What went wrong

Researchers explain artificial slate and shake products' spotty history

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Artificial slate and shakes fall into the common category of shingle products in that they are steep-slope roofing products overlapped to shed water to the edges of a building.

There are many demands on shingles. To function successfully, they must be shaped and oriented to shed water reliably. Shingles also must be durable so they can be safely installed and maintained throughout their expected life spans, resist wind and perform effectively under local weather conditions. And because most steep-slope roof systems are visible, shingles must be attractive, retaining their desired appearance throughout their expected life spans.

The history of artificial slate and shakes made from fiber-reinforced cement is a mix of success and failure. But this is not surprising when you review how the changes occurred within the industry.

What happened

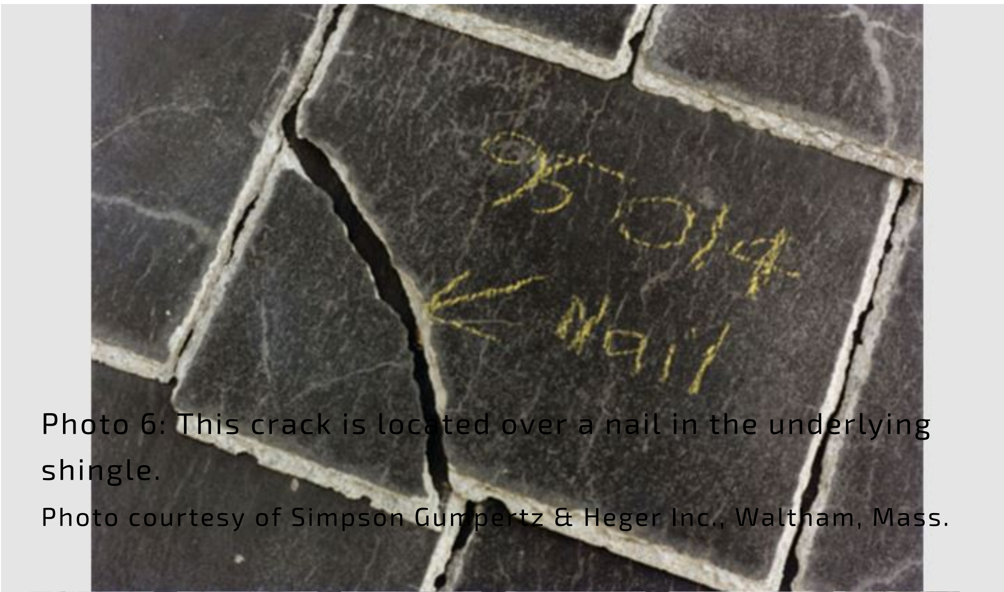
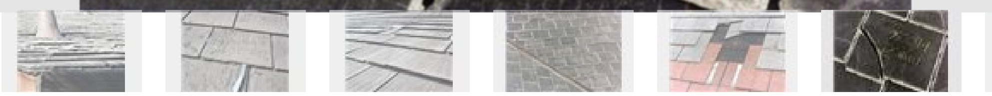


Photo 6: This crack is located over a nail in the underlying shingle.

Photo courtesy of Simpson Gumpertz & Heger Inc., Waltham, Mass.



Before the 1980s, most artificial roofing slate was made from asbestos-cement, a material that had a long track record of successful performance. When the use of asbestos became forbidden, manufacturers rushed to replace asbestos-containing products with cement-based products reinforced with nonasbestos materials.

Products were quickly introduced into the marketplace with little research and development relative to the products' desired life. Products that looked "good" when tested shortly after they were manufactured were produced, delivered and installed without studying the long-term effects of weathering on the material properties.

As a result, these materials experienced extensive failures during the early 1990s, well before the end of their intended life spans, which often were advertised to be 30 to 50 years.

Roofing contractors and building owners became unwitting research agents for the new artificial slate replacement products. When it became clear there were fundamental problems with these materials, contractors and owners were met with neglect, denial, inappropriate counter-claims and lawyers by the manufacturers. Virtually every product introduced during the 1980s and 1990s has been pulled from the market and is, fortunately, no longer available.

