Investigating the causes of deterioration in concrete blocks in Southern Ireland

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INTRODUCTION

Concrete blocks are very widely used in the construction of domestic, light-industrial properties and in many other types of construction throughout the UK and the Republic of Ireland. Their many benefits include low cost, ready availability and the fact that they can be manufactured from a very wide range of aggregate types. The performance requirements for concrete blocks are typically lower than those of many forms of structural concrete enabling reductions in manufacturing costs by allowing relatively low cement contents to be used.

A consequence of the low cement contents characteristic of concrete blocks of this type is high void content and this can lead to increased susceptibility to deterioration in aggressive environments due to increased sensitivity to internal weakening processes such as those resulting from pyrite degradation (RICS The Mundic Problem) in aggregate [1]. This paper discusses two factors that have contributed to poor concrete block durability in the Republic of Ireland. One of which is the use of micaceous aggregates in the Donegal area of the Republic of Ireland and the other is the use of pyritic aggregates in Co. Mayo in the Republic of Ireland.

CONCRETE BLOCKS CONTAINING MICACEOUS AGGREGATES AND FREE MICA

Rock types in common use as aggregate in concrete block manufacture in Donegal are phyllite, schist and micaceous quartzite. These lithologies contain significant amounts of mica. The fine grain size and foliated texture of phyllite and schist / micaceous quartzite contributes to the tendency for these rock types to generate flaky particles and abundant free mica on crushing.

Free mica is defined as separate mica flakes ("books") and is distinct from mica contained within aggregate particles. Free mica is potentially harmful if present in significant quantities in cement paste in concrete for the following reasons:

1. Increased water absorption, microporosity and permeability to moisture: The presence of abundant free mica in concrete has the effect of increasing the amount of water that is required for the concrete to be sufficiently workable for it to be moulded and compacted.

2. Reduced strength: The presence of free mica in cement paste in concrete can lead to significant reductions in compressive and tensile strength even when present in concrete at levels as low as 1% by weight of fine aggregate [2].
3. Reduced resistance to frost: The high microporosity of the matrix of the blocks promotes water absorption and rapid saturation in damp conditions. This makes the blocks highly susceptible to frost damage in freezing conditions.
4. Reduced resistance to weakening as a result of leaching: The high microporosity of the hydrated cement matrix promotes the absorption of moisture by the cement matrix and the potential for leaching and associated weakening of the cement hydrates.
5. Reduced benefits of using admixtures: High free mica contents can be detrimental to admixture performance.

The latest guidance on investigating the deterioration of concrete blocks in the Republic of Ireland is given in the IS 465: 2018 [3]. The IS 465 standard provides guidance on how to diagnose deterioration in concrete blocks containing high proportions of free mica as well as pyritic aggregates.

The guidance for investigating blocks with micaceous aggregates is subdivided into three Test Suites, each with progressively more detailed analysis required if the previous stage is deemed inconclusive. The recommended test suites are as follows:

- Test Suite A: Visual examination of sawn surfaces.
- Test Suite B: Thin section petrography, XRD quantification of mica and compressive strength testing.
- Test Suite C: SEM / EDX analysis and other specialised testing as appropriate

Petrographic examination is an essential first stage in establishing the cause of deterioration of concrete blocks with micaceous aggregates as it is often the case that factors other than high free mica contents are of greater significance in concrete block deterioration than free mica. The high void contents and typically low cement contents of concrete blocks tend to amplify the weakening effects of moisture ingress, leaching and frost damage, even without the presence of free mica.

XRD measurements of total mica content as recommended in IS 465 are of questionable benefit in assessing whether or not free mica is present in deleterious quantities, as this technique cannot distinguish free mica from the total mica content of the block. The critical factor in assessing the significance of the mica content of concrete is the amount of free mica in the cement paste and not the total mica content of the block or even the free mica content of the aggregate. The typical low cement contents of concrete blocks mean that even a small amount of free mica in the aggregate could result in a deleteriously high free mica content of the paste.

Micaceous dust from phyllite aggregates tends to be very fine grained and too fine grained to be reliably quantified petrographically using thin sections. X-ray diffraction cannot distinguish potentially harmful free mica from non-deleterious mica bound within aggregate particles. We have found X-ray phase mapping of polished surfaces to be capable of providing direct measurements of the free mica content of the cement paste and this technique has the advantage that the different types of mica can be distinguished (Figure 1). There are two stages to the X-ray phase mapping technique, the first of which is to establish the compositions of the mica by X-ray microanalysis of the free mica particles in the paste. The mica compositions are then plotted on a triangular phase plot that is used to select the mica phases to be mapped. The output from Oxford Instruments INCA allows the volume percentage of each mica phase to be measured and expressed as a percentage by volume of the cement paste.

There are currently no published limits for free mica content of aggregates in either British Standards or the ASTM standards. We have found that in most cases of poor concrete block durability due to micaceous aggregates that the free mica content of the paste is typically >5% by volume of the paste.

