11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009

BOND PERFORMANCE OF CONVENTIONAL AND HIGH PERFORMANCE FIBER-REINFORCED MORTARS

R. Gupta[1], S. Brzev[2], and W. McEwen[3]
[1] Faculty, Department of Civil Engineering, British Columbia Institute of Technology, Burnaby, BC, V5G 3H2, Canada, rishi_gupta@bcit.ca
[2] Faculty, Department of Civil Engineering, British Columbia Institute of Technology, Burnaby, BC, V5G 3H2, Canada, sbrzev@bcit.ca
[3] Executive Director, Masonry Institute of British Columbia, Vancouver, B.C. V5M 1M3, Canada
info@masonrybc.org

ABSTRACT
Bond development is key to the strength and durability of masonry structures and components. Various mortar types, with or without the inclusion of additives and admixtures, are currently being used in the industry. A recent study examined the performance of conventional and fiber-reinforced mortars. Their flow, compressive strength, air content and flexural bond strength were measured. The tests on five different conventional mortars indicated that for the various mortar types investigated, Type S mortars provided higher bond strength than Type N mortars. The results suggest that the higher cement content and lower air content resulted in higher flexural bond strength.

Fiber reinforcement is widely used to produce more durable cement-based concrete mixes. However, the use of fibers is not common in masonry mortars, and their affect on bond is not completely understood. A testing program showed that the addition of 0.3% by volume of two types of synthetic fibers, macro and micro, increased the bond strength by at least 44% for hollow brick specimens, and by 23% for solid specimens. While full scale construction trials have not examined the practicality of mixing and applying fiber-reinforced mortars, the laboratory program showed that micro fibers were superior to macro fibers for mortar bond.

KEYWORDS: mortar, brick, bond, fiber reinforcement

INTRODUCTION
Bond is an important property of mortar since it affects both the strength and serviceability of the finished masonry construction. Mortar should have sufficient bond to ensure water tightness, accommodate wall movements, and resist tensile stresses due to applied loads. Methods for determining the bond strength are well established by ASTM standards (e.g. bond wrench testing, four-point flexural tests-ASTM E 518, etc.), however the nature of bond mechanism and the parameters affecting bond strength, including the type of mortar and its properties, are not completely understood.

Among conventional mortars, Type N mortar has historically been used for masonry veneer construction. In some markets, Type S mortar used for structural masonry is also being used for veneer construction.

Although conventional mortars have historically showed good performance, an addition of new components is expected to improve mortar properties. The addition of fiber reinforcement to cement-based materials is known to improve their durability. Fibers are effectively used to control plastic shrinkage cracking and drying shrinkage cracking in concrete structures, and their presence has an effect of lowering the permeability of concrete and thus reducing bleeding of water. Depending on fiber type, fiber reinforcement is also expected to improve mechanical performance, deformability, toughness, impact resistance and fatigue endurance of cement-based materials. The presence of fibers in masonry mortars is expected to be beneficial for reducing both the length and the width of shrinkage-induced cracks [1-4].

The main objective of this study was to improve the understanding of the flexural bond mechanism in brick masonry, and the key parameters that affect bond strength. The study was divided into two phases: Phase I, focused on the conventional mortars, while Phase II focused on fiber-reinforced mortars. In Phase I, five different conventional Type S and N mortar mixes were tested. Type S and N mortars are the two types used in most new construction of structural and veneer masonry in North America and further details can be found in CSA A179. The five mixes had the following variables: pre-bagged or mason-mixed mortars, and mixes using cement-lime or mortar cement. In Phase II, another series of tests was conducted, in which conventional mortar was modified by adding randomly distributed fibers. It should be noted that since the two phases were conducted at different times, a direct comparison of the results is not possible. The key results of both phases are discussed in this paper. In addition to the bond wrench and compression tests that were used to determine mechanical properties of hardened mortars, flow tests were also conducted to evaluate and control the workability of the mortars during mixing. A specialty test to evaluate the tensile strength and toughness was conducted for mixes containing fibers. However, its discussion is omitted due to the limited scope of this paper.

MATERIALS AND MORTAR TYPES

Masonry Sand: Masonry sand was used in a damp condition for this study. Two separate batches of sand were used for each phase. These sands were used to prepare all the samples except for the pre-bagged mortar CN1. The moisture content of the sand was measured, and a sieve analysis was conducted to check the gradation in accordance with CSA A179-04. [5].

