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Strength and Durability of Concrete with Quarry Dust as a Sand Substitute

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Abstract

Growth has increased demand for natural sand, producing depletion and environmental difficulties. Quarry dust—a byproduct of rock crushing—is studied as a sustainable substitute for natural sand in M40-grade concrete. Significant effects on workability and compressive strength at various replacement weight percentages of 10%, 20%, 30%, and 40% are the main focus. According to IS 10262-2019 and IS 516-1959, 45 concrete samples were cast, cured, and evaluated at 7, 14, and 28 days. Replacing up to 20% of fine aggregate with quarry dust boosts compressive strength. The peak strength after 28 days was 46.35 MPa, significantly less than the average mix's 47.23 MPa. Performance diminishes beyond this threshold, with strengths decreasing to 35.21 MPa at 30% replacement levels and 34.04 MPa at 40%. The results show that quarry dust can replace natural sand due to its similar physical and chemical properties. Use of recycled industrial waste in concrete saves sand supply, decreases environmental harm, and supports circular economy. This study revealed that sustainable concrete production at 20% replacement may retain durability and strength. Quarry dust's environmental benefits may help the building industry become greener and more resource-efficient.

Keywords: M40 Concrete Mix, Quarry Dust, Fine Aggregate Replacement, Sustainable Construction, Compressive Strength.

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1. Introduction

Modern architecture depends on concrete, a composite material made of cement, fine aggregate, coarse aggregate, and water—because of its great strength, durability, and flexibility (Abu-Mahadi et al., 2023; Abu-Mahadi et al., 2024). Natural sand supplies are fast running out, though, because of its extensive use as a fine aggregate, which is causing major environmental problems including habitat degradation, groundwater depletion, and resource shortages. Given this growing issue (Akmal et al., 2023a; Shaheen et al., 2023), finding sustainable alternatives for natural sand is essential; quarry dust shows potential. Rock crushing produces quarry dust (Azhagarsamy et al., 2018; Nduka et al., 2018; Bahoria, Parbat, and Vairagade, 2019; Vamsi et al., 2020; Umar et al., 2024), which is frequently disposed of as waste, creating problems that lead to inadequate land use, air pollution, and water contamination. Yet, its physical and chemical characteristics are very similar to those of natural sand (Shaheen et al., 2023). Quarry dust is usually made up of crushed granite particles that are rich in silica (Azhagarsamy et al., 2018), trace amounts of feldspar and mica, and a specific gravity of about 2.6. Its fineness modulus ranges from 2.2 to 3.0, which is quite similar to the specific gravity (2.65) and fineness modulus (2.3 to 3.1) of natural sand. According to Priyankara et al. (2009), Jagadeesh et al. (2016), Dini et al. (2018), Emeka et al. (2018), Mohammed et al. (2018), Arinze et al. (2018), Arinze et al. (2018), Basha et al. 2019; Rahim et al. 2020; Uzodimma 2023; these commonality make quarry dust a viable and environmentally benign substitute for natural sand in the making of concrete, offering a possibility to minimize the environmental effect of building while promoting the concepts of the circular economy by recycling industrial waste. Examining its workability, compressive strength, and environmental advantages at various replacement percentages (10%, 20%, 30%, and 40% by weight), this study aims to validate quarry dust as a sustainable fine aggregate for M40-grade concrete. The findings are evaluated against those of traditional natural sand-based mixtures (Sudhakar et al., 2021; Akmal et al., 2023; Khan and Swati Pathak, 2023).This study intends to address environmental issues, lessen dependency on finite natural sand supplies, and offer a practical, affordable way to manage waste in the building sector by incorporating quarry dust into concrete.

2. Methodology

The authors would like to acknowledge the technical support by the concrete laboratory in the Civil Engineering Department at the Faculty of Engineering Technology, RUDN University.

1. **Materials and Proportioning**

- Cement: **448 kg/m³.**
- Fine Aggregate: Natural River sand, partially replaced by quarry dust at 10%, 20%, 30%, and 40% increments.
- Coarse Aggregate: Locally sourced granite **(20mm).**
- Water: Potable water, with a water-cement ratio of **0.44.**

2. **Experimental Setup and Procedures**

- Concrete mix were designed according to **IS 10262-2019** guidelines.
- Materials were by hand mixed, with precise weighing of each component.
- The mix was placed in cubic molds, compacted, and cured in water for **28 days.**
- A total of **45 specimens** were prepared and tested for compressive strength at intervals of **7, 14, and 28 days** using a universal testing machine, in accordance with **IS 516-1959** standards.

