

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

SPECIFICATION STRATEGIES FOR FIELD TESTING SUCCESS

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ABSTRACT

Although project documents often clearly define performance requirements for individual building enclosure components and systems, field quality control testing provisions are often underdeveloped. Since specification sections are typically written individually, based on finished work product, and materials may be covered in multiple specification sections, the difficult building enclosure details at interfaces between adjacent systems are not always effectively addressed. As such, the in-situ performance of building enclosures can remain inferior to specified criteria at these locations.

Simply specifying a test standard is likely insufficient for achieving the intended building enclosure performance. Opportunities exist to improve field quality control testing processes and procedures by means of developing project-specific testing matrices with input from building owners, designers, specifiers, consultants, manufacturers, and contractors. This session will include a summary of exterior wall field quality control tests associated with air and water barriers, windows, curtainwalls, and sealants. Lessons learned from a variety of projects will also be presented.

SPEAKERS

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SPECIFICATION STRATEGIES FOR FIELD TESTING SUCCESS

INTRODUCTION

Regardless of project delivery method, quantitative and qualitative project requirements are typically defined using both drawings and specifications (contract documents). Although specifications regularly define performance requirements for individual building enclosure components and systems, field quality control testing provisions are often underdeveloped and not communicated effectively.

This paper explores field quality control testing requirements associated with curtainwalls, air and water barriers (AWBs), and sealant joints, as well as inadequacies of current specification practices associated with these tests. Opportunities for improvement are also presented throughout. Specifications that include fully developed requirements for worthwhile and achievable field testing provide clear performance parameters for the constructed building.

FIELD QUALITY CONTROL TESTING

If implemented in a meaningful way, building enclosure field testing during construction can assess the adequacy of ongoing installation and provide opportunities to correct issues prior to project completion. Field testing is one process used to help ensure quality; however, quality does not have a universal definition. According to the Construction Specifications Institute (CSI), quality “refers to the project requirements established by the contract documents.” Thus, the definition of quality is always project-specific and requires forethought and coordination among building owners, designers, specifiers, consultants, manufacturers, and contractors. In addition, specifications reference industry standards that contain their own embedded definitions of quality and performance verification. Specifications must therefore anticipate and address conflicts and contradictions between industry standards and project-specific requirements.

Field testing performed during construction is often considered a quality control (QC) process; however, it also meets some qualifiers set forth in the definition of

quality assurance (QA). According to CSI, QA “refers to the procedures for guarding against defects and deficiencies before and during the execution of the work,” and QC “refers to the procedures for evaluating completed activities and elements of the design for conformance with the requirements.” It is not uncommon for the QC process of one work component to become the QA process for subsequent construction. As an example of this quality loop, pull-off adhesion testing is performed following air and water barrier (AWB) application. By definition, this appears to be a QC process (evaluating completed activities). However, AWB application is a prerequisite for cladding installation. Therefore, verifying adhesion of the AWB is also a QA process (guarding against defects before work execution) with respect to the work that follows. Despite this nuance, field testing during the construction phase will be referred to herein as a QC process.

CONTRACT DOCUMENTS

Drawings are most appropriately used to depict illustrative and quantitative project requirements, whereas specifications are used primarily to indicate qualitative requirements. Each specification section includes various materials and components that make up the final work product. For example, Section 072713 – Modified Bituminous Sheet Air Barriers, will include performance requirements for the exterior wall AWB system and should specify requirements for AWB materials, mastics, primers, and accessories. Similarly, Section 075419 – Polyvinyl Chloride (PVC) Roofing, will include performance requirements for the roofing system and may specify material requirements for the roof membrane, vapor retarder, insulation, termination bars, and ancillary system materials. However, specifications can fall short in providing a link between individual building components and performance requirements at transitions between components or systems.

The use of drawings is usually the best mechanism to illustrate/specify roof-to-wall transitions and continuity of the building enclosure control layers. However, unless

specifications are “closed” (single-source) and no substitutions are allowed, accurate transition details are often not fully developed until subcontracts are awarded and manufacturer products are selected and approved by the design authority and contractor. Reliance on delegated design, in which specific design information is generated by a supplier and not available during the design phase, complicates the development of effective and comprehensive integration details within the contract documents.

To properly specify an exterior wall AWB for a generic commercial building constructed of cold-formed steel-stud exterior walls sheathed with glass-mat gypsum sheathing and a roof with steel decking and concrete topping, there will likely be at least four additional specification sections associated with the structure and substrates that requires coordination with the exterior wall AWBs and roofing system specifications:

- Section 033000 – Cast-in-Place Concrete
- Section 053123 – Steel Roof Decking
- Section 054000 – Cold-Formed Metal Framing
- Section 061600 – Glass Mat Sheathing

The interfaces between adjacent systems and components and the structure and substrates supporting finished work products for the building enclosure control layers may introduce significant variables that can affect the in-situ performance of finished work. However, these variables are typically not accounted for when specifying performance requirements and materials (Part 2 of Specifications) and field QC testing requirements (Part 3 of Specifications). *Figure 1* presents examples of sections typically found in the three parts of individual CSI specification sections. Items related to the topic of this paper are boxed in red.

