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BEHAVIOUR OF REACTIVE SANDS IN CONCRETE. A CASE STUDY

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Abstract

The concrete of a ring road in the city of Bahía Blanca (Province of Buenos Aires, Argentina) has deteriorated despite ongoing repairs.

The extracted cores exhibit cracks parallel to the axis with less significant lateral cracking, which would cause a destructive process in a very short time. Studies were conducted by stereomicroscopy, polarised light microscopy, X-ray diffraction and scanning electron microscopy.

The coarse aggregate used is crushed granitic rock and the fine aggregate is natural sand, both of them being frequently used in the Bahía Blanca area. Sand is mainly composed of volcanic rocks with a vitreous matrix and subordinate amounts of sandstones, granitic rocks, quartz, feldspar, mafic minerals and unweathered glass particles.

The concrete shows abundant microcracking affecting the matrix and fine aggregates and, in some zones, the coarse aggregates as well. The cracks are usually filled with a birefringent material and are associated with carbonated zones in the matrix. Entrained air voids are partially filled with ettringite. Pavement deterioration has been associated with the development of the alkali-silica reaction due to the presence of potentially reactive materials in the fine aggregate.

1. INTRODUCTION

Seaside sand from the Province of Buenos Aires (Argentina) is mainly composed of volcanic rocks, quartz, feldspar, shell debris and heavy minerals. In localised zones, fragments of caliche (fine sediments irregularly cemented with calcium carbonate) are also common. The vulcanites occurring along the coastline have been transported from the Patagonian environment. The belt of sand dunes bordering the beach consists of fine to medium-grained sand composed mainly of light minerals. Although its exploitation is not as restricted as that of seaside sand, it is less frequently used in the construction industry [1].

The sand used as concrete aggregate in the area of Bahía Blanca (in the south of the Province of Buenos Aires) is mainly of marine origin and has generally formed from porphyritic volcanic rocks, sometimes set in a glassy matrix, with different degrees of alteration [2]. Based on both the glass content in the matrix of volcanic rocks and on the percentage of glass particles (between 5% and 15%), the material has been classified as potentially alkali-silica reactive. Various studies on these materials have been performed to evaluate their potential reactivity by conventional test methods (mortar bar test method, accelerated mortar bar test method, chemical test method and petrographic examination [3–6].

Numerous cases of concrete structures affected by the alkali-silica reaction (ASR) have been reported worldwide ([7] and references cited therein). In Argentina, especially in the area of Bahía Blanca, several deteriorated pavements due to ASR development have been identified, with volcanic rocks and glass being the main materials involved in this process [8–14].

As is well known, the ASR develops in the presence of reactive silica, alkalis and high moisture [e.g. 15].

Unsuitable (potentially reactive) aggregates are commonly used since in many cases they are the only ones available close to the work and cannot be replaced due to freight costs.

The aim of the present work was to study two concrete pavements from the ring road in the city of Bahía Blanca (Province of Buenos Aires, Argentina) in order to determine the causes of deterioration, identify the pathologies affecting the concrete pavement and avoid future problems. The pavement was built in 1994 (original concrete) and a sector was repaired in 2009.

2. MATERIALS AND METHODS

Concrete cores from a roundabout on National Route No. 33 on the ring road in the city of Bahía Blanca (Province of Buenos Aires) were examined. The pavement was built in 1994 and since then has been subjected to frequent repairs, the last one being in 2009. Currently, both the original concrete and the repairs show advanced deterioration, so cores were drilled from both concretes for their evaluation.

Petrographic studies were performed using a stereomicroscope, a polarising optical microscope on thin sections and a scanning electron microscope (SEM). Carbon-metallised samples were examined using an Olympus SZ-PT trinocular stereomicroscope, an Olympus B2-UMA trinocular petrographic microscope and a JEOL JSM 35 SEM equipped with an EDAX probe for qualitative elemental microanalysis.

