THE ROLE OF ALKALI-DOLOMITE REACTION IN DETERIORATION OF AN AIRPORT PAVEMENT

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Abstract

Petrographic examinations of a concrete pavement suffered cracking since 1996 showed that the dolostones used as aggregate were composed of mosaic dolomites in 10-80μm, a few of quartz and 2-5 vol% micro-crystalline quartz. Most of cracks in the pavements extended from the inner parts of dolostones to mortars, a few developed along or terminated at the boundaries of dolostones. SEM imagination showed that alkali-dolomite reaction took place in the dolostones, the coarse aggregates themselves expanded and cracked resulting in cracking of mortars due to dedolomitization. A few of micro-crystalline quartz in the coarse aggregates and in lithic fragments in fine aggregates also reacted with alkalis in pore solutions to form alkali-silica gels which expanded and cracked the concrete. The results of most of the cracks in the concrete were empty may indicate that alkali-dolomite reaction plays a major role in the deterioration of the pavements and alkali-silica reaction contributed less to cracking of the concrete.

Keywords: Pavement, concrete, dolostone, alkali-dolomite reaction, alkali-silica reaction

1 INTRODUCTION

An airport concrete pavement was built in 1993. The base of the pavement was an old concrete pavement which was built in 1953 and 350 mm in thickness. The newly constructed pavement was 180-200 mm in thickness. P.II 42.5R ordinary Portland cement with 0.95wt% equivalent Na_2O was used. A river sand with 2.87 modulus was used as fine aggregate. Crushed dolostones in 5-20 mm and 20-40 mm were used as coarse aggregates. The content of cement, sand and crushed dolostones was 310 kg/m^3, 680 kg/m^3 and 1285 kg/m^3, respectively. Water to cement ratio was 0.50.

The content of Na^+, K^+, Mg^{2+}, Cl^- and SO_4^{2-} ions in the soils near the pavements was 27-1964, 7-153, 8-212, 15-3593 and 20-1803 mg/kg. The content of Na^+, K^+, Mg^{2+}, Cl^- and SO_4^{2-} ions in water near the pavements was 64-780, 2-70, 4-114, 166-804 and 16-400 mg/L. The average temperatures of the coolest and the hottest months were -3.9^{o}C and 20.5^{o}C.

The average flexural strength of the pavement concrete at 28 days was 5.8 MPa. The deterioration of the pavement occurred in October, 1996 and developed continuously from 1996 to 2011. The pavement was demolished in 2012 due to bad performance. The deterioration was mainly in map cracking and partially in

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parallel cracking as shown in Fig. 1. The width of cracks ranged from 0.1-1.0 mm. Most of the cracks were not filled. A few of cracks were filled with white substances. There were displacements. Slight spallings occurred on the surfaces of few pavements.

Based on the damage characteristics, it was suspected that alkali-aggregate reactions might cause the deterioration of the pavements. Some believed that concrete might be deteriorated by alkali-carbonate reaction when a few of dolomitic limestones and dolostones were used as coarse aggregates [1-5]. Recently, a few of investigators believe that the deteriorations of concretes with dolomitic limestones were caused by ASR because they detected alkali-silica gels in the concrete [6-8]. This paper describes the damage characteristics of the pavement concrete and alkali-reactivity of the coarse aggregates. It is expected to reveal the reason for cracking of the pavement concrete contained with crushed dolostones.

2 MATERIALS AND METHODS

2.1 Materials

Concrete cores

Concrete cores in Φ150mm×200mm taken from the pavements were collected. Then about 100kg concrete cores were crushed to separate the aggregate and paste, and the coarse aggregate were picked up according to the colour of aggregate. The gathered coarse aggregates were weighed and gotten about grey aggregate 45wt%, green-grey aggregate 45wt% and white-grey aggregate 10wt%. The chemical compositions of aggregates tested by chemical titration referring to GB/T176-2008 are listed in Table 1, and the mineral compositions identified by X-ray diffraction analysis (XRD, KαCu target, scanning rate 2°/min) are shown in Fig. 2. It is seen that the grey, green-grey and white-grey coarse aggregates are mainly composed of dolomite. They also contain a small amount of quartz and calcite. By petrographic examination, the grey aggregates are composed of 10-80μm dolomites and about 2vol% dispersed micro-crystalline quartz. The green-gray aggregates are consisted of 10-70μm dolomites, a small amount of quartz and about 5vol% micro-crystalline quartz. The white-grey aggregates contain 10-60μm dolomites, a few of quartz crystals and about 3vol% micro-crystalline quartz. The typical microstructures of the coarse aggregates are shown in Fig. 3.

