

PETROGRAPHIC STUDY OF A BUILDING DETERIORATED DUE TO ALKALI-SILICA REACTION, IN BUENOS AIRES CITY (ARGENTINA)

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Abstract

The columns of a building from 1935, located in Buenos Aires city, show cracks that have put the whole structure at risk. A petrographic study was carried out in order to determine the origin of concrete deterioration.

The macroscopic characteristics and the reaction products developed in the cracks and in the reaction rims on the deleterious aggregates were analysed. In the selected material, X-ray diffraction and scanning electron microscopy and energy dispersive spectroscopy (SEM-EDS) were also used to determine the mineralogy.

The deleterious reactions that affect the concrete obliterate the mortar texture. Most of the coarse aggregates develop reaction processes with the precipitation of a low birefringence material, but without peripheral concentric cracks.

It is concluded that the structure has been deteriorated by the development of the alkali-silica reaction. The reactivity is clearly related to the coarse aggregate, especially to siliceous sandstones with a cryptocrystalline silica matrix and particles composed of different types of metastable silica such as chalcedony and agate.

Keywords: petrography, concrete, ASR, Argentina

1 INTRODUCTION

In Argentina, the number of engineering works affected by the alkali-silica reaction in different regions and in completely different environmental conditions has increased over the past years.

In this paper, a petrographic study is carried out in the concrete structure of a building built in 1935 in Buenos Aires in order to analyse the causes that led to its deterioration. The significant cracking present in the columns has put the structure stability at risk. The study focuses in the macroscopic characteristics as well as in the reaction products developed in the cracks and in the reaction rims around the particles of potentially reactive aggregates. Microcracking and the composition of both the fine and coarse aggregates, especially of the deleterious species, were evaluated on thin sections using a petrographic microscope.

Reaction products were identified mainly in the reactive aggregate-cement paste interfaces. Ettringite is common inside accidental air voids and in microcracks, sometimes associated with aluminosilicates.

In some areas, because of very strong silica leaching, a very porous material developed allowing the reaction products to crystallise. The deleterious reactions that affect the concrete obliterate the mortar texture. Most of the coarse aggregates develop reaction processes with the precipitation of a low birefringence material, but without peripheral concentric cracks. Both the cement paste and the aggregates are cracked.

2 MATERIALS AND METHODS

Cores were drilled from most of the concrete columns of the building structure. They exhibit significant cracking and textural changes in the aggregate-cement paste interface; coarse aggregate particles have reaction rims with abundant reaction products.

The following equipment was used: an Olympus microscope system with image processing capability coupled to an Olympus SZ-PT trinocular stereomicroscope; an Olympus B2-UMA trinocular petrographic microscope with a built-in Sony 151 A video camera, a high-resolution monitor and Image Pro Plus image processing; a JEOL JSM 35 CP scanning electron microscope

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equipped with an EDS probe, DX 4, with an ultrathin window, with a range of elemental analysis from Z = 5 (B) to Z = 92 (U); an Rigaku D-Max III - C X-ray diffractometer with Cu K α radiation of wavelength $\lambda=1.54178 \text{ \AA}$ and a graphite monochromator operated at 35 kV and 15 mA. Diffractograms were recorded from 2-60 $^{\circ}2\theta$.

3 RESULTS

3.1 Macroscopic characteristics

The concrete coarse aggregate is composed of gravel where siliceous sandstones and cryptocrystalline silica varieties (agate and chalcedony) prevail. They generally show signs of selective leaching processes, which are related to the particles of very fine-grained siliceous sandstones, and zones with relicts of fibrous silica (chalcedony).

The fine aggregate consists of natural sand composed mainly of quartz with a minor amount of sandstones. Most of the sand grains have developed reaction rims composed of siliceous and/or expansive reaction products. The particles where the matrix and/or the cement consist of cryptocrystalline silica show increased porosity due to the leaching of their constituent elements. Iron oxides when present, clearly show the distressed areas. Whitish areas in the mortar result from the silicification and argillization produced by the alkali-silica reaction.

