Proceedings of the 8th International Symposium on
Advances in Civil and Environmental Engineering Practices for Sustainable Development
ACEPS - 2021

Strength and durability characteristics of cement blocks incorporating quarry dust as river sand replacement

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ARTICLE INFO

Available online 07 October 2021

Keywords:
Masonry
River sand
Quarry dust
Cement blocks
Compressive strength
Durability

ABSTRACT

In Sri Lanka, due to the recent development in the construction industry, the demand for construction materials is rising quickly. River sand is primarily used for civil engineering constructions and especially for masonry house unit construction. The over-exploitation of river sand to encounter the demand has led to various harmful consequences. Considering the environmental issue due to the scarcity of sand, there are several alternative materials consider as river sand replacements in masonry block production. Quarry dust is one of such materials consider as river sand alternative due to its beneficial characteristic such as better contribution to the strength of the cementitious material, better workability, lesser cement consumption and eco-friendly. In the present study, the quarry dust replacement levels of 0, 33, 66, and 100 % of river sand are used for cement block production. The compressive strength, water absorption, sorption, and wet and dry resistance were tested for cement blocks after 28 days of curing. Test results show that, cement blocks with quarry shown better strength and durability characteristics.

1. INTRODUCTION

Cement sand block and fired clay bricks are major construction materials used for house construction in Sri Lanka. As shown in Figure 1, in Sri Lanka, 87% of the house units are constructed with cement blocks or fired clay bricks as wall materials.

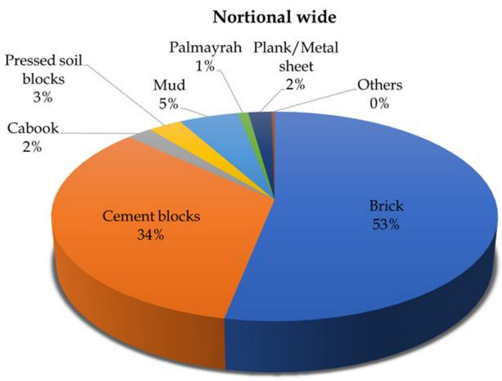


Figure 1 The material used for house units in Sri Lanka

Natural sand or river sand is a major aggregate used for cement sand blocks, and it is contributed to 70% to 80% weight. River sand has been the furthermost generally used fine aggregate in Sri Lanka, and over-exploitation of sand from river bed to encounter the demand has led to several destructive consequences. An excessive river sand consumption has very severe effects on the environment as follows;

- Increased in the depth of the river bed
- The water table is lowered
- Aquatic lives are disappeared from freshwater

The Geological Survey and Mines Bureau (GSMB) of Sri Lanka presently preserves records of all the licenses issued for sand mining and transportation. According to their records, the estimated annual sand supply is 7.99 million meter cubes, which is far lower than the projected demand (Yogananth et al.

2019). Considering the scarcity of sand, several research works have been carried out to explore the options of using alternative materials for river sand in the production of masonry blocks.

There are extensive studies on using agricultural waste, industrial waste, or construction and demolition waste as fine aggregate for river sand replacement. The findings from these studies show that agricultural waste as sand replacement satisfied the minimum strength requirement, durability under extreme environmental conditions is the major issue. Especially, high water absorption rate and resistance against chemicals are limited to their use (Jeyasegaram & Sathiparan 2020). In the case of industrial waste or construction and demolition waste, the preparation of these materials to fine aggregates is involved energy consumption and cost (Sathiparan & De Zoysa 2018; Dash et al. 2016).

In recent years, there is an interest in using quarry dust as river sand replacement in construction materials. Quarry dust is produced from crushing stones or granite into small sand-sized particles to be used as construction aggregate (Nigussie et al. 2019; Cortes et al. 2008; Ding et al. 2016). Quarry dust has some advantages over river sand such as better contribution to the strength of the cementitious material, better workability, lesser cement consumption and eco-friendly.

