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Utilization of Quartzite Waste and Mineral Admixtures in High Performance Concrete

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Abstract: The diverse demand for cement cannot be fully met by Ordinary Portland cement (OPC) alone. To address this demand while ensuring the durability analysis of modified concrete, In response to evolving needs, the incorporation of mineral additives and other by-products has become imperative to enhance performance without compromising quality.OPC cement and river sand are commonly used in the construction industry, but their availability is limited. Moreover, cement is a major contributor to CO_2 emissions. Therefore, partial substitution of cement and natural sand with waste materials or by-products is essential to maintain the quality of the final product. Partial replacement with materials like Fly Ash (FA), Silica Fume (SF), and quartzite waste (QW) as sand substitutes has been employed. The use of Fly ash, Silica fume with cement results in more durable concrete with lower chloride ingress and better finish compared to concrete made with 100% Natural River sand. Apart from cost-effectiveness, reducing reliance on river sand addresses environmental and sustainability concerns, making a significant contribution to modified concrete production. Compressive strength tests were performed after3days, 7days, 28 days, and 56 days. The optimal replacement rate for crushed quartzite material was identified as 30%. To assess the properties of concrete incorporating crushed quartzite, comprehensive analyses, including Compressive Strength, split tensile strength, flexural strength, and SEM Analysis, were conducted for both conventional and ideal concrete mixes.

Key Words: High performance concrete, Fly Ash, Silica fume, Quartzite Waste, Cement (OPC)

1.1. INTRODUCTION

Concrete stands as a prominent building material, surpassing other man-made substances in global usage. Cement, a key component of concrete, contributes significantly to environmental damage, being a major driver of climate change, responsible for 5% of man-made carbon dioxide (CO2) emissions. Ordinary Portland Cement (OPC), Type I, dominates construction use, especially where there is no exposure to sulfates in soil and groundwater, constituting about 60% of current construction cement usage. Thus, the utilization of by-products as partial or complete substitutes for constituent materials in green concrete mixes is imperative. The depletion of natural sand sources and the need to reduce concrete production costs have led to the utilization of lower quality sand sources and increased demand for alternative materials to sand as fine aggregates in concrete formation (Ankit and Jayesh, 2013). Consequently, there is a growing demand for inexpensive, environmentally friendly substitutes for cement and river sand, ideally sourced from by-products.

In efforts to enhance green concrete production, the partial replacement of cement with Fly Ash and Silica Fume, alongside using 100% Quartzite waste as fine aggregates, was evaluated. In the Indian Peninsula, there have been numerous attempts to incorporate Quartzite waste as partial replacement, typically up to 50%, in various construction applications. This not only aims to reduce the reliance on river sand but also to lower construction costs through economical concrete production. Previous research, as supported by Manassa (2010) and Sukesh et al. (2013), has demonstrated effective replacement of up to 20% of sand with Quartzite waste in conventional concrete. Studies by Ilangovan et al. (2008) and Sivakumar and Prakash (2011) have shown that the strength of Quartzite waste concrete residues is approximately 10-12% higher than that of traditional concrete. Divakar et al. (2012) investigated concrete behavior using rock fines as partial replacements for sand up to 50% and observed positive results in terms of quality and strength. Utilizing Quartzite waste as a substitute for sand in construction materials would help mitigate environmental issues stemming from the large-scale depletion of natural sources of river and mining sands (Ilangovana et al., 2008; Poonam et al., 2015). Quartzite Waste emerges as an efficient alternative to traditional sands, offering a viable solution in construction practices.

The overall construction costs escalate due to the transportation of sands from their original sources (Safiuddin et al., 2007). Quartzite waste is primarily employed on a large scale as a surface finishing material in roads and highways. Rezende and Carvalho (2003) utilized this stone dust as the principal improvement material for the base layer of flexible pavement and observed its satisfactory performance under field conditions. Safiuddin et al. (2007) and Lohani et al. (2012) reported that the workability of fresh concrete is enhanced, while the unit weight and air content remain unaffected in the presence of Quartzite waste. Quartzite waste residue also exhibits great potential for producing both normal and lightweight concretes. Ilangovana et al. (2008) noted that permeability is reduced; however, water absorption is higher than that of traditional concrete. Therefore, the quality of concrete could be affected if Quartzite waste residue is used in significant amounts.