While rarely implemented in modern construction projects, complete field QC testing information should clearly define the field QC process by answering “who, what, where, how, and when,” as presented in

PART 1 – GENERAL	PART 2 – PRODUCTS	PART 3 – EXECUTION
PRICE AND PAYMENT PROCEDURES Allowances Unit Prices Alternates	OWNER-FURNISHED PRODUCTS New Products Existing Products	EXAMINATION Verification of Conditions Preinstallation Testing Evaluation and Assessment
ADMINISTRATIVE REQUIREMENTS Coordination Sequencing Scheduling	SYSTEMS / ASSEMBLIES / MATERIALS Description Performance / Design Criteria Fabrication	PREPARATION Protection of In-Place Conditions Surface Preparation Demolition / Removal
SUBMITTALS Product Data Shop Drawings Manufacturers' Instructions	ACCESSORIES	ERECTION / INSTALLATION Special Techniques Interfaces with Other Work Tolerances
QUALITY ASSURANCE Qualifications / Certifications Preconstruction Testing Mock-Ups	SOURCE QUALITY CONTROL Tests and Inspections Non-Conforming Work Manufacturer Services	FIELD QUALITY CONTROL Field Tests and Inspections Non-Conforming Work Manufacturer Services

Figure 1 – Abbreviated summary of recommended CSI specification SectionFormat.

Figure 2. Once a QC test is clearly specified, a definitive statement of what exactly constitutes success or failure is also necessary.

While the necessity of some of these items may seem obvious, others are more often—and perhaps understandably—overlooked. Specifiers must be aware that simply stipulating a test standard will

ITEM	WHO	WHAT	WHERE	HOW	WHEN
COMPONENT / SYSTEM TO BE TESTED		X			
QUANTITY / TIMING OF TESTS		X			X
LOCATIONS OF TESTS			X		
TEST STANDARD / DESCRIPTION OF TEST				X	
TEST METHOD / METHODOLOGY				X	
PASS/FAIL CRITERIA				X	
PARTY RESPONSIBLE FOR TESTING / REPORTING	X				
REPORTING REQUIREMENTS		X		X	
REQUIRED ADDITIONAL TESTING IN CASE OF FAILED TESTS	X	X	X	X	X
PARTY RESPONSIBLE FOR COSTS ASSOCIATED WITH FAILED TESTS	X				

not necessarily provide all information regarding test implementation. For instance, some industry standards describe multiple test methods, and further elaboration is required to completely define the desired extent and breadth of testing. Furthermore, pass/fail criteria must be supplemented with information regarding the inevitable case of failed tests. For example, consider a particular test location that fails the initial field QC test and is subsequently remediated and retested until performance is deemed satisfactory. Most would agree that it would be judicious to test (and remediate and retest, if needed) locations with similar details throughout the project, perhaps using a random sampling protocol. Including such language in specifications, along with specifying the party responsible for costs associated with remediation and retesting, can smooth the path to a robust field QC testing protocol and a high-performing building enclosure.

Figure 2 – The “Who, What, Where, How, and When” of field QC testing specifications.



Figure 3 – Spray rack water testing performed on glazed curtainwall.



Figure 4 – Calibrated spray nozzle testing performed on glazed curtainwall.

CURTAINWALLS

Field QC water testing of curtainwalls is specified for most commercial construction projects. Spray rack water testing and calibrated spray nozzle testing are two common test methods.

Spray Rack Water Testing

ASTM E1105-15, *Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*, requires a test chamber and vacuum pump to apply differential pressure across the curtainwall during testing. AAMA 503-14, *Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems*, incorporates requirements of ASTM E1105 and is often specified in lieu of ASTM E1105 (Figure 3).

Calibrated Spray Nozzle Testing

Curtainwall water testing is sometimes also (or exclusively) specified by means of AAMA 501.2-15, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems*. This test method employs the use of a calibrated spray nozzle to spray water at localized areas of the curtainwall (Figure 4).

Curtainwall Specifications

Figure 5 paraphrases three different field QC specifications that have recently been issued for construction.

The field QC testing specifications for Project A are lacking in information. The most glaring omission is that although calibrated spray nozzle testing is specified, the extent and locations for testing are not.

Additionally, Project A specifies repair and retesting at failed test locations, but does not specify the party responsible for costs associated with the repair and retesting.

