Strength of Quarry Dust Modular Bricks and Wallettes Under Compression

Atikah Fatma Md Daud and Zakiah Ahmad

Abstract The compressive strength of masonry can be verified using two methods namely the unit strength method and the prism test method. The characteristics of masonry are influenced by the properties of bricks and mortar. This paper reports the investigation made on the compressive strength of bricks manufactured using quarry dust as sand replacement. Two types of bricks were prepared; hollow and solid modular bricks with size of 190 mm (H) $\times$ 100 mm (L) $\times$ 100 mm (T) which is a little bit bigger than the normal brick size. The compressive strength of the bricks have been evaluated using individual unit and mortar strength, prism and wallettes. The effects of different joint thickness on the compressive strength were also evaluated. The strength of solid modular block with thicker mortar joint was found to be higher the strength of hollow block. Based on the strength, both bricks passed the minimum requirement of brick for government project.

Keywords Bricks · Mortar · Compressive strength

1 Introduction

River sand has been the most popular choice for the fine aggregate component of concrete in the past, but overuse of the material has led to environment concern, the depleting of securable river sand deposits and a concomitant price increase in the material. Due to this situation, some developing countries are facing a shortage in the supply of natural sand. Therefore a lot of studies have been carried out to

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replace natural sand such as fly ash, slag, limestone etc. [1, 2]. Malaysia is one of the countries that are facing the same problems as other developing countries. Quarry dust is a waste product after the extraction and processing of rocks to form fine particles less than 6 mm. Quite a number of researchers have investigated the potential of using quarry waste and its effect on the strength, workability and durability of concrete [3].

Abdullah [4] investigated the mechanical properties of bricks produced using quarry dust as sand replacement at different mix proportions of cement: sand: quarry dust namely 1:10:0 (M1), 1:7.5:2.5 (M2), 1:5:5 (M3), 1:2.5:7.5 (M4) and 1:0:10 (M5) as well as 1:1:5 (control). The results showed that the bricks containing 100 % quarry dust (1:0:10 (M5)) gave the highest strength and the lowest water absorption compared to other ratios. That study showed that bricks with quarry dust as sand replacement has great potential for construction. This paper reports the investigation made on quarry dust brick masonry prisms and wallettes under axial compression with different thickness of mortars on the surface of solid and hollow bricks.

In order to have a strong masonry unit, there must be good bond between the bricks and the mortar and the strength of the joints depend on the strength of the mortar, types of mortar, thickness of the mortar etc.

A good bond between the units and the binding material is essential and determines how the masonry transfers and resists stresses due to various applied loads [5]. Under compression, the brick masonry will failed in different form of failure characteristics. A number of failure theories have been proposed for brick masonry in compression [6–9]. The theories make an assumption that the bond between brick and mortar remains intact at the time of failure of the brick or mortar. But studies have also shown that the masonry failure is generally accompanied by bond failure in situations where very low brick–mortar bond strength is used [10, 11].

Sarangapani et al. [11] showed the relationship between the bond strength and compressive strength by keeping the mortar strength constant. They observed an increased compressive strength when the bond strength of the masonry increased. Meanwhile, study by Venkatarama and Vyas [5] showed that masonry compressive strength is not sensitive to bond strength variations when the masonry unit is stiffer than the mortar. During the compression of masonry prisms constructed with bricks that are stiffer than the mortar, the mortar in the bed joint has a tendency to expand laterally more than the bricks due to its lesser stiffness. Due to the confinement of brick–mortar interface, the shear stresses at that interface resulted in an internal state of stress which initiates vertical splitting cracks in bricks that lead to failure of the prisms [12, 13]. The stresses developed are generally attributed to the mechanical inter-locking of cement hydration products into the surface pores of the bricks [14].

Gumeste et al. [15] reported that the crushing of weakest brick in a wallette specimen often determines the masonry strength rather than the interaction between brick and mortar and may mask the influence of the mortar strength on the masonry strength. He also concluded that the failure of masonry specimens using weak mortar is primarily due to loss of bond between mortar and brick units and in the case of stronger mortars failure is due to splitting of bricks.

As the performance of the bricks depends on the materials used and the performance of the walling depends on the properties of bricks and also mortar therefore this research investigated the compressive strength of hollow masonry manufactured using quarry dust as sand replacement as individual unit and also as wallet unit.

