BOND STRENGTH and WATER PENETRATION of LOW IRA BRICK and MORTAR

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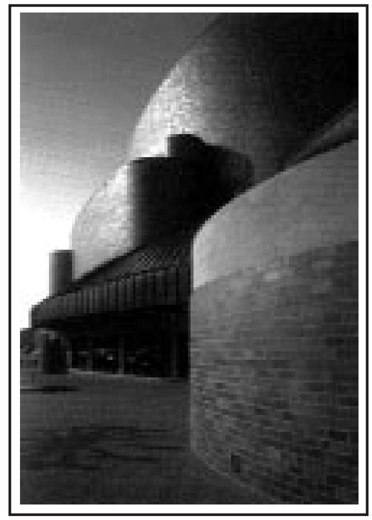
OVERVIEW

Brick with initial rate of absorption (IRA) less than 5gm/min/30 in^2 can be used successfully when laid in mortar having low water retention. In this research program, brick with IRA near 1 gm/min/30 in^2 and 4 gm/min/30 in^2 were combined with seven different mortars. Mortar materials were portland cement/lime, mortar cement and masonry cement. A control was established by combining a brick with a mid-range IRA, 15 gm/min/30 in^2, and portland cement/lime mortars. Flexural bond strengths were evaluated using the bond wrench. The combinations of materials which resulted in the highest and lowest bond strengths for each of the cementitious materials types were tested for water penetration resistance. This paper presents the parameters of the program, material properties, results, and conclusions.

KEYWORDS

Bond Strength
Brick
Cementitious Materials
Initial Rate of Absorption
Mortar Type
Water Penetration

INTRODUCTION



Investigations into brick/mortar bond strength and water penetration have identified a number of parameters which influence these properties of brick masonry. The initial rate of absorption (IRA) of brick is usually included among these parameters, as are mortar materials, Types, and properties. Early research indicated that brick with an initial rate of absorption less than 10 gm/30 $in.^2$/min did not develop sufficient bond and were not recommended. While this conclusion has been both questioned and refuted, the perception remains.

This research program was established to evaluate the performance of bricks which have initial rates of absorption lower than those recommended as a result of previous research. Bond strength and water penetration resistance were identified as the key properties to evaluate. A variety of mortar materials and mortar Types are included.

This study was undertaken with an objective to reduce as many of the variables which influence bond strength and water penetration as possible. In order to do so, brick were selected which were manufactured in similar processes. Flexural bond strength specimens were built with a template to reduce the influence of workmanship. A single mason was used to construct each series of prisms or walls. All prisms and walls were built under laboratory conditions and self-cured in plastic.

MATERIALS

Brick - Three brick were selected for this project. All are stiff mud, extruded brick with a red-firing body. The bed surface of each brick is wire cut and all are 100% solid. The face surfaces of the 1.0 gm IRA brick are die skin. Those of the other two brick are wire cut. Nominal dimensions are 4 inches wide by 2.25 inches high by 8 inches long. Each brick is from a different manufacturer and all are commercially available. Physical properties of the brick are given in **Table 1**. All values were determined in accordance with ASTM C 67 Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile, and are the average of five measurements. All brick met the requirements of ASTM C 216, Standard Specification for Facing Brick, Grade SW. All of the brick were very close to the dimensional tolerances for FBX brick. Brick with chips or cracks were not used to build test specimens. Although no quantitative measurements were made, the bed surface textures of the three bricks were visually rated. The 1.0 gm brick had the smoothest bed surface and the 15 gm brick the roughest.

Mortar - A total of seven different mortars were used, with cementitious materials comprising portland cement/lime, mortar cements, and masonry cement. Mortar Types included are S, N and O. Each mortar was mixed to the proportion specification of ASTM C 270, Standard Specification for Mortar for Unit Masonry. Types S and N mortar cements and masonry cements were used to prepare the respective mortars. Although mortar cement is not recognized by C 270, the same volumetric proportions in C 270 for masonry cements were used. Mortar properties were determined in accordance with ASTM C 270 and are given in **Table 2**.

The cementitious materials were purchased in bags. Each type of cementitious material is from a single manufacturer. Cementitious materials met the following standards:

portland cement	ASTM C 150, Type I
mortar cement	UBC 24-14, Types S and N
masonry cement	ASTM C 91, Types S and N
hydrated lime	ASTM C 207, Type S

Sand was blended to meet the gradation requirements of ASTM C 144, Standard Specification for Aggregate for Masonry Mortar. All mortar materials are commercially available.