Project B specifies that curtainwall systems that do not pass water penetration field QC tests will be considered defective but does not specify test parameters, complete pass/fail criteria, information regarding how to address defective curtainwall systems, and the party responsible for retesting costs. Additionally, it is critical for specifications to include test parameters, such as the required differential test pressure for water penetration tests. The definition of water penetration or leakage should also be specified.

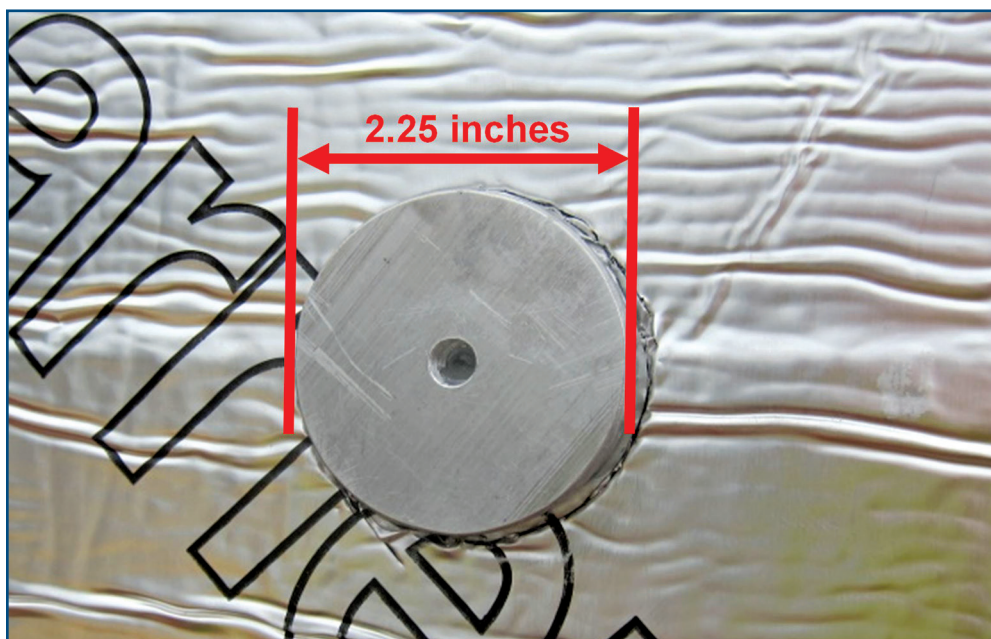
Note that ASTM E1105 defines water penetration (i.e., the default pass/fail criteria) as “penetration of water beyond a plane parallel to the glazing (the vertical plane) intersecting the innermost projection of the test specimen, not including interior trim and hardware, under the specified conditions of air pressure difference across the specimen.” Nonetheless, the authors recommended that water penetration or leakage be explicitly defined in the specifications because other standards for water testing—such as AAMA 501.2-15 and AAMA 503-14—have variations to the definition presented in ASTM E1105. A clear definition of water penetration or leakage would be a beneficial addition to all three of the project specifications presented in Figure 5.

PROJECT A	
A.	Test installed curtainwalls for water penetration resistance according to AAMA 501.2.
B.	Repair curtainwall components that have failed field testing and retest until performance is satisfactory.
PROJECT B	
A.	Water Penetration Test: Test installed curtainwalls for water penetration in accordance with ASTM E1105. Perform a minimum of two tests in areas as directed by the Architect.
B.	Curtainwall systems will be considered defective if they do not pass tests and inspections.
C.	Prepare test and inspection reports.
PROJECT C	
A.	Owner will engage a qualified testing agency to perform tests and inspections.
B.	Test Area: Perform tests on representative areas of curtainwall as selected by Architect.
C.	Field Quality Control Testing <ul style="list-style-type: none"> 1. Water-Spray Tests: Testing according to AAMA 501.2 and shall not evidence water penetration. Perform a minimum of three days of testing. 2. Air Infiltration Tests: Test according to ASTM E783 with a maximum allowable air infiltration rate of 1.5 times the rate specified for laboratory testing. 3. Water Penetration Tests: Testing according to ASTM E1105 at a minimum uniform static air pressure differential of 0.67 times the pressure differential specified for laboratory testing shall not evidence water penetration. 4. For each unsuccessful field test, perform repairs and retest. Also, another similar sample installation shall be selected and tested in addition to the areas originally chosen for testing. Any repairs or remediation conducted to pass a test must be implemented throughout the project. Contractor is responsible for costs associated with repairs, retesting, and additional required testing if it is determined that retesting is due to Contractor incompliance.
D.	Prepare test and inspection reports.

Figure 5 – Examples of curtainwall field QC specifications.

