Identification of Optimum Replacement Ratio of Processed Quarry Dust as a Substitute for Sand in Cement Plastering

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Abstract
The demand for sand is increasing due to construction activities. River sand scarcity causes illegal mining and environmental damage. The construction industry faces negative impacts if river sand becomes unavailable or scarce. Therefore, finding a suitable substitute is essential for the sustainability of the construction industry as well as preventing further degradation of the river ecosystem. Quarry dust, a byproduct of crushing is studied as a potential substitute. The investigation assessed the feasibility of using quarry dust as a partial replacement for river sand in wall plaster. Quarry dust was utilised to achieve the desired particle size distribution equivalent to that of sand. Five types of cement-sand-quarry dust wall plaster mortars were made. The volume ratios between sand and quarry dust were kept at 1:0, 4:1, 2:1, 3:2, and 0:1 while maintaining a constant cement amount for all mixtures. Then the strength and durability of plastering mortar were examined using destructive and non-destructive test methods. The obtained results were compared with wall plaster made from 100% sand. Results demonstrated that the optimal combination of strength, durability, and workability was achieved when using a sand-to-quarry dust ratio of 2:1. Also, this mixture reduced plastering mortar cost by 6%, recommending replacing 1/3 of the sand with resembled quarry dust for plastering mortar.

Keywords: Cement plastering, Durability, Quarry dust, River sand, Strength, Workability

1 Introduction

Plastering the walls is the process of making the surface of the walls smoother, especially if the surface is rough or uneven. Proper plastering works enhance the structure's aesthetic appearance and provide a protective shield against time, environmental elements, and abrasion. This improves wall durability and strength, ensuring a long-lasting structure. Cement plaster, a mixture of cement, sand, and water, is durable and commonly used for exterior walls, providing strength and protection against various weather conditions. A larger proportion of cement plaster is composed of river sand. River sand forms naturally as a result of weathering and erosion [1]. River sand remains a significant construction component due to its unique qualities, such as easy acquisition, well-graded nature, and evenly distributed grain sizes [2]. Sand is crucial for civil infrastructure, including buildings, roads, and bridges. As construction activities increase, demand for sand increases. The high demand for sand has led to unsustainable and illegal extraction methods, posing significant environmental hazards, including riverbeds, wetlands, and estuaries [3].

If there is no other material that can replace river sand, the construction industry will be rendered ineffective [4]. Quarry dust, manufacturing sand, offshore sand, dune sand, fly ash, and granulated waste are the currently identified substitute resources for sand [5]. Quarry dust, dune sand, and near-shore sea sand are the most common alternative materials that can be used in construction in Sri Lanka. Around 2,500 quarries are operating in Sri Lanka (2016) and the monthly production of aggregate might range anywhere from 1,500 m^3 to 15,000 m^3 [3]. Crushers break down rock, producing quarry dust and aggregates, making it more environmentally friendly and economically beneficial than river sand mining, also quarry dust is more readily available than river sand [2].

The usage of quarry dust and river sand can differ in construction applications due to their distinct qualities. The exact qualities of quarry dust and river sand can differ depending on the grade of the material [6]. Quarry dust has rough, angular particles, while river sand has smooth, rounded particles. Partial replacement of sand with quarry dust can affect the strength and durability of the final output [7]. However, considering different approaches, we can determine the most optimal substitution ratio of quarry dust for sand in construction works.

This investigation used quarry dust from Metal Mix (PVT) Ltd's Galpatha quarry site, which was produced as a waste product in the crushing plant. The key motivations behind this research were to reduce wall plastering costs, minimise environmental degradation and explore the potential of utilising quarry dust.

2 Literature review

Previous studies concentrated on exploring alternative replacements for river sand in concrete and mortar. When natural river sand is replaced with 100% quarry rock dust, compressive and flexural strength tests may be comparable to or better than the reference concrete constructed with natural sand. Contrary to conventional concrete, quarry rock dust concrete absorbs water at a somewhat higher rate. River sand can be replaced by quarry dust with proper water treatment for concrete [8]. Increased quarry dust percentage and fly ash in concrete enable complete sand replacement, reducing sand content [9] and up to 40% replacement of sand by quarry dust can be used in paver blocks [10]. These studies focused on evaluating the compressive strength (ASTM C109M), flexural strength (ASTM C348) [7], water absorption (ASTM C140) [11], flow table (ASTM C1437) [12], and rebound hammering test [13],[14]. These tests are essential for assessing the strength and durability of concrete and mortar in different applications.

