BOND STRENGTH OF MANUFACTURED THIN UNITS USING TRADITIONAL AND POLYMER MODIFIED MORTAR

Rizaee, Samira[1]; Hagel, Mark[2] and Shrive, Nigel[3]

ABSTRACT

Adhered thin manufactured veneer (ATMV) has been used extensively as the exterior layer in building envelopes over the past 15 years. The application of ATMV has never been regulated, so traditional mortar types were preferred as the adhering agent due to their lower initial cost compared to polymer modified mortars (thinset). However, there have been numerous bond failures in ATMVs when traditional mortars have been used. Thus, more knowledge is needed and consequently regulations should be implemented for safe application of ATMV. In this study, the bond strength of thin stones and thin brick to concrete block backing using polymer modified or Type S mortar was studied. Then the effects of age (7, 14 and 28 days and more) and testing temperature (20 and -40°C) were investigated. The first three stones did not differ significantly in their shear bond strength with polymer modified mortar, reaching a minimum of 2.1 MPa strength. This suggests that the shear strength with these stones is more influenced by the mortar than the stone units or that the stone types are very similar. When investigating the influence of mortar type, the maximum average shear bond strength using Type S mortar was 0.31 MPa indicating difficulty achieving the minimum bond strength of 0.35 MPa required by ASTM C1670. In contrast, the minimum strength achieved using polymer modified was 1.2 MPa, about 4 times greater than the strength achieved using Type S mortar. Statistical analysis of the test results shows that there are no significant differences in the strength with respect to age or temperature at testing. This suggests that the bond between the thin units and the adhering mortar gains most of its strength in the first 7 days and very cold temperature does not result in weaker bond strength.

KEYWORDS: *adhered manufactured thin stone, polymer modified mortar, shear bond strength, thin stone veneer*

---

[1] Ph.D., Civil Engineering Department, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada, srizaee@ucalgary.ca

[2] Engineering Director, Alberta Masonry Council, Suite 166, 3-11 Bellerose Drive, St. Albert, AB T8N 5C9, AB, Canada, markhagel@albertamasonrycouncil.ca

[3] Professor, Civil Engineering Department, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada, ngshrive@ucalgary.ca

INTRODUCTION

Adhered thin manufactured veneers (ATMV), including manufactured thin stones and thin bricks, have been used extensively in building envelopes over the past 15 years. However there has been almost no study or regulation of this application. Traditional mortar types were preferred as the adhering agent due to their lower initial cost compared to polymer modified mortars. However, there have been numerous bond failures in ATMV applications using traditional mortar types (some examples are shown in Figure 1), which have resulted in large recladding expenses, material and workmanship waste and lowering of the safety and reliability of ATMV. For safety reasons, the application of ATMV is now limited in height. This promotes the need for a more knowledgeable approach to ATMV applications. Therefore, the shear bond strength of thin stone/brick units using a traditional and a polymer modified mortar were studied considering age and exposure to extreme cold.

