

# BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

## THE LATEST AND GREATEST ENCLOSURE SYSTEMS...NEVER MIND

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## ABSTRACT

We are living in an innovative time as new ideas about how building enclosure systems function are being developed in greater numbers. Inspiring these new systems are the desires to cut costs or to improve the energy efficiency of cladding and roofing to make buildings more sustainable. Owners, architects, and contractors need to consider such systems with caution. In the past, there have been enclosure systems brought to market that were touted as “the latest innovative product,” only to fail spectacularly afterward. This paper will review the promises of several of these enclosure systems and discuss how they failed to live up to their expectations and the consequences of the failures. From the lessons learned, the paper will provide guidelines to follow when assessing new systems being marketed today.

## SPEAKER

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Since joining Wiss, Janney, Elstner (WJE) in 1982, MARK MORDEN has been involved in more than 500 investigations of deteriorated and distressed structures, including historic and contemporary buildings. His investigations typically involve building enclosure systems. He has special expertise in the construction and performance of masonry, EIFS, stucco, window and curtain wall systems, sealants, and general waterproofing systems. Mr. Morden is experienced at translating investigation findings and recommendations into remediation documents. This has included designing innovative solutions to complex problems, developing repair details, and authoring technical specifications.

Mr. Morden has authored several articles and papers on preservation and construction technology. His work has appeared in national publications and ASTM special technical publications. He has given technical presentations at several national preservation conferences.

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## INTRODUCTION

The United States in the 20th century was a place of incredible innovation. The ideas and inventions coming from this country changed the world and raised billions of people's standards of living. The freedom of anyone with a good idea and some financial backing resulted in unparalleled growth in the history of mankind. Examples of innovation include industrial production that made goods affordable, polio vaccine and other immunizations that helped eradicate diseases, the space program, and personal computers and the Internet that allow us to share information worldwide.

Unfortunately, with any innovative culture there are going to be several misses for every hit that makes it big. A vast majority of those misfires are identified early in the innovation process and abandoned for other workable ideas. However, some of those misfires make it to the public and are notable for their disasters. In the past 50 years or so, well known product failures include the Edsel automobile, New Coke, and Betamax video format. These products come and go, hopefully without causing too much personal and financial damage along the way.

The building industry has seen innumerable innovations in the 20th century: structural systems that can carry more loads with less material, HVAC systems that allow for complete control of a building's environment, and the use of computers for design and structural analysis. The segment of the building industry focused on building enclosures has also seen incredible breakthroughs. New materials have invigorated old systems, such as roofing membranes made from EPDM or PVC, and lightweight cladding systems like curtain walls that can be erected quickly and provide an abundance of natural light. Even old materials are being used in new ways, such as architectural terra cotta manufactured to hang on a building like a curtain wall.

As in the general society, the building industry and the building enclosure segment of the industry, in particular, have been subjected to some significant failures

of products and systems that were touted as "the next greatest thing." Not only did these products not live up to the performance expectations and promises of the manufacturers but in many cases, the systems caused significant damage to property and incredible financial hardship to the parties involved. This paper is a review of four of these systems that have been developed and marketed over the past 35 to 40 years. The products include silicone-based mortar additive in prefabricated brick panels, thin-marble cladding panels, barrier EIFS produced for residential construction, and oriented strand board wood fiber siding. The intent of this paper is to discover common themes within each of these failed systems so as to enable the development of strategies for evaluating new systems that come to market. With that information in hand, getting involved with products that are "too good to be true" and the potential problems they may create can be avoided.

## SARABOND

The continual development of building products and systems has been driven by the desire to construct lighter, and cheaper structures more quickly. Brick masonry does not lend itself to any of those characteristics. Brickwork walls are laid by hand, they are heavy, and the labor involved does not make them an inexpensive product compared to lighter or thinner wall systems. The development of the single-wythe cavity wall helped brick enclosure systems remain suitable for contemporary construction. Still, there were those who looked for other ways to make lighter and cheaper brick claddings more quickly. In the late 1960s and early 1970s, a major construction materials manufacturer thought it had an answer.

Sarabond was a polymer additive for masonry mortars.<sup>1</sup> The manufacturer developed and marketed Sarabond as a product that would increase the strength of mortar and allow the construction of thinner, less expensive masonry walls. Comparing the properties of standard brick masonry with masonry constructed with Sarabond mortar, it is clear that there is a significant

increase in the strength of the assemblies. For example, the compressive strength of ASTM C27<sup>2</sup> Type S mortar is 1,800 psi. The specification for mortar with the Sarabond additive lists the requirement for compressive strength as 5,000 psi. The flexural strength of brickwork has a modulus of rupture of 200 psi. Brickwork with Sarabond mortar has an average modulus of rupture of 360 psi.

The most common application of Sarabond mortars was to construct prefabricated brick panels, both as vertical cladding and overhead soffit panels. These panels could be constructed as a single-wythe, 10 feet tall and 14 feet long, without the need for steel reinforcing. The only metal components in the panels were embedded lifting lugs, used to lift the panels for transportation and erection, and embedded anchors to connect the panels on the building structure. The anchors typically consisted of 1/2-in-diameter bent bolts, either galvanized or cadmium-coated. The panel bolts would be anchored to steel plates, angles, and channels on the structure. The lifting lugs remained in the panels once their erection purposes were complete.

