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Long-Term, Hygrothermal Performance of Exterior Insulation and Finish Systems (EIFS)

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ABSTRACT: To control rain ingress, the Exterior Insulation and Finish Systems (EIFS) can be constructed with one of two design principles

- a drain screen (rain screen, pressure equalized rain screen—PER) approach
- a face sealed (barrier) approach

While the barrier approach has an inherently higher risk for moisture damage, it offers economic advantages and may be successfully used under a multitude of climatic and service conditions. Its performance evaluation is carried out in three steps:

1. Examine whether this system can be used for a specific set of climatic and use conditions

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2. Formulate necessary measures for material and field quality control in the design specifications
3. Examine the system for integrity under cycling environmental conditions and long-term performance

Step 1 of this evaluation is based on the moisture control strategy of the whole wall assembly. Step 2 requires the addition of several small-scale material tests, and Step 3 involves full-scale system testing. The full scale testing is necessary to incorporate several parameters that act on the system simultaneously (thermal stress, thermal and moisture originated expansion and contraction, structural movements, material changes caused by weathering and aging, presence of moisture, etc.). The interaction among these factors may provide conditions with severity significantly in excess of those achieved when these parameters are tested separately.

This discussion paper consists of three parts:

- Part 1:* Deals with the assessment of constituent materials of the EIFS with a view to ensuring (characterizing) hygrothermal performance of the system (by testing and characterization of the constituent materials, one may limit the range of variation in the hygrothermal performance of the whole system).
- Part 2:* Postulates a new test for evaluation of EIFS integrity under simulated exposure to climatic cycling.
- Part 3:* Recommends EIFS design solutions and construction details for both new and retrofit construction. These details are discussed in the context of specific environmental/climatic conditions. This will be published in a later issue of *JTIBE*.

Testing EIFS cladding systems for integrity under simulated exposure to climatic cycling involves preconditioning under simultaneous exposure to a water vapor gradient and temperature gradient followed by exposure to severe conditions of one-sided, uni-directional climatic cycling. The testing and characterization of the constituent materials (Step 1) coupled with the full-scale test for EIFS integrity under exposure to climatic cycling (Step 2) will increase the reliability of the EIFS systems in North America.

Part 3 fills the gap between the current understanding of moisture control principles and construction practices. Many small changes in materials and technology create a compound effect that increases the frequency of inadequate field performance. Though most inherent EIFS flaws may be minor, those, when coupled with a number of failures of wall systems involving EIFS, caused an adverse attitude toward EIFS, perhaps more prevalent in some regions of North America. This paper provides a fundamental framework to cement many of the previously postulated corrective measures into a coherent package aiming at the improvement of the EIFS reliability in North America.

KEY WORDS: Exterior Insulation and Finish Systems, EIFS, cladding systems, external insulation, base coats, water transmission, moisture engineering, lamina, hygric and thermal stresses, durability, integrity under simulated exposure to climatic cycling test, laboratory testing.

INTRODUCTION

EXTERIOR WALL ASSEMBLIES with an exterior insulation finish system (EIFS) contain a substrate (the supporting system) and a cladding system composed of an insulation board, a synthetic coating system consisting of one or more layers of a base coat that embeds a suitably treated reinforcing glass fiber mesh, and a finish coat. The synthetic coating system is commonly called the lamina. Each of these components has a clearly defined function such as mechanical support (strength and rigidity), reduction of heat flow, bonding (adhesion), resistance to crack initiation, resistance to water ingress, and surface texture and appearance.

EIFS cladding exists in two types, Polymer Based (PB) and Polymer Modified (PM) systems. Formerly, EIFS were classified as soft coat, thin, flexible for (PB) and hard coat, thick, rigid for (PM). The words soft, thin, and flexible are attributed to the higher polymer content in the base coat that results in a flexible thin coating, while the words hard, thick, and rigid are attributed to the relatively high cement content that result in hard, less flexible coating.

