

Iron Sulfides and Concrete

An RJLG Materials Insight Publication

Oxidation of Iron Sulfide Minerals

Iron sulfides are accessory minerals found in a variety of rock types, with pyrite (FeS_2) and pyrrhotite (Fe_{1-x}S) ($x = 0$ to 0.2), being most common. Under some conditions, these minerals can undergo oxidation reactions that have the potential to cause damage to concrete pavement or structures.

Pyrite in Rock Beneath Concrete Structures

Pyrite is common in shale and is a source of acid rock drainage (ARD), which occurs naturally in some environments as part of rock weathering and subsequent oxidation of the pyrite. This phenomenon is also known as acid mine drainage (AMD) when mining activities exacerbate the weathering process by exposing more pyrite to oxidation. ARD and AMD result in a lowering of pH of ground and surface water flowing away from the pyrite source due to the release of sulfuric acid.

If pyritic shale or iron sulfide-bearing rock are present beneath buildings or pavements, the volume change caused by the oxidation of iron can result in swelling of the soil and subsequent heaving of concrete slabs and foundations¹. In addition, the released sulfuric acid can react with calcite and other ions present to form expansive secondary sulfate minerals. Testing of shale for sulfide content is commonly performed when construction is planned, with limits varying by state and developer specifications.

Pyrite and Pyrrhotite in Concrete Aggregate

Iron sulfides are common in a variety of rock types and therefore may be present in aggregates used in concrete. Pyrite is the most stable iron sulfide mineral, but can still oxidize near the surface of concrete and stucco, leading to unsightly staining and pop-outs. In good-quality dense concrete, aggregate containing small amounts of pyrite can be successfully used without affecting durability of the structure.

Pyrrhotite oxidizes more readily in concrete than pyrite. Reactions between the resulting sulfuric acid and the cement paste may form secondary sulfate minerals causing significant expansion and cracking of the concrete. In the most severe cases, alteration of the cement paste results in weakening and loss of structural integrity of the concrete. The use of pyrrhotite-bearing aggregates has been found to be the root cause of extensive damage to thousands of homes and commercial buildings in Eastern Connecticut² and Quebec, Canada³⁻⁴.

A number of factors affect the rate and potential for damage due to oxidation of pyrrhotite, including the concentration of mineral, the concrete quality, the crystallographic mineral form, association with other iron sulfides, host rock mineralogy⁵, and the environment. The role of these factors and their effects on oxidation rate are not fully understood.



Figure 1. Pyrite cubic crystal on bedrock from Norway.



Figure 2. Cracked concrete foundation wall.



Figure 3. Stereo-optical micrograph of a polished cross section of painted stucco with rust staining showing pyrite sand grain near the surface.



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Therefore, consensus limits on the amount of pyrrhotite or any iron sulfide allowed in concrete aggregate have not yet been established in the United States. European standards for concrete aggregate have placed a limit of 1% total sulfur by mass, which is reduced to 0.1% total sulfur if pyrrhotite is identified in the aggregate.

Researchers have recently developed a three-phase procedure to evaluate aggregates for potential deleterious reaction due to oxidation of iron sulfides⁶. The procedure involves measuring total sulfur by LECO induction furnace, measuring oxygen consumption, and an accelerated mortar bar expansion test. Validation of this research is ongoing and will be coupled with new research efforts to identify appropriate limits for iron sulfide minerals in concrete aggregates to protect against future property damage while still permitting the use of aggregates containing non-deleterious quantities of iron sulfide minerals for concrete construction.

Referenced Standards

ASTM C33-18 Standard Specification for Concrete Aggregate
EN-12 620 (2003) Aggregates for concrete.

References

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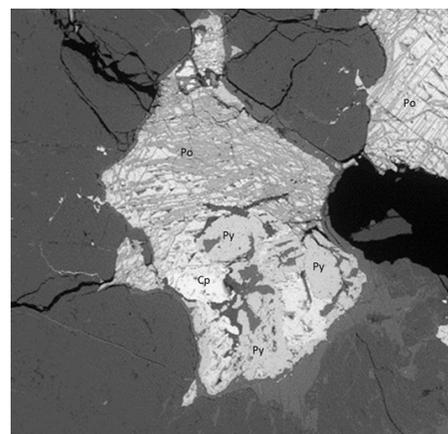


Figure 4. Backscattered electron (BSE) image of polished thin section of aggregate cracked due to oxidation of pyrrhotite. This aggregate has three different iron sulfide minerals present and in association with each other. The pyrrhotite (Po) can be seen in this image as the bright striated material. The striations are due to oxidation resulting in formation of iron hydroxides. The more stable pyrite (Py) and chalcopyrite (Cp) have not shown reaction.

Applicable RJLG Services

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- » Concrete Petrography ASTM C856
- » SEM/EDS of Concrete ASTM C1723
- » ICP-MS

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- » Sulfide Sulfur in Shale
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