The increase in the structural properties of the brickwork, due to the Sarabond additive in the mortar, allowed brickwork panels to be shop-fabricated and then transported to the building site. At the building, the panels were lifted into position and anchored to the building structure. The panels were much quicker to construct in the shop and erect on the building than traditional hand-laid brick on site. The reduction of materials made the panels lighter than traditional brickwork. The reduction of labor and materials brought down the costs. It appeared the manufacturer of Sarabond had developed the ideal solution to make brick cladding on multistory buildings a competitive choice for architects and owners. In the early 1970s, the first installations of prefabricated panels made with Sarabond mortar were completed.

It took only two to six years before the first signs of distress in the brickwork became apparent. Typically, the signs of distress were rust staining on the brick sur-

face and cracking in the panels. Investigations documented that cracking and corrosion staining were directly related to corrosion of the steel anchors and lifting lugs that were embedded in the brick panels. (Typically, the steel components were embedded in the brick over two inches.) This condition became a point of extreme concern and represented a danger to the public. The cracking and spalling of the brick and corrosion of the embedded anchors created situations where sections of the brickwork could fall from the building. In extreme situations, the panel anchor bolts could lose connection to the brick panels and compromise the panels' stability to remain on the building. Additional potential problems included water infiltration into the interior of the building through cracks in the panels.

Initially, building owners asked the Sarabond manufacturer to investigate the cracked and damaged panels to determine why the cracking was occurring and how it could be fixed. An example of the problems at an eastern community college illustrates the manufacturer's response as summarized in court documents (emphasis by author).

On June 1, 1973, the architect issued a certificate of substantial completion. Approximately six years later, on January 12, 1979, the Sarabond manufacturer informed the community college vice president for administrative services that the panels on the building, which were bonded with Sarabond, might cause corrosion to the panels if they were unprotected. The manufacturer encouraged the college to have the panels inspected by a qualified person and requested, if such an inspection took place, that it be present.

A representative of the college personally inspected the panels and discovered cracks in the mortar and rust stains on the panels. He reported his findings to the architect and the college's legal counsel, who recommended that the college immediately retain an independent party to inspect the panels. The college contacted an architect to conduct an inspection, but the inspection never occurred. Finally, in May of 1980, the college contacted the manufacturer and asked it to inspect the panels.

The manufacturer agreed to inspect the panels and instructed the college to cut and to remove panel sections for testing. Fourteen months later, *the Sarabond manufacturer issued its report and concluded that the cracks were not the result of Sarabond's adverse effect on unprotected steel. Instead, it concluded that the cracks were caused by freeze-thaw conditions.* Nevertheless, the college continued to detect new evidence of exterior cracking, as well as corrosion of the steel rods embedded within the panels. Consequently, the college approached a Sarabond expert and requested that he review the manufacturer's report. The expert reviewed the report and, contrary to the manufacturer's opinion, concluded that the cracks in the panels and the corrosion of the steel rods were a direct result of the adverse effects of Sarabond.

The college went on to sue the Sarabond manufacturer, one of many lawsuits that were brought against it over the next two decades.

As more buildings with Sarabond brick panels developed similar cracking problems, investigations by forensic architecture and engineering firms confirmed the real source of the panel distress: Sarabond.

Sarabond was a latex that contained equal parts water and a copolymer. The copolymer included the monomers polyvinylidene chloride, polyvinyl chloride, and polyacrylate. The saran latex was unstable in alkaline media such as Portland cement paste. When Sarabond was exposed to and reacted with Portland cement, the additive would degrade and slowly transform the bound chloride into free chloride ions. When there is a sufficient concentration of chloride ions in contact with steel, the steel will corrode, including galvanized and cadmium-coated steel.

In litigation involving a 30-story building in a city in the Midwest, the building owners hired William Hime of Wiss, Janney, Elstner Associates, Inc., Northbrook, IL, as their expert. Having analyzed mortar samples from over 100 Sarabond buildings, Hime was the leading authority on the chemistry and properties of the Sarabond additive. According to court documents, Hime testified to the following regarding Sarabond:

William Hime testified at trial that steel embedded in ordinary Portland cement mortar is generally resistant to corrosion. Normally, the high alkalinity of cement causes the steel to form a thin oxidized layer that resists significant corrosion. Sarabond, by contrast, releases inorganic chloride ions when mixed with Portland cement mortar. These chloride ions act as a catalyst, eating away the resistant layer of the steel. The result of this corrosive process is the buildup of a rust product which [*sic*] occupies between two and ten times more space than the original metal. The corrosion of the steel embedded in walls will continue until it exerts sufficient pressure to cause the brick and mortar to crack, separate from the building frame, and ultimately fall off the building. . . .

[According to Hime,] Sarabond would induce corrosion in every circumstance in which Sarabond's saran latex products are mixed in Portland cement mortar containing embedded steel. . . . It does not matter whether Sarabond is used in pre-fabricated masonry or "laid-in-place" masonry, single-story or multi-story buildings, tunnels or bridges, cold climate, warm climate, wet climate, or dry climate; in any circumstance involving metal embedded in a Sarabond-mortar mix, corrosion will occur.

Not only would the corrosion occur in every instance where Sarabond is used in masonry, but also the chloride ions were not consumed in the corrosive reaction with the steel. Therefore, they were still present to continue to corrode the steel elements until the elements were completely consumed. Once the process started, it would only stop once there was no more steel left to corrode.