2.1 River sand

River sand is the most common component used in cement wall plaster. Its primary function is to impart bulk strength and workability to the mixture [4]. It has the function of a filler and helps to guarantee that the finish is even and smooth by filling in any spaces or voids that may exist in the plaster. It does this by providing the cement with a strong foundation, which reduces the likelihood that the cement will fracture or shrink as it dries. This further contributes to the plaster's strength and durability. As a result, the sand that is used for plastering should have certain characteristics, as shown in Table 1 and Fig. 1 (IS - Indian Standard

Table 1: Properties of River Sand [8]

Property	SG	Bulk density (kg/m3)	Moisture content (%)	Fine particles less than 0.075 mm (%)	pH

Property	SG	Bulk density (kg/m3)	Moisture content (%)	Fine particles less than 0.075 mm (%)	pH
River sand	2.6	1460	1.50	6	5.5 – 7.5

In 2014, the annual demand for river sand was nearly 16 million cubic meters, which was double the amount needed in 2006 [15]. This need for sand and the scarcity of river sand has greatly increased over the past few years [16]. River sand mining impacts ecological, social, and physical contexts, causing direct and indirect effects on ecosystems and communities. When this form of resource exploitation is exposed to weak and poor regulatory regulation, it has the potential to have extremely harmful effects on the surrounding ecosystem [16].

2.2 Quarry dust

Quarry dust is a residual material produced by crushing stones in quarry crusher plants. Raw quarry dust, with particles less than 5 mm, is often considered residue, tailings, or a substance lacking value [8]. Dumping the quarry dust into an open field can pollute the air with ultra-fine particles. The disposal can be costly due to waste management regulations and additional expenses. To avoid these issues, it is crucial to use quarry dust as a cost-effective and environmentally friendly alternative to sand. To improve quarry dust quality, it is essential to compare it to river sand's properties. Improving gradation, and strength, and achieving saturated surface dry conditions can be challenging. Previous studies suggest using a washing plant with a dewatering screen to remove the fine fraction of quarry dust. In addition, they suggested that the quarry dust be placed inside a water tank for 24 hours so that the dust might get internally saturated with water and that the materials be put into saturated surface dry (SSD) conditions [17].

2.3 Research significance

The research gap addressed in this study was the lack of information regarding the suitability of quarry dust for wall plastering purposes. Alteration in the particle size distribution of quarry dust and its applicability in cement plastering was not extensively explored. Accordingly, the primary goal was to determine the optimal replacement ratio of quarry dust for river sand in plastering. Strength and durability are the essential properties of cement wall plaster's performance and longevity. In this context, research has been carried out to investigate the physical and mechanical properties of wall plaster made from varied proportions of quarry dust and sand.

3 Materials and methodology

3.1 Materials

3.1.1 River sand

The sand that is used in the process of plastering is generally regarded as being the most suitable option. The name "Manampitiya sand" is used for this study which is highly recommended for plastering works in the Sri Lankan context.

3.1.2 Raw quarry dust

Raw quarry dust has a particle size distribution ranging from 0 to 5 mm [8]. But the above range can be changed due to some factors such as particle shape, blind effect, moisture content of the particles, size of the raw material, sieving rate and angle of the mesh.

The raw material was gathered from several locations of the stockpile according to the standard sampling methods, and sieve tests were done on samples to check the gradation to determine whether or not it was suitable for plastering works. It was determined that quarry dust showed a significant deviation in the particle size distribution from the plaster requirement particle size. Therefore, this raw quarry dust had to be upgraded before being used for plastering by removing the fine particle fraction.

3.1.3 Processed quarry dust

To produce the processed quarry dust, a separate sieving plant was utilised to take the raw input of quarry dust. The process involved several stages to refine the material and obtain the desired particle size distribution.

3.1.4 Cement

INSEE Sanstha portland composite cement (PCC) consists of tri and dicalcium silicates, tricalcium aluminate, and calcium sulphate as gypsum. It has adhesive and cohesive properties and is capable of binding together mineral fragments in the presence of water to produce a continuous, compact mass of masonry.

3.2 Methodology

3.2.1 Preparation of mixtures

Sand and processed quarry dust were combined according to Table 2. The mixture names are assigned using the following notation S (ratio of sand) and Q (ratio of quarry dust). The grading was utilised for the required limitations. The cement, and sand (sand + QD) ratio is kept at 1:4. Sand with different proportions of quarry dust and while constant ratio of cement is used for making plaster mix.

