EFFECT OF TEMPERATURE AND AGING ON DIMENSIONAL CHANGES OF BRICKS AND MORTAR USED FOR MASONRY VENEER

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ABSTRACT

Masonry veneer is the non-structural part of a masonry wall that acts as a weather barrier. Moisture and temperature changes can lead to dimensional changes in masonry veneer that is constructed using bricks/blocks and mortar. Improper design and lack of movement joints can cause cracking in the veneer leading to ingress of moisture and aesthetic issues. Other than temperature and moisture, prediction of movement in veneer is complicated by other factors such as shrinkage of mortar in the joints and the age of the bricks. This research examines the amount of movement that occurs in masonry veneer walls due to temperature and aging. The results are used for predicting the spacing of movement joints in masonry veneer. Dimensional change of the individual components of a masonry veneer wall, and the sum of the individual movements were used to predict the total movement of a wall. Dimensional changes of clay masonry units were monitored using a modified length comparator base. Extreme temperature changes were induced to record length changes. Testing of multiple samples showed a variance in the coefficient of thermal expansion of each unit, and the results in some cases were lower than published values. Fresh bricks had higher expansion at temperatures exceeding 60ºC when compared to aged bricks. Also, the shrinkage of mortar was investigated and found to be 0.11 % in a 50 day period. Results from this study were used to predict overall length change in a veneer wall and this change was compared to typical joint thickness specified in industry standards.

KEYWORDS: masonry, veneer, expansion, movement, joints, temperature, age

INTRODUCTION

Masonry veneer is a non-structural masonry wall that is held to a support wall by brick ties. The veneer serves as a weather barrier. An important feature of masonry veneer is its aesthetic appeal. All masonry units will expand or contract based on their temperature. If the magnitude of this movement is large enough it can result in cracking of the masonry veneer. This cracking is unappealing and can allow moisture to penetrate the veneer. The movements in the wall can be accommodated by the placement of movement joints. Movement joints are strategically placed horizontal and vertical joints that to account for movements in the masonry units and the supporting wall. However, currently there are no National Building Code of Canada or Canadian Standards Association standards to dictate the placement of spacing joints (MIBC, 2011). Therefore, it is left up to the designer to use local industry recommendations and personal experience to place joints.

To address some of the above-mentioned issues, a project was initiated at BCIT. The purpose of this project was to examine the effect of temperature, moisture content and aging on movements within a masonry veneer. The effect of the age since manufacture of clay bricks was examined by first isolating the effect of temperature and moisture on expansion and contraction of masonry veneer (both vertically and horizontally). In this preliminary study, a limited number of masonry units and prisms were tested under different climatic conditions to determine how the displacement is affected by temperature and moisture.

In addition to individual components of a masonry wall, the behavior of built-up prisms (small walls) was studied. A test section of a large masonry wall of the Building Envelope Testing Hut (BETH) building at BCIT was also monitored. The test section of the wall of BETH was exposed to the environment, thus simulating real weather changes. Due to small change in the mean daily temperature (approximately ±5ºC) during the time when the wall was being monitored, and due to the limited accuracy of the testing apparatus, definitive conclusions could not be drawn for the test wall. The measurement of prisms will be explored in the future scope of this project.

The objectives of this research project were to design a testing method for measuring changes in length of masonry units, prisms, and the BETH building wall; to conduct testing on masonry units, prisms, and the BETH building wall; to analyze the test results and compare with industry recommendations; and to propose new recommendations to predict veneer movements.
This paper details the procedures and instrumentation used for determining the magnitude of movement within masonry veneer. The report will examine the results obtained from testing and the connection the results have with the application of movement joints in masonry veneer.

INSTRUMENTATION

One of the goals of this project was to develop a suitable method and test rig to measure the length change in the units. In this study, the unit testing was conducted using a length comparator. This length comparator is typically used to measure the length change of concrete/mortar prisms to determine shrinkage. This standardized test was modified to enable its use to measure the length change in bricks. The brick units required a larger length comparator base because they were smaller than the standard specified length of 285 mm. This base was machined out of a 304 stainless steel rod (Figure 1). Another 304 stainless steel rod was cut to the gauge length of the brick, 195 mm, and was used as a zeroing rod. The zeroing rod was stored and used at a constant temperature of approximately 22 ^{0}C to eliminate the possibility of the rod length changing between readings. As shown in Figure 1, a rig was used to place the brick straight. The rig allowed for the brick units to be measured in the same position for all the readings.