When chloride concentrations reach and exceed about 0.2% of the weight of the cement, corrosion of the steel will occur. The chloride levels for zinc are around 0.5%, and even higher concentrations are required for cadmium. Tests of the chloride levels in samples of Sarabond masonry were reported to be ten to 30 times the threshold level of chlorides that will corrode metal and eight to 12 times the level for causing zinc

corrosion.

It was ironic that the increased bond and tensile strength Sarabond provided to mortar and brick assemblies was due to the additive's polymeric structure and reaction with the cement system. However, as the polymer structure and chain degrade, the increase in strength that Sarabond provided eventually was lost.

As stated earlier, numerous lawsuits were filed against the Sarabond manufacturer by owners of buildings with Sarabond masonry. In one of the early trials, the discovery phase of the litigation uncovered documents that were particularly damning to the manufacturer. The first buildings in which Sarabond masonry was used were constructed in the early 1970s. At that time, the manufacturer was aware of the degradation mechanism of Sarabond and the potential for corrosion and cracking in brick constructed with Sarabond. Experiments by the manufacturer's researchers in 1971 and 1972 demonstrated the corrosion of steel, galvanized steel, and cadmium-coated steel; yet the manufacturer continued marketing the Sarabond product. Once these documents were uncovered, the manufacturer had no plausible defense for either Sarabond as a product or its availability on the marketplace. From that point on, the only lawsuits in which the manufacturer prevailed were those that involved legal procedures or expired statutes of limitation. The rest of the lawsuits were either decided for the plaintiffs or were settled by the manufacturer with terms favorable to the building owners.

The desire to develop a product that will revolutionize the building industry is strong and understandable. As has been demonstrated time and again, products that promise results that seem too good to be true usually are. The Sarabond manufacturer attempted to develop a product that would make relatively lightweight masonry panels a competitive cladding and failed. Today, prefabricated brick panels are made and sold. They are smaller in size than what was able to be constructed with Sarabond and they are fully reinforced to perform structurally. However, typically, these smaller panels are more stable and have a longer service life than what Sarabond was able to produce.

### THIN-MARBLE PANELS

Marble has been used as an exterior building material for thousands of years. Besides being a durable stone, marble is

relatively easy to carve and lends itself to providing ornamentation for various architectural styles. Up to the 20th century, load-bearing construction of exterior walls dictated that exterior stone panels had to be 4 inches or more in thickness. Twentieth century engineering advances and new techniques that allowed for the cutting of thinner stone panels brought about the possibility of using marble on the exterior of high-rise buildings. Thin marble panels were lighter, quicker to erect, and less costly than traditional masonry. It seemed to be an ideal option for using a durable and classic building material as a cladding system on high-rise buildings.

Thin-stone veneers became an accepted system for building cladding by the early 1950s, and dozens of design and engineering handbooks went into publication even before 1960.<sup>3</sup> "Before the advent of high-rise thin-veneer façades, such veneers were primarily utilized in building interiors: lobbies, hallways, and large rooms of monumental educational, cultural, medical, religious, civic, or commercial spaces. Utilizing hand-twisted copper wires, blind mortar anchor pockets, and plaster of paris spotting mortar, a traditional satisfactory hand-fastening methodology was developed for such interior use. With the advent of thin veneer exterior use, this same technique was initially applied with minimal regard to more severe exterior weather exposure."<sup>4</sup> By the 1970s, stainless steel anchors were primarily used. Anchor methods were developed that allowed for positive visual confirmation of attachment, rather than rely on interior, blind-anchor methods.<sup>5</sup>

With the advent of new stone-cutting technologies, marble panels for use as building cladding were able to be cut to 1¼ in (3 cm) thick. The most common attachment methods were to cut kerfs and slots into the edges of the panels. Strap anchors with bent legs were installed to engage the kerfs and slots and be anchored to the substrate support frame. The joints between panels were sealed with elastomeric sealants.

The 1970s were when the peak of popularity was reached for using thin-stone veneers. While there was a history of information about the material properties of stones used as building materials, there were little data about how these materials would perform in this new thin application, especially marble. Within a relatively short time after installation, thin-marble panels began to exhibit distress and deterioration.

The main deterioration mechanism of thin-marble panels used in exterior applications is hysteresis. Hysteresis, in thin-marble panels, is an irreversible expansion of stone due to thermal loading cycles. Hysteresis results in bowed marble panels accompanied by a reduction in panel strength. The bowing of the panels can also affect the engagement of stone anchors.

Marble primarily consists of calcite crystals, which are anisotropic. Anisotropic means that when the crystals are heated, they expand in different amounts in different directions. When the crystals cool, they cannot return to their original positions.<sup>6</sup> The repeated expansion and contraction from thermal cycling causes the crystal grain boundaries to fracture and loosen or dislocate adjacent calcite grains.<sup>7</sup> These loose grains fill the void created by the boundary fractures and prevent the crystals from contracting back to their original positions. This irreversible expansion of material can be as much as 20% of the original thermal expansion.<sup>8</sup>

Over time, this expansive growth generally will produce a bowed profile if the heating and cooling cycles are from a source at the front of the marble panel. The panels generally will dish if the thermal cycling source is at the back of the panel. When installed as a building cladding, the majority of bowed marble panels will typically occur on the south, east, and west elevations; those elevations have direct sun exposure. Thicker marble panels are better able to resist bowing and dishing since the thermal strains are less with the additional thermal mass and the mechanical restraint that is afforded by the overall depth of the panels.<sup>9</sup>

The grain dislocation due to the crystal grain boundary fractures can result in significant loss of flexural strength. Water penetration at open grain boundaries further worsens the problem by eroding the cementing binder that holds the calcite grains together.<sup>10</sup> This reduction in flexural strength will potentially lead to cracking of the panels. The loss of flexural strength can be up to 70% of the panel's original strength. This reduction of flexural strength will continue indefinitely at a reduced rate.<sup>11</sup> Eventually, the strength of the panel will reduce until the panels are unable to support design wind loads, resulting in the potential for failure of the panel and collapse.

