GROUT STRENGTH MEASURED USING NON-ABSORBENT MOULD SPECIMENS AND CORES SAW-CUT FROM MASONRY PRISMS

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ABSTRACT
The Canadian standard CSA A179-04, Mortar and Grout for Unit Masonry, specifies the use of non-absorbent cylinder moulds for sampling and testing grout used in grouted masonry construction. Research has shown that the water absorption provided by the concrete masonry units reduces the water content of the grout, resulting in an increase in the compressive strength of in-situ grout relative to the strength obtained from testing specimens cast in non-absorbent moulds. The Canadian standard CSA S304.1-04, Design of Masonry Structures, suggests a ratio of 1.5 between in-situ grout compressive strength and compressive strength values obtained from testing grout cast in non-absorbent cylinder moulds.

In this investigation, a series of fully grouted, 3-course high, running bond, 190 mm masonry prisms were constructed in the University of Alberta's structural laboratory using grout having 28-day compressive strength values varying from 10 MPa to 22 MPa and concrete masonry units with nominal strength values ranging from 15 MPa to 40 MPa. Grout cylinders having the dimensions of 100 mm diameter by 200 mm height were cast during prism construction as per CSA A179-04 and allowed to cure for a minimum of 28 days. The compressive strength of the in-situ grout was determined by cutting 75x75x150 mm prismatic cores from both tested and untested grouted masonry prisms air cured for a minimum of 28 days. In-situ strength values were subsequently compared to the strength of companion non-absorbent mould cylinder specimens. Prismatic cores saw-cut from the grouted prisms were tested in compression following a procedure similar to the one outlined in ASTM C1019 for block-moulded specimens. The test results suggest a narrow range (1.43–1.68) for the ratio between the in-situ and non-absorbent cylinder grout strengths, with a strong correlation between the 24-hour water absorption of the concrete masonry units receiving the grout and in-situ grout compressive strength.

KEYWORDS: grout strength, grouted masonry, compressive strength, non-absorbent molds, testing method

INTRODUCTION

Grout requires high slump for workability and flow to ensure that the cells of a concrete masonry element are fully filled where required. Consequently, grout will contain more water than is needed for complete hydration of the cement [1]. As the grout cures, the excess water can create capillary voids which results in a comparatively lower grout strength [2]. Drysdale and Hamid [3] suggested that the proportion specifications for grout given in the Canadian standard CSA A179 [4] should give cylinder compressive strengths between 7 MPa and 17 MPa when mixed to a suitable flow and sampled and tested in a non-absorbent mould.

Concrete mix design fundamentals suggest that the absorption of water from the grout by the concrete masonry units will lower the water/cement ratio and increase the in-situ grout strength relative to the moulded cylinder specimens. ASTM C1019 [5] provides methods for testing grout specimens moulded using concrete masonry units. This procedure is intended to replicate the water absorption that occurs within the cores of concrete masonry units, and results in a compressive strength 50% greater than the strength of grout cast in non-absorbent moulds [3]. This is also the strength ratio stated in Clause 12.4.1.2 of the Canadian masonry design standard CSA S304.1-04 [6].

Past research [7, 8, 9, and 10] shows a wide range for the ratio of in-situ to non-absorbent cylinder grout strength, varying from 1.15–2.29, with in-situ grout strength consistently higher than that of companion cylinder specimens. Of these investigations, only the Ocean Technical Report [7] specifically sought to establish this factor as the research focus.

Research by Hedstrom and Hogan [11] on grout specimens saw-cut from masonry prisms not subjected to compression loading showed that concrete masonry units with a water absorption rate of 5.38% and 11.25% yield approximately the same in-situ grout strength. Saw-cut specimens showed only a 10% increase in strength over those specimens tested using ASTM C1019. This served to validate the ASTM C1019 test strengths with in-situ strengths, however, the height to thickness ratio was not controlled between these two different types of specimens, and this may have contributed to the reported small difference.