The reaction products were separated under a magnifying glass and analysed by X-ray diffraction. A Rigaku D-Max III-C diffractometer with Cu Kα radiation and curved graphite monochromator, operating at 35 kV and 15 mA, with a 0.04 step and a counting time of 1 second per step, was used.

3. RESULTS

3.1 Original concrete

The core exhibits significant cracking, which intensifies towards the base. Surface cracks are less developed and filled with scarcely cemented argillaceous–silty sediments. From about

7 cm they increase both in length and opening and are partially filled with secondary minerals, mainly carbonates. The largest cracks affect the coarse aggregate. The fine aggregate components show reaction rims, while almost all the surface of the coarse aggregates is covered by these minerals.

3.1.1 Stereomicroscopy

The coarse aggregate is a granitic rock very rich in potassic feldspar with subordinate plagioclase and quartz. The mafic minerals are scarce (< 10%) and consist of micas and amphiboles.

The fine aggregate is natural sand with abundant volcanic rocks, among which andesites prevail. Subordinate amounts of quartz, monomineral particles (feldspar, pyroxenes and micas) and unweathered volcanic glass were identified. Very altered calcareous silt particles are scarce.

The mortar appears partially carbonated, especially in the cracked areas and at the aggregate–mortar interface. Concrete porosity is from moderate to low. Most of the pores are filled with reaction products.

Figure 1a shows a microcrack affecting two vulcanite particles of the fine aggregate. They are partially covered with reaction products. The mortar is completely altered, and its texture and components cannot be identified. Figure 1b shows an andesite particle with signs of reaction. The peripheral zones have been replaced by secondary minerals deposited in the weakness zones, especially the matrix. The mortar is coated with reaction products. The upper left angle of the photomicrograph shows a granitic particle of the coarse aggregate without any signs of alteration.

3.1.2 Petrography

The coarse aggregate consists of approximately 90% of crushed rock and 10% of natural gravel where quartzose sandstones prevail. The crushed rock consists of granite composed of subhedral orthose crystals with subordinate amounts of oligoclase and microcline that form 70% of the rock. They are twined, partially altered (mainly argillised). The texture is granular hypidiomorphic. Quartz, with undulatory extinction, sometimes cracked, with irregular contacts showing mortar textures and of anhedral habit fills the intercrystalline spaces. Mafic minerals are scarce, usually altered and appear as small patches in the intercystalline spaces. Partially chloritised hornblende is the most common. Associated calcite is usually observed in these zones.

The fine aggregates are polymictic natural sand consisting of 60% of volcanic rocks, mainly andesites, with abundant fragments with glassy matrices. The second most abundant are granitic rocks that in the finest size range form monomineral particles (quartz, feldspars, pyroxenes and amphiboles). A lower proportion of quartzite and unweathered volcanic glass was identified (~10%).

The mortar exhibits obliterated texture, essentially due to intense carbonation. The development of reaction rims is commonly observed. Entrained air voids are partially filled with ettringite and calcite.

Cracking is intense and mainly affects the mortar and the different lithic components of the fine aggregate. The coarse aggregate particles are slightly argillised.

Different types of cracks are distinguished. Mortar cracks, which are the most characteristic, are not very thick or long (not exceeding a few millimetres), are usually filled and rarely affect the lithic components of the fine aggregate. Then, there are longer and thicker discontinuous cracks, which are sometimes ramified, partially filled with either particulate material or calcite. They also affect the fine aggregate components, especially volcanic rocks with glassy matrices (Figure 1c). Figure 1d shows a cracked sand particle (volcanic rock) and a particle of the granitic rock that forms the coarse aggregate with no signs of reaction.