Improvement in concrete resistance against sulfate attack and reduced vulnerability, despite slightly higher water absorption compared to traditional concrete, suggests the suitability of Quartzite waste residues for robust concrete production, applicable even in specialty concretes like high-performance and self-consolidating types. Previous studies by Safiuddin et al. (2000) and Felekoglu (2007) demonstrated successful utilization of Quartzite waste in high-performance and self-consolidating concrete formulations without compromising compressive strength. This underscores the potential of Quartzite waste as a valuable resource, as highlighted by Hmaid (2015). The research aims to assess the impact of 100% Quartzite waste dust substitution for sand and partial replacement of cement with mineral admixtures on concrete properties, exploring novel combinations not previously investigated. Specifically, the study evaluates the effects of partial replacement with GGBS, silica fume, and 100% Quartzite waste dust as sand substitutes on concrete quality.

A. Materials

In the current assessment, JSW Ordinary Portland Cement (OPC) of 53 grades was utilized, conforming to IS 12269-1987 specifications. Locally sourced fine aggregate from the banks of Tungabhadra River was used, meeting IS specifications. Coarse aggregate, with nominal sizes of 20 mm and 12 mm, sourced from local Quartzite waste, also conforms to IS specifications. Fly Ash and silica fume were obtained from ASTRA Chemicals Pvt Ltd, Chennai. Quartzite waste was procured from a local site near Nanoor Village in Kurnool district, Andhra Pradesh state. The water used for casting and curing concrete test samples was free from acids, organic matter, suspended solids, and impurities that could adversely affect concrete quality.

Table- I: The results of tests conducted on various materials used in the investigation.

The test results for cement	**Normal Consistency Test**	**Specific Gravity test**	**Fineness analysis**	**Initial setting time of cement**	**Final setting time of cement**
	33%	3.12	7%	45 min	360 min
Test on fine aggregate(FA)	**Specific gravity**	**Water absorption**	**Fineness Modulus**	**Silt content**	**Bulk density kg/m³**
	2.58	0.5%	2.80	1.98 %	1575
Test on Coarse Aggregate (CA)	**Specific Gravity**	**Water absorption**	**Fineness Modulus**		
	2.76	1.0%	6.98		
Tests of Fly Ash	**Specific Gravity**	**Fineness (Blaines)**	**Residue % (45 micron)**		
	3.17	380	7.2		
Particulars of Quartzite waste Residue	**Specific gravity**	**Fineness Modulus**	**Moisture Content**	**Zone**	
	2.63	2.72	Nil	II	

B. Mix Proportions

Different distinctive mix proportions were prepared. The first blend was prepared from 100% stream sand and cement content to deliver conventional concrete. The second mix was prepared using 10% to 100% Quartzite waste with partially replaced with natural river sand. The rest of blends were prepared by partially supplanting cement with Fly Ash at Optimum dose of 15% and Silica Fume of 10% by weight. The water cement ratio for all the blends was fixed at 0.29, by weight. The grade of the concrete is M60.

Table- II: Mix Proportions for M60 grade concrete

Cement	382.5kg/m^3
Fly Ash	76.5kg/m^3
Silica Fume	51 kg/m^3
Fine Aggregate	716.17 kg/m^3
Coarse Aggregate	1186.56kg/m^3
Water	144 kg/m^3
SP	4.54l/m^3

C. Methods

This laboratory investigation aimed to assess the concrete's behavior in terms of strength characteristics and durability properties. The study examined mechanical and physical properties across varying proportions of Quartzite waste as fine aggregate, alongside optimal substitution levels of cement with mineral admixtures such as Fly Ash and Silica fume. Compressive strength tests were conducted on 150mm × 150mm × 150mm cube samples at ages of 3, 7 and 28days, following wet curing processes according to IS 9013: (1978) standards. Split tensile strength tests were performed on standard concrete cylinders with dimensions of 150 mm diameter and 300 mm height, adhering to IS: 5816-1970 protocols. Fresh concrete properties were assessed using the slump test to ensure optimal workability, conducted in accordance with IS 1199 -1959 standards for both on-site and laboratory sampling. The chemical admixture SP 430 Conplast super plasticizer was utilized to mitigate the need for excessive water usage in producing high-strength Fly Ash concrete, thereby preserving workability.

