Flexural bond strength of clay brick masonry

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Abstract

The intent of a new parametric study at the University of Calgary is to investigate the influence of several factors on the flexural bond strength of clay brick masonry. These factors include the absorption characteristics of the brick units, and varying construction and curing methods. A preliminary study was performed with a series of clay brick prisms built from different types of brick with various absorption characteristics, and cured at different conditions. The bond wrench test was used to determine the flexural bond strength between the mortar and brick. The results showed high variation, but did provide some indication of which factors may be contributing to the highly variable findings. The objectives of this continuing study are to eliminate the possible parameters that were causing the highly variable results, and to determine correlations between brick properties and bond strength. The results are presented in this paper. Further research will be ongoing to establish a more definite relationship between the various parameters and bond strength and to investigate effects of mortar, and curing conditions.
Keywords: masonry, clay brick, flexural bond strength, bond wrench, initial rate of absorption, sorptivity, absorption, construction method.

1 Introduction

Masonry is a composite material of clay or concrete units held together by mortar. An ineffective bond between the unit and mortar will cause cracking when subjected to lateral loading. Cracks increase susceptibility to moisture ingress, which leads to freeze-thaw damage, and corrosion of metal connectors. Therefore, the bond strength between the brick and mortar acts as an indicator of the overall quality of the masonry structure [1].

For many years, researchers have been interested in determining the factors that affect the bond at the interface of the two materials. These parameters

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include the absorption characteristics of the units (initial rate of absorption or IRA, sorptivity, and cold and hot water absorption), mortar properties (type, flow, and retentivity), curing conditions, and workmanship. It is difficult to determine the significance of one factor and its effect on the bond strength because no factor alone is responsible for good bond, making it difficult to devise an experiment to produce consistent results [2]. Numerous studies [3–7] have shown large differences in strengths and highly variable results, and no conclusive findings were obtained from replicating experimental procedures [1].

A preliminary study was performed at the University of Calgary in the summer of 2005 investigating the effects of various absorption properties of clay bricks (particularly the IRA property) and curing conditions on the flexural bond strength of clay brick masonry. Although the variability of the results was high, it did provide some indication of which factors may be contributing to these highly variable findings. The continuing study involves the investigation of two possible causes of variability with the objective to eliminate these factors, and also aims to determine correlations between brick properties and bond strength. This paper identifies the possible causes of variability, and presents the results when new methods were applied to eliminate these factors. Apparent correlations between different brick properties are also presented.

2 Stage 1: eliminate construction factors

2.1 Identifying the factors

The first factor identified from the preliminary study is that the mortar was mixed by an experienced mason. It was observed that the color and texture of the mortar joints varied. An explanation for this is that the amount of water added into the mortar was based on the experience of the mason, and each new batch of mortar may have differed slightly.

Another possible factor that contributed to the highly variable results is the height of the prism. For the preliminary study, 5-brick high prisms were used. It was hypothesized that the varying weight on each mortar joint along the height of the prism may have caused stress variation at the joints.

Lastly, CSA A371-04 [8] requires mortar joints to be 10 mm thick with a tolerance of ±3 mm. Although the joints were fairly consistent with all the prisms, this is also considered as a contributing factor to the high variations.

With these identified factors, the first stage of the current study was to attempt to reduce the variability by eliminating these factors using non-conventional construction methods.

2.2 Materials

2.2.1 Bricks

Three types of brick were used with various IRA values: tan (IRA = 10 g/min/200cm^2); red (IRA = 23 g/min/200cm^2), and cream (IRA = 42 g/min/200cm^2). These same brick types were also used in the preliminary study. All units are metric modular with dimensions 90 x 190 x 57 mm (W x L x H).

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2.2.2 Mortar

A general purpose Type S 1:0.5:4.5 (Portland cement:lime:sand by volume) mortar was used. The contents were proportioned and mixed in accordance with CSA 179-04 [9]. The amount of water added was measured (by weight) and recorded for future mixes. This entire procedure was performed by the researcher.