PRACTICE	ASTM D4541	ASTM D7234	ABAA 0002
Scoring around Specimen	Referenced Device: Scoring tool or circular hold cutter, or similar tool. May be required for thick-film, reinforced, and elastomeric coatings. When performed, use extreme care and clearly report with results. Ensure cut is normal to coating surface in manner that does not twist or torque test area and minimizes heat generation, edge damage, or microcracks.	Referenced Device: Core bit with drill press or hand drill. Required for coating thicker than 20 mils and for all reinforced and elastomeric coatings. Recommended for coating thinner than 20 mils. Ensure cut is normal to coating surface in manner that does not twist or torque test area and minimizes heat generation, edge damage, or microcracks.	Referenced Device: Utility knife or circular hole cutter Scoring of AWB around loading fixture is explicitly included in procedure. When using circular hole cutters, to avoid friction resulting in torsion applied to the bond interface and heat generation, a cutter with a kerf at the cutting edge is suggested.
Maximum Load Rate	150 psi/sec	30 psi/sec	0.97 psi/sec (58 psi/min) or 6 crank revolutions/min
Maximum Test Duration	100 sec	30 sec	Not specified
Definition of Failure (Termination of Test)	Test is completed when fixture detaches from substrate, pass/fail criteria is met, or maximum pull strength for instrument is reached.	Record force attained at failure. Failure is not explicitly defined.	Record force attained at failure. Failure is not explicitly defined.
Number of Tests	At least 3 replications to statistically characterize a test area.	At least 3 replications to statistically characterize a test area.	At least 3 replications to statistically characterize a test area (39 inches by 39 inches). Three pulls shall be considered a single test.
Size of Loading Fixture	Not specified (Loading fixture descriptions for different types of portable adhesion testers provided in Annexes)	Not specified (Paragraph 6.1.1 states that round loading fixtures are usually 2 inches in diameter, but diameter may range from 0.75 to 3 inches)	2.25 inch diameter Minimum thickness: 6 mm (metal) 15 mm (plywood)

Figure 6 – Pull-off adhesion testing; abbreviated summary of ASTM D4541, ASTM D7234, and ABAA 0002.



Field QC testing specifications for Project C are more complete than those for the other two projects presented, and most of the items listed in *Figure 2* are covered. This project example was not chosen because of what is missing in the specifications but rather for what is included. Project C specifies air infiltration testing in addition to both spray rack and calibrated spray nozzle testing. Not only should designers consider if multiple forms of water testing are necessary, but they should also consider the inadequacies of in-situ air infiltration testing of continuous curtainwalls according to ASTM E783, *Standard Test Method for Field Measurement of Air Leakage through Installed Exterior Windows and Doors*.

In order to meet the overall error limit defined in ASTM E783, extraneous air leakage must be no more than 50 percent of the total air flow measurement. This is nearly impossible to achieve on continuous systems, as the test area typically cannot be isolated from the surrounding areas due to communicative pathways in multistory curtainwalls or ribbon windows with continuous sill receptors. As such, air infiltration testing of continuous systems according to ASTM E783 is typically not recommended.

AIR AND WATER BARRIERS

Many project specifications stipulate field QC testing of the AWB material and/or limited areas of the AWB assembly.

Figure 7 – Loading fixture applied to AWB in preparation for pull-off adhesion testing.

PRACTICE	PARAGRAPHS
Building Depressurization (or Pressurization) with Infrared Scanning Techniques	4.2.1 and 7.2 to 7.2.5
Smoke Tracer or Theatrical Fog in Conjunction with Building Pressurization or Depressurization	4.2.2 and 7.3 to 7.3.3
Building Depressurization (or Pressurization) in Conjunction with Airflow Measurement Devices, or Anemometers	4.2.3 and 7.4 to 7.4.4
Generated Sound in Conjunction with Sound Detection	4.2.4 and 7.5 to 7.5.5
Tracer Gas	4.2.5 and 7.6 to 7.6.4
Chamber Pressurization or Depressurization in Conjunction with Smoke Tracer or Theatrical Fog	4.2.6 and 7.7 to 7.7.5
Chamber Depressurization in Conjunction with Leak Detection Liquid	4.2.7 and 7.8 to 7.8.6

Figure 8 – Seven test methods included within ASTM E1186-2017.

Pull-Off Adhesion Testing

ASTM standards for pull-off adhesion testing of AWB materials have traditionally been specified by means of ASTM D4541-17, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers* and/or ASTM D7234-12, *Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers*. Although both of these standards provide useful information regarding pull-off adhesion testing, they were developed for other applications before the widespread use of AWBs. As such, the Air Barrier Association of America (ABAA) recently issued ABAA 0002-2017, *Standard Test Method for Pull-Off Strength of Adhered Air and Water Resistive Barriers Using an Adhesion Tester*, a test method developed specifically for AWBs. There are significant differences between these standards, and an abbreviated summary of these test standards is indicated in Figure 6.