The length comparator uses a digital dial gauge to determine the change in length, not the absolute length. The specimen ends were drilled and invar gage studs, required by the ASTM standard, were epoxied in place. However, the hydraulic-cement mortar specimens were not drilled and epoxied but moulded with the gage studs in place meeting the requirements of the standard. Figure 1, shows a test being performed on a brick specimen.

The specimens were placed in the length comparator and a temperature reading was taken with a non-contact infrared thermometer (Figure 1). The specimens were measured at lab temperature and then placed in the oven and fridge to expose them to an extreme temperature. Dial gauge readings were taken at varying temperatures as the specimen cooled down or heated up in the lab temperature of approximately 22 ^{0}C.

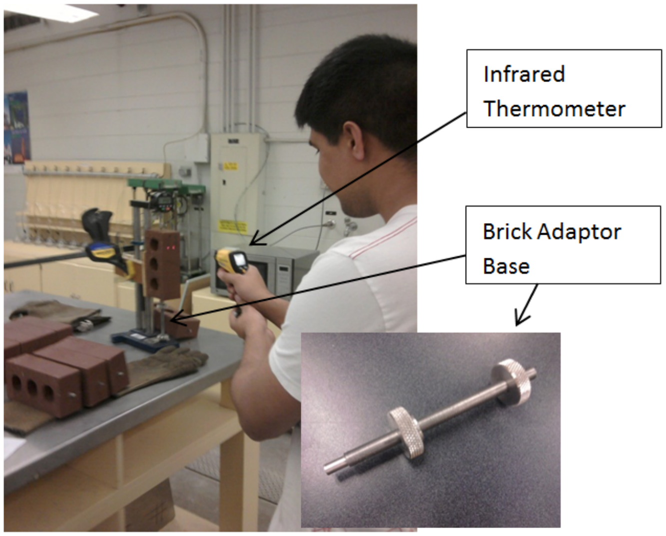

Figure 1: Brick Unit Testing Rig

SPECIMEN LENGTH CHANGE

Unit testing was conducted on representative mortar and two clay bricks. The coefficient of thermal expansion was determined for each unit. By ignoring the effect of pressure, the coefficient of thermal expansion can be determined by using the following formula:

$$\alpha = \frac{\Delta L}{L \cdot \Delta T}$$

where: α is coefficient of thermal expansion, L is gage length, ΔL is change in length, and ΔT is change in temperature.

The gauge length of the specimen excluded the length of the gage studs and was measured before a temperature change was induced. Length measurements were made along the axis of their longest dimension. The following section outlines the method, procedures and results for measuring the change in length of units due to varying conditions.

HYRAULIC-CEMENT MORTAR: LENGTH CHANGE DUE TO SHRINKAGE AND TEMPERATURE

The mortar units were prepared according to the ASTM C157/C157M standard, the *Standard Test for Length Change for Hardened Hydraulic-Cement Mortar and Concrete*. The mortar specimens used were 25 mm x 25 mm x 285 mm. A mold to create the specimens was constructed from Plexiglas to prevent moisture from being absorbed from the mortar. Figure 2 displays the mortar specimens with gauge studs embedded in mortar during mortar placement.

Figure 2: Hydraulic-Cement Mortar Specimen (Basra, 2012)

To simulate real world practices at a construction site, a professional mason was hired to construct the specimens. To ensure that the mortar mix for each prism had similar workability, flow tests were conducted. The flow test was done according to ASTM C1437 – 07, *Standard Test Method for Flow of Hydraulic Cement Mortar*. To determine a standard flow, the mason was instructed to mix the first batch of mortar. The amount of water used to achieve workability to the mason's liking was recorded along with the mixing time. Then, the procedure was repeated for the succeeding batches of mortar. A mix of 6.89 kg of water for every 36 kg of mortar mix was used and mixed for 10 minutes using a mixer paddle connected to a drill. The flow was measured for selected mixes, just to be certain that the workability of the mixes was consistent. Three readings were taken for each mix. This data is presented in Table 1. As can be seen in the table, the average flow for the three mixes was identical at 180mm. It can also be seen that the variability between the readings for the mixes was very low.

