14TH CANADIAN MASONRY SYMPOSIUM
MONTREAL, CANADA
MAY 16TH – MAY 20TH, 2021

# IN-FIELD SHEAR BOND STRENGTH TESTING OF ADHERED MASONRY VENEER

**Dillon, Patrick B.[1] and Dalrymple, Gerald A.[2]**

## ABSTRACT

Adhered Masonry Veneer (AMV) has increased in popularity in recent years and is becoming commonplace both in residential and commercial construction as an alternative to more conventional stone veneer systems. However, unlike stone veneer, AMV material characteristics and installation methods can vary considerably based on aesthetic considerations, manufacturer's installation requirements, and local installer means and methods. The variability of this application, coupled with detailing and integration challenges on the part of designers and specifiers, has led to an increase in AMV adhesion failures and durability problems.

Loss of adhesion has been observed to be one of the principal causes of failure of adhered masonry veneers. For over two decades, the TMS 402 prescriptive provisions have included requirements for the bond between the units and backing to develop a minimum shear strength of 345 kPa (50 psi). However, until recently there was no standardized test method that could be used for verifying the shear bond strength of installed AMV units in the field.

This paper presents a case study from an investigation in which in-field shear bond strength testing of AMV was performed for both investigation of an AMV failure and pre-construction quality control. The investigation employed a test methodology similar to that recently published in ASTM C1823. The field testing identified several insights regarding AMV installation and performance and highlights the importance of performing shear bond testing of AMV installations.

**KEYWORDS:** *adhered masonry veneer, adhered masonry stone veneer, ASTM C1823, field testing, shear bond testing, thin brick*

[1] Project Engineer II, WDP & Associates Consulting Engineers, Inc., Charlottesville, VA, United States, pdillon@wdpa.com

[2] Principal, WDP & Associates Consulting Engineers, Inc., Manassas, VA, United States, adalrymple@wdpa.com

## INTRODUCTION

Adhered masonry veneer (AMV) is a modern masonry system that has been developed to give the appearance of conventional masonry but at a lower cost. Unlike more traditional anchored veneer assemblies that are spaced away from the backup wall by an air cavity and laterally supported by veneer ties anchored to the backup, AMV is directly adhered to the backup. Multiple materials are used for adhering AMV units to the backup structure. TMS 602 [1] currently only addresses the installation of AMV using ASTM C270 [2] Type S mortar, which is the basic method that has been used since the 1950s [1] but is outdated and rarely used [3]. Today, there are numerous and varying applications methods and proprietary setting materials in use for AMV installations.

There are many challenges to installing AMV systems that are resilient for all the varying service conditions. Despite these challenges, the rate of AMV installations and number of products and methods for AMV installation have steadily increased over the years. Many of the varying methods for installing AMV are relatively new and do not have a long history of reliable service over time or documented testing to show their adequacy. In addition, unlike anchored masonry veneers which are installed by skilled masons, many AMV systems are not installed by skilled tradesmen or with adequate oversight or periodic inspections. As a result, there appears to be an increasing number of AMV failures on relatively new construction due to deficiencies in AMV installation.

Failures of AMV systems can occur via several possible failure modes: cohesive failure of the AMV unit, cohesive failure of the setting bed, cohesive failure of the substrate, structural failure of the substrate, adhesive failure between the AMV unit and setting bed, and adhesive failure between the setting bed and substrate. Cohesive failure of AMV units is generally not an issue if the units are fabricated in accordance with the applicable ASTM standard. Cohesive or structural failure of the substrate is generally not an issue unless incorrect or inadequate substrate materials are used.

TMS 402 requires AMV systems to either be installed in accordance with TMS 602 or to develop adhesion between the units and backing with a shear strength of at least 345 kPa (50 psi). Testing is to be performed in accordance with ASTM C482 [4], which is a laboratory test method for evaluating the bond strength of ceramic tile to portland cement paste. The test method only considers the bond strength between the unit and the mortar and neglects to evaluate the strength between the mortar and the backup. The scope of ASTM C482 does not provide an adequate representation of the bond strength of AMV under typical installed conditions. However, it appears that the recently developed ASTM C1823 [5] for testing of adhered dimension stone may be adapted to testing AMV systems.