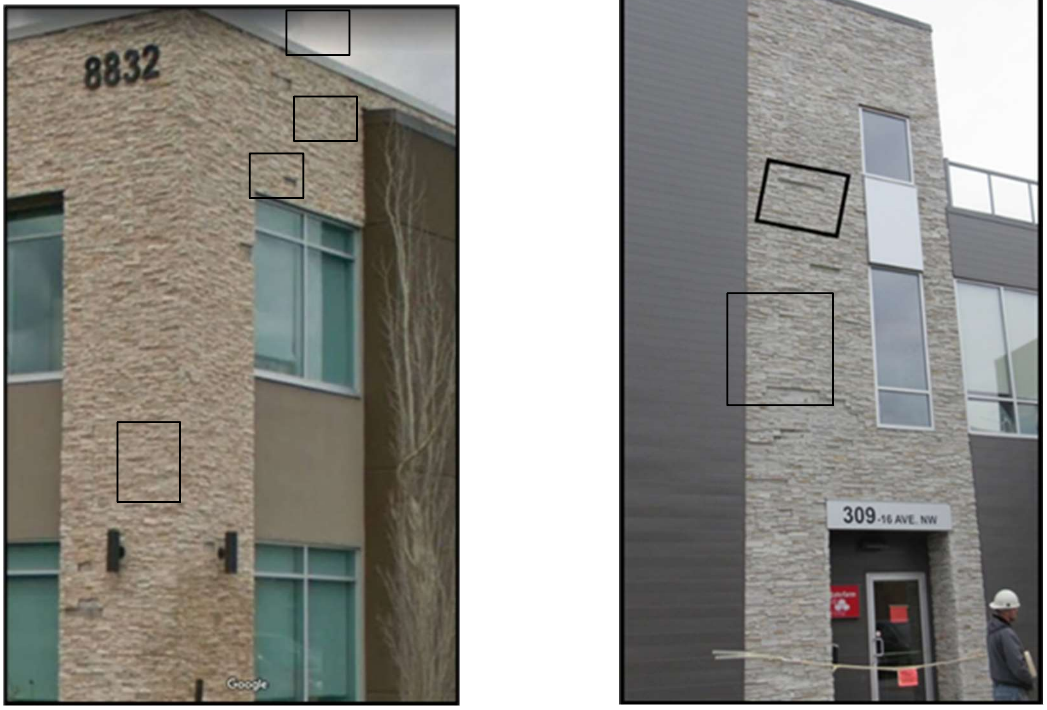


Figure 1: Bond failures in Adhered Thin Masonry Veneers [1]

Polymer Modification Effects on Bond Development and Strength

In addition to the cement hydration process that occurs in traditional mortar types, in polymer modified mortars, the polymers coalescence and fill in the voids as the mixture sets and hardens. The polymer particles create a film interlocked with the hydrated cement resulting in mechanical bonding between the polymers and hydrated cement within the mortar or with the mortar impregnated into the thin unit or concrete block backing. This modified Calcium-Silicate-Hydrate matrix coats the aggregate particles and fills or bridges the voids [2] resulting in decreased permeability. In addition, when micro cracks form, the polymer films bridge the cracks and restrain crack propagation resulting in increased tensile and flexural strengths [3]. The reduced water permeability improves the strength, durability and resistance to freeze-thaw and chemical damage of the resulting mortar [4].

Adhered thin manufactured veneer (ATMV)

ATMV walls consist of a structural backup wall and an exterior veneer, as shown in Figure 2. The backup wall can be concrete, concrete block, steel studs or wood studs with plywood sheeting covered with a layer of weather resisting barrier (WRB). The veneer consists of three main components: a layer of adhered thin manufactured stones/ brick, a layer of setting bed mortar and a layer of substrate. The adhered thin masonry units are bonded with a layer of setting bed mortar to the substrate. In cases where a concrete backup wall is used the substrate layer and WRB are optional. The thickness of manufactured thin stones has to be 40-65 mm (1 1/2-2 1/2") [5] while thin bricks are roughly 12-25 mm (1/2-1") thick.

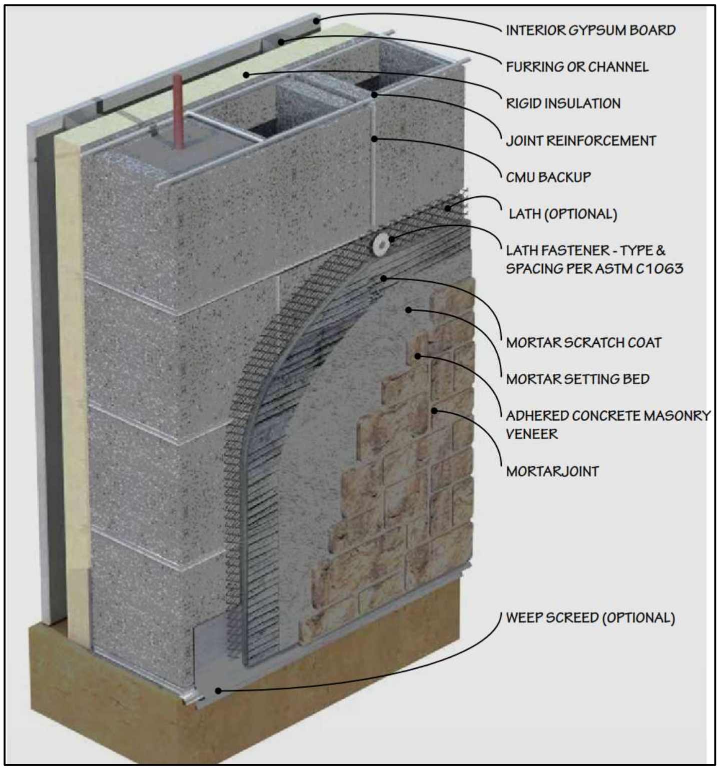


Figure 2: ATMV example [5]