Bricks: Both cored and solid clay brick units were used in this study. Brick units for Phase I and Phase II testing were the same colour mix from the same manufacturer. They had nominal dimensions of 194 mm length x 92 mm width (7 5/8” x 3 5/8”). Unit heights were 57 mm (2 ¼”) in Phase I and 66 mm (2 ½”) in Phase II. The cored units had three 38 mm (1 ½”) diameter cores. A typical cored brick used in the study is shown in Figure 1.

a)

b)

Figure 1: Sample components: a) a typical cored brick, and b) a typical prism used for the bond wrench testing

Cement & Lime: Type GU regular Portland cement, Type S mortar cement, Type S masonry cement, and Type S hydrated lime were used for preparing all laboratory-mixed mortars. Mortar cements and Masonry cements are similar products that contain cement and other materials that are designed to replace site proportioning of regular cement and lime. Mortar made with mortar cement has a lower air content limit of 12%, compared to the masonry cement limit of 18%.

Fibers: Two types of synthetic (polypropylene) fibers were used in Phase II testing: micro fiber (Fibermesh 150) and macro fiber (Fibermesh 300), as shown in Figure 2. The micro fiber contained multi-dimensioned fibers ranging from about 7 mm (0.27”) to 20 mm (0.78”), with a denier of 20. The macro fiber (also multi-dimensioned) contained fibers ranging from about 15 mm (0.59”) to 20 mm (0.78”), and had a much higher denier of 2600. A typical dosage of 0.3% of the total volume of a mortar batch was selected for both fibers, and all the test results were compared to the control mortar. The specific gravity and mechanical properties of these and some other comparable fibers are reported by Gupta [6].

a)

b)

Figure 2: Synthetic fibers used in mortars: a) close-up of micro fibers, and b) macro fibers being added to the mix

Mortar Types: The different types of mortar mixes used in this study are summarized in Table 1. Amongst the conventional mortar types studied in Phase I, one was pre-bagged (factory mixed with dry sand). Two mortar types were laboratory mixed using Type S mortar and masonry cements. Mortar mix CN4 and control mix CT were prepared from scratch using cement/lime proportioning in accordance with CSA A179-04 [5]. For phase II, a mortar cement control mix CT2 was used for comparison with fiber-reinforced mixes FR1 and FR2. Initially, a proportion of 0.55:1:3 (Water:Cement:Sand) was used, but the mixes were later adjusted to attain a flow of 180±20 mm (7±0.8”). The final proportions are summarized in Table 1. Note that additional water was required for mixes FR1 and FR2 to overcome the resistance provided by the fibers during mixing.

Table 1: Mortar Types and Mix Proportions

Phase	Mix Designation	Type	Components	Mixing	Water : Cement : Sand
I	CN1	Conventional	Type S pre-bagged mortar with sand	Factory	0.34 : 1 : 0[1]
	CN2		Type S masonry cement	Laboratory	0.70 : 1 : 3
	CN3		Type S mortar cement		0.74 : 1 : 3
	CN4		Type N mortar made with Type 10 cement and lime	Laboratory	1.14 : 1 : 0.5 : 4.5[2]
	CT	Control, Phase I	Type S mortar made with Type 10 cement and lime		1.7 : 1 : 1 : 6[2]
II	CT2	Control, Phase II	Type S mortar cement	Laboratory	0.71 : 1 : 3
	FR1	Fiber-Reinforced	Addition of 0.3% by volume of fiber type Fibermesh 150.		0.77 : 1 : 3
	FR2		Addition of 0.3% by volume of fiber type Fibermesh 300.		0.80 : 1 : 3

[1] Sand included in pre-bagged mortar, [2] Water:Cement:Lime:Sand.

MIXING, SPECIMEN PREPARATION, AND TEST SET-UP

The mortar mixes were prepared using a bucket and a drill-driven mixing paddle as seen in Figure 3.

Flow and Compressive Strength: Flow was measured in accordance with ASTM Standard C 1437-01 [7], and the test values are reported in the next section. Figure 4 shows the flow test process.

Figure 3: Mixing process in laboratory

Figure 4: Mortar flow testing in progress

a) b)

Figure 5: Mortar cubes: a) casting cubes in a mould, and b) compression testing

Mortar cubes were cast for the compressive strength testing according to ASTM Standard C 109 [8]. A minimum of three cubes were prepared for each mortar type and the tests were conducted after 28 days. A Tinius Olsen compression testing machine was used to apply load to the mortar cubes until failure according to ASTM C 109 [8].