The cement content does not exclusively separate these two systems. Some PB base coats contain cement, while others are made of completely noncementitious mixes. The components of the two systems are largely identical, except for the thickness of base coat and the method of attachment.

PB systems rely on adhesives, mechanical fasteners or a combination of both for attachment to the substrate; and rely strictly on the base coat adhesion to the insulation. PM systems rely largely on mechanical fasteners for the attachment to the substrate, and rely exclusively on fasteners for the attachment to the insulation (see Table 1).

Traditionally, wall systems with EIFS cladding are considered to be barrier walls which means that the exterior face is expected to provide most of the functional requirements of the wall, and in particular acts as the primary (and often the only barrier) to rain ingress. The exterior face, acting as the rain-barrier includes not only the EIFS cladding, but also fenestration, penetrations, and connections between all the components of the building envelope.

The rain-barrier created by the EIFS lamina and its support must remain impermeable to water during its expected service life. The effects of weathering, aging of materials, cracks in the lamina, effects of interface with connections between fenestration, etc., and EIFS and possible deterioration of the wall substrate must also be included in the evaluation. Therefore, to evaluate performance of the wall system, one must evaluate not only the initial performance but also its long-term performance under service conditions.

Although there are many examples of satisfactory long-term performance

90% of the EIFS failures could have been eliminated by proper design and building site control. If corrective measures are taken by the whole industry and they are early enough in the construction process, the rate of EIFS failures can be reduced to a small fraction of the current failure rate.

This paper distinguishes between design of cladding and that of a wall system. Cladding is a component of the wall and the functional requirements of cladding do not have to be as extensive as those of the wall. Nevertheless, often exterior cladding is defined as "those components of a building which are exposed to the outdoor environment and are intended to provide protection against wind, water, and vapour"⁶ or "the non-load bearing clothing of the walls and roof of a building, the skin used to keep the weather out."⁷

The exterior face, and in particular the cladding, need not be the only measure to control moisture entry from the outside if the wall is designed using multiple lines of defense (Bomberg and Brown, 1993). For instance, rain is permitted to pass through the "cladding skin" in drain-screen,⁸ rain screen⁹ or pressure equalized rain screen¹⁰ (PER) designs. In the three cases, drainage of water is provided by a drainage plane or a drainage plane coupled with an air space behind the cladding. If the air space has sufficient venting to the exterior to equalize the pressure difference between the exterior and the cavity [for instance, over 80% of long-term ("steady state") and 50% of transient wind conditions with frequency 2 Hz or less], the design may be classified as a PER design.

In the barrier wall (face-sealed) approach, however, the exterior face is the only means to control rain entry. The cladding, usually covering most of the exterior face, needs to provide such means. As discussed in later text, a significant test effort is aimed to control rain transfer through the EIFS lamina. Yet, the exterior face of a wall also includes windows and doors and other penetrations. All these penetrations must be equally impermeable to water if the barrier wall approach is to work.

The commentary on Part 5 (dealing with large buildings) of the 1990 edition of the National Building Code (NBC) of Canada states:

"When the sealants of a face-sealed cladding fail, the walls lose their water tightness and airtightness; this translates into severe disability of the envelope

⁶National Building Code of Canada, 1990 edition.

⁷Dictionary of Building, Scott, John S. Second Edition, Penguin Books Ltd., Harmondsworth, Middlesex, UK, 1974.

⁸Typical drain screen includes drainage plane, e.g., building paper without adjacent air space.

⁹Typical rain screen includes drainage plane with adjacent air space.

