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SHEAR AND TENSILE BOND STRENGTH OF MANUFACTURED STONE VENEER UNITS INDIVIDUALLY SECURED BY MORTAR ADHESION

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ABSTRACT

Thin masonry veneers individually secured by mortar adhesion (adhered masonry veneers) have become increasingly popular in the North American construction industry. As the height of the adhered masonry veneer increases, however, the reliance on mortar bond to attach the thin masonry cladding to the support structure also increases and the greater the risk of damage to property or injury if that bond fails. This paper explores the results of testing the shear and tensile bond strength of adhered manufactured stone veneer units when Type N, Type S, polymer modified stone veneer mortars, and improved modified dry-set cement (thinset) mortars were used. The results of the testing illustrated that two types of failures can occur, bond failure of the setting bed to substrate and bond failure of setting bed to the back of the stone unit. The testing also demonstrated that traditional Type N and Type S mortars had difficulty achieving the 0.35 MPa (50 psi) shear bond strength required by ASTM C482, ASTM C1780 and ASTM C1670 when the ASTM C482 test was modified to better replicate field installation of adhered masonry veneers. Only the thinset mortars consistently exceed the 0.35 MPa requirement.

KEYWORDS: *adhered masonry veneer, polymer modified mortar, structural design*

INTRODUCTION

Adhered thin masonry veneers have become increasingly popular in the North American construction industry. However, the reliance on mortar bond to attach the thin masonry cladding to the support structure is greater than traditional masonry because the mortar bond is not acting in compression, but in flexure, shear, and tension. In the past, Type N and Type S mortars used in traditional full bed masonry veneers have been used to construct the scratch coat that embeds the metal lath, as well as the setting bed used to bond the adhered masonry unit to the scratch

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coat in adhered thin masonry veneers wall systems. Type N and Type S mortars in full bed masonry veneers are pre-dominantly relied upon for strength in compression in the bed joint and to aid in mechanical anchorage of the masonry veneer to the structural wall using metal brick ties. Bond failures in the field with Type N and Type S mortars, have been observed to occur at the setting bed/masonry unit interface (Failure Mode I) as illustrated in Figure 1 or the setting bed/scratch coat interface (Failure Mode II) as illustrated in Figure 2. The former (Failure Mode I) has been most frequently observed in the field by the authors.

Figure 1: Failure Mode I - Bond Failure at the Stone Unit/Setting bed interface (setting bed visible).

Figure 2: Failure Mode II - Bond Failure at the Scratch coat/Setting bed interface (scratch coat visible).

Many theories exist on the causes of the bond failures which include stones breaking bond before setting if they are jarred during construction, initial rate of absorption creating inadequate mortar bond, freeze-thaw action, reduction in strength of the mortar bond with the addition of water for workability, and inappropriate type or proportion of bonding agent added to the setting bed mortar. In “jointed” applications the jointing between the stone provides more strength to the system when laid in a traditional fashion where joints are installed at the time the unit is installed due to the joints acting like horizontal and vertical reinforcement and facilitating composite action between stone units. However, the same failures have been observed in “jointed” applications as well, often when the joint installation is accomplished with a grout bag where the stone units are attached to the wall and joints are installed after the stone units have been set.

In order to better assess the shear bond and tensile bond strength adhered stone systems as they are constructed in Alberta, the Alberta Masonry Council commission testing at an ISO/IEC 17025:2005 accredited laboratory. This paper explores shear and tensile testing of adhered manufactured stone units.

TESTING PROGRAM

The testing investigated the shear and tensile bond strength of four popular brands of adhered manufactured stone [Stone I, Stone II, Stone III, and Stone IV], with four types of mortar [Type N, Type S, Polymer modified stone veneer mortar (Poly. Modified stone veneer mortar), ANSI-118.15 [1] thinset (improved dry-set cement) mortar] used for the setting bed adhered to 6 different substrates [Scratched Mortar block cast with Type N, Scratched Mortar block cast with Type S, Scratched Mortar block cast with Polymer modified stone veneer mortar, Scratched Mortar block cast with Type N and a structural weather resistant barrier (struct. WRB) and exterior grade cement board with structural weather resistant barrier]. Table 1 outlines the sample combinations of stone brand, substrate (a cast mortar block scored to simulate a scratch coat or an exterior grade cement board) and setting bed (mortar) that were investigated in the testing program.

