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Mechanical and bond properties of solid clay brick masonry with different sand grading

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HIGHLIGHTS

- The effect of sand grading on properties of mortar and masonry was evaluated.
- Main mechanical and bond properties of masonry with solid clay brick was tested.
- Sand grading has significant influence on mortar and masonry strength.
- Practical equations were developed to estimate mechanical properties of masonry.

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ABSTRACT

To evaluate the performance of unreinforced masonry buildings under different loading conditions such as lateral seismic load, the mechanical properties of masonry materials are required. Masonry is a composite material which consists of brick units and mortar joints bonded together. On the other hand, sand is the main ingredient of mortar and its characteristics such as grading can affect the physical and mechanical properties of mortar. In this research, a comprehensive experimental study was conducted to assess the effects of sand grading on the properties of mortar as well as masonry. Considering the main standard tests recommended for masonry as a composite material, the behaviors of masonry assemblages and prisms fabricated using three mortar mixes with coarse and fine sand grading were assessed to examine compressive strength, diagonal-shear strength, and brick-mortar shear and flexural bond strengths.

1. Introduction and background

Masonry buildings are still widely popular all over the world due to the inherently high compressive strength of available masonry materials, ease of construction, and their relatively low cost. Masonry structures are mainly made of masonry units such as bricks, blocks, and stones joined by mortar. Sand is a major constituent of masonry mortars. Therefore, mortar mix proportions and sand grading have a significant effect on the characteristics of fresh and hardened mortars. In the conventional construction practice, sand grading and water content are usually neglected. Meanwhile, proper sand grading ranges have been specified for sand mortar in ASTM C144 [1] and BS 4551 [2].

There are a limited number of studies on the effects of sand grading and water-cement ratio (W/C) on the mechanical properties of mortars and the characteristics of masonry. Some researchers studied the effects of sand grading and W/C on the properties of fresh mortar and strength of different types of mortars [3–9]. Generally, cement and lime-cement mortars with finer sand require higher water contents to reach a target flow resulting in a higher W/C. Furthermore, similar mortars with finer sand have lower compressive and flexural strengths as well as elastic modulus.

Regarding brick-mortar bond, Held and Anderson [10] investigated the effect of sand grading on the bond strength of lime mortars with three different types of bricks. They found out that sand grading affects the tensile bond strength of brick-mortar joint. Lawrence and Cao [11] studied brick-mortar joint behavior and showed that the bond is due to the permeation of cement hydration products into the voids of brick. Therefore, brick moisture plays a crucial role in absorbing the products of cement hydration. Rao et al. [12] investigated the effect of bond strength on the compressive strength of brickwork. Other studies on brick-mortar bond have been reported [13–16].

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Sarangapani et al. [17] conducted some tests on masonry prisms and showed that whenever the bond strength between mortar and brick is weak, prism failure generally occurs due to joint failure which could be the result of in-plane interaction between mortar and brick. Mohamad et al. [18] examined the effect of four kinds of lime-cement mortars on the compressive behavior of masonry prisms which were made of hollow and solid concrete blocks. They found out that type of mortar has an influence on axial stress–strain as well as the failure mechanism of masonry prisms. Reddy and Gupta [4] studied the influence of three different sand grading on the mechanical properties of brickwork. They carried out compressive and bond strength tests on masonry prisms and found that fine sand particles decrease the tensile bond strength of brickwork while compressive strength is not sensitive to this parameter. Sathiparan et al. [19] studied the effect of the void areas of hollow bricks on the mechanical characteristics of brick masonry including compressive strength and bond properties of masonry units. In another study, Singh and Munjal [20] examined the effect of type of mortar and brick on the compressive and bond strengths of brickworks. They measured bond strength through direct shear strength and bond flexural-tensile strength tests on four kinds of clay and concrete bricks and three types of lime-cement mortars and concluded that the compressive strength of brickwork is proportional to the compressive strength of mortar and masonry units. Other researchers studied the effect of mortar bond strength on the compressive properties of masonry prism [21–23] and the influence of the type of masonry unit on the mechanical properties of masonry [17,24–25].

