THE LOMAS BOULEVARD ROAD TEST SITE, ALBUQUERQUE (NEW MEXICO) – A CASE STUDY ON THE USE OF PREVENTIVE MEASURES AGAINST ASR IN NEW CONCRETE

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Abstract

A 155m-long experimental pavement section consisting of the westbound approach lanes to a bridge carrying Lomas Boulevard in Albuquerque, NM, was constructed in June 1992. Eleven different concrete mixtures incorporating highly-reactive natural gravel aggregates from two local sources were used to evaluate the efficacy of various preventive measures against ASR. In addition to two control sections, five sections were made with fly ash (Class F, Class C, 50-50 blend of F and C ashes) at a nominal replacement level of 20 percent. Lithium hydroxide monohydrate ($LiOH•H_2O$) was used in three sections at dosages of either 0.5 percent or 1.0 percent by mass of Portland cement. The laboratory testing program, carried out on core samples extracted from all the sections of the experimental pavement, included mechanical tests as well as semi-quantitative petrographic examination. After 16 years of service, sections incorporating Class C fly ash, were found to display the worst surface/internal deterioration. On the other hand, sections incorporating Class F fly ash and lithium hydroxide showed limited surface cracking and internal damage due to ASR.

Keywords: Concrete pavement, Fly Ash, lithium hydroxide, Stiffness Damage Test (SDT), Damage Rating Index (DRI)

1 INTRODUCTION [1]

Highly-reactive natural gravel aggregates have been exploited for the past few decades in the Albuquerque area, New Mexico. In order to avoid the development of ASR in highway structures incorporating natural gravel aggregates from the local Shakespeare and Placitas pits, a 155m-long experimental concrete pavement consisting of the 11m-wide westbound approach lanes to a bridge carrying Lomas Boulevard in Albuquerque, NM (Figure 1), was built in 1992 using the above sources of aggregate with a range of preventive measures, such as fly ash and lithium compound. This paper presents the results of the latest survey and the testing program carried out on core samples extracted in 2008 and 2009 from the various sections of the experimental pavement after about 16 years of service.

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2 MATERIALS AND METHODOLOGY

2.1 Materials [1]

Eleven different concrete mixtures incorporating natural gravel aggregates from two local sources, Shakespeare and Placitas, were used for the experimental pavement (Table 1). The total nominal cementitious materials and cement alkali contents were 395 kg/m^3 and approximately 0.55 percent of Na_2O_e, respectively [2]. Fly ash was incorporated at a nominal replacement level of 20 percent. The water-to-cementitious materials ratio of these mixtures was generally in the range of 0.40. Lithium hydroxide monohydrate ($LiOH \bullet H_2O$), in powdered form, was used in three sections at dosages of either 0.5 percent ([Li]/[Na+K]=0.67 or 91% of the "standard" dose[1]) or 1.0 percent ([Li]/[Na+K]=1.34 or 182% of the "standard" dose) by mass of portland cement.

2.2 Methodology

A visual survey was first carried out and a condition rating was attributed to each of the different sections of the pavement. Three to four cores (100 mm in diameter) were then extracted in October 2008 and in December 2009 (repeat for sections 5 and 6) from each of the 11 sections of the pavement. The cores were then subjected to petrographic examination and mechanical testing in the laboratory.

Petrographic Examination

The petrographic examination of the cores was carried out with two major objectives; 1) the evaluation of the damage due to ASR in the concrete (using the *Damage Rating Index* (DRI)); 2) the identification of the reactive aggregate materials/rock types (using the *Gel Pat Test* (GPT)) in the natural gravels used in the experimental concrete pavement. The first core of each section was cut in half lengthway and both surfaces polished. The first half was subjected to the *DRI* method and the second to the *GPT* method.