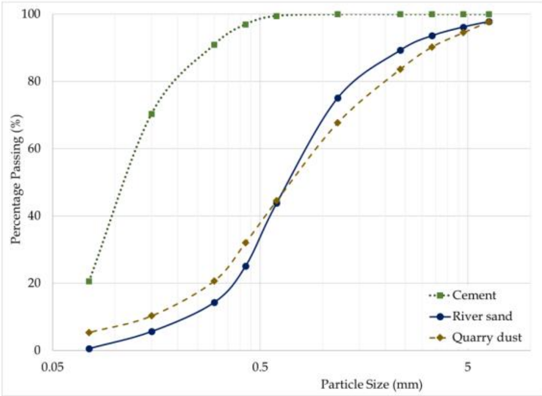
There are intensive published works of literature on quarry dust as a fine aggregate replacement for river sand in conventional concrete (Cortes et al. 2008; Ding et al. 2016; Goncalves et al. 2007; Li et al. 2009; Pilegis et al. 2016). However, the study on quarry dust as fine aggregate replacement for river sand in masonry block production is still limited. Therefore, this study was aimed at understanding the effect of the quarry dust on the compressive strength durability characteristics of masonry blocks.

2. MATERIALS AND METHODS

2.1. Materials Used

In the present study, two types of fine aggregates; river sand and quarry dust were used (Figure 2(a)). The river sand extracted from Muthayankattu river bed, Northern province and quarry dust obtained from manufacturing plant situated in Divulapitiya, Western province in Sri Lanka were used. Ordinary Portland cement with bulk density and specific gravity of 1362 kg/m^3 and 3.15, respectively, was used as the binder. The particle size distributions of cement and aggregates are presented in Figure 2(b).

(a)



(b)

Figure 2 (a) Fine aggregates used and (b) particle size distribution of the materials

Table 1 Characteristic of fine aggregates

Properties	**River sand**	**Quarry dust**
Density (kg/m^3)	1680.5	1641.0
Specific gravity	2.41	2.34
Moisture (%)	1.7	3.5
Water absorption (g/kg)	174	198
Fineness	2.89	2.97
Gravel (%)	3.8	5.5
Sand (%)	95.6	89.1
Silt + Clay (%)	0.6	5.4
Cu	4.01	6.72
Cc	1.10	1.12
USCS classification	SP	SW

Cu: Uniformity coefficient, Cc: Coefficient of gradation, SP: Poorly graded sand, and SW: Well graded sand.

The characteristics of river sand and quarry dust used in the present study are summarized in Table 1. Quarry dust is a lesser density and specific density, but river sand has more sand particles compared to quarry dust. The effective sizes of river sand and quarry dust corresponding to 90% finer are 2.52 and 3.31 mm, respectively, and that of 10% finer are 0.22 and 0.15 mm, respectively.

2.2. Mix Design

Workability is one of the vital parameters that disturbing the strength and durability of mortar. Sometimes, additional water may lead to bleed. Here, the water to cement ratio gradually increased by 0.5 and the slump value of the wet mix was observed in each stage. The procedure was conducted on all four types of mortar mix. For the selection of water to cement ratio to make sure of constant workability, the slump value was set as 30±5 mm.

Figure 3 presents the slump variation with the water to cement ratio. Results show that the workability of the fresh mix reduces with, increase in quarry dust content. To achieve the fixed slump value, fresh mix with quarry dust required more amount of water compared with fresh mix with river sand. As the quarry dust has a reasonable amount of dust that absorbed water and hence it is required more water to achieve a homogeneous mix. To achieve the 30±5 mm, the required water to cement ratio was equal to 1.35, 1.40, 1.45 and 1.50 for mortar with 0, 33, 66 and 100% quarry dust content, respectively.

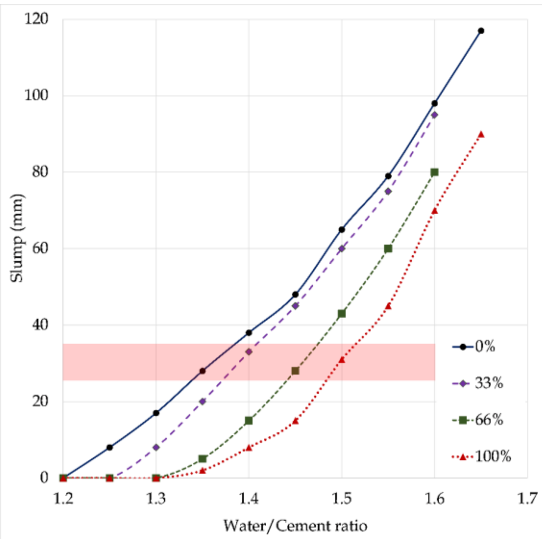


Figure 3 Slump variation with water to cement ratio

Table 2 presented the material mix proportion used for mortar and water to cement ratio to achieving the slump value of 30±5 mm. When a higher content of quarry dust is used in the mortar, the amount of water required for proper mix was increased dramatically.

