

THE OCCURRENCE OF AAR IN A CONCRETE STRUCTURE IN ITALY

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1. INTRODUCTION

The first cases of alkali-aggregate reaction (AAR) in concrete ascertained in Italy date back to the beginning of 80's and concerned essentially industrial floors [1]. From then on, increasing research into Italian aggregate characteristics [2,3], into their combination with the available types of cement [4,5] and into the effectiveness of existing and new test methods [6] led to a greater knowledge about this phenomenon. The diagnosis of AAR has been extended to include several types of industrial structures and buildings [7,8], not only in the Adriatic coast area, that is generally considered as the most critical one from the geological point of view.

The purpose of this paper is to illustrate one of these cases that was found to be particularly interesting due to the special environmental conditions and to the presence of more interacting decay factors.

2. CASE OF CONCRETE STRUCTURE DETERIORATION

2.1 External appearance and environmental conditions

An Italian chimney, having reinforced concrete framework and brick masonry walls, and built at the beginning of 60's near the sea-shore, showed the first signs of deterioration at the end of 70's. Map cracking along the vertical columns and transverse beams was observed, sometimes accompanied by white exudations and pieces of concrete falling away. Figures 1 and 2 show a typical chimney cross-section and some examples of cracks and exudations respectively.

The chimney environmental conditions were characterized by winds coming mainly from the sea, sea-water spray and high temperature combustion gases.

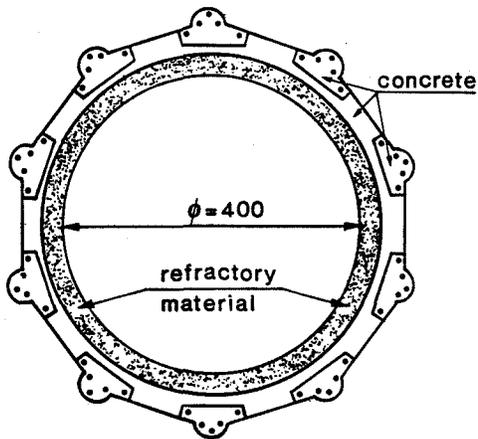


Fig. 1 Chimney cross-section

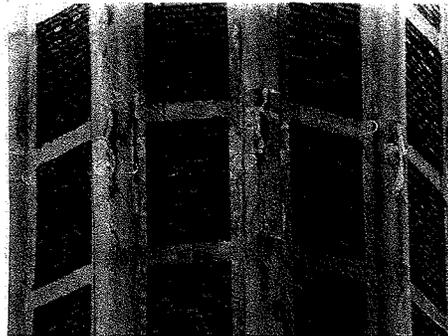


Fig. 2 Cracks and exudations in the chimney concrete

2.2 Investigations and Results

To identify the type of deterioration some pieces of concrete, which had fallen away from the chimney, were examined through physio-mechanical, chemical, mineralogical and SEM analyses.

2.2.1 Physio-mechanical analyses Cores drilled in the soundest-looking concrete showed a density of about 2250 kg/m³ and a compressive strength of about 20 MPa. Water absorption, by means of immersion at atmospheric pressure and under vacuum, was measured according to RILEM Recommendations 11.1 and 11.3, and produced average values of 7.3 and 13.1 % respectively.

2.2.2 Chemical analyses The average results of chemical analyses on concrete samples are reported in Table I. The internal part and the black external layer (directly in contact with the chimney fumes) were separately examined.

The analytical data shows that the aggregate was mainly formed by calcareous grains and a smaller amount of siliceous grains. A striking difference can be observed in the SO₃ and Cl⁻ contents. In fact the SO₃ content varies from 0.96% for the internal part to 1.90% for the external layer, while the chloride content varies from 0.03 to 0.010%. These high values were probably due to the penetration of both the combustion products of the fumes and the sea-water spray. The soluble silica content, evaluated according to Florentin's method (Italian Standard UNI 6505-73) is surprisingly low (0,5%); it has been confirmed by further analysis carried out on fine material only (0.78%) and this could support the hypothesis of the presence of cement with a low soluble silicate content. Unfortunately information on the type of cement used is not available.

Table I Chemical analysis of the concrete

Chemical determinations	external layer %	internal part %
Loss on Ignition	33.13	33.45
SiO ₂	18.05	19.16
Al ₂ O ₃	1.14	0.93
Fe ₂ O ₃	2.18	1.85
CaO	38.72	38.79
MgO	3.13	3.10
Na ₂ O	0.47	0.46
K ₂ O	1.17	1.27
SO ₃	1.90	0.96
Chlorides	0.10	0.03
Insoluble residue	19.58	21.03
Soluble silica	0.49	0.51

2.2.3 Mineralogical analyses Under the stereomicroscope, white alteration products, gel-filled microcracks within the aggregates and large carbonated areas, voids partially filled with layered gel (fig. 3) and some pebbles with reaction rims split off from the interior (fig. 4) were noted. An X-ray examination was carried out on the white products: calcite, and amorphous material, that had not reacted with diluted HCl, were found together.



