ISERME 2024 Proceedings
2nd September 2024 – Sapporo, Japan
https://doi.org/10.31705/ISERME.2024.12

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

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Abstract

River sand and cement are important construction materials, but their scarcity creates significant challenges for the construction industry. Quarry dust is being explored as a possible alternative, as crushed rock is a common aggregate source in Sri Lanka. Therefore, this study focuses on determining the possibility of using quarry dust as a partial replacement for cement and river sand in plastering mortar. Selected Manampitiya river sand and quarry dust from four quarries were subjected to sieve analysis (ASTM C136). Four quarry dust samples obtained from two different crusher types (cone crusher and vertical shaft impact crusher) were sieved to separate 0.1-2.36 mm particles and <0.1 mm particles to replace with sand and cement, respectively. Plastering mortar's cement-sand ratio was selected as 1:5 and developed in 12 mix proportions, varying the replacement of sand with quarry dust (0.1-2.36 mm particles) at 0%, 33%, 50% and 100%, as well as the replacement of cement with quarry dust (<0.1 mm particles) at 0%, 5% and 10%. The flow table test (ASTM C1437) was performed for each mix proportion to obtain the water-cement ratio of plastering mortar, which gives acceptable workability (105-115 mm). Four 50 mm cubic specimens from each mix proportion were prepared according to the obtained water-cement ratio. The cubic compression test (ASTM C109M) and water absorption test (ASTM C140) were performed for the cubic specimens after the completion of the 28-day curing period. Results indicate that the sand and quarry dust samples analysed are poorly graded. An increase in quarry dust in the plastering mortar reduced the workability, but it reached an acceptable range with a water-cement ratio of 1.1-1.2. All tested specimens indicate compressive strength >3 MPa, which was the minimum strength required for plastering. The compressive strength results indicate that the cement replacement can be further increased with 100% sand replacement. The durability of plaster slightly reduces with an increase in quarry dust proportion, indicating a maximum of 2.4% increment in water absorption for a 100% sand-replaced, 10% cement-replaced specimen compared to a specimen made from 100% sand. Furthermore, 100% sand replacement can achieve a cost reduction of 27%. Hence, it is recommended to replace sand 100% with quarry dust 0.1-2.36 mm particles for cement plastering.

Keywords: Quarry Dust; River Sand; Cement Plastering; Compressive Strength; Durability

1. Introduction

Plastering plays a crucial role in the construction industry, not only enhancing aesthetics but also providing protection against weather and wear. Different plastering materials offer various benefits: lime plaster offers flexibility, gypsum plaster sets quickly for smooth finishes [1], and cement plaster provides durability for both interior and exterior walls [2]. River sand, essential for plaster, faces increasing demand due to construction activities [3]. Overexploitation of sand from riverbeds to meet demand leads to several destructive consequences, such as deepening the riverbed, lowering the water table, riverbank failure, saltwater intrusions, coastal erosion, etc. [4].

Dune sand [5], fly ash [6], manufactured sand [7], [8], [9], offshore sand [7], and quarry dust [10] were studied by researchers as possible alternatives to river sand. Among these alternatives, offshore sand, manufactured sand, and quarry dust are gaining traction in the construction industry [10]. Cement, vital for building structures, faces environmental challenges in its production [11]. Among the studied alternatives for cement, such as recycled concrete powder [12], steel slag [13], eggshell powder [14], metakaolin [15], and quarry dust fines [16], quarry dust fines offer promising solutions [17]. Furthermore, there has been an enhanced interest in utilising quarry dust as an alternative to river sand in the construction industry recently due to its redundant nature, cost-effectiveness, and lower environmental impact than river sand [4].

Researchers have extensively explored the suitability of quarry dust as a replacement of river sand in concrete [3], [7], [8], [9], while there are limited studies of quarry dust as a replacement of river sand [10] and cement in cement plastering. Therefore, this study was aimed at addressing the significant research gap by examining the viability of quarry dust for cement plastering, an area often overlooked in previous studies.

