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FLEXURAL TENSILE STRENGTH OF CONCRETE MASONRY CONSTRUCTED WITH TYPE S MASONRY CEMENT MORTAR

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ABSTRACT

This paper investigates the relationship between the flexural strength of concrete masonry walls and prisms constructed using masonry cement mortars. Results obtained in this study are compared to results from previous studies and conclusions are presented with respect to the potential flexural bond strength of concrete masonry constructed with masonry cement mortars.

The research included testing of concrete masonry specimens using Type S masonry cement mortars. Three different cement manufacturers supplied the masonry cements. Ten walls were constructed for each of the mortars using nominal 203x203x406-mm (8x8x16-in.) hollow concrete masonry units. Flexural strengths of wall walls were determined in accordance with ASTM E 72. A uniform transverse load was applied over the face of the wall specimens by pressurizing an air bag sandwiched between the wall and a rigid test frame.

Three companion two-unit, stacked-bond prisms were fabricated during the construction of each wall and were tested in flexure using a bond wrench apparatus. In addition, the flexural bond strength of each mortar in combination with standard concrete testing brick was determined. Six prisms, each containing five mortar joints, were fabricated using controlled fabrication and curing.

NCMA's Research and Development Laboratory manufactured the concrete brick used in the construction of prisms for the mortar evaluation on a single cavity block machine. The only aggregate used in the manufacture of the concrete brick was limestone screenings. The concrete brick were taken from the same lot of units used in the mortar evaluation testing in the 1994 NCMA research [Thomas, et. al., 1995]. The mix design, manufacturing process, and physical properties of the concrete brick are similar to those units used in the research described by Melander [Melander et. al., 1993]. A summary of the concrete brick properties is included in Table 3.

Table 2 - Concrete Masonry Unit Properties

Physical Property	Measured Value
Width, mm (in.)	193.5 (7.62)
Height, mm (in.)	193.8 (7.63)
Length, mm (in.)	396.2 (15.60)
Weight, kg (lb)	14.38 (31.71)
Minimum Face Shell Thickness, mm (in.)	33.8 (1.33)
Minimum End Flange Thickness, mm (in.)	51.6 (2.03)
Minimum Web Thickness, mm (in.)	25.9 (1.02)
Equivalent Web Thickness, mm/m (in./ft)	196.7 (2.36)
Equivalent Thickness, mm (in.)	101.1 (3.98
Net Area Compressive Strength, MPa (psi)	20.0 (2900)
Density, kg/m^3 (pcf)	1815 (113.3)
Absorption, kg/m^3 (pcf)	195 (12.2)
Percent Solid	52.2
Net Area, cm^2 (in^2.	401 (62.1)

Table 3 - Concrete Brick Properties

Physical Property (average of 3 units)						
Width, mm (in.)	Height, mm (in.)	Length, mm (in.)	Gross Area Compressive Strength, MPa (psi)	Density, kg/m^3 (pcf)	Absorption, kg/m^3 (pcf)	Initial Rate of Absorption[1], g/min/193 mm^2 (g/min/30 sq in.)
92.2 (3.63)	57.1 (2.25)	189.2 (7.45)	39.5 (5680)	2227 (139.0)	127 (7.9)	35 (35)

[1] Initial rate of absorption values listed in table based on an average of five units.

Each of the three different masonry cements used to complete the research met the requirements of ASTM C 91-93 for Type S masonry cement. A summary of the compressive strengths and air contents for each of the three masonry cements used in this research are included in Table 4.

Table 4 - Masonry Cement Properties in Accordance with ASTM C 91

Type S Masonry Cement	Mortar Flow, %	Unit Weight kg/m^3 (pcf)	Air Content, %	Water Retention, %	28-D Cube Compressive Strength, MPa (psi)
A	108	1922 (120.0)	17.1	81.5	18.3 (2650)
B	109	1932 (120.6)	16.4	86.2	21.0 (3040)
C	113	1940 (121.1)	15.2	84.1	22.0 (3190)

The mortars were proportioned in accordance with ASTM C 270-91a using one part of Type S masonry cement and 3 parts of sand by volume. Mortars used to construct walls and companion prisms were made with a masonry sand that met the gradation requirements of ASTM C 144-91. Water was added to the mortar during mixing at the discretion of the mason to produce a workable consistency. All mortar was mechanically mixed for 3 to 5 minutes and any mortar unused 1-1/2 hours after initial mixing was discarded. Retempering of the mortar was permitted once, but stiff or hard mortar due to hydration was not used.

