Stucco Adhesion –

PRELIMINARY MOCK-UP TESTING

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INTRODUCTION

Richard Avelar & Associates[1] (RA&A) personnel have completed two years of mock-up testing and analysis of a phenomenon occasionally observed at deconstructed walls in which the exterior plaster cement (stucco) cladding has been found to be closely adhered to polyolefin[2]-faced flashing membranes, polymeric wraps, or asphaltic building papers from multiple manufacturers.

As an example, note that the layered flashing product seen in *Photo 1* has delaminated due to an unusually aggressive bond between the base membrane and the underlying stucco.

Eight rounds of comparative testing, totaling 15 large mock-up panels (see *Photos 2* and *3*) and 16 small mock-up panels (*Photo 4*), were carried out in 2013 and 2014 at a facility in Concord, California.[3]

The broad goal of this process was to explore a wide array of theories that had been offered to explain this "sticky stucco" condition. Each round of the testing was intended to generate datasets that served to support (or discredit) various hypotheses.

Subsequent rounds of testing were modified or redesigned to further explore informative data that had been produced or confirmed in prior rounds. To these ends, in a manner consistent with Bayesian analysis,[4] some hypotheses received extensive attention over the multiple rounds of testing, while lesser focus was given to some of the other tested variables.

The testing encompassed a range of material, time, application, moist-curing, and performance factors related to various stucco components, mixes, flashings, wraps, and papers. Evaluated products and

Photo 1 – Delamination of layered flashing product due to strong bonding of base membrane and stucco.

Photo 2 – These large mock-up panels (measuring 4 x 8 ft.) were lathed, scratched, and browned in July 2013. A finish coat was later applied after completion of the moist-curing process.

Photo 3 – Backside of testing frames with test panels in position. Note the weather-protective Plexiglas sheets (with ports that promote air flow) installed at the inside face of each mock-up wall.

materials included four bagged stucco cement mixes from four manufacturers; ten flashing membranes (six manufacturers); three asphaltic building papers (three manufacturers); two polyolefin wraps (two manufacturers); two "stucco sands"[5] from separate quarries; and, in lieu of traditional sand, a calcareous aggregate mix comprised solely of graded limestone granules.[6]

Pull-off Adhesion Testing

At the 31 mock-up panels, a Shimpo FGE digital force meter was used to carry out pull-off adhesion testing with 2-in.-square metal loading fixtures (see *Photos 5, 6,* and *7*) at about 600 total locations in general conformance with procedures outlined in ASTM D4541.[7]

Reports by previous investigators of this sticky stucco condition had indicated that pull-off adhesion data produced with similar 2-in.-square loading fixtures during mock-up testing could be considered representative of actual stucco-cladding performance in the field. (As further discussed below, these

Photo 4 – Small test panels (#16 through #31) measured 2 feet square.

Photo 5 – Typical layout for pull-testing the 2-in. loading fixtures with Shimpo FGE force meter.

Photo 6 – At test location #37, using 2-in.-square loading fixture, 96.0 pounds of vertical (tensile) force was not sufficient to pull the flashing plug from the stucco.

prior assessments by other consultants were proven erroneous.)

As seen in *Photo 5*, the 2-in.-square aluminum tabs first were attached with an epoxy adhesive[8] to the backside of separated sections (test "plugs") of the various flashings, wraps, and papers being evaluated.

After the epoxy had cured, a Shimpo FGE force meter[9] was threaded to the loading fixture and was aligned to apply tension approximately normal (i.e., perpendicular) to the test surface. Note: Some degree of unintended angularity is an inherent feature of such qualitative field-testing processes.

Then, the force applied to the loading fixture was increased until either the plug of material was detached from the stucco, cohesive failure of the product occurred, adhesive failure of the epoxy bond occurred, or we reached approximately 80 to 100 pounds of force. For example, per *Photo 6*, a plug of flashing material at test location #37 could not be separated from this particular stucco mix with

Photo 7 – At test location #37, the 2-in.-square section of the tested membrane that could not be pulled perpendicularly from the stucco easily could be peeled laterally (<2.0 lbf).

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96.0 pounds of vertical force.

However, as further reviewed below, it is important to emphasize (per ASTM D4541) that: "This test method maximizes tensile stress as compared to...shear stress." Therefore, for dynamic conditions where shear (or lateral) forces also are key performance factors, the results of pull-off adhesion testing should be considered qualitative and not necessarily representative of real-world performance.

