EXPERIMENTAL INVESTIGATION OF MECHANICAL PROPERTIES OF SOLID CONCRETE BLOCK MASONRY EMPLOYING DIFFERENT MORTAR RATIOS

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https://doi.org/10.26782/jmcms.2021.01.00009

Abstract

This research work aims to investigate experimentally the mechanical properties of solid concrete blocks as an individual unit and assembly (block masonry) employing different mortar mix ratios. The material properties of the concrete block unit, such as compressive strength and unit weight were explored by taking three samples from the four local factories. The block masonry assemblages were subjected to various load patterns for the evaluation of compressive strength, diagonal tensile strength and shear strength. For the bond, four types of mortars i.e., cement - sand (1:4), cement - sand (1:8), cement – sand - khaka (1:2:2) and cement - sand - khaka (1:4:4) were used in the joints of concrete block masonry assemblages. (Khaka is a by-product formed in the stone crushing process). For each type of mortar, three samples of block masonry were fabricated for compressive strength, shear strength and diagonal tensile strength, and tested in the laboratory. It is observed that the replacement of sand by khaka enhanced the mechanical properties of masonry.

Keywords: block masonry; mortar; khaka; compressive strength; diagonal tensile strength; shear strength.

I. Introduction

In most of the world especially in developing countries, masonry is used extensively in the construction industry. Masonry units such as clay bricks, stone and concrete blocks are common in construction. In Pakistan and its neighboring countries like India, Bangladesh and Iran, bricks are used widely as masonry infill and in load-bearing walls. Clay bricks are the most common type of masonry units used throughout the world. In several areas, either bricks are not available, or soil properties are not appropriate for preparing good quality bricks. Construction of brick masonry structures in such areas is not feasible. Concrete block masonry units can be
Muhammad Rizwan et al investigated for their use in masonry as an alternative in areas, where use of brick masonry is not feasible. Moreover, the use of block masonry as infill units in reinforced concrete frames has been on the rise. Block masonry infill panels provide an efficient and cheap alternative to brick masonry infill panels. Concrete block is an important building material used because of the economy and local availability. Furthermore, less workmanship is required for block masonry work which has increased its uses in the construction industry.

Most masonry structures are made without designing for seismic loading, which results in huge loss of life as seen in the previous earthquakes. It was explored by researchers earlier that the compressive strength of confined masonry panels enhanced by providing horizontal perforated units in contrast to traditional confinement in masonry system [I]. The individual components and their interaction as masonry structures (assemble) affect the overall strength and stiffness [II]. There are many different factors such as properties of individual components, joint thickness and block geometry which affect the strength and mode of failure of masonry elements [III-VI]. The compressive loads are mainly resisted by the blocks while the bond between blocks, load transfer and resistance to strains is achieved through mortar [VII]. Observations in different studies showed that when the thickness of the joint is reduced, the compressive strength and modulus of elasticity of masonry prism increases, which is related to the more lateral confinement of mortar joints in case of thin bond thickness [VIII-XI]. In a study on mud concrete, it is concluded that the cylindrical shaped specimens showed lower strength than the cubes shape specimens studied by researchers previously for normal concrete [XII]. In a study it is observed that using high strength mortar in the case of hollow concrete blocks masonry prism, the compressive strength is not significantly increased [XIII]. Research investigation conducted on the physical and mechanical properties of cellular lightweight concrete (CLC) block masonry and concluded that CLC is not suitable for construction in load-bearing walls [XIV]. The existing masonry structures present in the seismically active areas are predominantly vulnerable to major damages due to lower in-plane shear capacity [XV]. Mechanical properties’ assessment of local clay bricks showed that the average shear strength of local brick masonry is around 0.523 MPa [XVI]. Properties of solid clay brick masonry with different sand grading were conducted earlier in 2018, which showed that weak mortar instead of moderate mortar, when used in masonry, has an adverse effect on the shear and compressive strength as compared to the brick mortar bond [XVII]. It was also explored that incorporating frogs in the concrete blocks had no potential impact on structural performance [XVIII].