Yao and Nathan [12] reported grout strength ratios below 1.5 when comparing grout cores saw-cut from failed prisms to grout specimens cast in non-absorbent cylinders. It was concluded that the standard cylinder test is useful as a reference parameter. However, the strength of in-situ grout is stronger than the cylinder specimens, supporting the theory that in-situ grout compressive strength is higher due to water absorption.

This study examines the effect of water absorption and compressive strength of concrete masonry units on the strength of in-situ grout using specimens saw-cut from masonry prisms. Factors that may affect the relationships include the height at which the grout specimens are saw-cut from the masonry prisms, the moisture content of the concrete masonry units at the time of grouting, specimen capping type, specimen curing, and the range of grout slump and strength.

EXPERIMENTAL PROGRAM

Three-unit high fully grouted 190 mm concrete masonry unit prisms were built by qualified masons using type S mortar and a range of unit and grout strengths. The prisms were constructed

using the procedures outlined in Annex D of CSA S304.1-04, and air cured in the laboratory for a minimum of 28 days before grout cores were saw-cut. These prisms were part of a larger study at the University of Alberta that examined the unit strength method used in CSA S304.1-04. Table 1 identifies the nominal unit strengths, specified unit strengths, grout type, and number of prisms and grout specimens used in this study.

Table 1: Summary of Prism Construction and Grout Specimens

Nominal Unit Strength (MPa)	Specified Unit Strength (MPa)	Grout Type	Construction	No. of Prisms	No. of Grout Cylinders	No. of Grout Cores
15	22.34	Coarse, bag mix	Running bond using type S mortar	5	6	5
20	25.76	Coarse, ready-mix		5	6	5
30	39.41			5		5
40	51.35			5		5

The 24 hour water absorption and the compressive strength of the nominal 15, 20, 30, and 40 MPa concrete masonry units were determined in accordance with ASTM C140 [13]. For each nominal unit strength, the compressive strength was measured by testing five masonry units capped with sulphur in a 6600 KN MTS universal test machine. The water absorption was determined by comparing the saturated mass of three masonry units after 24 hour submersion in water to their mass after 24 hour of oven-drying at 100 ^{0}C.

During grouting of the prisms, and for each grout mix, six grout specimens were sampled and moulded in accordance with CSA A179 using non-absorbent cylinder moulds measuring 100 mm in diameter and 200 mm in height. Initial curing of grout specimens was as per CSA A179. Subsequently, the grout specimens were air cured until the age of 28 days in the laboratory prior to testing. The slump of the grout mixes varied from 170 mm to 220 mm.

Prismatic grout cores were saw-cut from both compression-tested and untested masonry prisms by manually breaking open the concrete masonry units, exposing the grout, and by subsequently cutting using a masonry saw. Cores were selected from the middle and upper courses of the masonry prisms to minimize the likelihood of mortar intrusions inside the grout core, and were inspected for any visible signs of damage before and after cutting. Grout cores from the tested prisms were cut from areas that exhibited no external signs of damage. A summary of the test program is given in Table 2.

Table 2: Summary of the Test Program

Property	Unit Compressive Strength	Unit Water Absorption	Grout Compressive Strength	
			Non-Absorbent Mould Specimens	In-Situ Prismatic Cores
Sampling Method	NA*	NA*	CSA A179	ASTM C1019
Test Method	ASTM C140	ASTM C140	ASTM C39	ASTM C39
No. of Specimens	5	3	6	5

* Not applicable

All grout cores were end-ground before tested in accordance with ASTM C39 [14] using a Forney FX 500 compression test machine, as shown in Figure 1. Grout core sizes were

maintained at 75x75x150 mm ±3 mm to follow the dimensions used for in-situ grout testing as per ASTM C1019, and to maintain the 2:1 height-to-thickness ratio of grout cylinders. Yi et al [15] found that the difference in compressive strength between a 100 mm by 200 mm cylinder and a 75x75x150 mm prism was less than 1% for identical concrete mixes, suggesting that a direct comparison between the two is valid. Schematics for both grout cylinders and prismatic cores are shown in Figure 2.