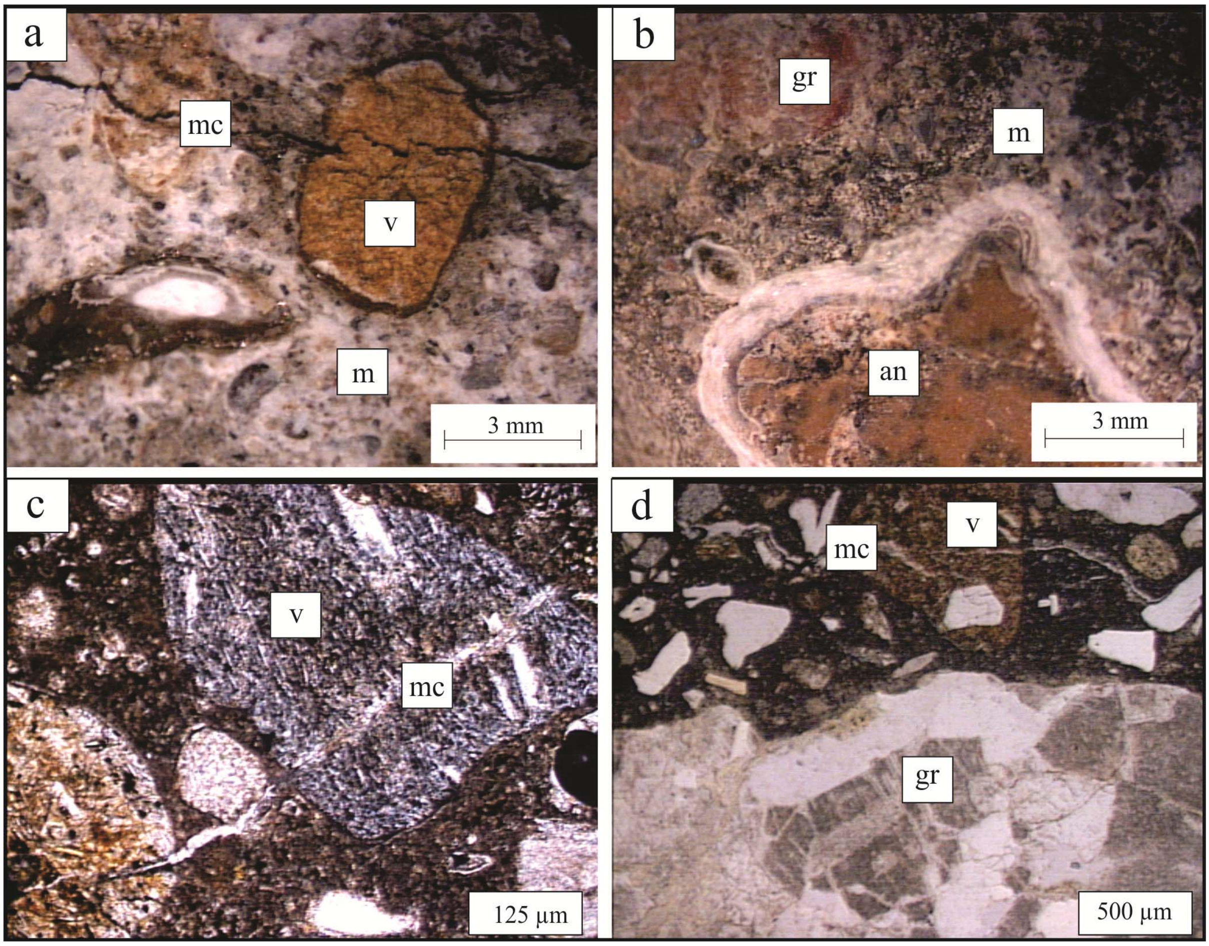

Figure 1: Original concrete. a: Microcrack (mc) affecting two vulcanite particles (v) of the fine aggregate. The mortar (m) is completely altered. b: Andesite (an) with signs of reaction. The mortar (m) is coated with reaction products, while the coarse granitic aggregate (gr) does not show reaction boundaries. c: Microcrack (mc) affecting the mortar and two fine aggregate particles (v). d: Cracked vulcanite (v) and particle of a granitic rock (gr) that forms the coarse aggregate with no signs of reaction.

3.2 Repair concrete

Clear signs of ASR development were observed at microscopic level. As in the original concrete, sand shows the most noticeable signs of reaction.