One significant variation among these test standards is the maximum load rate. ASTM D4541 specifies a maximum load rate up to 150 pounds per square in. (psi) per second. For AWBs,

the failure load is generally not more than 50 psi. Even at this upper bound for pull-off adhesive strength, ASTM D4541 allows the test duration to be anywhere from a fraction of a second to 100 seconds. The load rate can significantly affect the results when testing AWBs, as a very rapid load will often artificially inflate test results. ASTM D7234 specifies a lower maximum load rate, but still permits a large range. The maximum

load rate specified in ABAA 0002 is the most practical for current applications and is the recommended practice for testing AWBs.

Another notable variation among the test standards is the size of the loading fixture. The size is unspecified in ASTM D4541 and ASTM D7234, but ABAA 0002 indicates both a diameter and thickness. Different-sized loading fixtures introduce variability in test results and should be a consideration for specifiers (Figure 7).

Air Leakage Site Detection

Limited AWB assembly or transition testing is sometimes specified by means of ASTM E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*. However, this standard includes seven different test methods embedded within the document, as listed in Figure 8. Chamber Depressurization in Conjunction with Leak Detection Liquid (colloquially referred to as bubble gun testing) is often used in practice in accordance with Paragraphs 4.2.7 and 7.8 (Figure 9).



Figure 9 – Bubble gun device used for air leakage site detection.

AWB Specifications

Figure 10 paraphrases three different field QC specifications that have recently been issued for construction.

Field QC specifications for Project A references ASTM D4541 and indicates a minimum adhesion value but does not specify the type of substrate for which this requirement applies. Based on experience with glass-mat gypsum sheathing, substrate cohesive failure is often encountered before a pull-off value of 30 psi is attained; therefore, verifying an adhesive strength between the AWB and a glass-mat gypsum substrate of 30 psi is unlikely. For a test resulting in substrate cohesive failure (Figure 11),

the pull-off value obtained is indicative of a lower bound for the adhesive strength between the AWB and substrate. Any additional adhesive pull-off strength above the substrate cohesive strength value is moot. In addition to a cohesive failure within the substrate, specifications should mention other possible failure modes. In our experience, it is reasonable to categorize passing tests for any of the following situations:

1. Adhesive failure occurs between the AWB and substrate at a load greater than the minimum adhesive strength specified.
2. Cohesive substrate failure occurs before adhesive failure between the

AWB and substrate.

3. Epoxy used to attach the load fixture to the AWB fails at a stress greater than the minimum adhesive strength specified.
4. No failure occurs, but the specimen was loaded to a stress that was greater than the minimum adhesive strength specified. This could occur if the maximum strength for the loading apparatus is reached.

The newest revision of ASTM D4541 addresses the variety of failure modes described above by introducing two options for testing: Protocol 1 (test to fracture) and Protocol 2 (pass/fail test). Figure 12 is adapted from ASTM D4541-17 and presents a flow chart for reporting the results when following either protocol. Specifiers should be aware of this change and indicate which protocol should be followed. Protocol 2 is preferable for field QC testing of AWBs.

Field QC specifications for Project B also require testing in accordance with ASTM D4541, but minimum pull-off adhesion strength is not specified. There is limited publicly available research regarding minimum adhesive strength values, and many manufacturers of self-adhered AWB sheet materials do not publish pull-off adhesive strength test results. Results of recent field pull-adhesion tests performed by our office indicate average pull-off adhesive values of approximately 18 psi for self-adhered membranes installed on glass-mat gypsum sheathing.

PROJECT A

- A. Adhesion Testing: Test AWBs for minimum adhesion of 30 lbf/sq. in. according to ASTM D4541 for each 600 sq. ft. of installed AWB.
- B. AWBs will be considered defective if they do not pass tests and inspections. Remove and replace deficient AWB components, and retest.

PROJECT B

- A. Test: As determined by testing agency from among the following tests:
 1. Air-Leakage-Location Testing: AWBs will be tested for evidence of air leakage according to ASTM E1186, chamber pressurization or depressurization with smoke tracers or ASTM E1186, chamber depressurization using detection liquids.
 2. Adhesion Testing: AWBs will be tested for required adhesion to substrate according to ASTM D4541 for each 600 sq. ft. of installed AWB.
- B. AWBs will be considered defective if they do not pass tests. Remove and replace deficient AWB components for retesting as specified above.
- C. Repair damage to AWBs caused by testing.
- D. Prepare test and inspection reports.

PROJECT C

- A. Qualitative Air-Leakage Testing: Test AWBs for evidence of air leakage according to ASTM E1186.
- B. AWBs will be considered defective upon failure of inspections and specific testing required. Remove and replace deficient AWBs for retesting as specified above. Contractor shall be responsible to pay for retesting of assemblies failing the initial tests.
- C. Repair damage to AWBs caused by destructive testing.

Figure 10 – Examples of AWB field QC specifications.



Figure 11 – Examples of cohesive failure within a glass-mat gypsum sheathing substrate. The left photograph shows failure within the gypsum core and the right photograph shows failure of the glass-mat facer.