The current generation of artificial slate and shakes is based on rubber and plastic technology. Current products look realistic and are attractive when installed. Although the rubber and plastic industries have made single-ply roofing materials that have successfully withstood the test of time and outdoor weathering, current plastic and rubber slate and shakes do not have track records to match their warranties.

Roofing contractors have a legitimate expectation that the goods they purchase on behalf of their customers are fit for their intended purposes. What follows is a summary of years of research we performed that demonstrates slate and shakes manufactured from fiber-cement materials reinforced with cellulose fibers were doomed to fail from the start. Fiber cement made from wood fibers, newsprint, wood chips and combinations of these materials did not stand up to the test of time.

Why a new product?

The roofing industry, like all other industries, is constantly looking for the next innovative product that will revolutionize the industry and give someone a competitive advantage.

In addition, there is a faction of the architectural community that desires to always be on the cutting edge of technology in building design. These designers want to be the first to successfully incorporate a new or improved product into their next design.

Manufacturers also are constantly trying to improve their existing products to develop more cost-effective processes and increase profits or, as was the case with asbestos, replace an ingredient effectively banned from use by government regulations.

During the early 1980s, asbestos use was all but eliminated by government restrictions and bad publicity regarding the health threats reported from asbestos exposure. Asbestos is a natural mineral that is compatible with Portland cement; blended with Portland cement and aggregate, the material was manufactured into various products made from sheet goods. While they were in use, asbestos-cement products provided long-term, successful performance on steep-slope roof systems and as exterior wall cladding. Many asbestos-cement roofing products were manufactured to imitate slate and wood shakes.

With the loss of asbestos as a reinforcing medium, the roofing industry needed to find a substitute. Various polymeric materials, newsprint and wood fiber waste products were among the substitutions the industry considered. If the industry could effectively continue to manufacture the same product using essentially the same materials with a different reinforcing medium, it could continue to deliver products to an established marketplace. The new products also had to have price points similar to the asbestos-cement products so they'd have a significant cost advantage over natural slate and tile.

How a product starts

As manufacturers developed the new materials, it appears the inherent properties of the replacement fibers were largely ignored in the developmental research.

Although the exact amount and quality of such research is largely unknown, the performance record of the fiber-cement materials proves it was fatally limited to testing of products in the short run and that long-term exposure tests were omitted while the industry hoped the products would work as well as the products they were replacing.

Limited to short-term programs, performance testing did not examine the materials' long-term behavior characteristics. When the short-term test programs demonstrated the "new and improved" products could provide characteristics similar to the products they were replacing, the materials were introduced to the market. Most products were marketed with long-term warranties, implying the materials would perform as well as the asbestos-cement materials they were replacing.

Offering new and untried products with 30- to 50-year warranties left users with an essentially untested product that ultimately failed within the first few years of installation by disintegrating on roofs when exposed to normal weather conditions. When such failures occurred, the industry was unwilling or unable to make good on its obligations because of the large financial burden of virtually a total failure of all products delivered and installed.

We are not aware whether the roofing industry used any reputable testing agency that was qualified to determine the products' future viability. Although short-term "accelerated" tests have only a spotty record, the products' early widespread failures indicate the developmental research was superficial and certainly inadequate and did not identify the ultimate mode of failure. The industry seemed to resist acknowledging the products were defective even after extensive failures occurred.

When defects became apparent, we suspect manufacturers were as surprised and uninformed as their customers, installation contractors. Our experience shows that in the rising flood of failures, some manufacturers resorted to blaming installers for the problems and refusing to make good for the direct and obvious consequential damage. Some manufacturers even battled in court, trying to refute the clear evidence they had inserted a product unfit for use into the stream of commerce. The manufacturers appeared to hope the problem would go away by itself.