2 Materials

2.1 Brick

The bricks were supplied by Syarikat Kilang Papan Mohamad Yusuf dan Anak-anak as shown in Fig. 1. The brick size is 390 mm (L) × 19 mm (H) × 100 mm (W).

The bricks were manufactured using cement, sand and quarry dust with mix ratio of 1:5:5 (cement:sand:quarry dust).

2.2 Mortar

The mortar was prepared using a ready-to-use material named EMACO R1 and was used to replace the ordinary mortar mix. This is a fast curing mortar. EMACO R1 contains special cements, well graded sands and selected polymers to improve physical and application properties. The mortar was prepared by adding the water to the EMACO R1. Mixing water needed is 0.2 L for 1 kg of EMACO R1. This mortar was used in order to expedite the work. However the mortar has also been used by construction industry.

3 Test Methods

Before the construction of the wallette specimens, the properties of the materials that is going to be used, had to be known. The knowledge of the properties of the mortar and brick would assist in the next analysis. Compressive strength of brick.

The compressive strength of individual brick was determined in accordance with BS 3921:1985. Five (5) randomly picked bricks were first immersed in water for 24 h. After pat dried, the dimensions of the bricks were measured and then placed in compression machine.

To ensure a uniform bearing for the brick specimen, the specimen will be placed between 3 mm thick plywood sheets to take up irregularities. The brick was loaded at a rate of 3.0 kN/s.

Fig. 1 Brick with quarry dust

3.1 Compressive Strength of Mortars

The compressive strength of mortar was performed in accordance with BS4551:1980 of size 50 × 50 × 50 mm^3. Six (6) cubes were prepared and tested after 7 and 28 days.

3.2 Compressive Strength of Masonry

3.2.1 Construction of Prism and Wallettes

Masonry wallettes and prisms were constructed in accordance with EN 1052-1:1999 [16]. The prisms were constructed from 5 layers of bricks as shown in Fig. 2a and the wallettes were fabricated using stretcher bond formation as shown in Fig. 2b and each type were bonded with two (2) different thickness of mortar namely 10 and 15 mm in order to determine the effect of mortar thickness on the bond strength. The codes allow the height to thickness ratio of the test prisms to range 2.0–5.0 and the height to thickness ratio for the prisms and wallettes for 10 and 15 mm mortar are 4.5 and 4.3 respectively. A total of 12 wallettes specimens were constructed.

3.2.2 Compressive Strength Test

The compression test of the wallette specimens were tested based on BS5628-1:2005. Lateral variable displacement transducers (L.V.D.Ts) were set-up on each wallette as shown in Fig. 3 at three points on each wallette, one near mid-span, and the other two were located at one-third of the height from top and bottom respectively. Strain gauges of 67 mm gauge length were also attached. As for prism test, no LVDT's were attached to the specimen because strain was not measured (see Fig. 4).

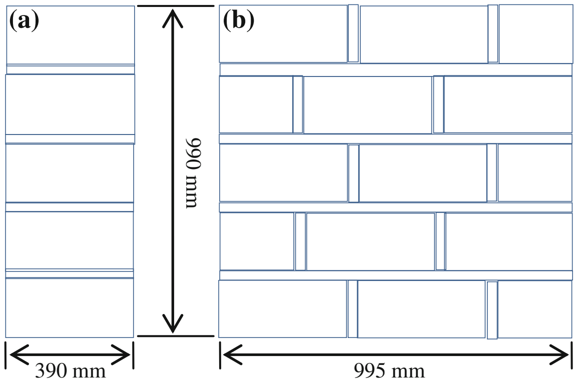

Fig. 2 Prisms; (**a**) 5-brick prism and (**b**) Stretcher bond wallette specimen

Fig. 3 Experimental set-up for testing of wallette

Fig. 4 Experimental set-up for testing of 5-brick prism

4 Results and Discussions

4.1 Compressive Strength of Brick and Mortar

The compressive strength of individual brick or mortar was determined using Eq. (1).

$$F_c = \frac{P_c}{A} \tag{1}$$

where F_c is the compressive strength in MPa; P_c is the maximum load at fracture in Newtons; and A is the cross-sectional area in millimetres.

The compressive strength of mortar and the bricks (solid and hollow bricks) are shown in Table 1.

