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Concrete Expansions Due to Sulfates-Aspects of Limitations and Causes

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Resumo/Resumen/Abstract

Expansões do Concreto Devidas aos Sulfatos- Aspectos de Limitações e Causas
Construções de várias épocas têm apresentado cenário de expansões que muitas vêzes são creditadas a:

- Decorrentes do histórico térmico;
- Decorrentes das Reações do Típo Álcali-Agregado, e até;
- Decorrentes de deformações estruturais

A autópsia- post morten- dessas estruturas de vários tipos e usos, tem levado a se deparar com fenômenos expansivos devido à reações por ataque de sulfatos e a ocorrência de etringita tardia.
Por outro lado as normas e/ou recomendações Internacionais não são plenamente concordantes quanto às limitações.
O Autor traz para um debate a necessidade de estabelecer cuidados mais profundos sobre essa ocorrência.

Expansiones del Hormigón Debido a Sulfatos-Aspectos de Limitaciones y Causas
Construcciones de Hormigón de diversas épocas han presentado muchas veces escenario de expansión se acreditan a:

- Derivados de la historia térmica;
- Derivados de las reacciones del tipo álcali-agregado y hasta;
- Derivados de las deformaciones estructurales

La autopsia-post morten- de estas estructuras de diversos tipos y usos, ha llevado a diagnóstico de fenómenos expansivos debido a las reacciones de ataque de sulfato y la ocurrencia de etringita retardada.
Por otro lado las normas y/o recomendaciones internacionales no son plenamente concordantes con respecto a las limitaciones.
El Autor presenta en un debate la necesidad de establecer una atención más profunda sobre este fenómeno.

Concrete Expansions Due to Sulfates-Aspects of Limitations and Causes
Constructions of various ages have presented many times expansion scenario that are credited to:

- Due to the thermal history;
- Due to the reactions of alkali-aggregate type, and
- Due to some structural deformations

The autopsy-post morten- of these structures of various types and use, has led to come across expansive phenomena due to sulfate attack reactions and the occurrence of Delayed Ettringite.
On the other hand the standards and/or international recommendations are not fully concordant with regard to limitations. The author brings a debate the need to establish deeper care about this phenomenon.

Keywords: Alkali aggregate reaction, alkali silica reaction, montmorillonite, pyrite, sulfides, sulfates, delayed ettringite formation, expansion.

1 Introduction

Silica minerals in aggregate that cause concrete deterioration by alkali-silica reaction it is not the unique harmful problem for concrete structures. Deterioration due to other harmful minerals day by day is discovered and becomes a new input for the concrete technology, and for the quality specifications and standards.

In Brazil since the years 60's the basaltic rocks were check to verify the soundness concerning the occurrence clays of the montmorillonite group, for its use as concrete aggregate. These tests and studies supplied information about their geotechnical and physical characteristics, including changes in their mechanical properties in the long term. In several cases, it was noticed that some basalts suffered degradation during storage, transport and after construction. The changes in characteristics of the rock material are attributed to intrinsic factors, related to the nature of the rock. From the point of view of civil engineering, these alterations are reflected, mainly, in reduction of rock resistance. In spite of the large amount of information on the use of basaltic rocks in civil construction, some aspects of these rocks remain not deeply studied

Nevertheless just the Alkali Aggregate Reaction (AAR), mainly the Alkali Silica Reaction (ASR) and the montmontrillonite clays grains in the rock matrix are is not the unique harmful problem for concrete structures

Some minerals as pyrite, pyrrhotite, and other, recently were considered as main causes of concrete deterioration, this due to that pyrite-bearing rock is being increasingly used for concrete aggregate, because of the decreasing supply of materials with good geological conditions under tolerable environmental conditions

At this point, some question can arises:

