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ASR Induced Blow-up in an Urban Concrete Pavement (Bahía Blanca–Argentina)

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The urban pavement at 600 Catamarca street in the city of Bahía Blanca (Argentina) burst lifting the concrete slabs at the contraction joint. The aim of this study was to investigate the causes that lead to the concrete deterioration. Aggregate constituent materials, their mineralogy, textures, condition of the paste and the aggregate–mortar interface were determined by a petrographic analysis of the concrete. A petrographic optical microscope, X-ray diffraction (XRD), scanning electron microscope (SEM) and energy dispersive X-ray (EDX) was used. Abundant ettringite development was noted both inside cavities and on the concrete surface. Its occurrence was confirmed by XRD and EDX analyzes. The aggregate deleterious constituents were mainly glassy vulcanites and volcanic glass, generally altered to argillaceous minerals of the montmorillonite group and strained quartz, with undulatory extinction. It was concluded that pavement deterioration was due to the alkali–silica reaction (ASR).

Keywords: Alkali–silica reaction (ASR); Concrete; Pavement; Microscopy; Slab failure

INTRODUCTION

In the world, an important number of concrete structures have been affected by the alkali–silica reaction (ASR). (Cavalcanti 1986; Albert and Raphael, 1986; Bérubé and Fournier, 1987; Fournier and Bérubé, 1991; Léger *et al.*, 1995; 1996; Qinhua and Weiqing, 1997).

In Argentina, civil engineering works frequently exhibit deterioration problems as a result of the development of the ASR, (Maiza *et al.*, 1999). In Bahía Blanca, ASR deterioration has been identified in a number of concrete pavements.

Aggregates that are not petrographically suitable are used on many occasions because they are the only ones available near the construction site.

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While it is well known that the local aggregate sources are reactive, the cost of importing non-reactive aggregate from elsewhere is prohibitive. Low alkali cements meeting the national standards are used when available. However, cements over 1% Na_2O equivalent are periodically imported from other parts of the country and overseas and have been used in the city for approximately 20 years.

The petrographic characteristics of the sand and gravel used to manufacture concrete in the city of Bahía Blanca indicate a high content of glassy volcanic rocks, mostly altered to argillaceous minerals of the montmorillonite group. Shreds of unweathered glass are commonly observed inside sand particles. In some quarries glassy components exceed 30% by weight. (Marfil, 1989; Marfil and Maiza, 1993; Maiza and Marfil, 1997). Despite the fact that these aggregates had been used in most of the works since the beginning of the twentieth century, there were no case histories of deteriorated structures due to ASR development. However, in recent years, urban pavements of an age that ranges between 8 and 14 years have started to show serious deterioration problems, (Marfil and Maiza, 1999). Partial repair is carried out in the affected areas using bituminous or concrete pavements. This is a temporary type of repair since the deterioration process proceeds leading to reduced joints, swelling due to restrained expansion of the concrete slab and map cracking until fragments of the material are displaced, in this case by a burst.

The results from studies conducted on an urban pavement at 600 Catamarca street in the city of Bahía Blanca (province of Buenos Aires, Argentina) are presented in this paper. The expansion evidenced by reduced joints could not absorb the stresses and, hence, a burst in September 1999 caused an accident where a motorcyclist was involved.

Our objective is to report the conclusions from the study that enabled identification of the causes of pavement deterioration. A petrographic study of hardened concrete was performed to determine the mineralogy and texture of the aggregates used, physical characteristics of the concrete, its structure and features exhibited in the deterioration process and burst stage.

METHODS

A survey of the affected area was conducted, showing that nearby contraction joints were tightly closed with bitumen draining from them.

FIGURE 1 View of the deteriorated pavement at 600 Catamarca street, after the burst.

An Olympus SZ-Pt trinocular stereomicroscope, an Olympus B2-UMA trinocular petrographic microscope, both equipped with a built-in SONY videocamera with a digital capture system, a JEOL JSM 35 CP scanning electron microscope, equipped with an EDX probe, DX4, with an ultrathin window with a range of analysis from $Z = 5$ to $Z = 92$ and a computer-based Rigaku X-ray diffractometer D-max III-C, 35 kV and 15 mA, with Cu Kα radiation and a monochromator, were used.