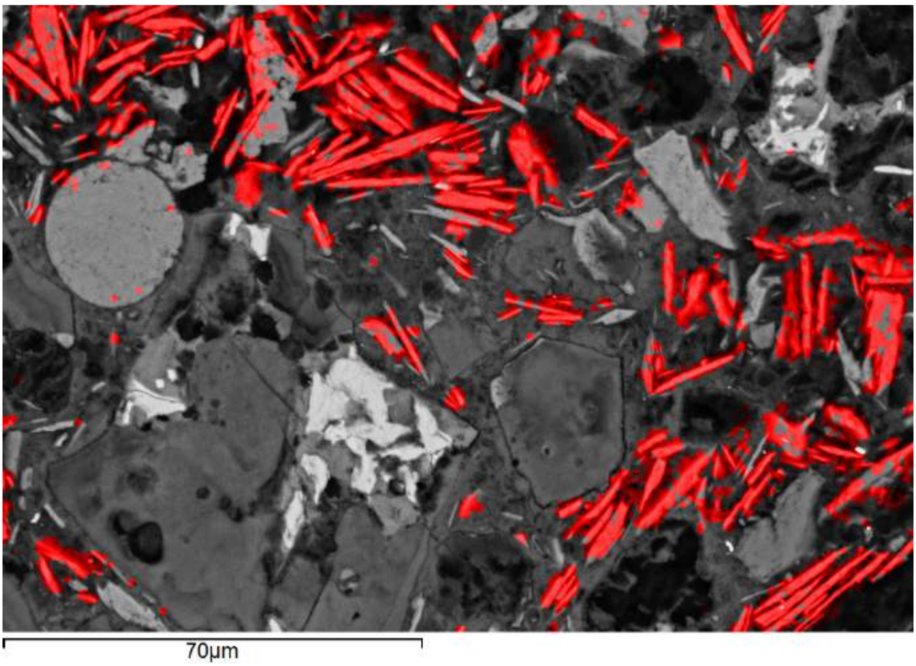

Figure 1: Phase map for muscovite superimposed on a BSE image of cement paste.

The key conclusions that can be drawn from the analysis of concrete blocks with potentially deleterious levels of free mica are as follows:

1. The potentially deleterious effects of free mica in aggregates are increased by the typically low cement contents of concrete blocks. We would advise that limits on mica content of aggregates should be linked to the binder content of the concrete in which the aggregate is being used. High cement content concretes can

potentially tolerate aggregates with higher free mica contents than concrete with low cement contents such as concrete blocks. It needs to be borne in mind that some aggregates can create problems due to variations in free mica content.

2. Consideration should be given to increasing the volume of matrix in the blocks thereby diluting the free mica content of the aggregate. This might be achieved by the following routes:
    a. Increased cement content
    b. Use of cement replacement materials (CRMs)
    c. Increased non-micaceous fines content.
3. In many cases where free mica is a factor in concrete block deterioration there are other causes for deterioration such as leaching and the ingress of moisture containing dissolved CO_2.

CONCRETE BLOCKS CONTAINING PYRITIC AGGREGATES

Some argillaceous limestone and meta-argillite aggregates used in concrete block manufacture in County Mayo, Southern Ireland contain significant amounts of pyrite much of which occurs in a high reactivity framboidal form. Framboidal pyrite occurs in spherical clusters of very fine pyrite crystals that individually, typically measure <5µm. It is the fine size of the pyrite crystals and high surface area of the pyrite in pyrite framboids that is the primary factor in their high reactivity. Note, pyrrhotite has not been detected by the authors in aggregates sued in the Republic of Ireland.

When exposed to oxygen and moisture pyrite (FeS_2) is liable to decompose forming various hydrated iron and iron-sulphate compounds as well as sulphuric acid. This process is described in detail in the literature, for example by Hawkins [4]. The principal processes leading to damage in concrete blocks as a result of pyrite alteration are as follows:

a. Acid attack: Gypsum formation by reaction between sulphuric acid generated by pyrite decomposition with carbonated cement paste, portlandite in cement paste.
b. Aggregate expansion due to the growth of gypsum in cracks within aggregate particles.
c. Aggregate expansion due to the swelling caused by the growth of ferrous sulphate alteration rims around pyrite framboids.
d. Sulphate attack resulting in ettringite and / or thaumasite formation by reaction between sulphates generated by pyrite decomposition and cement paste in concrete.

Many factors affect the rate of pyrite alteration in aggregate in concrete blocks and these include moisture availability, permeability, temperature and biological activity. The typically high permeability of concrete blocks means that in the damp conditions there is an increased potential for pyrite alteration to occur within the aggregate in concrete blocks.

