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Effect of Accelerated Climatic Ageing on the Behavior of Cement Plaster Made Out of Quarry Dust

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Abstract
This study investigates the long-term durability and mechanical performance of cement plaster incorporating 100% quarry dust as a sustainable replacement for river sand, with a focus on behavior under accelerated climatic ageing. Two mix ratios commonly used in external (1:4) and internal (1:6) wall plastering were prepared using both river sand and quarry dust as fine aggregates. Workability was evaluated using flow table tests, while compressive strength and water absorption were measured over a six-week period involving repeated thermal shock cycles to simulate severe environmental conditions. Results showed that quarry dust mixtures required significantly more water to achieve standard workability due to their angular and poorly graded particle structure. Despite this, all quarry dust-based mixes consistently exceeded the 3 MPa compressive strength threshold after ageing, comparable to river sand controls. Initial strength reductions from thermal shocks were mitigated by ongoing hydration, particularly in quarry dust specimens, while water absorption stabilized as calcium silicate hydrate developed. The findings demonstrate that quarry dust is a viable and durable alternative to river sand in cement plaster, supporting sustainable construction practices and resource conservation in regions facing sand scarcity.

Keywords: Cement plaster, Durability, Quarry dust, River sand replacement, Sustainable construction, Thermal shock

1 Introduction

River sand has been used as a building material ever since the construction industry began. The reason for that is the ease of acquisition and the well-graded nature [1]. However, increasing demand driven by rapid infrastructure development has led to rising prices and serious environmental impacts. Research has shown that global river sand resources could be exhausted by 2050 [2]. The annual sand demand in Sri Lanka reached approximately 7 to 7.5 million cubic meters in the year 2009 [3]. Excessive river sand mining has to severe consequences, including riverbank erosion, widening riverbeds, and biodiversity loss. In response to these challenges, researchers have explored sustainable alternatives to river sand for construction applications. Quarry dust, a byproduct of rock-crushing plants, has been recognized as a promising substitute. By 2016, Sri Lanka's 2,500 active quarries generated considerable quantities of quarry dust, with monthly aggregate outputs ranging from 1,500 to 15,000 cubic meters [4]. Quarry dust has very little usage, but it has a higher availability than river sand [1].

Quarry dust has been used as a popular alternative in cement plastering and concrete mixtures [5], [6], [7],. Most of the related studies have shown that an increase in quarry dust content causes to increase in water absorption as well as the compressive and flexural strengths while reducing the workability of mortar [5], [6], [7], [8]. The cement blocks made of 100% Quarry dust have shown acceptable workability, compressive strength, water absorbability, and a 27% reduction of plastering material cost [6].

Cement plastering remains a fundamental construction activity because it provides both protection and an aesthetic finish to a building. The cement:sand ratio in a plastering mixture is selected based on the purpose. General practice in the construction industry is to keep the cement:sand ratio for internal wall plastering is 1:5 to 1:6, while that ratio for external wall plastering is 1:3 to 1:4 [9]. Lower cement content is recommended for internal plastering because internal walls are less likely to be exposed to harsh weather conditions [9]. Higher cement content in external wall plastering ensures better strength and weather resistance for external walls [9]. To assess the desired workability of cement mortar, most of the researchers have used the flow table test [5], [6]. According to the ASTM C1437, mortar mix proportions were prepared to meet the standard flow values and to ensure consistent workability [5], [6]. Dhananjaya et al. [6] and Madhurshan et al. [5] have shown that using 100% quarry dust in plaster can achieve compressive strengths above 3 MPa, meeting standard requirements. While previous studies confirm the adequate strength of quarry dust-based plaster, the long-term durability of cement plaster remains unexplored.

Evaluating long-term durability is critical, as it determines the material's resistance to environmental stresses such as moisture fluctuations, thermal cycles, and weathering, which ultimately governs its service life and sustainability in construction applications. Accelerated Climatic ageing is an experimental technique that accelerates the normal decomposition process by using severe conditions or rapid cycles of temperature, relative humidity, and exposure to elements like O_2, CO, CO_2, SO_x, NO_x and UV radiation [10]. Researchers subjected their specimens to freezing-thawing cycles to simulate natural freeze-thaw weathering in cold climates, causing material degradation by cracking, spalling, or loss of mechanical properties [10], [11].