2. Literature Review

Workability, strength, durability and economic considerations are the key concerns of researchers when investigating novel concrete/cement plaster mix designs [3], [10], [16], [18], [19], [20]. Quarry dust, a by-product from crushing granite into construction aggregates, has angular particles compared to river sand's smooth ones [21], and it absorbs more water, impacting workability [2]. When there was an increase in the quarry dust content, a higher water/cement ratio was required to maintain constant workability [18]. However, complete replacement of sand with quarry dust has shown equivalent or best results in compressive and flexural strength tests compared to traditional concrete [16], [18], [19] /cement plaster [10]. Sundaralingam et al. [18] have shown that cement blocks made of 100% quarry dust substitution increase strength and durability while maintaining acceptable workability. Aliyu et al. [16] observed an increase in water absorption with the increase in quarry dust replacement, reducing the durability of concrete mortar. Madhurshan et al. [10] indicate that 1/3 replacement of processed quarry dust for sand imposes a 6% reduction in the total cost of plastering. Researchers evaluate workability, strength and durability using flow table test (ASTM C1437) [10], compressive and flexural strength tests (ASTM C109M and ASTM C140) [10], [16], [18], [19] and water absorption test (ASTM C140) [10], [18] respectively.

The cement-sand ratio in cement plastering depends on the requirement. A cement-sand ratio of 1:3 to 1:4 is recommended for external wall plastering, while 1:5 to 1:6 is recommended for internal wall plastering [20]. According to published literature on concrete mix designs, replacing 50% sand [19] and/or 10% cement [22] with quarry dust is acceptable since the compressive strength tends to reduce beyond this fraction. Madhurshan et al. [10] kept the cement-sand ratio at 1:4 and recommended replacing 33% sand with processed quarry dust for plastering mortar.

While prior research explored quarry dust as a river sand substitute across various applications [3], [7], [8], [9], [16], [18], [19], its potential for plastering had been neglected. Moreover, previous studies often relied on samples from single crusher facilities [10], disregarding potential differences due to crusher types and rock mineralogy. Furthermore, there were no studies on replacing quarry dust in 1:5 cement-sand ratio of cement plastering. Hence, this study focused on evaluating the feasibility of using non-processed quarry dust as a substitute for river sand and cement for a 1:5 cement-sand ratio in cement plastering. The study aimed to fulfil the critical need for durable and effective plastering materials in the construction industry by determining the best replacement ratio of quarry dust for river sand and cement through evaluating the samples by sieve analysis test (ASTM C 136), flow table test (ASTM C1437), compressive strength test (ASTM C109M) and water absorption test (ASTM C140). This comprehensive investigation fills a crucial gap in understanding and implementing sustainable construction practices.

3. Materials and Methods

3.1 Materials

Cement plaster consists of cement, sand, and water. Therefore, these materials, as well as quarry dust, were used in this study. River sand extracted from the Mahaweli river in the Manampitiya area is highly recommended for plastering projects in Sri Lanka because of its high quality. Thus, Manampitiya sand obtained from a sand supplier was used.

Standard sampling protocols were used to obtain raw quarry dust samples from four different metal quarries located in Sri Lanka. Quarries located at Galpatha and Meepe use cone crushers, whereas quarries located in Doratiyawa and Bandaragama use vertical shaft impact crushers to produce crushed aggregates. Using 5 mm mesh sieves for collection, the raw quarry dust had a particle size distribution ranging from 0 to 5 mm.

INSEE SANSTHA Portland Composite Cement (PCC) was utilised for this study. PCC is a type of cement that blends Portland cement clinker with additional cementitious elements such as fly ash, slag, silica fume, and limestone. PCC provides enhanced resistance to sulphate and chloride attacks, making it particularly suitable for use in challenging environmental conditions [23].

Normal drinking water was utilised for mixing the plastering paste and gathered from an accessible source.