The cores show severe cracking. Particles have detached from the core fracture surfaces due to the cohesion loss resulting from the leaching process that affected the aggregate-cement paste interface.

The morphological characteristics of the lithic components with reaction rims (rr) of the coarse aggregate are shown in Figure 1a. A particle (p) that has expanded after core drilling is shown; cracking is significant. Figure 1b is a detailed view of Figure 1a showing reaction rims (rr) in a gravel grain and cracking in three directions.

3.2 Observations with the stereomicroscope

Concrete is composed of a polymictic coarse aggregate where siliceous sandstones of different grain sizes prevail. There are some grains with compact and massive textures and others that are rather porous due to the strong leaching of their constituents. This phenomenon occurs on the surface forming a reaction rim, which generally shows a discoloration process. Oxidation has occurred in the most porous areas. Particles where iron has moved outwards to precipitate on their surface giving them a clear red colour are frequently observed. Many aggregate particles show surface dissolution phenomena, which have even caused separation of the grains. Other fragments of the coarse aggregate give evidence of a strong surface silicification, which appears as a whitish patina of cryptocrystalline silica. Greenish grains showing a siliceous-argillaceous alteration process with clear evidence of the increase in volume are common. In these cases cracking processes that affect the physical characteristics of concrete can be seen. Among the aggregate lithic components, especially with coarse quartz grains, there are signs of deformation and banding, and also the occurrence of silica with a fibrous habit (chalcedony) and a hyaline aspect (opal). The fine aggregate consists mainly of quartz, siliceous sandstones and feldspar.

The mortar shows evidence of significant alteration due to the presence of reaction products, especially in the zones with increased porosity. There are few very fine cracks, but larger cracks are visible, especially at the boundaries of reactive aggregate particles, and have even broken the rocky components.

Figure 1c shows a sand grain of ferruginous sandstone (fs) with abundant reaction product in its boundary area. A gel mass that partially covers a reddish brown sandstone particle is depicted in Figure 1d. Figure 1e shows an aggregate particle with development of abundant reaction product. The surrounding cement past is cracked, causing the detachment of the particle. Abundant gel (g) that has developed in the reactive aggregate-cement paste interface is shown in Figure 1f.

3.3 Petrographic microscopy

Thin sections analysed with the petrographic microscope, allowed to identify opal, trydimite and zeolites as the main reaction products.

The coarse aggregate is composed of fine-grained sandstone with cement and a siliceous matrix, which is either amorphous or cryptocrystalline, sometimes very ferruginous. Grains and particles containing quartz with a saccharoid texture and undulatory extinction (UEA $\approx 19^{\circ}$), with abundant fibrous silica (chalcedony), are also common. Granitic rock particles are scarce and they are generally rich in feldspar and quartz, and low in mica.

The fine aggregate is similar in composition. Quartz grains are abundant, generally with very irregular boundaries, and sandstones have sometimes been completely replaced by reaction products, especially chalcedony, trydimite, opal and clays. The mortar exhibits a very distressed texture, commonly characterised by microcracking and abundant reaction products that have developed due to ASR.

An aggregate-cement paste interface with reaction rim (rr) development is shown in Figure 2a. A crack (c) in three directions (viewed under plane polarized light) is depicted in Figure 2b. Figure 2c depicts the same crack viewed with cross polarized light to show that it is filled with an anisotropic reaction product that due to its optical properties can be assigned to zeolites with associated calcium carbonate (calcite). Figure 2d shows a highly cracked mortar area (c) with its texture completely obliterated.