METHODOLOGY

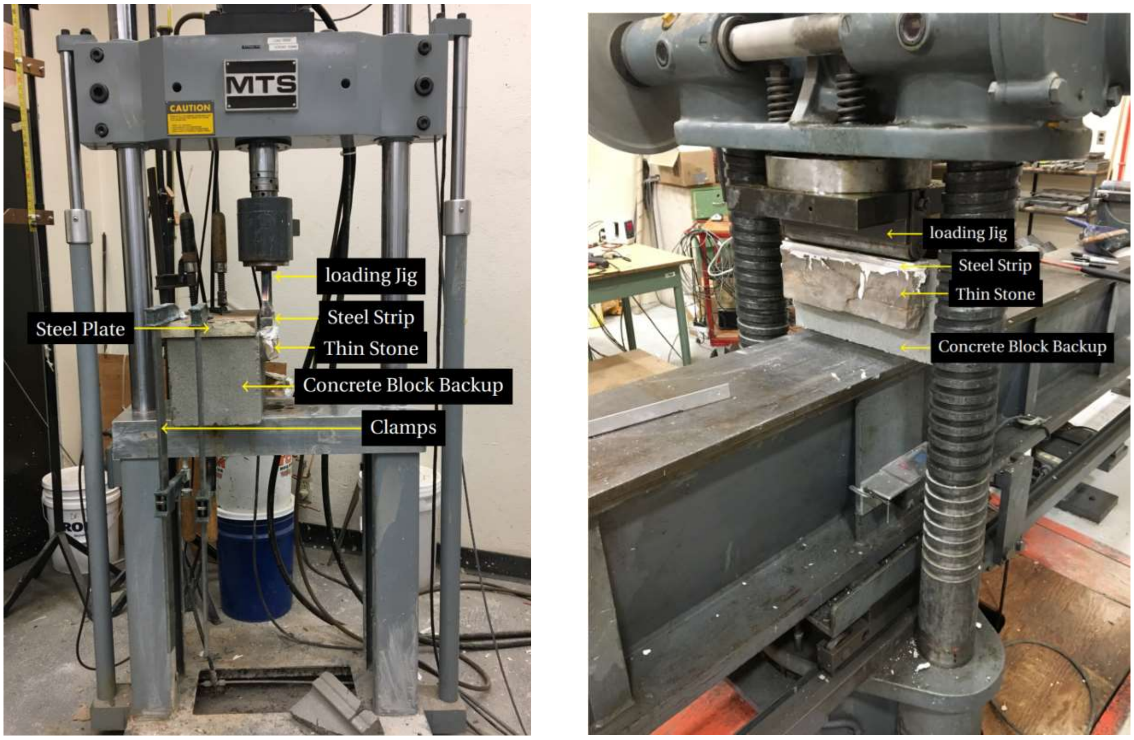
In the first phase of the study, the shear bond strength between three types of thin stone, Eldorado Brick (EB), Dutch Quality (DQ) and Stone Craft (SC), and Type S mortar (1: ½: 4½) and polymer modified mortar, compliant with ANSI A108/A118 [6], was investigated. In the second phase, the effects of age (7, 14 and 28 days) and testing temperature (20 and -40°C) on the shear bond strength of a fourth type of thin stone, Cultured Stone (CS), were investigated. Finally, in the third phase, bond strength of one type of Thin Brick (TB) to Type S and polymer modified mortar was investigated and compared to the thin stones. In addition, the effects of age on the shear bond strength in CS (one, 10, 11, 17 and 25 weeks) and in TB (one and 10 weeks) was also investigated.

Five samples were fabricated for each measurement according to ASTM C482-02 [7], so that the repeatability of the results could be examined and statistical comparisons could be made while the number of measurements were kept as the minimum required according to ASTM C482-02 [7]. Each specimen was made of a thin unit attached to a concrete block backing using either Type S or polymer modified mortar as shown in Figure 3. Samples were left to cure uncovered in the laboratory (20°C, 20-60% RH) for at least 7 days before testing to simulate curing in practice.

a) Conc block with mortar spread b) Thin stone/brick c) Specimen ready for testing

Figure 3: Shear Bond Test Sample Preparation

The tests in the first and third phase of the study were conducted using an electro-hydraulic servo-controlled MTS machine of 100 kN capacity, Figure 4a. Lack of availability of the MTS machine caused phase two of the study to be conducted using a manual 2000 kN capacity Amsler machine (Figure 4b). The MTS machine was programed to load the specimens at 3-5 kN/min, while the Amsler machine was hand-operated and the rate of application of load depends on the operator. Each specimen was placed in the applicable test machine and a steel plate weighing 31.6 kg was placed on the concrete block backing to counteract the over-turning moment due to the applied shear load on the thin unit and to stop the specimen from rotating. The specimens were also clamped to both sides of the test machine platen with two clamps to ensure the fixity of the backing. The test set-up is shown in Figure 4.