Table 2 Mix proportion of material quantities

Mix	Replacement level (%)	Cement	River sand	Quarry dust	w/c ratio
1	0	1.0	8.53	0.00	1.35
2	33	1.0	5.69	2.78	1.40
3	66	1.0	2.84	5.56	1.45
4	100	1.0	0.00	8.33	1.50

2.3. Specimen Preparation

With the prepared wet mortar mixes of different compositions, cubes with dimensions 100×100×100 mm^3 were cast to assess the variation of density, compressive strength, water absorption rate and sorptivity among the mixes. The cube casting outline is presented in Figure 4.

Figure 4 Cube casting procedure

2.4. Testing

2.4.1. Compression test

The compressive strength of the cube was assessed through a universal testing machine under a displacement-controlled method, according to ASTM-C109 (2020). Cement mortar cubes are 100×100×100 mm³ in size are placed between rigid steel plates (Figure 5). The loading technique is displacement-controlled monotonic loading at a rate of 5 mm/min. The applied force and displacement are measured by the testing machine load cell and stroke readings, respectively. For each mortar mix composition, six cubes were tested and the compressive strength (σ_c) of the cement mortar cube is calculated by the Eq (1):

$$\sigma_c = P/A \tag{1}$$

where P is the maximum applied load; A is the area of the bed face.

Figure 5 Testing of cubes for compression

2.4.2. Water absorption test

The water absorption tests were carried out for mortar cubes with different percentages of quarry dust. The mortar cubes were dried in a oven at 100°C for 24h. The weight of the mortar cube is then recorded as W_d. Then, the mortar cubes were submerged in water for 24 hours. After mortar cubes were removed from the water, the surface water is wiped off and the weights of the mortar cubes were recorded as W_S. For each mortar mix composition, three cubes were used and the water absorption of the mortar cube was computed by Eq. (2):

$$SWA = \frac{W_s - W_d}{W_d} \times 100 \tag{2}$$

2.4.3. Sorptivity test

The sorptivity is determined by the amount of the water absorbed by capillary rises. The mortar cubes after drying oven at a temperature of 70°C, the samples were placed in a recipient in contact with the level of water capable to submerge them less than 5mm height. The amount of water absorbed is measured by weighing the cubes before and after the capillary for the particular time interval. For each mortar mix composition, three cubes were used and sorptivity is calculated by the Eq. (3) (Sathiparan *et al.* 2017);

$$S = \frac{i}{\sqrt{t}} - I_0 \tag{3}$$

where S is the sorption rate measured in mm/min$^{0.5}$. i is the water absorption, t is the elapsed time in minutes and I_0 is the initial sorptivity rate.

$$i = \frac{W_C - W_0}{A\rho} \tag{4}$$

where W_0 is the oven-dry weight of the mortar cube, W_c is the weight of a mortar cube after capillary suction, A is the area exposed to the water and ρ is the density of water.

2.4.4. Wet and dry resistance test

Tests were done according to the ASTM-C138/C138M (2017) for the wet and dry cycle resistance test, the cubes were placed in the sequence of the water, lab atmosphere and oven at a temperature of +70°C for 12, 1, and 11 hours, respectively. The cubes were tested after the 3rd, 6th, 9th and 12th cycles. For each mortar mix composition and each cycle, six cubes were tested. The compressive strength of the mortar cube was evaluated through a universal axial compression testing machine under a displacement-controlled method.

3. RESULTS AND DISCUSSION

3.1. Density

Figure 6 represents the wet and dry density variation of cubes. Wet density was measured after 24 hours fully submerged in water after 28 days of curing. The density of mortar was increased with quarry dust percentage. The dry density was increased by 1.91 % when river sand was 100% replaced by quarry dust. Wet density has also shown a similar pattern of density variation. Due to the higher water retention ability of quarry dust, wet density is gradually increased with quarry dust.