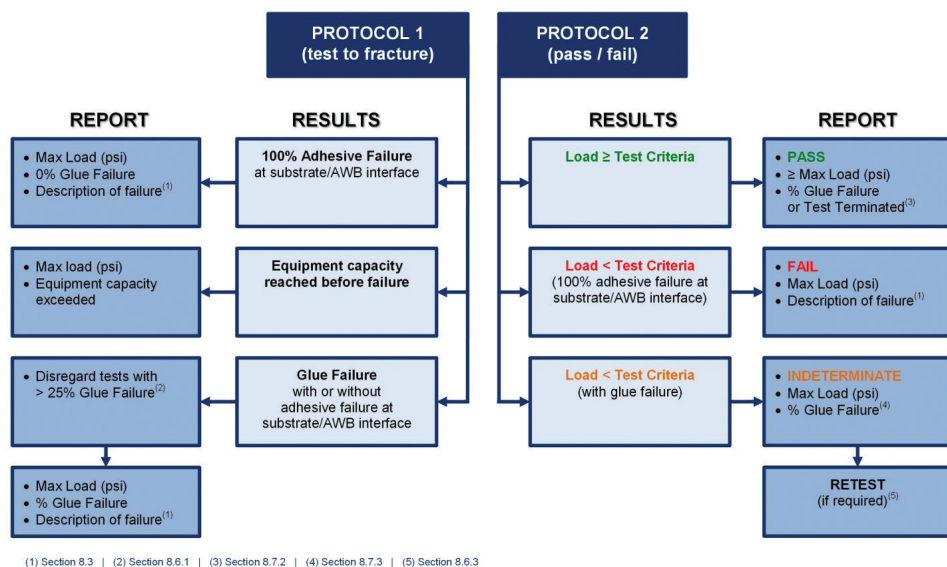


Figure 12 – Flow chart of results and reporting requirements for ASTM D4541 testing protocols (adapted from Fig. 2 flow chart from ASTM D4541-17 for AWB testing).

Project B also specifies ASTM E1186 testing. The specifications permit the test agency to select between chamber pressurization or depressurization using smoke tracers or chamber depressurization using detection liquids. For the case of bubble gun testing, the specifications do not indicate the operating parameters (i.e., the depressurization rate) or the pass/fail criterion (i.e., the depressurization limit). These values are essential for developing complete field QC specifications for bubble gun testing.

Project C specifies ASTM E1186 testing, but does not specify which of the seven test methods are to be implemented. Additionally, Project C does not specify any operating parameters or pass/fail criteria. Although the extent of remediation and retests are also unspecified, the specifications at least indicate that the contractor is responsible for costs associated with retesting.

SEALANT JOINTS

Field QC testing of field-applied joint sealants often includes adhesion testing of the sealant to the substrate.

Sealant Adhesion Testing

Sealant adhesion testing is usually specified via ASTM C1521-13, *Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints*. Method A for the “Tail” test procedure described within the standard is the appropriate test method for adhesion testing. Alternatively, sealant adhesion testing is sometimes specified via ASTM C1193-16, *Standard Guide*

for Use of Joint Sealants. Previous versions of ASTM C1193 (ASTM C1193-11a and older) included descriptions of the field adhesion testing method in Appendix X1, *Test Methods to Determine Sealant Adhesion*

Characteristics in Situ. Method A (Field-Applied Sealant Joint Hand Pull Tab), which bears similarities to Method A for the “Tail” test procedure in ASTM C1521, is commonly specified when referring to Appendix X1 of ASTM C1193. In the current version of ASTM C1193, however, field test methods are no longer included, and Appendix X1 is now a general index for the guide. In fact, ASTM C1193 references ASTM C1521 in multiple paragraphs as the standard for field adhesion test methodology. To avoid contradictions, specifiers should be well versed in the latest revisions to test standards. Specifiers must also be cognizant that manufacturers may have different and/or additional requirements than indicated in ASTM standards and, as such, clarifications to the ASTM standards may be required.

Joint Sealant Specifications

Figure 13 paraphrases two different field QC specifications that have recently been issued for construction.