Table 1: Adhered Stone Testing Program – Sample Combinations

Stone Brand	Substrate	Setting Bed
Stone I,II,III,IV	Type N mortar block scratched	Type N
	Type S mortar block scratched	Type S
	Type N mortar block scratched	Poly. Modified stone veneer mortar
	Poly. Modified stone veneer mortar	Poly. Modified stone veneer mortar
	Type N mortar block scratched	ANSI-118.15 thinset mortar
	Type N mortar block scratched+ struct. WRB	ANSI-118.15 thinset mortar
	Exterior Grade Cement Board+ struct. WRB	ANSI-118.15 thinset mortar

Adhered manufactured stone veneer units are typically manufactured from light-weight concrete and must weigh less than 0.72 kPa (15 psf) according to ASTM C1670-15 - *Standard Specification for Adhered Manufactured Stone Masonry Veneer (AMSMV) Units* [2]. The substrate is typically a 13 mm (½”) mortar embedding a self-furring metal lath. The mortar is scored to provide better bond and referred to as the scratch coat. The scratch coat is required to be a minimum 13 mm (½") and a maximum 19 mm (¾") according to ASTM C1780-15 - *Standard Practice for Installation Methods for Adhered Manufactured Stone Masonry Veneer* [3]. The mortar used to embed the metal lath can be Type N, Type S or a polymer modified mortar. Exterior grade cement board is also becoming more common and is now permitted by ASTM C1780-15 [3]. The exterior grade cement board replaces the metal lath and mortar scratch coat but requires the use of an ANSI-A118.4 [1] or ANSI-A118.15 [1] compliant modified dry-set cement mortar that are typically referred to in industry as thinset mortars. Clause 7.2.1 of the ASTM C1670-15 [2] and Clause X1.2 of ASTM C1780-15 [2]. require a shear bond strength of 0.35 MPa (50 psi) using a shear bond test based on ASTM C482-02 - *Standard Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste* [4] using tile sized 100 mm x 100 mm (4" x 4") samples for the adhered stone units cut from manufactured stone units and a smooth mortar block as per ASTM C482-02 [4]. There currently is no requirement for flexural or tensile bond strength of adhered manufactured stone units or assemblies in the ASTM C1670 or ASTM C1780 standards.

Shear bond tests of three samples for each combination were completed. The samples used full-sized manufactured stone units adhered to a mortar block substrate or cement board substrate and tested according to a modified ASTM C482-02 [4] test. Stone veneer units were provided directly from suppliers. The thickness of the manufactured stone samples varied depending on the manufacturer as full-sized units were supplied. Stone samples of approximately 102 mm x 102 mm (4" x 4") in dimension were cut, as needed; using a slow speed saw from actual manufactured stone veneer units.

Tensile bond tests of three samples for each combination were completed. Full-sized manufactured stone units were adhered to a mortar block substrate or cement board substrate and test according to a modified ASTM C952-02 - *Standard Test Method for Bond Strength of Mortar to Masonry Units* [5]. Stone samples of approximately 102 mm x 191 mm (4" x 7½") in dimension were cut, as needed, using a slow speed saw from actual manufactured stone veneer units. The "simulated scratch coat mortar blocks", used in both tests, were constructed with pre-formed 102 mm x 152 mm (4" x 6") moulds (Figure 3) using the appropriate pre-bagged mortar as per Table 1. The scratched surface was created with a 6.4 mm (¼") square notched trowel.

After the mortar blocks had *air cured* for a at least 24 hours (typical laboratory temperature of 21°C and 25% relative humidity), a selected mortar for the setting bed was mixed and applied to the manufactured stone unit sample using a pointed (brick) trowel or a fluid applied structural weather resistant barrier (structural WRB) was applied to the cured "simulated scratch coat" mortar block and allowed to cure.

