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Bond strength and compressive stress-strain characteristics of brick masonry

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ABSTRACT

In this study, masonry and its material characteristics such as compressive strength of masonry prisms, bricks, mortars as well as bond strength (i.e., flexural and shear bond strengths) of brick and mortar joint are determined experimentally. The compressive stress-strain curves of brick, mortar, and masonry have been plotted and five control points have been identified on the stress-strain curve of masonry. The control points on the stress-strain curve would be useful for performance based design of masonry. Four types of bricks and three different types of mortars have been used in the experimental study. The compressive strength of masonry and flexural bond strength are determined with a test on five bricks stack bonded prisms. A bond wrench apparatus fabricated as per ASTM standards was used for flexural bond strength test. The shear bond strength of masonry is predicted using masonry triplet. It is observed that the concrete bricks have low flexural as well as shear bond strengths due to less contact area.

1. Introduction

Brick masonry is still used as a construction material in most of the countries because of its good heat insulation properties, high compressive strength, easy availability, good soundness, durability, and the low cost. Masonry structures are an assemblage of brick and mortar units which are described as orthotropic, inelastic and non-homogeneous. The mathematical modeling of masonry structures requires the relationships of masonry with two constituent elements (i.e., brick and mortar) and its material properties such as stress-strain characteristics, modulus of elasticity, and bond strength between brick and mortar [1]. The mechanical properties of masonry such as compressive strength, stress-strain characteristics, and that of its constituent elements (i.e., brick and mortar) have been investigated by past researchers [1–8]. Kaushik et al. [1] have investigated the compressive stress-strain behavior of the masonry prisms constructed with local hand moulded burnt clay bricks and developed the analytical model for obtaining the nonlinear stress-strain curves of masonry. Gumaste et al. [4] studied the compressive strength behavior of various prisms and wallettes, constructed with two types of brick (i.e., table moulded bricks and wire-cut bricks) and five different types of mortar. Authors [4] derived an empirical relationship for masonry strength as a function of brick and mortar strengths. Gihad et al. [6] studied the stress-strain behavior of concrete block masonry prisms made with various kinds of mortar. Authors [6] observed that the mortar is primarily responsible for the non-linear behavior of masonry. Lumantarna et al. [7] have investigated the compressive stress-strain characteristics of masonry sample extracted from the existing masonry buildings of New Zealand. Authors [7] developed the relationship between the brick, mortar and prism compressive strength for prediction of compressive strength of existing New Zealand unreinforced masonry (URM) bearing wall buildings using the compressive strength of brick and mortar. Recently, Wu et al. [8] studied the uniaxial compressive stress-strain behavior of unstabilized block masonry prisms with various mortar compositions. Authors [8] observed that the compressive strength, tangent modulus, and Poisson's ratio of prisms are influenced by mortar strength to block strength ratio.

Another relevant property of masonry is the bond strength (i.e. flexural and shear bond strengths) between brick and mortar which plays an important role in the masonry structures to resist lateral or eccentric load [9]. In the masonry structure, in-plane forces which act parallel to the plane of the wall, are resisted by bond between brick and mortar [10]. Sarangapani et al. [11] investigated the flexural and shear bond strengths of masonry using different types of local brick and mortar. Authors [11] observed that the bond strength has increased 4 times that of the plain brick mortar interface by the use of epoxy coating as enhancing material. Reddy et al. [12] have studied the flexural bond strength of masonry using various blocks in combination with different types of mortar. The study showed that moisture content of the masonry and mortar strength have significant influence on the

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flexural bond strength of the masonry. Khalaf [13] demonstrated the Z-shaped test specimens for investigation of flexural bond strength and observed that the proposed Z-shaped specimen is capable of determining the flexural bond strength. The bond strength between brick and mortar is influenced by many factors such as types of mortar, surface characteristics, shape and size of frog, water absorptions of the brick, curing method, and workmanship [11–20]. Thamboo et al. [12] observed that smooth surface textured units exhibited higher bond strength (flexure and shear) compared to the rough surfaces. Reddy et al. [13] found that optimum moisture content of the masonry units is approximately 75% of the saturation value while the dry or fully saturated bricks result in poor bond strength. Thamboo and Dhanasekar [19] reported that dry cured thin layer mortar masonry specimens exhibit higher bond strength and Young's modulus compared to the wet cured specimens.

However, most of these past studies indicate that there are limited studies on all the mechanical properties required for mathematical modeling of bricks masonry structures. The aim of the present paper is to determine the mechanical properties such as compressive strength, stress-strain behavior, modulus of elasticity of masonry along with its constituents (i.e., brick and mortar). Moreover, flexural and shear bond strengths of masonry units are determined experimentally by combination of four different types of brick and three different types of mortar.

2. Research significance

The stress-strain characteristics and modulus of burnt clay and concrete bricks masonry have been presented which are useful for mathematical modeling of masonry structures for their linear and nonlinear response analysis. Furthermore, five control points defined on the stress-strain curve would be useful for the performance based design of masonry.