Adjustments were made to ensure optimal functionality while achieving the desired flow slump without compromising concrete quality. A dosage rate of 2% of the cement by weight was employed for the chemical admixture. Cementitious materials were mixed in a mechanical blender for 4 to 5 minutes at a speed of 80 rpm to ensure thorough blending. Water was then added and mixed with all supplementary cementitious materials for 5 minutes, followed by a 2-minute resting period to scrape off any unmixed powders from the paddle sides of the blender and incorporate them into the mixing bowl. Mixing continued for an additional 5 minutes before placing the fresh concrete into 3D-shaped molds. After complete mixing, the fresh paste was poured into 150 mm cube molds and vibrated for 1 minute to eliminate air bubbles. Immediately after casting, the molds were covered with polyethylene sheets to prevent water evaporation from the surface of the samples.

III. RESULTS & DISCUSSIONS

The mix design of concrete plays a crucial role in ensuring the desired properties of a concrete batch. Parameters such as compressive strength and workability can be adjusted during the design process and monitored periodically until the optimal concrete mix is achieved. Table 3 presents the compression test results of concrete mix proportions for the green concrete incorporating mineral admixtures.

A. Compressive Strength

As previously mentioned, cube tests were conducted in this study to determine the compressive strength of the concrete samples. Three samples of cubes were cast for each unique concrete mix. The samples underwent testing at four different curing periods: 7 days, 28 days. The test results for various cement blends are detailed in Table 3 and illustrated in Figure 2.

Figure 1. Samples placed in Curing pond for Curing

Table- III: COMPRESSION TEST RESULTS

Mix ID	Compressive strength (MPa)		
	3rd day	7th day	28th day
MCQ0	40.38	50.82	63.45
MCQ 10	42.78	53.57	66.42
MCQ 20	42.75	54.63	68.50
MCQ 30	44.41	56.23	70.28
MCQ 40	43.12	55.16	69.50
MCQ 50	40.56	51.80	67.28
MCQ 60	39.53	50.75	62.38
MCQ 70	37.36	49.28	61.46
MCQ 80	38.84	47.83	58.26
MCQ 90	35.75	46.32	57.89
MCQ100	36.20	45.82	56.15

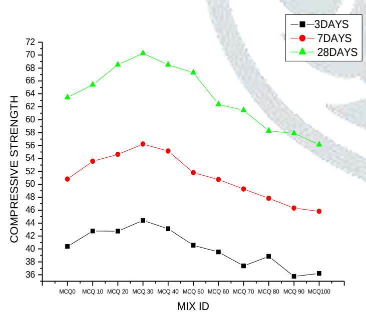


Figure 2: Variation in Compressive Strength among Different Mix IDs

The addition of fly ash and silica fume was observed to enhance the strength properties of the concrete mix. Specifically, data from Table III revealed that three specific mixes—MCQ20, MCQ30, and MCQ40—with 20%, 30%, and 40% replacement of Crushed Quartzite waste fine aggregate, respectively, exhibited superior compressive strengths of 68.50 MPa, 70.28 MPa, and 69.50 MPa. In contrast, plain natural fine aggregate concrete demonstrated a significant compressive strength of 63.45 MPa. Consequently, the optimized concrete mixes (MCQ20, MCQ30, and MCQ40) were selected for further experimental investigations.

