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The Disruptive Potential of Pyritic Shale Fill

Most of us have found a piece of “fool’s gold” in the gem bin at a museum gift shop. While this stable form of pyrite’s claim to fame is fooling the beholder, other finely-grained, microscopic, less stable forms of pyrite have long plagued the mining, environmental, transportation, and building industries with its deleterious side effects. This WJE Primer is intended to educate designers, contractors, and others in the building industry about the devastating potential of this mineral when it is sufficiently present in engineered fill materials.

Pyrite Origin and Degradation

Pyrite (iron sulfide or FeS_2) can be found throughout the world in many forms; however, the most perilous for the built world is finely grained (frambooidal) pyrite embedded within rock. The geologic production of pyrite requires an environment with a limited supply of oxygen, a sufficient supply of sulfates, along with organic matter and bacteria, iron, and tidal action. The most conducive place for production is a marine environment. This type of environment also tends toward the deposition of pyrite within metalliferous black shales and surrounding limestone bands. Formations of such metal-rich black shale and limestone are common in parts of the US and Canada.

Many forms of pyrite are stable. However, frambooidal pyrite readily degrades when exposed to air and moisture. Black shales with inherently weak bedding planes typically offer little protection of embedded frambooidal pyrite particles. Potential for exposure is increased if the pyrite-containing material is broken up (e.g., by crushing to produce aggregate, or by excavation, placement and compaction when used as fill). Placing material in a new environment can also increase exposure potential. Exposed pyrite reacts with the air and moisture in an



FIGURE 1. A PYRITIC SHALE FORMATION IS EXPOSED AT A QUARRY FACE. WITHIN THREE YEARS OF EXPOSURE, OXIDATION OF THE PYRITE HAS LED TO IRON OXIDE STAINING AND DEGRADATION OF THE SURROUNDING SHALE.



FIGURE 2. A RELATIVELY THICK BEDDING PLANE CONTAINED IN A SHALE FRAGMENT IS PICTURED. A BRASSY YELLOW PARTICLE COMPOSED OF IRON SULFIDE IS LOCATED WITH THE RELATIVELY THICK WHITE LAYER.

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FIGURE 3. A MICROGRAPH OF GYPSUM CRYSTAL GROWTH WITHIN AN OPEN BEDDING PLANE IN THE SHALE PARTICLE.

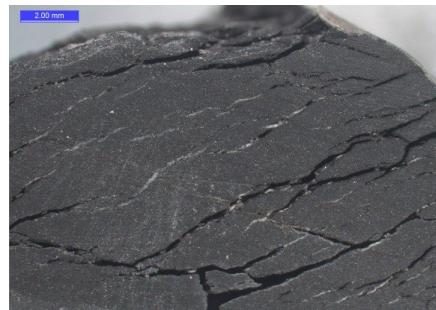


FIGURE 4. A SHALE PARTICLE HAS EXPANDED AT AND NEAR BEDDING PLANES. NOTE THE SECONDARY WHITE CRYSTAL (GYPSUM) GROWTH WITHIN THE EXPANDED BEDDING PLANES.



FIGURE 5. A HEAVED FLOOR SLAB HAS RESULTED IN A DOOR THAT CANNOT FULLY OPEN.

oxidation process, the byproduct of which is sulfuric acid.

This reaction can be accelerated by acidity, high humidity, and warmth. The presence of iron-oxidizing, sulfate-reducing, or sulfur-oxidizing bacteria can also act as a catalyst for this reaction. The introduction of sulfuric acid to a below-grade environment presents several potentially hazardous outcomes, including heaving due to volumetric expansion of certain fill materials, sulfate attack of embedded concrete elements, and corrosion of embedded metallic items.

Sulfate-Induced Heaving

The sulfuric acid (H_2SO_4) by-product of pyritic degradation can react with the calcium carbonate ($CaCO_3$) component inherent to common fill material such as limestone to form gypsum ($CaSO_4$). Since the products of gypsum formation occupy much larger volumes than the materials consumed, this process is expansive. As a result, fills containing significant amounts of framboidal pyrite, in combination with calcium carbonate, can cause substantial movements of supported or embedded

elements and exert large pressures on items that cannot freely move.

The uniformity and intensity of heaving caused by pyritic fill are primarily functions of the installed thickness and environmental conditions. Heave has been documented as early as six months after completion of a building. While volumetric expansion of pyritic shale has been documented to last as long as forty years, the rate of expansion between onset and exhaustion is an unpredictably complex function of numerous factors.