Cement

Portland cement from Jiangnan-Onoda Cement Limited Company in Nanjing, China was used. The content of SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, K_2O, Na_2O, SO_3 and loss on ignition (LOI) in the Portland cement was 19.4wt%, 2.96wt%, 4.73wt%, 64.0wt%, 2.35wt%, 0.68wt%, 0.11wt%, 2.58wt% and 2.81wt%. The equivalent alkali content of the cement is 0.56wt% Na_2O_{eq}.

2.2 Methods

Examination of concrete microstructures

The concrete microstructure was assessed by petrographic examination of (polished) thin sections.

Expansion testing of alkali-reactivity of the coarse aggregates

Alkali-silica reactivity of the coarse aggregates was tested according to RILEM AAR-2 [9] and CECS 48 [10]. Alkali-carbonate reactivity of the coarse aggregates was tested in light of RILEM AAR-5 [11].

Test of alkali content of concrete

The alkali content of concrete was tested according to BS 1881-124-1988 Testing concrete-Part 124-Methods for analysis of hardened concrete [12].

Examination of SEM

Elemental compositions of concrete constituents were qualitatively assessed on unpolished surfaces in a JSM-5900 scanning electric microscope instrument equipped with EDS, for phase identification purposes.

3 RESULTS

3.1 Patterns of cracks in the concrete pavements

Concrete surface examination

There are a few of cracks on the surfaces and in the inner part of concrete cores. The surficial cracks go to some extent into concrete as shown in Fig. 4. Some cracks across the coarse aggregates.

Polished section examination

The concrete cores were cut and polished to form polished sections. The polished sections were examined with a stero microscope. Fig. 5 demonstrates the typical cracks in the pavement concrete. Most of cracks spread from the inner parts of coarse aggregates to surrounded mortars. A few of cracks developed along or terminated at the boundary of the coarse aggregates as shown in Fig. 6. The cracks are mainly empty. There are few of pores and cracks filled with white substances which are alkali-silica gels as confirmed by EDS of SEM (Fig. 7).

Thin section examination

The concrete cores were cut and polished to form thin sections which were submitted to petrographic examination with a polarized microscope. Some of the coarse aggregates suffered from cracking and the cracks extended to mortars as shown in Fig. 8 and Fig. 9. Major cracks are empty and a few of cracks were filled. The filled cracks may contain alkali-silica gels as observed on polished sections (Fig. 7). The fine aggregates were composed of quartz crystals, feldspars crystals and a few of lithic fragments which contained quartz, feldspar, biotite and a small amount of micro-crystalline quartz which bring about few of cracks.

3.2 Alkali-reactivity of the coarse aggregates

The alkali reactivity of the coarse aggregates derived from the concrete cores were evaluated according to RILEM AAR-2 accelerated mortar bar test [9], CECS 48 autoclaved test [10] and RILEM AAR-5 accelerated concrete micro-bar test [11]. The results are shown in Table 2 and Fig. 10. The maximum expansions of CECS 48 accelerated mortar bars for the grey, green-grey and white-grey particles are 0.038% l/l, 0.051% l/l and 0.045% l/l, respectively. These expansions are all less than 0.1% l/l. The expansions of RILEM AAR-2 accelerated mortar bars prepared with the grey, green-grey and white-grey particles and cured for 14 days are 0.039% l/l, 0.081% l/l and 0.055% l/l, being less than 0.10% l/l. Therefore, the grey, green-grey and white-grey particles are classified as not alkali-silica reactive. The expansions of concrete microbars with the grey, green-grey and white-grey particles and cured for 28 days are 0.125% l/l, 0.188% l/l and 0.165% l/l, respectively. According to RILEM AAR-0, the grey, green-grey and white-grey particles are classified as alkali-carbonate reactive.