However, solid blocks are mostly used in construction industries in countries like Pakistan, India, and Iran. For masonry structures, specifically for unreinforced masonry, it is important to know its mechanical properties when used as an assemblage. So, there is a need to study the mechanical properties of the locally available solid concrete blocks used in masonry construction with different mortar mix ratios. Therefore, this paper presents an experimental investigation on solid concrete block masonry when used with a different type of mortar ratios. The basic properties of concrete block units such as compressive strength and unit weight were
determined. Compressive strength, shear strength and diagonal tensile strength were determined experimentally to explore the behavior of the concrete block masonry under the effect of lateral load in addition to gravity. The tests were conducted using the standard testing procedures: ASTM C140-03 [XXI] for testing of concrete masonry units, ASTM C109/C109M-08 [XXII] for compressive strength of mortar cubes, ASTM C1314-03b [XI] for a masonry compression test, ASTM E519-02 [XXIV] for diagonal tensile strength of masonry wallet and EN 1052-3 [XXIV] for shear strength of masonry triplet. Four types of mortars were considered; cement - sand mortar having one part of cement and four of sand (CS 1:4), cement - sand mortar having one part of cement and eight of sand (CS 1:8), cement - sand - khaka mortar having one part of cement, two of sand and two of khaka (CSK 1:2:2), and cement - sand - khaka mortar having one part of cement, four of sand and four of khaka (CSK 1:4:4). The inspiration of using cement - sand - khaka as the mortar is based on a study conducted on using cement - sand - khaka for the evaluation of lateral shear strength of clay bricks which showed a promising effect on the properties of brick masonry in terms of compression and shear strength of brick masonry [XXVI].

II. Methodology

Concrete block masonry is mainly subjected to compressive, shear and diagonal tensile stresses due to gravity and lateral forces. To find these properties, tests were performed at the Material Testing Laboratory of Civil Engineering Department of UET Peshawar, Pakistan on concrete block units and masonry. Masonry units were obtained from four different factories in District Peshawar, Pakistan. Three blocks from each factory were taken and the unit weight and compressive strength of each block were determined. To evaluate the mechanical properties of block masonry, concrete block units from the factory which corresponded to maximum compressive strength and reasonable unit weight were taken. Masonry assemblages were prepared using the four different types of mortars and were tested for a compression test, direct shear test and diagonal tension test according to ASTM and EN standards. The following sections briefly explain each of the tests performed.

II.i. Tests on block masonry constituent materials

Concrete block masonry unit tests as per ASTM C140-03

Three samples were taken from each of the four factories of solid concrete blocks in Peshawar, Pakistan. Using the ASTM standard guidelines and procedures, all the units were subjected to compression test as shown in Fig. 1. The unit weight and compressive strength of concrete block units were recorded. The concrete blocks brought from the Qamar Din Garhi Ring Road factory, showed maximum compressive strength and promising unit weight as shown in Fig. 6 and Fig. 7, respectively. To investigate the mechanical properties of masonry, concrete blocks from the Qamar Din Garhi Ring Road factory, located at Peshawar Pakistan were used for further evaluation and testing.
Fig. 1: Concrete block compression test

Mortar tests as per ASTM C109/C109M-08

The type of mortar used in this study includes CS 1:4, CS 1:8, CSK 1:2:2 and CSK 1:4:4. Mortar cubes of size 50 mm x 50 mm were made for the abovementioned types of mortar, and were tested after 28 days of moist curing to evaluate compressive strength. A total of 12 mortar cubes (3 for each type) were tested, whose testing setup is shown in Fig. 2. Compressive strengths of all mortar types and their average values are shown in Fig. 8 and Table 1, respectively. It was found that CSK 1:2:2 mortar type has a maximum compressive strength of 18184 kPa and CS 1:8 has minimum compressive strength of 5624 kPa.

Fig. 2: Mortar cubes compression test

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II.2. Tests on block masonry assemblages

Block masonry compression prism test as per ASTM C1314-03b

To determine the Compressive strength of block masonry, assemblages (prisms) having a length of 620 mm, the width of 203 mm and height of 475 mm were fabricated having 9.5 mm thickness of mortar. Three assemblages were tested to obtain the mean compressive strength after 28 days of moist curing for all four types of mortars bond as per the standard guidelines available in the ASTM C1314-03. The experimental setup for compressive strength evaluation is shown in Fig. 3. The calculated values were plotted for the compressive strength of all the mortar ratios as shown in Fig. 9. It was observed that maximum compressive strength of block masonry is obtained for CSK 1:2:2 mortar mix.