Project A describes a test method similar to the methods presented in ASTM C1521;

PROJECT A

- A. Extent of Field Adhesion Testing:
 1. Perform 10 tests for the first 1000 feet of joint length for each type of exposed exterior wall sealant and joint substrate. Perform 1 test for each 1000 feet of joint length thereafter.
- B. Field adhesion testing of sealants shall take place in the presence of a qualified technical representative of the sealant manufacturer.
 1. Test Method: Test joint sealants by hand-pull method described below:
 - a. Make knife cuts from one side of joint to the other, followed by two cuts approximately 3 inches long at sides of joint and meeting cross cut at one end. Place a mark 1 inch from cross-cut end of 3-inch piece.
 - b. Use fingers to grasp 3-inch piece of sealant between cross-cut end and 1-inch mark; pull firmly at a 90-degree angle to the joint in the direction of side cuts and hold the sealant in this position for 10 seconds; following the 10-second time duration pull sealant at a 180-degree angle parallel to the joint and hold the sealant in this position for 10 seconds. Pull sealant away from joint to the distance recommended by sealant manufacturer for testing adhesion.
 - c. For joints with dissimilar substrates, check adhesion to each substrate separately.
 2. Sealant manufacturer's qualified technical representative shall record test results, and observations of joint and sealant conditions, in a field adhesion test log.
 3. Repair tested joint sealants as recommended by sealant manufacturer.
 4. Sealant manufacturer shall provide written documentation of changes in product and/or application method required to address sealant failure, observe and document retesting as required by the Architect, and provide a written statement of compliance with applicable warranties.
- C. Remove sealants that fail to adhere to joint substrates during testing or to comply with other requirements. Retest failed applications until test results prove sealants comply with indicated requirements.

PROJECT B

- A. Field Adhesion Testing:
 1. Extent of Testing: Perform 1 test for each 300 feet of joint length.
 2. Test Method: Test joint sealants according to Method A, Field-Applied Sealant Joint Hand Pull Tab, in Appendix X1 in ASTM C1193 or Method A, Tail Procedure, in ASTM C1521.
- B. Evaluation of Field Adhesion Test Results: Sealants not evidencing adhesive failure from testing or noncompliance with other indicated requirements will be considered satisfactory. Remove sealants that fail to adhere to joint substrates. Retest failed applications until test results comply with indicated requirements.

Figure 13 – Examples of joint sealant field QC specifications.

however, an industry-recognized test standard is not referenced. Additionally, specific conditions on which to report when inspecting tested sealant joints, such as the presence of voids and sealant dimensions, are not specified.

Project B specifies two options for a standard test method—one of which is the now-obsolete reference to Appendix X1 of ASTM C1193—but does not specify the conditions on which to report when inspecting tested sealant joints. Paragraph 8.5 in ASTM C1521 notes that “photographs of test areas can be useful in studying and comparing adhesion results”; however, there is no mandatory language in the standard that requires photographs to be included in test reports. It is good practice to include specification language that requires photographic documentation of the sealant condition and geometry and for this information to be documented in sealant adhesion test reports.

Neither Project A nor B specifies the extent of sealant that should be removed and retested in the case of failed tests. For example, the specifications could be improved by indicating a minimum length in either direction of the failed test location of sealant that requires removal and replacement. The specifications could also be improved by indicating a minimum num-

ber of additional tests required when a failure is reported, and the party responsible for the costs associated with remediation and retesting.

FIELD QUALITY CONTROL TESTING MATRICES

Decisions regarding the extent and timing of field QC testing include cost-versus-risk tradeoffs. Ideally, project specifications include all information to define requirements for field QC testing. However, the realities of modern construction projects in which subcontracts are awarded prior to completion of construction documents do not always allow a linear process to occur. Due to the quantity of variables involved and the continued use of integrated project delivery methods, final field QC testing protocols can sometimes be more appropriately developed with input from owners, designers, enclosure consultants, construction managers, subcontractors, and manufacturers during design development. Informed cost-versus-risk decisions regarding the extent of testing can then be made by owners. Completed matrices should be incorporated in project specifications prior to issuance of construction documents.

The use of field QC testing matrices can be used as a bridge solution until some variant of building enclosure commission-

ing becomes more prevalent throughout the industry. Such matrices are visual summaries indicating field quality control tests on one axis and testing requirements on the other axis. *Figure 14* illustrates an example of a base matrix for multiple enclosure components and systems, and *Figure 15* shows an expanded example column for curtainwalls.

In most cases, an independent building enclosure consulting/testing firm retained by the owner is the most appropriate entity to assemble the field quality control testing matrix. The matrix should reflect the owner’s project requirements, the architect’s basis of design, and the requirements of project specifications. The matrix should be comprehensive enough to be executed by the developer of the matrix or by any other qualified testing entity retained to perform field testing.

SUMMARY AND CONCLUSION

According to the CSI, “Four Cs” are required for effective specifications:

- Clear: Use proper grammar and simple sentence construction to avoid ambiguity.
- Concise: Eliminate unnecessary words, but not at the expense of clarity, correctness, or completeness.


ITEM	Curtainwall	AWB	Joint Sealants	Roofing System	Waterproofing	Transitions
Component / System						
Quantity / Timing Of Tests						
Locations Of Tests						
Test Standard / Description						
Test Method / Methodology						
Pass/Fail Criteria						
Party Responsible For Testing / Reporting						
Reporting Requirements						
Required Additional Testing In Case Of Failed Tests						
Party Responsible For Costs Associated With Failed Tests						

Complete column headers with project-specific building enclosure systems and components requiring testing

Complete each box of the matrix with appropriate information (who, what, where, how, when) for specified systems and components

Figure 14 – Field QC testing matrix – base example.

