8	Maximum 3.0

4.1.3 Coarse Aggregate

Coarse aggregate of nominal size 20 mm and 12.5 mm, obtained from the local quarry confirming to IS specifications was used. The properties of Coarse aggregate are shown in Table 2.

Table 2. Physical Properties of Coarse Aggregate

Property	Test Result	IS 383:2016
Specific Gravity	2.72	2.60-3.00
Bulk Density (kg/m³)	1.545	
Water Absorption (%)	0.6	<2.0

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4.1.4 Quarry Dust

Quarry dust obtained from granite rock crushing operations was collected from a local quarry facility. The properties of Quarry Dust are shown in Table 3.

Table 3. Properties of Quarry Dust

Property	Quarry Dust	IS 383:2016
Specific Gravity	2.64	2.60-2.80
Bulk Density (kg/m³)	1,685	-
Fineness Modulus	3.12	2.6-3.2
Water Absorption (%)	1.8	-

4.1.5 Silica Fume

Silica Fume is a very pozzolanic mineral additive, typically utilized to enhance the strength and durability characteristics of concrete. Silica Fume interacts with calcium hydroxide produced during cement hydration, which enhances strength, and it also fills the gaps between cement particles, contributing to increased durability. Silica fume conforming to IS 15388:2003 was obtained from a ferrosilicon manufacturing unit. The material was supplied in densified form to facilitate handling and storage. The characteristics of Silica Fume are presented in Table 4 and Table 5

Table 4. Physical Properties of Silica Fume

Parameter	Value	Standard Requirements
Specific Gravity	2.21	2.20-2.30
Bulk Density (kg/m³)	576	-
Surface Area (m²/kg)	21,500	≥15,000
Moisture Content (%)	0.8	≤3.0

Table 5. Chemical Properties of Silica Fume

Compound	Percentage (%)	Specification
Silicon Dioxide (SiO2)	93.2	≥85
Aluminium Oxide (Al2O3)	0.8	-
Iron Oxide (Fe2O3)	1.2	-
Calcium Oxide (CaO)	0.6	-
Magnesium Oxide (MgO)	1.5	-
Loss on Ignition	2.4	≤6.0

4.1.6 Water

Water used for casting and curing of concrete test specimens is procured from the Concrete Technology Laboratory of the institute and is free from impurities which when present can adversely influences the strength of concrete.

4.2 CONCRETE MIX PROPORTION

M30 grade of concrete was designed as per the Indian Standard code of practice. The various ingredients for one cubic meter of concrete for different mixes used in the present investigation are shown in Table 6.

Table 6. Quantities of Ingredients per cum of M30 Grade Concrete

Mix ID	Silica Fume (%)	Quarry Dust (%)	Cement (kg/m³)	Silica Fume (kg/m³)	Natural Sand (kg/m³)	Quarry Dust (kg/m³)	Coarse Agg (kg/m³)	Water (kg/m³)
M0	0	0	395	0	682	0	1184	178
SF5-QD10	5	10	375	20	614	68	1184	178
SF5-QD20	5	20	375	20	546	136	1184	178
SF5-QD30	5	30	375	20	477	205	1184	178
SF5-QD40	5	40	375	20	409	273	1184	178
SF10-QD10	10	10	356	39	614	68	1184	178
SF10-QD20	10	20	356	39	546	136	1184	178
SF10-QD30	10	30	356	39	477	205	1184	178
SF10-QD40	10	40	356	39	409	273	1184	178
SF15-QD10	15	10	336	59	614	68	1184	178
SF15-QD20	15	20	336	59	546	136	1184	178
SF15-QD30	15	30	336	59	477	205	1184	178

V. RESULTS AND DISCUSSION

5.1 Compressive Strength

The variation of the cube compressive strength of M30 grade concrete for various percentages of Quarry Dust for different curing periods is shown in Fig.1. The superior mechanical properties achieved by the optimized mix (SF10-QD30) result from synergistic interactions between multiple enhancement mechanisms operating at the microstructural level

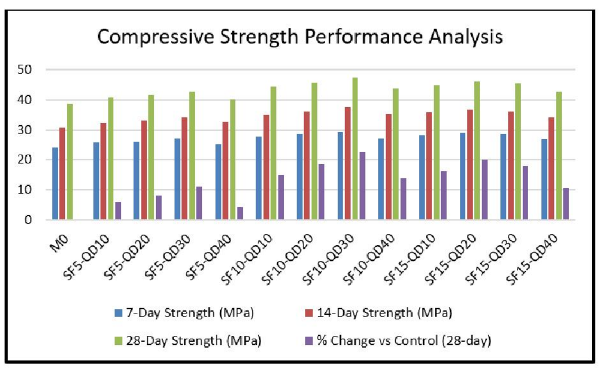

Fig. 1. Variation of Cube Compressive Strength of M30 Grade Concrete with different percentages of Silica fume & Quarry Dust.

Split Tensile Strength

The Split Tensile strength of M30 grade concrete for various percentages of Silica Fume & Quarry Dust for different curing periods is shown in Fig.2

Split tensile strength results demonstrate patterns consistent with compressive strength trends. The optimal mix (SF10-QD30) achieved 3.96 MPa, representing a 26.9% improvement over the control mix. This enhancement can be attributed to multiple factors working synergistically

Flexural strength results demonstrate consistent patterns with other mechanical properties. The optimal mix (SF10-QD30) achieved 6.12 MPa, representing a 26.2% improvement over the control mix.