From Table 1, it can be seen that the compressive strength of the hollow modular block using quarry dust is 3.46 N/mm^2 whilst for solid modular block the

Table 1 Compressive strength

Item	Compressive strength (MPa)
Mortar	23.3 (for 7 days) and 33.8 (for 28 days)
Solid brick	6.46
Hollow brick	3.46

compressive strength is 6.46 N/mm^2. According to EN771-1-6, a minimum mean value of compressive strength of masonry unit is 1.8 MPa to be used for masonry walls. In Malaysia, for any bricks to be used as construction materials, the minimum permissible average compressive strength specified by Public Works Department is 5.2 MPa for bricks and 2.8 MPa for hollow blocks per 10 samples taken at random from the Contractor's stock pile of 1,000 or part thereof [18]. Hence both types of quarry dust bricks passed the building requirement. These results also show that modular block unit is weaker than the mortar and it will give effect to the prism and wallette tests.

4.2 Compressive Strength of Masonry

Quality and consistency of workmanship has an enormous effect on the strength of masonry [17]. Therefore to ensure consistency in the construction of the samples, all wallettes and mortar batches were carefully controlled.

4.2.1 Characteristics of 5-Brick Prism

Figure 5 shows the compressive strength of prisms for solid brick. As expected that solid brick can resist more compressive load compared to hollow block. The compressive strength of solid brick is 70 and 154 % higher than hollow brick. This is due to the hollow section has not been filled with grout hence less mortar is actually bonding the surface of the bricks.

Failure of the masonry in compression was generally due to crushing and splitting of the bricks (Fig. 6) which later induced movement in the mortar as the load increased which supported the Gumeste et al. [15] findings where masonry with stronger mortars failure is due to splitting of bricks.

The compressive strength of masonry determined by the prism method is lower than the compressive strength determined using the unit strength method. The compressive strength of solid brick is 13 % higher than the compressive strength of prism for solid bricks for 15 mm thickness mortar. Meanwhile, the compressive strength of hollow brick is 55 % higher than the compressive strength of prism with hollow bricks with 15 mm mortar thickness.

This is due to the masonry prism failed in compression prior to reaching the load capacity of individual units. The restrain the unit places on the lateral

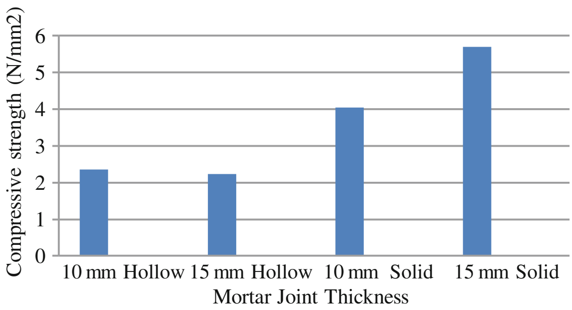

Fig. 5 Compressive strength of wallettes for different mortar thickness

Fig. 6 Failure of solid 5-brick prism

expansion of the mortar joint induces lateral tensile stresses in the unit. Thus the boundary restraints on the unit in the prism will never be as great as they are on individual units when placed in compression between steel bearing plates.

As mentioned earlier the compressive strength of masonry is affected by the compressive strength of units, the type of mortar used, workmanship and curing and these variables are largely reflected in the results of prism test. Therefore, prism test results are more representative of actual in-place performance of the masonry than are tests of component masonry materials. The unit method of masonry does not provide quality control on workmanship and curing as does the prism method.

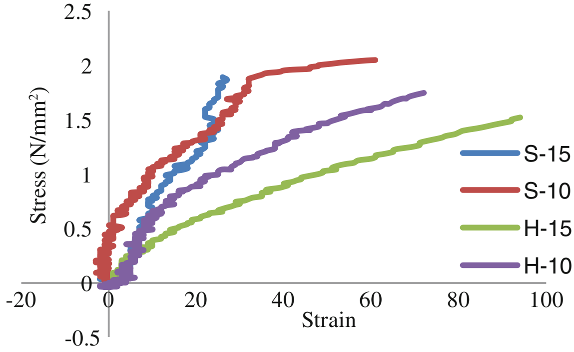

Fig. 7 Stress versus displacement graph for wallettes with different thickness of mortar

