# Manufactured Sand as River Sand Replacement for Masonry Binding Mortar

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***Abstract*—Binding mortar establish as an essential part of masonry for binding the masonry units together. Natural sand or river sand is used as a fine aggregate with cement for masonry binding mortar. Although the demand for river sand increases rapidly, on another side, the supply of good quality river sand is reduced due to restrictions in river sand mining. Therefore, there is increasing interest in finding alternative materials for river sand. Manufactured sand is one of the alternatives as it has some advantages over river sand. It provides a better contribution to the strength of the cementitious material, better workability, lesser cement consumption, and eco-friendly. The present study is focused on the progress of a sustainable masonry binding mortar by experimental investigations with manufactured sand as a replacement for river sand. Test for compressive strength was conducted on brick, binding mortar with various combinations of river sand and manufactured sand and masonry prism with different binding mortar. Test results showed that manufactured sand incorporated binding mortar not only shows better compressive strength itself but also significantly improved the compressive strength of masonry.**

***Keywords—masonry, compressive strength, river sand, manufactured sand***

## I. INTRODUCTION

Cement sand block is a major construction material used for house construction around Sri Lanka. In the Northern province, around 66% of the house units are constructed with cement blocks masonry as shown in Fig. 1.

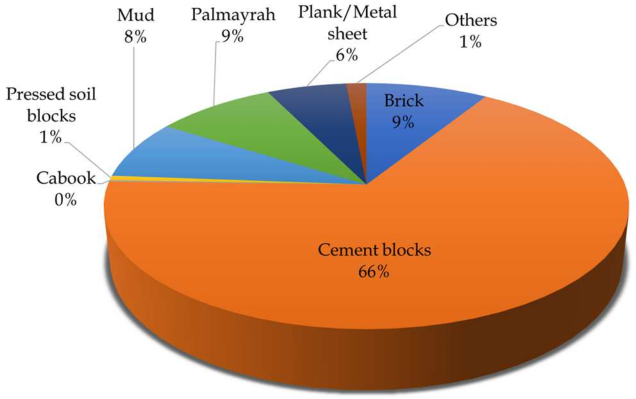

Fig. 1. The material used for house units in Northern Sri Lanka [1]

Binding mortar establishes as a fundamental part of masonry for binding the masonry units together. Natural sand or river sand is used as fine aggregates mixed with cement for masonry binding mortar. The fine aggregate contributes to 70% to 80% weight of the binding mortar. Due to rapid growth in housing construction in recent years, the demand for river sand increases rapidly, but on the other side supply of good quality river sand is reduced. Overexploitation of river sand by mining closer to the river bed is directed to several environment-related consequences. Therefore, authorities restrict sand mining from river beds [2]. This leads to a reduction in the supply of good quality river sand for construction. Therefore, there is increasing interest in finding suitable alternatives for river sand.

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 cement mortar with agricultural waste as sand replacement satisfied the minimum compressive strength requirement. However, durability under extreme environmental conditions is the major issue for using these materials as construction materials. Especially, high water absorption rate and resistance against chemicals are limited their use [3]. In the case of industrial waste or construction and demolition waste, convert these materials into fine aggregates is involved additional energy consumption and cost [4], [5].

In recent years, there is an increased interest in using manufactured sand (m-sand) as river sand replacement in construction materials. M-sand is produced from crushing stones or granite into small sand-sized particles to be used as construction aggregate [6]–[8]. M-sand 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. Published literature reported m-sand used as fine aggregate to replace natural sand in conventional concrete [7]–[9]. Shen et al. [10] reported that the presence of high fine content and water absorption characteristic of m-sand, increase the water demand for mortar mix. On the other hand, the presence of m-sand improved the mechanical characteristics and durability aspect of the concrete [11].

Although intensive published literature on the use of m-sand as fine aggregate in conventional concrete, the study on the use of m-sand as river sand replacement in the masonry binding mortar is still limited. As binding mortar is one of the factors affects the overall strength of masonry structure, good mechanical characteristic of binder mortar is important. The strength of binder mortar depends on the cement-sand mix ratio, water-cement ratio as well as physical and mechanical properties of the fine aggregates. Therefore, when fine aggregate other than river sand is used for binder mortar, the effect of that fine aggregate should be checked. So, the present study was aimed at understanding the effect of m-sand incorporated binding mortar on the compressive strength of masonry.