2.1 Expected Contributions to Sustainability

The probable use of quarry dust as a sustainable substitute for natural sand in the building of concrete is examined in this study. In addition to lowering dependency on river sand, which helps to slow down environmental degradation, this technology supports better waste management in the building sector by reusing a by-product of quarrying activities. Using quarry dust in concrete is in keeping with the circular economy's objectives and delivers an environmentally responsible option that preserves durability and strength. These results suggest to the prospects of new ecologically friendly building approaches, asking the sector to embrace them without sacrificing structural integrity.

Table 1: Normal concrete [M40 grade].

Mix ratio	1	1.57	2.46
Materials (kg)	Cement = 14.34	Fine aggregate=22.61	Coarse aggregate =36.68

Table 2: Replacement Materials.

Material	**Cement**	**Fine aggregate**	**Coarse aggregate**	**Quarry dust**
Weight (kg) 10 % Replacement	14.34	20.35	36.68	2.26
Weight (kg) 20% Replacement	14.34	18.09	36.68	4.52
Weight (kg) 30% Replacement	14.34	15.83	36.68	6.78
Weight (kg) 40% Replacement	14.34	13.57	36.68	9.04

3. Results and discussion

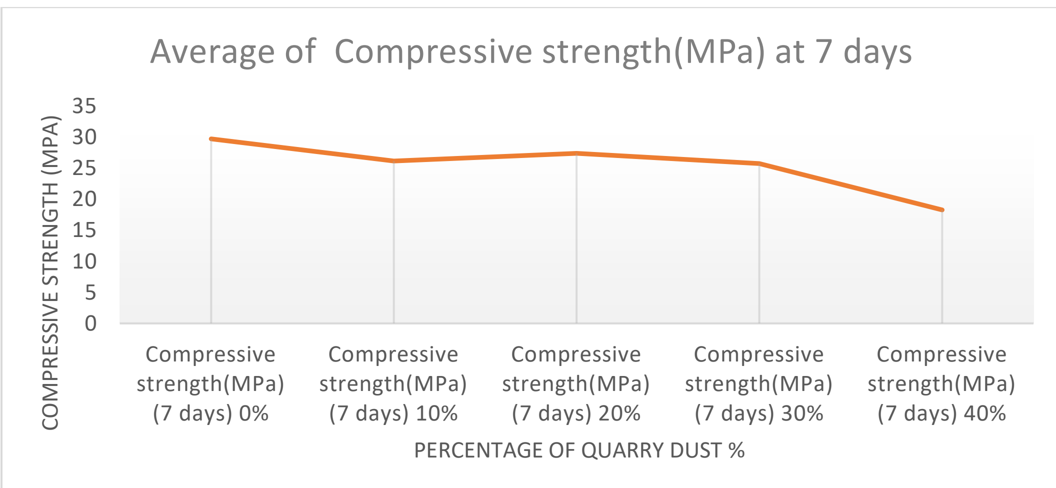
Table 3: For normal m40 concrete.

DAYS	7 DAYS	14 DAYS	28 DAYS
Compressive strength (MPa)	29.71	43.20	47.23

Table 4: Samples of concrete.

Samples	1	2	3	Average
Compressive strength (MPa) at 7 days 10%	26.22	26.48	25.78	26.16
Compressive strength (MPa) at 14 days 10%	42.05	42.22	41.69	41.98
Compressive strength (MPa) at 28 days 10%	46.49	46.58	46.00	46.35
Compressive strength (MPa) at 7 days 20%	27.2	27.06	27.38	27.38
Compressive strength (MPa) at 14 days 20%	40.98	40.84	40.98	40.93
Compressive strength (MPa) at 28 days 20%	44.88	45.11	44.75	44.92
Compressive strength (MPa) at 7 days 30%	23.56	26.05	27.65	25.75
Compressive strength (MPa) at 14 days 30%	37.78	27.28	32.27	32.44
Compressive strength (MPa) at 28 days 30%	34.88	35.24	35.51	35.21
Compressive strength (MPa) at 7 days 40%	16.8	18.89	19.11	18.27
Compressive strength (MPa) at 14 days 40%	29.15	34.67	33.06	32.29
Compressive strength (MPa) at 28 days 40%	33.42	34.88	33.82	34.04

Figure 1: Average Compressive strength (MPa) at 7 days.



The data in Figure 1 shows how varying amounts of additive incorporation affect the 7-day compressive strength of concrete. The results reveal that the maximum early strength is attained in the control mix (0% additive), demonstrating that traditional concrete delivers the optimum early-stage compressive strength. This is particularly vital for construction projects where early load-bearing capacity is critical, such as high-rise buildings, precast elements, and formwork-dependent structures. The superior early performance of traditional concrete can be attributable to the well-established hydration process of cement, which occurs without interference from other additives that might slow down strength increase.