The bowing of the panels potentially could also affect the engagement of the

panel anchors. The cutting of kerfs or slots into the edges of the panels results in very thin cross sections of marble in front and behind the slots. The bent leg of the anchor strap, or in some cases pins, could come to bear on the back face of the kerf as the panels bowed outward. If the stresses were high enough, the face of the kerf or slot could fail and would no longer be engaged with the anchor. To exacerbate the situation, these failures would not be apparent by visual inspection. In extreme cases, the thin marble panel could be anchored to the building only by the adhesion of the sealant in the joints around the perimeter of the panel.

Another source of kerf/slot and anchor failure was freeze/thaw damage. If the anchor grooves at the top of the panels were not filled with sealant or other material, water that infiltrated the perimeter sealant joints could collect in the kerfs and slots. Again, due to the thin cross section of the kerf or slot walls, freezing water could crack and fracture the panels. If this occurred around the anchors, then disengagement was a possibility.

The two most often cited buildings with failed thin-marble claddings are the Amoco (now AON) building in Chicago and Finlandia Hall in Helsinki, Finland. Both buildings were clad with white Italian Carrera marble panels, both experienced deterioration of the panels relatively soon after construction was complete, and both buildings were reclad with new stone panels.

The Amoco Building is an 84-story office tower. The exterior façades are composed of vertical columns in a chevron shape alternating with metal and glass curtain walls. The building was completed in 1972. By 1979, bowed and cracked panels were being observed on the exterior cladding. WJE was hired by Amoco to investigate the extent of panel deterioration. Of the 44,000 panels on the building, 230, or .052%, were cracked at panel connections; 1,870, or 4.3%, were cracked away from panel connections; and the maximum outward bowing was three-eighths of an inch.<sup>12</sup> The extent of the distress was not considered significant at that time. Amoco proceeded to continue to monitor and repair panels as needed.

By 1985, additional bowing and cracking of the panels were observed and the conditions were occurring at an increasing rate. WJE was again asked to perform a condition survey of the marble panels. The results this time showed a significant increase in distressed conditions. The num-

ber of panels cracked at the connections was 2,780, or 6.3% of the total panels. Panels cracked away from the connections were 5,440, or 12.4%, and the maximum outward bowing was 1-1/8 in.<sup>13</sup>

Because of the abrupt increase in distress, WJE performed extensive testing of marble panels that were removed from the building and of original attic stock panels that were stored in a controlled environment at the interior of the building. The tests evaluated the performance of the panels after accelerated weathering cycles in an attempt to predict future behavior and strength of the panels. At the end of the testing, the conclusion was that the deterioration of the panels was irreversible and would be continual. The recommendation to Amoco was to remove all of the thin-marble panels from the building and install an alternate cladding.

Thin-granite panels from Mt. Airy, NC, were selected for the recladding after testing demonstrated that this stone was durable and could successfully support design loads. Granite has a different composition than marble, and granite panels would not be subject to the same bowing and reduction of strength. The strength and stability of the granite made it an appropriate choice as a new cladding. The cost to construct the Amoco building in 1972 was approximately \$110 million. The cost to reclad the building with new granite panels in the early 1990s was approximately \$80 million.

Finlandia Hall was designed by the great Finnish architect, Alvar Aalto. The building, opened in 1971, holds a concert hall and congress. The exterior cladding was 1¼-in (3-cm) white Carrera marble panels. Within several years of construction completion, bowing of the panels was noticed. The condition worsened until, in the late 1980s, it was decided that repairs needed to be initiated. Public safety and architectural aesthetics were the main factors behind the decision to renovate the façade. By 1991, safety nets were hung along the length of Finlandia Hall to protect pedestrians from potential cladding failures from above.<sup>14</sup> Alternate materials were considered, including granite panels. In 1993, the building came under the protection of the Finnish National Board of Antiquities.<sup>15</sup> The board declared that the exterior should be kept "equivalent to the original." The new marble panels were required to match the appearance of the original stone. This aesthetic requirement even included the diagonal veining pattern of the original panels.<sup>16</sup>

Towards this end, white Carrera marble was chosen again for the cladding on Finlandia Hall, albeit as a slightly thicker panel, with the knowledge that recladding of the building will most likely be necessary about 20 years later. The recladding was completed in 1999. By 2001, the bowing and deformation of the new thin marble panels was apparent. Accompanying the deformation was the reduction of strength of the marble, around 20% to 30%.<sup>17</sup> The second-generation panels are still on the building.