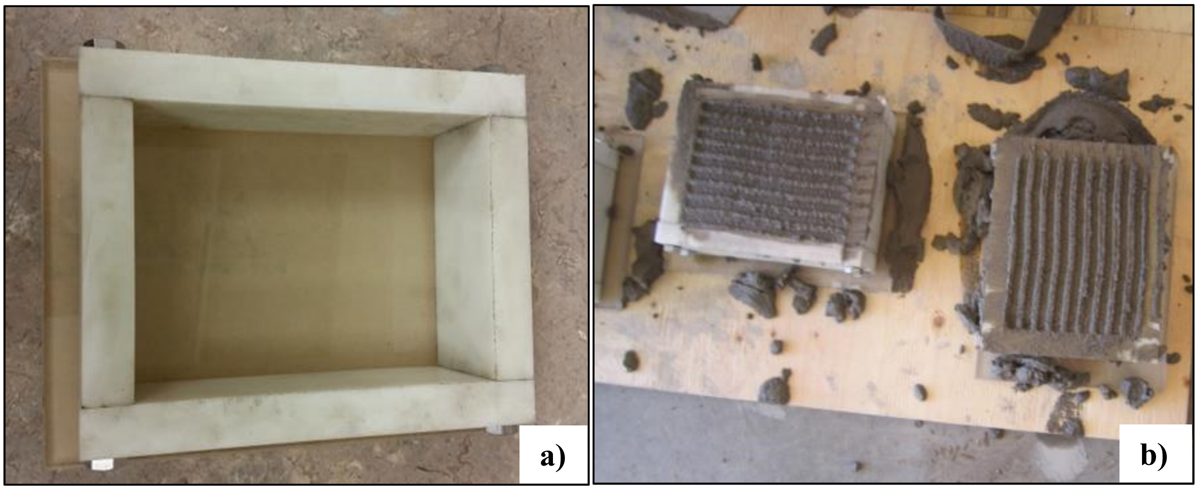

Figure 3: a) Mortar Block Mould and b) Mortar Block Samples.

Cement board substrate samples were constructed using a 13 mm (½") exterior grade cement board fastened with the manufacturers fasteners to a 2x6 wood stud cut to 152 mm (6") in length (Figure 4). A fluid applied structural weather resistant barrier (structural WRB) was applied to the cement board and allowed to cure.

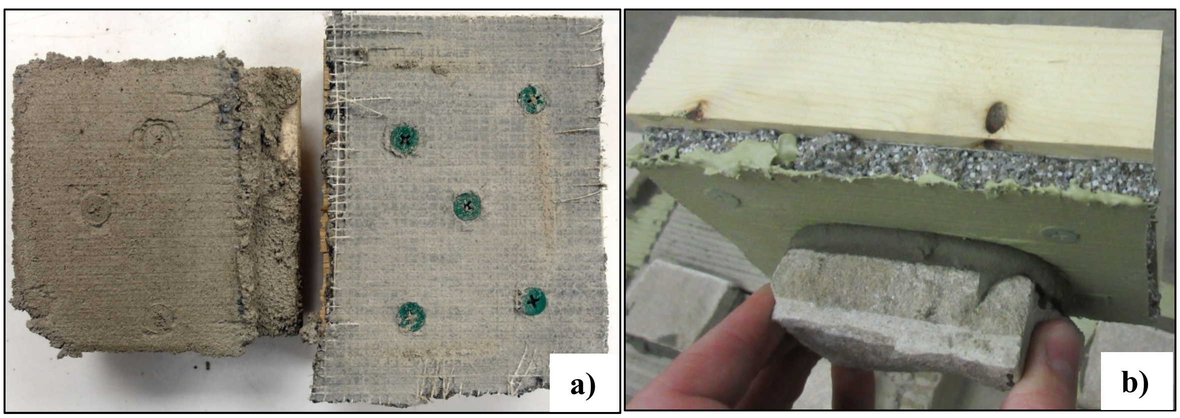

Figure 4: a) Cement Board Substrate b) Cement Board Substrate with Structural WRB.

A "fully buttered" manufactured stone unit sample was then adhered to the "simulated scratch coat mortar block" substrate or the exterior grade cement board substrate according to mortar manufacturer's/stone manufacturer's installation instructions, working the mortar into the substrate, leaving an approximate 13 mm (½") seam of mortar between the stone and the scratch coat. Excess mortar was then removed from the edges of the stone and the sample was *air cured* at room conditions for 7 days prior to testing (typical laboratory temperature of 21°C and 25% relative humidity).