Table 1: Flow Data for mortar

	Flow Reading (mm)			
Sample	1	2	3	Average
1.1, 1.2	180	180	181	180
2.1, 2.2	179	180	181	180
3.1	180	182	178	180

The mortar specimens were tested for linear shrinkage according to the ASTM C157/C157M standard, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*. However, the specimens were not tested at the time intervals indicated in the standard. To expedite the linear shrinkage, the mortar specimens were placed in an incubator at approximately 31^{0}C and the shrinkage was measured over a two month period. The purpose of storing the mortar in an incubator as opposed to room temperature was to simulate a much more severe drying condition that would result in higher shrinkage. Figure 3 summarizes the linear shrinkage of some representative samples tested.

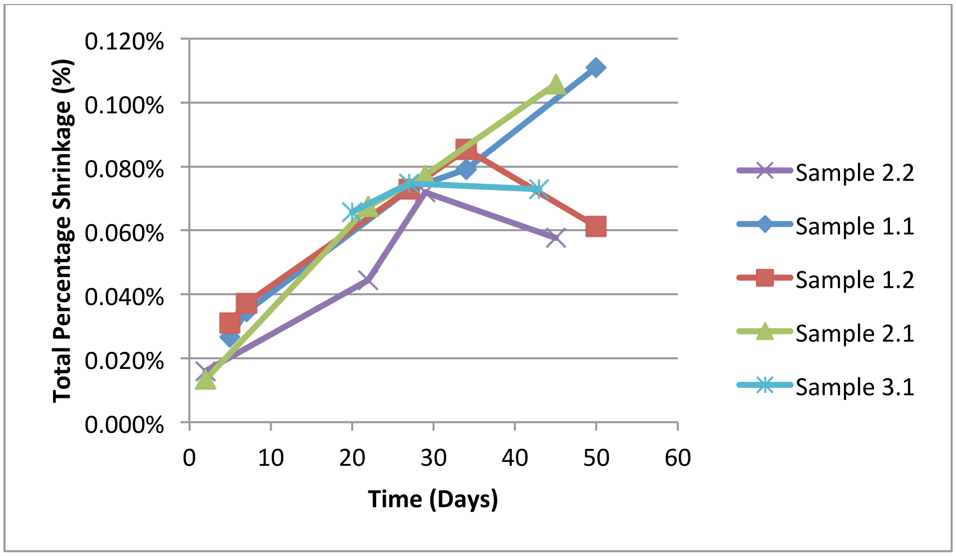

Figure 3: Masonry mortar's linear shrinkage over time

Figure 3 indicates the linear shrinkage of each sample over time. All specimens experienced shrinkage during the first four weeks of curing. This can be attributed to the loss of moisture during the early-age. Three of the specimens showed signs of either reduced rate of shrinkage or expansion when compared to the reading taken at around 35 days. The reason behind the samples expanding after 35 days cannot be clearly explained due to limited number of samples. However, the maximum observed shrinkage in the mortar samples was **0.11 %** in a **50 day** period.

The mortar samples where left in the incubator for a month to allow any further shrinkage to occur. Thereafter, the same samples were used to study the effect of temperature on dimensional change of cured mortar. The specimens were placed in the oven or fridge, and were left in this condition for 30 minutes before measuring any length change.

The graph below displays the relationship between temperature and length change for the mortar samples. The graph has been normalized by zeroing the initial reading for each specimen to represent the effect that an increase in temperature has on the length of a mortar specimen. As expected, it is clear that an increase in temperature causes the specimen to elongate. However, over a temperature change of 58.5 ^{0}C, the maximum length change in any sample is only 0.173 mm. Since the mortar sample is 285 mm long, this represents a 0.06 % increase in length over a large change in temperature. Using this information and a gage length of 285 mm, the coefficient of thermal expansion was calculated.

The average coefficient of thermal expansion was determined to be 5.5 x 10^{-6} mm/mm/^{0}C; this result is approximately 25% lower than the lower end of the published range of 7.3 x 10^{-6} mm/mm/^{0}C to 13.5 x 10^{-6} mm/mm/^{0}C for hydraulic cement mortar (TET, 2012). It should also be noted that the calculated value is an upper bound value and the other samples would have an even lower coefficient of thermal expansion.