Damage Rating Index (DRI) [3]

The method consists in evaluating the condition of concrete through a count, under the stereomicroscope, of the number of petrographic features of deterioration on polished concrete sections at a 16x magnification. The polished sections are then photographed and a grid is drawn on the section, which includes a minimum of 200 grid squares, 1 cm by 1 cm in size. Each grid square is then examined under the stereomicroscope to determine the *Damage Rating Index* (DRI). The latter represents the normalized value (to 100 cm^2) of the presence of petrographic features after the count of their abundance over the surface examined has been multiplied by weighing factors representing their relative importance in the overall deterioration process. The Table 2 gives the weighing factors proposed by Dr. Grattan-Bellew from the National Research Council of Canada and used in this study [3].

Gel Pat Test (GPT)

The *Gel Pat Test* was used to confirm the potential alkali-reactivity of the various rock facies of the aggregate materials through the formation of alkali-silica gel in a strong alkaline solution [4]. Polished sections from the second half of the first core of each set were photographed and immersed in a 1N NaOH solution at 38°C for a period up to 42 days, period over which the sections were examined and photographed regularly to identify gel formation over reactive aggregate particles. Thin sections were made with the concrete containing rock particles that showed deposits of reaction products on their surface.

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[1] The "standard"/recommended dose of lithium is [Li]/[Na+K]=0.74

Mechanical testing

Additional cores from the 2008 coring campaign, were subjected to the *Stiffness Damage Test* (SDT) and, upon completion of the test, the cores were crushed in compression.

Stiffness Damage Test (SDT)

The SDT was originally proposed by Chrisp et al. [5] but recently, the method was slightly modified and used for estimating the expansion attained to date by ASR-affected concrete [6,7,8]. Two concrete core specimens extracted from each of the different sections of the Lomas Boulevard experimental pavement were subjected to five cycles of uniaxial loading/unloading up to a maximum of 10 MPa in accordance with the modified SDT method proposed by Smaoui et al. [6]. The Figure 2 illustrates typical results of the SDT. Cores affected by a low degree of damage generally show low dissipated energy (or surface area under the first loading/unloading cycle expressed as Joules/m^3), while those with significant internal damage will show much higher dissipated energy values (large surface area for the first cycle) and total plastic deformation [6].

3 RESULTS

3.1 Visual Inspection

A visual survey was performed of the various sections of the Lomas Boulevard experimental pavement. Figure 3 illustrates the typical condition of the various pavement sections and gives the results of the condition rating developed on site (based on the degree of cracking from minor to severe). It has to be noted that all pavement sections display some (localized) cracking. The sections incorporating lithium (0.5%, 1.0% and Lomar™ admixture) and Class F fly ash were in the best overall condition and showed only minor cracking.

3.2 Petrographic composition of the concrete aggregates

The composition of the aggregate materials, which was determined from the petrographic examination of polished sections obtained from the various sections of the pavement, is given in the Figure 4. The volcanic rock types, rhyolite to andesite, form the majority of the material, followed by quartzite, quartzitic sandstone and siltstone, granite and minor amount of limestone. The volcanic rock types have the highest potential for ASR, while the quartzites and sandstones show a moderate to mild potential for ASR. Fournier et al. [9] reported one-year concrete prism expansion of 0.320% and 14-day accelerated mortar bar expansion of 1.056% for an aggregate from the Placitas pit. The aggregate is thus considered as very highly reactive according to the AASHTO standard practice PP 65 [10].

3.3 Damage Rating Index

The Figure 5 presents a compilation of the DRI values obtained from the cores of the experimental pavement and Figure 6 illustrates deterioration petrographic features observed. The DRI values range from 101 to 695, which suggest degree of damage ranging from low to moderate-severe. The sections 5 (Shakespeare; Class C fly ash) and 6 (Shakespeare, Control) are showing the highest degree of damage. The cores recovered from the sections incorporating lithium (sections 1, 2, 3, 10) and Class F fly ash (sections 4 and 10) showed low degree of damage. Overall, the petrographic examination of all cores highlighted the presence of internal cracking in a significant number of coarse aggregate particles, which is not surprising considering the history of the aggregate material, which includes weathering (since the aggregate is a natural gravel) and some mechanical stresses during the aggregate processing operations.