Bond Wrench Set-up: The prisms were constructed in compliance with ASTM C 1072-05a [9], by laying four bricks with three mortar joints, and then stacking two additional bricks on top to simulate the weight of a five-joint prism. A minimum of three specimens were prepared for each mortar type; resulting in testing of a minimum of 18 joints for each mortar type. Fibers were expected to improve the bonding and interlock between bricks (especially in cored bricks), hence for the mixes containing fibers, both solid and cored bricks were used. Specimens were covered with plastic sheets during the 28 day curing period. Before testing, the frame was levelled, and the brick specimens carefully aligned in the clamping brackets. Figure 6 shows the bond wrench testing frame built according to ASTM Standard C 1072 – 05a [9]. The load was applied using a hydraulic pump. For Phase II, the set-up was modified to include a load cell and a digital display.

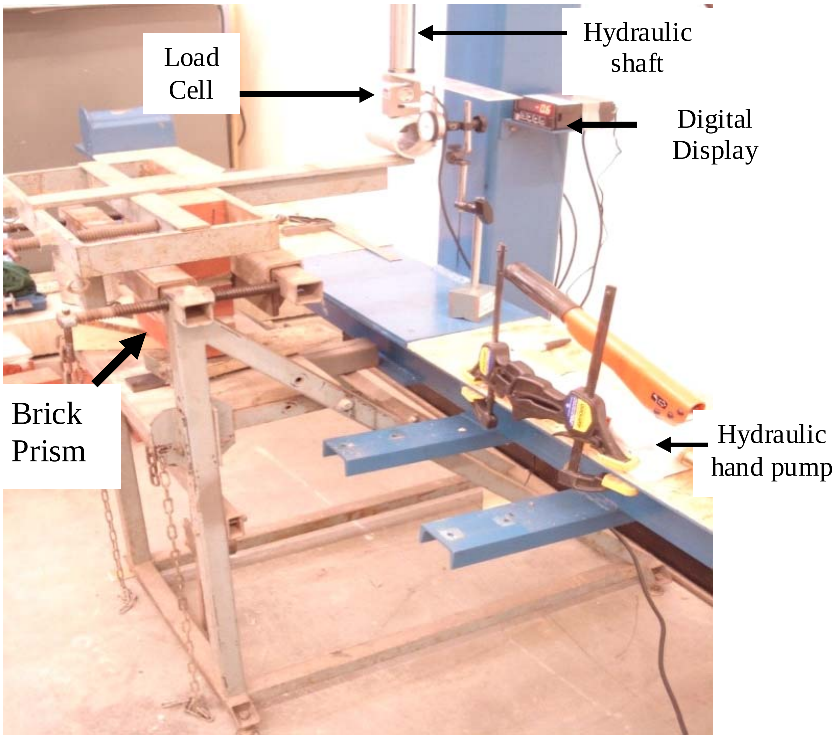

Figure 6: Specimen being tested in the testing frame

RESULTS AND DISCUSSION

Fresh Mortar Properties: The flow values for different mixes are presented in Table 2. For Phase I, the flow was between 181 mm (7.12") for mix CN2 and 202 mm (7.95") for mix CN3. For Phase II, the water content was adjusted to have a flow within a range of 190±5mm (7.48±0.19").

Hardened Mortar Properties: The average compressive strength values are presented in Table 2 and Figure 7. For the conventional mortar types, mix CN1 and the control mix CT had compressive strengths of more than 15 MPa (2175 psi), while the other three mixes had compressive strengths between 10.4 MPa (1508 psi) and 12.1 MPa (1755 psi). For the mixes tested during Phase II, the compressive strength ranged from 7.7 MPa (1116 psi) to 8.5 MPa (1232 psi). Even though mixes FR1 and FR2 (containing fibers) had higher water content than the control mix, their compressive strengths were similar to the control mix CT2 (8.2 MPa or 1189 psi). For the bond wrench test, the load values at which each joint failed were recorded and the flexural bond strength values were calculated using Equation 1 (Cl.8.1, ASTM C 1072-05a), as follows

$$F_g = \frac{6(PL + P_l L_l)}{bd^2} - \frac{(P + P_l)}{bd} \quad (1)$$

where F_g is the gross area flexural tensile strength (MPa); P is the maximum applied load (N); P_l is the weight of the loading arm (N); L is the distance from centre of prism to loading point (mm); L_l is the distance from centre of prism to centroid of loading arm (mm); b is the cross-sectional width of the mortar-bedded area, measured perpendicular to the loading arm of the upper clamping bracket (mm); and d is the cross-sectional depth of the mortar-bedded area, measured parallel to the loading arm of the upper clamping bracket (mm).