Figure 1: Test set-up for a Typical Prismatic Grout Core

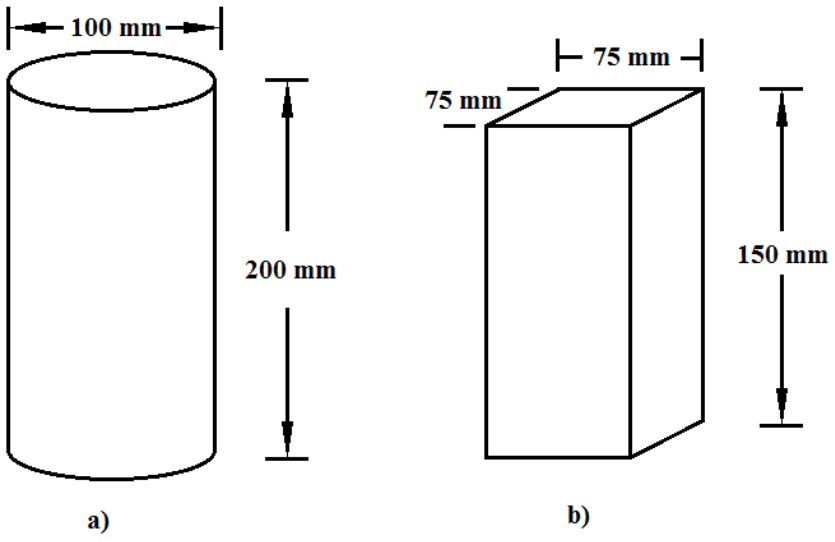

Figure 2: Dimensions of the a) Grout Cylinder Specimens and b) Prismatic Grout Cores

RESULTS AND DISCUSSION

A summary of the water absorption and compressive strength test results for the various concrete masonry units is given in Table 3. Except for the 15 MPa units, all concrete masonry units met CSA A165 limit on maximum water absorption. The concrete masonry units had significantly higher specified strengths than designated by the producer, and the range of water absorption values was found to be similar to that of previous research [e.g. 11]. A strong correlation was found between the 24 hour water absorption values and the specified compressive strength of the masonry units calculated in accordance with CSA S304.1-04 as shown in Figure 3.

Table 3: Test Results for Concrete Masonry Units

Unit Strength (MPa)	24 hour Water Absorption			Unit Compressive Strength (MPa)		
	Average (kg/m^3)	Average (%)	COV (%)	Average	COV (%)	Specified
15	248.0	14.11	1.06	26.72	3.13	22.34
20	195.1	10.59	2.70	33.00	13.38	25.76
30	161.8	7.95	5.82	47.14	2.14	39.41
40	122.5	5.76	7.33	53.79	7.57	51.35