a) MTS-testing as in Phases I and III b) Amsler testing -Phase II

Figure 4: Shear Bond Strength Test Machines

RESULTS

Since the variation in the bond strength was expected to be large (the Coefficient of Variation was found to be between 6% and 29%), using only average values to compare the shear strength values of different groups would likely not reveal actual relationships. Hence, for better comparison, the test results of each group are presented in box plots, which show the median, quartiles and any outliers in the results - see Figure 5. Box plots help in graphical presentation of all the values, their variation and make comparisons between groups easier. To determine whether the strengths in different groups are statistically different from one another, one way Analysis of Variance (ANOVA) tests with a confidence level of 0.95 were conducted. The ANOVA test results always match visual interpretation of the results from the box plots.

The results of tests in Phase I, II and III are presented in Table 1 and Figure 6. In the first part of the study, the shear bond strengths of three thin stone types, Eldorado brick, Dutch Quality, Stone Craft (EB, DQ and SC), adhered to concrete block using polymer modified mortar (EB: 2.22 ±0.27, DQ: 2.52±0.74, SC: 2.11±0.36 MPa) and Type S (EB: 0.15±0.14, DQ: 0.23±0.06 MPa) mortar were examined after curing for seven days and testing at ambient laboratory conditions (20°C, RH = 20-60%). It can be seen in Figure 6 that the shear bond strengths of these stones are not significantly different from each other using polymer modified mortar, reaching an average minimum of 2.1 MPa in DQ. However, the strength with Type S mortar, varying from 0 to 0.29 MPa, does not meet the minimum requirement of 0.35 MPa, by ASTM C1670 [8].

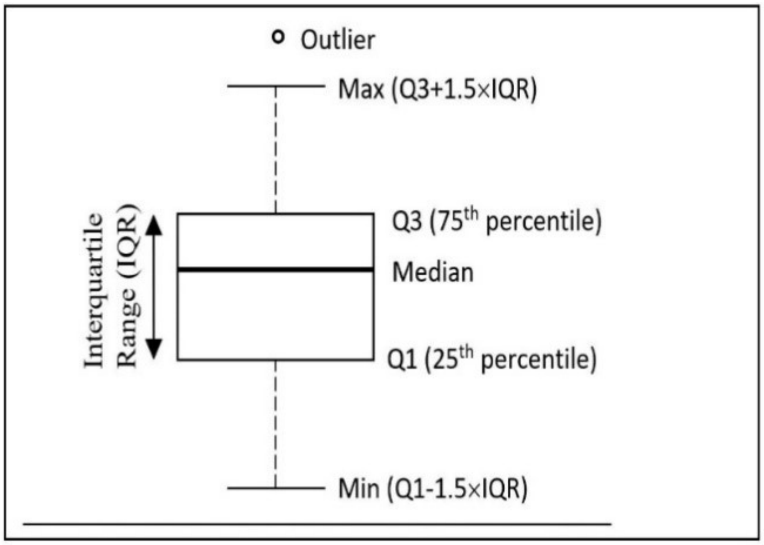


Figure 5: Box Plot Components and Definitions

Comparing the results of the first and second phases of the study, shown in Figure 6, the shear bond strength between CS units and polymer modified mortar (1.20 ±0.55 MPa) is significantly different and lower than for EB, SC, and DQ units. The reason was expected to be the manual operation of the high capacity Amsler machine used in phase II instead of the computer-controlled MTS, resulting in greater variation and lower strength. However, the bond strengths using Type S mortar are similar and do not show any difference amongst groups suggesting that Type S mortar does not develop a great bond with the thin units suggesting no influence of the unit types on bond strength.

Table 1: Shear Bond Strength-Ph I, II, III using Laticrete (L) and Type S (S) Mortars

Group\ Sample No.	**EB L (I)**	**SC L (I)**	**DQ L (I)**	**CS L (II)**	**CS L (III)**	**TB L (III)**	**EB S (I)**	**DQ S (I)**	**CS S (II)**	**TB S (III)**
1	1.83	1.58	1.62	1.41	1.17	2.87	NA*	0.15	0.05	0.24
2	2.44	2.89	2.18	1.74	1.18	1.83	0.31	0.19	0.24	0.15
3	2.34	3.52	2.16	0.89	1.11	1.42	NA	0.29	0.36	0.24
4	2.28	3.02	2.48	0.39	1.65	1.82	0.07	0.27	0.23	0.20
5		1.92		1.57	0.93	1.97	0.07	0.24	0.00	0.13
6		2.17								
Avg (MPa)	2.22	2.52	2.11	1.20	1.21	1.98	0.15	0.23	0.18	0.19
SD	0.27	0.74	0.36	0.55	0.27	0.54	0.14	0.06	0.15	0.05
COV	0.12	0.29	0.17	0.46	0.22	0.27	0.92	0.25	0.85	0.28