Block masonry wallets test as per ASTM E519-02

To determine the diagonal tensile strength of block masonry, assemblages were constructed having a length of 620 mm, a width of 203 mm and a height of 640 mm having 9.5 mm thickness of mortar. Three such assemblages were tested to obtain the mean diagonal tensile strength of concrete block after 28 days for all four types of mortar bond. The samples were tested according to the ASTM E519-02, for which the experimental setup is shown in Fig. 4. The data obtained for this test was analyzed and it was concluded that the mortar mix of CSK 1:2:2 is having a maximum diagonal tensile strength of 4626 kPa as shown in Table 2.

Fig. 3: Block masonry compression test

Fig. 4: Block masonry wallets test

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Fig. 4: Diagonal tensile strength test on block masonry wallet

**Block masonry triplet tests per EN-1052-3**

To determine the direct shear strength of block masonry, assemblages consist of three blocks arranged one on top of the other and joined with each other by mortar. The block masonry prism had a length of 305 mm, a width of 203 mm and a height of 475 mm having a 9.5 mm thickness of mortar. Three such assemblages were tested to obtain the mean direct shear strength of concrete blocks after 28 days for all four types of mortars bond as per the standard procedure mentioned in EN 1052-3. The experimental program and testing setup for the direct shear test conducted at the laboratory is shown in Fig. 5. It was explored that the mortar mix CSK 1:2:2 is having maximum direct shear strength of 184 kPa as shown in Table 3.

Fig. 5: Triplet shear test
III. Results and Discussion

Results of concrete block masonry units’ tests as per ASTM C140-03 revealed that the sample of concrete blocks from the Qamar Din Garhi Ring road factory measuring 305 mm x 203 mm x 152 m had reasonable unit weight and maximum compressive strength than others. It was also found that CSK 1:2:2 has maximum compressive, shear and diagonal tensile strength.

![Compressive strength of concrete blocks from different factories located at Peshawar, Pakistan](image1)

**Fig. 1:** Compressive strength of concrete blocks from different factories located at Peshawar, Pakistan

The unit weight of the samples brought from the Peshtakhara Chowk factory was comparatively higher than others. Because of the maximum compressive strength and reasonable unite weight, concrete block units from Qamar Din Garhi Ring road factory and their assemblages were subjected to compression, direct shear, and diagonal tensile tests for evaluation of mechanical characteristics.

![Unit weight of concrete blocks from different factories located in Peshawar, Pakistan](image2)

**Fig. 7:** Unit weight of concrete blocks from different factories located in Peshawar, Pakistan

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The mortar was tested in the Universal testing machine as per ASTM C109/C109M-08. It is observed that CSK 1:2:2 has the highest compressive strength in contrast to other mortar ratios. The overall and average results of four types of mortars cube strength are shown in Fig. 8 and Table 2, respectively.

![Fig. 8: Compressive Strength of Mortar Cubes](image)

**Table 1: Average compression strength of mortar cubes**

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>Average compressive strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 1:4</td>
<td>12082</td>
</tr>
<tr>
<td>CSK 1:2:2</td>
<td>18184</td>
</tr>
<tr>
<td>CS 1:8</td>
<td>5624</td>
</tr>
<tr>
<td>CSK 1:4:4</td>
<td>9182</td>
</tr>
</tbody>
</table>

It is observed that by replacing one-half of the volume of sand in CS 1:4 mortar by khaka the compressive strength increased by 50.50% and by replacing one-half of volume of sand in CS 1:8 mortar with khaka the compressive strength increased by 63.26%.

Results of block masonry compression tests are shown in Fig. 9, and it was found that replacing one half of the volume of sand in CS 1:4 and CS 1:4 mortars with khaka slightly increased the compressive strength.

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Fig. 9: Average Compressive Strength of Block Assemblage

In the case of CS 1:4 mortar when one-half of the volume of sand was replaced with khaka, the compressive strength of block masonry assemblage increased by 2.26% and by replacing one-half of the volume of sand in CS 1:8 mortar with khaka, the compressive strength increased by 4.50%, respectively.

Diagonal tensile tests were carried on three samples of each mortar mix on block masonry wallets as per ASTM E519-02. The detail of diagonal tensile strength of all sample with variation in the mortar ratio along with average diagonal tensile strength are shown in Fig. 10 and Table 2, respectively.