The samples best represent an adhered stone application in drystack application or a jointed application where the joints are installed after the stones are laid with a grout bag. In these installations the individual stone units rely on the bond between the setting bed and the substrate with little or no composite action between units.

A fixture used to load the specimen in shear was fabricated using the specifications of the "Fixture" prescribed in ASTM C482-02 [4] (Figure 5a). The aesthetic textures on the front surface of the stone units created an irregularity that did not permit the use of the steel key typically associated with an ASTM C482-02 [4] shear bond test. This key was replaced with a piece of felt cloth, to alleviate point loads. One or more steel strips (25.4 mm x 203 mm x 6.4 mm (1" x 8" x 1/4")) were set on flat face to help localize the force applied by a *manual hydraulic press* by positioning the metal strips on the edge of the stone closest to the mortar joint, to mitigate the effects of torque. A loading jib used to load the specimen in tension was fabricated using the specifications of the "Loading Jigs for Cross-Brick Couplets" prescribed in ASTM C952-02 [5] (see Figure 5b). The irregularity of the textures on the back surface of the stone unit samples occasionally created uneven loading not typically experienced in the standard ASTM C952-02 [5] bond strength test.

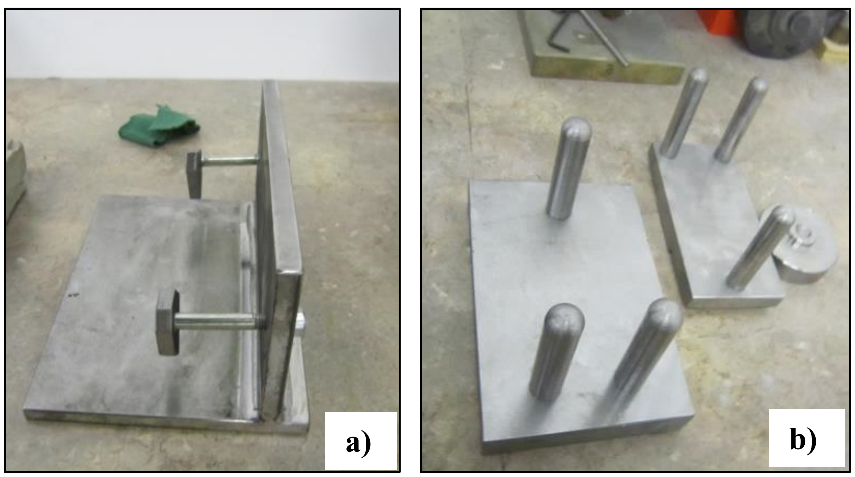

Figure 5: a) Shear Bond Test - "Fixture" b) Tensile Bond Test - "Loading Jig".

The Carver^{TM} Model C hydraulic laboratory press (Figure 6a) was calibrated with a digital pressure gauge prior to testing by an ISO17025 accredited calibration laboratory. The use of a manual hydraulic press prevented strict conformance to the ASTM C482-02 [4] bond test which requires a controlled loading rate of 0.90 kN/min +/- 0.09 kN/min (200lb/min +/20lb/min). The pressure at failure was recorded by the digital pressure gauge in pounds per square inch (psi). This pressure was then converted to the force exerted on the specimen by the hydraulic ram by multiplying by the ram area of 3.293 in^2. The ram area was obtained during calibration of the hydraulic press and gauge, and found to be consistent with the value provided in the Carver^{TM} Model C's technical specifications. The force values were then converted to the shear bond strength in psi by dividing by the area of the setting bed in contact with the failure surface. Due to the limitation of the manual hydraulic press, loading rates were determined as calculated values using maximum pressure over total time tested.