Table 2: Proposed sample proportions

Sample name	Volume ratio (sand: quarry dust)
S1Q0	1: 0
S4Q1	4: 1
S2Q1	2: 1
S3Q2	3: 2
S0Q1	0: 1

3.2.2 Plastering for the wall

The unplastered cement brick wall with dimensions of 6 m x 1.4 m was selected for this investigation. It was separated into five separate segments for each of the plaster mixtures. The thickness is maintained at 12 mm for plastering.

3.2.3 Casting of specimen

The test specimens were cast as cubes of 50 x 50 x 50 mm and beams of 160 x 40 x 40 mm. Following the proportion of samples that were made, the cast specimens were removed from the mould after 72 hours and allowed to dry at room temperature.

3.2.4 Test methods

The compressive strength of each segment of the plastered wall was evaluated using the rebound hammer test, and a visual inspection test was performed to identify the cracks and visual defects. The rebound hammer test measurements were taken at ten random points within the segments and test results were interpolated according to the inverse distance weighted (IDW) method to numerically standardize the distribution of them.

Mortar mixtures were tested in a flow table apparatus (ASTM C1437), cubic specimens were used for analysing compressive strength and water absorption (ASTM C140), and beam specimens were used to study the flexural strength of the mortar. The mortar’s compressive (ASTM C109M), and flexural strengths (ASTM C348) after 3, 7, and 28 days of curing were determined and average values of three specimens were plotted for each mixture type.

4 Results and discussion

4.1 Sieve analysis results

Fig. 1 shows sieve analysis results showing mixed proportions satisfying gradation limits, indicating sand and quarry dust combination aligns with the desired particle size distribution. A well-graded mixture can enhance the overall performance of the plastering mortar by improving cohesion and reducing voids within the mixture [18].

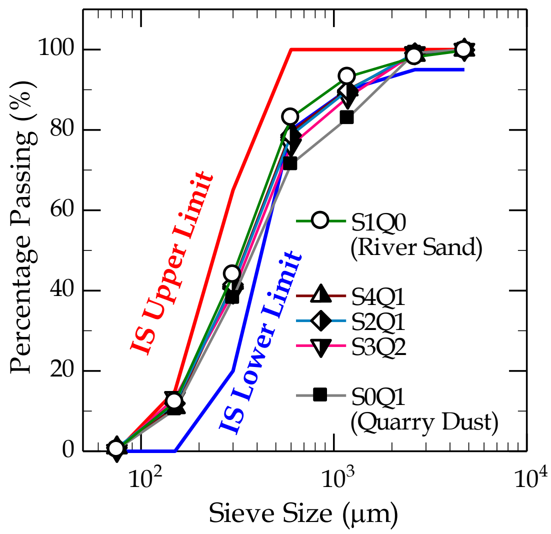

Figure 1: Sieve analysis results of samples

4.2 Compressive strength

Fig 2. (a) shows the compressive strength of the mixtures. Results were analysed and compared with S1Q0. The compressive strength of test plaster mixtures exhibited a significant pattern, with cement plaster's strength decreasing with quarry dust addition. The strength increases in S2Q1 and decreases with the increased amount of quarry dust. Previous studies revealed that micro porosity, packing and interlocking of the particles in the plaster mix may be affected by the particle size distribution. The fineness modulus of quarry dust may be different from those of sand and result in lesser strength [6].

In addition, quarry dust's chemical composition may include substances or reactive chemicals that might hinder hydration and weaken the material. Replacement of the sand the compressive strength depends on the quarry dust location from where the quarry dust was taken [9].

According to IS 1542:1992, the standard minimum required compressive strength value is 3 MPa at 28 days.