3.2 Methods

3.2.1 Material Preparation

Table 4 Plastering mortar mix proportions

		Cement replacement by quarry dust (%)		
		0	**5**	**10**
Sand replacement by quarry dust (%)	0	S1Q0C0	S1Q0C5	S1Q0C10
	33	S2Q1C0	S2Q1C5	S2Q1C10
	50	S1Q1C0	S1Q1C5	S1Q1C10
	100	S0Q1C0	S0Q1C5	S0Q1C10

Following ASTM C136, collected sand and quarry dust samples were oven dried to constant mass at a temperature of 110 ± 5 °C. Then, the sand was sieved to separate particles less than 2.36 mm. Controlling the increase of quarry dust fines in cement plastering is critical because of their effect on water bleeding [21]. Therefore, quarry dust was sieved to collect particles between 0.1 mm and 2.36 mm for sand replacement and less than 0.1 mm for cement replacement. The cement-sand (sand + quarry dust) ratio was kept at 1:5, and 12 mix proportions were developed varying the replacement of sand with quarry dust (0.1–2.36 mm particles) as well as the replacement of cement with quarry dust (<0.1 mm particles). Table 1 shows the plastering mortar mix proportions of sand and quarry dust. Each combination is indicated by the notations S (sand ratio), Q (quarry dust ratio), and C (cement replacement percentage).

The flow table test was performed following ASTM C1437 on all mix proportions to determine the optimal water-cement ratio, which gives acceptable workability. The water-cement ratio incrementally increased by 0.1 from an initial ratio of 1.0, and the flow value of each mix was measured at each step. This procedure was executed for all mortar mix proportions until they reached the standard flow value of plastering mortar (110±5 mm), which gives consistent workability.

3.2.2 Casting of specimens

Cubic specimens with 50 x 50 x 50 mm dimensions were crafted following ASTM C109M and ASTM C140 standards to examine the compressive strengths and water absorptions of each mix proportion. The preparation process involved strictly adhering to predetermined water-cement ratios, as determined by the workability test, to ensure uniform workability across all mixtures. After casting, each specimen was carefully extracted from the moulds after 24 hours and left to naturally dry at room temperature. This approach ensured standardised conditions for assessing the compressive strengths and water absorptions of the mix proportions under investigation.

3.2.3 Test methods

After undergoing a 28-day curing period, the prepared cubic specimens were tested according to ASTM C109M and ASTM C140 to assess their compressive strength and water absorption characteristics, respectively. The compressive strength test was conducted to evaluate the strength of the cement plaster, while the water absorption test was performed to determine its durability.

Prior to material preparation, sieve analysis was conducted for sand and quarry dust samples obtained from four quarries adhering to ASTM C136.

4. Results and Discussion

4.1 Particle size distribution

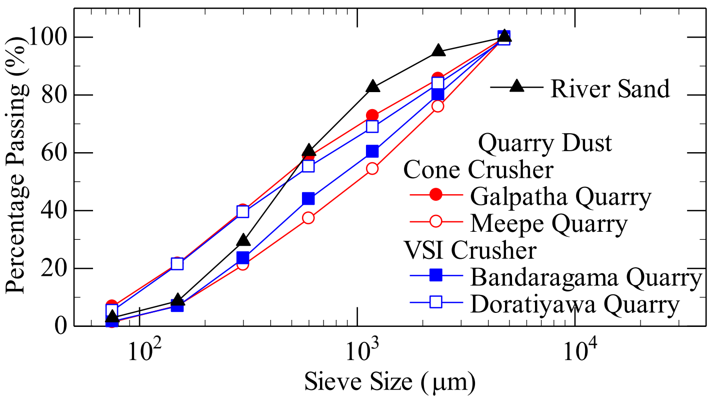

Figure 7 Particle size distribution of sand and quarry dust

Figure 1 indicates the particle size distribution obtained for sand and quarry dust used in this study. Despite being collected from similar crusher types, quarry dust samples from cone crushers (Galpatha and Meepe) and vertical shaft impact crushers (Bandaragama and Doratiyawa) showed differences in particle size distributions. Particle size depends on the crusher design, adjustment capabilities, and work performance, as well as the material's specific characteristics [23], [24]. Hence, variations in particle size distribution were observed with similar crusher types.

The coefficient of uniformity (Cu) and the coefficient of curvature (Cc), which are used to characterise the gradation of soil, were calculated for the obtained particle size distribution curves of sand and quarry dust using equations 1 and 2.