Test values were averaged and any major anomalies were excluded. As is generally the case with bond wrench tests, a high standard deviation was recorded (see Table 2). The average compressive strength and bond strength values for all mortar mixes are graphically presented in Figure 7.

Table 2: Compressive Strength and Flexural Bond Strength Values

Phase	Mix Designation	Flow Values in (mm)	Compressive Strength (MPa)	Flexural Bond Strength (Standard Deviation) (MPa)	
				Solid Bricks	Cored Bricks
I	CN1	191	17.0		0.60 (0.38)*
	CN2	181	11.4		0.87 (0.85)
	CN3	202	12.1		1.32 (0.64)
	CN4	187	10.4		1.76 (1.05)
	CT (control)	191	15.8		2.68 (1.78)
II	CT2 (control)	187	8.2	0.48 (0.17)	0.25 (0.06)
	FR1	190	7.7	0.59 (0.15)	0.4 (0.13)
	FR2	190	8.1	0.74 (0.06)	0.36 (0.15)

*- the procedure for solid masonry units was followed, since it was determined that the ratio of net and gross area is 81%, thus the units can be treated as solid per Cl.8.1 of ASTM C 1072-05. For converting values in the table to imperial, use: 1 MPa = 145 psi and 1 mm = 0.0393”

The following comments can be based on these test results:

1. For all the mortar mixes, no direct correlation was observed between compressive strength and flexural bond strength, as shown in Figure 7.
2. Cement-lime mortars exhibited higher flexural bond strength than mortar cement/masonry cement mortars, as evidenced by the higher average bond strengths of CN4 and CT mortars compared to CN1, CN2 and CN3 mortars tested in Phase I.
3. Type S mortar provided higher initial flexural bond strength than Type N mortar, as evidenced by the higher average bond strength of CT mortar compared to CN4 mortar tested in Phase I. Based on the results of this study, Type S mortars adhere better to brick units then Type N mortars, likely due to their higher cement content. This finding contradicts the view of some that lime enhances flexural bond strength, whereas cement only enhances its compressive strength.