## II. MATERIALS AND METHODS

### *A. Material Used*

In the present study, the following materials were used for mortar and masonry prisms preparation.

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- Cement: Ordinary Portland cement was used as the binder material, described in Sri Lanka standard SS855. The density and specific gravity of the cement are 1360 kg/m$^3$ and 3.1, respectively.

- River sand: It was obtained from the Muthayankattu river bed, Northern province in Sri Lanka. River sand was sieved in the size range of less than 10 mm.

- M-Sand: It was obtained manufacturing plant situated in Divulapitiya, Western province in Sri Lanka.

- Brick: Brick available in the local market with a size of 200×85×55 mm$^3$ were used for casting masonry prisms. The characteristic compressive strength and water absorption rate are 5.88 MPa and 8.3%, respectively.

Fig. 2 illustrates the particle size distribution of the cement, river sand, and m-sand. The characteristics of river sand and m-sand are summarized in Table I.

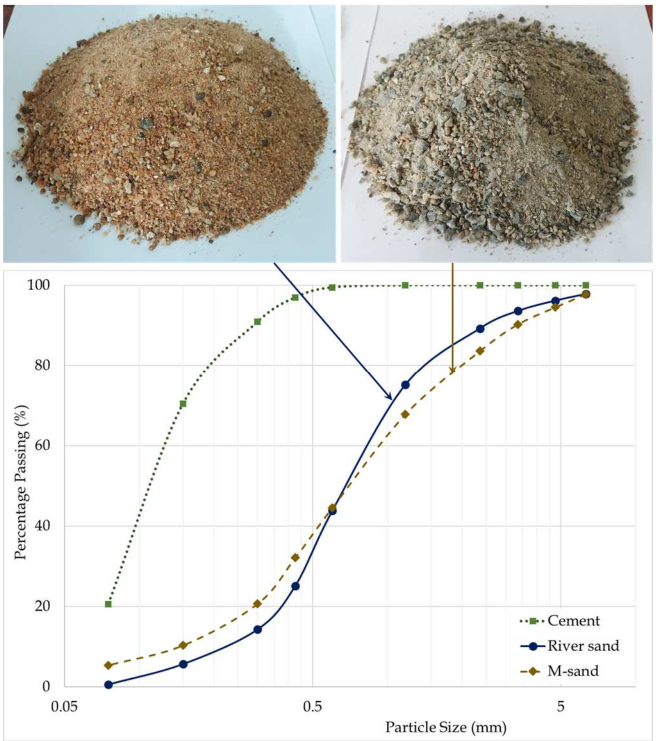

Fig. 2. The particle size distribution of raw materials

TABLE I. MATERIAL CHARACTERISTIC OF FINE AGGREGATES

| Properties | River sand | M-Sand |
|---|---|---|
| Density (kg/m$^3$) | 1680.5 | 1696.9 |
| 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 |
| Uniformity coefficient (Cu) | 4.01 | 6.72 |
| Coefficient of gradation (Cc) | 1.10 | 1.12 |

Both river sand and m-sand are with almost the same density, but river sand has more sand components compared to m-sand. However, m-sand has both higher gravel as well as fine particles. The effective sizes of river sand and m-sand 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. M-sand shows a more well-distributed particle size than river sand. According to the Unified Soil Classification System (USCS), river sand has been classified as poorly graded sand (SP) and m-sand classified as well-graded sand (SW).

### *B. Mix Design*

Mortars were prepared with a 1:6 volume ratio of cement to fine aggregates, according to the mixing procedure in European standard BS-EN-998-2 [12] for mortar class M4 (Mortar designation (iii)). For the preparation of fresh mortar mix, to make sure constant workability for all the mix, the water to cement ratio was selected based on water required for the slump value equal to 30±5 mm. Table II summarizes the proportion of raw material and water to cement ratio applied for each mortar mix. When the proportion of m-sand increased in the mortar, it is observed that water requirement increased.

Cubes with dimensions 100×100×100 mm$^3$ were cast and used to determine the compression strength of mortar. For each mortar type, masonry prisms were prepared consist of four bricks and three binding layers. The thickness of the bonding layer was maintained at 10 mm. Six samples were prepared in each type of mortar and masonry prism.