2.3 Specimen preparation

To eliminate the varying weight on the mortar joints along the height of the prism, it was decided to build 2-brick high prisms. To have all the prisms built the same, a simple jig was designed for proper alignment of the units and to ensure a 10 mm mortar joint in between. The jig consists of four wooden right angled pieces, with an M6 hex screw embedded in the middle. The screw head has a diameter of 9.8 mm and sits on the bed face of the brick, and all the corner pieces are held together by a heavy-duty elastic. A full bed of mortar is then placed, and the top brick is added (Figure 1). Afterwards, the elastic is removed and the corner pieces are pulled out.

A total of 110 prisms were made, and all were air-cured at ambient laboratory conditions (temperature of 20ºC and relative humidity 21%).

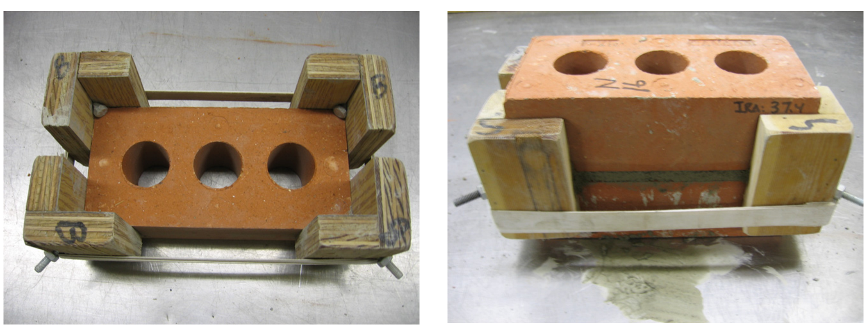

Figure 1: Prism construction with jig.

2.4 Test method

The bond wrench method described in CSA S304.1 Annex E [10] was used to determine the bond strength of the masonry prisms. The test apparatus and method have been used in other studies as well [11].

2.5 Results and discussion

Specimens were tested at 7 and 28 days. The average bond strengths and standard deviations are plotted, and shown in Figure 2. It can be seen that the variability for the 7-day cure is much greater than the 28-day cure. It is also surprising to see that bond strengths tend to be greater at 7 days then at 28 days. But due to the highly variable results, it is difficult to make any conclusions.

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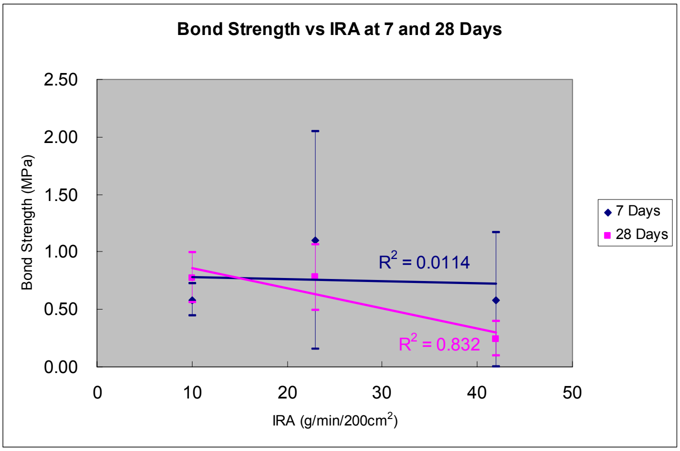

Figure 2: Bond strengths of three brick types at 7 and 28 days.

3 Stage 2: eliminate brick-to-brick variability

3.1 A new factor to consider

It is obvious from Stage 1 that despite controlling most workmanship variables, large variability still exists. Therefore, in this stage the variability in brick absorption properties for each individual brick were taken into consideration. This variability has been reported in the literature as well. With a sample of 20 of the same brick type, Lauersdorf and Robinson [12] observed that individual brick IRA ranged from 14.9 to 39.4 g/min/194 cm^2. Bailey *et al.* [13] reported that an individual brick unit may even exhibit significantly different IRA values from one bed face to another.

Therefore, for the second stage, brick couplets were paired up according to their individual IRA and sorptivity values. Care was taken to ensure that the tested bed face was the one on which mortar was placed.