This paper is the first in a two-paper series discussing the application of in-field direct shear bond strength testing to adhered masonry veneer (AMV) assemblies. This paper provides an overview of AMV systems and presents a case study of an investigation of AMV installations that included the use of in-field direct shear bond strength testing. The second paper [6] presents a discussion of adapting recently published test procedures in ASTM C1823 to field testing AMV assemblies.

## CASE STUDY

The authors recently performed in-field testing of AMV assemblies as part of an investigation to evaluate and repair an AMV failure. The in-field testing was performed for both forensic investigation of a partially failed AMV system and quality control testing of a newly installed AMV mockup panel. Both series of tests were performed on the same structure as part of the same investigation and repair project.

The project was located at a large theater structure in the southern United States. The exterior walls of the structure were constructed of reinforced concrete tilt-up panels. A complete remodel of the building was performed in the early 2010s during which the exterior paint was to be removed from the panels and replaced with an adhered manufactured stone veneer (AMSV) assembly. During the renovation, AMSV was installed on a total wall surface area of approximately 1,510 $m^2$ (16,200 $ft^2$). The AMSV units varied in size from approximately 150 $cm^2$ (24 $in^2$) to 1860 $cm^2$ (288 $in^2$). Approximately seven years after installation of the AMSV, portions of the veneer at one of the panels began to separate from the substrate and progressively collapse over the period of a month (Figure 1). Luckily, no persons were harmed during the veneer failure.

a) Initial Failure b) At Three Weeks c) At One Month

**Figure 1: Veneer Failure Progression**

### *Initial Investigation*

A forensic investigation was performed at the building to evaluate the cause of the failure and assess the risk for additional failures. The initial stage in the investigation was to remove the remaining AMV units at the failed panel to mitigate the risk of falling units and observe the conditions of the units and backup. At the time of the removal, only a few sections of the veneer remained on the panel, including a large section that had separated from the substrate except for at the corner (Figure 1c). As the removal proceeded, many of the units were removed by hand or with simple hand tools. Often, units would separate from the backup as adjacent units were removed or would come off in small groups. Overall, it appeared that the units were generally better bonded to each other by the joint mortar than they were to the backup.

The units removed during the initial stage of the investigation generally separated from the backup with the setting bed mortar still adhered to the backs of the units, indicating an adhesive failure at the substrate. A distinct comb pattern was visible in the setting bed mortar at all of the units (Figure 2), indicating that the units had been installed using a thin-set installation method but with insufficient pressure during setting for the mortar to spread and fill all of the voids. Significant voided areas were present on many of the units, particularly the larger units (Figure 2).

**Figure 2: Comb Pattern and Voids at Setting Bed Mortar**

Unit removal was repeated at the adjacent panel to determine if the conditions and potential for failure were the same as the failed panel. This panel had not exhibited failing units or other visible signs of potential failure. Some of the units appeared to be well bonded to the tilt-up concrete backing and necessitated the use of a rotary hammer with tile chisel bit for removal. Some of the veneer units appeared to have been debonded prior to demolition because they would come off with the adjacent unit. In general, the veneer removal became increasingly easier and faster as the demolition work progressed from top to bottom of the wall panel.

The removal of well-bonded units typically left some setting mortar bonded to the face of the backup and some of the well-bonded units came off in pieces. The poorly bonded or debonded units left little to no setting mortar bonded to the backup and generally came off intact and sometimes came off with adjacent units. Near ground level, a 17-square-foot section (Figure 3) separated and fell to the ground as one unit was being removed from the wall by hand.

The setting mortar on the units from the second panel generally showed the same notched trowel comb pattern as that observed at the failed panel, but the total voided area was generally less on units that came from the top portion of the panel (Figure 4). At the upper portion of the panel, much of the panel surface was still covered with remnants of setting mortar, indicating a combination of adhesive failure at the substrate and cohesive failure of the mortar. The condition of the setting mortar and observed failure modes became similar to those at the failed panel as the work progressed down the face of the wall.