TABLE II. MIX DESIGN USED FOR CASTING CUBES

| Mix ID | Cement | R-Sand | M-sand | W/C ratio |
|---|---|---|---|---|
| MS0 | 1.00 | 8.53 | 0 | 1.35 |
| MS2 | 1.00 | 5.69 | 2.78 | 1.40 |
| MS4 | 1.00 | 2.84 | 5.56 | 1.45 |
| MS6 | 1.00 | 0 | 8.33 | 1.50 |

### *C. Testing*

For each mortar type, slump, setting time, and evaporation rate on fresh mortar were measured. Slump and setting time was measured according to ASTM-C143/C143M [13] and ASTM-C403/C403M [14], respectively.

To measure the evaporation rate of mortar, the test was done according to the procedure recommended by CSN-EN-16322 [15]. For each mortar type, the fresh mortar was filled in 100 mm diameter and 25 mm high aluminum cylinder to make sure evaporation was done through the top surface only. Then specimens were kept in the lab environment (30 ºC temperature and 80% humidity) to dried out and the weight of the specimen was measured at particular time intervals. Weight of the aluminum cylinder container (V) and the following weight were determined: mass of the mortar with container after a particular time of drying ($m_t$) and mass of the dry mortar with container ($m_d$). In particular time, moisture retention was determined by (1).

$$\text{Moisture retention} = (m_t - m_d)/V \qquad (1)$$

The compressive strength of the brick unit (200×85×55 mm$^3$) mortar cubes (100×100×100 mm$^3$) was determined by applying a monotonic loading rate at 0.01 kN/s. There were six samples tested for obtaining average compressive strength. The axial compression test was performed on masonry prisms under displacement control, according to BS EN 1052-1 [16]. Fig. 3 shows the test setups used to determine the compressive strength of brick, binding mortar, and masonry prism.

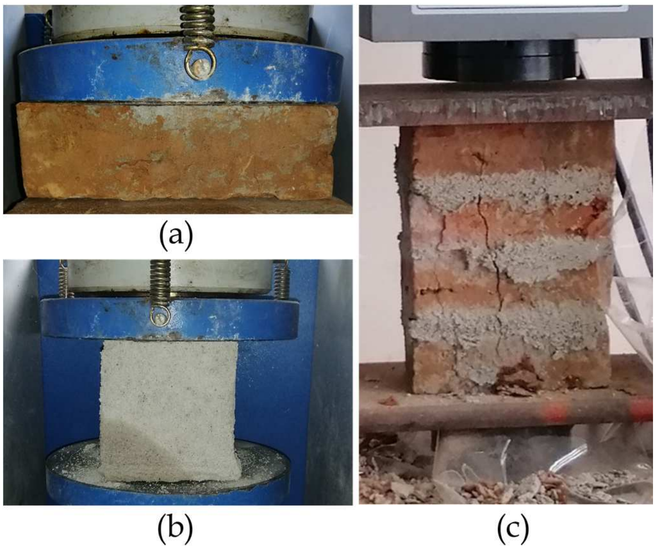

Fig. 3. The testing set for compression test on (a) brick, (b) mortar, and (c) masonry

## III. RESULTS AND DISCUSSION

### A. Fresh Mortar Properties

For proper workability and bond characteristics of the brick-mortar intersection, some specific properties of fresh mortar are important. The most significant characteristics of fresh mortar are slump, setting time, and water retention capability.

#### 1) Slump

Workability is one of the vital parameters that disturbing the strength and durability of mortar. Sometimes, additional water may lead to bleed. The water to cement ratio gradually increased by 0.5 and slump value was observed in each stage of the mix. 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.

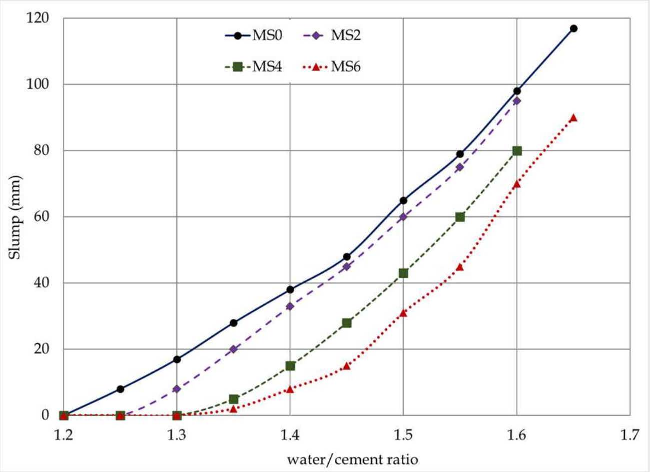

Fig. 4. Slump variation with water to cement ratio for fresh mortar

Fig. 4 presents the slump variation with the water to cement ratio. Results show that the slump of the fresh mix reduces with an increase in m-sand content. To achieve the fixed slump value, fresh mix with m-sand required more amount of water compared with fresh mix with river sand. As the m-sand 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, 1.4, 1.45, and 1.5 for MS0, MS2, MS4, and MS6 mortar, respectively.