Mortar batch sizes varied throughout the research based on the specimens to be constructed on each individual day. Mortar batches were typically sized to accommodate the construction of a single wall specimen and the three companion prisms associated with that wall.

The properties of each of the different masonry cement mortars (Type S masonry cement mortars A, B and C) were documented in accordance with ASTM C 270-91a, using the same constituents used in mixing the mortar for wall and companion prism specimen construction. Results of that testing are summarized in Table 5.

Table 5 - Mortar Properties in Accordance with ASTM C 270

Type S Masonry Cement Mortar	Mortar Flow %	Unit Weight kg/m^3 (pcf)	Air Content, %	Water Retention, %	28-D Cube Compressive Strength MPa (psi)
Mortar A	109	1864 (116.4)	17.6	84.4	14.5 (2110)
Mortar B	107	1852 (115.6)	17.1	86.9	19.6 (2840)
Mortar C	107	1944 (121.4)	11.1	84.1	17.1 (2480)

Mortars used to construct concrete brick prism specimens for the mortar evaluation were made using a 50/50 blend of standard graded and 20-30 Ottawa silica sand. A batch size of approximately 28 L (1 cu ft) supplied enough mortar for prism fabrication and mortar testing. Water was added to produce a flow of 125±5%.

CONSTRUCTION AND CURING OF TEST SPECIMENS

A journeyman mason, with more than 15 years experience in concrete masonry construction, constructed all test specimens using good construction techniques.

Wall Specimens

Wall specimens were constructed within an open polyethylene bag which was laid flat on a smooth, level concrete floor. All units used in the flexural wall test specimens were laid in face shell bedding with mortar joint thicknesses of 9 mm ± 3 mm (3/8 in. ± 1/8 in.). Units in each course were shoved tight against adjacent units to form head joints that were 9 mm ± 3 mm (3/8 in. ± 1/8 in.). All mortar joints were struck and tooled with a concave jointer after they were thumbprint hard. The units used in the construction of the walls were kept in laboratory air for a period of not less than 48 hours prior to construction. Half units used for the ends of the wall on even numbered courses were saw-cut at mid length from full-size units. The mason laid the first seven courses while standing on the floor of the laboratory. The final five courses were laid from a scaffold of 1.4 m (4 1/2 ft) in height. The overall dimensions of the wall specimens were 1.2 m (48 in.) in length and 2.4 m (96 in.) in height. A total of 30 full-size units and 12 half units were used for each wall specimen.

The specimens remained in laboratory air for a period of approximately 24 hours at which time each face of the specimen was sprayed with water until the surface was saturated to a point that water was observed to flow down the face of the specimen. Immediately after the specimen was sprayed, the bag in which the specimen was constructed was pulled up above the mid-height of the wall. Another polyethylene bag was then placed over the top of the wall and extended down below the mid-height of the wall such that the top and bottom bags overlapped by more than 15 cm (6 in.). The two bags were taped together to provide an airtight seal.

Prism Specimens

Companion prisms were constructed within an open polyethylene bag on a smooth, level concrete floor. The prisms were constructed in stack bond configuration, two units high, and with one face shell bedded mortar joint (identical to the flexural walls) at 9 mm ± 3 mm (3/8 in. ± 1/8 in.) thickness. All mortar joints were struck and tooled with a concave jointer after they were thumbprint hard.

After the mason had finished laying the seventh course (of 12 total courses) of a wall specimen, the three companion bond wrench prisms for that wall were constructed. The same care and workmanship used in constructing the walls was used in constructing the prisms.

Units used to construct the companion prisms were taken from the same pallet as those used to construct the corresponding walls. This insured that the moisture content of the units (and other properties of the units) used for the prisms was comparable at the time of fabrication to that of the units used in the construction of the flexural walls.

The prisms were also sprayed with water in a similar manner to walls approximately 24 hours after construction. Immediately after being sprayed, the companion prisms were placed into a large polyethylene bag on a wooden pallet. The bags were sealed to provide an airtight seal. Each bag held approximately 15 prisms.

