Investigation of Strength and Durability of High-Performance Concrete Incorporating Partial Replacement of Sand with Quartzite Waste

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Abstract — Concrete is the most widely used construction material due to its versatility, strength, and durability. However, the continuous exploitation of natural river sand as fine aggregate has led to environmental degradation and scarcity of resources. This research investigates the feasibility of using Quartzite Waste (QW) as a partial replacement for fine aggregate in High-Performance Concrete (HPC). Various replacement levels of Quartzite waste (0%, 20%, 40%, 60%, 80%, and 100%) were examined for their impact on workability, compressive strength, split tensile strength, flexural strength, and durability properties such as water absorption and acid resistance. The results reveal that a partial replacement of 40–60% yields optimal mechanical and durability performance. Thus, incorporating Quartzite waste in HPC not only promotes sustainable waste management but also enhances the mechanical and durability performance of concrete.

Keywords: High-Performance Concrete, Quartzite Waste, Sand Replacement, Strength, Durability, Sustainable Materials

I. Introduction

Concrete plays a crucial role in infrastructure development. The increasing demand for natural river sand has resulted in environmental concerns such as riverbed depletion, loss of biodiversity, and ecological imbalance. To address this, alternative fine aggregates from industrial or quarry wastes are being explored. One such promising material is Quartzite Waste, generated during the processing of quartzite rock in stone cutting and crushing industries.

Quartzite waste is a hard, non-reactive, and high-silica material possessing excellent mechanical properties and chemical stability. Its utilization in concrete production can help reduce waste disposal issues and lower dependency on natural sand.

High-Performance Concrete (HPC) is designed to achieve superior strength, workability, and durability using mineral admixtures like silica fume and fly ash. Integrating Quartzite waste in HPC can further enhance its performance while contributing to environmental sustainability.

Quartzite is a metamorphic rock primarily composed of quartz. It's extremely hard and durable. During quarrying and processing of quartzite for construction or decorative purposes, waste is generated in the form of:

- Dust or fines
- Chippings
- Powder or sludge

This waste is typically discarded, posing disposal challenges and environmental issues.

A. *Why Use Quartzite Waste in Concrete?*

Advantages:

- Sustainability: Reduces the need for natural sand mining.
- Waste Management: Utilizes industrial byproducts effectively.
- Mechanical Strength: Quartzite has a high silica content, potentially enhancing strength.
- Durability: Its hard texture may contribute to abrasion resistance.
- Eco-Friendly: Supports circular economy principles.

B. *Challenges:*

- Angular and rough texture may affect workability.
- Requires sieving and possible treatment before use.
- Can increase water demand if not optimized.

II. Literature Review

Siddique and Aggarwal (2016) investigated the use of industrial wastes, including quartzite, as partial replacements for natural sand in concrete. They reported that quartzite waste possesses high hardness and low water absorption, which improves the density and overall strength of concrete when used up to 30% replacement.

Natarajan and Kumar (2020) specifically studied high-performance concrete with 10%, 20%, 30%, and 50% replacement of sand by quartzite waste. Their results showed that 30% replacement yielded the highest compressive and tensile strength due to better particle packing and enhanced bonding between the cement paste and aggregate. Ali and Ahmad (2018) studied concrete with 0–50% quartzite waste replacement for fine aggregates. They found that compressive strength increased up to 40% replacement due to the angular shape and rough texture of quartzite particles, which provided better interlocking and reduced voids. Beyond 50% replacement, workability decreased, slightly reducing strength.

Natarajan and Kumar (2020) also confirmed that 20–30% replacement improved compressive strength by 8–12% compared to conventional concrete. Mehta and Monteiro (2014) highlighted that the microstructure of HPC with hard mineral aggregates, such as quartzite, improves tensile and flexural strength. They noted that the strong bond between quartzite particles and the cement matrix enhances load transfer under tension and bending.

III. Objective

- To evaluate the feasibility of using quartzite waste as a partial replacement for fine aggregate in HPC.
- To determine the optimum replacement percentage of quartzite waste for maximum strength and durability.
- To assess the effect of quartzite waste on workability, compressive strength, flexural strength, and split tensile strength.

IV. RESULTS AND DISCUSSIONS

A. *Workability*

Workability is a property of fresh (plastic) concrete that indicates how easily it can be mixed, placed, compacted, and finished without segregation or loss of uniformity. It is one of the most important properties of fresh concrete because it directly affects the strength, durability, and appearance of hardened concrete.