3. Experimental details

3.1. Material and mix design

3.1.1. Brick unit

In this study, four different types of locally available bricks were used. Three of them were burnt clay bricks while the other was concrete brick. These bricks are designated as C1, C2, C3, and C4. The burnt clay bricks were manufactured by manual moulding process and then burning them in kilns. The concrete bricks were made with a mixture of portland pozzolana cement, sand, coarse aggregate, and water. The damp mixture is then tamped into the mould. Concrete bricks were cured in water for 28 days before use. The approximate sizes of burnt clay bricks and concrete bricks are 230×110×75 mm (length × width × height) and 200×100×100 mm, respectively. Frog for burnt clay bricks had dimensions of 150×50×15 mm, whereas no frog was there for concrete bricks. Compressive strength and water absorption of these bricks were determined as per IS 3495 [21]. Compressive load was applied on the bricks using 1000 kN capacity of Universal Testing Machine (UTM) in displacement control manner at the rate of 0.01 mm per sec until failure occurs. ASTM C-67 [22] was adopted to determine the initial rate of absorption (IRA) of bricks. The average compressive stress-strain response of these bricks is shown in Fig. 1. This response is obtained by average data from tests of five samples for each type of brick. It is seen that for the burnt clay bricks (C1-C3), initially the curve is linear up to about one-third of the ultimate failure stress after which it becomes nonlinear, whereas for the concrete bricks, it is linear up to the peak compressive stress. The material properties such as brick compressive strength (f_b), strain at peak stress, failure strain, and secant modulus of elasticity (E_b) are presented in Table 1. The failure strain is defined throughout this paper as the strain corresponding to stress equal to 80% of the peak stress in the post peak region. This definition of the failure strain is arbitrary in the sense that after reaching the peak stress, a sudden drop in stress value is observed with small increment in the strain. Thereafter, strain is increasing with higher rate due to crushing of masonry. The modulus of elasticity is defined as secant modulus throughout the work and it is calculated by measuring the slope between ordinates from 5% to 33% of the ultimate strength of the specimens as per standard ACI 530-02 [23]. It has been perceived that the secant modulus of elasticity of burnt clay bricks varies between 125 and 200 times of its compressive strength (f_b) of the brick, whereas for concrete bricks it is observed to be 356 times of compressive strength (f_b) of bricks.

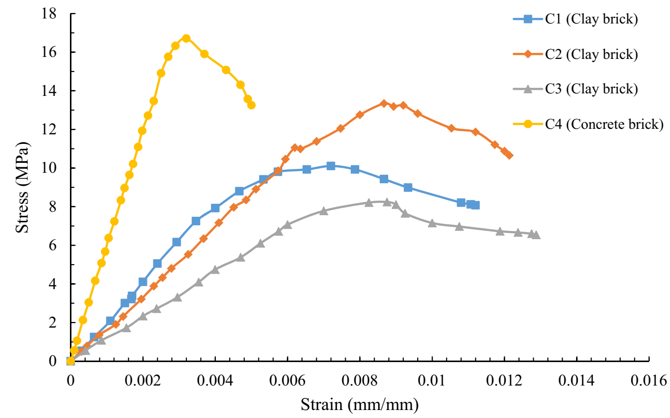

Fig. 1. Compressive stress-strain response of brick units.

3.1.2. Mortar mix

Three mixes consisting of cement: lime: sand proportions (1:0:3, 1:1:4, 1:0:5) were prepared using a Hobart mixer by weight batching. Portland pozzolana cement (PPC) as a binder, hydrated lime, and local river sand for the fine aggregate were used to prepare the mortar specimens. The material properties of the Portland pozzolana cement and local river sand used are same as described by Singh et al. [24]. The compressive strength test of 70.7 mm cubes of these mortars was performed as per IS 2250:1981 [25] after the age of 28 days. The compressive stress-strain response of these mortars is shown in Fig. 2. These responses are based on average of six specimens of each mix. As shown in Fig. 2, initially the curve is linear up to the peak stress, and then a sudden drop in stress is observed. The average ultimate compressive strength (f_j), strain at peak compressive stress, failure strain, and secant modulus of elasticity of mortars are presented in Table 2. The secant modulus of elasticity is found to vary between 65 and 80 times of compressive strength of the mortar.

3.2. Specimen preparation

A total of 120 masonry prisms were fabricated using combination of each kind of brick and three types of mortar to determine the compressive strength and flexural bond strength of the masonry. The masonry prisms were cast with five bricks stack bonded with specific types of mortar. The thickness of mortar was maintained from 10 to 12 mm. The size of burnt clay brick masonry and concrete brick masonry prisms are 230×110×423 mm and 200×100×540 mm, respectively. Moreover, masonry triplets were cast with each kind of brick and mortar to determine the shear bond strength of masonry. Each triplet was cast with three bricks and 12 mm thick mortar. Burnt clay bricks prism & triplets were immersed in water for 24 h before manufacturing, to avoid the absorption of water from the fresh mortars. Masonry prisms and triplets were cured in moist conditioning at a temperature of 25 ± 3 °C by wet jute bag for 28 days.