The core has significant vertical cracks (parallel to the axis) with less significant lateral cracking. Cracks are partially filled with a fine particulate material of argillaceous–silty type with abundant volcanic glass. This characteristic remains up to about 10 cm from the exposed surface. Abundant calcite and ettringite have crystallised deeper in the same cracks.

3.2.1 Stereomicroscopy

The same fine and coarse aggregates as in the original concrete were used for the repairs. The coarse aggregate is a granitic rock rich in potassic feldspar with subordinate plagioclase and quartz. Mica, with a smaller amount of amphiboles, is the predominant mafic mineral. The fine aggregate is a natural sand composed of abundant volcanic material (volcanic rocks and glass), with quartz and feldspar in a lower proportion.

The concrete has normal porosity. Entrained air voids are partially filled with calcium carbonate mainly.

There is clear evidence of reaction especially affecting the fine aggregate components. The coarse aggregate components show reaction rims but in a lower proportion. Cryptocrystalline silica, materials with conchoidal fracture and fine ettringite needles were identified as reaction products.

Figure 2a shows an intense reaction process, which developed mainly on the fine aggregate components. The siliceous exudate comes from reactive particles, mainly glassy vulcanites, and then extends towards the matrix. The loss of water causes mass contraction giving rise to microcracks. The mortar shows intense carbonation, mainly in the periphery and inside concrete voids.

Figure 2b depicts a partly massive "rosette-like" reaction material.

3.2.2 Petrography

The coarse aggregate is a granitic rock consisting of weakly argillised orthose and oligoclase phenocrysts of subhedral habit with unmixing textures. They form between 65% and 70% of the rock. Anhedral quartz occurs in the intercrystalline spaces with moderate deformation, is cracked and has locally developed mortar textures. The mafic mineral is biotite with subordinate altered amphiboles, mainly chloritised. The percentage of mafic minerals is between 12% and 15%. The coarse aggregate particles are commonly cracked showing iron and calcium carbonate oxide precipitation, which gives the rock a particular texture allowing the flow of leaching solutions. However, no changes in the physical characteristics of the rock were observed.

The fine aggregate is well-rounded polymictic natural sand. It is composed of 50% of volcanic rocks, 30% of quartzose sandstones cemented with silica and 20% of monomineral particles (quartz, feldspar, amphiboles and pyroxenes) and unweathered volcanic glass. In the vulcanites andesites prevail over rhyolites. Their texture varies from felsitic to holohyaline (>90% of glass). This material has conserved its original flow and vesicular texture. Massive glassy particles of various colours were also observed, the most common being brownish-grey and greenish. Irregular forms characteristic of volcanic glass particles are common.

The mortar texture is not homogeneous; there are well conserved zones and others are intensely carbonated. The latter are always associated with crack zones. Reaction rims and microcracks both in the matrix and cross-cutting the reactive sand particles are common. Diffuse boundaries in the fine aggregate-mortar contact were identified. Air voids are sometimes filled with calcite, portlandite and ettringite.

Figure 2c shows the severely cracked mortar and the composition of sand, where volcanic rocks prevail, as well as very unweathered glass fragments. Another zone with a high content of volcanic rocks that are also cracked is depicted in Figure 2d.