The values of workability in terms of compaction factor are tabulated as below

Mix ID	Fine Aggregate in %		Compaction Factor
	Natural FA	Quartzite FA	Compaction Factor
CN	100	0	0.88
QFA-10	90	10	0.85
QFA-20	80	20	0.84
QFA-30	70	30	0.83
QFA-40	40	40	0.82
QFA-50	50	50	0.81
QFA-60	40	60	0.81
QFA-70	30	70	0.8
QFA-80	20	80	0.79
QFA-90	10	90	0.78
QFA-100	0	100	0.77

Table 1: Workability of concrete for Fine aggregate replacement

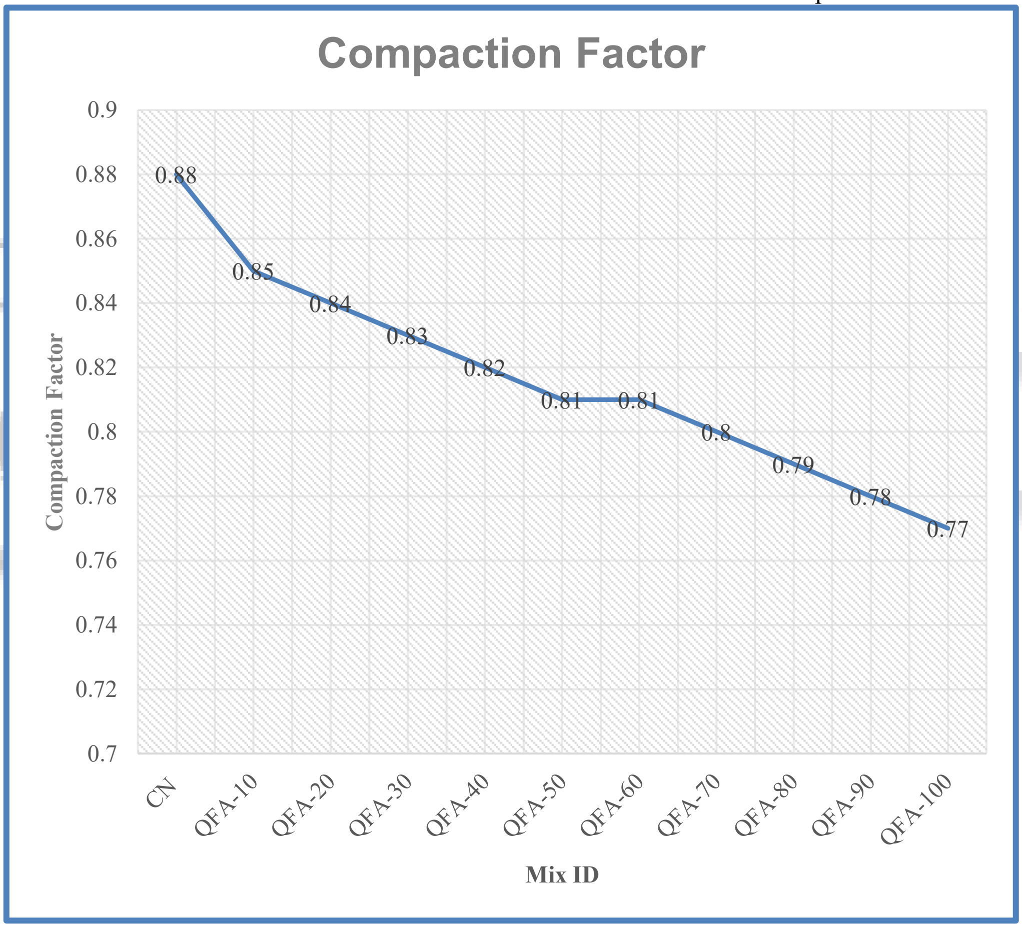

Fig. 1: Workability Test Results

The workability of concrete comprising crushed Quartzite waste as partial replacement for natural sand (fine aggregate) has decreased from 0% to 100%. When cement was replaced partially by Fly-ash (FA) 15% and silica-fume (SF) 10% also workability decreased to the concrete. "Workability assessment of the concrete was conducted using the Compaction factor method across all sample specimens. The workability of concrete containing crushed Quartzite waste as partial replacement for natural sand (fine aggregate) has decreased from MCQ0% to MCQ100%.

B. *Evaluating The Compression Strength of the Concrete Mixes*

Definition:

Compressive strength is the ability of hardened concrete to withstand axial loads without failure. It is the most important mechanical property of concrete, as it directly influences its structural performance, safety, and durability.

It is defined as

$$f_c = \frac{P}{A}$$

Where:

- f_c = compressive strength (N/mm² or MPa)
- P = maximum load applied at failure (N)
- A = cross-sectional area of the specimen (mm²)

In this Experimental study, various mixes of concrete were prepared with crushed Quartzite waste was partially replacing with the natural sand (fine aggregate) to the tune of 0% to 100%. Natural sand (fine aggregate) was replaced with 0% to 100% for the Quartzite waste, the test of compressive strength of the concrete was carried out on the concrete specimens (cube) of standard size i.e., 150 mm x 150 mm x 150 mm in a CTM (compression testing machine). The loading was maintained at a constant value of 2.5 KN/Sec.