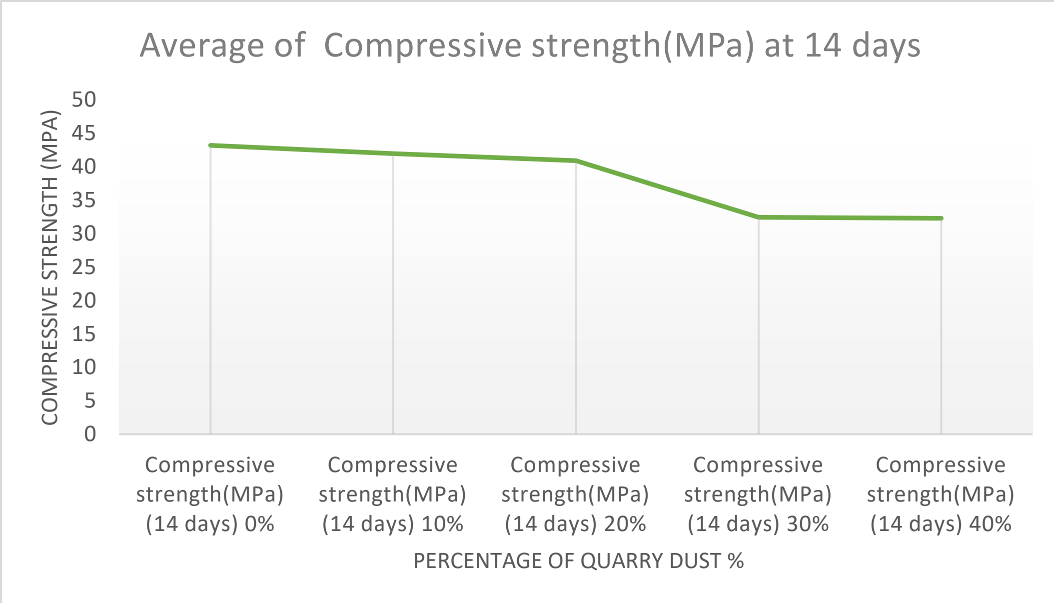
As the additive proportion goes above 0%, a steady reduction in early compressive strength is noticed over the 7-day curing period. Concrete with 10% addition shows merely a slight loss in strength compared to the control mix. This shows that a tiny quantity of additive does not dramatically impede initial strength development, making it a reasonable option for applications where early load-bearing capability is not a main concern. The very constant performance at this level shows that mild additive incorporation can be applied without considerably compromising the concrete's integrity.

At an extra level of 20%, the compressive strength continues to be generally comparable to that of the control mix, while a minor decline is visible. This illustrates that moderate replacement levels may still be feasible in structural applications that can accept a slight reduction in early strength. While the strength is not as strong as that of the 0% additive mix, the difference is not large enough to render the mix unacceptable for regular building demands. Thus, for projects where sustainability and material optimization are sought over early strength, a 20% additive fraction could serve as a good balance between performance and resource efficiency.

However, at a 30% additive level, the downward trend in compressive strength becomes more noticeable, showing a shift in the concrete’s performance characteristics. This reduction shows that as the additive concentration grows, the mix begins to demonstrate less cohesion and bonding, which reduces the total strength gain. The strength loss at this stage may be owing to dilution effects, where the proportion of cementitious material available for effective hydration is diminished due to the presence of the addition. Although concrete at this level may still be structurally viable for non-load-bearing applications, it becomes less suited for purposes where high early strength is a vital requirement.

The most substantial loss in compressive strength occurs at the 40% additive level, where a rapid decline in early strength is recorded. The steep fall at this stage reveals that excessive additive concentration affects the concrete matrix, weakening its internal structure and greatly reducing the hydration process. This discovery is particularly crucial for construction scenarios where early strength development is imperative, such as in precast concrete production, rapid building schedules, or projects needing early removal of formwork. The large loss of strength at this level implies that a high fraction of the addition impairs the fundamental load-bearing capacity of the concrete, making it unsuitable for most structural applications.

Figure 2: Average Compressive strength (MPa) at 14 days.