3.2 Materials

3.2.1 Bricks

Two types of bricks were used: tan and red (both these brick types were used in the previous tests). Prior to construction, each individual brick was tested for its IRA and sorptivity properties in accordance with CSA A82-06 [14], and ASTM C1585 [15].

More than 600 brick units were tested for IRA. For the red brick, individual IRA values ranged from 25.6 to 59.2 g/min/200cm^2 (difference of 33.6 g/min/200cm^2), whereas for the tan brick IRA ranged from 6.6 to 20.1 g/min/200cm^2 (difference of 13.5 g/min/200cm^2). Therefore, it was decided to pair up the red bricks according to IRA and the tan bricks according to sorptivity. Approximately 200 of the tan bricks were further tested for sorptivity which

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ranged from 0.0226 to 0.099 mm/s$^{0.5}$. Bricks with matching values were paired up (tolerance of ±0.2 g/min/200cm^2 for IRA, and 0.0001 mm/s$^{0.5}$ for sorptivity) for prism construction.

3.2.2 Mortar

The same mortar preparation used in Stage 1 was used in Stage 2.

3.2.3 Specimen preparation

The same method from Stage 1 was used in Stage 2 to construct the prisms. A total of 50 matched IRA prisms were constructed, and were cured for 14 days: 7 days air-cured at ambient laboratory conditions, and 7 days covered with a sheet of plastic. Only 25 matched sorptivity prisms were built, and all were cured for 14 days, and covered with a plastic sheet for the whole curing duration.

3.3 Test method

As in all the previous tests, the same bond wrench method was used to determine the bond strength of the masonry prisms.

3.4 Results and discussion

The results from the matched IRA prisms are shown in Figure 3.

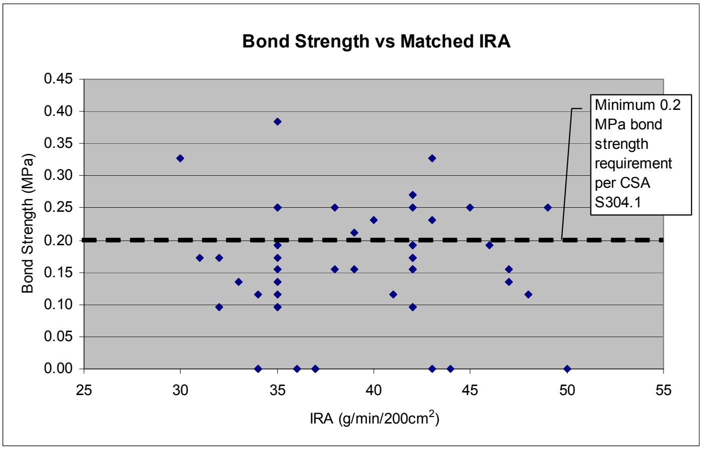

Figure 3: Bond strengths of the matched IRA prisms.

CSA A371-04 [8] uses IRA as a guideline to ensure proper bond strength in masonry construction. It suggests that a brick unit with IRA of 30 g/min/194 cm^2 is considered a high IRA brick. Without prewetting, the brick will absorb excessive amount of water and improper curing of the mortar will occur leading to poor bond strength.

Despite controlling a number of identified factors, no correlation can be seen in Figure 3 between bond strength and IRA. Although more than half the prisms failed at bond strength below 0.2 MPa (the minimum bond strength required by

CSA S304.1 [10]), it is possible to have good bond strength without prewetting high IRA bricks. It is also noted that the curing length and conditions did not conform exactly to the procedure outlined in CSA S304.1 [10].

Although the tan prisms were matched according to sorptivity, it was of interest to examine the relationship between bond strength and IRA of these prisms. Interestingly, the IRA values were also quite closely matched. The largest IRA difference was 5.4 g/min/200cm^2. The IRAs for each prism were averaged, and then plotted with the corresponding bond strength (Figure 4). Similar to the matched IRA prisms, no correlation is observed between IRA and bond strength.

Figure 5 presents the results of the matched sorptivity prisms. It can be seen that no correlation is apparent between sorptivity and bond strength either.

