AAR IN PORTUGUESE STRUCTURES. SOME CASE HISTORIES

M.O. Braga Reis; H.S. Silva and A.S. Silva
Laboratório Nacional de Engenharia Civil
Av. Brasil, 1799 Lisboa Codex - Portugal

ABSTRACT

Alkali-siliceous reactions are in the origin of an increasingly larger number of major deterioration in concrete structures. Geological materials that, since long ago have been considered as excellent aggregates for manufacturing concrete are nowadays distrusted because they are the cause of such phenomena. Today, the knowledge of the adequateness of geological materials for that purpose and the measures that became indispensable to avoid or reduce the consequences of their use are a field of research and standardization of undeniable importance and economic validity. This paper presents some considerations on the nature of climatic and geologic conditioning factors in Portugal and some cases of concrete structures affected by AAR are refered to.
Keywords: AAR, climatic factors, geologic factors, case studies.

INTRODUCTION

In 50's and 60's there was a great increase in public works construction in Portugal, mainly dams and bridges. To satisfy the demand there was also an important development of the cement industry and different factories were built all over the country. In spite of the variability of the quarries, the composition of the different Portuguese portland cements did not differ significantly, bearing in general low level alkalis, sporadically raising 0.8% Na_2O equiv.. Otherwise, Portugal has a mild climate and so it could be thought that only in some restricted zones, where special weather conditions prevail, namely high level of humidity, AAR deterioration of aerial structures could be sustained. Although all these circumstances, some cases of AAR have arised in several concrete structures, predominantly in dams.

In Portugal, apart from a small number of ASR cases where reactions have occurred at high rates immediately after construction, most of the cases of AAR deterioration correspond to ASSR of slow-late-expansion type. Taking into consideration the nature of existing aggregates (Silva, H. 1992), (Silva et al. 1996), a future increase of structures damaged by AAR is expected.

This paper presents some considerations on the nature of climatic and lithological AAR conditioning factors in Portugal and describes two cases of damaged concrete structures whose causes of deterioration were investigated at LNEC.

AAR CONDITIONING FACTORS

Climatic factors

Concerning aerial structures in particular, the climatic factors to which works are submitted must be taken into account. The Portuguese climate does not generally present conditions too favourable for the development of this type of pathologies in aerial structures. The country is situated in a region with an Atlantic temperate climate. In average, the maximum annual rainfall reaches in some Northern zones of the country about 2000mm, while in Southern zones rainfall rarely reaches 600mm. The rainfall frequency is also higher in the North, especially in the Western border, close to the sea, where it reaches values higher than 100 days/year.

Furthermore, in the coastal zones there is a larger number of aerial concrete structures due to the higher population density. It is also in the North that is concentrated the highest hydroelectric potential and therefore a large number of concrete hydraulic structures is situated in this region.

Lithologic factors

In Portugal there are almost all types of rocks. The predominant igneous rocks belong to the family of granites and gabbros, mainly basalts, and occupy about 30% of the mainland. The predominant sedimentary rocks are of a carbonate nature, such as limestones, marly limestones, marls, dolomitic limestones and dolomite, which outcrop in about 10% of the territory and of a clastic nature, especially sandstones, conglomerates, sand, and clays, which are distributed over about 20% of the mainland. The metamorphic rocks outcrop in the other 40% of the territory, and are predominantly composed of schists, almost always associated to metagreywackes, quartzites, marbles and rocks of gneissic and amphibolic nature. In some regions calcedonic and opaline silica may occur, such as lyddite, chert, fhtanite and silicifications.

The macrozoning of the geologic aggregate resources which can be sources of reactive silica forms and of alkalies for ASR was carried out and presented also in this Conference (Silva et al. 1996). The best conjugation of geologic and climatic factors for alkali-silicious reactions development in aerial structures has a high probability in the Northern region of the country.

SOME CASES HISTORIES

Very different types of damaged concrete structures have been investigated, ranging from dams (Cabril, Alto Ceira, Pracana among others) to bridges (Duarte Pacheco and Arrabida) and it is assumed that many others are also affected by AAR. Besides structures at mainland it was studied also the case of Santa Maria's runway (Azores) where basaltic aggregates from the island were used.