3.4 SEM, EDS, XRD

The material analysed was developed at the reactive aggregate-cement paste interface and inside the microcracks. Figure 2e shows a SEM image of the ASR product. In the EDS analysis Si, Al, O, Ca and minor amounts of K and Na were identified (Figure 3a). A zeolitic structure belonging to the clinoptilolite-heulandite group ($\text{KNa}_2\text{Ca}_2(\text{Si}_{29}\text{Al}_7)\text{O}_{72}\cdot 24\text{H}_2\text{O}$) comparable to the ICDD card number 39-1383 was determined by X-ray diffraction [1]. The main reflections were identified at 8.90 Å and 3.97 Å. The diffractogram is presented in Figure 3b. Figure 2f shows the material developed inside air voids and cracks. Its chemical composition, analysed by EDS, is S, Al, Ca and O (Figure 3c). An ettringite structure ($\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}\cdot 26\text{H}_2\text{O}$) comparable to the ICDD card number 41-1451 was identified by X-ray diffraction. The main reflections appear at 9.7 Å and 5.6 Å (Figure 3d).

4 DISCUSSION

Research on the alkali-silica reaction (ASR) in Argentina started in the 1950s when a study was conducted on the pavement of a route that links the cities of La Plata and Punta Lara in the province of Buenos Aires. In 1956, a special committee was set up to work on this subject. The pavement was so badly damaged that the route could not be opened as scheduled due to the major repairs that had to be made. Since then, this subject has been dealt with by a large number of researchers [2]; at a worldwide level, investigations have been carried out by [3, 4, 5, 6, 7, 8, 9, 10,11,12], among many others.

The alkali-silica gel found in concrete is a material of variable composition consisting of SiO_2 , Ca, Na and K together with other minor elements [13]. A possible explanation for gel crystallization has been proposed by Dron and Brivot [14]. The amount of gel observed in thin-section frequently cannot be correlated with the severity of the alkali-silica reaction and the damage may occur when limited amounts of gel form [15,16].

There are a range of microproducts associated with gel that have been observed with the scanning electron microscope and gel formation that are generally not observable by the light microscope [17].

In a previous work, the authors studied the concrete used in dams, spillways and focused mainly on pavements in the area of Bahía Blanca (in the southern end of Buenos Aires province) [18]. In this region, the first studies to identify the ASR as the cause of deterioration in concrete pavements date from about 1994 [19, 20]. Most of the fine aggregates (natural sand of different origins) used in concrete manufacture has lithic components classified as deleterious, such as (acidic and basic) volcanic rocks with weathered and unweathered glassy matrices, volcanic glass and chalcedony. There are no other deposits in the area with alternative components to substitute them [21]. The coarse aggregates consist of gravel, composed of rocks and minerals similar to those of the sand, and two types of rocks used as crushed aggregates – a granite classed as innocuous and a quartzite that has been classified as slow-reacting with respect to the ASR [22]. The pavements usually show map-type cracking, the closure or compression of joints, slab expansion, an elevated riding surface showing popouts at damaged areas, as well as heaving, cracking, concrete uplift, separation of the base that in many cases has broken causing blowouts [23]. There are two rehabilitation methods that are commonly used; one of them consists in cutting the slabs and filling the slots in the pavement with concrete of similar composition, which can last no more than 5 years; the other one consists in grading and resurfacing with bituminous pavement. In the former the repair is of a temporary nature because the expansive process continues and when the slabs get into contact, the pavement breaks. In the latter case, the asphalt cover behaves as an impermeable layer, absorbs heat differentially and increases the deleterious reaction rate. In this case the repair will last less than 3 years.

In most of the cases, deteriorated concretes show whitish exudates. These products were studied by XRD and SEM/EDS, and identified as a gel that is later crystallized into zeolitic structures with the resulting increase in volume that causes expansion and cracking [24]. It is also quite common to find ettringite associated with ASR products [25]. Many authors, have studied the increase in volume as a result of ettringite crystallization.