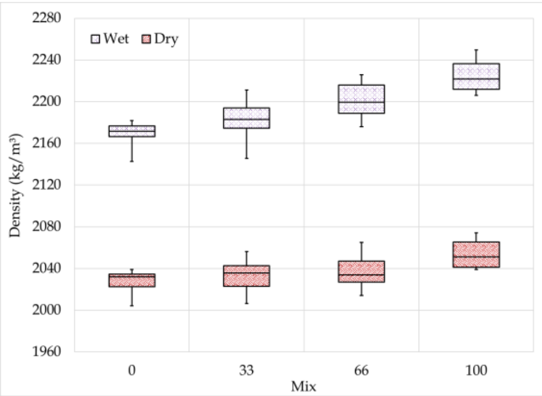


Figure 6 Density variation of the hardened mortar

3.2. Compressive Strength

Compressive strength is considered an important property of any mortar mix. Quarry dust has some favorable physical properties such as have a finer particle, well-graded particle size distribution, consisting of sharp edges which may provide enough stronger bond with cement molecules than river sand in a rounded shape (Thivya & Aarthi 2019). These physical properties of quarry dust could influence in compressive strength of mortar. The angular shape and texture of crushed stone may cause better interlocking between particles and reduce the voids in the hardened mortar, which could lead to an increase in the strength of mortar. Also, due to better water retention ability, water availability for the cement hydration reaction process to generate the calcium silicate hydrate (C-S-H) gel is continued for a longer period. So, it increases the compressive strength of mortar. Also, these finding indicate that the angular shape and rough surface texture of the quarry dust contributed to the compressive strength of the mix by aggregate interlock and improved bond between the cement gel and aggregate particles. Marek (1995) and Martins et al., (2016) also have been obtained the similar results.

Figure 7 represents the compressive strength variation of cubes in dry and wet conditions. The compressive strength was lower for wet mortar specimens compare to dry conditions. The compressive strength was gradually increased with quarry dust percentage in each condition. For 100% river sand, compressive strength was reduced by 29.19% in wet conditions. The compressive strength was reduced by 29.3, 34.0, 34.5 and 33.5% in wet conditions compared with dry conditions for 0, 33, 66, 100% quarry dust replacement, respectively. It is shown that wet conditions adversely affect the compressive strength when quarry duat replaced river sand in the mortar.

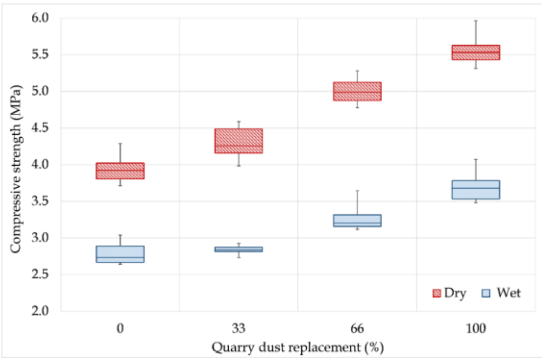


Figure 7 Strength variation of the hardened mortar

3.3. Water Absorption Rate

Figure 8 illustrates the water absorption rates of the mortar cubes with various river sand and quarry dust compositions.

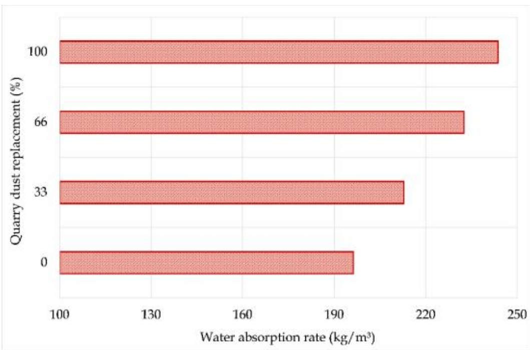


Figure 8 Water absorption rate variation

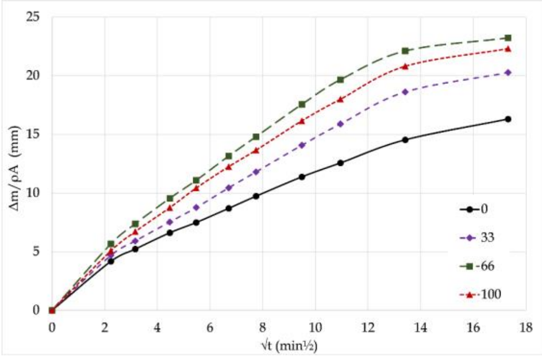
Results reveal that water absorption increases with the accumulation of quarry dust in the mix. As expected, the higher quarry dust content intensifies the water absorption. Mortar cubes with 100% quarry dust absorbed 24% more water than cubes with 100% river sand. The recommended maximum water absorption rate for solid medium weight cement blocks according to ASTM-C90 (2016), is 240 kg/m^3. Noticeably, even mixed composition with 100% quarry dust satisfied the standard requirement. An increase in water absorption with quarry dust replacement might be because of the high water absorption behavior of quarry dust powder (Kottukappalli Febin *et al*. 2019).