RESULTS

Slabs were lifted over 0.3 m and dislodged from the ground, causing extensive cracking that led to the displacement of large fragments of material. The condition of the pavement is shown in Fig. 1.

Observations in the Stereomicroscope

The pavement exhibited a high degree of deterioration from the extensive cracking that affected the mortar and reactive aggregate particles (Fig. 2). There was a white massive material inside the cracks. Most of the deleterious materials exhibited reaction rims, in some case lined with a whitish material. Other particles had undergone an advanced reaction process that made them brittle with marked zeolitization and argillization.

Cavities formed by air voids were lined and sometimes filled with a material of a rosette-like fibrous habitat attributed to ettringite. Reaction products were removed for their subsequent analysis by SEM–EDX.

Petrographic Microscopy

Hardened concrete was studied on thin sections to determine the petrography of the coarse and fine aggregates, as well as the condition of the paste and the aggregate–mortar interface.

The coarse aggregate was a crushed rock of granitic composition, classed as suitable to be used in concrete manufacture.

The fine aggregate was sand composed mainly of volcanic rocks (40%) that were mostly basic and glassy. The glass was both unweathered and altered to argillaceous minerals of the montmorillonite type. Another deleterious component was particles of unweathered glass with a concentration of approximately 8% by weight of sand.

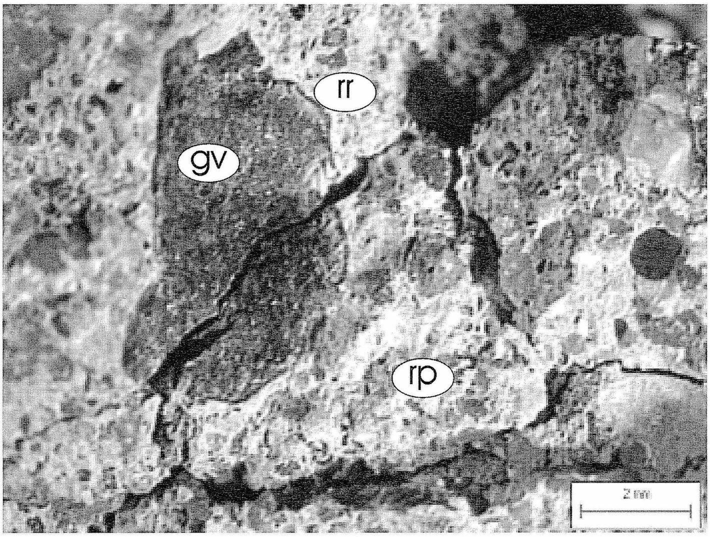

FIGURE 2 Extensive cracking affecting the mortar and reactive particles (glassy vulcanites: gv), with development of reaction products (rp) and reaction rims (rr).

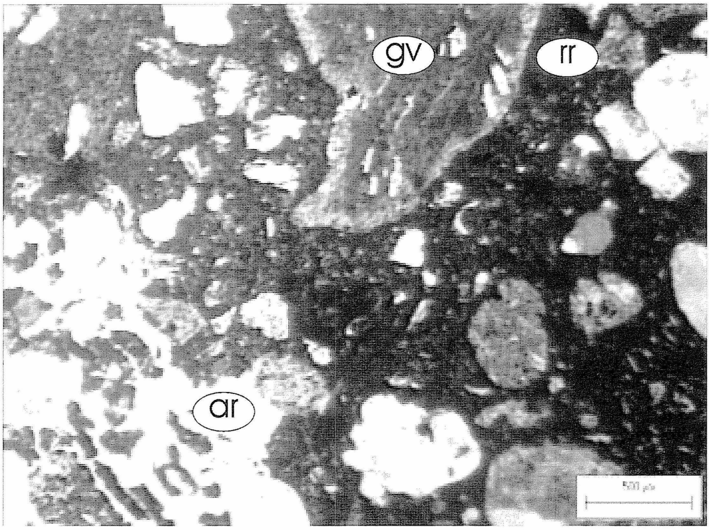

FIGURE 3 Thin section of concrete pavement. Development of reaction rims (rr) at glassy vulcanite particles (gv) and paste argillization (ar) with obliteration of the aggregate original texture.