Mix ID	Fine Aggregate in %		COMPRESSION STRENGTH		
	Natural FA	Quartzite FA	7days	21 Days	28 days
CN	100	0	50.82	50	63.45
QFA-10	90	10	53.57	53.1	66.42
QFA-20	80	20	54.63	54	68.5
QFA-30	70	30	56.23	55.6	70.18
QFA-40	40	40	55.16	55	69.5
QFA-50	50	50	51.8	53.2	67.28
QFA-60	40	60	50.75	49	62.38
QFA-70	30	70	49.28	49.6	61.46
QFA-80	20	80	47.83	46.4	58.26
QFA-90	10	90	46.32	46.3	57.89
QFA-100	0	100	45.82	44.2	56.15

Table 2: Compressive Strength of specimens of concrete in MPa

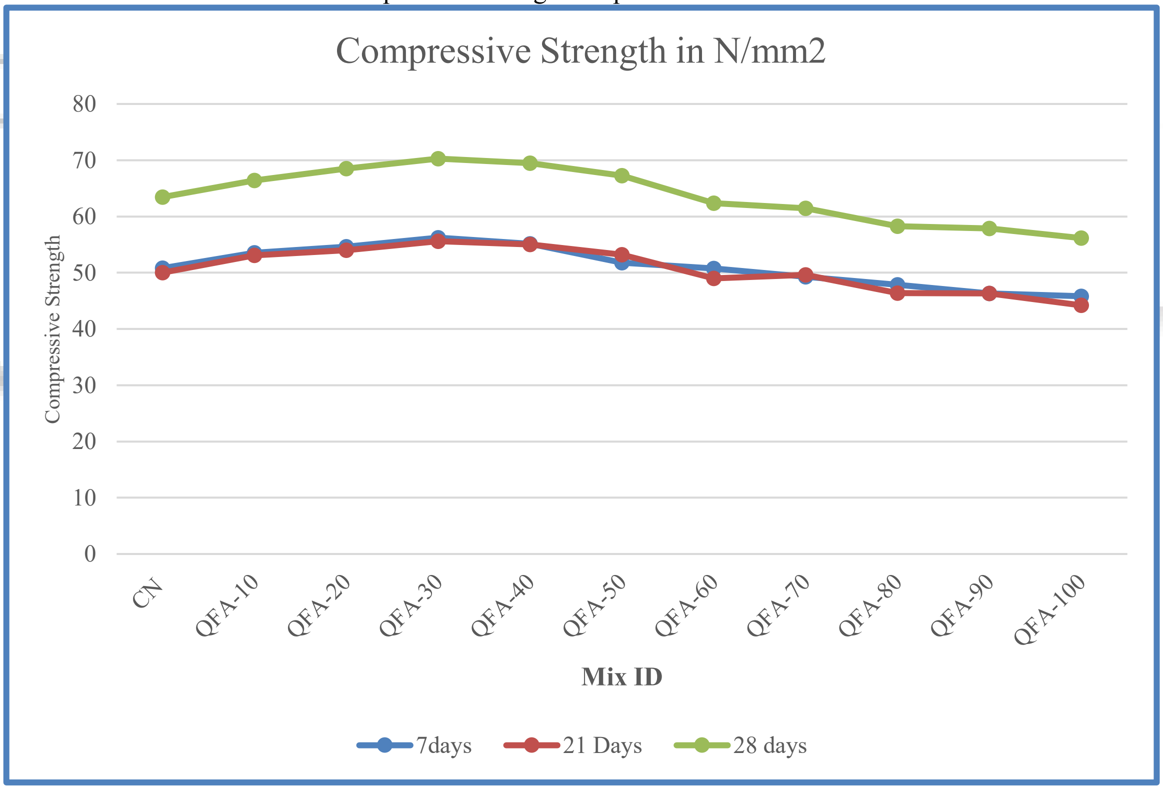

Fig. 2: Compression Strength of Different proportional mixes

The test results revealed that the partial replacement of natural sand (fine aggregate) by crushed Quartzite waste got increased the compressive strength of concrete mix MCQ30. A higher compressive strength of 70.18 MPA was noticed for the 30% partial replacement of crushed Quartzite waste on the concrete, with augment in the proportion of partial replacement by crushed Quartzite waste above 30% replacement of crushed Quartzite waste the ability (strength) of the concrete got decreased.

The compressive strength of the concrete was improved to a greater extent due to the bonding of the Quartzite waste surface texture and hydration of cement with the Quartzite waste. The addition of silica-fume (SF) to the concrete mix increased the density of the concrete and compressive strength of the concrete. This concrete strength improvement can be attributed to the pore-filling effect of fine particles of silica fume. Fly ash was used as a partial replacement substance for cement. It improved the cementitious property of the ingredients of concrete in combination with the cement.

V. CONCLUSION

- Quartzite waste can be effectively used as a partial replacement for fine aggregate in high-performance concrete.
- Optimum replacement level is between 40% and 60%, beyond which workability and strength decline.
- Compressive strength increased by 8–10% at 60% replacement compared to control mix.

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