¹⁰Typical pressure equalized rain screen includes drainage plane with pressure equalized air space.

strength shall be determined according to ASTM D1682-84 after being conditioned according to UEAtc M.O.A.T 22: 1988, Section 3.2.4 Method A. The reinforcement mesh shall have a minimum mesh size of 10 mm, and a minimum breaking strength of 35 N/mm. The loss in ultimate breaking strength must not exceed the following:

1. At least 15 N/mm in the case of an adhesive system
2. At least 25 N/mm when EIFS relies on mechanical fasteners

- *Water vapor permeability*

The water vapor permeability of the lamina shall be determined in accordance with ASTM E96-95. The lamina, applied at the maximum recommended thickness, shall have a water vapour permeability:

- at least twice that of the insulation board on which it is to be applied
- however, not less than 170 ng/Pa·s·m² when applied over mineral fibre insulation

- *Physical properties of thermal insulation*

1. Rigidity and deformation, usually assessed by testing either compressive or flexural strength
2. Thermal resistance
3. Moisture performance, usually assessed by testing water absorption and water vapor permeability

- *Sealants and gaskets used for expansion joints*

The selection of appropriate sealants and the principle of design of expansion joints are discussed later in the text.

- *Water absorption by lamina*

The water absorption of the lamina shall be determined according to UEAtc M.O.A.T 22: 1988, Section 3.3.1.2. The moisture absorption of the base coat must not exceed 10% by weight.

- *Resistance to water ingress*

The resistance of the lamina to water ingress shall be determined according to UEAtc M.O.A.T 22: 1988, Section 3.3.1.1 or ASTM proposal for water transmission through reinforced base coats of class PB. Both tests are similar except that the ASTM proposal uses 100 Pa (immersion of 10 mm below water surface) and exposure of 72 hours, while the UEAtc uses 50 Pa. Traditionally, the minimum time for the entire surface of the base coat to appear damp must not be less than two hours. Observe, however, that period until the water penetration is observed depends largely on the characteristics of test method used.

- *Mildew and fungus resistance*

The mildew and fungus resistance of the finish coat shall be determined in accordance with the procedures outlined in Military Standard 810B, or ASTM proposal for determining the fungi resistance of insulation

Does it mean that an EIFS wall system provided with lamina that passes one of these tests will not suffer moisture damage? Not at all. As stated in the introduction, the exterior face of a wall includes not only the cladding, but also windows, doors, penetrations for HVAC, electrical outlets, and a host of other penetrations as well as the construction/expansion joints. All of these penetrations must be equally impermeable to water if EIFS based on the barrier wall (face sealed) approach is to perform. Therefore, evaluation must be focused on the system and not on component testing.

Nevertheless, one has learned a great deal from the testing of moisture performance of the lamina. Research of Piper and Raab (1995) highlighted a few interesting observations:

1. All EIFS specimens (class PB) that failed at 137 Pa pressure had thickness much smaller in the failed area than the average thickness; for instance, the base coat was less than 1 mm in the failed area while on average thickness of the base coat was 1.6 mm, 1.8 mm, or even 2.6 mm thickness for different samples (total lamina thickness varied from 2.5 mm to 3.6 mm).
2. Except for one case, if the base coat did not fail in the water penetration test when 137 Pa of air pressure was applied, it did not fail when increasing air pressure in steps between 299 Pa and 862 Pa.
3. Water up-take tubes (Rilem test method 11.4) were affixed to laminas which failed ASTM test E 331-86 at 137 Pa and to those which did not leak. The Rilem test method showed a much higher rate of absorption through the failed areas, i.e., confirmed the discrepancies obtained in the ASTM test E 331-86 performed at 137 Pa.

The thickness of the base coat has a critical effect, but also composition,¹³ porosity, and aggregate size affect water transmission. The minimum thickness specified by EIMA¹⁴ for the base coat has recently been increased to 1.6 mm (Piper and Raab, 1995) and the new ASTM proposal on testing "Resistance of the lamina to water penetration of class PB EIFS" specifies 299 Pa as the minimum air pressure.

Does this change alleviate the problem? In the opinion of the authors—definitely not. The same ASTM draft proposal states: "In applying the results of tests by this test method, it should be noted that the performance of an EIFS or its components, or both, may be a function of proper installation and adjustment. In service, the performance will also depend on the rigidity of supporting construction and the resistance of the EIFS to de-

¹³Iceland, with rapid and large changes in temperature, requires highly flexible coatings. Michael Rust, private communication.