$Cu = D60/D10$ equation 1

$Cc = (D30)^2/(D10 \times D60)$ equation 2

Where:

Cu = Coefficient of uniformity D10 = Passing particle size at 10%

Cc = Coefficient of curvature D30 = Passing particle size at 30%

D60 = Passing particle size at 60%

Cu and Cc, determined by the graph analysis, are shown in Table 2. In soil classification, a Cu over 4 for gravel and 6 for sands indicates a well-graded soil, with Cc ranging from 1 to 3. Soils are considered poorly graded when either Cu or Cc deviate from the defined limits [25]. The analysis found that the sand and quarry dust samples used in this study were poorly graded.

Table 2 Cu and Cc of sand and quarry dust

Material	**Cu**	**Cc**
Sand	4.46	1.19
Quarry dust from		
Galpatha quarry	7.26	0.78
Meepe quarry	8.00	0.93
Bandaragama quarry	6.67	0.86
Doratiyawa quarry	8.11	0.61

4.2 Workability

Figure 2 shows the flow index of plastering mortar mixtures against the water-cement ratio when cement replacement is 0%. Figure 2 clearly indicates that increasing the sand replacement percentage with quarry dust reduces the plastering mortar's workability. Consequently, higher amounts of sand replacement with quarry dust necessitate more water to achieve an acceptable flow index (110±5 mm). This phenomenon is attributed to quarry dust's high water absorbing characteristics, which are due to its porous and angular nature [26]. However, an acceptable flow index for all plastering mortar mixtures can be achieved with a water-cement ratio of 1.1–1.2. Hence, specimens for the cubic compression test and the water absorption test were prepared according to the obtained water-cement ratio of each mix proportion. Similar results were observed for the plastering mortar mixtures with 5% and 10% cement replacement ratios.

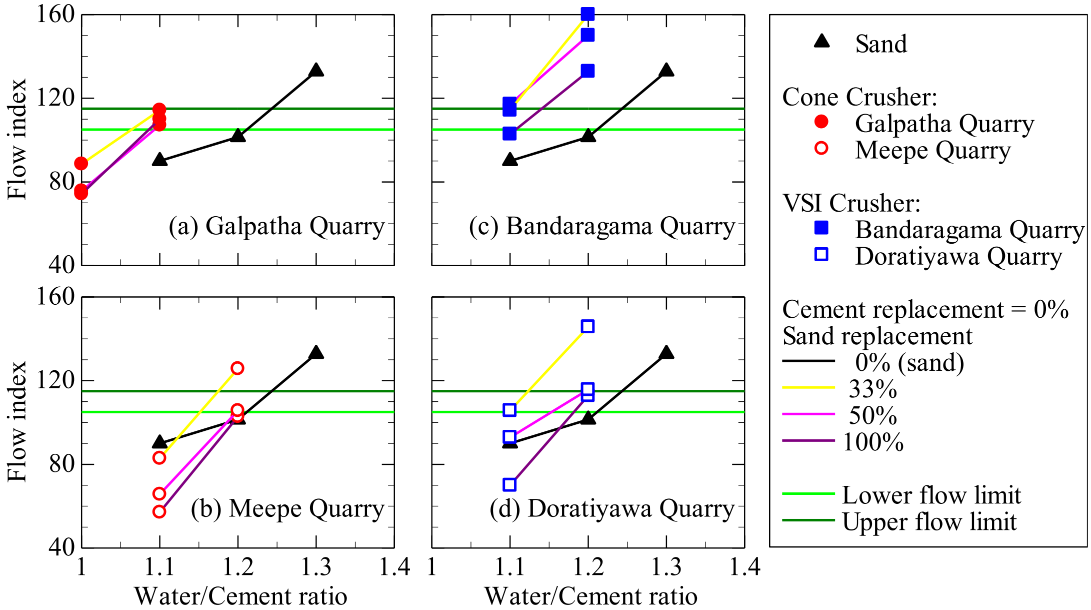

Figure 2 Plastering mortar mixtures' flow index against the water/cement ratio of (a) Galpatha quarry, (b) Meepe quarry, (c) Bandaragama quarry, and (d) Doratiyawa quarry when cement replacement is 0%