Field performance

On behalf of users, owners and installers, we investigated fiber-cement slate and shake products produced by several manufacturers during the 1990s. Following is a summary of some of our observations:

- Trouble with some fiber-cement products often started during unloading and stockpiling of the products. Some slate displayed cracks while other pieces curled. However, this was not the major problem.
- A short time after installation, the slate and shake products began to deteriorate. Contractors reported the products curling, developing cracks and often disintegrating completely. Deterioration was reported to progress quickly; in some instances, contractors reported any attempt to walk on a roof for repairs destroyed all tiles touched. In one case, we were engaged to investigate a 30,000-square-foot roof in such poor condition that the contractor could not find 12 undamaged tiles for laboratory testing.
- Our general observations revealed some discolored or faded products. Others curled without cracking but opened enough to allow water into buildings. In general, most fiber-cement materials quickly became unfit for roofing or became so unattractive owners were unhappy with the appearance.

After we were retained to investigate failures of fiber-cement slate and shakes of different manufacturers, we realized there was an apparent common factor in their compositions. As a result, we undertook a testing program to find the reasons for the problems.

Investigating the problems

We investigated and tested 11 artificial shake and slate products manufactured by nine manufacturers. Our investigations involved hundreds of roofs in more than 20 states. Some roofing products failed before installation was completed. Few survived past their tenth year of exposure.

The figure on page 47 summarizes our observations during field sampling of the 11 products investigated. The figure lists typical field observations recorded on weathered samples.

A ″yes″ in any cell of the figure denotes a widespread condition, meaning that not just one or two or even a few shakes or slates show the condition listed, but there is an overall system failure. For example:

- Cracking of the top coating includes micro-cracking or the start of general deterioration.
- Top-surface exfoliating is frequently the next step in the deterioration process.
- Widespread through-cracking of slates or shakes allows water into a system; broken slates or shakes can act as a sliding board for workmen on the roof, and the shards can be missiles when they fall from a roof.
- Warped or cupped slates or shakes are often a prelude to cracking with or without rooftop traffic and admit more windblown rain than was intended by the system. Maintenance of a roof system and rooftop equipment is impractical if a roof cannot support foot traffic.
- Soft or ″punky″ top surfaces invite and encourage water penetration.
- Moss or grass growth are not necessarily detrimental to a roof system, but their presence indicates the long-term presence of water, which almost always damages roofing materials.
- Exfoliation of the layers is the principal failure mode of products made by pressing together matrix layers. The separation is caused by water intrusion and swelling of the lamina.

Typical field observations

Producer	Shingle or shake identity	Cracked top coating	Coating—top surface exfoliating	Shingle cracked	Warping, cupping	Soft, punky top surface	Moss or grass growth	Layers coming apart
A and B	1	Yes	Yes	Yes	Yes	Yes	Yes	No
C	2	Yes	Yes	Yes	Yes	Yes	Yes	No
C	3	Yes	Yes	No	No	Yes	Yes	No
D	4	No	No	No	Yes	No	No	Yes
E	5	Yes	Yes	Yes	Yes	No	No	Yes
F	6	Yes	Yes	Yes	Yes	No	No	No
G	7	Yes	Yes	Yes	Yes	No	No	No
H	8	Yes	Yes	Yes	No	No	No	Yes
I	9	No	No	Yes	Yes	No	No	No
I	10	No	No	Yes	Yes	No	No	No
J	11	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A summary of observations during field sampling of 11 artificial slate and shake products

Water, and not just freeze-thaw action, is the fundamental source of these distresses on products. Many manufacturers attempt to avoid problems by limiting the application of fiber-cement products to geographical areas that see few freeze-thaw cycles. This was of some use, but the manufacturers failed to realize wet-dry cycles (without freeze-thaw) will similarly damage roofing materials.

Individual products

Without naming companies, we provide discussions of individual producers and their products. The information includes statistics we obtained by performing laboratory testing during our investigations.

In our discussion of each product, we present values for a "handleability" index as follows: U = 0.5 P?/t where P is breaking load in pounds; ? is the deflection at break; and t is the test specimen's thickness.

