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RA&A White Paper – May 26, 2015

Stucco Adhesion Mockup Testing

Richard Avelar & Associates, a forensic architectural and construction consulting firm founded in 1976 in Oakland, California, has completed two years of mockup testing and analysis of a phenomenon occasionally observed at deconstructed walls where the exterior plaster cement ("stucco") cladding has been found to be adhered to underlying polyolefin[1]-faced flashing membranes, polymeric wraps or asphaltic building papers from multiple manufacturers.

Eight rounds of comparative testing (totaling 31 mockup panels) were carried out in 2013 and 2014 at a shop in Concord, CA. The broad goal of this process was to explore a wide array of theories that had been offered to explain this 'sticky stucco' condition. The testing encompassed a range of material, time, application and performance variables related to stucco mixes, flashings, wraps and papers:

- Evaluated products and materials included 4 bagged stucco cement mixes from different manufacturers; 10 flashing membranes (6 manufacturers); 3 asphaltic building papers from three manufacturers; 2 polyolefin wraps from two manufacturers; 2 'stucco sands'[2] from separate quarries; and a calcareous 'sand' mix comprised of graded limestone granules.[3]
- At the mockup panels, a digital force meter was used to carry out 'pull-off adhesion' testing with 2-inch square metal 'loading fixtures'[4] at approximately 600 locations in general conformance with procedures outlined in ASTM D4541.[5]

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, some hypotheses received extended attention over the multiple rounds of testing, while lesser focus was given to some of the tested variables.

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[1] *"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.

[2] ASTM C897-05, Standard Specification for Aggregate for Job-Mixed Portland Cement-Based Plasters, ASTM International, West Conshohocken, PA, 2014, www.astm.org

[3] No specific products, materials or manufacturers are identified within this Report.

[4] Reports by previous investigators of this 'sticky stucco' condition had indicated that pull-off adhesion data produced with similar 2-inch square loading fixtures during mockup testing could be considered representative of actual stucco-cladding performance in the field.

[5] 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

General Observations, Suppositions and Analysis:

a. At the mockup panels, widely varying stucco adhesion readily (but not always) could be produced at all of the tested polyolefin membranes.

b. The occurrence rates and magnitude of stucco-to-flashing adhesion measured at the mockup panels far exceeded actual rates and conditions documented in the field, presumably because:
   i. the large surface area (2-inch square) of the loading fixtures that were used for the ASTM D4541 testing served to increase the likelihood of stucco adhesion to the substrates; and
   ii. this pull-off testing process over-emphasizes tensile bonding while failing to replicate shear (lateral) forces that occur at typical stick-framed stucco-clad buildings.

c. Various observations from the multiple rounds of testing suggested that:
   i. stucco-to-flashing adhesion produced at the mockup panels likely represented a complex interaction between the stucco mixture and the surface layer of the polyolefin flashing material;
   ii. the formation (or failure) of any such complex bonding process appeared to occur very early during the stucco-curing process;
   iii. this complex bonding can be facilitated by solar heating of additional water introduced by traditional moist-curing protocols and/or localized rainwater infiltration; and
   iv. 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 mockup testing strongly support the following preliminary findings –

1. The tested polypropylene-faced flashing membranes generally experienced a diminished degree of stucco bonding than comparable polyethylene-faced products.[6]
   - Note: reflecting market availability, 8 of the 10 tested flashing membranes were polyethylene-faced.[7]
2. Where occurring during the mockup 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'[8]) marketed by any cement manufacturer.
4. However, some premium stucco mixes that have been <u>additionally enriched</u> by the stucco installer can adhere to certain asphaltic building papers – perhaps via a mechanical bond due to curing of this highly-flowable plaster to fibers sticking up from these specific papers.

[6] Engineering experts have reported that the configuration of polyethylene molecules make them more prone to "hydrogen bonding" than polypropylene molecules --- it is reasonable to speculate this fact may play a role in the varying stucco bonding that was observed during the mockup testing at all of the polyolefin flashing materials.
[7] 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.
[8] '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.

5. Similarly, stucco mixes that have been field-modified to be unusually 'lean' (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 is neither more (nor less) 'sticky' than identical mixes that have been hand-applied.
7. Mockup pull-off adhesion data produced with 2-inch square loading fixtures should not be considered representative or predictive of actual or expected performance at stick-framed buildings.[9]
8. The physical processes that promote unexpected levels of stucco adhesion to various flashings and wraps very likely represent a highly complex matter for which there are no simple explanations.[10]

Additional Review:

a. FTIR (Fourier transform infrared spectroscopy) analyses of two of the tested 'premium' cement mixes identified two distinct chemical admixtures:
   - A *polycarboxylate ether polymer* (aka, 'superplasticizer')[11]; and
   - A *rosin-ester based compound*.

b. At one of mockup 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*) did not substantially affect the presence (or absence) of any stucco-to-flashing adhesion measured at the mockup panels.

c. However, this same chemically-increased premium stucco mix did bond aggressively to one of the two asphaltic building papers tested at this mockup panel.
   - Subsequently, FTIR testing of stucco that was strongly adhered to a third asphaltic building paper (by yet other manufacturer) that had been sampled by RA&A personnel at a nearby project similarly revealed an unusually high concentration of the very same proprietary chemical – presumably added by the stucco installer to increase pumpability of the plaster mix.

d. 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.[12]

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[9] As noted, during this mockup testing 'sticky stucco' conditions readily (but not always) could be replicated with the 2-inch square loading fixtures at all 10 of the tested polyolefin membranes and at both of the tested polymeric wraps under a wide range of testing conditions.

[10] Opinion: some prior testing and analysis of this 'sticky stucco' condition have been flawed by failures to account for critical variables.

[11] http://en.wikipedia.org/wiki/Superplasticizer

[12] No close microscopic examination to confirm (or disconfirm) this supposition was carried out.

e. Subsequent experimentation with sand-to-cement ratios indicated that stucco mixes which had been modified to be unusually lean also have an increased likelihood of strongly adhering to certain brands of asphaltic building papers.
   - It should be noted that one of the tested asphaltic building papers experienced no such bonding throughout the mockup testing process.[13]

f. Limited head-to-head experimentation with a traditional bagged 'common' cement produced virtually the same adhesion levels (using the 2-inch square loading fixtures) as was measured at one of the tested premium cements at otherwise-identical mockup panels.

Discussion:

The practice by some stucco installers of adding proprietary chemical agents (often by alternate suppliers) into premium cements that already have been enriched with unknown admixtures, including proprietary acrylics, 'soaps', superplasticizers and rosin-ester compounds, could violate applicable building codes and 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[14] 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' testing values. Mockup testing, analysis and/or reporting that emphasize tensile bonding while failing to consider shear (lateral) forces may be fundamentally flawed.

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All management, design, implementation, sampling, data collection, record-keeping and reporting of this stucco mockup testing was controlled by the authors of this white paper, who are solely responsible for the professional opinions, assessments and recommendations expressed herein. Due to the limited and multifaceted nature of the comparative testing, analytical and evaluation processes encompassed by this report, no specific products, materials or manufacturers are identified.

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[13] No further comparative testing, evaluation or physical analysis of potential differences between these various building papers was carried out.
[14] ASTM C1324-10, Standard Test Method for Examination and Analysis of Hardened Masonry Mortar, ASTM International, West Conshohocken, PA, 2010, www.astm.org