Symptoms of slab heaving (often mistaken for settlement) include sloping walking surfaces; cracks and offsets in slabs; cracked, buckled, and crushed drywall; binding doors; and separating or crushed millwork. Effectively managing the symptoms (e.g., grinding slabs, adjusting and under-cutting doors, repairing finishes) is almost always an iterative and disruptive process that ultimately accumulates significant effort and costs. Addressing the cause to prevent future heave requires a one-time project to demolish and reconstruct the slab-on-grade (which, by proximity, necessitates the removal and

reconstruction of most interior finishes and systems below the ceiling line) such that all pyritic shale fill material can be removed and replaced with a stable fill material.

Sulfate Attack

In addition to gypsum crystal growth causing expansion of the fill material, sulfates from the gypsum can leach into surrounding sub-grade concrete elements, such as grade beams, pile caps, retaining walls, and footings. Soluble sulfates can react with calcium aluminates contained in the portland cement to form ettringite (calcium sulfo-aluminate hydrate), which has a volume greater than the reactants. This expansive reaction occurs within the cementitious matrix, causing internal cracking and, ultimately, disintegration of the concrete. Removal and replacement of affected concrete is the only effective method for addressing concrete suffering from severe sulfate attack.

Avoidance

Most quarries that produce aggregate fill materials are cognizant of formations that may contain pyritic material; however, contamination during processing or

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FIGURE 6. A ONE INCH-WIDE CRACK WITH A THREE-QUARTER-INCH VERTICAL OFFSET WAS DOCUMENTED IN A CONCRETE FLOOR SLAB OVER PYRITIC SHALE FILL. PORTIONS OF THE SLAB HAD HEAVED UPWARD MORE THAN TWO INCHES OVER THREE YEARS BEFORE THE SLAB AND UNDERLYING FILL WERE REMOVED.



FIGURE 7. A FLOOR SLAB OVER PYRITIC SHALE FILL AND DOWELED INTO A PERIMETER GRADE BEAM EXHIBITED A LARGE CRACK WITH VERTICAL OFFSET AND ROTATION ABOUT THE DOWEL POINT INTO THE GRADE BEAM.

stockpiling or even negligence can result in use of pyritic shale fill materials. As such, contractors and professionals should be aware of locations and formations that contain pyrite and should be knowledgeable of the physical characteristics of pyritic shale.

Pyritic material has been documented in several areas around the world including Japan, Norway, Great Britain, Saudi Arabia, Canada, and the United States. In the United States, the Appalachian Mountains are a known source of pyritic material. Several midwestern, southwestern, and northwestern states have pyritic formations, as well. Luckily, pyritic shales are generally stratigraphically confined. Therefore, knowledge of formations and their locations can greatly reduce the risk of use of pyritic fill materials.

Most construction project materials specifications refer to the specifications of state Departments of Transportation (DOT) to define the quality expectations for aggregate materials. However, the limitations imposed by most DOT specifications to preclude the use of aggregate with deleterious amounts of pyrite are vague and unenforceable at best (e.g., "reasonably free from iron sulfide"). This is due in part to the lack of a consensus threshold value below which the risk of expansion due to pyritic degradation is acceptable.

According to a report published by the Virginia Transportation Research Council for the Virginia Department of Transportation, sulfur content greater than 0.1 percent combined with a calcium carbonate source has the potential to cause upward pressure on overlying slabs. Using this or any appropriate benchmark, chemical testing

can be used to determine whether or not a fill material contains excessive sulfur. Pyrite can be found in solid limestone aggregate; however, as long as the particles remain encased by limestone, there is little risk of oxidation and the related deleterious effects. As such, chemical testing of aggregates should be accompanied by a petrographic evaluation to best understand the reactive potential.

Conclusions

Pyritic shale fill materials can result in significant damages and associated repair costs to surrounding construction. Aggregate used as fill material with as little as 0.1 percent pyrite content can produce damaging movements of supported and adjacent construction and promote an environment for sulfate attack on sub-grade concrete elements. Much like knowing how to identify and differentiate fool's gold from real gold to avoid a costly mistake, a building industry that understands the characteristics and ramifications of pyritic shale fill materials will avoid costly and disruptive repairs.

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