* Bond failure before testing

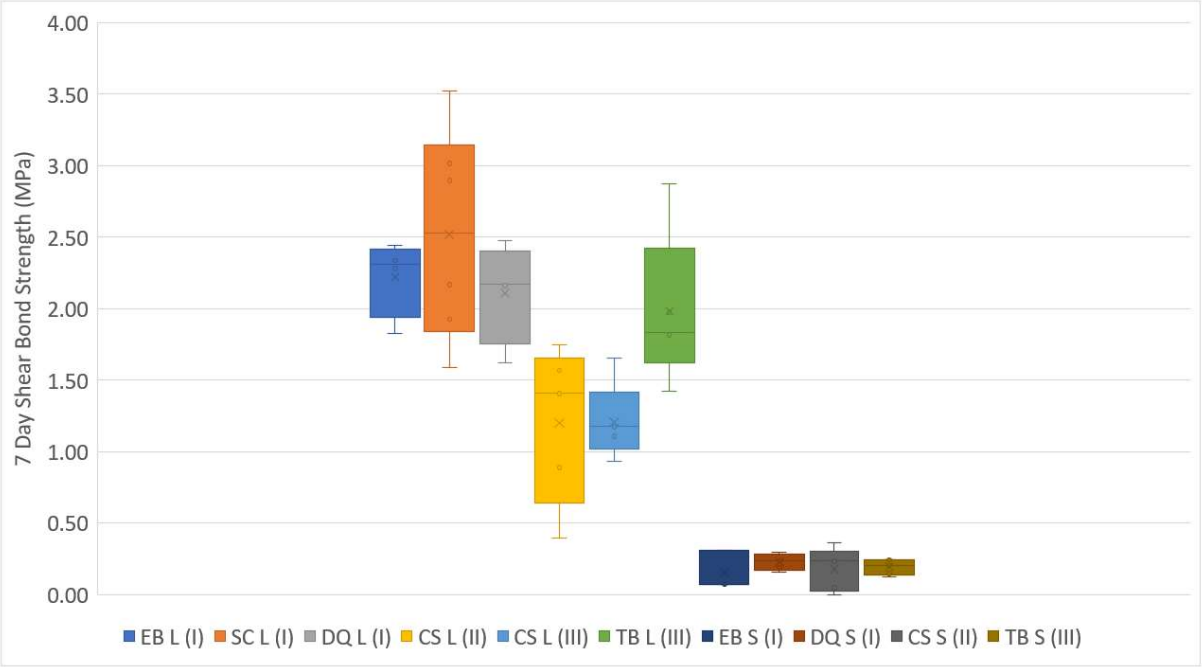


Figure 6: Shear Bond Strength-Ph I, II, III using Laticrete (L) and Type S (S) Mortars

Looking at the test results from all three phases, it is clear that the strength of TB (1.98±0.54 MPa) is similar to EB, SC, and DQ determined in phase I and the strengths of CS in phases II and III are similar (1.20±0.55 and 1.21± 0.27 MPa), but different from the stones in the first phase and TB. This shows that although the Amsler machine was used in the second phase, the results from the MTS and Amsler machines are statistically similar with higher variability using the Amsler machine. Therefore, the reason for the difference in the bond strength of CS from EB, SC and DQ is probably more related to the type of stone than the type of testing, and this needs to be investigated further.

The other results from phase II are shown in Figure 7, where samples constructed with Type S or polymer modified mortar were cured at ambient temperature (A) and tested at either ambient (20°C) or -40°C. The maximum shear bond strength using Type S mortar was low (0.31 MPa on average), indicating again that Type S mortar has difficulty achieving the minimum bond strength of 0.35 MPa required by ASTM C1670 [8]. In contrast, the strength achieved using polymer modified mortar was 1.2 MPa on average, some four times greater than that achieved with Type S mortar. Statistical analyses of the results showed no significant difference in the strength versus age or testing temperature, despite the trend for strength increasing slightly with age for specimens tested at 20°C.