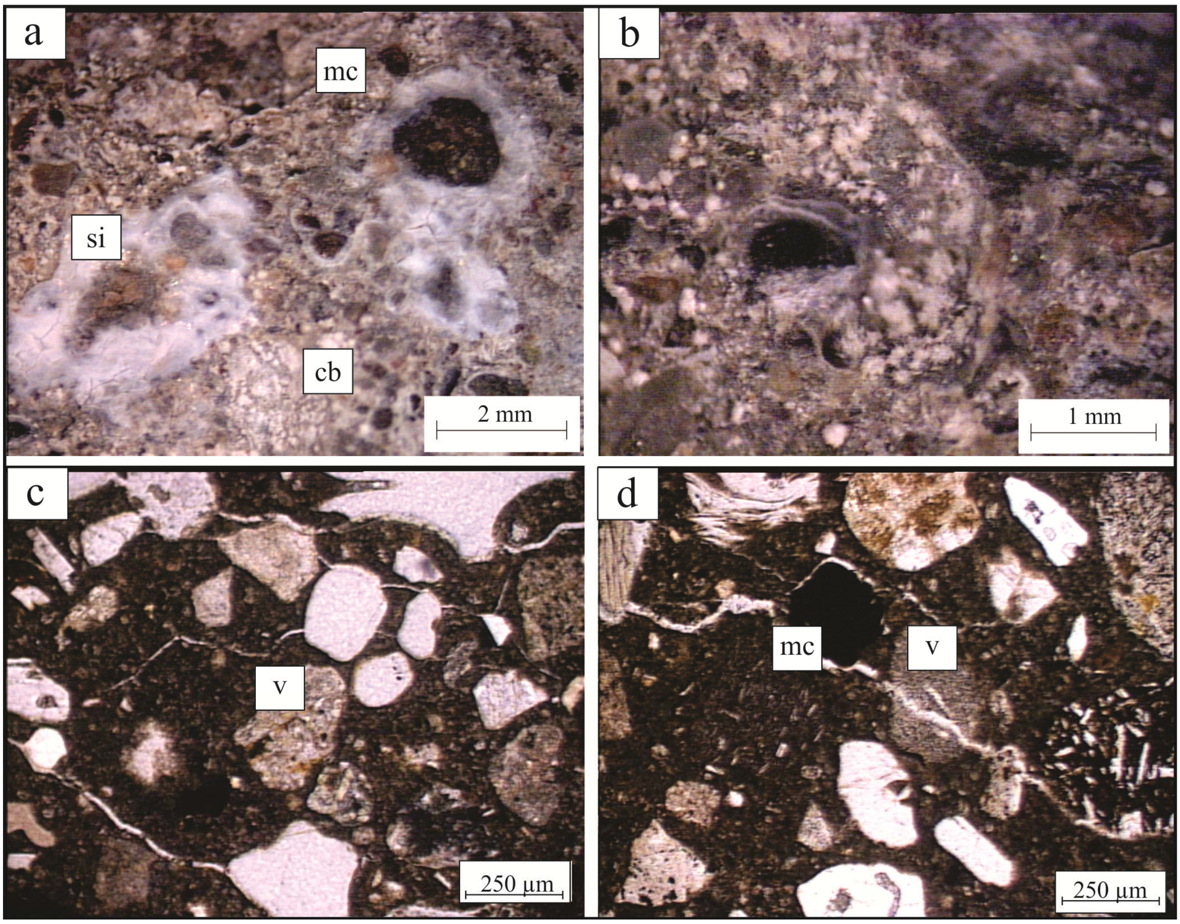

Figure 2: Repair concrete. a: Siliceous reaction material (si) on a reactive particle. A microcrack (mc) on the carbonated mortar (cb) can be seen. b: Massive rosette-like product in the mortar. c and d: Microcracks affecting volcanic rocks (v) of the fine aggregate.

3.3 Scanning electron microscopy (SEM)

The reaction material from both pavements was separated under a stereomicroscope to be analysed by SEM. Although different morphologies were observed, it consists almost entirely of portlandite, calcite and calcium silicates with subordinate ettringite. The morphology and composition of laminar silicates associated with the ASR are shown in Figure 3a-d. The reaction products identified are very rich in calcium and without Na and K.