The results in Figure 2 indicate the continued strength advantage of the 0% additive concrete mix and further verifies the patterns reported at the 7-day mark. The traditional mix's remarkable structural integrity during the early and intermediate curing stages is underscored by the fact that it retains the highest compressive strength even after 14 days of curing. This is especially vital for fast-moving construction projects, load-bearing buildings, and precast elements where early and intermediate strength are crucial variables. The constant strength gain in the 0% mix shows that the lack of additives maximizes strength development by permitting the cement hydration process to run naturally without dilution or intervention. A steady decline in compressive strength becomes increasingly obvious as the increased % grows. When compared to the original mix, concrete mixes with 10% and 20% additions only display small strength reductions. This shows that the addition has a small impact on strength increase at these levels, conserving a considerable amount of the concrete's load-bearing capabilities. These results show that in applications like non-critical structural components, pavements, and general-purpose concrete where a minor loss of intermediate strength is not a serious issue, an additive content of up to 20% may be a viable substitute. Although these mixes don't perform as well as typical concrete, they are nevertheless worth taking into account for specific applications due to their reasonable strength retention, potential economic and sustainability benefits, and other aspects. Even after 14 days, there is a noticeable loss in compressive strength at 30% and 40% additive loading. It appears that excessive additive incorporation affects the concrete's capacity to keep structural integrity during the intermediate curing period, as indicated by the rapid decline at these higher values. Higher porosity and lower cement bonding are presumably to blame for this, as they have a deleterious effect on the hydration process and overall strength retention. Because of this, concrete that contains a lot of additives (more than 20%) could not be suited for structural applications where continuous strength growth is required.

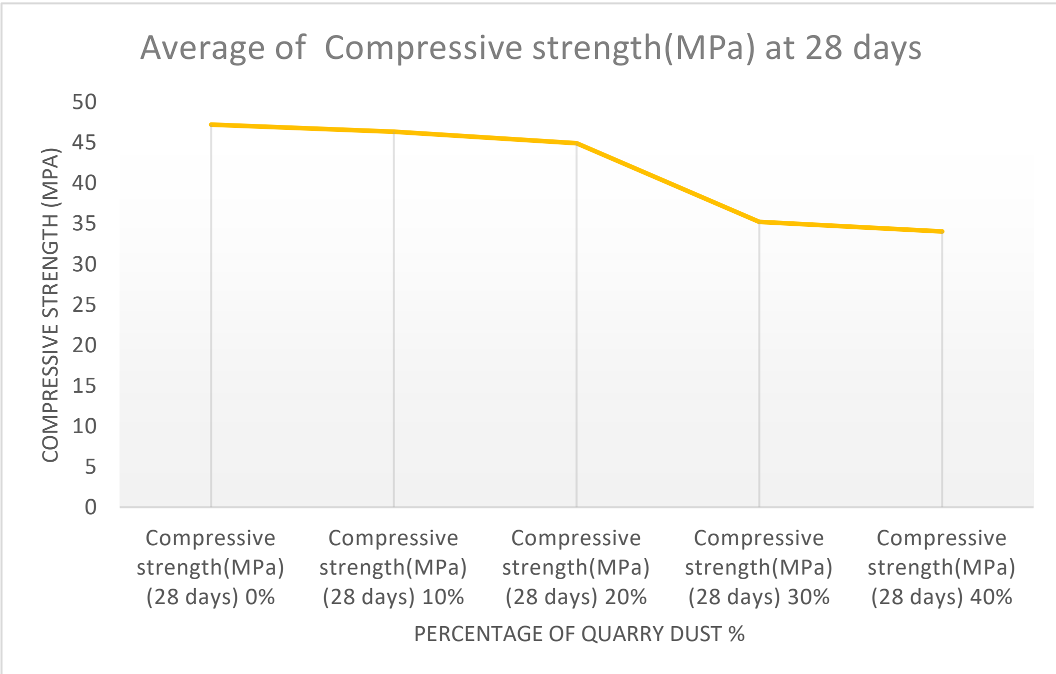


Figure 3: Average Compressive strength (MPa) at 28 days.

The 28-day compressive strength data (shown in Figure 3) support the same patterns noted in the previous phases, confirming that the concrete mix with no additives (0% replacement) is the strongest. This result is anticipated because conventional concrete has the advantage of an unbroken hydration process, which enables cement particles to properly connect and gradually reach their maximum strength.

Strength gradually decreases as the replacement proportion of quarry dust rises. The compressive strength stays relatively close to the original mix at modest replacement levels (10% and 20%), indicating that using minor amounts of quarry dust can be done without noticeably lowering performance. However, the strength decrease becomes considerably more apparent at higher replacement levels (30% and 40%). This suggests that using too much quarry dust reduces the concrete's longevity and long-term strength, which makes it less appropriate for structural applications requiring high strength.