4.3 Compressive strength

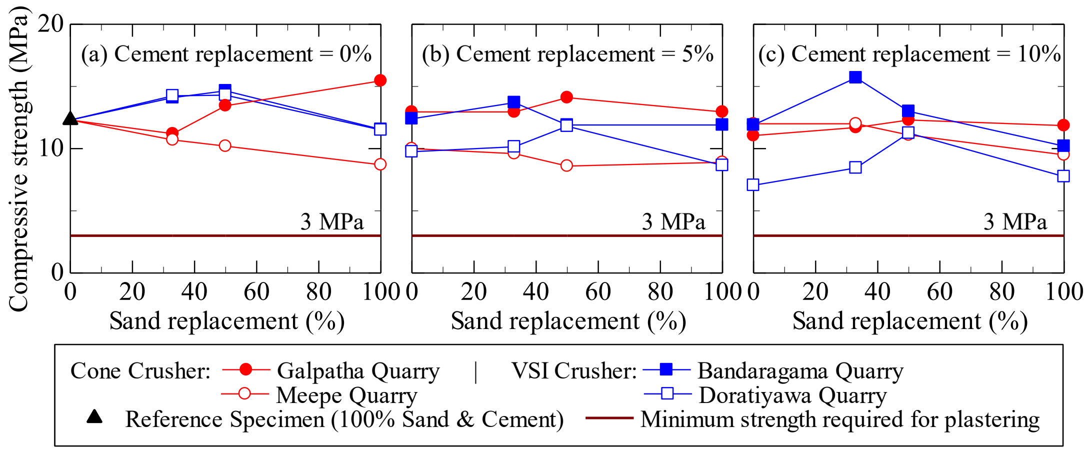

Figure 3 Compressive strength variation with sand replacement when cement replacement is (a) 0%, (b) 5%, and (c) 10%

The compressive strength variation of specimens with sand replacement for 0%, 5% and 10% cement replacement were shown in Figure 3. A specimen made without replacement with quarry dust was shown in Figure 3 (a) as a reference specimen (specimen with 0% sand replacement and 0% cement replacement). Figure 3 indicates that the compressive strength of all specimens exceeded 3 MPa, which was the minimum strength required for plastering according to IS 1542 (1992). Hence, 100% sand replacement with 0.1-2.36 mm quarry dust particles can be recommended for cement plastering with a 1:5 cement-quarry dust ratio. Figure 3 further indicates that the cement replacement percentage can be increased beyond 10%.

Regardless of the quarry's location or crusher type, the compressive strength gradually increases and then decreases, showing a maximum with increasing quarry dust amounts as a replacement for both sand and cement (Figure 3). Sirianni et al. [24] identified the different sizes and irregular shapes of quarry dust particles, along with their chemical composition, including compounds or reactive substances that prevent hydration and weaken the material, as possible contributors to strength reduction. Moreover, slight differences in the compressive strength variation of specimens were observed among quarry locations (Figure 3), probably due to the differences in particle size distribution and mineralogy of quarry dust. Onyelowe et al. [27] observed similar behaviour and suggested that the packing variations within the cement mixture, as well as differences in the mineralogy of quarry dust, as potential variables.