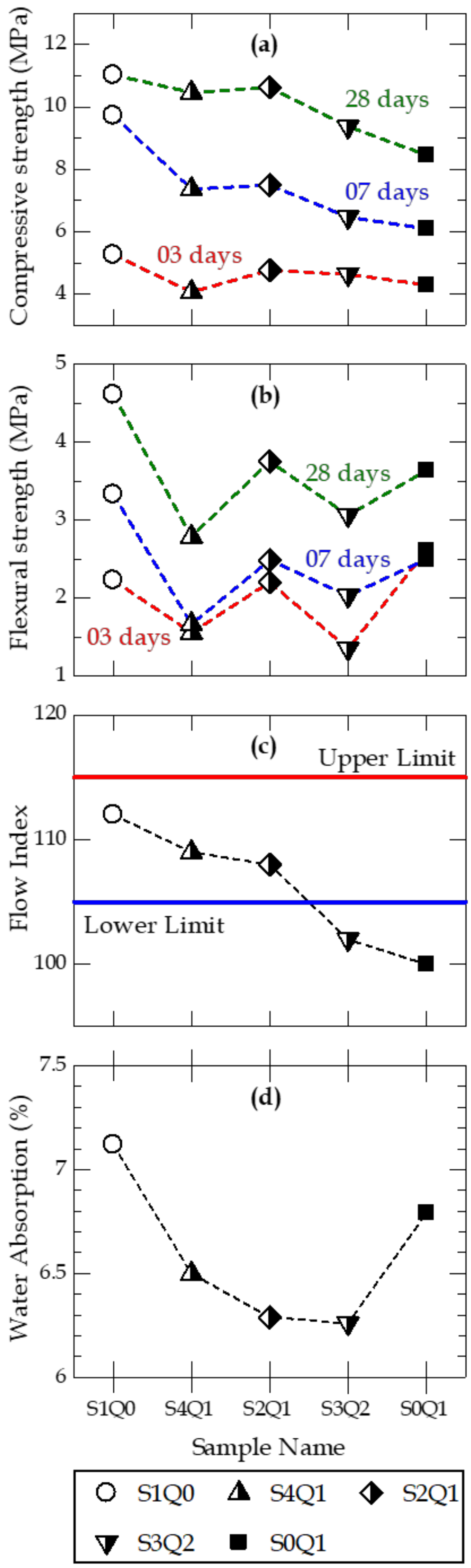

Figure 2: (a) Compressive strength, (b) Flexural strength, (c) Flow index, (d) Water absorption of samples

When comparing with the reference S1Q0 mixture, the S4Q1 and S2Q1 are more suitable for plastering in terms of compressive strength which showed the smaller deviation from the reference mixture.

4.3 Flexural strength

Fig. 2. (b) shows the flexural strength of the mortar. Results were compared with the reference S1Q0. The trend of quarry dust mixes performing comparatively weaker in flexural strength persisted. This fluctuating pattern indicates that the incorporation of quarry dust in the plastering had an impact on the material's ability to resist bending forces. The variations in the results can be caused by factors such as the quarry dust's interfacial qualities, particle size distribution, and bonding characteristics.

However, S2Q1 and S0Q1 showed improvements in flexural strength compared to other mixtures with higher quarry dust proportions, suggesting that an appropriate balance of sand and quarry dust can enhance flexural strength properties. The quality and consistency of the quarry dust, as well as variations in the porosity and permeability qualities, can all contribute to the flexural strength differing from that of the sand-cement combination [8]. This result suggests that S0Q1 and S2Q1 are suitable for plastering when compared to the reference S1Q0 mixture in terms of flexural strength.

4.4 Flow table test

Workability depends on the water-cement ratio and the aggregate’s water absorption capacity [9]. Fig. 2. (c) shows the flow index of the mixtures and S1Q0 and S4Q1 showed higher flow index values, indicating good workability. This also suggests that even though the addition of quarry dust may have a slight impact on reducing workability. Crusher dust has a rough texture, requiring more water for surface weighting than sand. This consumes water, reducing workability and affecting the net water available [9].

4.5 Water absorption

Fig. 2 (d) shows the water absorption results, indicating that there is no significant deviation of these values. Therefore, this suggests that incorporating quarry dust within certain proportions did not lead to a notable increase in water absorption after the curing period of cement plaster. Mortar durability is influenced by water absorption. Higher absorption leads to reduced durability [8].

4.6 Visual testing

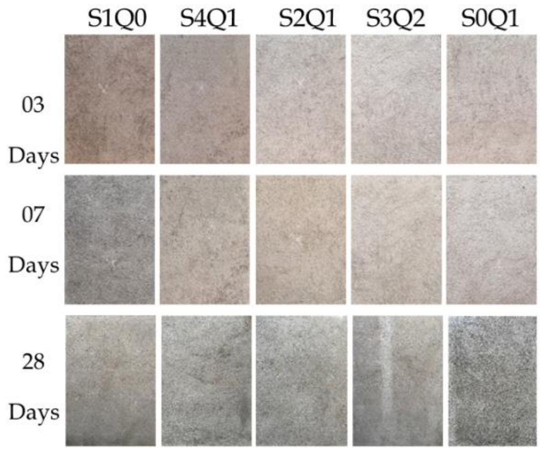

Figure 3: Visual testing of the wall

Fig. 3 shows the visual inspection of the wall through photography, a comprehensive assessment of its overall appearance and quality was obtained. Through observation of the surface texture in each tested wall area, it was possible to find that there was a fine smooth variation concerning each proportion of plaster. However, there were no visible rough patches or unevenness within the test areas with the ageing of the plaster. Although the inspections for undulations, delamination and blistering were done, there were no significant deviations related to these mentioned defects.