The mortar was cracked; the cracks had traversed across in the paste and deleterious aggregates. Figure 3 illustrates the aggregate and paste, showing reaction rims on the boundaries of glassy vulcanite particles. A fraction of the mortar was severely cracked as a consequence of the development of an argillization process from the glass of vulcanite particles.

X-ray Diffraction

The material from inside the cracks, reaction rims and surfaces of the reactive aggregates was analyzed by XRD. A zeolite of the clinoptilolite–heulandite ($KNa_2Ca_2(Si_{29}Al_7)O_{72}\cdot 24H_2O$), (ICDD 39-1383) group was identified as the reaction product (Fig. 4(a)). This material presented the highest intensity of reflection at 8.9 Å and could be easily discriminated from ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$), which had the characteristic reflection at 9.7 Å, as shown in Fig. 4(b). The latter occurred mainly inside cavities of air voids and on the deteriorated concrete surface.

Scanning Electron Microscopy—EDX

An analysis of the fibrous material identified as ettringite by XRD was performed. The morphology of the crystals is shown in Fig. 5(a). The EDX analysis (Fig. 5(b)) revealed the presence of S, Al, O and Ca, in proportions attributed to be ettringite.

Figure 6(a) illustrates the reaction product from the deleterious aggregates. It developed as reaction rims and inside microcracks. Figure 6(b) gives its chemical composition determined by EDX (Si, Al, O, Ca, Na and K), which was attributed to zeolite identified as clinoptilolite by XRD.

REMARKS

From the comparison of the examined pavement with both sound and deteriorated pavements, (Maiza *et al.*, 1999; Marfil and Maiza, 1999), it can be seen that in all the analyzed cases the same fine aggregate was used. Older pavements (over 20 years of age) are sound and show no signs of deterioration, whereas in those constructed as from 1984, the occurrence of ASR development has frequently been reported.

On inquiring about the cements used, it was found that deteriorated pavements had been built with high-alkali cements.

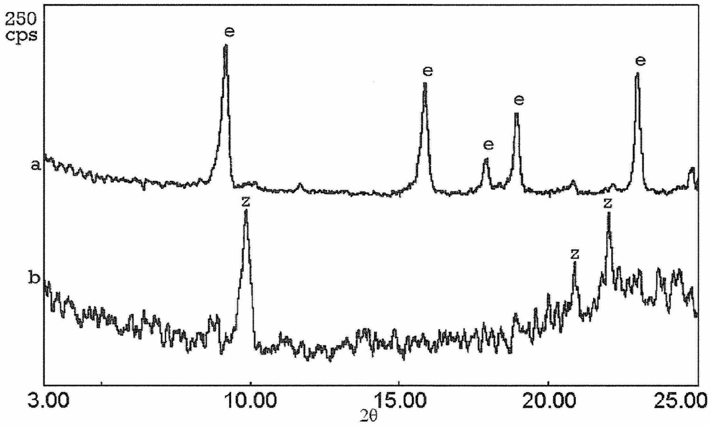

FIGURE 4 XRD of the reaction products. (a) Ettringite (e). (b) Zeolite (z). Their spectra show clear differences.

CONCLUSIONS

1. The pavement has deteriorated due to the development of the ASR.
2. The deleterious species are unweathered and altered glassy vulcanites, and unweathered volcanic glass.
3. Reaction products are zeolites of the clinoptilolite–heulandite group and ettringite.
4. If aggregates available in the Bahía Blanca area are to be used, it is recommended that either the cement be checked before making concrete structures or necessary studies be conducted to use ASR inhibitors.