**Figure 3: Area of Veneer that Fell as a Unit**

**Figure 4: Mortar Setting Bed Near Top of Second Panel**

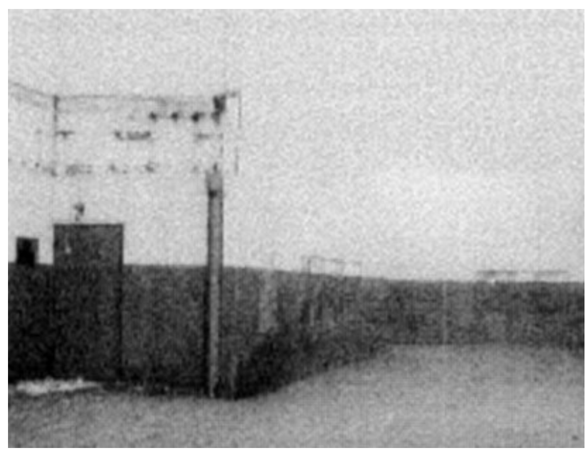
At both panels, the remnants of two different colored paint coatings were observed on the tilt-up concrete surface and adhered to the setting mortar on the back faces of many of the units (Figure 5). The coating from grade to about six feet above grade appeared to be shade of violet and above six feet the coating appeared to be a shade of white. The shades and patterns appeared to match those shown in the pre-renovation photographs of the building exterior (Figure 6). The coating near the top of the wall appeared to be in better condition and was better bonded to the concrete backup whereas the coating near the base of the wall was flaking off at many locations and would often come off with the unit.

(a) Violet-Colored Paint

(b) White-Colored Paint

**Figure 5: Paint Coatings Adhered to Back Side of Units**

(a) Paint Remaining on Backup after Demolition



(b) Paint Pattern Prior to Veneer Installation

**Figure 6: Comparison of Paint Color Pattern with Pre-Installation Photo**

After the initial stage of the investigation at the first two panels, the investigation proceeded to the remaining veneer panels using non-destructive investigation methods. During the visual observations, the bottom units at several locations were observed that had separated from the backup and were resting on grade. Sounding was performed from grade at selected locations to investigate the percentage of the veneer area that have may have been debonded. Approximately half of the area included in the sounding survey area appeared to be debonded from the backup. Based on the high proportion of debonded veneer area, additional testing was recommended to verify and quantify the net bond strength of the veneer.

***Shear Bond Testing for Forensic Investigation***

At the time of the investigation, there was no standard field test method available for shear bond testing of adhered masonry units. ASTM C1823 was still under development under the direction of ASTM Committee C18 on Dimension Stone. A shear bond test apparatus and test methodology were developed based on a draft of the ASTM C1823 standard. More details regarding the apparatus and test modifications are provided in the companion paper [6].

The locations of the shear bond testing were selected randomly among the veneer to obtain a representative sample of the various conditions, such as orientation and height. The test was performed by isolating the stone section to be tested. The perimeter mortar joints were removed using a diamond blade hand grinder to cut the joint mortar around the perimeter of the stone to the precast concrete substrate. Mortar fragments were then carefully removed via hand tools. Testable sections of stones were then isolated by saw cutting through the stone unit to the precast concrete substrate, typically in three passes, using an angle grinder with diamond blade. Remaining stone fragments were then carefully removed via hand tools. An example of a stone specimen prepared for testing is shown in Figure 7a. Stone specimen size was generally set to equal or exceed 230 $cm^2$ (36 $in^2$) based on information contained in the draft ASTM C1823 standard.

After preparation, the shear testing apparatus was mounted to the wall surface with proprietary concrete anchors (Figure 7b). The testing apparatus was leveled, and the loading plate was set at the contact level of the stone to bonding mortar. The loading plate was advanced until contact was made with the stone bearing surface. Load was applied to the test sample using a hydraulic ram powered via a hand pump. The failure load was recorded, and direct shear bond strength was calculated based on the gross stone specimen bond surface area.