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Water Penetration Walls, Ready For Test

FLEXURAL BOND STRENGTH

Specimens and Curing

All decisions in building the flexural bond strength specimens were made to reduce variables. A total of thirty joints was tested for each brick/mortar combination in order to provide better analytical results. All of the specimens were made by the same mason. Each mortar bed was spread 3/4 in. thick and compressed to 3/8 in. Each specimen contained only one joint to eliminate disturbance by subsequent brick laid on top. All mortar joints were flush cut. Each two brick-one joint specimen was enclosed in a plastic bag immediately after laying for a "self cure". A surcharge of one brick was placed on each brick/mortar combination. Specimens were cured for twenty eight days at laboratory temperatures.

Test Results

After twenty-eight days the single joint specimens were removed from the plastic bags and tested in accordance with ASTM C 1072, Standard Test Method for Measurement of Flexural Bond Strength. Results for each brick/mortar combination are given in **Table 3**.

Table 1. Brick Properties[1]

Initial Rate of Absorption gm/30 in^2/min	1.00	4.30	15.10
24 hr. Cold Water Absorption	0.80	3.8	6.0
5 hr. Boiling Water Absorption	0.80	5.7	7.9
Compressive Strength, psi	19,938	21,950	16,801
Density, lb/ft^3	147.6	143.4	135.7

[1]Average of five specimens

Table 2. Mortar Properties[1]

Cementitious Materials	Portland Cement/Lime			Mortar Cement		Masonry Cement	
Type	S	N	O	S	N	S	N
Flow							
Initial	110	110	108	114	115	113	115
Final	90.0	100	99.0	92.0	87.0	89.0	100
Water Retention, %	81.8	90.9	91.7	80.7	75.6	78.8	87.0
Cone Penetration, mm	56	57	58	53	51	53	64
Compressive Strength[2]							
28 Day psi	4248	2132	882	3220	3285	3157	1472
Air Content, %	1.5	1.1	1.4	8.7	9.3	13.8	15.8

[1]Average of three measurements
[2]Measured on 2" (50mm) cubes.

Discussion

With the 1.0 gm brick the anticipated trend of bond strength with mortar materials and Types was achieved. That is, the portland cement/lime and mortar cements gave nearly equivalent values for each mortar Type. Further, the masonry cement values were lower, approximately 83% for the Type S and 76% for the Type N of the corresponding values with portland cement/lime and mortar cement. For each mortar material, the bond strength decreased as mortar Type changed from S to N to O.

With the 4.3 gm brick there was near parity in bond strength with Types S and N mortars of different cementitious materials. The mortar cements provided bond strengths 10 to 20 percent higher than the equivalent portland cement/lime mortars. The Type N mortar cement gave the highest value in the program. The masonry cement mortars also performed well, exceeding or nearly equaling the portland cement/lime and mortar cements for all but the Type N mortar cement. Mortar cements reversed the trend of reduced bond when going from Type S to N.

With the 15 gm brick, the range in bond strength values with the different portland cement/lime mortar Types was the least of the three bricks. The highest value was achieved with the Type N mortar. The Type S mortar yielded uncharacteristically low bond strength.

With one exception, for each of the mortar materials and mortar Types there was an increase in bond strength as the brick IRA increased and as surface roughness increased. The only exception to this trend was with portland cement/lime Type S mortar. The 4.3 gm brick had a higher bond strength than the 15 gm brick. The bond value fell less than 7% with this transition. The difference in bond strength between the 1 gm brick and that of the 4.3 gm brick was consistently less for Type S mortars than it was for Type N mortars. Further, these differences were greater with mortar cements than with portland cement/lime mortars. Thus, portland cement/lime mortars gave more consistent values of bond strength. Bond strength with mortar cements and masonry cements is more dependent on properties of the brick.

Although mortar water retention was not selected as a variable in this program the mortars exhibited a wide range of water retention values. Comparing bond strength and mortar water retention provides interesting results. For low IRA bricks combined with portland cement / lime and mortar cements, the mortars of the same Type that have lower water retention result in higher bond strengths. Indeed, the mortar cement Type N that gave the highest bond strength had the lowest water retention. With the 15 gm brick the Type S portland cement/lime mortar that had an uncharacteristically low bond strength had the lowest water retention of portland cement/lime mortars.

Water Penetration Walls, Ready For Test

Table 3. Flexural Bond Strengths[1]

Brick IRA gm/30in²/min	Portland Cement/Lime S	Portland Cement/Lime N	Portland Cement/Lime O	Mortar Cement S	Mortar Cement N	Masonry Cement S	Masonry Cement N
1.00	92.40	80.96	65.03	94.18	82.17	77.42	61.94
4.30	109.0	105.4	80.47	120.7	127.2	122.0	104.6
15.1	101.4	115.1	94.0				

[1]Average of 30 joints (psi)

WATER PENETRATION RESISTANCE

Specimens and Curing

The brick/mortar combinations to be evaluated for water penetration resistance were based on the results of the flexural bond strength tests. The objective was to contrast the performance of the brick/mortar combinations within each cementitious materials type which gave the lowest and highest bond strength. The two low IRA brick were considered together when making the selection. Thus, the following brick/mortar combinations were selected for water penetration testing.