Fig. 3 Void partially filled with layered gel (~12x)

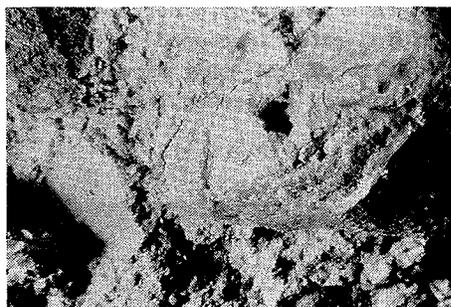


Fig. 4 Pebble with reaction rim split off from the interior (~12x)

On examining thin sections under the polarized-light microscope, chert, calcedony and strained quartz particles were found both in the fine and the coarse fractions of calcareous aggregate with inclusion of clay mineral. In some particles extensive corrosion was observed: the alteration has progressed inwards and the exact location of the edge was obscured (fig. 5). In other cases very fine-grained silica diffused out and Ca(OH)₂ penetrated into the reacting pebbles (fig. 6).



Fig. 5 Edge alteration in a pebble (80x)

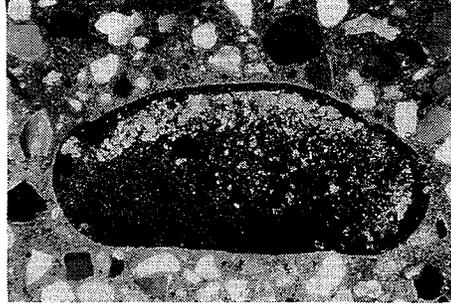


Fig. 6 Silica of a pebble replaced with calcium carbonate (20x)

2.2.4 SEM Analyses The SEM analysis revealed that massive gels, sometimes overlaid with crusts of crystalline reaction products, had formed near the aggregate particles, inside and along fracture surfaces. A typical example of massive gel is shown in fig. 7. Different morphologies of crystalline products were observed.

The results of semi-quantitative EDS (Energy Dispersive Spectrum) analysis varied considerably from point to point as far as both the CaO/SiO_2 ratio and the alkali content are concerned [9]. In general, the gel found in the pores was much richer in calcium ($\text{CaO}=35\%$; $\text{SiO}_2=25\%$) than that found in the veins and cracks within the aggregate particles ($\text{CaO}=14\%$; $\text{SiO}_2=66\%$). According to what has been ascertained by other authors too [10], the alkali content decreased as the CaO/SiO_2 ratio increased.

Crystals of the type shown in fig. 8 were sometimes observed and the EDS analysis clearly indicated that they consist of Sulphur and Calcium.

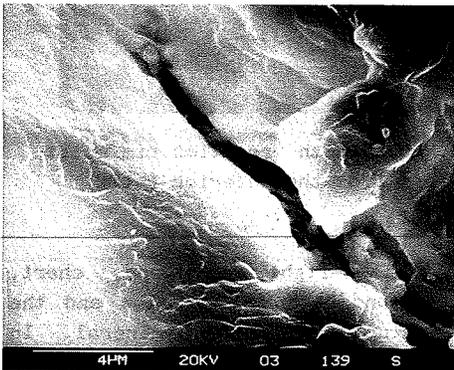


Fig. 7 Massive gel

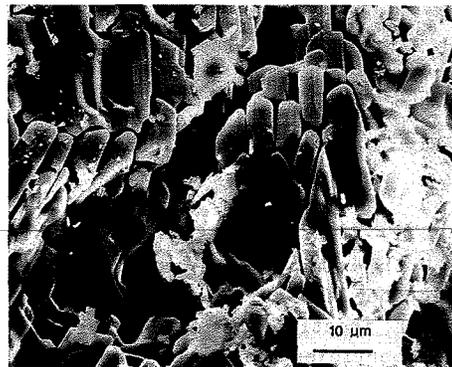


Fig. 8 Gypsum crystals

3. DISCUSSION

The optical analyses carried out locally within the concrete through the stereomicroscope, the polarized-light microscope and the SEM showed the presence of the typical features of Alkali-Aggregate Reaction.

On the contrary, chemical analyses on a larger mass of concrete revealed a very low soluble silica content, that probably represents the total sum of the binder silicates and of the reaction products. It is worth noting that part of the gel generated within the concrete exuded through the cracks and diffused out.

The presence of reactive aggregates, the considerable alkali and chloride levels found by the chemical analysis and the even higher levels found locally by the SEM microprobe, together with the favourable environmental conditions (high temperature, humidity and sea-water spray) allowed a magnified alkaline reaction to take place. In particular, the high level of chloride in the environment probably caused an high hydroxyl ion concentration in the concrete pore solution. According to some authors [11] this concentration could be similar to that produced by a cement with an equivalent alkali level. Several works have pointed out the influence of alkali chlorides on AAR and an hypothesis of the reaction mechanism has been proposed [12, 13].

To quantify the contribution of this reaction to the decay of the concrete under examination is, however, a difficult task: disruptive expansions, in fact, could also be due to the sulphate attack and in particular to the formation of secondary gypsum.

4. CONCLUSIONS

The network of cracks in the concrete structure examined, the type of alteration observed in the aggregates and the chemical composition of the gel found in the concrete led to the formulation of a diagnosis of Alkali-Aggregate Reaction.

The aggressive environmental conditions (high temperature and humidity) and the vicinity of the sea certainly enhanced this reaction. The presence of a sulphate attack also contributed to the concrete decay.

The case in question and several other ascertained in Italy, particularly on concrete structures near the sea, where concrete can absorb alkali from the sea - water spray, confirm that alkaline chlorides have a harmful influence on AAR.

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