#### 2) Setting time

Fig. 5 presents the initial and final setting time of fresh mix with various river sand and m-sand combination. The setting time is indicated the amount of time that mortar can be workable after mixing fresh mortar. The initial and final setting times of the mortar containing m-sand were longer than mortar containing 100% river sand. Also, an increase in the m-sand content, further prolonged the setting time. Due to the fine particle content of m-sand and its water retention nature, it took more time to harden for mortar with m-sand.

The initial setting time of the block with 100% river sand occurred at 120 min, and replacement of 33.3, 66.7, and 100% of m-sand enhanced the initial setting time to 140, 160, and 175 min, respectively. A similar trend was observed for the final setting time as well.

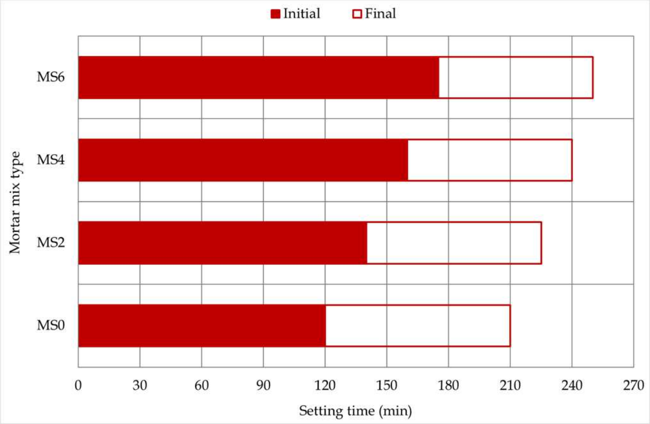

Fig. 5. Initial and final setting time of the fresh mix

#### 3) Water retention capability

The bond between brick and mortar intersections is essential to obtain the desirable masonry strength properties. Since fresh mortar is placed over the moisture absorptive materials such as fired bricks, the water retention capacity of the fresh mortar is a significant property for improving the strength of masonry. Only by retaining adequate water, a proper bond can be generated between brick and mortar. By satisfied this, masonry can reach desirable strength properties.

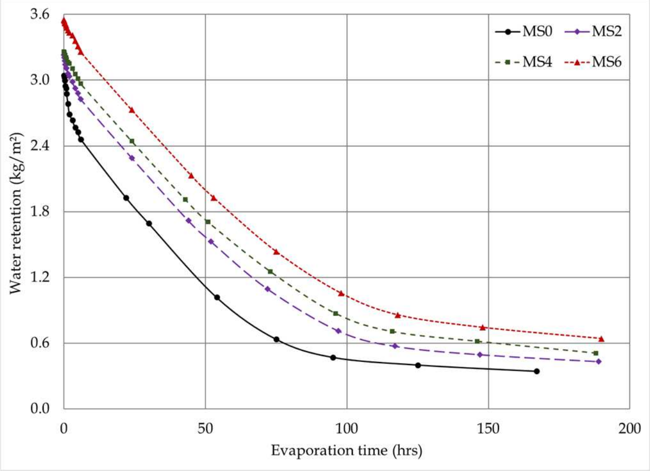

Fig. 6. Water retention variation with time

Fig. 6 shows the water retention variation with time for each mortar mix. In the first phase of drying, evaporation occurs at a rapid rate because an ample amount of moisture is available on the surface of the material for evaporation. In the second phase of drying, evaporation becomes slower because less amount of moisture is available at the surface of the material that can evaporate.

It is observed that the initial drying rate increased with m-sand content. The initial drying rate was 0.175, 0.099, 0.064 and 0.057 kg/m².h for MS0, MS2, MS4 and MS6 mortar mix. A similar trend was observed for the second phase drying rate, however, variation in drying rate considerably less. The secondary drying rate was 0.032, 0.033, 0.034 and 0.037 kg/m².h for MS0, MS2, MS4 and MS6 mortar mix. Also, blocks with 100% m-sand had the longest duration of the first phase of drying. These results indicate that the mortar mix with m-sand was had better water retention capacity (taken more time to evaporate the moisture) compared with mortar mix with 100% river sand.