The handleability index is a relative term that measures a material's capability to be handled without breaking. We have found products with a high handleability index can be installed and serviced without experiencing damage. Typical values of the handleability index for steep-slope oofing products are:

- Cedar shakes: 74 pounds
- Slate: 8 to 64 pounds depending on source and orientation to grain
- Asbestos-cement roof-ing products: 1.8 to 32 pounds depending on thickness

Based on slate's successful performance as a steep-slope roofing product, we consider a roofing product should have a minimum handleability index of 8. However, other factors may affect product breakage, including size, shape and attachment method.

Producers A and B—Product 1

These products are unique in that they have the lowest density of the artificial shake or slate shingles that were offered to the industry because of the perlite (lightweight aggregate) incorporated in their formulations. Portland cement and expanded perlite are the principal ingredients. Minor additions include fibers from cardboard (thick paper), clay and tallow.

With water added, these materials are pressed into molds, dried, lightly coated for color, dried, packaged and sent to the field. Producer A started the production of shakes. The business was sold to Producer B, and a new product was announced. We compared the products manufactured by the two producers and found the products to be identical.

Our field investigations showed the top coating flakes off the shakes; the surfaces have a spider web of cracks, many extending through the body. The surfaces feel soft, powdery and eroded. Many shakes cup upward and support luxuriant growth of grass and weeds.

Laboratory data reveal these shakes have the lowest density of this group of manmade products, the highest water absorption (46 to 64 percent) and next to the lowest flexural strength (208 pounds per square inch [psi]). A 3.4-pound handleability index shows they are more brittle or friable than natural slate, which we have measured to have a minimum 8-pound index handleability.

Producer C—Products 2 and 3

Producer C provided two products to the market. Product 2 was shake-like with some corrugations or ridges down its face and a flat underside. Product 3 had a greater resem blance to tile and had reinforcing fins on its underside. Both had similar compositions: ground wood that had been previously treated to reduce soluble sugars mixed with Portland cement and water, pressed into molds, oven dried, sprayed with a surface coating, packaged and shipped.

During our field investigations, we found extensive surface erosion with many wood fibers exposed to the weather, frequent cupping of Product 2 and cracked shakes.

Product 3 had built-in gutters between the tiles that were often blocked by dirt and rooftop debris. These gutter dams caused water to drain over the edges of the gutters onto the underlying asphalt felt water-shedding membrane—in many cases eroding a path through the felts.

Laboratory tests showed these products to have a similar density (1.4 g/cm^3) and flexural strength (617 psi), below the minimum saturated modulus of rupture (798 psi) listed in ASTM C1225, "Standard Specification for Fiber-Cement Roofing Shingles, Shakes, and Slates."

The 4.2-pound handleability index shows the products are more friable than natural slate. Product 2 had a warp or cupping (see Photo 1) of 3/4 of an inch that is flattened by a modest 24-pound load on the front edge. Water absorption of 24 to 25 percent is consistent with many other fiber-cement shingles and shakes.

Producer D—Product 4

Producer D manufactured its products outside the U.S., and details of the manufacturing process are not known. These products are characterized by a strong—almost baked—enamel top coating. At one time, we considered Producer D the only one with a good performance record. Then, we began getting reports of cup-ping and top coating delamination.

Product 4 was reported to us to be reinforced with polymeric fiber reinforcement. The main problem with this product was color instability and curling, not extensive product breakage. Producer D has discontinued distribution in the U.S.

Producer E—Product 5

Producer E manufactured a cellulose-cement product using a cylinder machine similar to the equipment used to make asbestos-cement sheets and shingles where the thickness was made of relatively thin sheets laminated together. Product 5 curled and became embrittled—probably because of carbonation of the free alkalis present—and frequently delaminated after weathering (see Photo 2). Walking on the roof broke the shakes (see Photo 3).

The 4.2-pound handleability index illustrates the products are more friable than natural slate. The 31 percent water absorption is much too high for a weather-durable product. Frequent wetting and drying in tropical environments caused the product to soften to the point that it could easily be broken by hand.