- Correct: Present information accurately and precisely. Carefully select words that convey exact meanings.
- Complete: Do not leave out important information.

In order to achieve the “Four Cs,” field QC testing paragraphs in Part 3 of specifications must include information regarding the “who, what, where, how, and when” with respect to testing. The authors recommend including additional Cs such as criteria for success/failure, and communication, coordination, and collaboration between parties and project stakeholders when developing a project-specific field QC testing matrix. Implementing meaningful field QC testing can provide a level of assurance that installed enclosure components/systems will meet specified performance criteria. 

REFERENCES

AAMA Standard 501.2, *Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls and Sloped Glazing Systems*. AAMA, Schaumburg, IL, 2015.

AAMA Standard 503, *Voluntary Specification for Field Testing of Newly Installed Storefronts, Curtain Walls and Sloped Glazing Systems*. AAMA, Schaumburg, IL, 2014.

ABAA Standard 0002, *Standard Test Method for Pull-Off Strength of Adhered Air and Water Resistive Barriers Using an Adhesion Tester*. ABAA, 2017.

ASTM Standard C1193, *Standard Guide for Use of Joint Sealants*. ASTM International, West Conshohocken, PA, 2011. DOI: 10.1520/C1193-11. www.astm.org.

ASTM Standard C1193, *Standard Guide for Use of Joint Sealants*. ASTM International, West Conshohocken, PA, 2016. DOI: 10.1520/C1193-16. www.astm.org.

ASTM Standard C1521, *Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints*. ASTM International, West Conshohocken, PA, 2013. DOI: 10.1520/C1521-13, www.astm.org.

ITEM	Curtainwall
Component / System	Unitized curtainwall
Quantity / Timing Of Tests	3 tests at approximately 20%, 50%, and 80% completion. Allow internal and perimeter seals adequate time to cure prior to testing.
Locations Of Tests	See attached sketch. Each test location shall be 3 unitized panels wide by 1 panel tall.
Test Standard / Description	ASTM E1105-15
Test Method / Methodology	Procedure A, uniform static air pressure difference (Paragraph 12.1 of ASTM E1105-15). Uniform static air pressure difference of 10 psf shall be applied across the test specimen during each test.
Pass/Fail Criteria	Failure is defined as water penetration in accordance with ASTM E1105-15, Paragraph 3.2.3 – penetration of water beyond a plane parallel to the glazing (the vertical plane) intersecting the innermost projection of the test specimen. Failure is further defined as a collection of more than 0.5 ounce of water on top of an interior horizontal framing member surface as described in AAMA 503-14.
Party Responsible For Testing / Reporting	Building enclosure consultant retained by owner (costs borne by owner). Contractor shall provide boom lift to allow access to test areas, and ensure areas near test areas are clear of ongoing work.
Reporting Requirements	ASTM E1105-15, Paragraph 13.1. Additionally, include 1) a list of witnesses during testing, and 2) a minimum of 10 representative photographs. Issue reports within 5 days of test completion.
Required Additional Testing In Case Of Failed Tests	For each unsuccessful field test, perform repairs and retest. Also, Architect shall select another area (similar size and access requirements) for additional testing. Repairs required to pass a test must be implemented throughout the project. Repairs which increase maintenance requirements of the curtainwall will not be permitted.
Party Responsible For Costs Associated With Failed Tests	Contractor responsible for costs associated with repairs, retesting, additional required testing, and any forensic investigations.

Figure 15 – Curtainwall testing requirements (expanded example to be included in matrix).

ASTM Standard D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. ASTM International, West Conshohocken, PA, 2017. DOI: 10.1520/D4541-17, www.astm.org.

ASTM Standard D7234, *Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers*. ASTM International, West Conshohocken, PA, 2012. DOI: 10.1520/D7234-12, www.astm.org.

ASTM Standard E783, 2002 (2010). *Standard Test Method for Field Measurement of Air Leakage through Installed Exterior Windows and Doors*. ASTM International, West Conshohocken, PA, 2006. DOI: 10.1520/E0783-02R10, www.astm.org.

ASTM Standard E1105, *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference*. ASTM International, West Conshohocken, PA, 2015. DOI: 10.1520/E1105-15, www.astm.org.

ASTM Standard E1186, *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*. ASTM International, West Conshohocken, PA, 2017. DOI: 10.1520/E1186-17, www.astm.org.

CSI *Construction Specifications Practice Guide*. The Construction Specifications Institute, Alexandria, VA. 2011.

CSI *Manual of Practice, The Project Resource Manual, 5th ed.* The Construction Specifications Institute, Alexandria, VA. 2009.

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