### *B. Effect of M-sand in the Binding Mortar*

Fig. 7 shows that the compressive strength mortar cube is increasing consistently with m-sand content in the mortar. M-sand 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 [17]. These physical properties of m-sand 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.

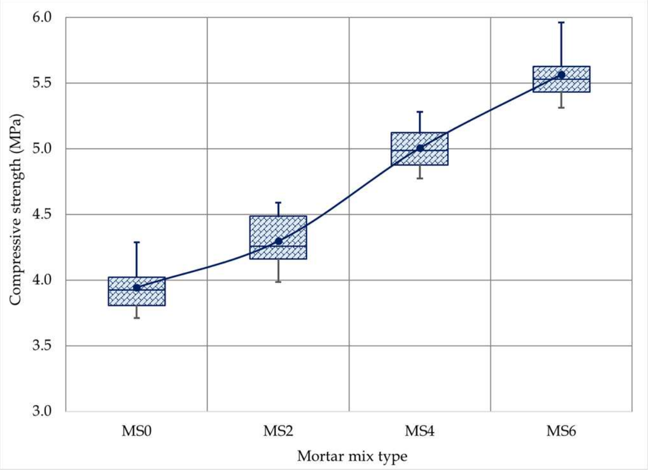

Fig. 7. Compressive strength variation of mortar

As the results show in Fig. 7, the compressive strength of mortar was varying with the various proportion of m-sand replacement after 28 days curing periods. The compressive strength of mortar was gradually increased with the m-sand percentage increased. The highest compressive strength was obtained when the river sand was replaced by 100% of m-sand. The raise of strength by 41.4 % when 100% river sand (3.94 MPa) was replaced by 100% m-sand (5.57 MPa). Published literature confirms that, when river sand was replaced by 100 % of m-sand, the concrete also showed a similar trend [18]–[19].

### *C. Compressive Strength Characteristics of Masonry*

Fig. 8 present the typical crack pattern observed during the experimental program. In this experimental program, binding mortar is weaker than brick unit, initially crushing of mortar occurred and due to that mortar is forced to move in the lateral direction. Therefore, uneven strain compatibility has occurred at the brick-mortar interface. This uneven strain is initiated by the splitting tensile crack at the brick-mortar interface. When the load is increased, cracks initiated in the binding mortar propagate through the brick units.

Fig. 8. Failure pattern observed in masonry prisms

Fig. 9 presents the compressive strength of masonry prisms for four types of mixed proportion. The compressive strength of the masonry prism is increased with the percentage of m-sand increased in the binder mortar. The mean value of masonry prism with MS0 and MS6 binding mortar were 2.11 MPa and 2.62 MPa respectively. Compressive strength is increased by 24.17% when river sand was fully replaced by m-sand in the binding mortar. When river sand was replaced by m-sand, finer particles were increased. It caused improvement in compressive strength due to the shape and texture of m-sand. Sharp edges may generate a stronger bond between brick-mortar interfaces. It may attribute to improve the overall compressive strength of the masonry.

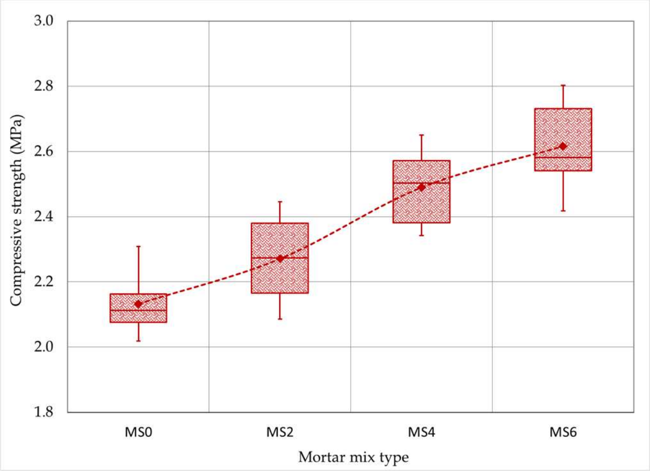

Fig. 9. Compressive strength variation of masonry

Compressive strength masonry mainly depends on brick strength, mortar strength, and the type of brick mortar used.