¹⁴EIFS Industry Members Association.

terioration by other causes, such as vibration, thermal expansion and contraction, impacts, etc.”

In the opinion of the authors, a simple, small scale, moisture transmission test either using ASTM (laboratory only) or Rilem (either laboratory or field measurements) approach are sufficient to address the water transmission through lamina. These tests not only involve a specified water head, but they also provide for evaporation from the water front and vapor diffusion ahead of the water field. In the opinion of the authors, a rigid specimen support in the large scale ASTM test does not allow the specimen deformation to be different from that obtained in the small scale test and therefore does not provide more information than a simple, small scale, moisture transmission test.

Moisture flow when vapor diffusion is associated with sorption and capillary condensation (Kelvin's law) is complex; nevertheless such a flow is typical for prolonged periods of rain (or high humidity). In addition, differences between night and day temperature may also increase moisture content in the lamina. These are conditions that enhance moisture penetration. These conditions may affect rain ingress to a greater extent than a short exposure to high air pressure differentials applied in an expensive test machine. (The use of such a machine could only be beneficial when cracks and sealant failures are present—a high pressure differential is necessary during system evaluation, but not for characterization of lamina.)

Discussion on the Significance of Water Ingress Testing

Two important variables related to water penetration not yet addressed are the rigidity of the substrate and quality control during application.

There are dramatic differences between European and United States/Canadian perceptions of EIFS. In Europe the failure rate of EIFS is very small (as low as 1%),¹⁵ while a field study reported by Kenney and Piper (1995), stated that 91% of examined buildings that were over nine years old had cracks sufficient to allow water penetration. These diverse surveys may be attributed to two fundamental differences between European and North American practice:

1. *Rigidity and moisture sensitivity of the substrate.* Masonry or concrete substrates that are used in Europe are both rigid and not sensitive to moisture. Such substrates can fulfill, to a great extent, the functions of a cladding. Observe that the treated gypsum boards are not included in the UEAtc recommended substrate list.

¹⁵This statement comes from Prof. Hugo Hens during discussion after the paper on EIFS failures, presented at ASHRAE conference Thermal VI, Dec. 1995 in Florida.

2. *Technical specifications for the base coats are different, namely:*

- Much thicker, min. 2.5 mm thick of dry base coat in Europe against 1.6 mm (now called minimum wet thickness).
- European installation of the base coat is typically made in two layers, while typical North American installation is in one layer (Kenney and Piper, 1995).
- Portland cement content is lower in Europe (maximum of 20%). The low cement content reduces water penetration, vapor sorption, loss of flexibility as the cement hydrates, and reduces the severity of alkali attack on the glass fiber mesh.

As already recommended by Kenney and Piper (1995), the EIFS installation procedures must be changed to limit the percentage of cement added to the base coat and to require that the base coat be a minimum of 2.5 mm thick. Note that Kenney and Piper (1995) found in the field study that 64% of the buildings, on which the base coat thickness was determined, had thickness less than the manufacturer's standard. Piper and Raab (1995) showed that water penetration may be associated with uneven thickness of the base coat. While three EIFS samples had an average base coat much in excess of the 1.6 mm required by EIMA, in those places where water penetration took place, the base coat thickness was 1.1 mm or less.

This discussion highlights the importance of proper design specification that must be enforced by the process of quality control in the application stage. Since maintaining a minimum total thickness and thickness of base coat layer covering the mesh are critical to the hygrothermal performance of EIFS as well as impact resistance, one would also like to impose on the EIFS industry that the base coat thickness be measured and recorded in the log-book of the contractor even if these changes increase the price of EIFS.

It may also be assumed that applying the base coat in two stages makes the process of quality control more effective. The EIFS industry can also examine if there are other means to enforce the appropriate thickness of the base coat layer above the mesh. For instance, one could introduce an innovative type of mesh or coloring admixture that forces the applicator to use enough material to cover the mesh.