Producer F—Product 6

Producer F manufactured shakes made from Portland cement and ground wood with various additives, including fly ash, aluminum hydrate, aluminum sulfate and water. The mixture was pressed into molds, dried, lightly painted and shipped after curing.

The principal negative field observation is a constant tendency for the bottom edges of these shakes to cup upward. Many broken shakes were recorded. Any roof-top traffic caused the shakes to crack—often near the fasteners—where the crack is covered by the higher row of shakes.

The shakes' flexural strength at 1,000 psi is the second highest of the shakes tested. The water absorption is 22 percent. The handleability index is 1.9 pounds—the second lowest in this group. The distance between the shakes' bottom of the front edge and a flat reference table averaged 0.3 of an inch. A modest 44 pounds cracked the shakes and pressed them flat. These cupping and fracturing tendencies make maintaining a roof system with these products difficult if not impossible.

Producer G—Product 7

Product 7 is composed of about 35 percent wood fiber and about 65 percent hydrated cement. The shakes' top surfaces are quite porous, and many shingle samples were cracked.

The average water absorption was 35 to 51 percent of the shingles' dry weight. We found weathered surfaces absorbed water up to 16 times faster than unexposed surfaces. Wetting and drying of the fibers causes cycles of the fibers swelling and shrinking. In addition, soluble alkali salts migrated into the fibers and were converted to calcium carbonate—a well-known process of carbonation that embrittles shingles.

Producer H—Product 8

This product was manufactured by sifting a "snow" of paper fibers, Portland cement and fumed silica onto a wet moving belt, spraying water, compressing and shaping the wet snow, cutting, punching nail holes, drying and autoclaving. Final operations included washing the efflorescence off the surface and spraying on a clear acrylic coating to provide a shiny finish.

The first public report of this product's poor performance was in 1995. We found cracked and broken slates during our many field investigations (see Photo 4). These slates were designed to be hung (see Photo 5) on incompletely driven nails (as are natural slates) in plywood decks. A high percentage of the cracks in the slates were over the nail heads (see Photo 6) of the shakes. Blotchy color variation marred some roofs.

We observed small cracks in the surfaces of products waiting to be installed. These cracks contained some of the acrylic coating applied at the factory. Therefore, these cracks are a result of the manufacturing processes and are independent of exposure to the elements. On one job, shards were falling to the ground before the work was completed.

Laboratory testing showed a significant decrease in flexural strength, deflection at break and handleability index in the samples that had been exposed to the weather when they were compared with the unexposed samples. The deflection at break was less than the thickness of the nail heads typically used to install these products, explaining the high frequency of cracks in the product over the nail heads.

Producer I—Products 9 and 10

Product 9 is a fiber-cement shake similar but not identical to many others. We believe it is cast in molds, compressed, dried and top-coated. The producer provided a 50-year warranty. Within a relatively short time, the producer introduced Product 10 and offered a 30-year warranty.

Unlike other fiber-cement shakes, the top surfaces of these are dense and relatively intact. We saw the exposed shakes cup upward on every roof (see Photo 7). Almost any that were lying flat were broken (see Photo 8). These broken shakes channeled rain into the roof system and onto the secondary water barrier (underlayment), eroding it so water eventually leaked into the building. Warped shakes were prone to break under foot traffic, making rooftop maintenance impractical because any traffic would add to the number of broken shakes.

Producer I wrote that Product 9 was composed of 80 percent Portland cement and 20 percent wood fiber. We found 30 to 37 percent ignition loss in Product 9 and 24 to 26 percent in Product 10. The higher percentage ignition losses relative to the reported wood fiber content indicates the wood fiber component absorbed and held moisture. Wood fibers swell when they absorb moisture, contributing to dimensional instability.

Ignition loss is a laboratory procedure that measures the loss of mass during a controlled burning process. The test measures the amount of combustible material and free moisture contained in a material. The test is performed below the temperature that would drive chemically bonded water from the cement matrix.