To better conceptualize such differences, consider a Velcro bond that cannot readily be pulled apart but can easily be peeled apart. Per *Photo 7*, we see that the same flashing plug that exhibited such a strong tensile bond to the stucco substrate (<2.0 lbf) could be peeled off very easily.

General Observations, Suppositions, and Analysis

1. At the mock-up panels, widely varying stucco adhesion could readily (but not always) be produced at all of the tested polyolefin membranes.
2. The occurrence rates and magnitude of stucco to flashing adhesion measured at the mock-up panels far exceeded actual rates and conditions documented in the field, presumably because:
   - A. The large surface areas (2-in. square) of the loading fixtures that were used for the ASTM D4541 testing served to increase the likelihood of stucco adhesion to the substrates.
   - B. This pull-off testing process overemphasizes tensile bonding while failing to replicate shear (lateral) forces that occur at typical stick-framed, stucco-clad buildings.
3. Various observations from the multiple rounds of testing suggested that:
   - A. Stucco-to-flashing adhesion produced at the mock-up panels likely represented a complex interaction between the stucco mixture and the surface layer of the polyolefin flashing material.
   - B. The formation (or failure) of any such complex bonding seems to occur within the first week of the stucco-curing process.[10]
   - C. This complex bonding could be facilitated by solar heating of additional water introduced by traditional moist-curing protocols and/or localized rainwater infiltration.[11]
   - D. Cold weather or small amounts of dust and debris or other minor variables (e.g., substrate irregularities) can be sufficient to prevent the initiation of this complex adhesion process.

Findings

Data collected during the eight rounds of mock-up testing strongly support the following preliminary findings.

1. The tested polypropylene-faced flashing membranes generally experienced a diminished degree of stucco bonding than did comparable polyethylene-faced products.
   - Note: Reflecting market availability, eight of the ten tested flashing membranes were polyethylene-faced.[12]
2. Where occurring during the mock-up testing (or in the field), these broadly distributed conditions of stucco adhesion to polyolefin membranes or polymeric wraps are not specific to particular products by any particular manufacturer.
3. Similarly, field occurrences of stucco-to-membrane or stucco-to-wrap adhesion do not appear to be related to specific bagged mixes (whether common or premium)[13] marketed by any cement manufacturer.
4. However, as further reviewed below, some premium stucco mixes that have been additionally enriched by the installer can adhere to certain building papers—perhaps via a mechanical bond due to curing of this highly flowable plaster to fibers sticking up from these specific papers.
5. Similarly, stucco mixes that have been field-modified to be unusually "rich" (e.g., reducing the sand-to-cement ratio to achieve atypically high levels of plasticity or flowability) also have an increased likelihood of adhering to certain brands of asphaltic building papers.
6. Pump-applied stucco (*Photo 8*) appeared to be neither more nor less sticky than identical mixes that had been hand-applied.

Photo 8 – Typical pump (or "gun") application of stucco brown coat atop prior scratch coat.

7. Mock-up pull-off adhesion data produced with 2-in.-square loading fixtures may be informative for some qualitative evaluation purposes, but should not be considered predictive or representative of actual or expected performance at stick-framed buildings.[14]
8. The physical processes that promote unexpected stucco adhesion to various flashings and wraps very likely represent a highly complex matter for which there are no simple explanations.[15]

Additional Review

1. Fourier transform infrared spectroscopy (FTIR) analyses of two of the tested premium cement mixes identified two distinct chemical admixtures:
   - A polycarboxylate ether polymer (a.k.a. "superplasticizer"[16])
   - A rosin, ester-based compound
2. At one of the mock-up panels, an extra amount of the proprietary admixture (separately marketed by its manufacturer) contained within one of these two premium cements was added to the tested mix, thereby substantially increasing its flowability.
   - This increased chemical enrichment (which reportedly is a common practice by some installers when similar premium plaster cement products are pump-installed per *Photo 8*) did not substantially affect the presence (or absence) of any stucco-to-flashing adhesion measured at the mock-up panels.
3. However, this same chemically increased premium stucco mix did bond aggressively to one of the two asphaltic building papers tested at this mock-up panel.
   - Subsequently, FTIR testing of stucco that was strongly adhered to a third asphaltic building paper (by yet another manufacturer) that had been sampled by RA&A personnel at a nearby project similarly revealed an unusually high concentration of the same proprietary chemical—presumably added by the stucco installer to increase pumpability of the plaster mix.
4. In both cases, such stucco-to-paper adhesion appeared more likely to represent a simple mechanical connection to fibers sticking up from the asphaltic paper rather than the complex bonding process believed to be occurring at the polyolefin flashings and polymeric wraps.[17]