Thermal shock testing is another method that gives a sudden thermal shock to the material that undergoes the testing process. For example, a concrete cube oven dried at 200- 800 °C and suddenly inserted into the water tank, giving an instant thermal shock [12].

The deterioration of cement-asphalt mortar under wetting-drying cycles was examined by [13] alternating 7-day water immersion and 7-day air drying for up to 8 cycles, followed by compression testing at various strain rates [13]. Results showed significant reductions in compressive strength (up to 40.48%) and elasticity modulus (up to 35.51%), especially at lower strain rates, highlighting the damaging effects of repeated moisture exposure [13].

The effect of thermal shock on mortar has been investigated by heating specimens to 100–900°C and cooling them by air or water, followed by shear testing and X-ray CT scans to assess internal damage [14]. Water quenching caused more severe cracking and greater shear strength deterioration, especially in specimens with preexisting flaws, highlighting the critical impact of cooling methods on thermal degradation [14].

This study aims to evaluate the mechanical and durability performance of quarry dust-based cement plaster under accelerated climatic ageing. Thermal shock testing was employed as the primary technique, as it replicates rapid temperature and moisture fluctuations similar to those encountered during service life. Through this approach, the study provides insights into the degradation mechanisms and long-term serviceability of quarry dust-based plaster, extending current knowledge beyond short-term strength assessments.

2 Materials and Methodology

2.1 Materials

River sand extracted from the Mahaweli River in the Manampitiya area, which is widely recommended in the local construction industry, was obtained from a local supplier. Obtained river sand was sieved to remove particles larger than 2.36 mm.

Quarry dust obtained from the Galapatha Metal quarry was sieved, and the fraction retained within the particle size range of 0.1-2.36 mm was used when preparing specimens for testing.

Further, Portland Composite Cement (42.5 N strength class) was used for this study.

2.2 Methodology

2.2.1 Mixture Preparation

Following ASTM C136, the collected river sand and quarry dust samples were oven-dried to remove moisture. Then, following ASTM D6913, Sieve analysis was conducted to determine the particle size distribution of the raw river sand and raw quarry dust samples.

Next, the dried raw sand sample was sieved through a 2.36 mm sieve to remove particles exceeding this size fraction. Similarly, the dried raw quarry dust was sieved to retain particles within the 0.1 mm–2.36 mm size range, which were subsequently used for test specimen preparation. Quarry dust particles finer than 0.1 mm are known to cause water bleeding and adversely affect plastering performance [8] Therefore, particles smaller than 0.1 mm were removed prior to specimen preparation.

This study was conducted on both internal and external wall plastering, where cement:sand ratios were 1:4 and 1:6, respectively.

100% quarry dust replacement for cement plastering was recommended by [6]. Therefore, plastering was prepared by replacing 100% quarry dust and a cement:sand plaster was used as the reference sample.

2.2.2 Flow table test

The optimum water content of each ratio was obtained using the flow table test following ASTM C1437, until they showed the standard 110±5 mm flow value on the flow table.

2.2.3 Casting Specimens

According to [5] and [6], ASTM C109M and ASTM C140 standards were used to evaluate the compressive strength and water absorption of plastering mortars and used 50 mm cubic specimens. Similarly, 50 mm cubic molds were used to prepare specimens for testing following ASTM C109M.

Seven specimens for each mix ratio were cast using both river sand and quarry dust as fine aggregates. The cement and aggregate mixtures were prepared with the optimum water content determined through the flow table test (ASTM C1437), ensuring adequate workability. The prepared plastering mortar was placed into 50 mm cubic molds and allowed to set under ambient conditions for 48 hours. Subsequently, in accordance with ASTM C150, the demolded specimens were submerged in water bath for a period of 28 days.

2.2.4 Thermal shock testing procedure

After 28 days of curing, the specimens were removed from the water bath and allowed to drain naturally for three days. Subsequently, one specimen from each mix was selected for compressive strength testing. The remaining specimens were oven-dried at 105 °C for a duration of eight hours. Following the drying process, the specimens were immediately immersed in a water bath and maintained under immersion for 16 hours.