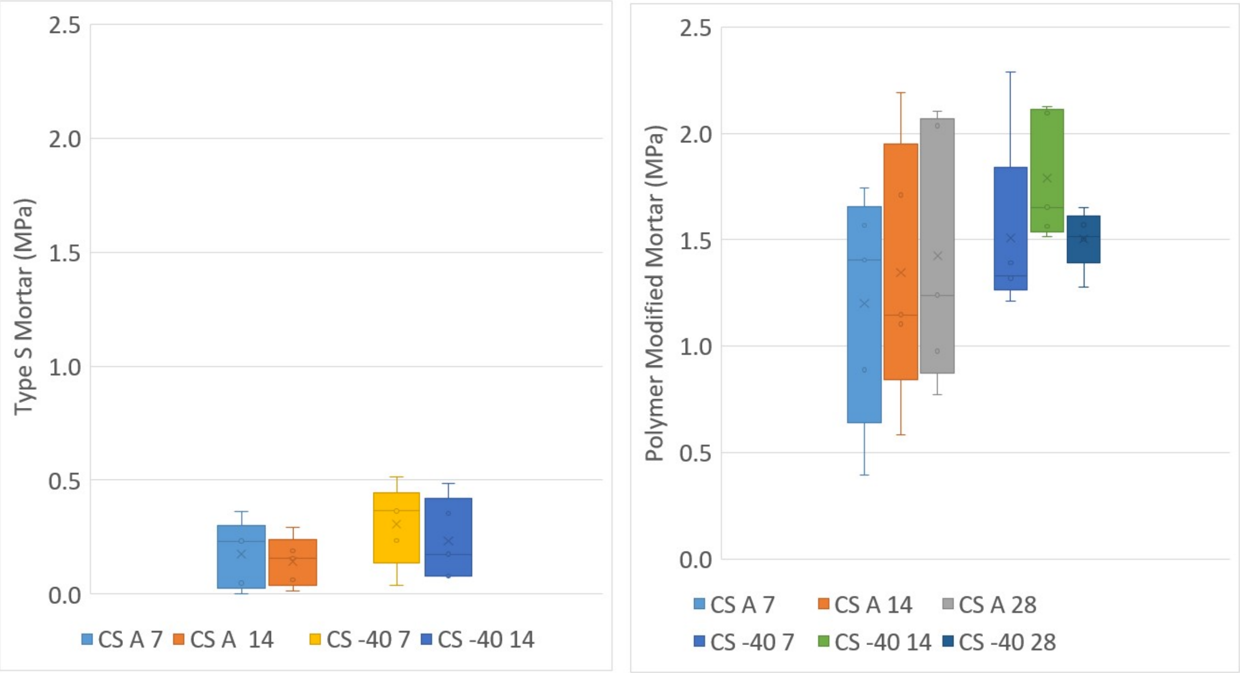
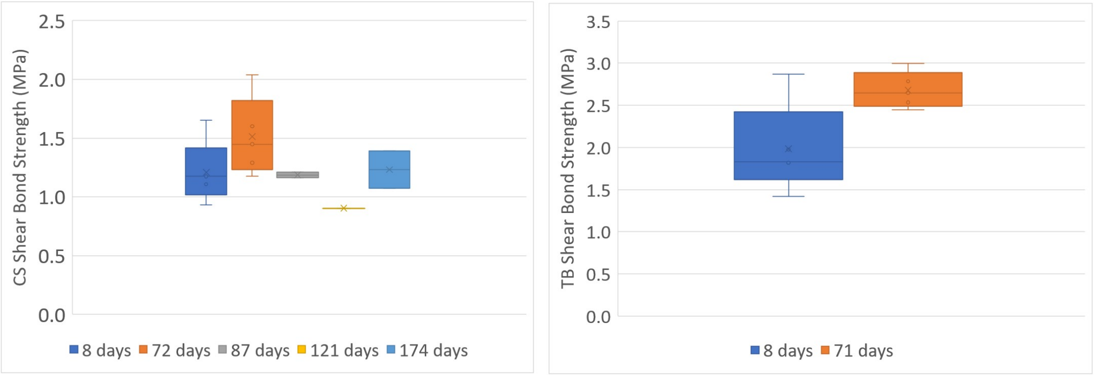


Figure 7: Shear Bond Strength Test Results for Phase II

The effect of age when tested on cultured stone and thin brick was also studied in the third phase, shown in Figure 8. Similar to the second phase the bond strength did not change over time in CS even at 25 weeks. However, in TB the bond strength at 10 weeks was significantly greater than one week. This observation implies that the shear bond strength with thin bricks improves over time, while the average bond strength at 7 days is significantly greater than the minimum required.