Unreinforced masonry buildings are still constructed in some regions such as the Middle East and South America. To evaluate the structural performance of these buildings, the mechanical characteristics of masonry unit, mortar, unit-mortar bond, and masonry prism are required. By focusing on sand grading of mortar and mortar mix proportions, the current research can provide useful insights into the understanding of mechanical properties and brick-mortar bond strength of masonry walls made of solid clay brick. Most of the tests on masonry specified in such standards as ASTM were covered consistently in the experimental program. Thus, the results could be directly employed for analytical modeling, design, and assessment of new or existing masonry buildings. In general, the primary goal of the present study is to examine the effect of sand grading and cement content on the mechanical characteristics of masonry brickwork.

2. Experimental program

In the present study, firstly, the effects of sand grading on the properties of mortar including flow, compressive strength, and elastic modulus are examined, and afterwards the mechanical characteristics of masonry prisms such as compressive strength, diagonal tension (shear) strength, flexural bond strength, and shear cohesion are investigated. The material properties, specimen preparation procedures, and standard test procedures are explained in this section.

2.1. Materials

Type II Portland cement as specified in ASTM C150 [26] and hydrated hydraulic lime as specified in ASTM C141 [27] were used to fabricate the mortars. Two kinds of manufactured sand, namely fine sand and coarse sand, with grading curves shown in Fig. 1, were utilized. The fine sand whose grading curve is within the limits specified in ASTM C141 [1] has the maximum aggregate size of 2 mm, fineness modulus of 2.3, and sand equivalence of 47. However, coarse sand, which represents the conventional sand used for brickwork in Iran, has the maximum aggregate size of 4.75 mm, fineness modulus of 3.27, and sand equivalence of 36. It is noticeable that coarse sand does not comply with standard grading limits. By counting intensity peaks, the semi-quantitative X-ray Diffraction (XRD) test indicated that the sand was composed of large amounts of Calcite (86%) and Quartz (13%) minerals.

Table 1
Compositions of mortars.

Mortar Mix (C:S) or (L:C:S)	Sand Grading	W/C
1:3	Coarse	0.65
1:3	Fine	0.78
1:5	Coarse	1.02
1:5	Fine	1.11
1:1:6	Coarse	1.66
1:1:6	Fine	1.99

Note: C = Cement, L = Lime, S = Sand.

Table 2
The properties of solid clay bricks.

Sample Condition	Compressive Strength, f_b (MPa)	Flexural Strength, f_r (MPa)
Dry	13.86 (4.8)	3.14 (29.7)
Saturate	13.26 (3.3)	2.53 (18.9)

Note: Value in parentheses represent coefficient of variation in percentage

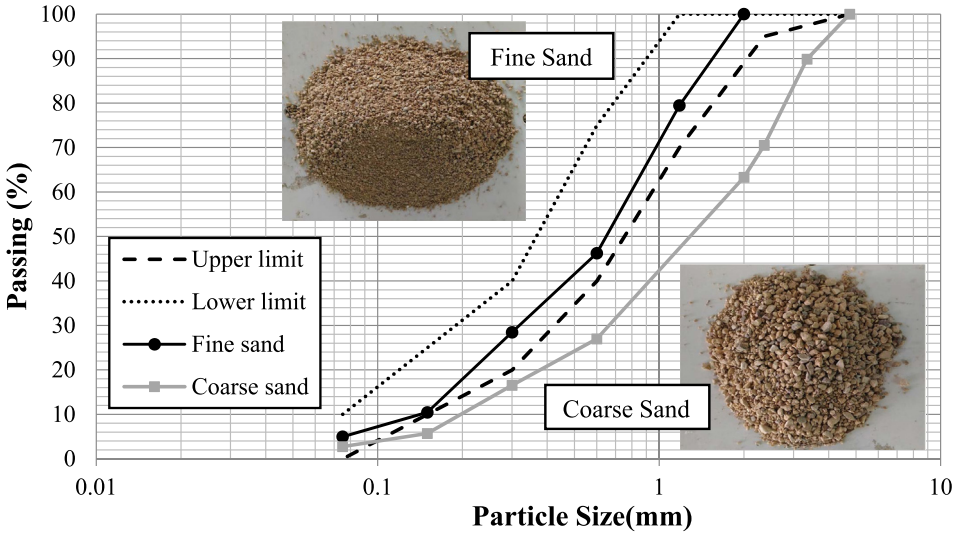

Fig. 1. Fine and coarse sand grading curves compared to ASTM C144 [1].