Twelve of the test samples failed by debonding from the concrete back-up during the preparation of the samples for testing when exposed to small forces generated by hand grinders and hand tools. One sample failed as the shear testing apparatus was being mounted to the wall surface. All 13 test specimens that failed during test setup experienced failure of the adhesive bond between the mortar setting bed and substrate, indicating a significantly inadequate bond strength between the bonding mortar and substrate.

Seven stone samples exhibited sufficient adhesive bond to the precast concrete substrate to permit testing. Due to the prior failures of stone samples during preparation for testing, samples N6-15 and N6-16 were prepared to be tested as whole units in lieu of preparing smaller size test samples. Test sample N6-15, with a gross area of 715 $cm^2$ (111 $in^2$), failed at a shear bond stress of 31 kPa (4.5 psi). Test sample N6-16, with a gross area of 555 $cm^2$ (86 $in^2$), could not be tested to failure due to the stroke length of the loading ram being exceeded. After completion of testing at sample N6-16, test samples were prepared based on smaller sample sizes as previously discussed.

The direct shear bond strengths obtained from samples that were sufficiently bonded to permit testing ranged from a low of 30 kPa (4.4 psi) to a maximum shear bond stress of 227 kPa (32.9 psi).

These test results fell significantly below the prescriptive code-required minimum shear bond strength of 345 kPa (50 psi) for AMV systems. The field investigation revealed that the principal cause of the veneer failure was improper preparation of the substrate surfaces. Large, voided areas in the setting beds were also a significant contributing factor in the veneer bond failure. The field testing of the AMSV panels showed that the average shear bond strength of the veneer units was significantly lower than the code-prescribed minimum values. Based on these results, it was recommended that the existing AMSV units be completely removed and replaced, the precast concrete panel surface prepared, and the AMSV replaced.

(a) Joints Removed Around Specimen (b) Apparatus Mounted to Wall

**Figure 7: Photographs of Text Specimen Preparation**

***Shear Bond Testing of a Mockup Panel***

A protocol was developed for installation of a replacement veneer. Included within the protocol were requirements for substrate preparation and unit installation based on industry recommendations and requirements for quality assurance using in-field shear bond strength testing. A mockup panel was constructed at one of the previously demolished veneer panels to evaluate the effectiveness of sandblasting as a means of substrate preparation. The sandblasting produced a surface profile on the face of the tilt-up panel that corresponded to ICRI CSP 3 [7]. The sandblasting was able remove the majority of the remaining coating from the wall surface, but some small, isolated areas of coating remained. Observations were performed during the AMSV unit installation to verify that the installation protocol was being followed, namely that the units were being fully buttered and pressed into intimate contact with the backup.

Quality assurance testing was performed on the mockup panel 18 days after installation using the same apparatus and test methodology used during the field investigation. Early testing at 18 days, in lieu of 28 days, was performed in anticipation that the reinstallation project could be started sooner and that quality assurance testing during the execution of the overall installation could be performed at early stages to identify potential surface preparation and installation issues.

Eight specimens were tested: two whole units and three units that were each divided into two specimens. Overall, the total sample area included in the 18-day tests was approximately 3050 $cm^2$ (473 $in^2$). The area-weighted average gross bond strength of the 18-day tests was 356 kPa (51.7 psi), with half of the test samples falling below the code-prescribed 345 kPa (50 psi) minimum value. Since half of the test specimens did not meet the code requirements during the first round of mockup testing, a second round of quality assurance testing was performed after the mortar had cured for a minimum of 28 days.

(a) Substrate Preparation (b) Installed Mockup Panel

**Figure 8: Photographs of In-Place Mockup Panel**

The second round of testing was performed 34 days after installation using the same apparatus and methodology. Nine specimens were tested: one whole unit and four units that were each divided into two specimens. Overall, the total sample area included in the 34-day tests was approximately 3030 $cm^2$ (469 $in^2$). The average gross bond strength of the 34-day tests was 478 kPa (69.3 psi), which represented an increase of approximately 34% over the 18-day tests. The quality assurance testing verified that, with adequate substrate preparation and installation practices, the AMSV units could be installed at the concrete tilt-up panels to meet the code-required bond strength.