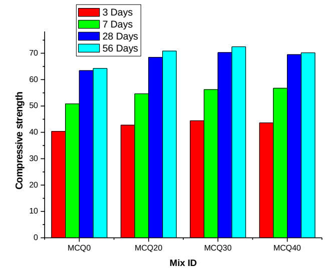


Fig.3 Graph for Compressive strength

B. Split tensile strength

Split tensile strength is a critical property of concrete as concrete structures are highly susceptible to brittle failure due to various types of impacts and loading conditions. However, concrete's tensile strength is considerably lower compared to its compressive strength. The standard test to determine concrete's tensile strength is conducted indirectly. This test, known as split tensile strength testing, is performed by applying a tensile force to a cylindrical concrete specimen until it fractures.

As per IS: 5816-1970, a standard test cylinder of concrete sample measuring 300 mm x 150 mm is positioned horizontally between the loading surfaces of a Compression testing machine. The compression load is uniformly applied diametrically along the length of the cylinder until failure occurs along the vertical diameter. To ensure the uniform distribution of this applied load and to mitigate the impact of high compressive stresses near the load application point, pieces of plywood or steel plates are placed between the sample and the loading platens of the testing machine. The concrete cylinder fractures into two parts along this vertical plane due to the indirect tensile stress induced by the poisons effect.

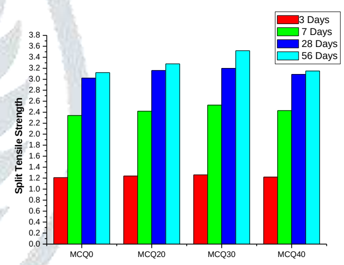


Fig.4 Differences in spilt tensile strength for various mix id

C.FLEXURAL STRENGTH

The flexural strength of concrete beam specimens, each of standard size 100mm x 100 mm x 500 mm and without reinforcement, was determined. These concrete specimens underwent testing under three-point loading, following the procedure outlined in the Indian Standard Code (IS 516), using a Universal Testing Machine. During the experiments, loading was applied at a rate of 1.5kN/sec, and the failure load of the concrete beam specimen was recorded. The test results for flexural strength of the reference and Quartzite waste-modified concrete are presented in Table 5.4. It was observed that all the modified mixes exhibited higher values of flexural strength compared to the conventional mix (MCQ0). Specifically, mix MCQ30 of M60 grade concrete, with 30% replacement of natural fine aggregate by Quartzite waste, demonstrated the highest flexural strength compared to the other mixes studied. A higher flexural strength of 6.36 MPa was recorded for Mix ID MCQ30, surpassing the values observed for the other mixes (Karthik et al., 2015 & Iravani et al., 1996).

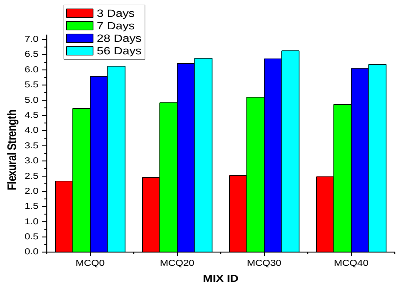


Fig.5 **Fig.5 Differences in Flexural strength for various mix id**

4. SCANNING ELECTRON MICROSCOPIC (SEM) ANALYSIS OF CONCRETE MIXES

SEM analysis is widely used in civil engineering to assess concrete robustness. It captures high-resolution images, revealing spatial variations, crystal structure, and chemical composition of specimens. With magnification from 20X to 30,000X, SEM provides detailed insights into concrete quality.

4.1 Scanning Electron Microscopic Analysis of Conventional Concrete

In the current research, SEM analysis was conducted on specimens of both conventional concrete mix and Quartzite waste concrete mix. The conventional concrete mix comprised standard ingredients such as cement, fine aggregate (river sand), natural blue metal coarse aggregate, and water, with the addition of admixtures - silica fume and fly ash - partially replacing cement. SEM images of the normal concrete mix specimens were captured at magnification levels of 1.5kx, 2kx, 3kx, 4kx, and 7kx.