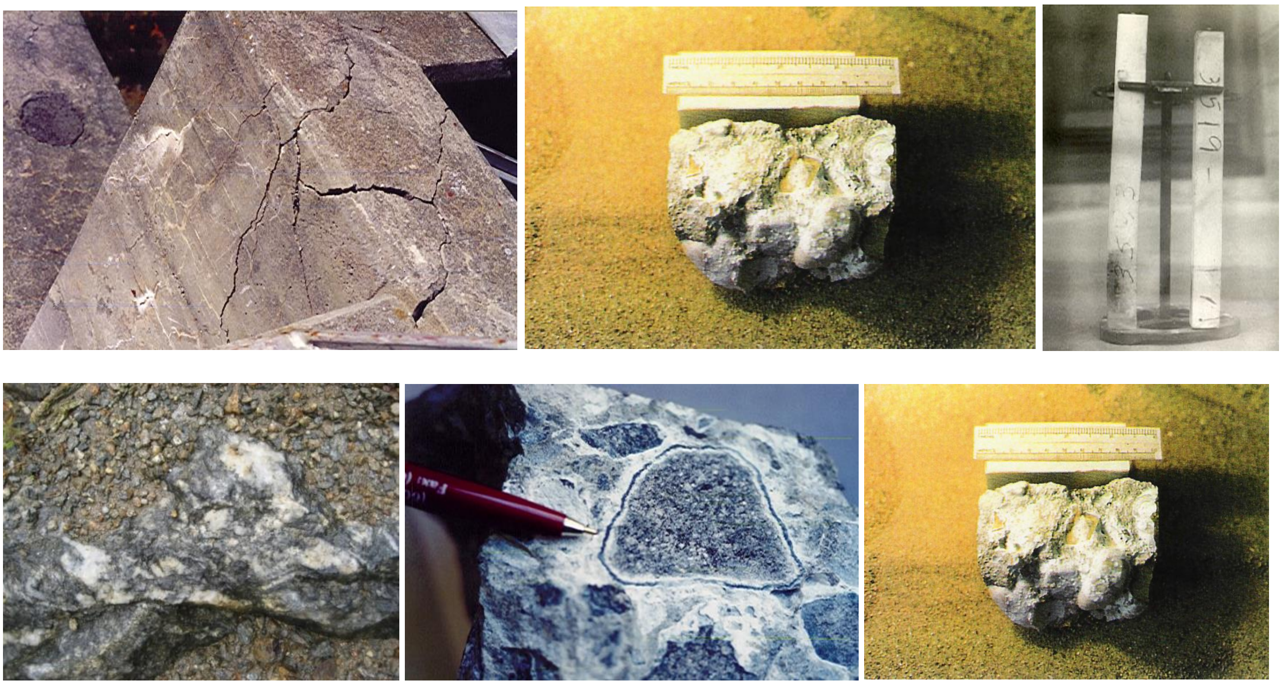
> Q-a- Are the available tests, in different standards, adequate to detect the harmful condition of all rocks available for all rock type to produce aggregates?
> Q-b- Are the available codes, adequate to give a safety support for the citizen in a Legal Condition?
> Q-c- How are the limits to be considered as safe?

2 Phenomena Aspects

The author in this paper have not the intention to explain the details of each one of the expansive processes that can occur with the aggregates or the aggregate combination with cements and water. However has the intention to show some cases and references that some diagnostics has been performed, developing therapies that in most cases the symptoms are similar but the medicine it is not correct.

2.1 Alkali Aggregate Reaction/Alkali Silica Reaction

This phenomena, besides been known since the year's 30 in some time receive a diagnose as "thermal cracks", or "plastic-settlement crack" or "drying shrinkage crack" or "construction joint no treated- cold joint"!



Figs. 1 – Aspects concerning ASR phenomena

2.2 Montmontrillonite clays grains in the rock matrix

Clay minerals are almost ubiquitous in soil and rock and are among the most reactive silicates. They affect the engineering behavior of soil and rock both as materials of construction and as foundation materials.

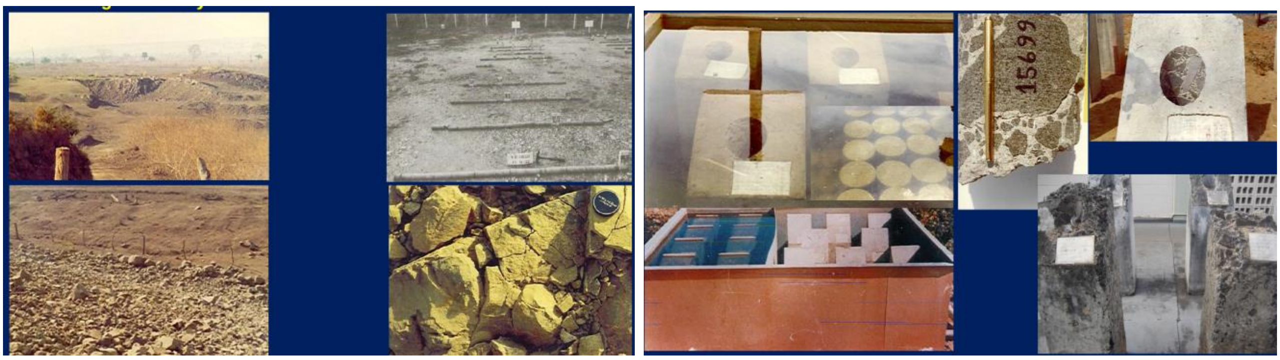
Figs. 2 – Aspects concerning expansive phenomena due to montmorillonite clays in the basalt under accelerated test

The presence of clays sometimes goes undetected or is disregarded in the conventional examination of aggregates so the potentially harmful effects on concrete durability are missed. Igneous rocks often make excellent aggregates but clay minerals are sometimes present due to the alteration of primary minerals by weathering or hydrothermal action.