## RECOMMENDATIONS AND CONCLUSIONS

The results of all three series of tests are shown in Table 1. Within each of the three series of tests, a slightly positive correlation was observed between the net bond strength (in terms of stress) and the size of the test specimen. It appears that testing specimens cut from units yields slightly lower ultimate bond stress than testing whole units.

The shear bond testing at the mockup revealed that nearly all of the units tested contained voided areas or air pockets within the setting bed. Given that the mockup was installed with greater supervision than is reasonably anticipated during normal AMV installation, it is likely that voids and air pockets in setting beds are more frequent in AMV installations than the industry may realize. Since there has been no standardized field testing required of AMV installations to date, there is very little field data available regarding the quality of AMV installations to verify if the quantity of observed voids is an anomaly or are typical for AMV installations. The presence of voids and air pockets highlights the importance of periodic in-field testing of AMV installations to verify that the installation practices are achieving the code-required bond shear strength.

Based on the original construction submittals, the original units were adhered using a latex-portland cement mortar complying with ANSI A118.4 [8], which is capable of developing greater bond strengths than ASTM C270 mortars. ANSI A118.4 only addresses bond strength to ceramic tile and not to the substrate. As observed during this investigation, using a setting bed mortar with higher bond strength will not overcome shortcomings in substrate preparation or installation practices.

**Table 1: Results for Three Series of AMV Shear Bond Tests**

| Investigation | | | | Mockup Round 1 | | | | Mockup Round 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | Area, cm$^2$ | Stress, kPa | Notes | Test | Area, cm$^2$ | Stress, kPa | Notes | Test | Area, cm$^2$ | Stress, kPa | Notes |
| P3-10 | - | - | 1 | M1-1 | 260 | 322 | 4 | M2-1 | 286 | 300 | 3 |
| P3-11 | - | - | 1 | M1-2 | 199 | 486 | 6 | M2-2 | 261 | 423 | 3, 6 |
| P3-12 | - | - | 1 | M1-3 | 256 | 379 | 6 | M2-3 | 418 | 838 | 5, 7 |
| P3-13 | - | - | 1 | M1-4 | 260 | 431 | 3, 6 | M2-4 | 368 | 550 | 3 |
| N6-14 | - | - | 1 | M1-5 | 506 | 335 | 6 | M2-5 | 275 | 449 | 6 |
| N6-15 | 715 | 31 | | M1-6 | 321 | 330 | 6 | M2-6 | 370 | 506 | 3, 7 |
| N6-16 | 555 | 159 | 8, 10 | M1-7 | 369 | 293 | 3 | M2-7 | 367 | 480 | 3 |
| E5-17 | 272 | 211 | | M1-8 | 881 | 480 | 9, 10 | M2-8 | 351 | 308 | 3, 6 |
| E5-18 | - | - | 1 | | | | | M2-9 | 333 | 312 | 4 |
| E5-19 | 310 | 213 | | | | | | | | | |
| E5-20 | 243 | 72 | | | | | | | | | |
| E5-21 | - | - | 2 | | | | | | | | |
| W-22 | 290 | 30 | | | | | | | | | |
| W-23 | - | - | 1 | | | | | | | | |
| W-24 | - | - | 1 | | | | | | | | |
| W-25 | - | - | 1 | | | | | | | | |
| W-26 | - | - | 1 | | | | | | | | |
| W-27 | - | - | 1 | | | | | | | | |
| W-28 | - | - | 1 | | | | | | | | |
| W-29 | 252 | 227 | | | | | | | | | |
| W-30 | - | - | 1 | | | | | | | | |

**Notes Legend**

| | |
|---|---|
| 1 | Bond failed during specimen preparation. |
| 2 | Bond failed during test apparatus setup. |
| 3 | Not fully bedded at 1 corner |
| 4 | Not fully bedded at 2 corners |
| 5 | Large voided area at 1 edge |
| 6 | Air pockets observed in bedding mortar |
| 7 | Large air pocket observed in bedding mortar |
| 8 | Stroke length of ram exceeded. |
| 9 | Specimen exceeded capacity of test apparatus. |
| 10 | Test terminated before failure. |