It appears that the water penetration test directly relates to the quality and thickness of the base coat. To reduce the risk of water penetration, we need thicker base coats. But substrates used in North America are often less rigid than those used in Europe. To have a system performing over the long-term, there may be a need for higher elasticity¹⁶ of the lamina used in North America. And there is the question of substrate moisture sensitivity. As

¹⁶Though, as rigidity changes with time, testing must involve "aged" specimens.

noted by French (1992), the most serious and costly type of failure is where water collects in the gypsum causing its paper facing to debond.

In effect, the level of moisture sensitivity of materials used in the wall system, the risk of moisture entering the wall not through the lamina but through joints and junctions, may be more important than the risk of moisture entering through the lamina. In other words, the results of a water penetration test performed on the base coat may have a rather small significance in the holistic evaluation that must be undertaken by the designer. To assist the designer, one needs a test that evaluates the EIFS integrity under simulated exposure to climatic cycling conditions. This test may be used by the designer to confirm experimentally the required level of hygrothermal performance of the whole system.

A System Performance Evaluation Is More Than Evaluation of Its Constituent Materials

This analysis was started with water transmission through the lamina. Such diverse systems aspects as the rigidity and moisture sensitivity of the substrate, manner of application of the adhesive, and quality control in the base coat installation had to be analyzed to assess the use of these tests. So far, however, the central issue—what is the fraction of water that may be found within the EIFS clad wall that has passed through the lamina and what fraction enters through the “other pathways”—has not been addressed.

A substantial number of buildings have developed problems due to water infiltration caused by faulty windows,¹⁷ open sealant joints, faulty parapet flashing, and improperly flashed louvers (Kenney and Piper, 1995).

Kudder and Lies (1995) underlined the role of discretely applied adhesives in the transfer of water along the surface of the insulation. They indicated the “risk of widespread system failure” because the moisture penetration is not confined to the vicinity of the moisture entry point. They recommend only full adhesive applications using a notched trowel.

One must differentiate between the moisture coming through the lamina and moisture coming through the joints. Both have a detrimental effect on the substrate and the whole wall system. The first step should be to ensure that moisture coming through the lamina has no negative effect on the EIFS substrate. The second step is to see whether the moisture coming through acceptable flashing designs, along with the moisture coming through the lamina, negatively affect any material contained in the wall. One may quantify what is an acceptable level of water entering through the joints and

¹⁷Brown et al. in this issue of *JTIBE* showed that water entered around and between two single windows, and through the insulated cavity was led to and ultimately accumulated by the EIFS substrate.

penetrations; one may assess the effect of this moisture in the integrity test and certain additional small-scale tests to make sure that no significant moisture damage occurs.

Since, however, one has little impact on every industry involved in the wall construction, then one has to consider the worst scenario cases in water infiltration and design the wall in such a way as to expect moisture to get into the wall. This would lead one to call upon the provision of a drainage plane and secondary lines of defense. Such lines of defense become the criteria for design.

- If the main concern of EIFS moisture performance is the effect of entrapped moisture on moisture sensitive materials such as gypsum board (exterior grade, even when treated with silicones, implies ability to handle contact with water over short periods but not a prolonged exposure to moisture entrapped in the system), then we have several options:
 1. Replace gypsum with moisture insensitive cement board
 2. Use a waterproof membrane protection for the gypsum board (that also functions as a drainage plane)
 3. Provide drainage through an air gap between insulation and substrate combined with a drainage plane or drained air gap created within the thermal insulation, and use partial mechanical attachment (see Egan, 1995)
- If enhancement of technical solutions appears to be associated with a 10%–30% price increase [price differential between different types of EIFS (Egan, 1995)], then the EIFS industry should acknowledge that there is a significant difference in the service-free period of different EIFS types. A clear difference between three to eight years of service free for the less expensive solution but fifteen to twenty-five years service free (except for color of the surface) for the more expensive solutions should create the win/win situation for both the “owners” and the “manufacturers.”
- If the thirty years service life is to be the norm for EIFS industry (Fleury, 1995), the North American EIFS industry must address a number of “system” issues. More specifically, there is a general lack of information regarding the following areas:
 1. Mechanical properties of the constituent materials in the composite containing lamina and thermal insulation, and specifically data on linear or volume changes of either lamina or thermal insulating materials as a function of temperature and moisture content¹⁸

¹⁸As discussed later in this paper, the hygric stresses are one of the main reasons of crack propagation in the lamina.