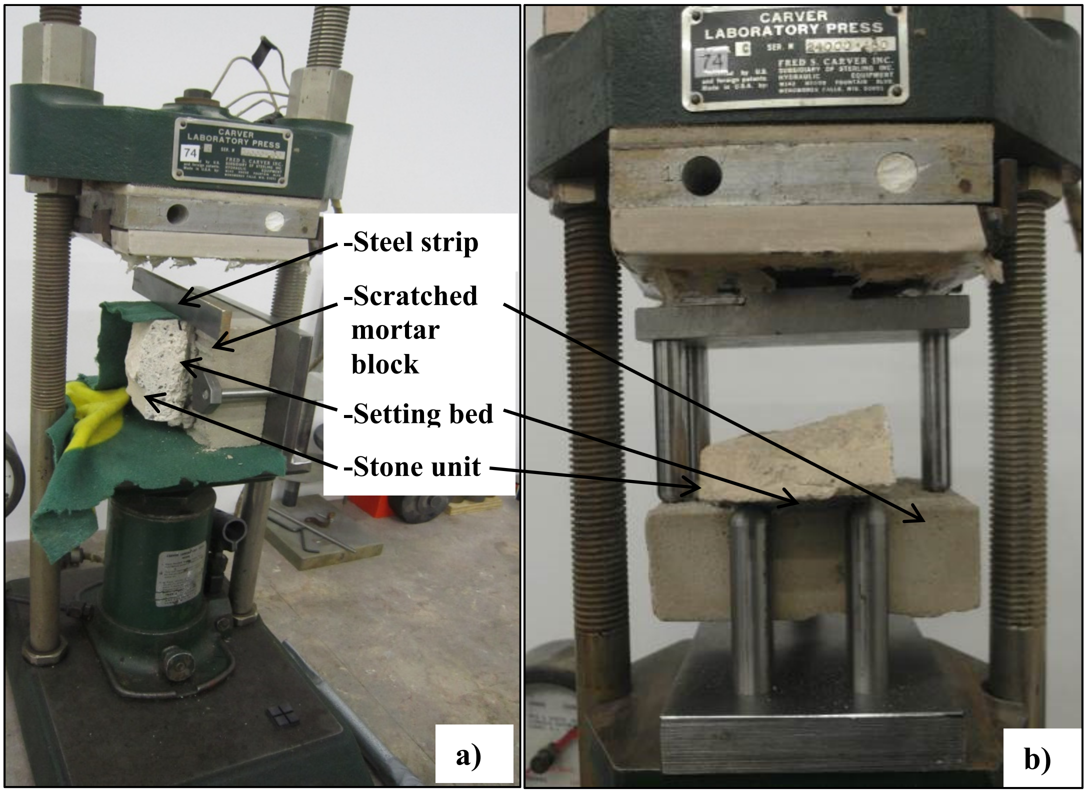

Figure 6: a) Shear Bond Test Set-up b) Tensile Bond Test Set-up.

RESULTS AND DISCUSSION

The two distinct failure modes (Mode I & Mode II) observed in the field were also observed with the shear bond tests when pre-bagged Type N, Type S and the pre-bagged polymer modified stone veneer mortars were used for the simulated scratch coat and setting bed (Figure 7).

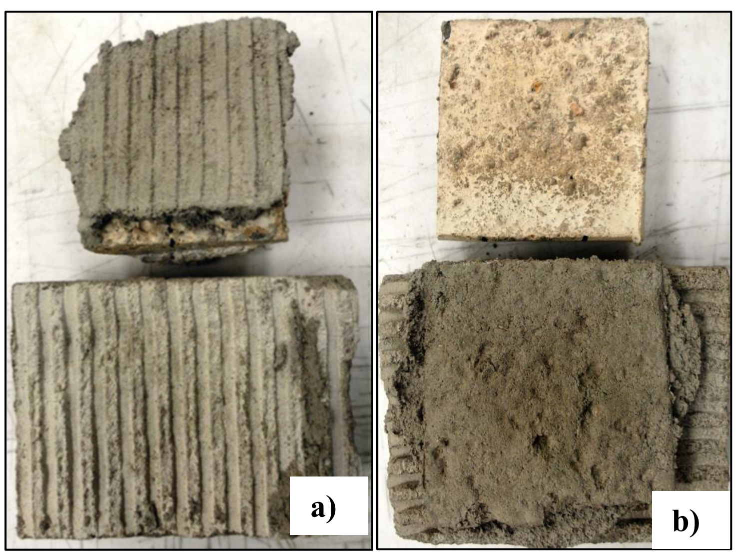

Figure 7: a) Shear bond failure, scratch coat/setting bed interface at 0.057 MPa.
b) Shear bond failure, stone unit/setting bed interface at 0.097 MPa.