Based on the findings of this investigation, the bond strength between the setting bed mortar and the backup is a critical failure mode that should be verified. Testing is especially important when AMV units will be bonded to previous construction. Current industry recommendations for substrate preparation are based on qualitative criteria, such as “sound;” “suitable for bonding;” “free of dirt, waterproofing, paint, form oil, or any other substance that could inhibit the mortar bond;” or “rough texture” [9]. These criteria are typically sufficient to produce strong bond strengths when the units and mortar are installed per the manufacturers’ instructions. The qualitative surface criteria are generally easy to satisfy in new construction but may be much more difficult to obtain when performing alterations to existing construction.

Existing concrete and masonry surfaces might require special surface preparation to be suitable for AMV installation. The required level of surface preparation is generally specified in terms of an ICRI CSP number [7]. The surface preparation procedures outlined in ICRI Technical Guideline 310.2 [7] provide varying degrees of cleaning and profiling. The surface preparation method used in the mockup created a surface profile greater than the required CSP number but left small, isolated areas of coating on the surface. Although the mockup backup was not completely "free" of the existing coating, it was sufficient for the mockup to develop an average bond shear strength greater than the code-required value. Without a quantitative measure of the surface performance, more invasive and costly preparation methods may have been required to create a surface that was free of the existing coating.

There are currently no requirements for special inspection of backup surfaces prior to installation of AMV units or during installation of AMV units. But even if inspections of the back were performed, there may be concealed underlying conditions that may affect the bond strength to the backup. In some cases, inspections using only qualitative criteria may force the installer into using overly intensive surface preparation methods. Bond strength testing provides a quantitative and objective measure that better represents a veneer installation's performance than qualitative criteria alone. Bond strength testing should be incorporated into the quality control procedures for AMV installation to ensure that the veneer will perform as intended.

There is currently no standard test method for verifying the adhesion between AMV units and the backup. The currently referenced standard, ASTM C482, does not address bond adhesion to any of the various backup materials. This case study has shown that the methodology of ASTM C1823 can be easily adapted for use in testing AMV installations in the field for both investigation of existing installations and construction quality control. The authors recommend that standardized test procedures be developed for testing AMV based on the existing ASTM C1823 methodology, either as a new standard or as guidelines for adapting ASTM C1823 to AMV testing.

## REFERENCES


[1] TMS 402/602 (2016). *Building Code Requirements and Specifications for Masonry Structures*, The Masonry Society (TMS), Longmont, CO.

[2] ASTM C270-19ae1 (2019). "Standard Specification for Mortar for Unit Masonry." ASTM International, West Conshohocken, PA.

[3] Thompson, J.; Bennett, R.; Dalrymple, G. A.; Clark, C.; Hochwalt, J.; and Trimble, B. (2019). "Proposed Changes to the TMS 402/602 Adhered Veneer Provisions." *Proceedings of the Thirteenth North American Masonry Conference*, Salt Lake City, UT, USA.

[4] ASTM C482-20 (2020), "Standard Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste." ASTM International, West Conshohocken, PA.

[5] ASTM C1823/C1823M-20 (2020), "Standard Test Method for Shear Bond Strength of Adhered Dimension Stone." ASTM International, West Conshohocken, PA.

[6] Dillon, P. B. and Dalrymple, G. A. (2021). "Adapting ASTM C1823 for Testing Adhered Masonry Veneer." *Proc. 14$^{th}$ Canadian Masonry Symposium*, Montreal, QC, Canada.

[7] ICRI 310.2R-2013 (2013). “Technical Guideline 310.2 – Selecting and Specifying Concrete Surface Preparation.” International Concrete Repair Institute, Saint Paul, MN.
[8] ANSI A118.4-14 (2014). “Modified Dry-Set Cement Mortar.” American National Standards Institute, Washington, DC.
[9] MVMA (2017). *Installation Guide and Detailing Options for Compliance with ASTM C1780*, 5th edition. Masonry Veneer Manufacturers Association, Herndon, VA.