Next mention is made of two cases where it was diagnosed the occurence of ASR and that prove the reactivity of aggregates, initially not considered as potentially harmful to concrete. The cement used was, in both cases, ordinary portland cement.

Case n° 1 - Alto Ceira Dam

Characterization of the structure and of damage

The dam, on Ceira river in the center of Portugal, was completed in the end of 40's, and started operating in 1950. It is a 36m high cylindrical arch dam with a 103m crest length and a thickness of concrete between 1.5m in the crest and 4.5m in the base of the central cantilever. The aggregates are essentially composed of quartzite in sizes higher than 20mm, quartzite and philonean quartz and siliceous metapelite in sizes between 2 and 20mm, and quartzitic, feldspathic (especially microcline) and rarely metapelitic and micaceous sands in sizes less than 2mm. Quartzite is strongly laminated with high undulatory extinction angles and intergrowths of microcrystalline quartz.

Since its early lifetime, the dam has been presenting progressive vertical displacements of the crest and horizontal displacements of the arch towards upstream. Simultaneously, intense cracking was mainly developed in the horizontal plan due to the liberation of tension stresses throughout the downstream face and in an area corresponding to the oscillation of the operation levels of the reservoir in the upstream face.

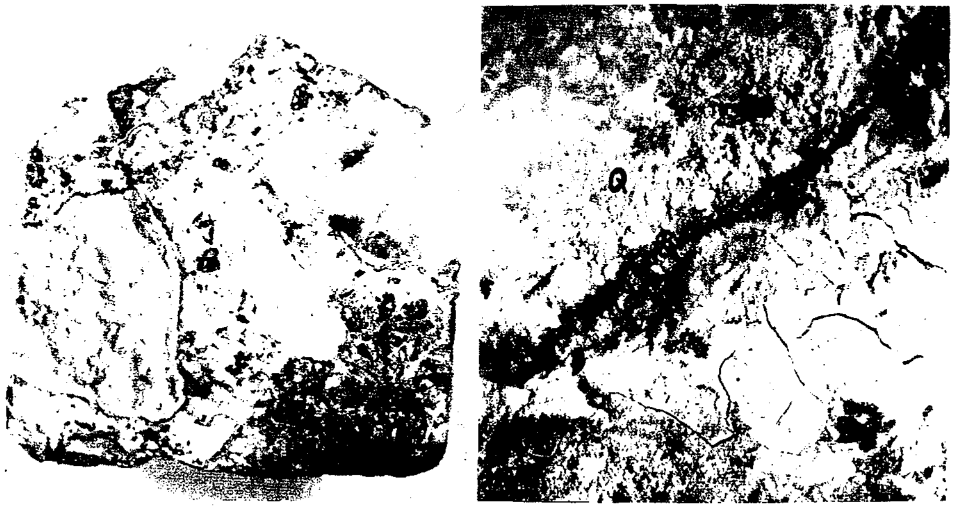
Research results and conclusions

Besides a detailed visual inspection, the methodology of damage diagnosis involved laboratory testing on concrete cores, including in particular, chemical analysis, X-ray diffractometry (XRD), petrographic and SEM/EDAX analysis, reactivity tests of the aggregates and expansion tests of concrete cores (Reis 1991), (Silva & Rodrigues 1990).

Petrographic analysis revealed the existence of ASR phenomena caused by siliceous aggregates, such as microcrystalline quartz occurring between lamellas of quartzite, metapellites and microcline. SEM/EDAX analysis have confirmed the presence of alkaline calcium silicates, predominantly potassic, as gels and crystalline products. Gels in cracks and in reaction rims round aggregate grains and white deposits filling voids and aggregate/paste interfaces were detected directly by visual inspection of concrete cores (Fig. 1). XRD analysis of these white deposits revealed the presence of a crystalline product, characterized by an intense reflection about 12 Å, which was identified as a zeolite type mineral corresponding to an hydrated calcium and potassium silicate. This type of compound is often refered in the literature, as the crystalline ASR rosette-like products (Cole et al. 1981), (Shayan 1988). These rosette-like products were really detected by SEM (Fig. 2).