Fig. 10: Diagonal tensile strength of block assemblage

Table 2: Average diagonal tensile strength

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>Average diagonal tensile strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 1:4</td>
<td>2949</td>
</tr>
<tr>
<td>CSK 1:2:2</td>
<td>4626</td>
</tr>
<tr>
<td>CS 1:8</td>
<td>1558</td>
</tr>
<tr>
<td>CSK 1:4:4</td>
<td>2595</td>
</tr>
</tbody>
</table>
It was observed that by replacing one half of the volume of sand in CS 1:4 and CS 1:8
mortars with khaka, the diagonal tensile strength of block masonry assemblage
increased by 56.86% and 66.55%, respectively.

Block masonry triplets’ tests were conducted at the laboratory as per the guidelines
available in EN-1052-3. The overall results for three samples for four types of
mortars along with the average direct shear strength are shown in Fig. 11and Table 3,
respectively.

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>Average direct shear strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 1:4</td>
<td>90</td>
</tr>
<tr>
<td>CSK 1:2:2</td>
<td>184</td>
</tr>
<tr>
<td>CS 1:8</td>
<td>74</td>
</tr>
<tr>
<td>CSK 1:4:4</td>
<td>108</td>
</tr>
</tbody>
</table>

It is observed that by replacing one-half of the volume of sand in CS 1:4 and CS 1:8
mortars with khaka, the direct shear strength of block masonry assemblages increased
by 104.44% and 45.94%, respectively.

A similar study on triplet shear strength was conducted on clay bricks [XXV]. The
shear strength value for the various mortars are shown in Table 4.

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>Direct shear strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Block</td>
</tr>
<tr>
<td>CS 1:4</td>
<td>90</td>
</tr>
<tr>
<td>CSK 1:2:2</td>
<td>184</td>
</tr>
<tr>
<td>CS 1:8</td>
<td>74</td>
</tr>
<tr>
<td>CSK 1:4:4</td>
<td>108</td>
</tr>
</tbody>
</table>

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The increase in concrete blocks masonry shear strength while replacing the half volume of sand by khaka in CS 1:4 was 104.44% while for clay bricks it is increased by 37.96%, respectively. Furthermore, replacing half of the volume of sand with khaka in CS 1:8, the shear strength increased by 45.94% and 8.62% for block and brick triplets, respectively.

IV. Conclusions

The incorporation of khaka in the mortar showed enhancement in the mortar compressive strength. It was also found experimentally that the diagonal tensile strength and shear strength of concrete block assemblage increased when khaka was introduced in the mortar by replacing half of the volume of sand. A slight increase in the compressive strength of block assemblage was also recorded, whereas using khaka in the mortar replacing sand. Overall, the addition of khaka in mortar replacing volume of sand showed better performance for concrete block masonry assemblage.

The following conclusion has been summarized from the current experimental study:

- It was observed that by replacing one-half of the volume of sand in CS 1:4 mortar with khaka, the compressive strength of block masonry assemblage increased by 2.26%.
- Replacing one half of the volume of sand in CS 1:8 mortar with khaka, the compressive strength of block masonry assemblage increased by 4.50%.
- It was also found that by replacing one half of the volume of sand in CS 1:4 mortar with khaka, the diagonal tensile strength of block masonry assemblage increased by 56.86%.
- One half of the volume replacement of sand in CS 1:8 mortar with khaka showed a 66.55% increase in the diagonal tensile strength of block masonry assemblage.
- The increase in concrete blocks shear strength upon replacement of one half of the volume of sand with khaka in CS 1:4 was 104.44% while for clay bricks it is increased by 37.96%. Similarly, replacing half of the volume of sand with khaka in CS 1:8, the direct shear strength increased by 45.94% and 8.62% for block and brick triplets, respectively.

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

References


IV. B. Lima, A. N. Lima, and W. S. Assis, "Study of the influence of compressive strength and thickness of capping-mortar on compressive strength of prisms of structural clay blocks.”.

V. B. Lima, A. N. Lima, and W. S. Assis, "Study of the influence of compressive strength and thickness of capping-mortar on compressive strength of prisms of structural clay blocks.”

VI. Badrashi, "Experimental investigation on the characterization of solid clay brick masonry for lateral shear strength evaluation (Master of Science in Civil Engineering (Structural Engineering) dissertation)," 2008.


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