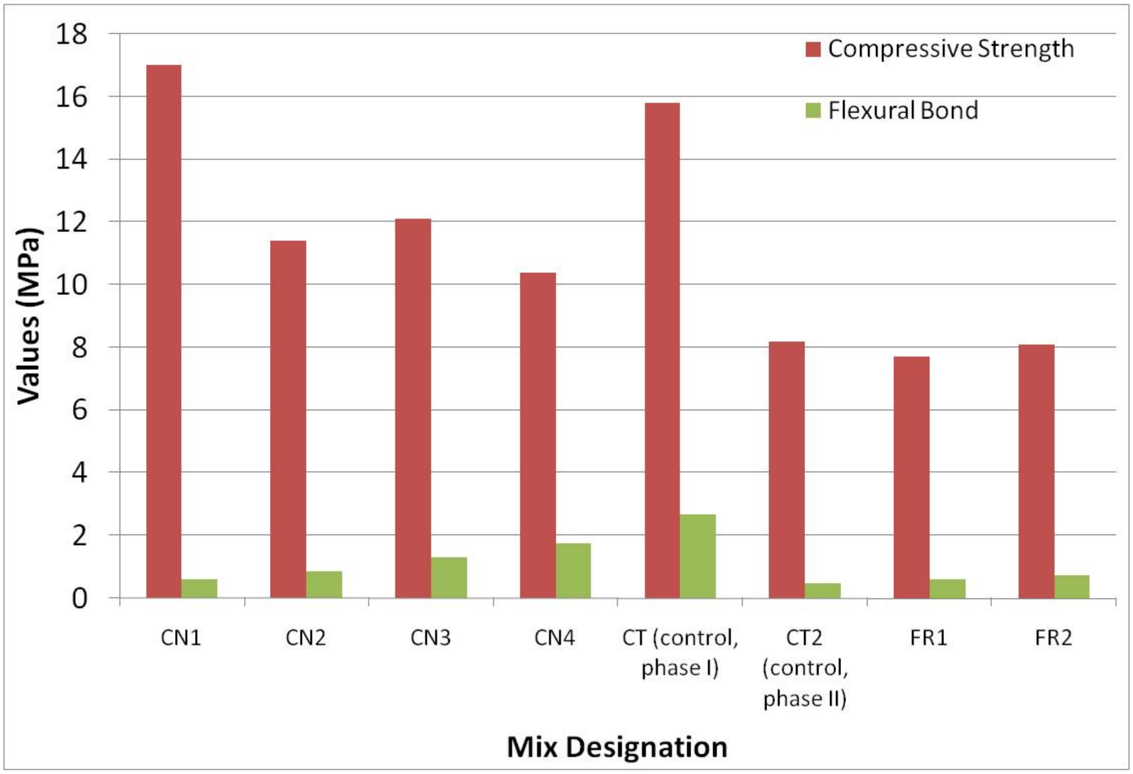

Figure 7: Compressive strength and flexural bond strengths for all mixes

4. Phase I test results show that a decrease in air content is accompanied by an increase in flexural bond strength (see Figure 8).

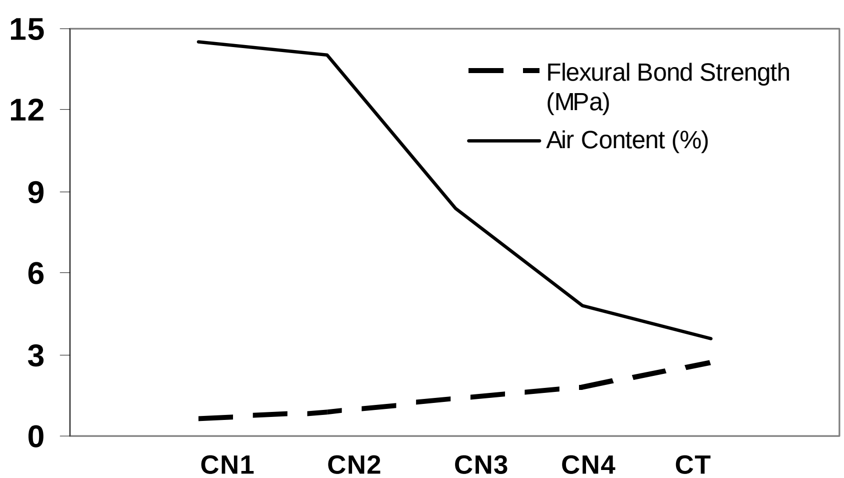

Figure 8: Flexural bond strength versus air content for the Phase I mortar mixes

5. The effect of fiber content on the flexural bond strength of both cored and solid brick specimens compared to the control specimens is shown in Figure 9. In most cored specimens, the cores appeared to be not completely filled with mortar, and there was no

evidence of mechanical bonding. This resulted in lower bond strength values when compared to the solid brick specimens. Note that reported bond strength values for cored bricks are lower bound values as calculation of bond strength based on net area will be much higher. However, for both solid and cored units, addition of fibers resulted in a definite increase in bond strength when compared to their respective control specimens. Micro fibers increased the bond strength by 23% and 60% for solid and hollow brick specimens respectively. Similarly, an increase of 54% and 44% was observed for solid and hollow brick specimens respectively when macro fibers were added.