The high DRI results obtained for the cores extracted from the sections 5 and 6 are however characterized by significantly higher proportions of features typically resulting from ASR, i.e. cracks with reaction products both in the aggregate particles (Cr+RPCA) and in the cement paste (Cr+RPCP). Overall, the degree of cracking in the cement paste (CrCP and Cr+RPCP) is very high for the cores extracted from sections 5 and 6. Dark «reaction» rims were observed surrounding aggregate particles in all core specimens, which suggest that this feature was not necessarily indicative of a significant/high degree of damage due to ASR; such rims may thus be resulting, at least partially, from natural weathering processes of the natural gravel particles.

The low degree of damage obtained for the cores from the lithium and Class F fly ash sections (1 to 4) incorporating the Shakespeare reactive gravel confirmed the efficacy, about 16 years after construction, of the above measures used for preventing deleterious expansion and/or cracking due to ASR in the Lomas Boulevard experimental pavement. It is difficult at this stage to conclude on the efficacy of the preventive measures used in the pavement sections incorporating the Placitas aggregate because of the low degree of internal damage (from the DRI values) observed in the control specimen extracted from the section 9.

3.4 Gel Pat Test

The rock particles that have generated significant amounts of gel in the GPT correspond to volcanic rock types, i.e. dacites, rhyolites, latite and some andesites (Figure 7 and 8). The alkali-silica reactivity of the above materials is related to the fine-grained siliceous matrix, sometimes devitrified, of the rock particles. The rhyolitic facies shows zones rich in fine-grained quartz with chalcedony (spherulites) microtextural characterisitics.

3.5 Mechanical Testing

As presented in the Figure 9, low values of dissipated energy (DE) were obtained for the cores extracted from the sections 1, 4 and 7 to 11, which suggests low internal degradation [6,7]. On the other hand, cores from the damaged sections 5 and 6 generally gave much higher dissipated energy values. The cores extracted from the lithium sections (sections 1 and 10 - 1.0% LiOH) gave amongst the lowest DE values. Similar trend was obtained for the compressive strength determinations. Cores from the sections 5 and 6 showed significantly lower compressive strengths (Figure 9) than the rest of the specimens tested, which confirmed that the concrete sections show a higher degree of internal damage that can be related to ASR based on petrographic examination.

4 CONCLUSIONS

An experimental concrete pavement was constructed in June 1992 in Albuquerque, NM. The 3-lane pavement used eleven different concrete mixtures to evaluate different methods for preventing ASR with a local highly-reactive gravel aggregate material. Concrete cores were extracted from the above sections in 2008 and 2009 and subjected to a number of laboratory investigations, including petrographic examination (*Damage Rating Index (DRI)*) and mechanical testing (*Stiffness Damage Test (SDT)* and compressive strength determinations).

The petrographic examination of the cores indicated that the control and the Class C fly ash concrete sections incorporating the Shakespeare reactive aggregate suffered from moderate-severe internal damage due to ASR. Typical ASR-related petrographic features of deterioration included the presence of cracks filled with alkali-silica gel in the reactive aggregate particles as well as in the cement paste. Reaction/weathering rims were observed in all cores examined and their frequency could not be correlated with the degree of internal damage due to ASR. The cores incorporating lithium hydroxide monohydrate (91% and 182% of the “standard”/recommended dosage) and 20% class F fly ash did not show significant internal damage due to ASR. The observations obtained from petrographic examination were confirmed by the mechanical testing of companion sets of cores extracted from the various sections of the experimental pavements. The cores from the most damaged sections 5 and 6 indeed displayed high dissipated energy values for the first of the five loading/unloading cycles in the SDT, lower modulus of elasticity and compressive strength values.