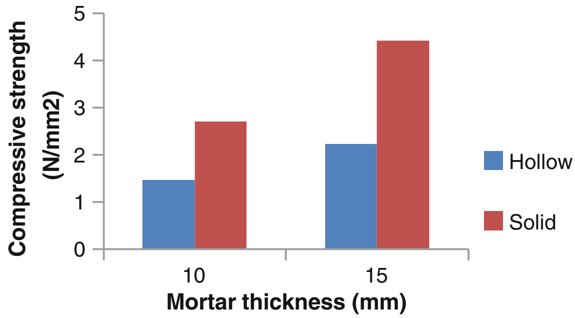

Fig. 8 Compressive strength of wallettes for different mortar thickness

4.2.2 Characteristic of Wallette

In Fig. 7 the stress versus strain of wallettes for different thickness of mortar shows almost similar behaviour for all samples even though the thicknesses of mortar joints are different.

Almost all specimens the collapse occurred when the specimens reached maximum load but with different vertical shortening. Wallettes with hollow bricks collapse at lower maximum load but higher vertical displacement which reflected ductile behaviour.

The results of the compressive strength testing of masonry using wallettes with different mortar thickness are presented in Fig. 8. Once again it can be seen that the compressive strength of wallettes with solid brick can resist more compressive load compared to hollow block. As the mortar thickness increases, the compressive strength also increases. The compressive strength of wallettes with solid brick and 15 mm mortar thickness is 97.8 % higher than wallettes with 10 mm mortar thickness.

The failure mode of wallette with 15 mm mortar was found to have higher degree of failure compared to 10 mm mortar joint thickness. Wider and longer vertical cracks can be seen (Fig. 8) on wallette with 15 mm mortar. Similar crack patterns were also observed on the wallette with 10 mm mortar thickness (Fig. 9).

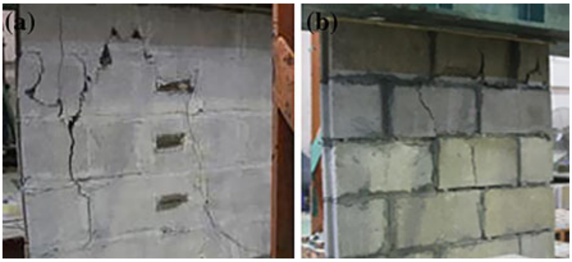

Fig. 9 Crack observed in the wallettete test; (**a**) 15 mm mortar thickness and (**b**) 10 mm mortar thickness

These vertical cracks mainly occurred in the bricks and not along the mortar line. These further masked the effect of mortar strength on masonry strength. The vertical stress gets concentrated at perpendicular direction and leads to splitting of the brick. Such behaviour has also been reported by Matthana [10].

The compressive strength of prisms with 15 mm mortar thickness is higher than compressive strength of wallettes by 29 %. However, compressive strength of prism is lower than the compressive strength of masonry unit by 13 %. For hollow bricks, there is no significant different in the compressive strength of prism and wallette with 15 mm thick mortar but this compressive strength is lower than the compressive strength of brick unit by 55 %.

At this point of time, the use of wallette for strength determination is hence more reliable. It may be necessary to test larger number of wallettes with different types of bond to arrive at reliable strength results. This study can be further enhanced by testing the brick–mortar bond strength.

5 Conclusion

The compressive strength properties of masonry bricks made from quarry dust as sand replacement were investigated. The following conclusions were derived:

(a) The compressive strength of solid masonry unit is higher than hollow modular block. The thicker the mortar joint, the higher the compressive load.
(b) The compressive strength of the masonry unit passed the minimum permissible average compressive strength specified by Public Works Department is 5.2 MPa for bricks and 2.8 MPa for hollow blocks. Hence the use of hollow bricks will allow for material saving as compared to solid bricks.
(c) As the compressive strength of mortar used is higher than the compressive strength of bricks, the failure of the masonry in compression was generally due to crushing and splitting of the bricks.
(d) The compressive strength of prisms with solid bricks for 15 mm mortar thickness is higher than compressive strength of wallettes by 29 %. However, compressive strength of prism is lower than the compressive strength of masonry unit by 13 %.

(e) There is no significant different in the compressive strength of prism and wallette for hollow bricks with 15 mm thick mortar but this compressive strength is lower than the compressive strength of hollow brick unit by 55 %.

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