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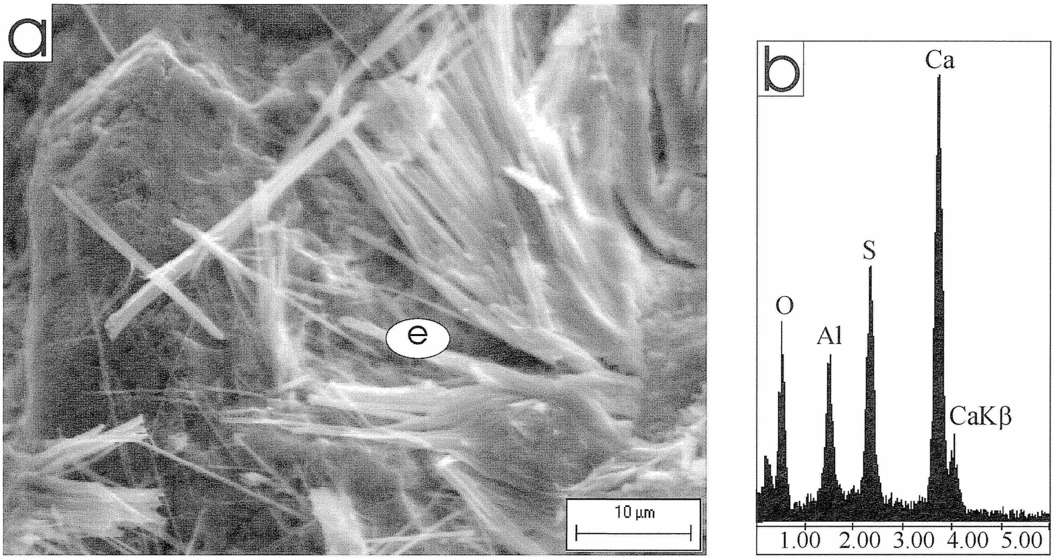

FIGURE 5 (a) Fibrous crystals that developed in the deteriorated concrete, identified as ettringite (e) by XRD. (b) EDAX of the material shown in 5(a).

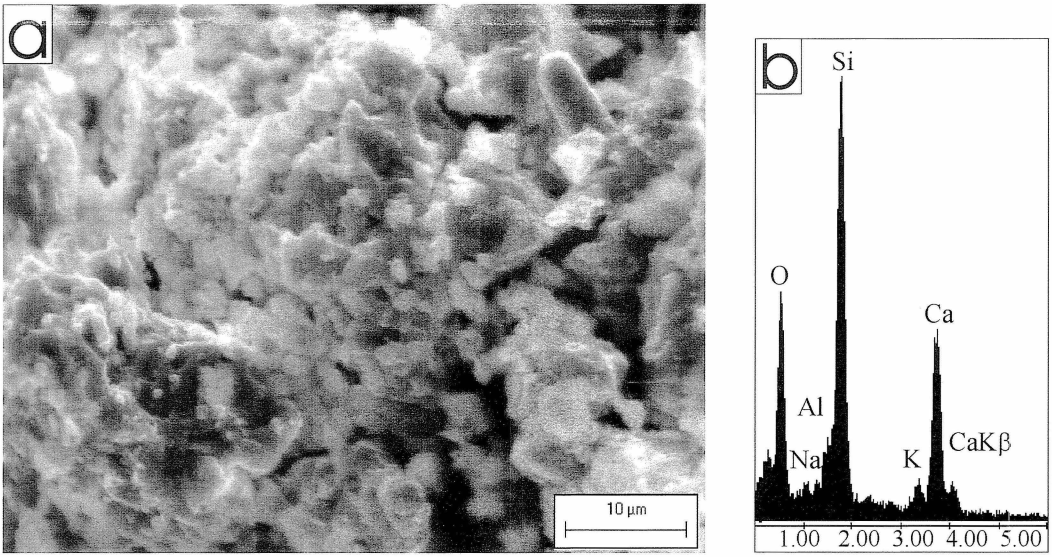

FIGURE 6 (a) Reaction product that developed from the reactive aggregates, identified as clinoptilolite by XRD. (b) EDAX of the material shown in (a).

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