The results presented above confirmed that the use of lithium-based products (LiOH 1.0 and 0.5%, Lomar™ admixture) and of about 20% class F fly ash was effective in reducing/controlling expansion and cracking in concrete pavement sections incorporating the highly-reactive NM (Shakespeare) aggregate material after about 16 years in service.

5 REFERENCES

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TABLE 1: Preventive measures used in the Lomas Boulevard experimental pavement. [1]		
Pit	**Section**	**Preventive measure**
Shakespeare	1	1.0% LiOH ([Li]/[Na+K]=1.34 or 182% of the “standard” dosage)
	2	0.5% LiOH ([Li]/[Na+K]=0.67 or 91% of the “standard” dosage)
	3	Lomar™ Admixture (commercial mix (superplasticizer) with lithium)
	4	Class F Fly Ash (20%) (Cholla Generating Station, Phoenix)
	5	Class C Fly Ash (20%) (Tolk Generating Station,Texas Panhandle)
	6	None (Control)
	7	Blend of Class F and C Fly Ash (20% - 50% Class C - 50% Class F) (Escalente Generating Station, NM for the F ash; Tolk Generating Station,Texas Panhandle for the C ash)
Placitas	8	Class F Fly Ash (20%) (Cholla Generating Station, Phoenix)
	9	None (Control)
	10	1.0% LiOH ([Li]/[Na+K]=1.34 or 182% of the “standard” dosage)
	11	Class C Fly Ash (20%) (Tolk Generating Station,Texas Panhandle)

TABLE 2: Petrographic Features and Weighing Factors for the DRI. [3]		
Petrographic feature	**Abbreviation**	**Weighing factors**
		Grattan-Bellew and Mitchell 2006
Crack in coarse aggregate	CrCA	x 0.75
Open crack in coarse aggregate	OCrCA	x 4.0
Crack with reaction products in coarse aggregate	Cr+RPCA	x 2.0
Coarse aggregate debonded	CAD	x 3.0
Reaction rim around aggregate	RR	x 0.5
Crack in cement paste	CrCP	x 2.0
Crack in cement paste with reaction products	Cr+RPCP	x 4.0
Air void lined or filled with reaction products	RPAV	x 0.50

FIGURE 1 : Localization of the Lomas Boulevard experimental concrete pavement in Albuquerque, New-Mexico.

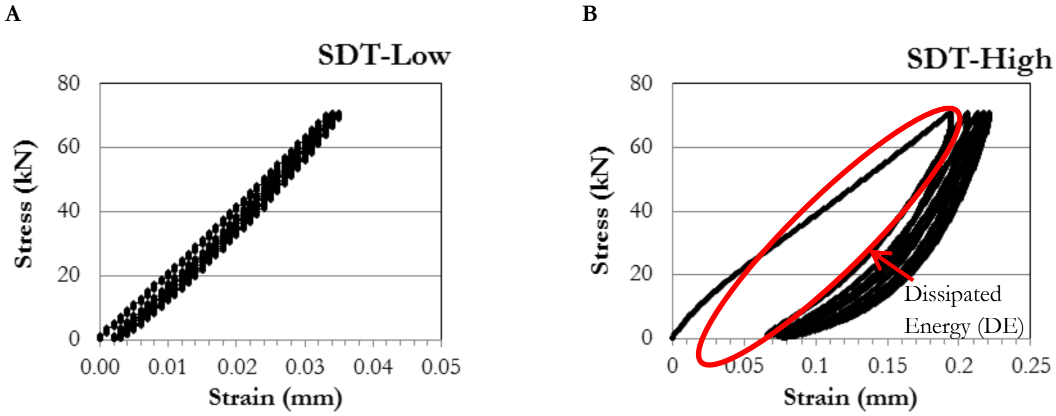
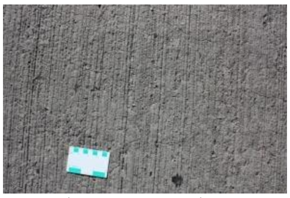


FIGURE 2 : Graphs illustrating typical examples of SDT results for an «undamaged» concrete specimen (A) and a concrete showing significant cracking due to ASR (B). The large hysteresis (area under the curve) for the first of the five loading/unloading cycles in the SDT is typical of internal damage in concrete, in this case caused by ASR.