Thin-stone panels are still being used as exterior claddings. One of the lessons learned from the failures of the original thin-stone panel systems is to combine the stone panels with a rigid backup system such as precast concrete. The composite nature of these systems helps the stone panels resist the expansive forces that thermal loading can impart on the stone. This enables the stone cladding to maintain material strength. A composite panel solution allows for relatively quicker, lighter, cheaper, and durable stone claddings but not to the extent that the original thin panels were purported to achieve.

## **EXTERIOR INSULATION AND FINISH SYSTEMS (EIFS)**

Similar to Sarabond and the desire to develop brick cladding that was quicker, lighter, and cheaper to construct, EIFS appeared to be the ideal system to satisfy those material criteria. However, in their quest to develop the ideal building material, the EIFS manufacturers took the concept too far. The result was an oversell of the initial EIFS barrier system on expectations and results that led to extensive leakage and property damage throughout the United States.

Briefly, EIFS comprises two components: rigid insulation board and the lamina. The lamina comprises a polymer-modified, cementitious base coat, fiberglass-reinforcing mesh encapsulated in the base coat, and an aggregated acrylic-based finish coat. Initially, EIFS sold in the United States was bonded to the substrate sheathing using the base coat as an adhesive. Later modifications to the product included the addition of screw anchors and washers to mechanically secure the insulation boards to the framing system. Though not a part of the manufactured EIFS, the other critical components to the cladding are sealant joints between EIFS panels and where EIFS terminate at openings and pen-

etrations.

The history of EIFS began in Europe. The precursor to the EIFS we know today was cement-lime plaster applied over mineral wool on the exterior of houses in Sweden in the 1940s.<sup>18</sup> This cladding became popular in other parts of Europe over the next 20 years. The development of EIFS in Europe was advanced in the early 1950s. In 1950, BASF AG was granted a patent for expanded polystyrene (EPS) insulation board. According to Sto Corporation, the first synthetic plaster was developed, which was an organic plaster using water-based binders. By the late 1950s, EPS and synthetic resin materials were being used together. The EIFS we are familiar with today were marketed in Germany in the early 1960s. The German system included rigid EPS insulation boards with mesh-reinforced coatings. The insulation improved the thermal performance of the typical masonry building construction, and the polymer-modified coatings provided flexibility and the ability to resist cracking and water infiltration compared to traditional cement plasters (stucco).

In 1969, EIFS was introduced to the United States by Dryvit Systems, Inc. The Arab oil embargo of 1973 and the increase in oil prices throughout the 1970s gave building owners and architects the opportunity to use a cladding system that was more energy-efficient than traditional systems. The first use of EIFS were on commercial buildings. EIFS were lightweight, installed relatively quickly, were less expensive than other cladding systems, and had the potential to create a variety of shapes and profiles on a façade. As the popularity of the product grew, the industry began marketing it to the residential market. By the early 1990s, EIFS were firmly established as a residential cladding.

American EIFS systems differed from European systems. First, American systems typically were applied on framed construction. Initially, in commercial buildings, the framed construction was metal studs. When EIFS began to be used in residential construction, wood-framed construction was common. The polymer-modified coatings used in Europe were thicker than those used in America. A base coat thickness of approximately 1/8 to 3/16 in (3 to 5 mm) is typical in European installations. By contrast, in the United States, base coats are installed about 1/16 to 3/32 in (1.6 to 2.4 mm) thick.<sup>19</sup> Mesh reinforcement installation in the thicker base coats of Europe is

performed by applying an initial layer of material, installing the mesh, and then applying a second layer of coating to fully encapsulate the mesh and correct inconsistencies in coating thickness. The mesh installation in the American systems is performed during the single-step application of the base coat, which requires the plasterer to encapsulate the mesh and maintain coating thickness at the same time.

When EIFS were first sold in America, it was designed to be a barrier system. The EIFS manufacturers relied on the continuity of the lamina and the installation of proper sealant joints to resist water infiltration. For this reason, the installation of building paper behind the insulation or flashings to collect and direct water to the exterior was not part of the EIFS design or installation. Since the base coats in the American system were relatively thin, application of a quality barrier EIFS required the diligence of the contractor working in partnership with the manufacturer's representative to ensure that all steps were installed correctly and to specification. There was less room for error compared to the European systems. If water breached the lamina in the European system, the masonry substrate provided a substantial barrier against water infiltration to the interior. In addition, masonry is not nearly as moisture-sensitive as the substrate products used in American lightweight construction.

This need for precision installation is where the problems with barrier EIFS began. When barrier EIFS caught on in the residential market boom, the manufacturers lost contact with the installers. Inadequately trained applicators began installing the EIFS without a clear understanding of the subtleties and critical points of installation. Corners were cut either through ignorance of proper detailing or the desire to finish one job quickly. Without an on-site presence of the manufacturers' representatives, deficient systems were installed that did not meet the manufacturers' specifications.

In-house personnel for EIFS manufacturers, as early as 1984, were aware of problems developing with their systems. Internal documents revealed warnings about moisture infiltration through their systems and the potential water damage to sheathings, structure, and interior finishes. By the late 1980s and early 1990s, the forensic architecture and engineering field was beginning public discussion about the shortcomings of barrier EIFS systems and

the need for changes. Since the lightweight construction systems were not going to change, the EIFS manufacturers were called upon to modify their systems to better manage water infiltration.