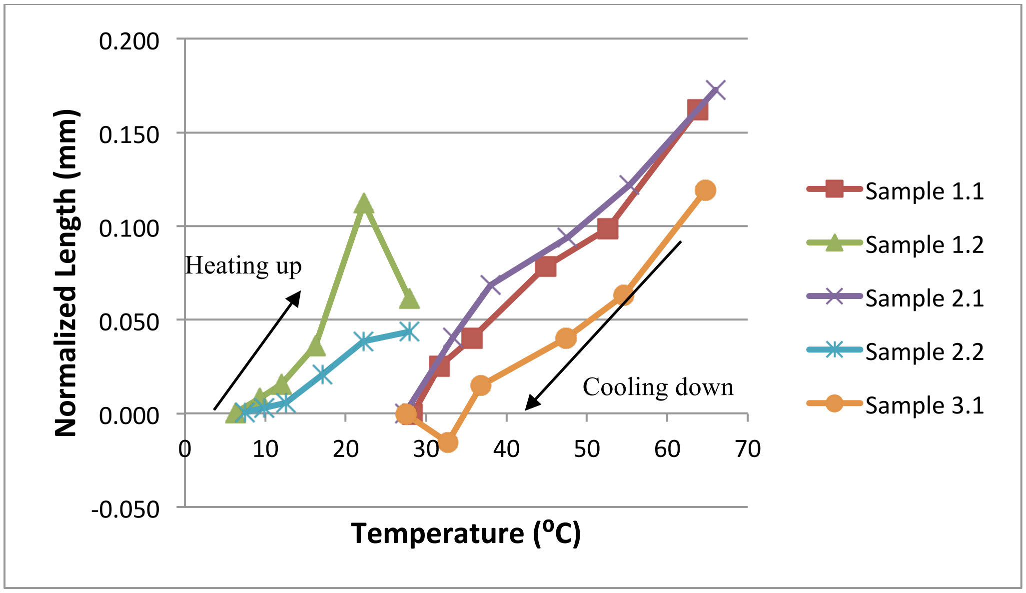

Figure 4: Relationship between Mortar Length Change and Temperature Change

CLAY BRICK: LENGTH CHANGE

The clay bricks were also tested for length change using the length comparator and a modified set-up. As described previously, the modification included an adaptor for the length comparator to accommodate the smaller length of the bricks. The brick units used were 95mm x 55mm x 195mm. The samples were divided into two categories: fresh bricks and typically aged bricks. The typically aged bricks were about three months old, and simulated what typically would be purchased from a distributor. The fresh bricks were kept sealed in plastic wrap after arriving from the plant until they were used in this research project. Two fresh and two typically aged bricks were placed in both the oven and fridge to reach a target temperature, and then allowed to cool or heat-up to ambient conditions respectively. The specimens were left in the oven (temperature around 65ºC) and fridge (temperature around 3ºC) for 30 minutes to allow uniform heating/cooling to take place. An error occurred in the initial readings for the fresh bricks placed in the fridge which was caused by improper zeroing. Also, the second aged oven data appears to be erroneous due to instrumentation error associated with the seating of the studs in the apparatus. This is shown in figure 5, but not included in the calculations and discussions below. Erroneous values for the fridge and oven samples are not included in calculating the coefficient of thermal expansion reported in this paper.