The equation for compressive strength of masonry prism provided in (2) is taken from Eurocode 6 [20].

$$f_k = K f_b^{\alpha} f_m^{\beta} \tag{2}$$

where $f_b$, $f_m$, and $f_k$ are the compressive strength of brick or block, mortar, and masonry, respectively. $K$, α, and β are constant. Eurocode recommended 0.55, 0.7, and 0.3 for $K$, α, and β, respectively for brick masonry with general-purpose mortar.

Table III shows the predicted compressive strength of the masonry with m-sand incorporated binding mortar, calculated based on the formula outlined in Eurocode 6, transformed into a relationship (3). As the same brick type for all the masonry prisms, so $f_b$ is constant.

$$\frac{f_k^{(ms)}}{f_k^{(c)}} = \left(\frac{f_m^{(ms)}}{f_m^{(c)}}\right)^{0.3} \tag{3}$$

where: $f_k^{(c)}$, and $f_m^{(c)}$ are compressive strength of masonry and mortar with 100% river sand; $f_k^{(ms)}$ and $f_m^{(ms)}$ compressive strength of masonry and mortar with m-sand.

The analysis showed that variation with experimental value and predicted value increase in a positive way when m-sand content increases. It indicates that, not only mortar strength itself, bond characteristic between brick and m-sand incorporated mortar also contributed to higher compressive of masonry prisms.

TABLE III. EXPERIMENTAL AND PREDICTED STRENGTH OF MASONRY

| **Mix ID** | **Characteristic compressive strength (MPa)** | | | **Estimated strength (MPa) by (2)** | **Variation (MPa)** |
|---|---|---|---|---|---|
| | ***Brick*** | ***mortar*** | ***Masonry*** | | |
| MS0 | 5.88 | 3.60 | 1.91 | - | - |
| MS2 | 5.88 | 3.91 | 2.03 | 1.96 | +0.07 |
| MS4 | 5.88 | 4.70 | 2.28 | 2.07 | +0.21 |
| MS6 | 5.88 | 5.19 | 2.37 | 2.13 | +0.24 |

To predict the compressive strength of masonry with m-sand incorporated binding mortar, statistical regression analysis was carried off using characteristic compressive strength data of brick, mortar, and masonry. An equation developed according to the regression analysis is given in (4). The coefficient of determination ($R^2$) value corresponding to the equation for compressive strength of masonry prism is 0.99 and the standard error of estimate (σ) is 0.03.

$$f_k = 0.26 f_b^{0.70} f_j^{0.59} \tag{4}$$

In here, the value β equal to 0.59, which higher than the value recommended by Eurocode (0.30). It shows that m-sand incorporated binding mortar characteristics significantly affect the masonry properties compared with general-purpose mortar.

## IV. CONCLUSION

The present study reports the effect of using m-sand as a partial or full replacement for river sand in masonry binding mortar. Various characteristics of fresh mortar and compressive strength of mortar and masonry were assessed by varying the m-sand content. From the results, the following conclusion can be drawn.

- Mortar with m-sand content required more water to achieve the particular slump value. However, for the fixed slump, the setting time and water retention capability were improved with the replacement of m-sand in the mix.
- Hardened mortar with m-sand shows higher compressive strength compared with mortar with river sand. A similar trend was observed for masonry with m-sand incorporated binding mortar.
- In addition to m-sand has been positively influenced the compressive strength of binding mortar strength itself, the bond characteristic between brick and binder mortar interface also improves with m-sand incorporated in binding mortar.

These results indicate that m-sand can be used efficiently to produce more sustainable masonry binder mortar. The utilization of m-sand for masonry binder mortar reduces the river sand usage and therefore, reduces environmental pollution caused by sand mining at the riverbed.

However, before it is recommended for construction purposes, the durability of binder mortar and bond characteristics of mortar - brick intersection have to study. So, it is also recommended that further research should be conducted to determine the durability of m-sand replaced cement mortar when exposed to severe environmental conditions such as wet and dry cycle, alkaline attack, and acid attack. In addition, a study on shear strength and bond strength of masonry with m-sand incorporated mortar is recommended. One of the major factors that limit the use of m-sand in masonry binder mortar is the larger amount of stone particles in the sand. In the present study, the m-sand was sieved before it was used for binder mortar. Therefore, the effect of aggregate size and amount of stone particle in the m-sand on the strength of masonry is needed to get the concrete idea about using M-sand as masonry binding mortar.

## ACKNOWLEDGMENT

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