4.7 Rebound hammering test

Fig. 4 shows the Strength variation during rebound hammering tests, and it may be caused by surface irregularities in wall plaster, such as smoothness or texture. If certain areas had different smooth levels, the rebound hammer might yield different values compared to the areas with rougher or softer surfaces [14]. Substrate variation in the wall material and moisture content could impact rebound hammering test results, as the density and composition may not be homogeneously distributed [13]. Higher moisture contents in certain areas could lead to soften the plaster, resulting in lower rebound values compared to the drier areas.

The compressive strength and rebound hammer analysis exhibited a correlation of 0.8996865, indicating a close similarity in the test results patterns. With this strong correlation in place, we can confidently draw valuable insights from the rebound hammer test results regarding compressive strength.

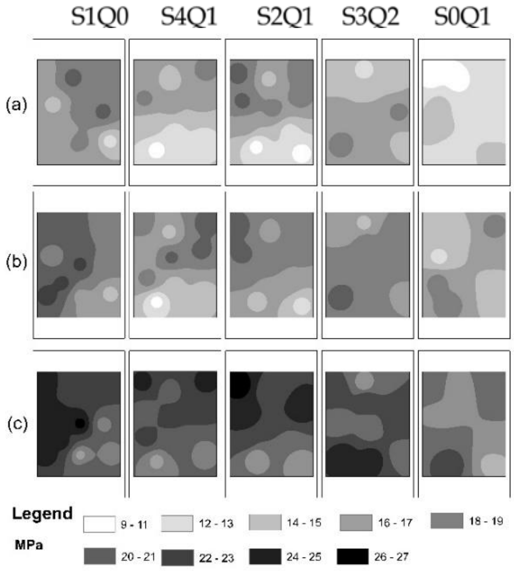

Figure 4: Rebound hammer test compressive strength distribution of (a) 3 days (b) 7 days (c) 28 days

4.8 Cost analysis

Table 3: Volume calculation needed for plastering one square foot

Description	Thickness of the plastering (mm)	Area to be plastered (cm^2)	Volume to be plastered (cm^3)	Dry volume of the plaster (cm^3)	Volume of cement (cm^3)	Volume of sand/QD (cm^3)
In metric units	12.5	900	1125	1518.75	303.75	1215

Table 4: Price of the materials

Material	Amount (Qty)	Price (Rs.)	Unit price (Rs.)
River sand	100 ft^3	24000	240
Processed quarry dust (Metal Mix quarry & crusher)	100 ft^3	11000	110
Cement	50 kg	2250	45

Table 5: Price comparison of plastering one square foot area

Proportion	S1Q0	S4Q1	S2Q1	S3Q2	S0Q1
Total price (Rs.)	29.97	28.86	28.11	27.44	24.4
Cost reduction (%)	0.0	3.7	6.2	8.4	18.6

5 Conclusion

The required particle size distribution for plastering can be achieved by the proper mixing of sand and processed quarry dust. Findings suggest that quarry dust in plaster mixtures affects properties but doesn't significantly compromise the performance on plastered surfaces. The mixtures still exhibit favourable characteristics such as acceptable workability, strength, and water resistance, indicating their suitability for plastering applications. According to the test results, the S2Q1 mixture is a suitable option for plastering works. Which is composed of 1/3 replacement of processed quarry dust for sand. Also, it is economically viable which showed a 6% reduction in total cost for plastering.

However, it is important to note that the suitability of any plaster mixture may also depend on specific project requirements, environmental conditions, and regional factors. Furthermore, it is recommended to conduct additional testing to assess the thermal properties, chemical reactivity, radioactivity, and resistance to acidic conditions of the S2Q1 mixture. Porosity and particle interlocking can affect the mortar strength and SEM analysis can be used for further study. Most of the total cost of cement plastering depends on the amount of cement used. Therefore, further research should focus on reducing the cement content by increasing the quarry dust amount for plastering.

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