3.3 Alkali content of the pavement concretes

The coarse aggregates were carefully get rid of by crushing the concrete cores and the obtained mortars were treated with 1:1 HCl to dissolve the cementitious materials. The acid insoluble residues were separated from solutions by filtrating. The content of Na^+ and K^+ ions in the filtrated solutions were measured with a flame photometer referring to GB/T176-2008. The calculated alkali content of three concrete cores derived from runway was 3.65, 4.42 and 4.82 kg/m^3 respectively. These values are higher than that calculated by multiplying cement content with alkali content of cement, which was 2.91 kg/m^3. The increase of alkali content of the pavement concretes may be caused by supplying alkali by salty water or soils.

3.4 Alkali-dolomite reaction of the coarse aggregates

Figure 11 shows the microstructure of near-surface zone of a coarse aggregate derived from a concrete core. The dolomites were locally altered to flake and small granular particles. The small granular particles may be calcite and the flake may be brucite as demonstrated by EDS patterns in Fig. 12. This indicates that the coarse aggregates suffered from dedolomitization.

4 DISCUSSION

The coarse aggregates in the pavement concretes are composed of 10-80□m dolomites, a few of quartz and about 2-5vol% micro-crystalline quartz. The results of RILEM AAR-2 accelerated mortar bar test and CECS 48 autoclaved test show that the coarse aggregates are not alkali-silica reactive. The expansions of concrete microbars with the coarse aggregates and cured for 28 days are 0.125-0.188% 1/l. According to RILEM AAR-0, the coarse aggregates are classified as alkali-carbonate reactive.

The original alkali content of the pavement concrete was 2.91 kg/m^3. The alkali content of the concrete increased to 3.65-4.82 kg/m^3 after exposed to salty environment for 19 years. This promoted alkali ensured continuous take place of alkali-dolomite reaction and alkali-silica reaction in the concrete.

Accompanying dedolomitization of dolomite in the coarse aggregates, the coarse aggregates themselves expanded and cracked. As a result, the surrounded mortars cracked. A few of micro-crystalline quartz in the coarse aggregates and in lithic fragments in fine aggregates also reacted with alkalis in pore solutions to form alkali-silica gels. These gels expanded and cracked the concrete. Petrographic examinations showed that most of the cracks in the concrete were empty. This tends to suggest that alkali-dolomite reaction might play a major role in the deterioration of the pavements and alkali-silica reaction contributed less to cracking of the concrete.

5 CONCLUSIONS

(1) The coarse aggregates in the concretes composed of 10-80 μm dolomite, a few of quartz and 2-5 vol% micro-crystalline quartz are alkali-carbonate reactive and not alkali-silica reactive.

(2) The deterioration of the pavements is mainly due to alkali-dolomite reaction in the coarse aggregates. Alkali-silica reaction caused by a few of micro-crystalline quartz in the coarse aggregates and in the lithic fragments in the fine aggregates contributed to a less extent to the cracking of the pavements.

Acknowledgement

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TABLE 1: The chemical compositions of the coarse aggregates.

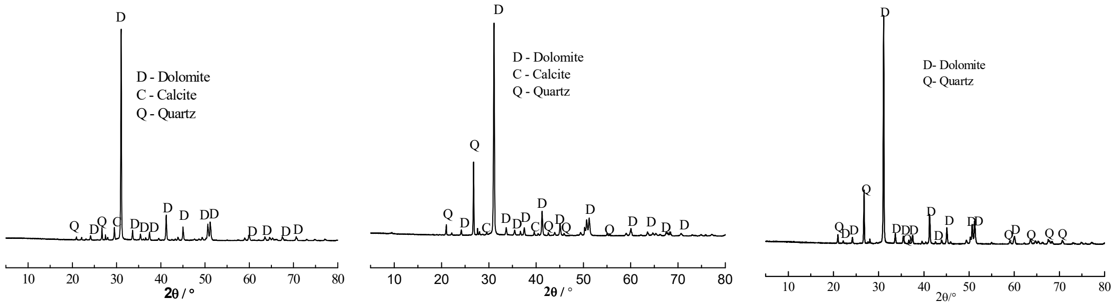
Coarse aggregates	Chemical compositions /wt%						
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Loss	Total
Grey particle	3.20	0.05	0.07	31.43	21.22	41.66	97.63
Green-grey particle	13.90	0.55	0.63	27.04	19.42	36.89	98.43
White-grey particle	18.21	0.05	0.55	24.08	16.93	39.57	99.39

TABLE 2: Expansion of CECS 48 accelerated mortar bars.