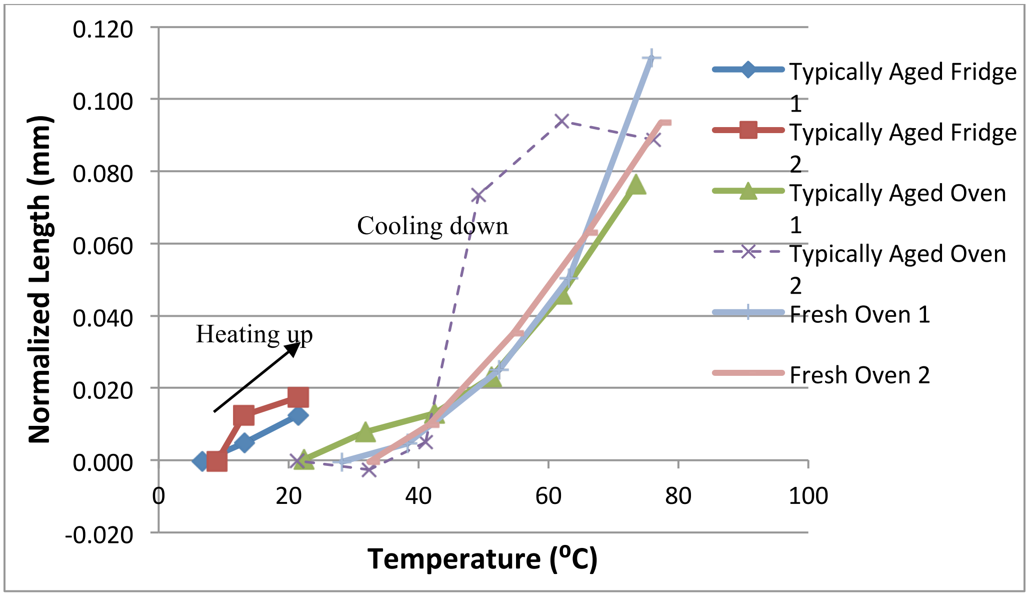

Figure 5: Relationship between Brick Length Change and Temperature Change

Figure 5 shows a summary of the relationship between temperature change and length change for the brick samples. From the graph it can be seen that the length change and coefficient of thermal expansion for fresh and aged bricks was similar for most part of the temperature change, except when the temperature exceeded 60ºC. It can also be seen that the rate of change of the thermal coefficient was different for different temperature ranges. The coefficient increased with increasing temperatures. Based on this limited data, the fridge samples appear to have a similar rate of length change as the oven samples for temperatures below 40^{0}C. Over a temperature change of about 46 ^{0}C the maximum length change of a brick was only 0.111 mm. The brick samples are 195 mm long, so a 0.111 mm elongation represents a **0.057 %** increase in length. The coefficient of thermal expansion was determined using the elongation and temperature change over regular temperature intervals. The average of the each interval's change in strain over change in temperature was determined as the coefficient of thermal expansion.

DISCUSSION OF RESULTS

The modified test instrument used in this study was used to measure the change in length in all specimens. The test results for the typically aged brick, (#2) shown in Figure 5 using a dotted line, were considered to be erroneous and were attributed to the misfit of the studs on the specimens in the test rig. Using a gage length of 195 mm the average coefficient of thermal expansion for the typically aged bricks was determined to be **4.9x 10^{-6}mm/mm/^{0}C**. This result obtained for the limited number of samples is lower than the published value of 7.0 x 10^{-6}mm/mm/^{0}C for clay bricks (BIA, 2006). It should also be noted that BIA assigns a single coefficient irrespective of the temperature. Based on the findings of this project and the discussion above, this single value of coefficient needs further investigation.

The summation of the individual components' movements was used to infer the movements of an entire wall and required spacing of movement joints. There are many factors that need to be considered for determining joint spacing for specific projects. One example of an industry recommendation for movement joint spacing suggests a spacing of 7-10m of wall length with a width of 10 mm (MIBC, 2012). According to the analysis of the recorded results in this research project, a masonry wall constructed of fresh bricks would only expand 2.9 mm when exposed to temperature change of 60 ^{0}C; this is without taking into consideration that mortar will undergo shrinkage at early-ages. Therefore, the total predicted movement of a brick wall appears to be very small. However, it should be noted that these findings are based on measurements conducted on individual components of a masonry wall. To come up with conclusive results on whether the current industry recommendations are sufficient, confirmatory testing must be done on small scale prisms and eventually on full-scale walls, and the initial few weeks after construction of the walls must be closely monitored.

Through testing of the masonry units, it was determined that fresh bricks expand at a similar rate as aged bricks, except at very high temperatures. It was also evident that the coefficient of thermal expansion changes for different temperature ranges. Based on the thermal properties of the masonry units, the current industry recommendations for movement joint placement and size seem to be adequate for the thermal movements occurring in brick walls. However, the moisture induced expansion needs to be included in these calculations to confirm the findings.

FUTURE CONSIDERATIONS

To determine the actual movement in a wall, prisms were created and tested in this research project. The goal was to measure the dimensional changes in a small scale wall and compare it to the combined length change of individual components of the wall. However, due to the lack of accuracy/resolution of the measurement device, definitive conclusions could not be drawn. This needs to be considered in future research. Full scale walls for in-situ measurements could be accurately measured using laser sensors that have a range of 500+ mm with a resolution of 0.6 μm (Epsilon, 2012). The samples should also be exposed to differential interior and exterior temperature to simulate real conditions experienced by a veneer wall. Further research is also needed to work with a larger sample size of fresh bricks and study the differences in properties when compared to aged bricks. This study should also be extended to concrete blocks.

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