One major problem to which the EIFS manufacturers had to respond was why sealant joints were not remaining intact. Open joints were direct channels for water to infiltrate the system and reach the wood or gypsum sheathing, wood or metal studs, and building interiors. The repeated wetting of moisture-sensitive materials was causing deterioration, rot, and organic growth within wall cavities and interiors. With the lack of a weather-resistive barrier and flashings in the barrier EIFS system, once moisture entered the system, there was no means to drain it to the exterior.

The systemic failure of sealant joints was the result of an EIFS manufacturer-published detail. Where the EIFS terminated at a joint, the installer was to coat the return face of the insulation board with base coat and mesh and the finish coat. The sealant, with an open cell-foam backer rod, was to be installed within the joint and bonded to the finish coat. Moisture in the wall or that infiltrated through the finish coat would collect in the foam backer rod behind the sealant. The moist rod would hold the moisture against the finish coat, causing the finish coat to soften and weaken. The stress of the sealant on the softened finish coat would cause the finish coat to separate from the base coat and leave the joint open to water infiltration. This one detail failure was responsible for a majority of water damage problems with barrier EIFS.

Adding to the problems was the EIFS manufacturer's lack of initiative regarding the defective sealant joint detail. EIFS manufacturers admitted the need to modify the detail so the finish coat was stopped at the face of the joint and not applied to the return faces. The sealant was to bond to the base coat only. While the EIFS manufacturer had published a memo announcing the change in detail, there did not appear to be a concerted effort to make sure the change was implemented at all levels of the EIFS installation chain. For several years after the memo was released, contractors were still installing sealant joints with finish coat on the return faces of the joints.

As more and more cases of water infiltration and damage were discovered in EIFS-clad buildings, lawsuits began being filed in abundance. Similar to the example

of Sarabond, EIFS manufacturers and contractors claimed the observable problems were not due to EIFS but some other source of damage. The manufacturers claimed that these were installation problems and not failures of the EIFS barrier systems. A majority of damage in EIFS-clad buildings was located below window openings and other penetrations. Though the manufacturers were on record as having to modify defective sealant joint details, they and the contractors would frequently blame the leaks on improper window assemblies and installation methods.

Two events in 1996 brought about the end of barrier EIFS systems. In March of 1996, United States Gypsum Corporation (USG) announced that it would discontinue sales of its barrier EIFS systems. USG's decision was based on a report of investigations of EIFS installations on homes in North Carolina by the National Research Council of Canada (NRCC), which USG funded. Citing its own research and that of the NRCC, USG stated "that these systems could not adequately accommodate water penetration. In existing structures clad with barrier EIFS, elevated moisture levels had led to deterioration of water-sensitive materials in the walls."<sup>20</sup> USG stated it would focus on water-management finish systems.

The second event occurred in September 1996. A class action lawsuit in North Carolina was authorized against nine EIFS manufacturers by homeowners whose houses were clad with EIFS. To avoid trial, the manufacturers settled the claims in 1999 without admitting fault or liability for the damages to the residences.

While no verdict was rendered on the EIFS manufacturers, the North Carolina action brought about the practical end of barrier EIFS. Insurance companies began withholding coverage for contractors installing barrier EIFS. Window manufacturers would not issue warranties on projects where their products were installed in EIFS-clad buildings. It seemed no one wanted to be associated with barrier EIFS in any form.

The EIFS industry was not left behind, however. During the 1990s, while fighting lawsuits and claiming there were no problems with barrier EIFS, the manufacturers were already developing water-management finish systems. The systems included drainage cavities, weather-resistive barriers, and flashings to collect and drain water back to the exterior. This has become the

standard EIFS system. The evolution of EIFS from a barrier to a drainage cavity system has produced a cladding that is more durable and stable than its predecessor.

EIFS held the potential of being an immensely popular building system that was lightweight, relatively inexpensive, quick to install, and easy to form into a variety of shapes and forms. Unfortunately, the manufacturers pushed the ability of EIFS to resist water infiltration too far. They oversold the system's capabilities without acknowledging apparent limitations. If their ambitions for the product had not been so high, they could have adapted the European systems to American lightweight construction and avoided 30 years of defective construction.

### **ORIENTED STRAND BOARD (OSB) LAP SIDING**

The story of OSB lap siding is similar to that of barrier EIFS. A product's potential was oversold and the material underdelivered on performance. While the product did not afford a quicker installation time or a lighter-weight alternative to traditional wood siding, it was less expensive. Another benefit to using OSB siding included that it was a "green" product that used the wood from aspen poplar and southern yellow pine trees, among other species, which are fast-growing, easily renewable trees. In addition, siding was advertised to have more consistent material properties than plywood or sawn wood siding.

OSB sheathing was developed in the late 1970s. Louisiana-Pacific (LP) opened its first OSB mill to manufacture "Inner Seal" sheathing. In 1985, LP expanded its product line and began marketing OSB Inner Seal exterior siding. Prior to Inner Seal siding, OSB was used as floor, wall, and roof sheathing board when protected by building paper or other weather barriers. Inner Seal was one of the first OSB products that was intended to be exposed to the elements. The siding still required weather protection in the form of paint layers. Inner Seal was sold as both lap siding boards and sheet siding panels. The addition of an overlay to provide a faux wood grain and texture to the products apparently is how Inner Seal differed from standard OSB sheathing. LP heavily marketed Inner Seal siding as a beneficial alternative to sawn-wood siding and offered a 25-year limited warranty.