3.1 Performance of Different Quarry Dust Replacement Levels

- **0% Quarry Dust (Control Sample)**

The control mix (0% replacement) served as the benchmark for evaluating alternative mixes, achieving compressive strength values of:

29.71 MPa at 7 days
43.2 MPa at 14 days
47.23 MPa at 28 days

These results confirm that standard concrete without quarry dust replacement delivers the highest strength across all curing stages, making it the most reliable option for high-strength structural applications.

- **10% Quarry Dust Replacement**

At 10% replacement, the concrete mix exhibited strength values of:

26.16 MPa at 7 days
41.98 MPa at 14 days
46.35 MPa at 28 days

These results indicate that a small percentage of quarry dust can be combined without significantly compromising compressive strength. Particularly, the 28-day strength remains very close to the control mix, demonstrating that up to 10% replacement can be implemented without major performance loss.

When compared to other studies:

Umar et al. (2024) reported much lower strengths of 16.69 MPa at 7 days and 29.09 MPa at 28 days, with no data available for 14 days.

Vamsi et al. (2020) recorded 27.11 MPa, 28.55 MPa, and 29.65 MPa at 7, 14, and 28 days, respectively, values significantly lower than those obtained in this study.

These comparisons suggest that quarry dust incorporation at 10% can enhance strength when optimized correctly, making it a viable alternative to natural sand.

- **20% Quarry Dust Replacement**

At 20% replacement, the compressive strength results were:

27.38 MPa at 7 days
40.93 MPa at 14 days
44.92 MPa at 28 days

Although slightly lower than the control, the 28-day strength remains within an acceptable range, confirming that a 20% replacement level does not significantly compromise performance.

When compared to other studies:

Umar et al. (2024) reported significantly lower values of 15.55 MPa at 7 days and 26.40 MPa at 28 days, with no intermediate data.

Siddiqui et al. (2023) recorded much lower compressive strengths of 14.95 MPa, 16.67 MPa, and 25.00 MPa at 7, 14, and 28 days, respectively.

Umar et al. (2024) observed higher strengths of 31.48 MPa, 32.88 MPa, and 33.92 MPa at 7, 14, and 28 days, but still lower than those obtained in this study.

These results confirm that 20% quarry dust replacement provides an optimal balance between sustainability and structural integrity, making it a viable alternative for concrete mix design without significant performance drawbacks.

- **30% and 40% Quarry Dust Replacement**

At higher replacement levels, compressive strength reductions became more evident:
30% replacement: 35.21 MPa at 28 days
40% replacement: 34.04 MPa at 28 days
These values represent a notable decline from the control mix, suggesting that excessive quarry dust content weakens the overall concrete matrix, potentially due to:
Reduced cementitious bonding
Higher porosity levels
Interruption in hydration reactions
Similar trends are highlighted by comparison with other studies:
Vamsi et al. (2020) obtained 27.78 MPa, 29.20 MPa, and 30.10 MPa with a 40% replacement, and 35.70 MPa, 36.95 MPa, and 37.85 MPa at 7, 14, and 28 days, respectively, with a 30% replacement.
Specific mix designs and curing circumstances can affect performance at greater replacement levels, as demonstrated by Azhagarsamy et al. (2018), who showed noticeably higher strengths of 31.86 MPa, 42.67 MPa, and 63.48 MPa at 3, 7, and 28 days for a 60% replacement mix.
With a 50% replacement, Akmal et al. (2023) obtained 36.7 MPa at 28 days, indicating that mix adjustment is essential to reaching a satisfactory strength.
The study's findings demonstrate that quarry dust can successfully substitute natural sand in M40 concrete up to a 20% level while maintaining a high enough compressive strength for structural uses. Significant strength decreases take occurred above this point, rendering replacement levels of 30% and 40% inappropriate for high-strength concrete.
Limiting the replacement level to 20% is advised for applications requiring good structural integrity and durability in order to provide sufficient load-bearing capacity and long-term performance. Higher quarry dust replacements might still be taken into consideration for non-structural applications or circumstances with lower strength needs, though, as long as the right mix changes and curing procedures are followed.
This study demonstrates a sustainable method of producing concrete by using quarry dust in place of some of the sand, allowing for resource conservation while upholding performance requirements necessary for building.

4. CONCLUSIONS

In summary, this study concludes that quarry dust can effectively replace natural sand in M40 concrete up to a 20% level, where compressive strength remains sufficiently high. For applications demanding strong structural integrity and durability, replacements above 20% may lead to compromised performance, making 20% the recommended limit for quarry dust substitution in M40-grade concrete. This approach enables sustainable use of quarry dust without sacrificing the structural qualities essential for construction.

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