5. Subsequent experimentation with sand-to-cement ratios also indicated that stucco mixes that had been modified to be unusually rich (e.g., reduced sand) also have an increased likelihood of strongly adhering to certain brands of asphaltic building papers.
    - Note: One of the tested asphaltic building papers experienced no such bonding throughout the mock-up testing process.[18]
6. Limited head-to-head experimentation with a traditional bagged common cement produced virtually the same adhesion levels (using the 2-in.-square loading fixtures) as was measured at one of the tested premium cements at otherwise identical mock-up panels.

DISCUSSION

It is known that some installers of pump-applied premium stuccos commonly will take measures—such as greatly reducing the sand-to-cement ratio and/or adding proprietary acrylics, soaps, and other proprietary admixtures—intended to further increase the fluidity or pumpability of the mix.

Our preliminary mock-up testing indicated that such practices can potentially create stucco mixtures that tend to bond extensively to certain asphaltic building papers, even though these products reportedly had been manufactured in compliance with minimum industry standards and acceptance criteria identified within their product-specific ICC-ES evaluation reports.[19] We advise that future impartial forensic analyses of any such stucco-to-paper bonding should consider the possibility that this condition could be related to atypical installer modifications of the stucco mix.

Note that our FTIR testing of only two premium stucco products revealed two totally distinct forms of chemical enrichment. Likely, other manufacturers of similar premium mixes employ proprietary chemical compounds that differ greatly from the two that we identified. We suggest that the practice by some installers of substantially modifying their mix ratios and adding other chemical compounds to these proprietary stucco mixes in order to create their own special stews might be inconsistent with applicable building codes (e.g., Section 2507 of the International Building Code) and perhaps should be independently evaluated by industry groups.

RECOMMENDATIONS

1. In a manner similar to the installation of structural concrete, general contractors and their stucco subcontractors should maintain written records of all aspects and variables of the stucco mix design and application at every project.
2. All forensic evaluations of this sticky stucco condition should include petrographic and FTIR examination (including the addition of methyl ethyl ketone to the FTIR extraction solvent media) and chemical analysis per Section 9 of ASTM C1324[20] of the stucco samples to better identify what materials are contained within the actual mix applied to the building.
3. Future investigators should pay close attention to substantive differences between "pull" and "peel" values, as demonstrated by *Photos 6* and *7* above. Mock-up testing, analysis, and/or reporting that emphasize tensile bonding while failing to consider shear forces may be fundamentally flawed.
4. To be considered valid, any product-specific findings issued by future investigators should be confirmed by rigorously controlled testing of closely comparable products from different manufacturers.

SUMMARY

Due to the limited nature of our comparative testing and evaluation processes, no specific products, materials, or manufacturers are identified. Management, design, and implementation of our testing, data collection, record-keeping, sampling, and subsequent reporting procedures were controlled by the authors of this article, who are solely responsible for the professional opinions, assessments, and recommendations expressed above.

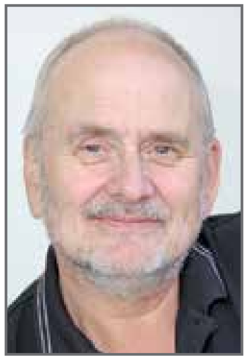
The full scope and extent of this testing were not preplanned; therefore, the tested materials were sourced (and replenished, as needed) from a variety of suppliers at various times. Other than simple physical observation, no efforts were made to ensure that particular products were identical to previously purchased products with the same names. Similarly, for some of the mock-up testing, a single roll or box of a specific material was sufficient; no testing effort was made to reconfirm observed data and results with a separate roll or box of the same product from a different supplier.

Therefore, the multifaceted analyses, suppositions, and findings outlined above should be considered preliminary, exploratory, and informative—but not definitive.