2. Design and frequency of expansion¹⁹ and control joints (distances may be related to the mechanical properties to constituent materials)
3. Details of joints²⁰ with foam sealant composites (Baerveldt, 1995)
4. Details of EIFS on thermal insulation edges, details of flashing with flexible membranes rather than metal flashing (parapet flashing etc.)

Closing Remarks on Testing EIFS Constituent Materials

Generally speaking, EIFS evaluation can be done with small scale material tests and proven field performance of a specific cladding system design. Based on certain successful field performance of EIFS applications, one could assess an EIFS performance through prescriptive specifications for designs and materials supported only by the testing of constituent materials. However, such assessment would have to be limited to specific designs (including the substrate on which it is installed) and climatic conditions, i.e., to the proven tradition. However, the European tradition requires moisture insensitive substrates (masonry or concrete) and proper rain penetration measures (e.g., parging on the back of masonry veneer).

This approach does not require system testing, and since numerous requirements have been developed through American and European testing organizations, there is a sufficient basis for testing of constituent materials. This approach, however, relies strictly on the designer's knowledge of how to assemble these constituent materials and components into a durable wall system. Since we have previously established that the designer must take full responsibility for the moisture management system, this approach does not offer much help to the designer.

EIFS evaluation can also be done with small scale tests for evaluating constituent materials and the full-scale, climatic-cycling test for the whole system. Then, EIFS integrity could be experimentally assessed under the worst case scenario that includes combination of substrates, insulation, and lamina materials. As the joints and junctions are points of probable moisture entry into the wall system, their inclusion in the system testing becomes a necessity. Furthermore, as climatic originated movements (expansion and contraction) caused by climatic changes depend on both size of the uninterrupted lamina and restraint from relative movements of the substrate, full scale panels must be tested.

¹⁹EIFS systems with EPS are required to place a fastener strip that is mechanically attached and bonded to the wall mineral fibre at every floor level above two stories in height. Michael Rust, private communication.

²⁰Most building scientists do not accept one stage sealant joints, but require two stage joints, for instance, using a wet sealant on the backer rod and a low density foam (often one component foam), a polyurethane foam/sealant composite. These two options are acceptable when coupled with additional drainage capabilities.

It is evident that testing EIFS for integrity under cycling environmental conditions and evaluating its long-term hygrothermal performance will enhance the knowledge of the designer and increase the reliability of EIFS in North America. The second part of this paper will examine the EIFS test for integrity under simulated exposure to climatic cycling that also includes wetting with a water spray. The third part will address the balance between the wetting and drying ability of these systems.

PART 2

Part 1 of this paper reviewed the assessment of constituent materials of EIFS and postulated a need for additional system testing. A test that evaluates system integrity under simulated exposure to climatic cycling is proposed in this paper. In the first instance, however, we will highlight the interaction between environmental and mechanical loads.

Effect of Moisture on Crack Propagation

The following example illustrates the effect of moisture on crack propagation through the EIFS lamina. This example is taken from thesis work "Analytic Models to Compute Transient Thermal Stresses In Bi-material Structures" that was recently performed at the University of Waterloo.²¹

Three different experimental types of EIFS lamina were applied to 50 mm thick expanded polystyrene board and examined for crack propagation. Type A consisted of lamina with no reinforcing mesh; type B and C consisted of lamina having different reinforcing mesh characteristics. Since most cracks initiate at points of high stress concentration or places where expansion is inhibited, and the test was performed on small scale specimens (250 mm × 250 mm), a corner 10 mm × 10 mm was cut out to facilitate the crack initiation. Sixteen identical specimens were prepared and tests were performed on 4 dry and 12 wet specimens.