Prism Specimens for Mortar Evaluation

Prism specimens for the mortar evaluation were constructed in accordance with Uniform Building Code Standard 21-20 [ICBO, 1994]. That procedure utilizes a jig, mortar template, and drop hammer to standardize fabrication of the specimens.

Immediately after construction, each prism was covered with a plastic bag, temporarily sealed to the working surface, and left in place for 24 ± 4 hours. The next day, each prism was removed from its jig, placed and sealed in the same plastic bag and moved to a storage area in the laboratory. The prisms were removed from the plastic bags 24 ± 4 hr prior to testing and remained in laboratory air until tested.

TEST PROCEDURES

Flexural wall testing was performed in accordance with Section 12 of ASTM E 72-80. A uniform transverse load was applied over the face of the wall specimens by pressurizing an air bag sandwiched between the wall and a rigid test frame (Figure 1). The uniform lateral load was incrementally increased until the maximum flexural resistance of the wall was achieved. Testing was terminated when a fracture occurred through a mortar joint, the face shell of a concrete unit, or a combination of the two, on the tension face of the wall.

Testing of the bond wrench prisms was performed in accordance with ASTM C 1072-86. Although this ASTM test method provides sample schematics of a bond wrench testing apparatus for testing concrete brick prisms, it does not include similar schematics for CMU prisms. For the purpose of this research, a bond wrench testing apparatus was developed to permit the testing of prisms made from concrete masonry units. The configuration of the bond wrench used is illustrated in Figure 2.

The concrete brick bond wrench prisms were tested in accordance with the procedures of ASTM C 1072-86.

TEST RESULTS AND OBSERVATIONS

Results of wall and companion prism tests are summarized in Table 6. All 30 wall specimens tested in this research failed in bond, i.e. a separation occurred on the tension face of the specimen at the interface between the mortar and the CMU. Of the 90 companion prisms constructed for this research, 84 failed in bond, 3 were block failures (a fracture occurred completely through the CMU while the mortar joint and the bond between the mortar joint and the CMU remained intact), and 3 failed prior to testing during handling.

Less variation was observed in the test results of the wall specimens in comparison to the results of the companion prisms. The coefficients of variation within each set of 10 walls were approximately half of the coefficients of variation observed in each set of 30 CMU bond wrench specimens.

Table 6 - Results of Wall and Companion Prism Tests

Results of Wall Tests			Results of Companion Prism Tests		
Wall Specimens	Avg. Mod. of Rupture KPa (psi)	COV[1] (%)	Prism Specimens	Avg. Mod. of Rupture MPa (psi)	COV[1] (%)
Walls 8S(A)-1..10	965 (140)	22	Prisms 8S(A)-1..30	910 (132)	42
Walls 8S(B)-1..10	590 (86)	18	Prisms 8S(B)-1..30	425 (62)	41
Walls 8S(C)-1..10	895 (130	28	Prisms 8S(C)-1..30	980 (142)	47

[1] COV = Coefficient of Variation

The results of the concrete brick prisms from the mortar evaluation phase of this research program are included in Table 7. The flexural tensile strengths of the concrete brick prisms do not correlate well with the CMU wall and prism strengths. This poor correlation is probably due

to differences in the mortar aggregate, methods of construction, methods of curing, and testing variables between those specimens constructed using CMU and those constructed using concrete brick.

The range in recorded bond strengths for the three different Type S masonry cement mortars used in this research (89 psi to 115 psi) is within the range of bond strengths reported by Melander [Melander, et. al, 1993] (54 psi to 166 psi) for Type S masonry cement mortar using concrete brick prisms. The greater variation in results from that study is probably due to the greater number of different masonry cements evaluated (16 versus 3).

Table 7 - Mortar Evaluation Prism Tests

Prism Specimens	Avg. Modulus of Rupture KPa (psi)	COV[1]
Prisms MCM(A)	790 (115)	17
Prisms MCM(B)	640 (93)	22
Prisms MCM(C)	615 (89)	27

[1] COV = Coefficient of Variation

CONCLUSIONS

Evaluation of Mortars

The average flexural tensile strength of concrete brick prisms reported by Melander [Melander, et. al, 1993], using 16 different Type S masonry cement mortars, was 765 KPa (111 psi), 12% greater than the 680 KPa (99 psi) average for the three mortars tested in this research program. If the 16 mortars from the previous research combined with the 3 mortars from this research are considered to be representative of the range of Type S masonry cement mortars available throughout the industry, resulting average flexural tensile strength for 19 mortars would equal 750 KPa (109 psi) and flexural strength values of the walls and CMU prisms tested in this research should be adjusted by 1.10 to yield representative values as shown in Table 8.