In order to evaluate the possibility of expansive reactions prosecution accelerated expansion tests on concrete prisms stored in NaCl saturated solution at 50° C were performed (tests based in Danish mortar bar method). The results have shown residual potential reactivity of the aggregates.

Experimental results allowed to conclude that the concrete deterioration process is related to the occurrence of ASR, essentially due to reactive silica of cataclastic quartz (measurements have shown undulatory extinction angles between 25 and 37°) and cryptocrystalline quartz (occurring between lamellas of quartzite and metapellites) and alkalis, mainly potassium, from feldspars, namely microcline.



a) b)

Fig. 1 a) Reaction rims round quartzitic grains, b) detail showing a gel rim (G) in the quartzite (Q)/paste interface.

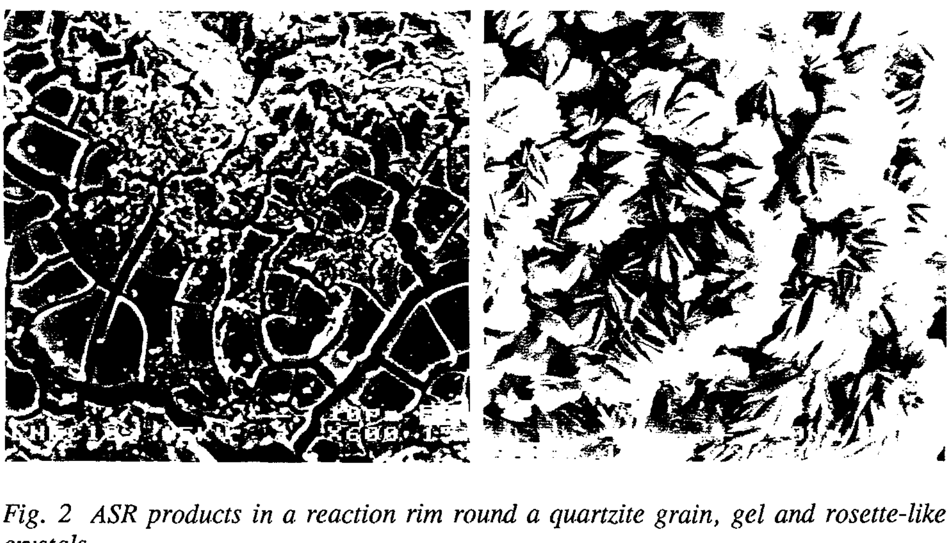


Fig. 2 ASR products in a reaction rim round a quartzite grain, gel and rosette-like crystals.

Case n° 2 - Duarte Pacheco Bridge

Characterization of the structure and of damage

The bridge is located in the Alcântara Valley, a short distance from river Tagus estuary in Lisbon. It was built in the 40's. It is a reinforced concrete structure formed by a roadway supported by slender piers which are supported, in the central zone of the valley, by a circular arch with a span of about 100m linked by 85m long transition portal frames to two lateral arches with a 43m span each. Almost all the information about the structure was lost, but it is known that in its manufacturing coarse limestone aggregate from the region (turonian limestone) and alluvial sands, mainly composed by quartz and some feldspars (orthoclase, albite and oligoclase--albite), were used.

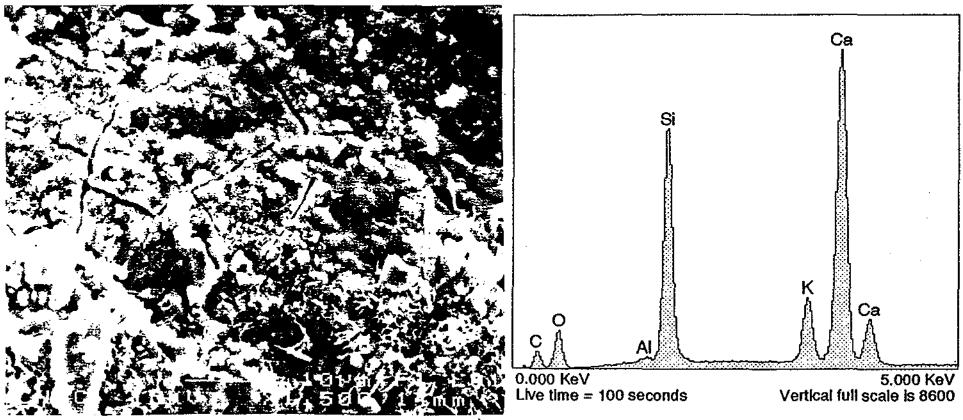
Visual inspection has shown dispersive cracking in arches and piers, more pronounced at the river-side. In the piers it was observed also aligned cracking following the main reinforced bars from 0.1 to 1mm wide. Localized spalling of the concrete is evident. The areas of greater deterioration are located in the central arch over the road where traffic is more intense, specially in zones more exposed to rain and sunshine. The preliminary inspection of the structure had suggested concrete deterioration due to chloride-induced corrosion of the reinforced steel.