Figs. 3 – Aspects concerning expansive phenomena due to montmontrillonite clays in the basalt under wetting and dry tests

A typical example was the secondary clay minerals in some basalts that causes dimensional instability with potentially serious effects on long-term durability of concrete. Similar problems have been reported with dolerites.

Contamination of basaltic rocks with clays of the montmorillonite group causes the expansion and failure of the rocks when exposed to moisture changes. When these rocks are used as concrete aggregates, contamination may produce concrete degradation. In Argentina, there are some bridge structures affected by this process, as reported recently [1].



Figs. 4 – Aspects of a basalt quarry the expansive phenomena and long-term tests performed with expansive basalt- CESP Laboratory- Ilha Solteira since 1972

2.3 Sulfide minerals in the rock for aggregate

The diagnosis of any concrete deterioration starts with visual site inspection. Visual inspection of concrete foundations will include the identification of any evidence of deformation, cracking (pattern and intensity), exposure conditions including water drainage, etc.. Visual inspection also helps selecting sampling locations. Concrete samples are drilled through the foundation walls for petrographic examination. Concrete cores are examined for any sign of deterioration and some cores were selected for further testing.

Recently a document [2] **Report of the Pyrite Panel -** June 2012 "**Letter to the Minister for the Environment, Community and Local Government"-Dublin,** had informed**:**

> *"…In the course of our work, the Panel got an insight into the very serious problems that arose due to the presence of reactive pyrite in the hardcore used as infill under the floors of houses. While house construction was generally perceived as a low risk activity, what has happened in the case of pyrite clearly illustrates the devastating problems that can arise on a huge scale when a number of conditions coalesce to form the perfect storm. Many of the physical effects of the pyrite damage are clearly visible for everybody to see but, even if the remediation work is successfully undertaken, an indelible mark has been left on the lives of homeowners and families - and the past few years have been a nightmare for them….*
>
> *….However, on 31 August 2011, Home Bond issued a letter to the homeowners covered by the Home Bond Warranty Scheme stating that, taking into consideration legal opinion, expert technical advice and the decision of Mr Justice Charleton in the case of James Elliot Construction (JEC), they did not consider that they were liable for damage arising from pyritic heave and consequently they would not progress claims for damage resulting from reactive pyrite. Premier Guarantee continue to process claims for damage associated with pyritic heave….*
>
> *....The Panel endeavored to establish the scale of the problem by estimating the number of ground floor dwellings that may have pyritic hardcore. Of the 74 estates identified to the Panel, the total number of ground floor dwellings is 12,250. Approximately 850 of these have made a claim with a guarantee provider and approximately 1,100 have been remediated or are in the process of being remediated (on 12 estates). Therefore, in considering the extent of possible future exposure to pyritic heave, the Panel is of the view that, taking the most pessimistic view, there may be approximately 10,300 more dwellings with reactive pyrite present in the hardcore…."*

Besides, of these, in many concrete structures these Sulfide phenomena is diagnosed as AAR or ASR. In some opportunities this Author is requested to analysis reports concerning harmful expansion in concrete structures, previously diagnosed as AAR.

Additional analysis using X-ray Fluorescence and Diffraction were important tools, including chemical analysis and optical microscopy to indicate the percentages of sulfur present. The x-ray diffraction warn about the various phases present sulfated. The investigations of the microstructure of the concretes were also fundamental investigation of the deterioration since it was possible to see the chemical attack by sulfates.