No	Coarse aggregates	Expansion of specimens /% 1/1		
		10:1*	5:1*	2:1*
1	Grey particle	0.027	0.033	0.038
2	Green-grey particle	0.028	0.038	0.051
3	White-grey particle	0.028	0.034	0.045

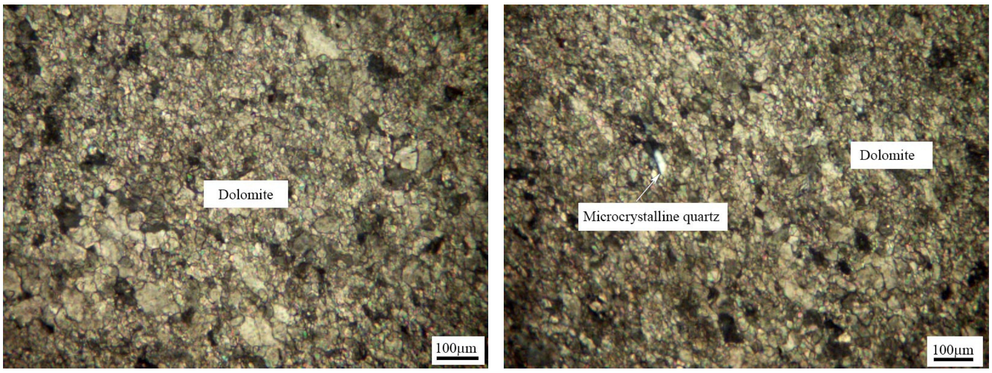
Note: *-Ratio of cement to aggregate.

FIGURE 1: Typical cracks of the pavements.

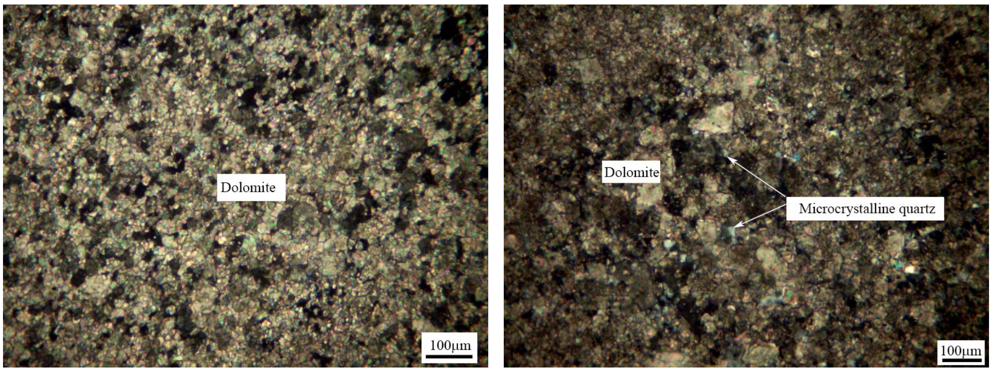


(a) Grey particle (b) Green-grey particle (c) White-grey particle

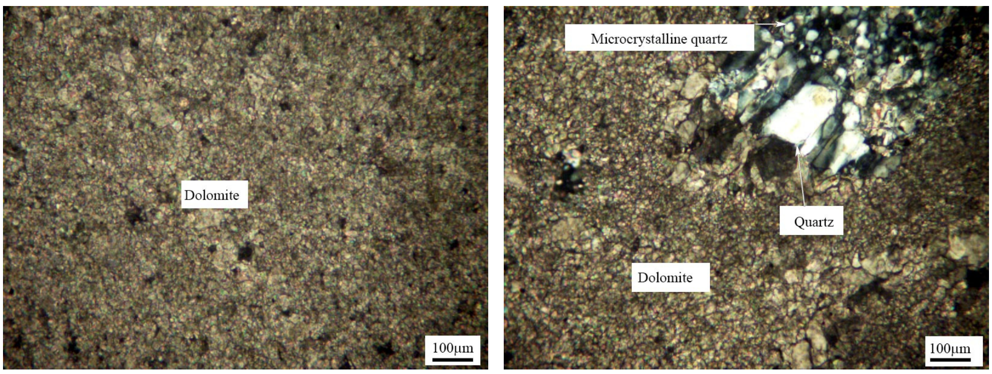
FIGURE 2: XRD patterns of the coarse aggregates.



(a) Grey particle



(b) Green-grey particle



(c) White-grey particle

FIGURE 3: Microstructures of the coarse aggregates.