This drying–wetting cycle was repeated for four times. Upon completion of the fourth cycle, the specimens were removed from the water bath, and their wet masses were measured. The specimens were then oven-dried again at 105 °C for eight hours, after which the dry masses were recorded. These wet and dry mass values were used to calculate the water absorption of each specimen.

After the weighing procedure, specimens were kept under ambient laboratory conditions for two days. After these two days, the procedures for the second week were started on the following day. On the first day of the second week, one specimen from each mix was tested for compressive strength in accordance with ASTM C109. The remaining specimens continued to undergo the same drying–wetting cycle, which was repeated for five weeks.

2.2.5 Water absorption

Water absorption was calculated according to equation 1, using the recorded wet and dry mass values of the specimens.

$$WA\ \% = \frac{m_w - m_d}{m_d} \times 100\% \qquad (1)$$

Where *WA%* is the water absorption value, m_w is the wet mass and m_d is the dry mass of the specimen.

3 Results and discussion

3.1 Particle Size Distribution

Figure 1 shows the particle size distribution (PSD) curves obtained for river sand and quarry dust.

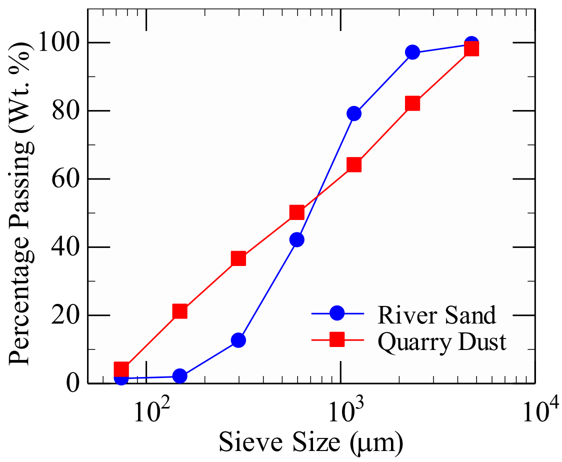

Figure 1: Particle size distribution

River sand, being naturally occurring, consists of well-rounded particles with varied sizes formed through weathering and transportation processes [15]. Figure 1 indicates balanced distribution of fine, medium, and coarse particles, reflected in the gentle slope of river sand PSD curve. Quarry dust, as an artificial byproduct from stone crushing operations, contains predominantly angular particles with sharp edges [16]. The mechanical crushing process produces a higher proportion of fine particles, resulting in a steeper curve indicating poor gradation compared to natural sand (Figure 1).

The coefficient of uniformity (Cu) and the coefficient of curvature (Cc) were calculated to characterize the gradation of river sand and quarry dust using the following criteria.

$$Cu = \frac{D60}{D10} \quad (2)$$

$$Cc = \frac{(D30)^2}{D10 \times D60} \quad (3)$$

Where Cu is the Coefficient of uniformity and Cc is the Coefficient of curvature.

Table 1: Particle Size Distribution Test Results

	River Sand	Quarry Dust
D10 (Passing at 10%) (µm)	264.3	101.5
D30 (Passing at 30%) (µm)	478.0	237.1
D60 (Passing at 60%) (µm)	882.2	1014.3
Cu	3.3379	9.9959
Cc	0.9799	0.5460

Table 2: Classification of Soil (ASTM D2487)

Cu ≥ 6	1 ≤ Cc ≤ 3	Well-graded sand
Cu ≤ 6	Cc ≤ 1 or Cc ≥ 3	Poorly-graded sand

According to the soil classification chart (Table 2), the river sand and quarry dust, which were selected for this study, were poorly graded (Table 1 and Table 2). Poorly graded sand and quarry dust might cause low compaction density, poor shear strength, high permeability and lower bearing strength [17].

3.2 Workability

Figure 2 indicates the water-cement ratio against the external plastering mortars (1:4) and internal wall plastering mortars (1:6) made of sand and quarry dust as fine aggregate. According to Table 3, 1:4 mixture proportion required 50% excess water volume to achieve the standard flow index for the plaster made from quarry dust compared to river sand. Considering the 1:6 mixture proportion, it showed 28% excess water volume to reach the standard flow index value for the plaster made out of quarry dust compared to sand.