Figs. 5 – A gallery in a Dam; the leakage in a construction joint ad the sediment with a brown-red color inducing the sulfate [3]

2.4 Delayed Ettringite Formation (DEF)

The expansive sulphate internal reaction due to Delayed Ettringite Formation (DEF) can damage concrete structures severely. The primary ettringite (a hydrous calcium trisulphoaluminate) is a normal reaction product formed from the reaction of C_3A and C_4AF with gypsum during the plastic stage of the hydration of Portland cement. However, when peak temperatures in concrete are over **about 65°C**, the sulphates may be incorporated in other cement phases. After concrete hardening, the very slow formation of higher volume secondary ettringite may occur as water is taken into the crystal structure that can lead to potentially disruptive expansion. DEF is defined as the formation of ettringite in a concrete after setting, and without any external sulphate supply, but with a water supply. DEF appears in concretes exposed to frequent humidity or contact to water, and subjected to a relatively high thermal treatment (> 65°C) or having reached equivalent temperatures for other reasons (massive cast-in-place concrete, concrete casting during summer, thermal cured precast elements etc).

Figs. 6 – Concrete precast beam steam cured in a temperature greater than 70^{o}C, and the scenario of cracks due to DEF.

3 Lessons learned

3.1 Montmontrillonite clays grains

The tests are simple (Wet and Dry) or by soaking in ethylene glycol. In a practical way, the inspection in the quarries can help to recognize de harmful expansion as shown in Figure 4.

3.2 Alkali Aggregate Reaction- Alkali Silica and Alkali Carbonate Reactions

In ASR, aggregates containing certain forms of silica will react with alkali hydroxide in concrete to form a gel that swells as it adsorbs water from the surrounding cement paste or the environment.

These gels can induce enough expansive pressure to damage concrete. Typical indicators of ASR are random map cracking and, in advanced cases, closed joints and attendant spelled concrete. Cracking due usually appears in areas with a frequent supply of moisture, such as close to the waterline in piers, near the ground behind retaining walls, near joints and free edges in pavements, or in piers or columns subject to wicking action.

Alkali-silica reaction can be controlled using certain supplementary cementitious materials. In proper proportions, silica fume, fly ash, and ground granulated blast-furnace slag have significantly reduced expansion due to alkali-silica reactivity.

Alkali-carbonate reactions are observed with certain dolomitic rocks. Dedolomitization, the breaking down of dolomite, is normally associated with expansion. This reaction and subsequent crystallization of brucite may cause considerable expansion. The deterioration caused by alkali-carbonate reactions is similar to that caused by ASR; however, ACR is relatively rare because aggregates susceptible to this phenomenon are less common and are usually unsuitable for use in concrete for other reasons.

3.3 Sulfide minerals in the rock for aggregate

The mineral Pyrite or Iron Pyrite is an iron sulphide with the chemical formula FeS_2. The name Pyrite is derived from the Greek word (Purites) meaning “of fire”. In ancient Roman times this name was applied to several types of stone that would create sparks when struck against steel

Pyrite is usually found associated with other sulphides or oxides in quartz veins, sedimentary rock and metamorphic rock as well as in coal beds. Despite been nicknamed “**fools gold**” it is sometimes found with small quantities of gold.

It is important that the sulfides expansions be not considered as AAR/ASR. Additional analysis using X-ray Fluorescence and Diffraction can help to reach the correct diagnose.

3.4- Delayed Ettringite Formation

In concretes stored or permanently used in a dry climate (e.g. interior elements), ettringite is hardly detectable, even after many years of use. However, if a concrete is exposed to alternating moisture conditions during use, then ettringite crystals can be detected in the voids already after a short time (6 months) without evidence of any serious impairment of the properties of the solid concrete. A white layer enriched with ettringite is often found on aggregate surfaces. If the concrete has been heat-treated or if elevated temperatures occur during drying the effect of accumulation of ettringite in pores and contact zones between aggregate and hardened cement paste is enhanced. In damaged concrete, ettringite is also to be found in the cracks.

Ettringite can be formed from monosulfate during freeze-thaw attacks with and without de-icing salt. Monosulfate is always formed during the hydration, as described above. Ettringite is very stable under freeze-thaw attacks, while monosulfate is partially transformed into ettringite. The sulfate which this requires was not available before the frost attack occurred. Concrete damage in conjunction with the formation of ettringite in hardened concrete is the result of complex long-term processes in which the concrete composition, technological factors during concrete production, and the effects of the surroundings are important. With preventive measures it is therefore not sufficient to take into account only one influencing factor, such as the chemical composition of the cement. All factors which lead to disruption and damage of the microstructure can also promote the formation of ettringite in hardened concrete.

4 Comments

The harmful expansions of concrete are at this moment no deeply dominated technically. The defenses, exception to AAR, are no so known, and the in the Standards there are not, yet, limits very well recognized.

The published paper (as [2] from Dublin) had informed an impressive data concerning the pyrite aspects in a large number of houses.

These induces that the Technical Community need be advised to develop additional effort to adopt new rules.

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