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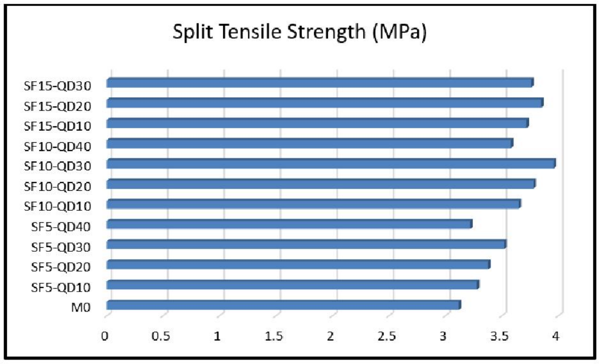

Fig. 2. Variation of Split Tensile Strength of M30 Grade Concrete with different percentages of Silica fume & Quarry Dust.

Flexural Strength

The Flexural strength of M30 grade concrete for various percentages of Silica Fume & Quarry Dust for different curing periods is shown in Fig.3

Flexural strength results demonstrate consistent patterns with other mechanical properties. The optimal mix (SF10-QD30) achieved 6.12 MPa, representing a 26.2% improvement over the control mix.

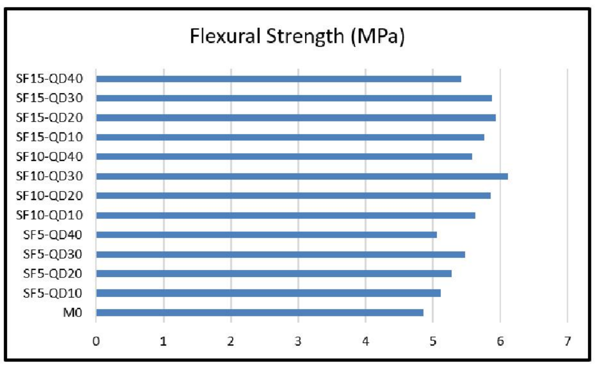

Fig. 3. Variation of Flexural Strength of M30 Grade Concrete with different percentages of Silica fume & Quarry Dust

Water Absorption

The water absorption of M30 grade concrete for various percentages of Silica Fume & Quarry Dust for different curing periods is shown in Fig.3

Water absorption results demonstrate significant improvements with incorporation of silica fume and quarry dust. The optimal mix (SF10-QD30) achieved 3.12% water absorption, representing a 27.1% reduction compared to the control mix

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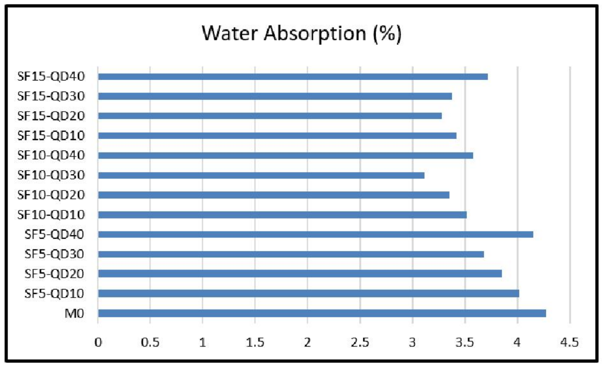

Fig. 4. Variation of water absorption of M30 Grade Concrete with different percentages of Silica fume & Quarry Dust

Economic Analysis

Economic feasibility represents a critical factor determining practical adoption of concrete modified systems. A comprehensive cost analysis was conducted comparing material costs for the control mix and optimized modified mix (SF10-QD30). The analysis incorporated current market prices for all constituent materials in the Indian context, considering regional availability and typical procurement quantities for medium-scale construction projects.

The economic analysis results indicates :

The 22.6% increase in compressive strength enables potential reduction in structural member dimensions while maintaining equivalent load- carrying capacity.

The 27.1% reduction in water absorption indicates significantly enhanced durability characteristics

Reduced cement consumption (39 kg/m³ less than control) decreases environmental impact and potentially qualifies for green building incentives.

VI. CONCLUSIONS

This comprehensive investigation into M30 grade concrete incorporating silica fume and quarry dust has generated significant findings regarding mechanical properties, durability characteristics, economic viability, and environmental sustainability.

The combination of 10% silica fume (by weight of cement) and 30% quarry dust (by weight of fine aggregate) emerged as optimal across all performance parameters. This combination achieved 47.2 MPa compressive strength at 28 days, representing a 22.6% enhancement over control concrete. Split tensile and flexural strengths demonstrated proportional improvements of 26.9% and 26.2% respectively.

All modified concrete mixes exceeded the characteristic compressive strength requirement of 30 MPa for M30 grade concrete, validating technical feasibility across the investigated range of material combinations.

Water absorption decreased by 27.1% for the optimal mix, indicating substantial microstructural refinement and enhanced resistance to permeation of water and aggressive ions.

Initial material costs increase by approximately 32.6% for the optimal mix compared to conventional M30 concrete. However, comprehensive life cycle cost analysis reveals economic parity within 12-15 years when considering enhanced durability, reduced maintenance requirements, and potential structural optimization. For infrastructure projects with long design lives, the modified concrete presents clear economic advantages alongside technical and environmental benefits.

The experimental investigation's findings suggest that the production of concrete used in structural applications can be partially substituted with quarry dust and silica fumes.

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