FIGURE 4: Cracks in the concrete cores.

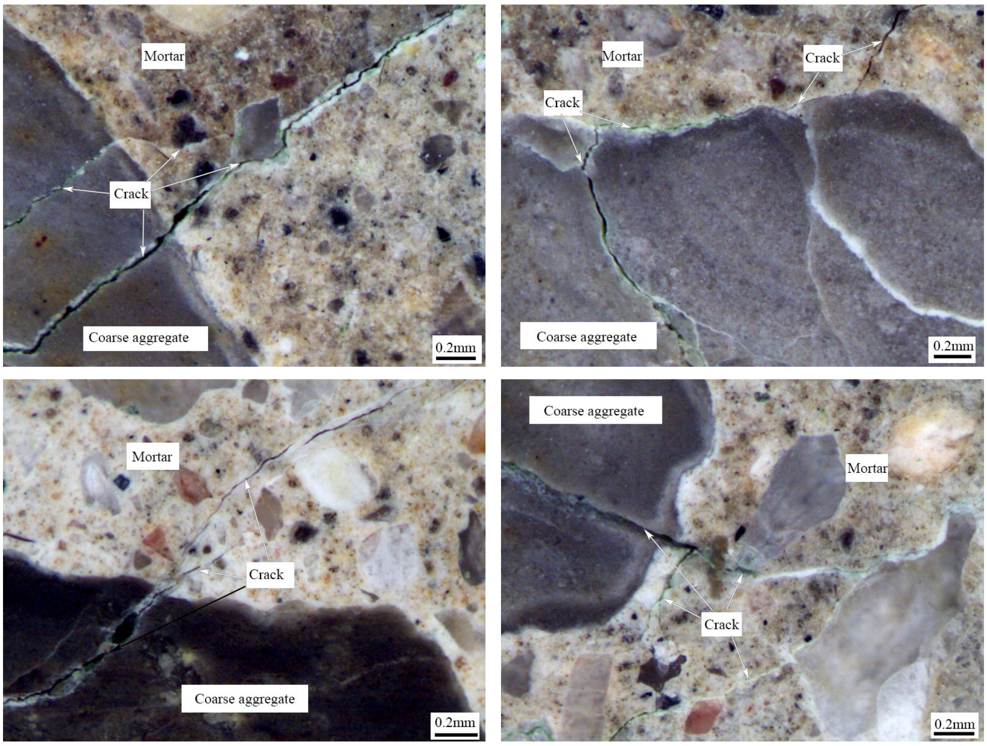


FIGURE 5: Typical microcracks of polished sections of the pavement concretes.

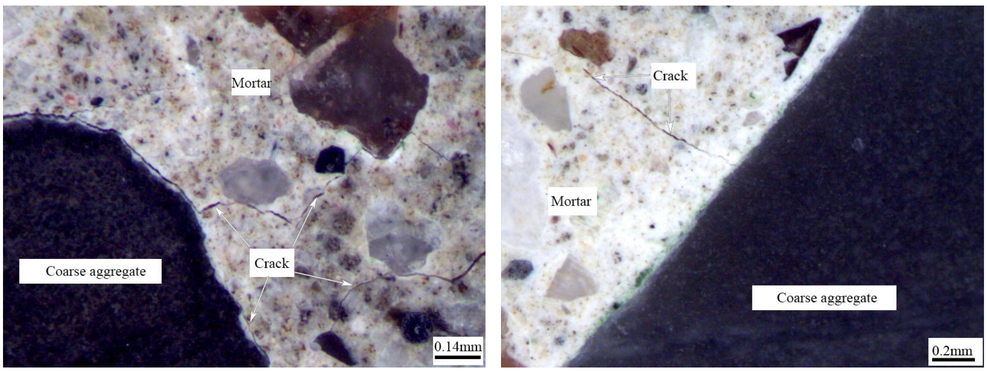


FIGURE 6: A few empty microcracks developed along or terminated at the boundary of the coarse aggregates.