Research results and discussion

Inspection methodology included "in situ" tests (carbonation depth and potential corrosion measurements) and core drilling for lab testing. Lab tests included mainly compressive strength of cores and chemical determination of chlorides and sulfates. Later, experimental work was complemented with macroscopic and microscopic examination (binocular, polarising microscope, SEM/EDAX), X-ray diffraction and expansion tests of concrete cores (Reis et al. 1993).

The results of the corrosion potentials measurements have not shown, even in the more cracked areas, the existence of active corrosion at the steel surface. The low concrete chloride contents, allied to the fact that there was not detected by SEM/EDAX chlorides in the rebar corrosion products and that the carbonation near the rebars was not significant, have pointed out to the fact that rebar corrosion was not the initiating mechanism of concrete cracking

SEM/EDAX analysis revealed the presence of typical ASR products, gels and crystalline forms, in paste and limestone/paste interfaces (Fig. 3). These products are calcium and potassium silicates, beeing the gels richer in Ca than crystalline products. The occurrence of these ASR products in limestone/paste interfaces suggest the existence of reactive silica inclusions in the limestone as will be expected in turonian limestones. In fact, petrographic examination of thin sections of concrete samples have confirmed the presence of reactive silica forms (chert and silex) inclusions in the limestone aggregate. It was also observed the occurrence of ettringite, in acicular crystals and massive forms, disseminated in the paste and filling voids and microcracks (Fig. 4). The presence of ettringite was also detected by XRD analysis. SEM examination of the thin sections prepared for petrographic analysis have shown also some interesting aspects revealing signals of ASR and eventual sulfate attack (Fig. 5,6).



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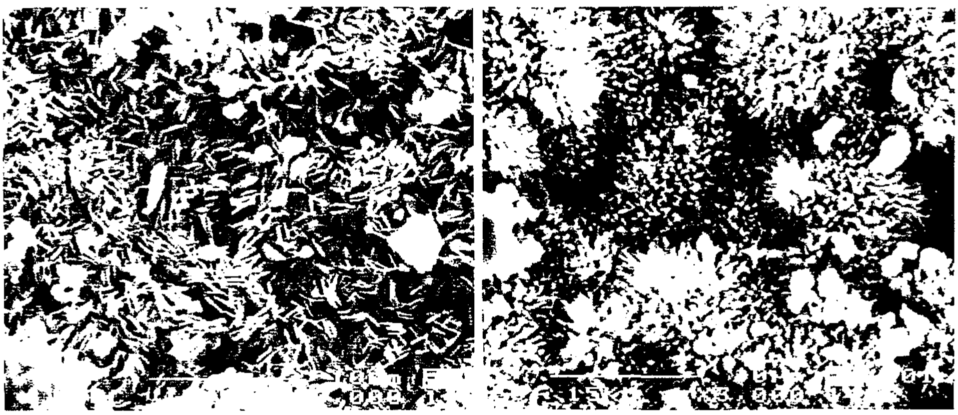