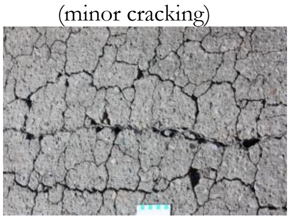


Section 1 : 1.0% LiOH
Shakespeare Pit
(minor cracking)

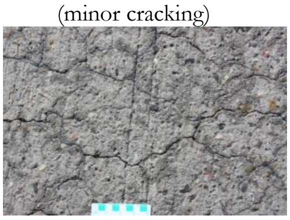
Section 2 : 0.5% LiOH
Shakespeare Pit
(minor cracking)

Section 3 : Lomar™
Admixture; Shakespeare Pit
(minor cracking)

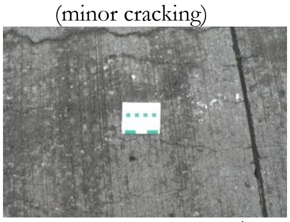
Section 4 : Class F Fly Ash
Shakespeare Pit
(minor cracking)



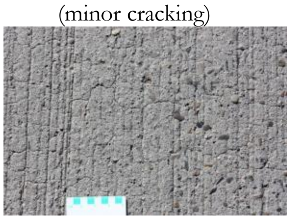
Section 5 : Class C Fly Ash,
Shakespeare Pit
(severe cracking)



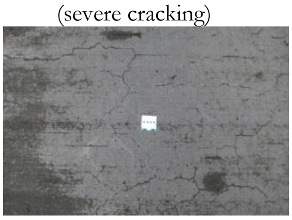
Section 6 : None
Shakespeare Pit
(severe cracking)



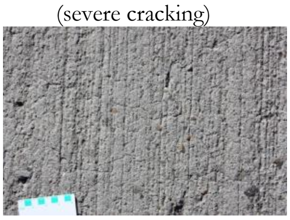
Section 7 : Blend Class F/C
Fly Ash; Placitas Pit
(moderate cracking)



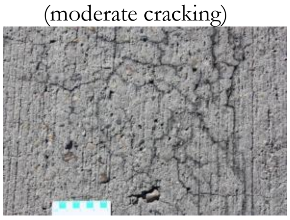
Section 8 : Class F Fly Ash
Placitas Pit
(minor cracking)



Section 9 : None
Placitas Pit
(minor to moderate
cracking)



Section 10 : 1.0% LiOH
Placitas Pit
(minor cracking)



Section 11 : Class C Fly Ash
Placitas Pit
(moderate cracking)

FIGURE 3 : Apparent surface deterioration of the 11 sections of the Lomas Boulevard experimental concrete pavement. Also, the condition rating is provided (from minor to severe cracking).

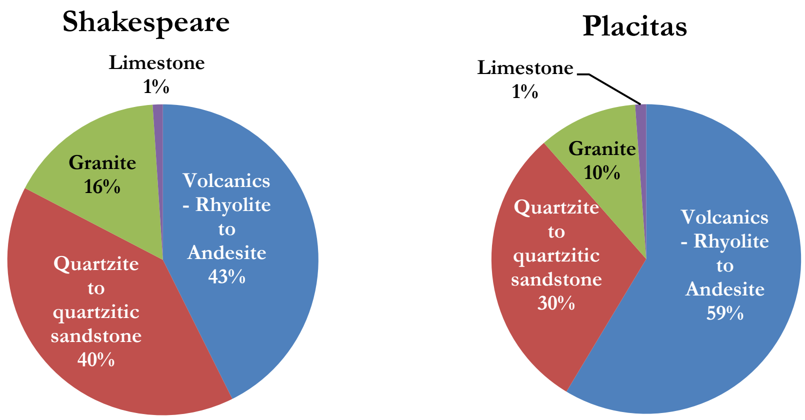


FIGURE 4 : Petrographic facies corresponding to each pit, as seen in cores from the concrete pavement.