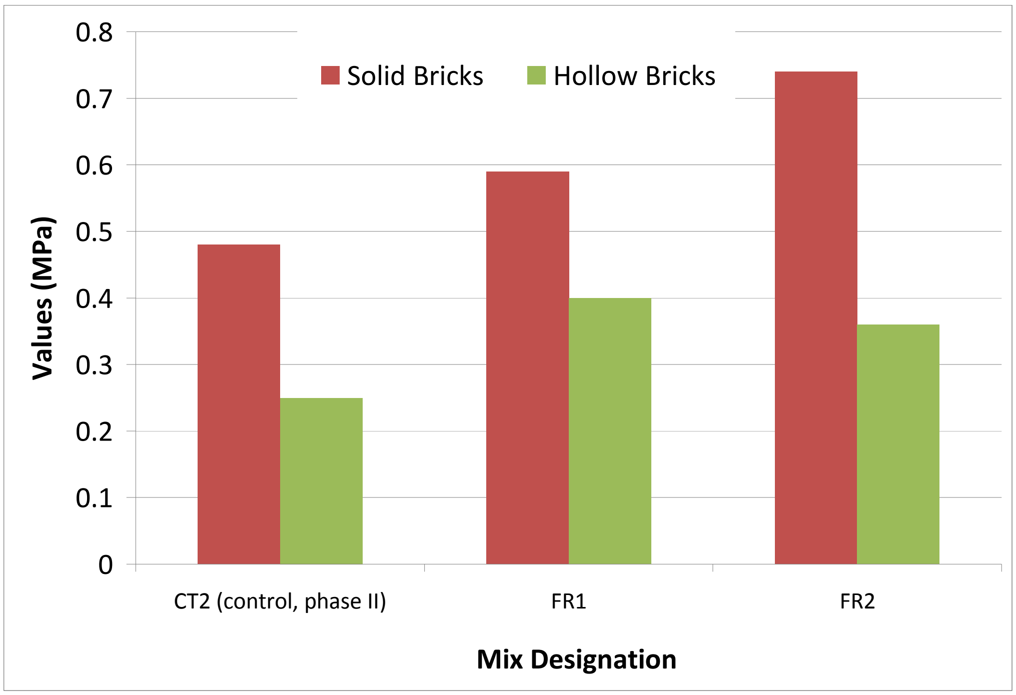

Figure 9: Comparison of flexural bond strength for fiber reinforced mixes

CONCLUSIONS

Based on flexural bond strength data from Phase I of this study, Type S cement-lime mortar appears to provide higher bond strength than Type N cement-lime mortar, and the Type S mixes using mortar cement and masonry cement. The results also suggest that higher cement content results in higher flexural bond strength, and that a decrease in air content is accompanied by an increase in the flexural bond strength.

Phase II results show that even though a higher amount of water was added in the mixes containing fibers (to attain a similar flow), their compressive strength was comparable to the control mix. This higher flow may also have had a positive effect on bond strength. Fiber-reinforced mortars with 0.3% volume of synthetic fibers had at least 44% and 23% higher bond strength in hollow and solid specimens respectively (when compared to control mix corresponding to conventional mortar). For practical construction reasons, the use of micro fibers is recommended for further field study.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the BCIT students Foaad Soleymany, Amin Hassanshahi, and Michael Meslin, who performed the testing discussed in this paper. The authors greatly appreciate the assistance and support throughout the course of this study provided by Rocky Pantiluk of Basalite Concrete Products, J.P. LeBerg of the Masonry Institute of British Columbia, and Ken Zeleschuk of the BCIT Department of Civil Engineering.

REFERENCES

1. Banthia, N., Azzabi, M. and Pigeon, M. (1993) "Restrained Shrinkage Cracking in Fiber Reinforced Cementitious Composites", *Materials and Structures*, RILEM (Paris), 26 (161), 405-413.
2. Bloom, R. and Bentur, A. (1995) "Free and Restrained Shrinkage of Normal and High Strength Concrete", *ACI Materials Journal*, 92 (2), 211-217.
3. Grzybowski, M. and Shah, S.P. (1990) "Shrinkage Cracking of Fiber Reinforced Concrete", *ACI Materials Journal*, 87 (2), 138-148.
4. Khajuria, A. and Balaguru, P. (1992) "Plastic Shrinkage Characteristics of Fiber Reinforced Cement Composites", *Fiber Reinforced Cement and Concrete* (Ed. R.N. Swamy), E&FN Spon, London, 82-90.
5. CSA A179-04. (2004) "Mortar and Grout for Unit Masonry", Canadian Standards Association, Mississauga, ON, Canada.
6. Gupta, R. (2008) "Development, application and early-age monitoring of fiber-reinforced 'crack-free' cement-based overlays", Doctoral thesis submitted at the University of British Columbia, Vancouver, Canada.
7. ASTM C1437-01. (2001) "Standard Test Method for Flow of Hydraulic Cement Mortar", ASTM International. West Conshohocken, PA, USA.
8. ASTM C109/C109M-02. (2002) "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars", ASTM International. West Conshohocken, PA, USA.
9. ASTM C 1072-05a, (2005) "Standard Test Method for Measurement of Masonry Flexural Bond Strength", ASTM International, West Conshohocken, PA.