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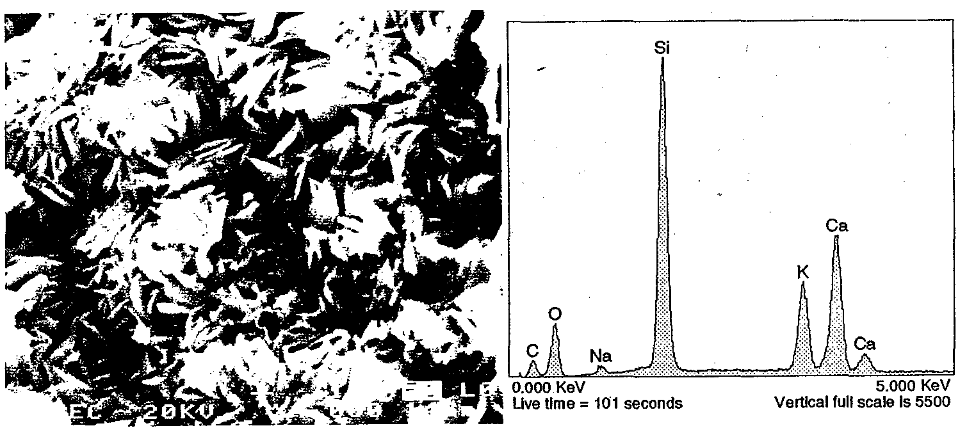

c)

Fig. 3 ASR products in limestone/paste interfaces. a) Gel with microcracking and EDAX spectra, b) Lamellar and acicular crystalline products co-existing with gel, c) Lamellar crystals and EDAX spectra.

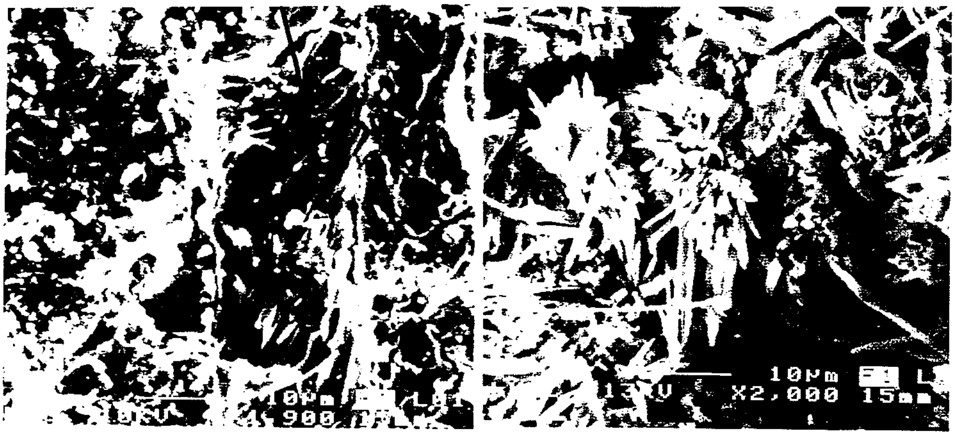

Fig. 4 Ettringite crystals near a steel rebar/cement paste interface. Vein of massive ettringite (arrow) and acicular crystals bunches.

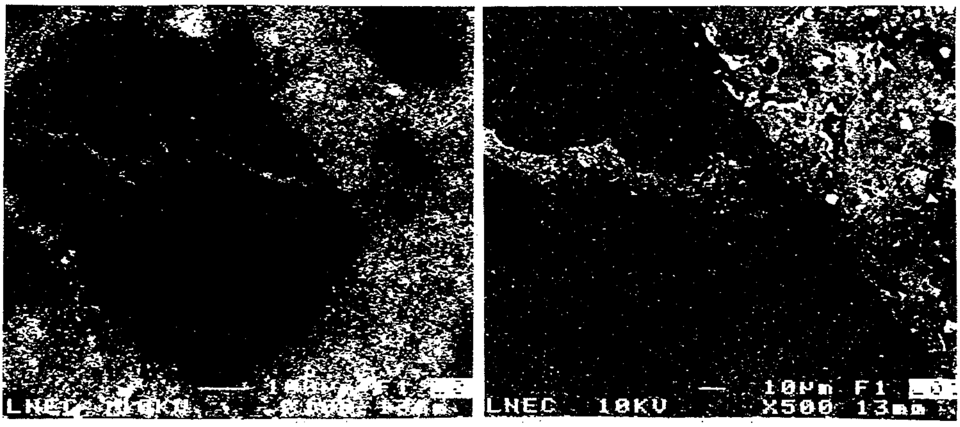

Fig. 5 Microcracked silica grain. Detail showing a vein of calcium alkaline silicate filling the crack.