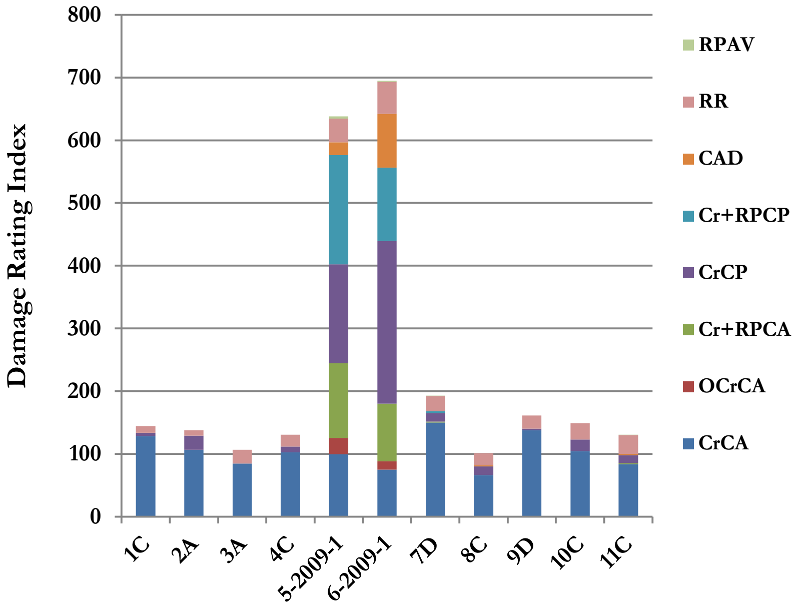
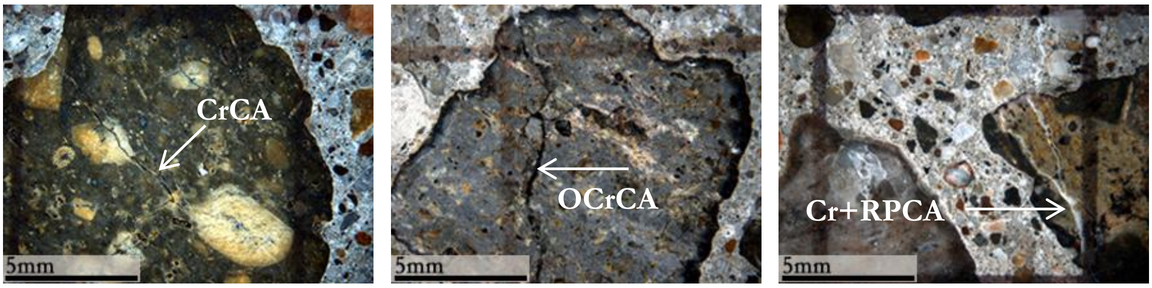
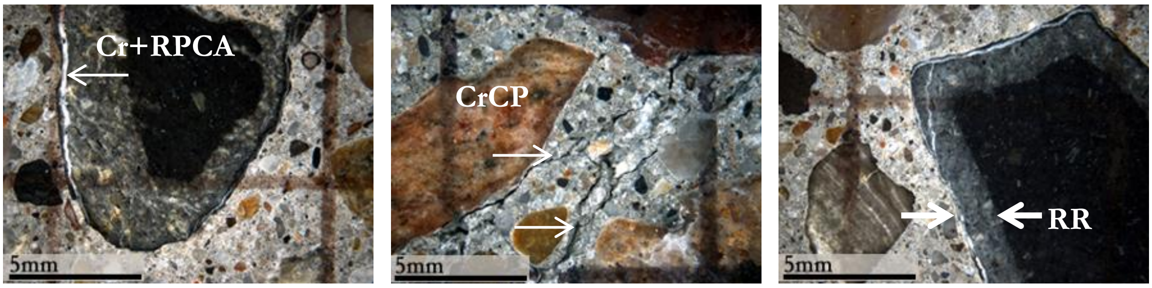


FIGURE 5 : **Damage Rating Index** (DRI) compilation of the concrete pavement sections (see Table 2 for abbreviations of the petrographic features).