5 CONCLUSIONS

- The coarse aggregate is mostly reactive due to the presence of opal, sandstones with cryptocrystalline and amorphous silica cement, chalcedony, trydimite and strained quartz.
- The fine aggregate also contains the same reactive mineralogical species.
- There is macro- and microcracking.
- Reaction products were determined, mainly expansion-producing ones (zeolitic structures and ettringite).
- The cement paste exhibits an obliterated texture and the interface affected by the reactive process.
- This evidence allows concluding that the concrete is affected by ASR, which is at a full development stage.

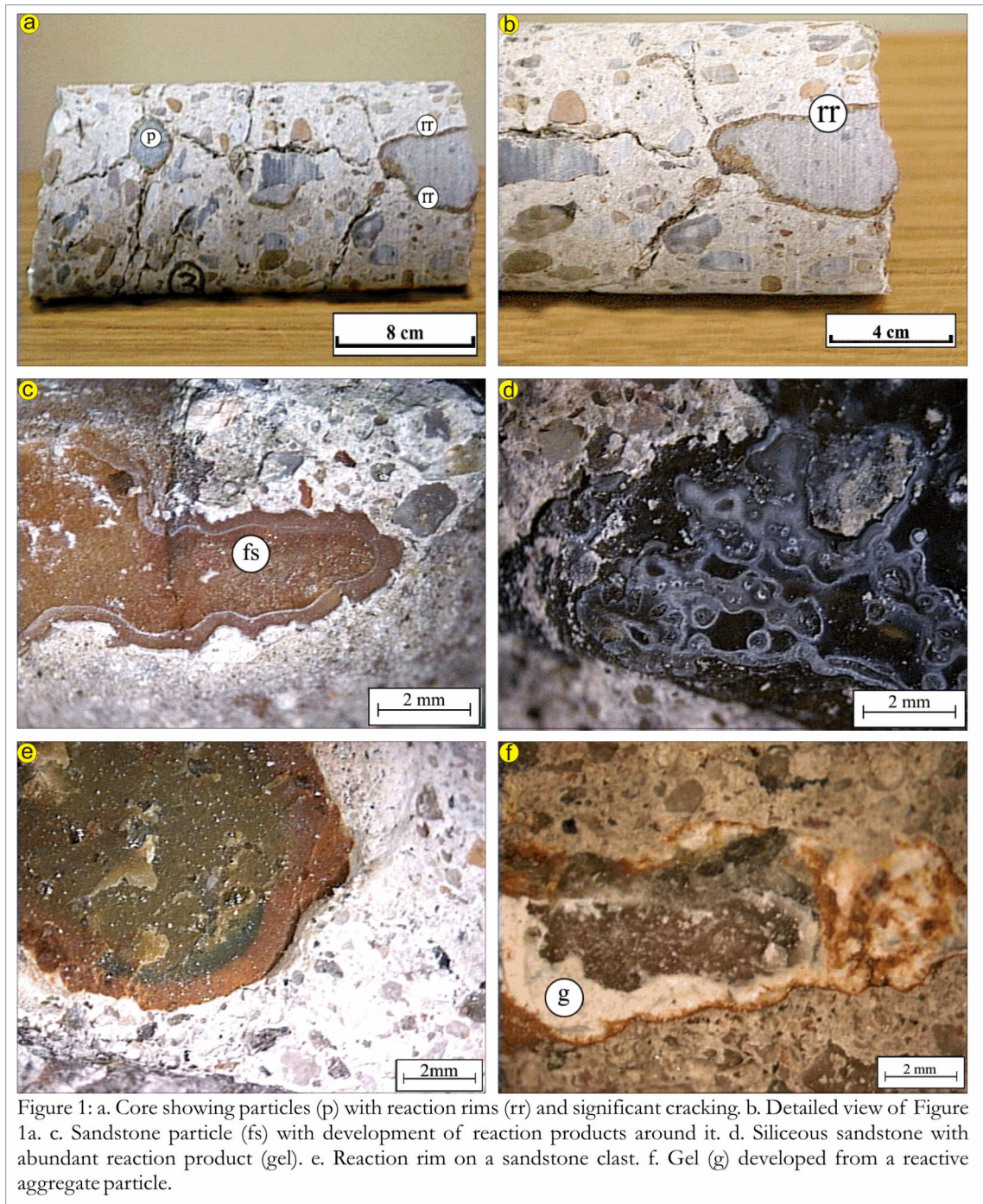
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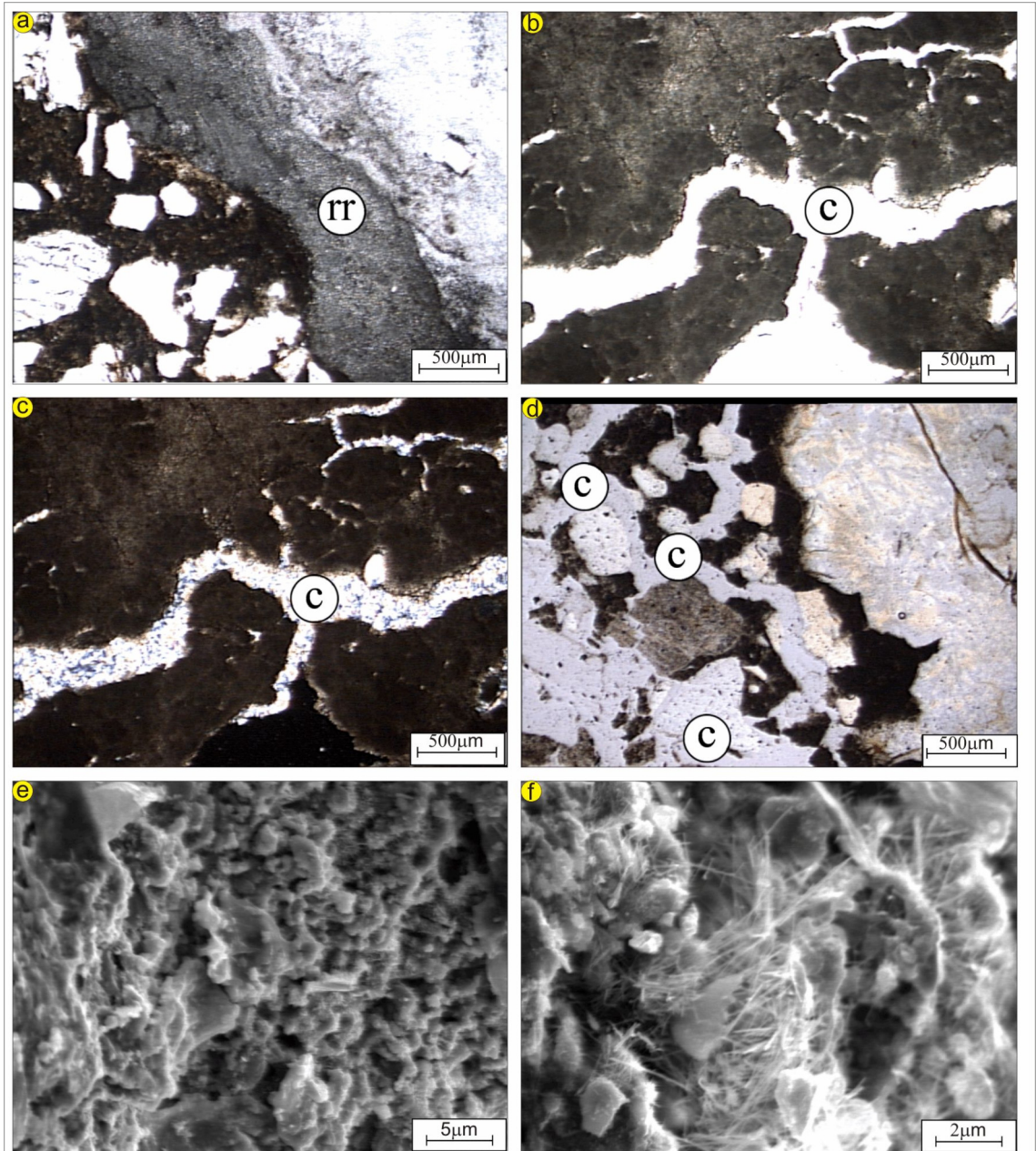