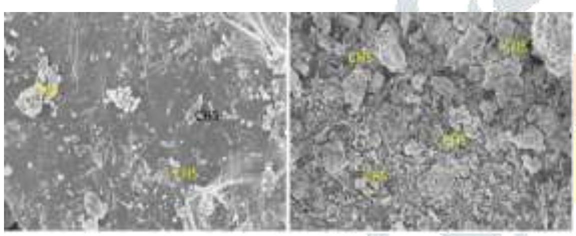
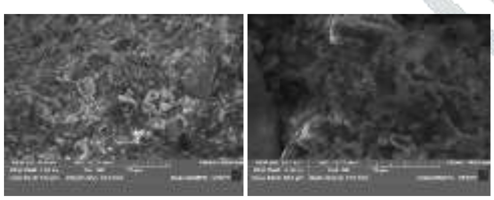


Figure .6 Scanning Electron Microscopic (SEM) Images of Conventional Concrete at 4kx and 7kx Magnifications



From the 2.5kx-, 5kx-, and 7.5kx-SEM images of normal concrete mix specimen, it is evident that a higher amount of fly ash is bound with the cement particles, while silica fumes appear as white collated balls. The composition of conventional concrete, prepared with fly ash and silica fume as admixtures, sheds light on the binding capability of cement and admixtures with other ingredients, as well as the density of the concrete.

4.2 Scanning Electron Microscopic (SEM) Analysis of Modified Quartzite waste Concrete

Specimens of modified Quartzite waste fine aggregate concrete (MCQ30), prepared with 30% replacement of natural fine aggregate by Quartzite waste fine aggregate and with the addition of silica fume and fly ash, were examined under a scanning electron microscope. Images at magnifications of 2.5kx, 5kx, 7kx, 25kx, and 50kx were captured and studied.

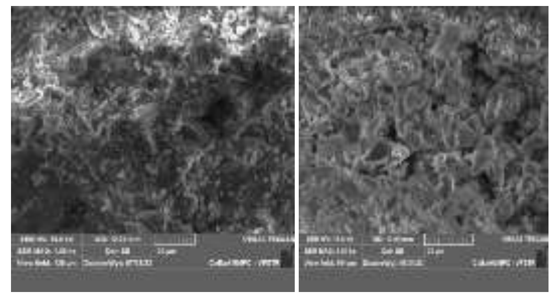


Fig.7 Scanning Electron Microscopic (SEM) Images of Modified Quartzite waste Concrete at 3kx and 2kx and 1.5kx Magnifications

5. Conclusions

1. An alternative material for fine aggregate was identified and experimentally validated. A design mix for M60 grade concrete was formulated based on the ACI mix design method, incorporating silica fume and Class F fly ash to achieve high-performance concrete.
2. Different concrete proportions were established by replacing fine aggregate with varying percentages of Quartzite waste.
3. The mechanical properties, including compressive strength, split tensile strength, and flexural strength of the concrete, were evaluated at different stages of the concrete's aging process. It was observed that the compressive strength of the concrete increased with a 30% replacement by Quartzite waste fine aggregate, reaching a high compressive strength of 70.28 MPa. However, with 40% replacement, the compressive strength gradually decreased.
4. The high compressive strength was attributed to the bonding of Quartzite waste with cement, fly ash, and silica fume during the hydration process, resulting in dense concrete. The rough texture of Quartzite waste facilitated enhanced bonding with the binding materials.
5. The split tensile strength of the concrete increased with an increase in Quartzite waste fine aggregate, and an optimum of 30% replacement was observed, resulting in a split tensile strength of 3.20 MPa. This was marginally higher compared to conventional concrete.

6. Additionally, the flexural strength of the modified Quartzite waste concrete significantly increased compared to conventional concrete, with a high flexural strength of 6.36 MPa observed for Quartzite waste concrete compared to 5.78 MPa for conventional concrete.

7. The increase in flexural strength was attributed to the high density of Quartzite waste fine aggregate and its bonding with the binding material in the concrete.

8. SEM (Scanning Electron Microscopy) analysis of high-performance concrete shows a dense microstructure, which improves the bonding between cement and fine aggregate.

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