In the early 1990s, evidence of problems with Inner Seal siding began to be reported. The siding boards would swell, and the lay-

ers would separate. Organic growth would take root in the swollen layers and cause further deterioration. The swelling would also force fasteners out and loosen the panel anchorage. In extreme cases, the siding would completely decay and disintegrate. The problems were most prevalent in locations that have moist environments such as Florida, Georgia, and the Pacific Northwest. A majority of the installations were on residential buildings, though Inner Seal was also used on commercial structures.

LP investigated the claims of product deterioration but, in nearly all cases, stated that improper installation and maintenance were the causes of the problem. In instances where LP admitted to defective Inner Seal siding, their warranty limited the remedy that LP had to provide twice the cost of the original siding material.<sup>21</sup> Labor for installation and other costs to repair damage due to water infiltration through defective siding was not covered by the warranty.

To understand how the failures of the Inner Seal siding occurred requires an understanding of how OSB is made. OSB is fabricated out of layers of thin wood chips or wafers that are impregnated with resin adhesive and wax and formed into a mat on a continuous conveyor belt. The mat starts out about 6 in thick when it is sent into a press. Under pressure, the 6-in mat is compressed into the thickness of building sheathing, e.g., 1/2 or 5/8 in. The press also is heated to activate and cure the resin adhesive, which bonds the layers together. When the newly pressed and glued boards exit the press, the moisture content of the wood chips is about 2% to 3%. At that point, the OSB wood wafers will begin to absorb moisture from the air to reach the natural equilibrium of the environment.

When OSB absorbs moisture, the wood wafers will swell perpendicular to their grain. The swelling of the wafers produces expansion in the out-of-plane direction of the OSB, increasing the panel thickness as well as expanding the panel dimensions in plane.

OSB is an engineered wood product, as described above. In addition to being engineered for performance, it was also engineered for economy. The least amount of materials were used that were necessary to meet the minimal performance standards set for the product. This included the minimal amount of resin needed to glue the wood chips together to form OSB. When the wood wafers swell due to moisture infiltra-

tion, the expansion creates stress on the adhesive bonds between layers of chips. If the stresses exceed the capacity of the resin adhesive, separations and delaminations within the OSB panel will occur.

The LP Inner Seal installation requirements state that the siding had to be painted with 100% acrylic latex to a minimum dry film thickness of 2 mils. The installer was directed to ensure that all edges were completely painted and to consult with the paint supplier for "proper application techniques" and environmental conditions for a successful paint application. LP excluded themselves from the performance of field-applied finishes.<sup>22</sup>

The critical location on the Inner Seal was the lower drip edge of the siding boards. Edges that were not completely painted were susceptible to water infiltration. The wood chips absorbed the moisture to such an extent that the swelling stresses fractured the resin adhesive bonds, causing splitting of the board layers. This allowed more moisture to be absorbed into the boards. The voids created by the splitting of the material provided a location for airborne fungal spores to land and grow within the boards, contributing to the deterioration of the product. The destructive cycle of wetting and splitting of the OSB wood chip layers eventually caused the disintegration of the boards.

Faced with the reality of hundreds of thousands of board feet of deteriorating Inner Seal siding, LP stood by its claim that the problems were due to improper installation and finish application or lack of maintenance. They may have had some standing with that defense. However, Inner Seal was similar to barrier EIFS in that the siding boards required a precise and nearly perfect installation to avoid deterioration from water absorption. The precision required to properly construct both types of cladding systems was a variable over which the manufacturers of either system did not exercise adequate control.

The requirement to apply the paint to a dry-film thickness of 2 mils is slightly thin for typical siding applications. For a product that is susceptible to deterioration from water absorption, this is not enough paint to provide the necessary protection, particularly for the location of the vulnerable drip edge. Spray application of paint coatings may give the appearance of complete coverage; but unless the surface is back-rolled or brushed, there may not be sufficient millage to protect the boards. Similarly, the appear-

ance of coverage to the naked eye does not mean that there are not small holidays in the coating through which water can pass. The stated finish requirements for Inner Seal do not contain special emphasis on the urgent need for complete coverage of the drip edge or an increase in the dry mil thickness for this location. An installer reading the LP requirements would have no indication regarding the special attention towards coating the panel drip edge. There was a fine margin for error in installation of the siding.

The wave of litigation against LP began in Florida in the early 1990s. Initially, the company attempted to settle claims through its warranty program. However, the limitations in the 25-year warranty meant that generally, LP only had to pay a few hundred to a few thousand dollars for each claim. Typically, this was insufficient to repair all deterioration and damage associated with the failed Inner Seal siding. In its Securities and Exchange Commission filing in 1994, LP reported that it had paid out approximately \$37 million to settle warranty claims on 15,000 residences.<sup>23</sup> By 1995, LP was involved in a multitude of legal actions. Faced with the prospect of defending national lawsuits in different courts, loss of stock value, and general public image degradation, LP decided the best course of action would be to find a way to resolve all disputes quickly.<sup>24</sup>

In April 1996, settlement terms were finalized that established a national fund from which claims of Inner Seal deterioration and damage would be paid to owners with siding installed on their buildings prior to January 1, 1996. The settlement fund would be available for seven years. Owners with qualifying siding who reported damage by 2003 were eligible for recovery of damage. LP ended up paying up to \$500 million to settle Inner Seal siding claims. Also notable is that in April 1996, LP reissued its "Inner Seal Lap Siding Installation Instructions." In the updated version, special emphasis in text and graphics are given to the importance of painting the drip edge side of the siding boards and the minimum required dry-film thickness of paint is increased to 2.5 mils. However, a note also states, "Research has indicated that the optimum thickness for the primer and top coats is 4 to 5 dry mils."