The latest guidance on investigating the deterioration of concrete blocks in the Republic of Ireland is given in IS 465: 2018 [3]. The guidance given in IS 465 for investigating blocks with pyritic aggregates is subdivided into a series of Test Suites with progressively more detailed analysis required if the previous stage is inconclusive. The recommended test suites are described as follows:

- Test Suite A: Visual examination of sawn surfaces.
- Test Suite B: Chemical testing for cement content, total sulphur and acid-soluble sulphate and detailed thin section petrography.
- Test Suite C: SEM / EDX analysis and other specialised testing as appropriate

Chemical testing for sulphate and total sulphur is often seen as one of the most reliable indicators of potentially deleterious levels of pyrite and pyrite-related alteration. The difficulties with chemical testing is in setting threshold values for acceptable levels of sulphur and sulphate and more significantly, the errors involved in determining values for total sulphur and sulphate content.

In the UK the RICS publication on the Mundic Problem advises "values of up to 0.5% of SO_4 (0.6% SO_3) by mass of concrete considered normal" [1]. The difficulty with this limit is that without taking into consideration the cement content of the concrete it is not possible to understand the significance of the sulphate levels. In other words 0.6% SO_3 by weight concrete would be normal for a 15% cement content but not for a 4% cement content where 0.6% SO_3 sulphate by mass of content would equate to a 15% (SO_3) sulphate content by weight of cement which would clearly be cause for concern. The Mundic report also advises of an upper limit of 1% pyrite by weight of concrete equivalent calculated from the chemically determined total sulphur and acid-soluble sulphate values.

The limiting values for pyrite content and total sulphur given in The Mundic report are unrealistically high for some of the aggregates containing framboidal pyrite in use in the Republic of Ireland. The above statement is based on observations of pyrite-related degradation in rock types with less than 1% of framboidal pyrite and with total sulphur contents of <0.7%.

Our experience in Ireland shows that a realistic limiting value for sulphate content would be 6% SO_3 by weight of cement. For a concrete block with a cement content of 4% this would be equivalent to a total sulphur content of 0.24% SO_3 by weight of concrete.

Chemical testing in isolation can be misleading and microscopic techniques such as petrographic examination (Figure 2) and SEM analysis are critical to diagnosing whether or not the aggregate is of a type that might have a potential for pyrite-related deterioration and whether or not pyrite-related deterioration has occurred.

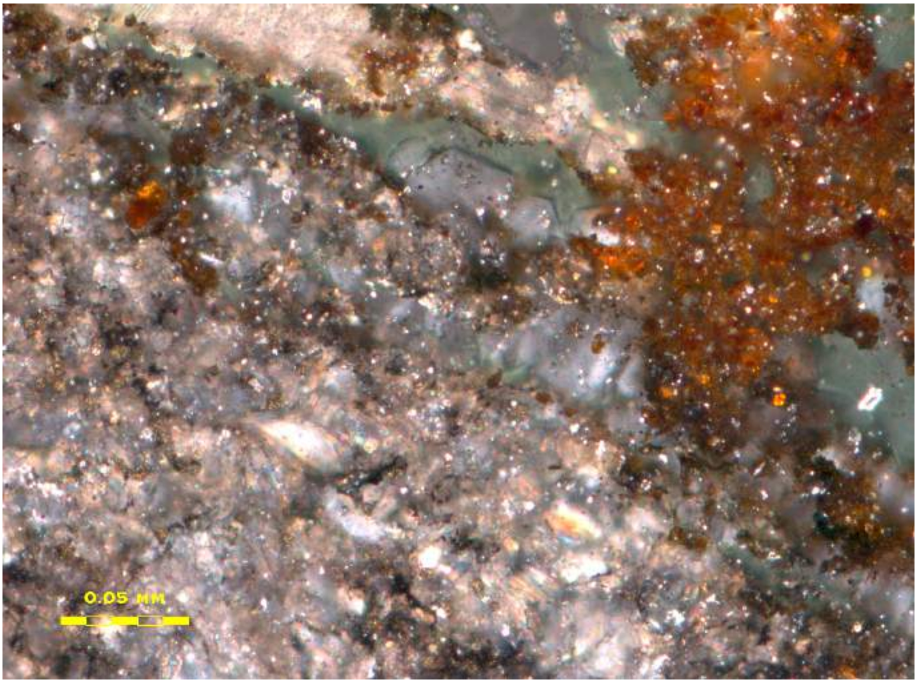

Figure 2: Thin section, reflected light view showing muddy limestone aggregate in a concrete block exhibiting pyrite alteration and expansive gypsum formation.

The key conclusions that can be drawn from the analysis of concrete blocks with potentially deleterious levels of pyrite are as follows:

1. The potentially deleterious effects of pyritic aggregates are increased by the typically low cement contents of concrete blocks.
2. Pyritic aggregates may be suitable for use where moisture can be excluded
3. Pyritic deterioration of aggregate in concrete blocks is in our experience uncommon in the Republic of Ireland.
4. Chemical testing cannot be relied upon in isolation for investigating the deterioration of concrete blocks with pyritic aggregate
5. In many cases although pyrite is considered to be the primary factor in deterioration there are often other causes for deterioration such as leaching and the ingress of moisture containing dissolved CO_2

ACKNOWLEDGEMENTS

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