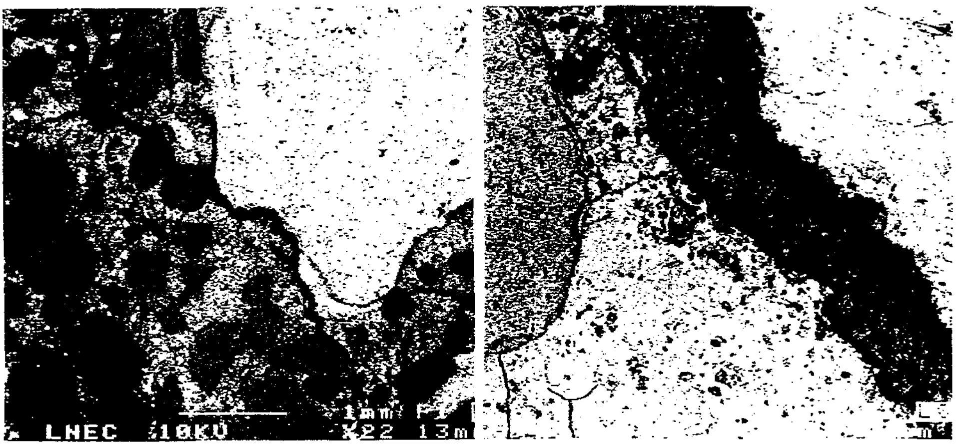

Fig. 6 Microcracking in the paste. Detail showing ettringite crystals filling a crack.

Ettringite formation is often associated to ASR in the concrete. But in the present case the frequency of occurrence may be an indication of sulfate attack caused by sulfates coming from outside. In fact the results of sulfate determinations in concrete have shown a little increase of the content at the concrete surface. Attending to the intense traffic in the area, in particular under and over the central arch of the bridge, the contamination of the concrete by sulfates may be explained by the liberation of SO_2 in the motor vehicles escape gases.

Expansive tests of concrete cores in KCl and NaCl saturated solutions at 50° C have shown residual potential reactivity of the aggregates.

Conclusions

From all experimental results it may be concluded that the concrete deterioration would have its origin in an internal cause in result of ASR, due mainly to the reactive silica inclusions in the limestone aggregates. An eventual attack by sulfates of external origin, as a result of the atmospheric pollution, would also contribute to the deterioration. Subsequently, concrete cracking would provided, in some places, conditions of reinforcing steel depassivation and consequent appearance of corrosion, causing thus the increase of cracks width and concrete spalling.

References

Cole, W.F. et al. 1981, "Products formed in an aged concrete", Cement and Concrete Research, 11(3),443-454.

Reis, M.O.B. 1991, "Study of Alto Ceira Dam Concrete. Chemical and Mineralogical Analysis" (in Portuguese), LNEC Internal Report, Lisbon

Reis, M.O.B., Salta, M.M., Eustáquio, E.M. & Silva, A.S. 1993, "Study of the Causes of Deterioration of Duarte Pacheco Bridge Concrete" (in Portuguese), LNEC Internal Report, Lisbon

Shayan, A. 1988, "Alkali-aggregate reaction in a 60-year old dam in Australia", The International Journal of Cement Composites and Lightweight Concrete, 10(4),259-266.

Silva, H.S. 1992, "Study on Ageing of Concrete and Masonry Dams. Physical and Chemical Alteration of Materials" (in Portuguese), Thesis, LNEC, Lisbon

Silva, H.S., Reis, M.O.B. & Silva, A.S. 1996, "Geologic Conditioning of ASR Development. A Brief Evaluation of Portuguese Mainland", Proc. of the 10th International Conference on Alkali-Aggregate Reaction in Concrete, Melbourne

Silva, H.S. & Rodrigues, J.D. 1990, "Study of Alto Ceira Dam Concrete. Petrographic Analysis" (in Portuguese), LNEC Internal Report, Lisbon