First, a high degree of water saturation was introduced by immersing EIFS specimens, with the lamina facing down, in water for 72 hours. Moisture migration was then introduced by means of thermal gradient driving moisture towards lamina that was placed on the cold side. A temperature difference about 30°C across the specimen was applied for 24 hours.

The specimen was then removed for about half an hour and turned around for testing. The difference in temperature across the specimens' surfaces was then increased to 60°C with the laminas, now facing the warm side.

²¹Yuri Stephan Muzychka, M. Eng. Thesis, Mechanical Engineering, U. of Waterloo, 1995.

	Type A	Type B	Type C
Treatment	Tests/Cracks	Tests/Cracks	Tests/Cracks
wet	12/12	12/11	12/0
dry	4/2	4/0	4/0

Type A, not having any reinforcing mesh was the weakest. The results were not surprising; thermal shock alone, applied to a dry specimen caused a failure rate of 50%. The presence of moisture increased the failure rate to 100%. The test showed no cracking on dry specimens of Type B and C, yet, almost all specimens of Type B cracked when the lamina was wet.

This example illustrates the significance of moisture content on the integrity of specimens. It also leads one to believe that EIFS should be tested in conditions (including moisture) similar to the ones found under typical service and climatic conditions. The integrity test must also be performed on full scale specimens because movements due to climatic changes, such as expansion/contraction, depend on the size of the uninterrupted lamina.

What does the full scale mean? European experience derived from testing the durability of glass reinforced stucco indicates that the minimum size of the assembly should not be less than 2 m (7 ft) in each dimension.

Concept of the Test for EIFS Integrity

One of the parameters affecting integrity of a cladding system is moisture entrapment. The integrity test should therefore involve conditions that not only may lead to moisture entrapment but also that represent field exposure (uni-directional, one-sided cycling of the weather). Exposing a dry specimen to conditions of one-sided, uni-directional climatic cycling could gradually increase its moisture content until a "failure" might occur. However, such a test would normally require a very long period of exposure. After all, damage caused by moisture usually happens after many years of exposure.

To achieve a high level of moisture content before initiating the actual integrity test, preconditioned EIFS specimens over a period of twenty-eight days will be used to introduce a certain amount of moisture into the EIFS.

The preconditioning causes accumulation of moisture in EIFS resulting from the simultaneous exposure to water vapor concentration and temperature gradients. Moisture moves because the thermal gradient creates a strong driving force (a constant thermal gradient has been shown to be one of the most effective methods to achieve moisture saturation in closed-cell cellular plastics). The EIFS specimen forms a divider between two environments:

- $24 \pm 2^{\circ}\text{C}$ with $90 \pm 5\%$ RH
- $-10 \pm 2^{\circ}\text{C}$, with ambient relative humidity

The EIFS lamina should be placed on the cold side during both the preconditioning as well as during the actual testing.

In a cold climate, where a uni-directional heat flow prevails during the winter period, moisture flows toward the cold side, resulting in zones of low moisture content on the warm side and high moisture content on the cold side (whether this zone is located at the cold surface of the specimen or at some distance from the cold surface depends on the nature of the surface layer as well as its drying ability). Starting the integrity test after achieving high moisture content reduces the number of climatic cycles required for this test. The integrity test employs conditions that represent a typical field exposure (uni-directional, one-sided cycling of the weather).

During the integrity test, the specimen is cycled between two environments over twenty days (forty cycles)²²:

- warm side temperature $30 \pm 2^\circ\text{C}$, and relative humidity 90% RH
- the weather side, chamber temperature varies between $-20 \pm 2^\circ\text{C}$ (cold period) and $15 \pm 3^\circ\text{C}$ (warm period) at ambient relative humidity

These conditions are identical to the heat-cold cycle specified by UEAtc (June 1988), except that hot and cold periods are somewhat longer, due to experience from the research on the companion test method that is being developed by the ASTM C16 Thermal Insulation committee. Furthermore, the severity of the proposed test method is much higher because of a possible moisture entrapment during the preconditioning stage.