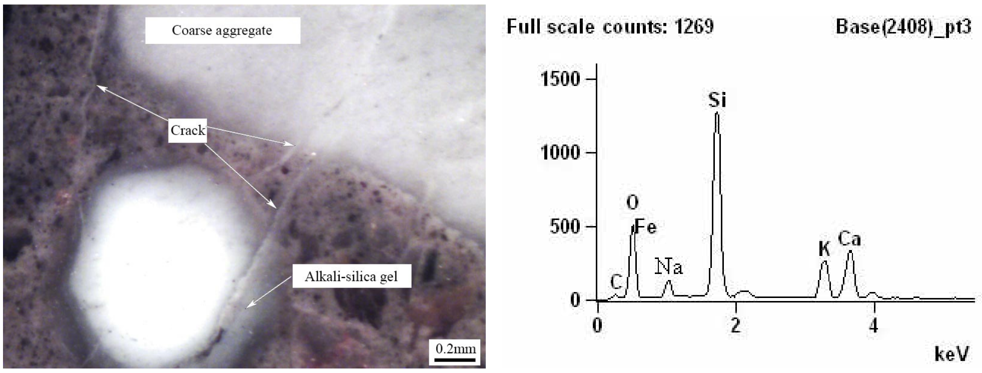


FIGURE 7: Alkali-silica gel deposited in pore and microcracks and its composition.

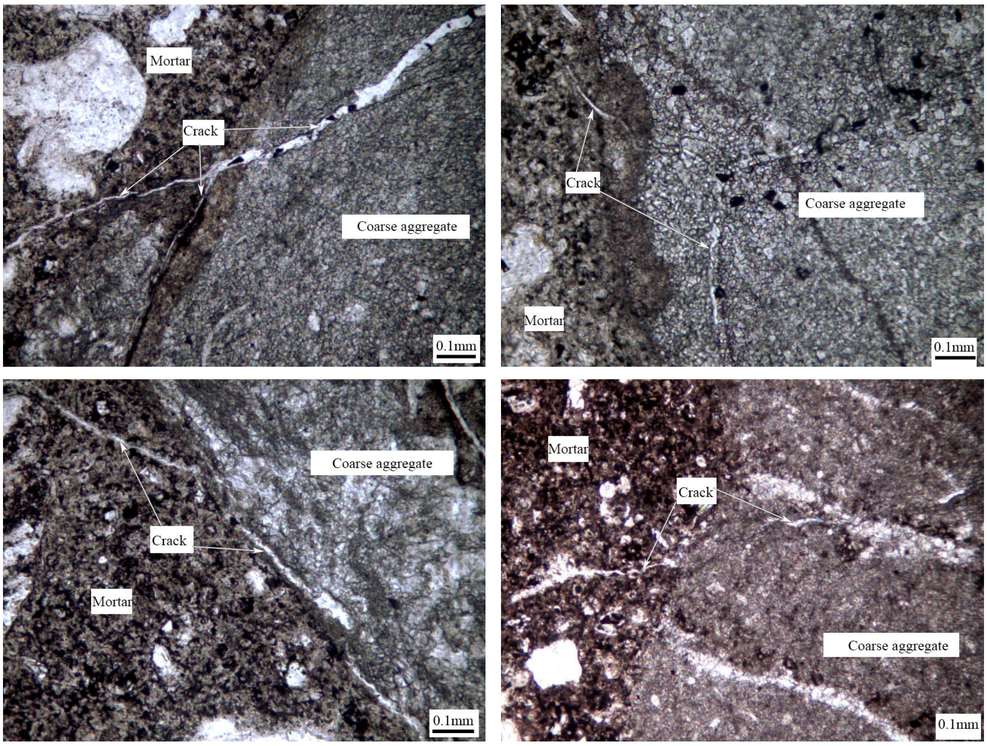


FIGURE 8: Typical microcracks in the pavement concretes.