FACTORS INFLUENCING THE BOND STRENGTH/ DISCUSSION

Formation of bond and development of bond strength between the thin units and mortar is believed to be influenced by several factors inherent to the unit and mortar physical and mechanical properties [9]. These factors include unit properties such as moisture content, initial rate of absorption (IRA), total water absorption, saturation coefficient, modulus of rupture [10] and sorptivity [11]. Factors related to mortar include the composition, flow, water retentivity [12] air content [13] and compressive strength [10]. These factors were examined by Rizaee [14]. Amongst unit material properties mentioned, there is a noticeable difference in the sorptivity values. Sorptivity was determined following the requirements by ASTM C1585-04 [15]. Sorptivity in CS was the highest, 0.44 mm/min$^{1/2}$, with sorptivity in DQ, SC and EB being similar (0.23-0.29 mm/min$^{1/2}$) and sorptivity in TB the lowest 0.084 mm/min$^{1/2}$ (Figure 9). The high sorptivity in CS may have resulted in more fluid being absorbed from the mortar mixes, leaving mortar with less water for hydration and thereby less bond strength than with the other types of units.



a) Cultured Stone b) Thin Brick

Figure 8: Age Effect on Shear Bond Strength-Phase III

Regarding the mortar properties, the mortar composition and compressive strength appeared influential. The traditional Type S mortar (1:0.5:4.5) achieves higher bond strength than Type N mortar [16] and Masonry Cement mortar [9]. On the other hand, polymer modified mortar improves adhesion and toughness. This mortar requires less water for the same amount of workability resulting in less porosity and higher resistance to water ingress and durability. Polymer modified mortars trap the water in the internal pores due to polymerization at the surface and this water hydrates the cement further [2]. The Polymer modified mortar used in this study consisted of 56% sand, 4.5% calcium carbonate, 18% gray cement, 12% white cement, 3.8% ethylene vinyl acetate (E/VA), 4% admixtures, which include other polymers such as acrylate, 0.33% cellulose ether and 1.4% other additives by percentage of dry mass [17]. Type S mortar is composed of 1 unit cement, 0.5 unit of lime and 4.5 unit of sand by volume. Comparison of the composition of the two mortars distinguishes the addition of polymers and other additives in the Polymer modified mortar, which results in improved strength using Polymer modified mortar.

The 7 day compressive strength of the mortars was measured according to CSA A179-14 [18]. The compressive strength of polymer modified mortar, 18.6±0.4 MPa, was in the range, 16.6-19.3 MPa, reported by "MVIS^{TM} Veneer Mortar, DS-60-0320" [19]. The compressive strength of Type S mortar was 10.7±0.6, which is typical for this mortar. The compressive strength of the polymer modified mortar is 75% greater than that of Type S mortar, showing how polymer modification improves compressive strength.

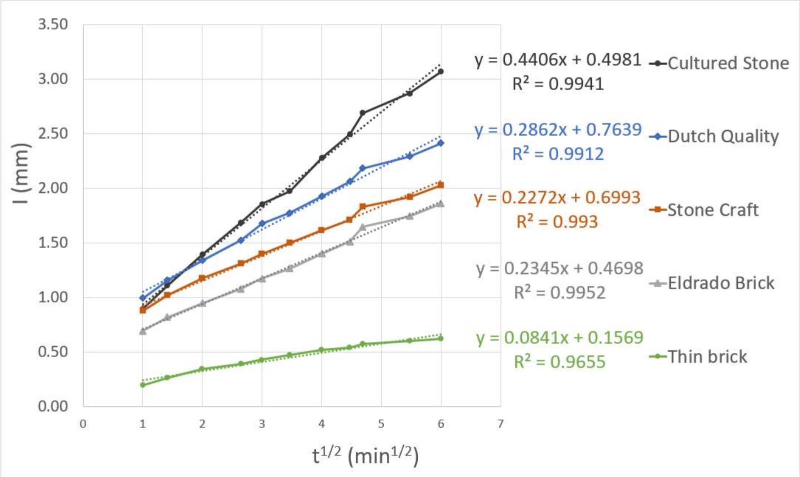


Figure 9: Sorptivity Graph

CONCLUSIONS

The results in this study indicate that the bond between masonry thin units and the adhering mortar gains most of its strength in the first 7 days when polymer modified mortar is used: therefore, there is no reason to cure for longer time. Samples made using Polymer modified mortar maintained their strength when exposed to temperatures as low as -40°C. When the traditional Type S mortar is used, regardless of the type of stones, the aging or testing temperature do not change the strength significantly and the samples have difficulty achieving the minimum required strength, indicating the inability of Type S mortar to create sufficient bond strength. Analysis of the test results from this study demonstrates the need for requiring polymer modified mortar as the adhering agent for masonry thin unit applications. It appears from these tests that this type of mortar is able to provide good bond over a range of relevant temperatures.