4.4 Durability

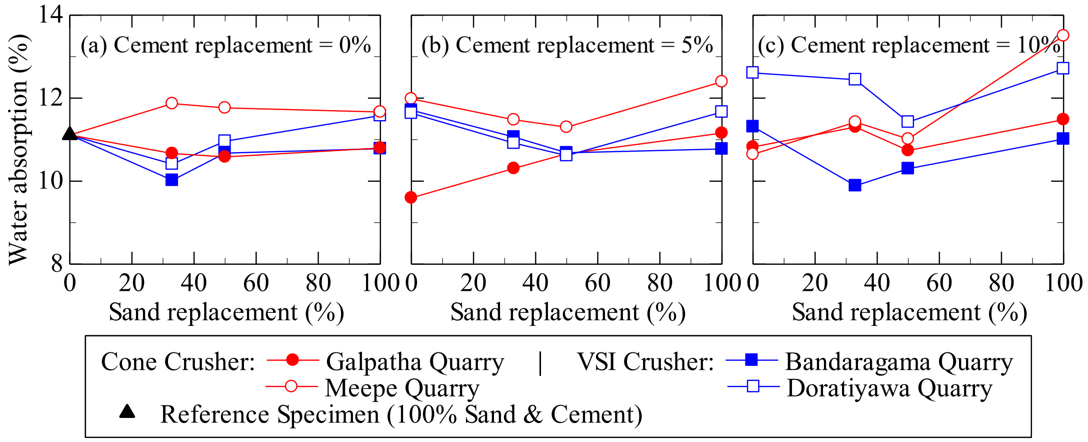

Figure 4 Variation of water absorption with sand replacement when cement replacement is (a) 0%, (b) 5%, and (c) 10%

Figure 4 indicates the water absorption of specimens with sand replacement for 0%, 5% and 10% cement replacement. Like compressive strength results, water absorption variation also does not depend on the quarry's location or crusher type (Figure 4). The water absorption of specimens gradually decreases and then increases, showing a minimum. 100% sand replaced 10% cement replaced Meepe quarry specimen showed the highest water absorption, indicating 2.4% more water absorption than the reference specimen. An increase in water absorption is an indication of a reduction in durability [16]. According to Figure 4, specimens do not indicate an extreme increase in water absorption with quarry dust replacement, confirming the recommendation of replacing sand 100% with 0.1-2.36 mm quarry dust particles for cement plastering with a 1:5 cement-quarry dust ratio.

Water absorbability is strongly related to the interconnected pore volume of the material [28]. Packing variations within the specimen as well as the differences in particle size distribution are the possible reasons for the pore volume variations, resulting in differences in the observed water absorption patterns (Figure 4).

The compressive strength against water absorption of tested specimens was shown in Figure 5. Compressive strength decreases with increasing water absorption, confirming the pore volume variations of the specimens. Specimens with more interconnected pores absorb more water. Further, more pore space within the specimen reduces grain-to-grain contact, reducing the strength of the specimen.

4.5 Cost analysis

The cost analysis was performed for a cement-sand/quarry dust ratio of 1:5. The cement plaster thickness was taken as 12 mm and considered plastering a 1 m^2 area. Accordingly, the calculated volumes of cement and sand/quarry dust were listed in Table 3, whereas the material prices were listed in Table 4. This cost estimation was done for sand replacement from 0% to 100% with 0.1-2.36 mm quarry dust particles, since the maximum cement replacement percentage was not found in this study.

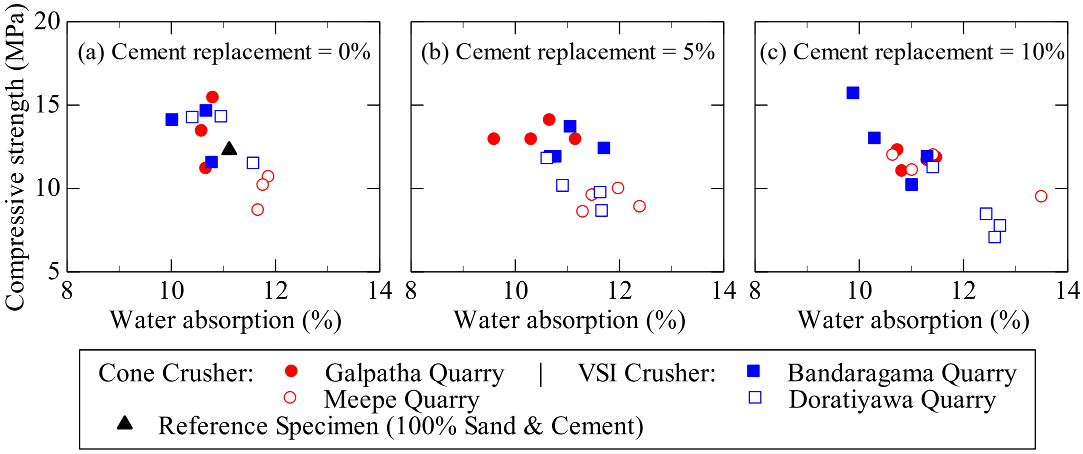

Figure 5 Compressive strength against water absorption when cement replacement is (a) 0%, (b) 5%, and (c) 10%