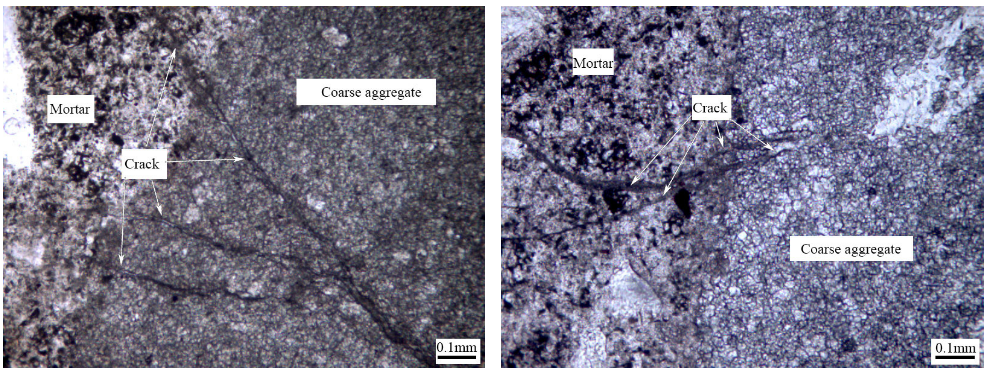
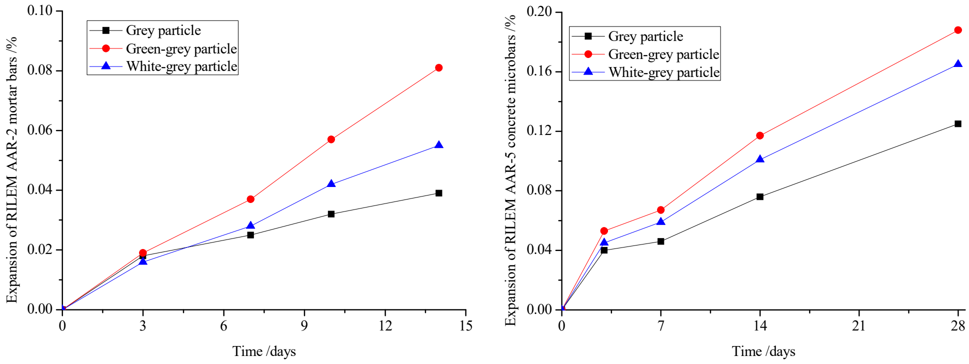


FIGURE 9: A few of filled cracks in the pavement concretes.



(a) Expansion of RILEM AAR-2 mortar bars (b) Expansion of RILEM AAR-5 concrete microbars

FIGURE 10: Expansions of RILEM AAR-2 mortar bars and RILEM AAR-5 concrete microbars.

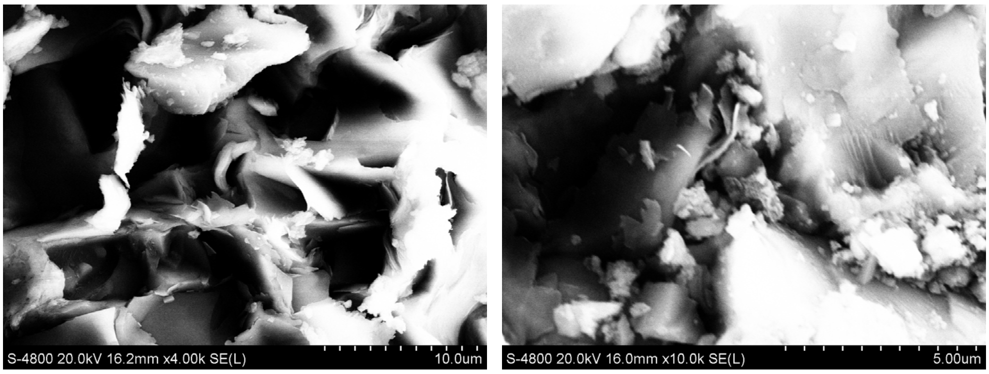
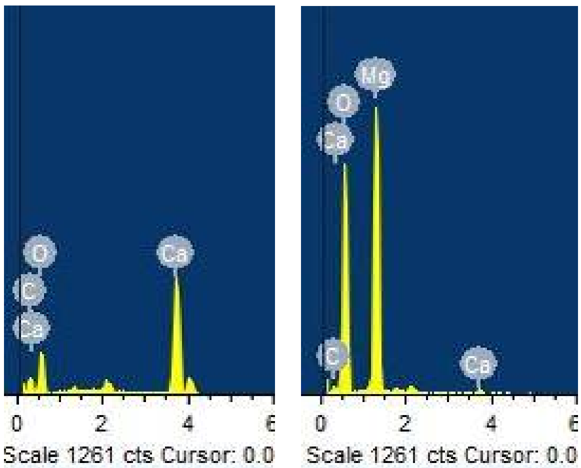


FIGURE 11: Locally altered dolomites in the near-surface zone of a coarse aggregate form a concrete core



(a) Granular particle (b) Flake

FIGURE 12: EDS patterns of the small granular particle and flake in Figure 11.