Table 8 - Relationship of Flexural Tensile Strengths of Mortar to Typical Mortars

Type S Masonry Cement Mortar Used in this Research				Typical Type S Masonry Cement Mortar Used Throughout the Industry {2}	Ratio of {2}/{1}
Mortar A	Mortar B	Mortar C	Average {1}		
795 KPa (115 psi)	640 KPa (93 psi)	615 KPa (89 psi)	680 KPa (99 psi)	750 KPa (109 psi)	1.10 1.10

Correlation of Wall and Prism Tests

Results of prism and wall tests are compared in Table 9. The average correlation factor between the modulus of rupture values of walls and prisms is 1.12 (wall MOR divided by prism MOR). It is recognized that this correlation factor is derived by comparing a single joint specimen to a multiple joint specimen. Because the correlation factor is only prescribed for

relating these two types of specimens, no additional statistical evaluation considering number of joints is necessary.

Table 9 - Correlation Factors for Wall and Prism Test Results

Results of Wall Tests		Results of Prism Tests		
Wall Specimens	Avg. MOR, KPa (psi)	Companion Prism Specimens	Avg. MOR, KPa (psi)	Wall MOR Divided By Prism MOR
Walls 8S(A)-1...10	965 (140)	Prisms 8S(A)-1...30	910 (132)	1.06
Walls 8S(B)-1...10	595 (86)	Prisms 8S(B)-1...30	425 (62)	1.39
Walls 8S(C)-1...10	895 (130)	Prisms 8S(C)-1...30	980 (142)	0.92
			Average	1.12

The 1994 NCMA research [Thomas et al, 1995] concluded that it is reasonable to compare CMU flexural bond wrench prism test results directly with flexural wall results. The ratio of wall to prism modulus of rupture values for specimens constructed using masonry cement mortars appears to support the conclusion from the 1994 NCMA research that CMU bond wrench testing and flexural wall testing of CMU specimens yield similar results.

Determining Allowable Stress Design Values for Flexural Tension

Nominal Flexural Tensile Strengths. Table 10 summarizes flexural tensile strengths determined in this research. These values provide the basis for developing recommended design values for flexural tension.

Table 10 - Summary of Test Results of Assemblages Constructed with Type S Masonry Cement Mortar

	CMU Wall Specimens		CMU Prism Specimens		Concrete Masonry	
Type S MC Mortar	Avg. MOR, KPa (psi) {1}	No. of Specimens {2}	Avg. MOR, KPa (psi) {3}	No. of Specimens {4}	Avg. MOR[1], KPa (psi) {5}	No. of Specimens[2] {6}
Mortar A	965 (140)	10	910 (132)	28	925 (134)	38
Mortar B	595 (86)	10	425 (62)	30	470 (68)	40
Mortar C	895 (130)	10	980 (142)	29	960 (139)	39
Average	820 (119)	---	770 (112)	---	785 (114)	---

[1] These modulus of rupture values are a combined average of all concrete masonry flexural test specimens tested in this research, with walls and prism individual test values weighted evenly:

$$\{5\} = [\{1\}\{2\} + \{3\}\{4\}] / [\{2\} + \{4\}]$$

[2] The total number of prism and wall specimens tested in this research: $\{6\} = \{2\} + \{4\}$

As shown in Table 10, the average flexural tensile strength of all CMU specimens tested in this research program was 785 KPa (114 psi). This value should be adjusted to account for

Table 12 - Allowable Flexural Tensile Stresses Recommended for Concrete Masonry, KPa (psi)

Masonry Type: Normal to Bed Joints. Hollow Units. Ungrouted Construction					
Masonry Cement Mortar Type	Nominal Width of Wall, mm (in.)				
	102 (4)	152 (6)	203 (8)	254 (10)	305 (12)
M or S	455 (66)	370 (54)	290 (42)	290 (42)	290 (42)
N	280 (41)	235 (34)	180 (26)	180 (26)	180 (26)

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