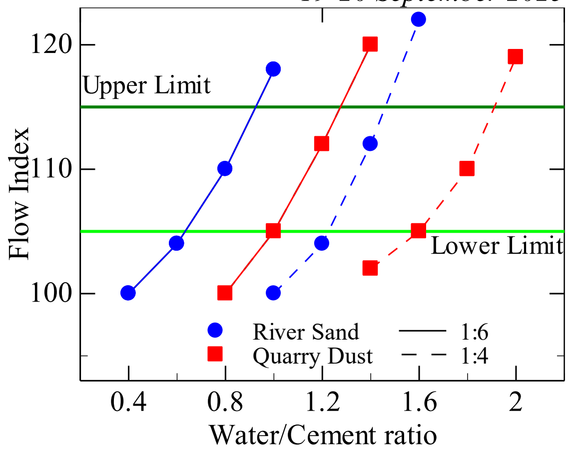

Figure 2: Water:Cement Ratios of mix proportions

Table 3: Water:Cement Ratios of Mix Proportions Yielding Acceptable Workability

Mix Proportion	Water:Cement Ratio	
	River Sand	Quarry Dust
1:4	0.8	1.2
1:6	1.4	1.8

The reason for this phenomenon is that quarry dust consists of angular-shaped particles, and it causes increased pore volumes inside the plaster [16].

The overall water demand increased due to the higher volume of sand used (Figure 2). Greater sand (or quarry dust) content requires more water to ensure adequate bonding with the cement particles. While the addition of extra water enhances the workability of the mix, it can adversely affect the final strength of the plaster [18].

3.3 Compressive Strength

Figure 3 presents the compressive strengths of the specimens throughout the testing period.

As shown in Figure 3(a), quarry dust and sand specimens exhibited a decreasing trend while maintaining a slightly similar gradient of degradation until the second tested weeks. The compressive strength of quarry dust specimens was lower than river sand specimens due to low workability, low bonding and internal pore spaces due to the angular nature of the particles [18]. Meanwhile the 1:6 ratio indicates low compressive strength compared to the 1:4 ratio due to low cement content and high cement-water ratio [18].

After the second tested week, specimens of both proportions have shown a considerable increment in their compressive strength values Figure 3(a). The possible reason for that is the continuous hydration process of cement plaster specimens [19], [20], [21].

The hydration process of cement plastering continues even after the pre-curing period of 28 days at a significantly reduced rate. This extended hydration process drives the plaster material through enhanced compressive strength and durability [19], [20], [21]. The phenomenon which governs the hydration process is that non-hydrated cement particles trapped within the matrix slowly react with available moisture, forming additional calcium silicate hydrate (C-S-H) gel. This process can continue for months or years under favourable humidity conditions [19], [20].

Plasters achieve 95% of their strength during the first 28 days while increasing measurable compressive strength up to 90 days in controlled conditions [20], [22]. In addition, exhibits durability enhancement, continuing hydration reduces capillary porosity, improving resistance to environmental stressors. The hydration process is highly reliant on the presence of moisture, with [20] indicating that maintaining a relative humidity above 80% yields the best results. In practical terms, applying protective coatings that help retain internal moisture while still permitting some vapor to escape can significantly enhance the effectiveness and durability of cement plaster [19], [22].

While the specimens were immersed in water for 16 hours daily, it accelerated the hydration process, and it affected the increase of compressive strength of the specimens (Figure 3(a)).

The hydration process commences once the specimen is cast, exhibiting a rapid increase during the first 28 days, after which the rate of hydration gradually decreases [20]. Until two weeks, the thermal shock degradation has overtaken the hydration process (Figure 3(a)). Therefore, the graphs show a dipping trend. Nevertheless, after the second tested week, the hydration process has come up against the thermal shock degradation. Consequently, the compressive strength of all proportions has increased (Figure 3(a)).

In the 1:4 mix ratio, the compressive strength of quarry dust specimens has increased before the sand specimens (Figure 3(a)). It can be concluded that the hydration process had a considerable effect on quarry dust specimens rather than river sand specimens due to high porosity.