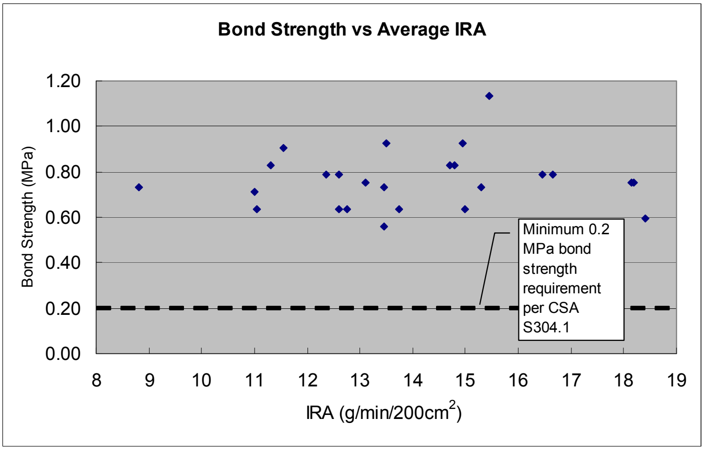

Figure 4: Bond Strength vs. average IRA from the matched sorptivity prisms.

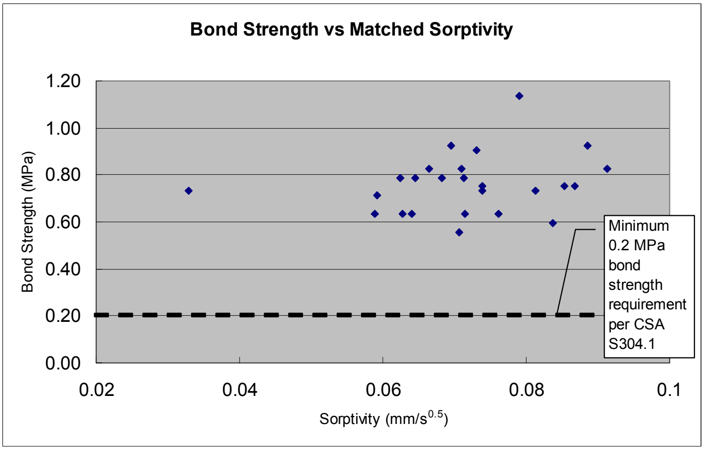

Figure 5: Bond strengths of matched sorptivity prisms.

4 Relationship between various brick properties

As a supplement to this current study, it was of interest to determine whether typical brick unit properties (IRA, sorptivity, 24 hour cold water absorption, and compressive strength) correlate to each other.

4.1 Bricks

Two types of bricks were chosen: tan, a relatively low absorption brick (same type that was previously used) and light tweed, a relatively high absorption brick that had not been used before. Ten bricks of each type were randomly chosen from the pallet for various property comparisons.

4.2 Properties

Four brick properties were determined: IRA, 24 hour cold water absorption, and compressive strength were determined in accordance with CSA A82-06 [14]; and sorptivity was determined in accordance with ASTM C1585 [15].

4.3 Results and discussions

Sorptivity and 24 hour cold water absorption were plotted against IRA for each individual brick, and is shown in Figure 6. It can be seen that the sorptivity correlates well with IRA, but 24 hour cold water absorption does not appear to correlate to IRA. Compressive strength of the unit was plotted against each absorption property for each individual brick (Figures 7–9). It can be seen that compressive strength correlates well with the IRA and sorptivity properties, but not the 24 hour cold water absorption property.

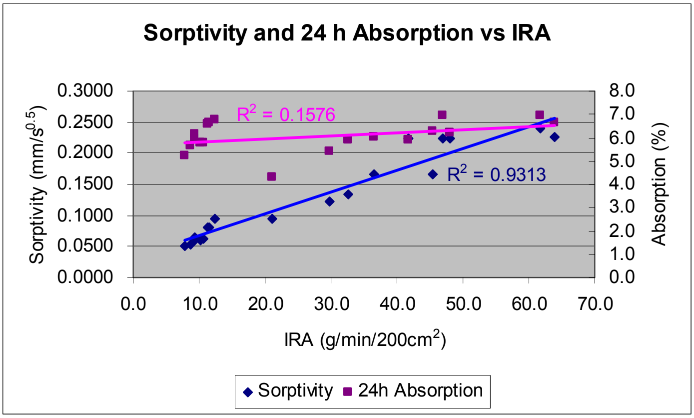

Figure 6: Relationship between various absorption properties with IRA.