3.4. Sorptivity

Figure 9 represents the sorptivity variation of each mortar mix. It illustrates that after three hours of capillary sorption, the cube with 100% quarry sand as the replacement was become fully wet. The sorptivity coefficient of the cube is defined by the gradient of the line of best fit, and for any porous materials, the initial (sorption rate within first 5 min.) and subsequent (10 min to 2 hours) sorptivity coefficients are defined to check the durability. The initial sorptivity coefficients are 1.87, 2.09, 2.53 and 2.27 mm/min$^{0.5}$ for the cube with 0%, 33%, 66%, 100% quarry dust replacement, respectively. It is shown that the cube with quarry dust absorbs the water at a faster rate at the beginning. The initial sorptivity coefficients are 0.94, 1.27, 1.58 and 1.45 mm/min^{½} for cube with 0, 33, 66, 100% quarry dust replacement, respectively.

Sorptivity is the transport of water in porous materials due to surface tension acting in capillaries. It is a function surface tension of the water, water absorption characteristic of raw materials and also the pore structure of the porous solid. As quarry dust have a higher water absorption characteristic contribute the higher sorptivity. However, as quarry dust is a well-graded one, for higher quarry dust content, cubes become well packed and therefore reduce the porosity. Due to this, there is a reduction in sorptivity for the 100% replacement level.

(a)



(b)

Figure 9 (a) Mortar cubes after three hours of sorption (left to right: 0, 33, 66, 100%) and (b) sorption rate variation

3.5. Wet and Dry Resistance

Figure 10 shows the residual compressive strength to initial compressive strength with the number of wet and dry cycles. The compressive strength was gradually decreased with increases in the number of wet and dry cycles. The reduction of strength due to different thermal expansion of mortar mix causes microcracks to appear on the surface of cubes after few cycles passed. The repeated action of wet-dry developed the microcracks. Due to that water gradually enters into the cubes through the cracks which may reduce the overall compressive strength of the mortar specimen. So, the compressive strength of the mortar specimen was reduced with the number of cycles increased.

After the 12th cycle, the compressive strength was reduced by 25.6%, 20.9%, 18.0% and 17.9% for mortar cubes with 0%, 33%, 66%, 100% quarry dust, respectively. This shown that mortar cube with quarry dust performs well in wet and dry resistance.

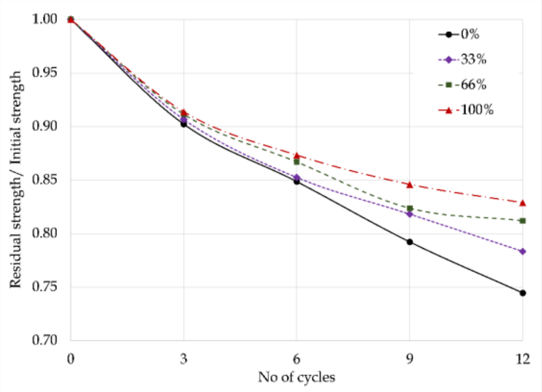


Figure 10 Compressive strength variation with wet and dry cycles

4. CONCLUSION

The present study examined the compressive strength and durability characteristics of cement-sand mortar when river sand is substituted with quarry dust partially or fully. Findings from the experimental program are summarized below:

(i) With the increase in the quarry dust content, a higher water/cement ratio was required for maintaining constant workability.

(ii) The addition of quarry dust in the mortar tends to slightly increase densities. The higher increase in wet density was observed due to higher water absorption characteristics of quarry dust.

(iii) The compressive strength of the mortar cubes improved with the addition of quarry dust. Although compressive strength reduction rate due to wet conditions increased with quarry dust, still compressive strength of mortar cubes with 100% quarry dust was higher than that of 100% river sand.

(iv) The water absorption rate, initial and subsequent sorptivity values increased with the accumulation of quarry dust. This could be attributed to the water absorption characteristics of the quarry dust.

(v) Wet and dry cycle resistance improved with quarry dust content in the mortar. Higher compressive strength was observed after wet and dry cycles for mortar cubes with quarry dust compared with that of river sand.

The findings of this study emphasize that the replacement of quarry dust for river sand in cement mortar does provide higher compressive strength. However, the addition of quarry dust resulted in the loss of workability.

5. ACKNOWLEDGMENTS

The authors express their sincere gratitude for the support given by Concrete Lab, Department of Civil Engineering, Faculty of Engineering, University of Jaffna.

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