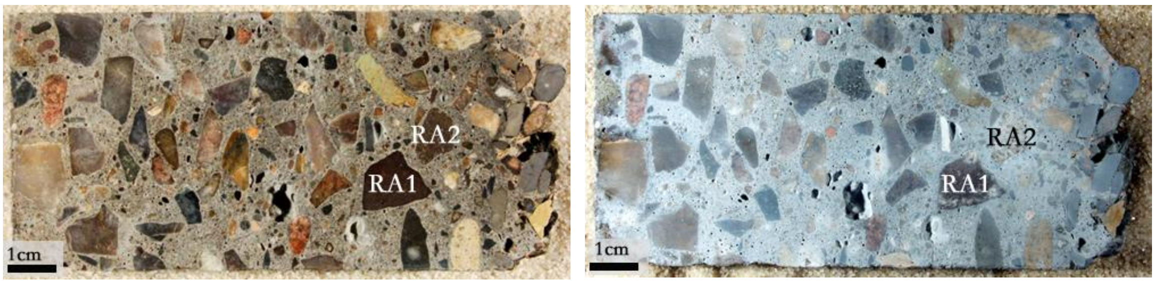


Crack in the coarse aggregate | Open crack in the coarse aggregate | Crack with reaction product in the coarse aggregate

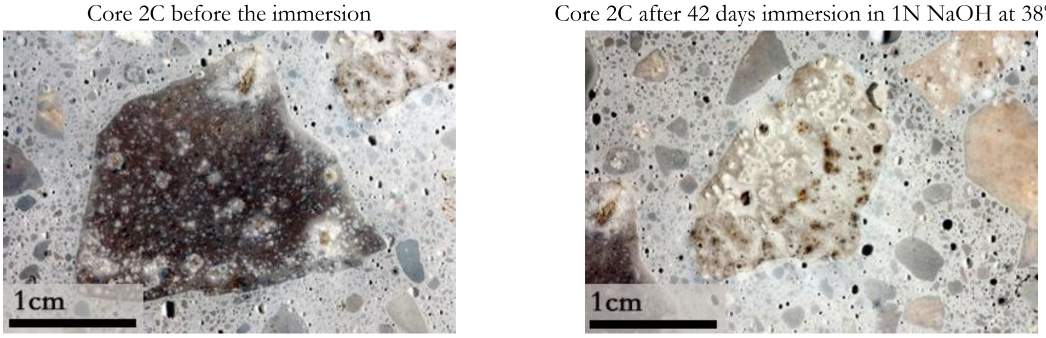


Crack with reaction product in the coarse aggregate | Cracks in the cement paste | Reaction rim on a coarse aggregate

FIGURE 6 : Micrographs showing deterioration petrographic features observed in the experimental concrete pavement cores.



Core 2C before the immersion | Core 2C after 42 days immersion in 1N NaOH at 38°C



Gel deposits on reactive aggregate particle #1 (RA1) | Gel deposits on reactive aggregate particle #2 (RA2)

FIGURE 7 : Identification of reactive aggregate (RA) after GPT.