Table 3 Volume calculation of materials

Description	**In Metric Units**
Thickness of the plastering	12 mm
Area to be plastered	1 m x 1 m
Volume to be plastered	0.012 m^3
Volume of Cement	0.002 m^3
Volume of Sand or QD	0.01 m^3
Density of Cement	1440 kg/m^3

Table 4 Price of the materials

Material	**Amount (Qty)**	**Price (Rs.)**	**Unit Price (Rs. /m^3)**
River Sand	1 Lorry cube (2.83 m^3)	24000.00	8480.57
Quarry Dust	1 Lorry cube (2.83 m^3)	7500.00	2650.18
Cement	50 kg (0.053 m^3)	2250.00	64800.00

Table 5 Cost comparison of plastering mortar mix propotions

Proportion (Sand replacement %)	**S1Q0 (0%)**	**S2Q1 (33%)**	**S1Q1 (50%)**	**S0Q1 (100%)**
Sand amount (m^3)	0.010	0.007	0.005	0.000
Cement amount (m^3)	0.002	0.002	0.002	0.002
Quarry Dust amount (m^3)	0.000	0.003	0.005	0.010
Sand Price (Rs.)	84.81	56.54	42.40	0.00
Quarry Dust Price (Rs.)	129.60	129.60	129.60	129.60
Cement Price (Rs.)	0.00	8.83	13.25	26.50
Total Price (Rs.)	**214.41**	**194.97**	**185.25**	**156.10**
Price reduction with reference to S1Q0 (%)	**0**	**9**	**14**	**27**

Table 5 presents the plastering mortar mix propotion's cost comparison. It is obvious that the 100% sand replacement with quarry dust reduce the plastering cost of materials by 27%.

5. Conclusion

The sand and quarry dust used in this study were poorly graded and showed different particle size distributions. However, the resulting plastering mortar maintained acceptable workability, compressive strength, and water absorbability. Increasing the quarry dust content decreases the workability of plastering mortar due to its higher water demand, necessitating additional water to maintain acceptable workability. The increase in quarry dust reduces the compressive strength of the cement plaster due to changes in particle size distribution. An increase in the interconnected pore volume due to the higher quarry dust fraction in the mixture also decreases the compressive strength of the cement plaster and influences water absorbability.

Compressive strength as well as water absorption test findings indicate that quarry dust fines (<0.1 mm particles) might replace more than 10% of cement. Specimens composed of 100% quarry dust demonstrated satisfactory workability, compressive strength, and water absorbability and indicated a 27% reduction in plastering material cost, making it a viable option for a 1:5 cement-sand ratio in plastering. The economic benefit, combined with the satisfactory performance of the cement plaster, suggests that quarry dust is a practical alternative to sand in construction applications.

Further testing is advisable to evaluate the thermal properties, chemical reactivity, radioactivity, and resistance to salt and acidic conditions of mixtures comprising 100% sand replacement with quarry dust. These additional assessments would provide a comprehensive understanding of the suitability and performance of such mixtures in various environmental conditions. Additionally, it is recommended to study the possibility of replacing more than 10% of cement with quarry dust fines to explore further benefits and applications.

Acknowledgment

We wish to extend our sincere gratitude to all academic and non-academic staff of the Department of Earth Resources Engineering, Mr. V. Sivahar, Head, Department of Materials Science and Engineering at the University of Moratuwa, for their assistance throughout this study. Special thanks to Eng. M. Wimal, General Manager, Metal Mix Pvt. Ltd.; Eng. Kamal Nishantha, Deputy General Manager, Supreme Ready Mix; and Eng. Dilup Gunasinghe, Assistant General Manager (Mining, Production & Quality), Senarath Groups, for providing us with the necessary materials for this research.

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