Product 9's water absorption is 29 percent; the handleability index is 7 pounds. Product 10's water absorption is 8 percent; the handleability index is 7.2 pounds. Thus, densification improved the water absorption but did nothing for the product's strength. No statistically significant improvement was found in the cupping.

Producer J—Product 11

Product 11 was unique in that it was prepared in layers to make up the tapered shake. The bottom layer was a 0.003-inch-thick polyethylene terephthalate membrane with random directional fibers and a plant fiber- and aggregate-filled Portland cement matrix incorporating a 0.013-inch-thick isotactic polypropylene mesh with a square 1/2-inch pattern topped with a dense cementitious pigmented material.

We were unable to recover a whole sample from the field—the shakes almost disintegrated as they were removed from the roof. The top surfaces were powdery and broken. These shakes, at 170-psi flexural strength, had the lowest flexural strength of the group of manufactured slates and shakes tested.

What it means

Our conclusions about the performances of the many fiber-cement slate and shake products are based on our extensive product investigation and testing.

Wood-, paper- or perlite-reinforced Portland cement slate and shake products are not suitable for use as long-term roof coverings where they are expected to get wet. The fundamental weakness such products exhibit is a lack of durability (cracking and disintegration) and dimensional instability (warping and cupping) in the presence of water.

The fundamental materials science error common to all but one of these products was the use of a moisture-sensitive and dimensionally unstable material (wood fibers) within a brittle medium (Portland cement mortar). The Portland cement mortar lacked the tensile properties to resist the swelling of the wood fibers, so the material broke down during wetting-drying cycles.

During the 10 years covered by this report, there have been many instances when even casual testing, such as a simple water spray or submersion test and product mockup testing, would have shown the dangers inherent in these formulations. The facts remain:

- There are no test methods or programs that accurately predict roof system durability.

- Only a roof system's historical durability in a similar environment is an appropriate performance indicator.
- Long-term warranties may be the worst indicator of durability.

As a further and more important lesson, we have learned the industry must advance research capabilities extensively and recognize fallibility of inadequate testing before introducing new materials into the roofing marketplace.

The next generation

There are a number of artificial slate and shake products available that are manufactured using rubber and plastic materials. Products made with EPDM certainly have a sister product with a long-term performance history in single-ply roofing. The products are offered in styles to imitate slate in all the colors found in natural slate, as well as all shapes and sizes of imitation wood shakes.

Some of these products have been on the market for more than 10 years and reportedly have been installed throughout the U.S. All the products we reviewed are offered with 25- to 50-year warranties, a period of time that should be considered long-term relative to the products' track records.We have little experience with the performance of these products at this time. We suspect the reason is, in part, because we haven't been called to look into any project failures. It is not the nature of our engineering consulting business to be hired to look at successful installations that continue to function as intended.

The installations we have seen are attractive and appear to achieve the desired look of slate or shake roofing. We hope these products will continue to perform and maintain their appearances for a long time.

However, based on our experiences in the roofing industry, we offer the following advice if you use any product that does not have a history of successful use that matches the intended life of a roof system:

- There is no test or group of tests that can predict a roof system's service life except the test of time.
- Installing a roof system that has less of a track record than its expected life is an experiment; this is acceptable as long as its owner is a willing participant.
- There are different interpretations of "performance" and "failure." Is the product that was selected to provide a desired appearance a failure when it quickly loses its applied finish even though it doesn't leak?
- Try to get a clear, upfront understanding of the owner's expectations. Explain the remedies available for poor performance.
- Investigate other installations, and talk to the owners regarding their experiences.
- Follow manufacturers' installation instructions.
- Warranties are legal documents that are used as sales tools. Warranties provide more protection for roofing manufacturers than they provide purchasers. Do not rely on a warranty to ensure performance.

Author's note: We wish to acknowledge the influence of our late friend, colleague and mentor Carl G. Cash on the preparation of this article. Carl was instrumental in many of the investigations and much of the research that went into the evolution of the information and the conclusions presented here. Much of this was written with Carl's voice in the back of our heads, continuing to guide us in the present as he did when he was with us.

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