RECOMMENDATIONS

The use of Type S mortar in adhered thin masonry veneer applications is not recommended. However, polymer modified mortar which usually creates bond strengths substantially greater than Type S is recommended as a more reliable and economical solution. In addition, curing for only 7 days is sufficient using polymer modified mortar.

ACKNOWLEDGEMENTS

The authors would like to thank MITACS, the Alberta Masonry Council and The Masonry Society for their financial support and the Department of Civil Engineering, University of Calgary for technical support.

REFERENCES

[1] Rizaee, S., Hagel M. D. and Shrive N. G. (2020). “Shear Bond Strength of Manufactured Thin Stones Considering Various Adhesion Methods.” *Proc., 17th International Brick and Block Masonry Conference*, Krakow, Poland.

[2] Kaeding A. O. and Maass J. E. (2003). “Polymer Modified Concrete (ACI 548.3R-03).” International Concrete Abstracts, Farmington Hills.

[3] Ohama Y. (1995). “Polymer modified Mortars and Concretes.” in Concrete Admixtures Handbook: Properties, Science and Technology, 1153 pages.

[4] Blaga A. and Beaudoin, J. J. (1985). “Polymer Modified Concrete.” Canadian Building Digest, Division of Building Research, National Research Council of Canada, Ottawa, ON, Canada.

[5] MVMA (2017). “Installation Guide and Detailing Options for Compliance with ASTM C1780 for Adhered Manufactured Stone Veneer.” Masonry Veneer Manufacturers Association.

[6] ANSI (2015), “American National Standard Specification for the Installation of Ceramic Tile (ANSI A108, and A118).” American National Standards Institute, Anderson, South Carolina, USA.

[7] ASTM (2014), “C482-02, Standard Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste.” American Society of Testing and Materials, West Conshohocken, PA, USA.

[8] ASTM (2016). “C1670/C1670-15, Standard Specification for Adhered Manufactured Stone Masonry Veneer Units.” American Standard Test Method, West Conshohocken, PA, USA.

[9] Shrive N. G. and Reda Taha M. M. (2004). “Bond Strength of Clay Masonry Prisms Constructed with Normal and Fly Ash Substituted Mortars.” *Proc., 13th International Brick and Block Masonry Conference*, Amsterdam, Netherlands.

[10] Sise, A. (1984). “Flexural Bond Strength of Masonry.” MSc. Thesis, University of Calgary, Calgary, AB, Canada.

[11] Reda Taha, M. M., El-Dieb A. S. and Shrive N. G. (2001). “Sorptivity a Reliable Measurement for Surface Absorption of Masonry Brick Units.” Materials and Structures, vol. 34, 438-445.

[12] Ritchie T. and Davison J. I. (1963). “Factors Affecting Bond Strength and Resistance to Moisture Penetration of Brick Masonry,” ASTM, STP320, 16-30.

[13] Sugo, H. O., Page A. W. and Lawrence, S. J. (2000). “A Study of Bond Strength and Mortar Microstructure Developed Using Masonry Cement.” *Proc., 12th International Brick and Block Masonry Conference*, Madrid, Spain.

[14] Rizaee, S. (2021). “Bond Strength of Adhered Manufactured Thin Stone/Brick Masonry Veneer Units to Setting Bed Mortar at Different Temperatures and Different Cycles of Freeze-Thaw.”, PhD Thesis, University of Calgary, Calgary, AB, Canada.

[15] ASTM (2004). “ASTM C1585 Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes.” American Society for Testing and Materials, USA.

[16] Meslin, M. and Brzev, S. (2006). “Effect of Mortar Type on Flexural Bond Strength of Brick Masonry.” Civil Engineering Research Project from BCIT, Report No. CERP – 2006/01.

[17] Laticrete International (2018). “Environmental Product Declaration of Cement Mortar for Tile Installation.” Laticrete International, Inc., Bethany, Connecticut, USA.

[18] CSA.A179-14 (2014). Mortar and Grout for Unit Masonry, Canadian Standards Association, Mississauga, ON, Canada.

[19] Laticrete International (2020). “MVIS TM Veneer Mortar (DS-60-0320).” Laticrete International, Inc., Laticrete International, Inc., Bethany, Connecticut, USA.