OSB is a moisture-sensitive product. It has a successful history as an engineered wood product for interior use as sheathing panels. The error with Inner Seal was to

believe that a relatively thin paint coating over which LP had no control, especially at the drip edge, would be able to adequately protect its product in an environment where it was susceptible to deterioration and failure.

## CONCLUSION

Innovations in construction technology have led to the creation of lighter and cheaper materials that enable quicker erection of buildings. Most innovations are beneficial and successful in those goals. As discussed in this paper, there have also been significant failures of products that were purported to be able to make large advances in the building enclosure field. Several aspects of these failed systems are similar:

- **Attempting to stretch materials and systems with a proven performance history and capabilities beyond what they were able to handle.** By trying to extend materials beyond limits of proven performance, manufacturers were leaving very little margin for error. Sarabond attempted to make prefabricated masonry into "precast concrete" by radically increasing the strength of mortar. Unfortunately, that which increased the mortar's strength also led to masonry deterioration. Thin-marble panels had no history to indicate that they could perform in such a "lightweight" material. Barrier EIFS took a system that had a proven record of performance in Europe and failed to adapt it to lightweight and moisture-sensitive construction methods in America. LP Inner Seal siding attempted to use a moisture-sensitive material in an exposed environment with only minimal protection from the elements.
- **Creating systems for which there was no historic precedent from which to be able to predict future behavior of the systems.** The cladding systems studied had no history of performance by which to judge how durable they would be. (EIFS had success applied to masonry substrates but not installed over moisture-sensitive, lightweight construction systems.) The individual components of the various systems were durable materials. Brick, mortar, and stone, for example, were time-tested materials.

However, when used in new combinations or with new products, there was no history of performance. There was faulty logic in linking the past performance of one material with predicted future performance of that material being used in new combinations or in untried configurations. This may have been a good selling point to convince professionals and building owners to try the new systems. Time shows that because material A works in application B, that does not mean it will also perform in application C.

- **Lacking sufficient material, structural, and accelerated weathering testing prior to introducing the products and systems to the market.** It is clear in each of these case studies that the implications and performance of the materials and system were not fully tested or evaluated before being released in the market. What is not clear is if the companies felt that they had performed their due diligence and were confident of performance. On the other hand, there is the question of the desire to reach the market as quickly as possible; the companies were willing to take a calculated risk that they would address problems or defects as they occurred. In the case of Sarabond, there was evidence that the manufacturer was aware of the destructive effects of Sarabond towards metals, but they sold the product anyway. Whatever the reasons, the complete failure of these systems reveals, in hindsight, that not nearly enough testing was performed.

New products are being introduced to the construction market all the time. The latest wave includes materials and systems that are touted to be “green,” energy-efficient systems that will reduce building resource consumption while having minimal impact on the earth’s resources. No doubt, many or most of these materials and systems will perform as advertised or at least come close. However, as history has shown, there will be products that are potential disasters waiting to happen. To protect oneself from being involved in these questionable systems, consider these tips.


1. Do not be an early adapter. Wait to see how the system or material per-

forms over five years or more. Successful in-service performance should be demonstrable in several applications.

2. Verify whether or not product formulations have changed in recent years, and if they have, why. This could be an indicator of a response to previous problems, or it could be a legitimate improvement on an already successful product.
3. Research other installations to observe how they have weathered and if there are problems. Talk with building owners, property managers, or building engineers.
4. If a traditional material is now being used in a way that is new and untested, be wary. Understand the properties of the material being used and what the capabilities and limitations are. Louis Kahn is known for his quote, “What does a brick want to be? It wants to be an arch.” If someone is trying to make brick into a beam, then be skeptical.
5. Research for stories of litigation. The case studies described here generally occurred before the Internet boom and the access to information that we have today. At that time, there were limited means for building owners and professionals to connect and relay stories and information about building systems. Companies were able to delay having to face the reality of the product failures for years longer than if such problems occurred today. If you are considering a new material or system, do some research to find out if there are stories regarding problems or litigation actions regarding the product.
6. Warranties essentially say nothing. Warranties give an idea about how long a manufacturer expects the product or system to perform. Usually the remedies for defective products are very limited regarding what the manufacturer has to provide. Do not select a product or system with a long-range warranty, figuring that if something goes wrong the manufacturer will make good. Most times, they will not be required to, or they may have gone out of business. Be aware if the company funding the warranty is not the parent company name, such as an LLC. This funding company may have

been created to limit the amount of money paid out in case of material failure.

7. Request information on testing programs and product development prior to the system’s being put on the market. If the manufacturer will not provide documented testing of its product, then be wary. A manufacturer that is not completely transparent and forthcoming with the testing and performance history of its product or system should be a red flag of warning. Ideally, the testing information should be from an independent laboratory and not the manufacturer’s own testing program.
8. Do your own testing. If the project is of sufficient size or importance, it may be appropriate to conduct your own testing of the material or systems.
9. Consult with building envelope experts for advice on the known pros and cons about a material or system.

In the end, the classic consumer protection mantra may be the best guide. If a product or system sounds too good to be true, it probably is. 

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