REFERENCES

1. Richard Avelar & Associates (www.ravelar.com) is a forensic architectural/construction consulting firm founded in 1976 in Oakland, CA.
2. "Polyolefins can be divided into two main types, polyethylene and polypropylene, which are subdivided into several grades for different applications." *Polyolefin Reaction Engineering*, João B. P. Soares and Timothy F. L. McKenna, published 2012 by Wiley-VCH Verlag GmbH & Co. KGaA.
3. While the physical testing process was funded jointly by RA&A and a large manufacturer of polyolefin-faced flashing membranes marketed throughout North America, all analysis and reporting of the collected data were carried out privately (and funded separately) by each party. RA&A principal consultants Lonnie Haughton and David Field are solely responsible for all opinions, analysis, assessments, and recommendations expressed within this article.
4. L. Haughton, "Bayes' Rule, Bayesian Thinking, and the Extrapolation of Destructive Testing Data," *Interface*, August 2013 (www.rci-online.org/interface/2013-08-haughton.pdf).
5. ASTM C897-05, *Standard Specification for Aggregate for Job-Mixed Portland Cement-Based Plasters*, ASTM International, West Conshohocken, PA, 2014, www.astm.org.
6. This batch of graded limestone granules was donated to our testing by a major stucco cement manufacturer (whose proprietary system includes additional materials that promote pumpability of their limestone-rich mix).
7. "The test determines the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached." ASTM D4541-09e1, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, ASTM International, West Conshohocken, PA, 2009, www.astm.org.
8. Generally, we had best success with the Simpson Strong Tie "Set 22" epoxy adhesive.
9. http://shimpoinstruments.com/force_gauges.
10. Further testing is recommended to evaluate the results of our limited sampling of this timing matter.
11. While our data suggests a potential correlation among stucco bonding, traditional moist-curing protocols, and hot sunny weather, this speculative assessment remains nothing more than a hypothesis worthy of additional testing.
12. It is important to note that the generic term "polyethylene-faced" represents a broad range of greatly dissimilar flashing products with differing compositions and physical properties.

13. Premium cement mixes are those bagged or packaged products to which proprietary chemical admixtures or "soaps" have been included by the manufacturer to modify various performance properties of the plaster, including its "flowability," "plasticity," and "pumpability" for gun- or pump-application purposes.
14. As noted, during this mock-up testing, sticky stucco conditions could readily (but not always) be replicated with the 2-in.-square loading fixtures at all ten of the tested polyolefin membranes and at both of the tested polymeric wraps under a wide range of testing conditions.
15. In our opinion, some prior litigation-related testing and analysis of this sticky stucco condition have been flawed by failures to account for critical variables in what is certainly a highly complex process. (Reference the very relevant parable of the blind men describing an elephant: https://en.wikipedia.org/wiki/Blind_men_and_an_elephant.)
16. http://en.wikipedia.org/wiki/Superplasticizer.
17. No close microscopic examination to confirm or disconfirm this supposition was carried out. We suggest that future investigators may wish to carry out scanning electronic microscopy (SEM) of selected samples.
18. While we speculated that this product contained a greater percentage of asphalt and/or a lesser number of fibers sticking up from the kraft paper, no further comparative testing, evaluation, or physical analysis was carried out.
19. International Code Council Evaluation Service (http://www.icc-es.org/Evaluation_Reports/).
20. ASTM C1324-10, *Standard Test Method for Examination and Analysis of Hardened Masonry Mortar*, ASTM International, West Conshohocken, PA, 2010, www.astm.org.



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Polyiso R-value Report Released

The Polyisocyanurate Insulation Manufacturers Association (PIMA) has released a research report demonstrating that the R-value of polyiso roof insulation shows no significant variation within the average winter and summer temperature ranges across North America.

The report was developed as a comprehensive response to recent articles that questioned the thermal performance of polyiso roof insulation in colder climates.

The research report concludes that:

- The primary reason for any apparent reduction in polyiso roof insulation thermal value in colder climates is related to the use of an unnecessarily low estimate of "mean reference temperature" to calculate R-values in cold climates.
- Polyiso roof insulation R-values, when calculated using an adjusted mean reference temperature range indicated by the analysis of North American climate data, appear to be higher than the values suggested by some recent articles and do not differ significantly from current PIMA member-published R-values.

As a result of these research findings, PIMA concludes that roof insulation R-values currently published by its members continue to provide the best guide for building designers seeking prescriptive insulation thermal performance information.

"It is unfortunate that the relevant thermal testing range for polyiso roof insulation appears to have been misinterpreted by some members of the thermal insulation and roofing industries," said Jared Blum, President of PIMA. "This new report sets the record straight and provides useful thermal performance information for roofing designers and building owners."

A copy of the research report, "Thermal Resistance and Mean Temperature: A Report for Building Design Professionals," is available for download at PIMA's website (www.polyiso.org).