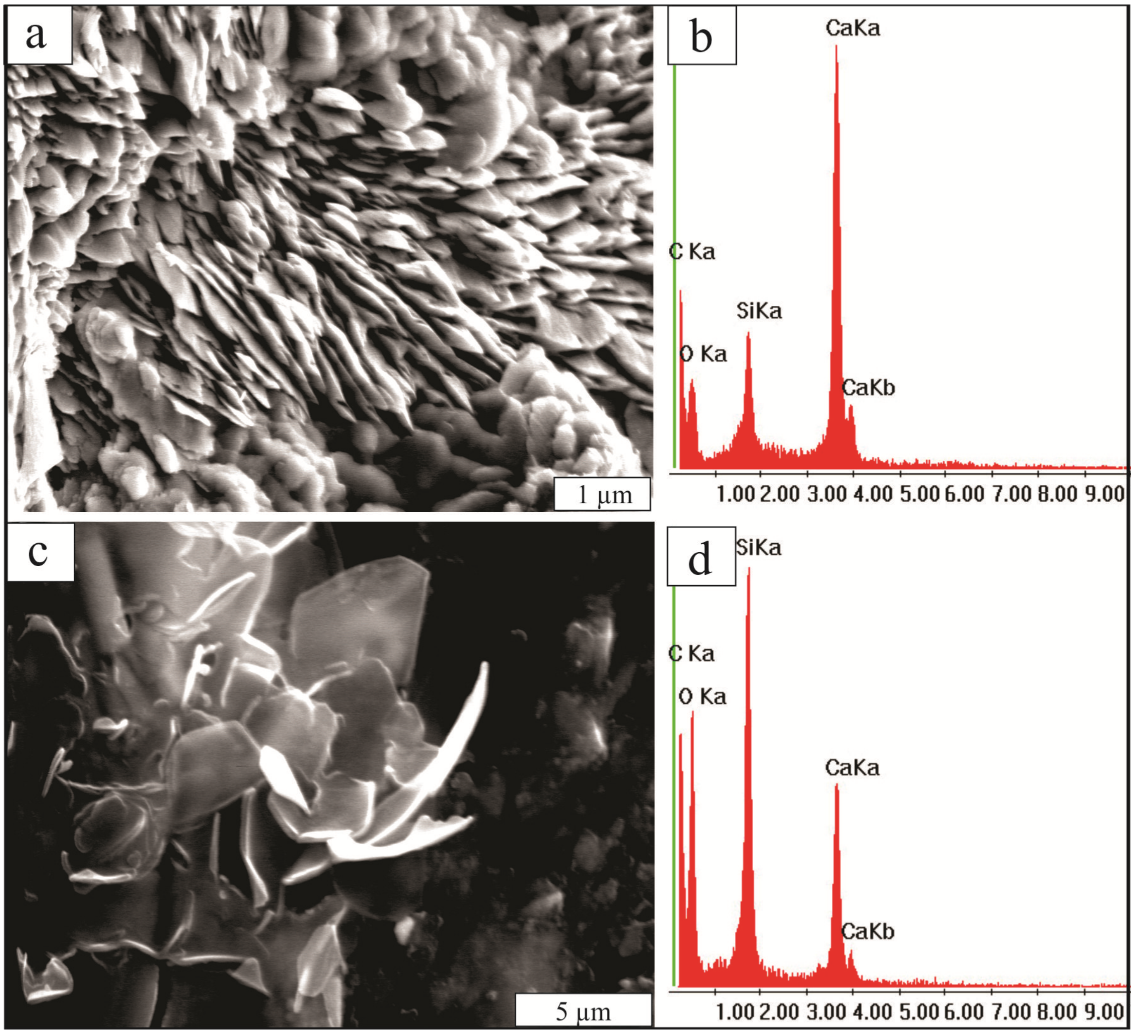

Figure 3: SEM. a: Morphology of the material that developed on the concrete surface. b: EDS of the material observed in 3a. c: Products associated with the ASR. d. EDS of the material shown in c.

3.4 X-ray diffraction

The material found on the original concrete surface, in the aggregate–mortar contact areas and inside entrained air voids was separated. Calcium carbonates (calcite, vaterite and aragonite) were identified (Figure 4). The background rise in the diffraction pattern between 20 and 30 º (2θ) is due to the presence of amorphous material. As the reaction products (calcium silicates) and ettringite observed by SEM have very low crystallinity, they could not be detected by this method. Feldspar belongs to the fine aggregate.