However, all proportions have shown enough compressive strength values more than the minimum required strength value of 3 MPa throughout the testing period, and results didn't indicate considerable compressive strength deviations between quarry dust and river sand

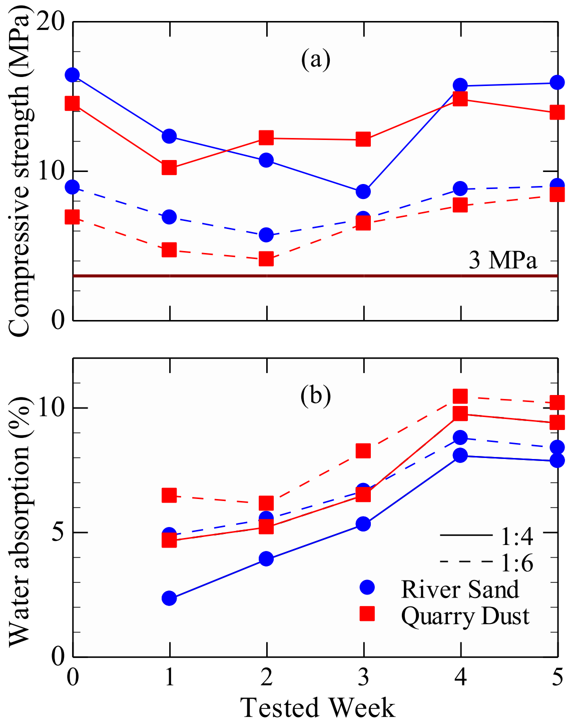

Figure 3: Temporal variation of (a) compressive strength and (b) Water absorption with mix proportions.

3.4 Water Absorption

Figure 3(b) shows the water absorption variations of the tested specimens throughout the testing period.

According to Figure 3(b), the water absorption of all specimens shows a slightly similar pattern. Until the fourth tested week, the water absorption rate has rapidly increased (Figure 3(b)). It can happen due to new microcrack formation under the thermal shock degradation process. After the fourth tested week, the rapid water absorption rate has slowly decreased. The reason for that rate drop might be due to filling pore spaces and microcracks by calcium silicate hydrate (C-S-H) gel [20].

Figure 4 shows the variation in water absorption of the final specimens for all mix proportions, representing additional samples that were not tested for compressive strength. Since these specimens were continuously monitored for water absorption throughout the testing period, the Figure 4 reflects the progressive variation in water uptake over time. Similar to Figure 3(b), these specimens exhibited an increase in water absorption up to the third week, after which the absorption stabilized, indicating ongoing hydration of the plaster and gradual filling of microcracks.

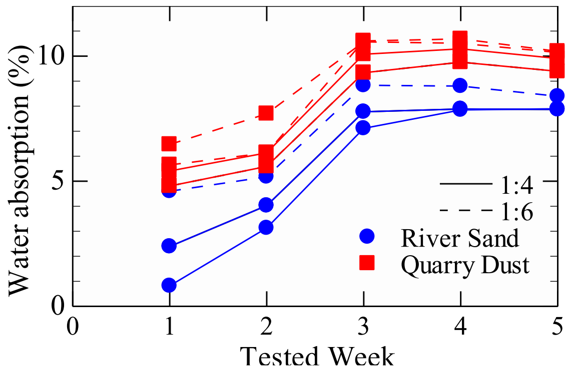

Figure 4: Variation in water absorption of the final specimens (excluding those tested for compressive strength)

4 Conclusion

In the Sri Lankan context, the main climatic phenomenon is rainfall and sunny skies. Investigating the long-term behavior of cement plasters made from river sand and quarry dust under an accelerated climatic ageing process simulating wet and dry seasons, helps to state the reliability and suitability of quarry dust as an alternative construction material.

By maintaining a control system in parallel with the experimental system, this study presents more insights into qualitative analysis rather than quantitative analysis. According to the results in this study, quarry dust behaves acceptably compared with river sand as an alternative for cement plastering. While river sand is the best-known additive for cement plastering, quarry dust exhibits a slightly parallel strength variation to the river sand.

Nevertheless, since the main objective of this study was to investigate the durability of cement plaster made from quarry dust, this result is not enough to conclude. As the hydration process took place, the degradation of the samples was disturbed. Therefore, a clear conclusion of the long-term degradation process and durability of cement plaster made of quarry dust cannot be drawn.

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