Water Penetration Specimen Matrix

Brick IRA gm/30in²	Portland Lime S	Portland Lime N	Portland Lime O	Mortar Cement S	Mortar Cement N	Masonry Cement S	Masonry Cement N
1.0			•		•		•
4.3	•				•	•	
15.1		•	•				

Three walls of each brick/mortar combination were constructed. The sets were built in a random order to avoid potential systematic errors which might have occurred if a particular order had been maintained. All walls were built by the same experienced mason employed by a local mason contractor. All walls of a particular brick/mortar combination were built on the same day. Mortar water content was adjusted to the mason's preference. The mason was instructed to lay full bed joints, with shallow furrowing permitted. The head joints were to be full. The walls were constructed by laying the bed joint along the 52 in. length of each wall, then buttering the end of the brick one at a time before setting it on the bed joint. The brick were laid to a line pulled across the three walls being built. The joints were struck flush. Mortar joints on the face exposed to the water source were tooled with a concave jointer after the top course was laid. A final tooling was done approximately 30 to 60 minutes later. Workmanship was judged to be excellent.

The walls were constructed in accordance with ASTM E 514, Water Permeance of Masonry, on inverted steel angles. Flashing was built into the wall to collect water which would pass completely through the wall. Each of the walls was enclosed in plastic sheeting for the first seven days after completion. Total curing time for the walls ranged from 35 to 42 days. The ambient temperature was maintained between 60 degrees F and 75 degrees F during fabrication and subsequent curing. The backs of the walls were whitewashed to aid in observing dampness.

Test Results

Water penetration resistance was measured in accordance with ASTM E 514. The brickwork exposed to the water flow of 3.4 gal/ft²/hr was 3 ft wide by 4 ft high. Each water chamber was pressurized to 10 psf.

Results of the water permeance tests are given in **Table 4**.

Discussion

The excellent performance of all low IRA brick and mortar combinations was observed. Given the disparity in bond strengths and the differences in cementitious materials, one would have expected more divergence in percentage of damp area and the presence of visible water. The high water penetration with the 15 gm brick and Type O mortar was not expected.

With the 1.0 gm brick, location of dampness corresponded to mortar joint locations. It is not an indication that voids in the head joints are sources of water leakage. The total area of the dampness was considerably less than the total mortar joint area. Mortar accounts for 18.1% of the wall area with the 1.0 gm brick, and 18.6% with the 14.3 gm brick. damp areas averaged only 3.3% and 7.3% respectively.

For the low IRA bricks there is no apparent relationship between time to first dampness and to the area of dampness, to the bond strength, to the brick IRA, nor to the mortar materials. It is interesting to note that as mortar Type changed from O to N to S the time to first dampness increased. This increase also held for the 15 gm brick.

Table 4 Water Permeance Results

Brick IRA gm/30 in²/min	1.0			4.3			15	
Mortar Type	portland cem/lime O	mortar cement N	masonry cement N	portland cem/lime S	mortar cement N	masonry cement S	portland cem/lime N	portland cem/line O
Time to first Dampness[1] min	30	60	35	210	30	60	15	10
Time to first visible water[1] min	none	none	none	none	none	none	30	15
% area of dampness[2] 4hr	5	2	3	8	7	7	90	100
Total water collected[2] 4 h, liter	none	none	none	none	none	none	.65	.50

[1]Minimum of three measurements
[2]Average of three measurements

There is no overall relationship between the percent area of dampness and bond strength. The percent area of dampness increased as IRA and other absorption properties of the brick increased. The percent area of dampness increased as brick density decreased. Within each brick type the area of dampness generally increased with decreasing bond strength and with increasing mortar water retention. Furthermore, for the low IRA brick the portland cement/lime mortars gave the highest area of dampness, although the difference was small.

Recommendation

For brick having IRA less than 5 gm, use mortars that have low water retention.

Definition of Water Retention

The ability of mortar to resist the loss of water to an absorptive masonry unit.

CONCLUSIONS

1. The flexural bond strength of masonry cement mortar changes more with brick IRA than that of portland cement/lime and mortar cement mortars.

2. Mortar cements develop flexural bond strengths equivalent to those of portland cement/lime mortars with low IRA brick.

3. Flexural bond strength of low IRA brick improves as mortar water retention decreases.

4. Flexural bond strengths of very low IRA brick can equal or exceed those of higher IRA brick with proper selection of materials and Types.

5. Water penetration resistance is not related to flexural bond strength.

6. Walls of low IRA brick can be built to have no water penetration.

7. For walls of uncored brick and excellent workmanship water penetration resistance is directly related to brick density and inversely related to brick absorptions.