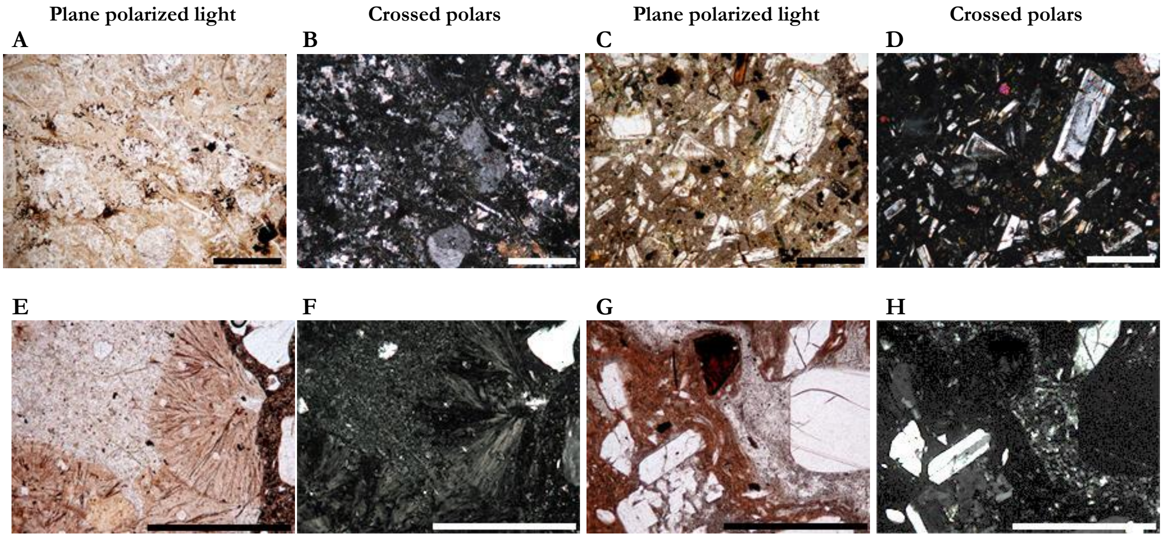


FIGURE 8 : Micrographs of the reactive rock facies as determined by the GPT. A-B: Rhyolite, C-D: Andesite, E-F: Rhyolite with radiating (spherulite) quartz, and G-H: Rhyolite with flowing texture. Scale: 1mm.

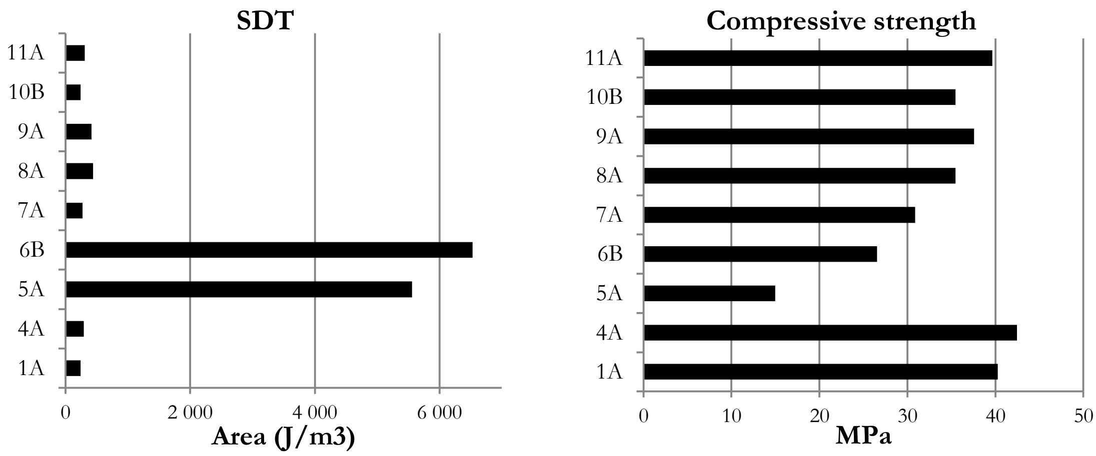


FIGURE 9 : SDT and compressive strength results of core from the different concrete pavement sections.