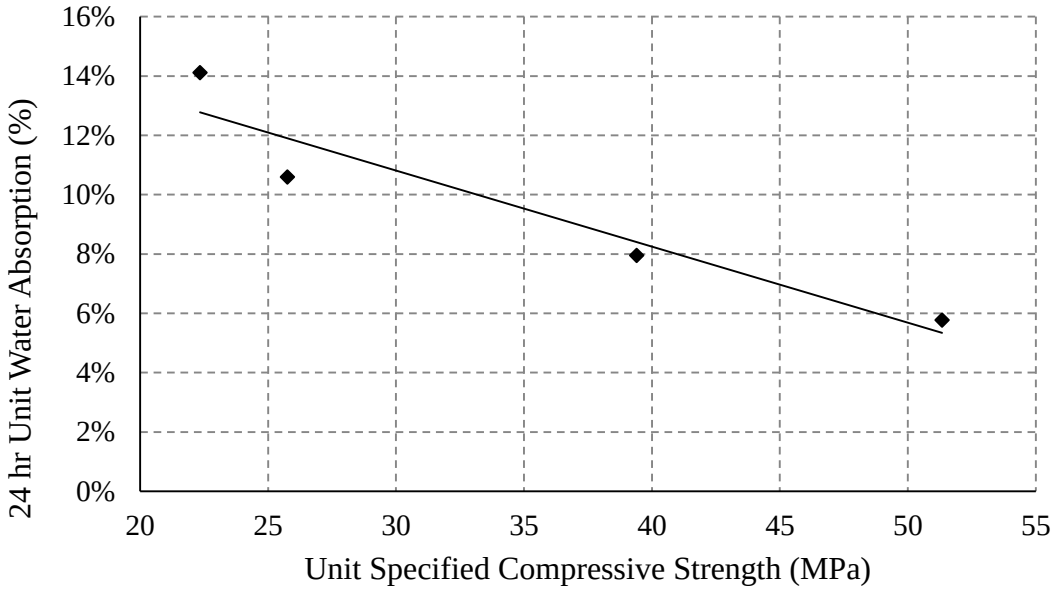

Figure 3: Water Absorption versus Concrete Masonry Unit Compressive Strength

The results show a strong linear trend where increased unit strength correlates with lower water absorption. This is anticipated because concrete masonry units with higher compressive strength tend to require a higher cement content and greater compaction during manufacturing for the same aggregate type. These will typically result in lower porosity and water absorption [3].

Table 4 provides a summary of the compressive strength test results for grout cast in non-absorbent cylinders. Both grout mixes had relatively high slump values resulting in compressive strengths lower than the strengths claimed by the suppliers. Table 5 gives a summary of the compression test results for the prismatic grout cores saw-cut from untested masonry prisms. As noted in Table 1, five (5) grout cores were tested for each nominal unit strength. The reported

grout strength ratio was computed as the average compressive strength of the grout cores divided by the average compressive strength of the grout cylinders.

The grout strength ratio of core-to-cylinder is plotted against the water absorption and compressive strength of the concrete masonry units in Figures 4 and 5, respectively. Due to the inverse relationship between water absorption and compressive strength (shown in Figure 3), Figures 4 and 5 are expected to show opposing correlations.

Table 4: Test Results for Grout Cast in Non-Absorbent Cylinder Moulds

Unit Strength (MPa)	Compressive Strength (MPa)			Slump (mm)
	Individual	Average	COV (%)	
15	23.52	22.16	6.56	170
	23.47			
	20.09			
	22.84			
	20.66			
	22.37			
20	10.09	10.60	4.54	220
	10.56			
30	10.11			
	10.61			
40	11.36			
	10.90			

Table 5: Test Results for Grout Cores Saw-cut from Untested Masonry Prisms

Unit Strength (MPa)	Compressive Strength (MPa)			Cylinder-Moulded Strength (MPa)	Strength Ratio
	Individual	Average	COV (%)		
15	39.13 38.51 38.12 34.92 35.24	37.18	5.27	22.16	1.68
20	18.49 16.51 14.04 18.39 14.13	16.31	13.37	10.60	1.54
30	18.53 18.00 18.01 15.81 16.02	17.27	7.30	10.60	1.63
40	16.15 16.10 14.17 15.27 14.22	15.18	6.36	10.60	1.43

As anticipated, grout specimens taken from untested masonry prisms show an increase in grout strength ratio with the increase in the unit water absorption. The majority of data points were

above the presumed ratio of 1.5. The grout strength ratio generally conforms to the results of past research and ranges from 1.43–1.68.

Compression tests were also performed on prismatic grout cores saw-cut from prisms previously tested to compression failure. The test results are summarized in Table 6. In general, these results showed a similar trend to those from the untested prisms, but tended to have higher coefficients of variation likely due to internal micro-cracks from compression testing that were not detected by visual inspection.