The ANSI-A118.15 [1] thinset (improved modified dry-set cement) mortar only had one mode of failure (Figure 8) regardless if the substrate was a Type N simulated scratch coat, Type N simulated scratch coat with the structural WRB or cement board with the structural WRB.

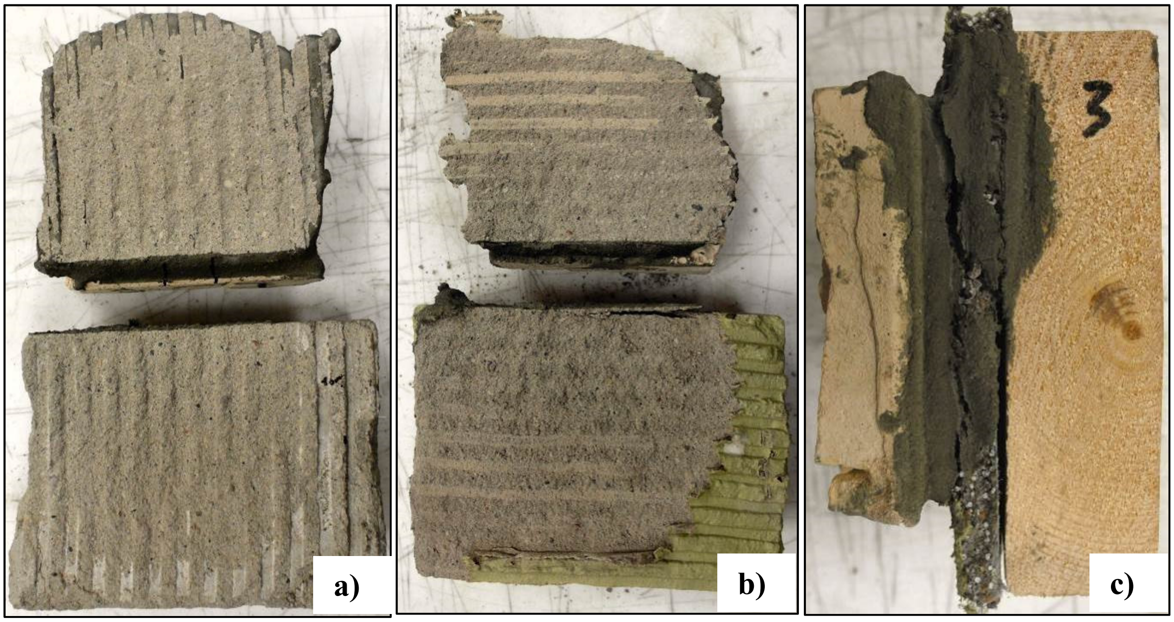

Figure 8: a) Shear bond failure, scratch coat/setting bed interface at 0.63 MPa. b) Shear bond failure, scratch coat + struct. WRB/setting bed interface at 0.55 MPa. c) Shear bond failure, cement board + struct. WRB/setting bed interface at 0.86 MPa.

Table 2 and Table 3 below provide the average values from testing of the shear bond strength depending on the failure mode. Table 4 below provides the maximum values from testing of the three samples tested for both the shear bond and tensile bond tests.

Table 2: Average Shear bond strength for Failure Mode I.

Failure at setting bed to stone unit interface for all four stone manufacturers		
Sample Assembly	**Average Shear Bond (psi)**	**Average Shear Bond (MPa)**
Type N scratch - Type N setting bed	15	0.10
Type S scratch - Type S setting bed	20	0.14
Type N scratch - Poly. Modified setting bed	30	0.21
Poly. Modified scratch coat - Poly. Modified setting bed	42	0.29

It can be seen from Table 4 that the maximum values obtained in the testing from all four stone brands (84 samples tested in total) was less than 0.35 MPa (50 psi) shear bond requirement of ASTM C1670 and ASTM C1780 when testing according to the modified ASTM C482-02 [4] procedure with the use of either Type N and Type S mortars for the setting. However the modifications to the ASTM C482-02 [4] made in this testing program better represent the installation methods for adhered manufactured stone veneer actually employed in Alberta. From Table 4 it can be seen that the use of polymer modified stone veneer mortars for the setting bed exceeded the 0.35 MPa minimum requirements with the maximum values from the tests. However, Table 1 and Table 2 demonstrate that the average results of the tests with a polymer modified stone veneer mortars setting bed did not achieve the 0.35 MPa minimum.