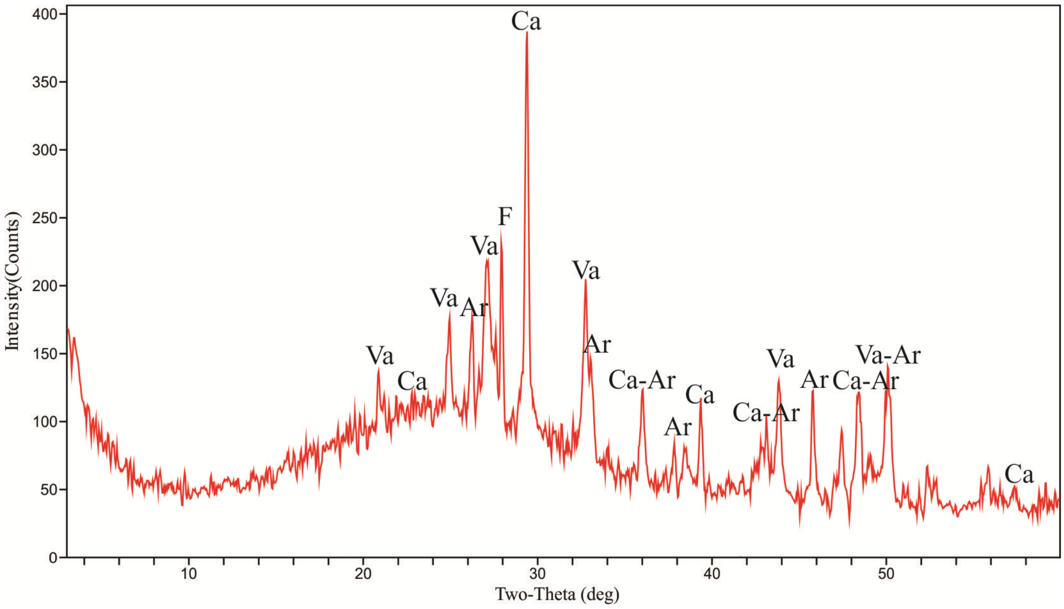

Figure 4: XRD of reaction products. Va: vaterite, Ca: calcite, Ar: aragonite. F: feldspar.

4. CONCLUSIONS

- The aggregates of the original concrete and those used in the repair are lithologically similar. The coarse aggregate is a crushed granitic rock and the fine aggregate is natural sand consisting almost entirely of volcanic rocks with a glassy matrix. Unweathered volcanic glass is also abundant.
- The original pavement, which was built in 1994, shows clear signs of deterioration due to the development of expansive processes associated with the ASR.
- The concrete used in the repair carried out in 2009 has also deteriorated due to the ASR, although the deterioration process is less advanced.
- The reaction processes are mainly linked to the potentially reactive materials of the fine aggregate (volcanic rocks with a glassy matrix and volcanic glass).
- The coarse aggregate is usually sound, although the repair concrete rock has a higher content of strained quartz and saccharoidal texture.
- Abundant calcium carbonate (calcite, aragonite and vaterite) and portlandite were identified both in the mortar and inside entrained air voids. A lower proportion of ettringite was observed.
- The SEM analysis revealed calcium silicates directly associated with the ASR, without sodium and potassium, which would indicate that the reaction products are at an advanced developmental stage.
- Cracking of the original concrete occurred in various stages. Microcracks filled in a first stage were identified, although some of them were reactivated and filled with new reaction products. They mainly affect the mortar but are closely related to the devitrification and alteration of volcanic rock matrices on the outer surfaces of labile lithological components.
- The previous study of a deteriorated concrete and the diagnosis of the deterioration process are of outmost importance when making decisions about its repair or partial

replacement in order to avoid future problems. This will contribute to performance enhancement of the zones repaired, reduction in maintenance costs and service continuity.

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