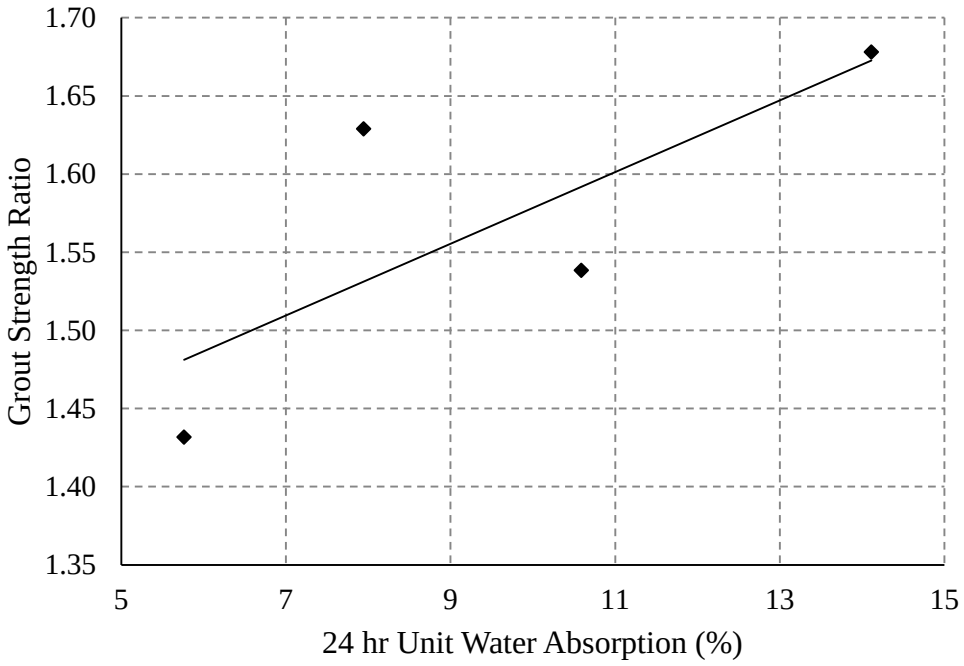

Figure 4: Correlation between Grout Strength Ratio and Unit Water Absorption

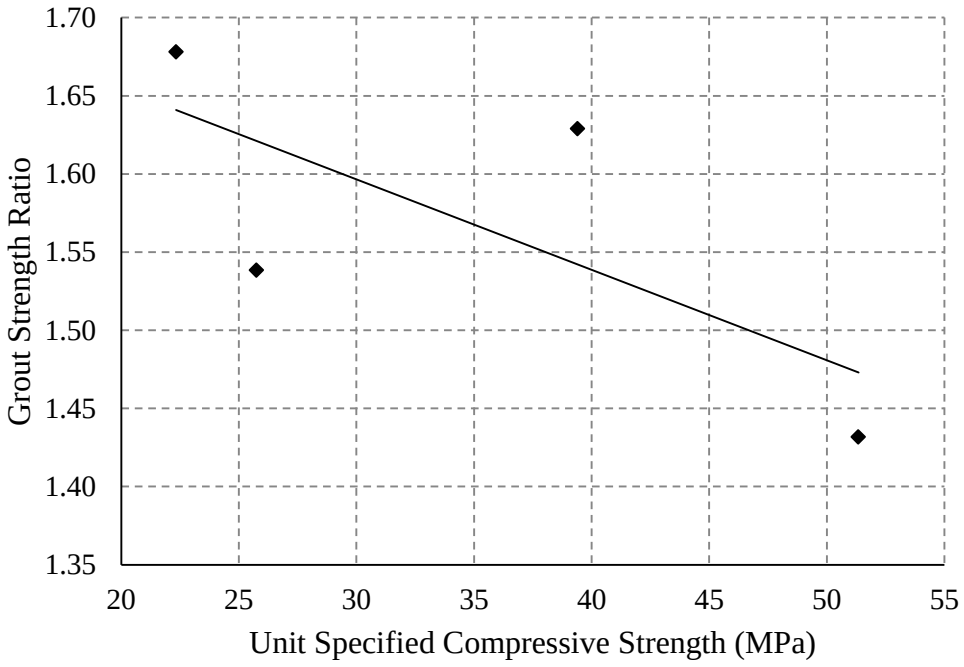

Figure 5: Correlation between Grout Strength Ratio and Unit Compressive Strength

Table 6: Test Results for Grout Cores Saw-Cut from Tested Masonry Prisms

Nominal Unit Strength (MPa)	Grout Compressive Strength (MPa)			Grout Strength Ratio
	Individual	Average	COV (%)	
15	29.79 24.89 32.25 30.38 26.85	28.83	10.18	1.30
20	14.77 17.35 16.61 11.04 22.69	16.49	25.70	1.56
30	19.94 15.43 18.70 16.78 20.13	18.19	11.22	1.72

The summary of the test results from available literature presented in Table 7 yields an average value for the grout strength ratio of 1.47, which is very close to the 50% increase suggested by CSA A179-04. These results are for block-moulded grout specimens prepared using the procedure outlined in ASTM C1019, which is intended to replicate in-situ grout strength within the concrete masonry units.

Table 7: Summary of the Findings from Available Literature

Investigation	Grout Compressive Strength (MPa)		Grout Strength Ratio
	Cylinder-Moulded Specimens	Block-Moulded Specimens	
Ocean Technical Report [7]	25.6	35.2	1.37
	23.0	34.9	1.51
	19.0	27.6	1.45
Bexton and Tedos [8]	24.0	34.0	1.42
Sturgeon et al. [9]	35.2	43.4	1.23
	29.0	44.3	1.52
	17.7	26.4	1.49
	10.3	16.5	1.60
Drysdale and Hamid [10]	13.1	18.5	1.41
	17.6	21.3	1.21
	2.8	30.9	1.49
	41.1	47.2	1.15
	7.6	17.4	2.29
Average			1.47

CONCLUSIONS

Test results corroborate those reported in past research. The compressive strength ratio of grout cores saw-cut from grouted masonry prisms to grout specimens cast in non-absorbent moulds is in the order of 1.5. Water absorption by the concrete masonry units increases the compressive strength of the in-situ grout when compared to the strength otherwise obtained for the same grout in non-absorbent moulds.