The level of moisture entrapment achieved during the preconditioning stage depends on the hygrothermal performance of all EIFS layers: the substrate, the thermal insulation, and the lamina. To examine an effect of the finishing coat, it is recommended that a part of the test specimen is provided with the base coat only (i.e., no finishing coat is applied). Moisture entrapment will be insignificant in a properly designed EIFS system, while a large quantity of moisture may be trapped if the design does not allow a sufficient flow-through of moisture through the EIFS. It is therefore required that a vertical joint between two substrates be located in the centre of the test specimen.

The total cycling period is twelve hours, divided equally into cold and warm exposures. The warm exposure (at least three hours at $15 \pm 3^\circ\text{C}$)

²²The required number of cycles is always controversial. ASTM C666 standard for testing concrete requires 300 cycles. ASTM E6.58 subcommittee postulated 60 cycles for testing EIFS. Experience with insulating concrete and other porous materials (cf. ch. 26 of ASTM Moisture Manual) indicate that number of cycles is not as important as reaching the critical moisture content for a part of the system. Therefore, a stringent preconditioning procedure was recommended for this test procedure. Furthermore, using 30°C increases partial pressure of water vapour.

ends with the transition period not longer than two hours. Water with temperature of $15 \pm 5^\circ\text{C}$ is applied during the last sixty minutes of the high temperature exposure. Then, air in the chamber is cooled to $-20 \pm 2^\circ\text{C}$. The cold exposure at $-20 \pm 2^\circ\text{C}$ (at least three hours) ends with a transition period (heating air in the chamber over not more than one hour).

Observe that the integrity test requires faster heating of the chamber than its cooling. This is in agreement with the concepts of failure envelope for elastomeric materials and sealants. Gutowski (1990) observed that sealants or adhesives frequently fail due to the initiation and propagation of flaws (cracks) which are developed either at the interface or in the body of the sealant/adhesive, postulating that "the use of fracture mechanics to analyse the mechanism of failure and the expected service life of the bonded structure may thus be useful." Along these lines, Gutowski (1990) showed that the fracture energy for an elastic adhesive is highly dependent on viscoelastic losses being a function of crack propagation rate, temperature, and the strain level.

While recognizing that performing the integrity test under simulated environmental cycling on the wall mock-up that would have been exposed to a specified design load and bending moments caused by a design wind load would greatly benefit the EIFS evaluation, this cannot be postulated as a standard test for the EIFS. Even though such a test may be used to evaluate long-term performance of structural insulating panels, unless EIFS is specifically identified as contributing to the load-bearing performance of the wall, the standard test for EIFS does not involve any load-bearing assessment.

The air temperature on the outer surface is $30 \pm 2^\circ\text{C}$ and water with a temperature $15 \pm 5^\circ\text{C}$ is sprayed on the surface. This action increases the moisture content of the surface, and if the specimen surface is cracked or it is prone to hygroscopic/capillary moisture actions, it will likely increase the moisture content within the specimen. Oscillating temperature on one side of the specimen causes moisture movements back and forth within the inner parts of the EIFS specimen. Because of differences in moisture transmission properties of the different layers, there would be moisture accumulation at some interfaces. To find if this moisture accumulation, alone or in conjunction with other climatic factors, causes any detrimental effect (delamination, cracking, blistering, or sagging) is the merit of this test.

The purpose of the integrity test is to assist the designer in evaluating water management of the whole system. Therefore, the test panel should include the same substrate as used in field applications, typical fenestrations such as vinyl windows (the highest coefficient of expansion), decorative frames (if used), wall penetrations, the window flashing, and at least one expansion joint.

Concluding Remarks on EIFS Integrity Test

This proposal addresses the hygrothermal performance of the lamina as well as their joints over the service life of the EIFS cladding. Realizing that one must evaluate not only the initial performance of materials but also the field performance of the cladding system as affected by aging of materials, possible cracks in lamina, and substrate deterioration, a test for EIFS integrity under simulated exposure to climatic cycling is necessary.

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