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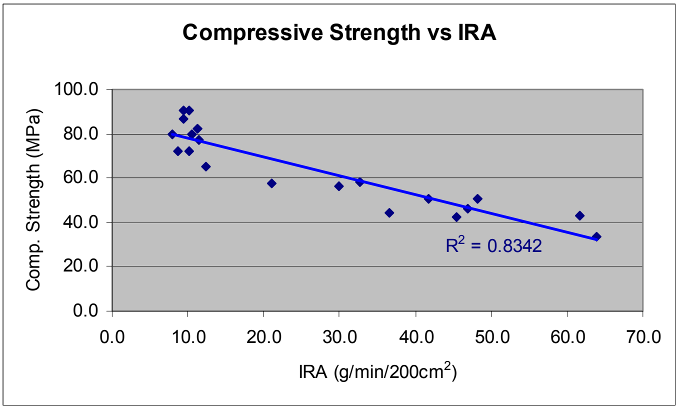

Figure 7: Relationship between compressive strength and IRA.

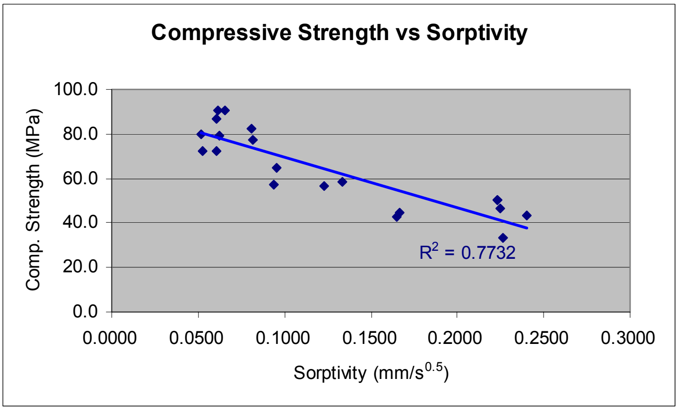

Figure 8: Relationship between compressive strength and sorptivity.

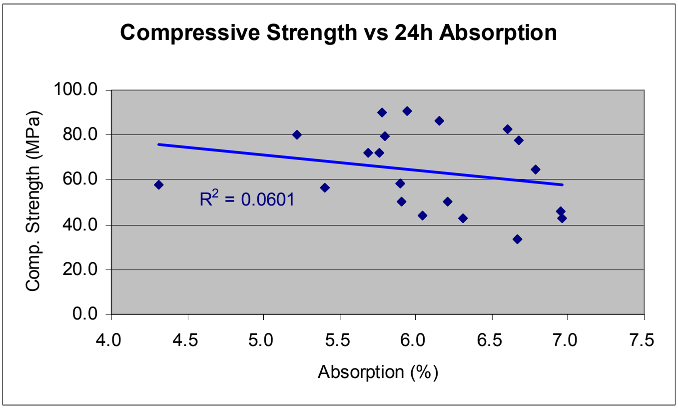

Figure 9: Relationship between compressive strength and absorption.

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5 Conclusion

This study has shown that despite controlling various factors that affect the bond strength of masonry, such as construction methods, and brick-to-brick variability, there is still a lack of correlation between the flexural bond strength and IRA. Therefore, the question is raised whether Canadian standards should use IRA as a guideline to ensure good bond strength. In addition, no correlation was found between the bond strength and the sorptivity property of brick units, however, relationships between typical brick unit properties were found. More research is needed to determine how these relationships can be applied to the flexural bond strength, and how other factors such as mortar, and curing may also affect bond strength.

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