This finding supports the grout strength relationship given in CSA S304.1-04 used for calculating the development length of reinforcement embedded in grouted masonry construction. It further supports the various notes in CSA S304.1-04 and CSA A179 which state that the compressive strength of grout cast in non-absorbent cylinder moulds need only be in the order of 10–12 MPa. These values are less than the compressive strength of concrete masonry units, however, when multiplied by the absorbent/non-absorbent grout strength ratio, they exceed the strength of a standard 15 MPa unit.

The results reinforce the understanding that grout strengths offered by non-absorbent cylinder moulds tested in accordance with CSA A179 are not quantitatively representative of the grout strength within the masonry, much as standard mortar strength testing using 50 mm cubes is not representative of the strength of mortar in the constructed masonry. Use of non-absorbent cylinders to establish grout strength is simply a convenient means to demonstrate compliance with stated minimum strength values required by the CSA masonry standards.

Several material and construction variables could affect the grout absorbent/non-absorbent strength ratio. Additional testing is needed to investigate: the height at which the cores are saw-cut from the constructed masonry, the moisture content of the concrete masonry unit at the time of grouting, a full range of grout water content and grout strengths, and property specification grouts in accordance with CSA A179.

ACKNOWLEDGEMENTS

This research was funded by a Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development Grant with the Canadian Concrete Masonry Producers Association (CCMPA). The second author is financially supported by an NSERC Post Graduate Scholarship. Concrete masonry units were supplied by CCI Industries. Inline Masonry, Precision Masonry, and Scorpio Masonry supplied the mortar, grout, and labour.

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