Figure 2: a. Aggregate-cement paste interface showing the development of a reaction rim (rr). b. Microcracking in three directions (c) (viewed under plane polarized light). c. The same image as the above viewed with cross polarized light. d. Cement paste with significant microcracking. e. Gel morphology viewed with SEM. f. Ettringite morphology viewed with SEM.

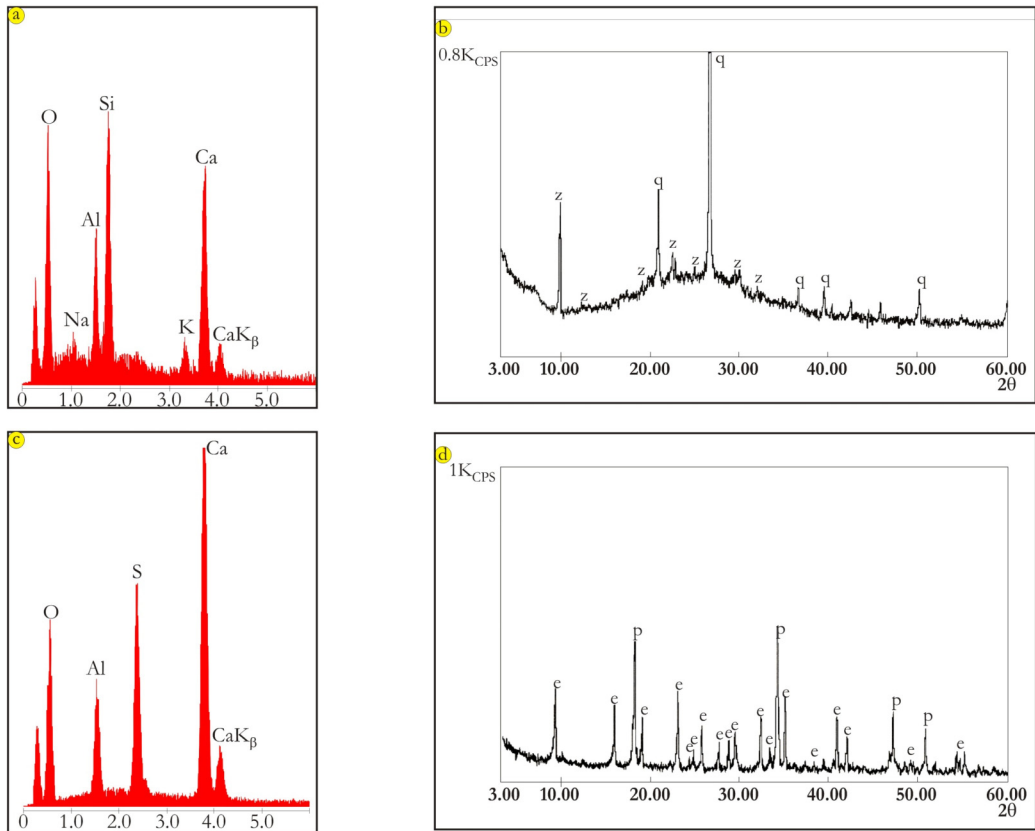


Figure 3: a. EDS of the material observed in figure 2e. b. XRD of the product of ASR. z: zeolite, q: quartz. c. EDS of the material observed in figure 2f. d. XRD of ettringite (e) with portlandite (p) development on the concrete surface.