Figure 8 and Table 3 demonstrates that the use of an ANSI-118.15 [1] thinset (improved modified dry-set cement) mortar for the setting bed guarantees a Failure Mode II form of failure regardless of the substrate. The shear bond values exceed the 0.35 MPa minimum in each case. However the information from a Failure mode II is not as useful as it is the shear bond capacity of the substrate. For example, an average strength of 0.71 MPa (103 psi) for the cement board structural WRB and thin set mortar combination in Table 3 indicates that the shear capacity of the cement board is 0.71 MPa not the ultimate bond strength of the setting bed to the substrate or the setting bed to the stone unit.

Table 3: Average Shear bond strength for Failure Mode II.

Failure at setting bed to substrate interface for all four stone manufacturers		
Sample Assembly	**Average Shear Bond (psi)**	**Average Shear Bond (MPa)**
Type N scratch coat - Type N setting bed	19	0.13
Type S scratch coat - Type S setting bed	16	0.11
Type N scratch coat - Poly. Modified setting bed	32	0.22
Poly. Modified scratch coat - Poly. Modified setting bed	32	0.22
Type N scratch - ANSI-118.15 thinset setting bed	70	0.48
Type N & struct. WRB – ANSI-118.15 thinset setting bed	69	0.48
Cement board & struct. WRB - ANSI-118.15 thinset setting bed	103	0.71

Table 4 also demonstrates that the use of an ANSI 118.15 thinset (improved modified dry-set cement) mortar for the setting bed guarantees a Failure Mode II form of failure regardless of the substrate. The shear bond values exceed the 0.35 MPa minimum in each case. However the information from a Failure Mode II is not as useful as it is the shear bond capacity of the substrate. For example, an average strength of 0.71 MPa (103 psi) for the cement board structural WRB and thin set mortar combination in Table 3 indicates that the shear capacity of the cement board is 0.71 MPa not the ultimate bond strength of the setting bed to the substrate or the setting bed to the stone unit.

Table 4: Maximum Shear bond and Maximum Tensile bond strengths achieved in the test.

Sample Assembly	Max. Shear bond (psi)	Max. Tensile bond (psi)	Max. Shear bond (MPa)	Max. Tensile bond (MPa)
Type N scratch coat - Type N setting bed	21	14	0.14	0.09
Type S scratch coat - Type S setting bed	32	12	0.22	0.08
Type N scratch coat - Poly. Modified setting bed	57	33	0.39	0.23
Poly. Modified scratch coat - Poly. Modified setting bed	65	25	0.45	0.17
Type N scratch - ANSI-118.15 thinset setting bed	117	64	0.81	0.44
Type N & struct. WRB - ANSI-118.15 thinset setting bed	104	86	0.72	0.59
Cement board & struct.WRB - ANSI-118.15 thinset setting bed	183	69	1.26	0.48

CONCLUSIONS

The testing program represented an initial effort in establishing the shear and tensile bond strength of adhered stone veneers when modifying the ASTM C482 ceramic tile test and ASTM C952 tensile bond test standards to better represent an adhered stone assembly as constructed in a drystack configuration in Alberta. The testing program focused on establishing a reasonable shear and tensile bond strength for adhered stone installations with little emphasis on investigating the nature of the failures. Improvements to the shear bond testing method are needed to isolate the two distinct modes of failure. Further investigations into the nature of failures, is also recommended as future research initiatives.

The testing demonstrated that the use of thinset mortars for the setting bed typically achieve shear and tensile bond strengths 7 to 10 times greater than traditional Type N and Type S setting beds and virtually eliminate unit sag (unintended bearing of masonry units on one another). In the absences of additional testing, these mortars are recommended directly adhered thin masonry veneers are individually secured by mortar when the installation height is greater than 2 m (6.5 feet) above grade.

ACKNOWLEGEMENTS

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