Long-term effectiveness of sealers in counteracting alkali–silica reaction in highway median barriers exposed to wetting and drying, freezing and thawing, and de-icing salts

Mathieu Champagne, Université Laval, Département de géologie et génie géologique: 1065 avenue de la médecine, Québec (QC), Canada G1V 0A6, mathieu.champagne.8@ulaval.ca

Mélissa Roy-Tremblay, Ministère des Transports du Québec : Secteur matériaux synthétiques et essais spéciaux, 2700 rue Einstein, Québec (QC), Canada G1P 3W8, melissa.roy-tremblay@transports.gouv.qc.ca

Benoît Fournier, Université Laval, Département de géologie et génie géologique: 1065 avenue de la médecine, Québec (QC), Canada G1V 0A6, benoit.fournier@ggl.ulaval.ca

Josée Duchesne, Université Laval, Département de géologie et génie géologique: 1065 avenue de la médecine, Québec (QC), Canada G1V 0A6, josee.duchesne@ggl.ulaval.ca

Benoit Bissonnette, Université Laval, Département de génie civil et génie des eaux: 1065 avenue de la médecine, Québec (QC), Canada G1V 0A6, benoit.bissonnette@gci.ulaval.ca

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INTRODUCTION

Alkali-silica reaction (ASR) is one of the main deleterious processes affecting the durability of concrete infrastructures worldwide [1]. Fortunately, ASR performance test methods improved in such a way that potential reactivity of “most” aggregates is identified prior to their use in concrete. However, many structures around the world were built with reactive aggregates before the risk posed by ASR was recognised and are now affected with severe signs of deterioration [2]. Since the socio-economic impact of replacing such structures is considerable, owners usually seek for efficient and timely repair approaches to maximise the lifespan of such structure. In the case of ASR-affected structures, repair consists of preventing further degradation due to the reaction rather than restoring the concrete to its original state [3]. When possible, the favored repair measure is to prevent any water uptake by the concrete and decrease the internal humidity. For this purpose, different surface treatments like hydrophobic penetrating sealers (silane, siloxane, etc.) [4,5], coatings (epoxy resins, acrylic, polyurethane, etc.) [5,6] or pore-blocking sealers (silicate-based solutions) [7,8] can be applied. These repair measures can be applied at relatively low-cost; however, their long-term efficiency under natural environmental conditions is yet to be verified. This paper is a follow-up study on the effectiveness of some promising sealers that were used to counteract ASR in highway median barriers exposed to environmental conditions in the early 1990’s by Bérubé et al. [4]. This was accomplished by assessing concrete’s condition through petrographic tools.

In 1991, different types of sealers were applied on ASR-affected highway median barriers that had been subjected to severe exposure conditions (wetting and drying, freezing and thawing and de-icing salts applications) since their construction in 1982 [4]. The concrete elements incorporating an alkali-silica reactive limestone started to show signs of deterioration due to ASR between 5 to 10 years after construction. All barrier sections in the zone selected for treatment exhibited a similar surface condition characterized by moderately severe map cracking at the time of treatment. Four ≈6 m-long barrier sections were first sealed with a silane (two), an oligosiloxane and a polysiloxane, while an additional silane treatment was applied in 1994 to one of the barriers previously sealed with silane. Their condition monitoring over 10 years showed that the aesthetic appearance of these median barriers was considerably improved, particularly those sealed with the silane. Furthermore, six years of measurements revealed that internal humidity was significantly reduced and expansion either stopped or decreased.

MATERIALS AND METHODS

In 2016, i.e. about 25 years after their first treatment, a visual inspection was carried out and pictures of the barriers of interest were taken, i.e. the four treated barriers, an untreated barrier and a barrier sheltered by a viaduct. Also, two cores were extracted from each of the above barriers to assess their internal damage. The cores were then split in two and one half polished using a portable wet stone grinder with a range of diamond-impregnated wet resin polishing pads. The polished section was then analysed through the Damage Rating Index (DRI), a semi-quantitative petrographic damage assessment tool developed by Grattan-Bellew & Danay [9].

The Damage Raring Index – DRI

The DRI method is performed with the use of a stereomicroscope (about 15x magnification) where damage features generally associated with ASR are counted through a 1-1.5 cm^2 grid drawn on the surface of a polished concrete section. The number of counts corresponding to each type of petrographic features is then multiplied by weighting factors, whose purpose is to balance their relative importance towards the mechanism of distress (for instance ASR) (Table 1). For comparative purposes, the final DRI value is normalized to a 100 cm^2 area [9]. The weighing factors proposed originally by Grattan-Bellew & Danay [9] were chosen on a logical basis for ASR [10,11]. Following their work, the DRI was performed in many research programs (e.g. [12-15]) to assess the concrete's condition. But, because of the absence of a standard procedure for the DRI, different weighing factors, sample preparations and grid sizes were applied by the authors, thus making direct comparison of DRI results from one study to another quite difficult. The results of a recent intralab variability study on the DRI by Villeneuve et al. [10] encouraged most (if not all) recent studies involving DRI (e.g. [11,16-22]) to apply a new set of weighing factors (Table 1), sample preparation and grid size, in a collective effort towards comparing results from different labs. Furthermore, the reliability of the new procedure was assessed by Sanchez et al. [11, 17, 20], and a DRI damage classification for ASR was proposed by Sanchez et al. [20] and Fournier et al. [23] using Villeneuve et al.'s [10] procedure.

Condition assessment of the median barriers

The extent of surface cracking on the median barriers was assessed by image analysis of a series (≈3) of pictures of the same barrier taken with different angles. The weighted average *total length of cracking* (L_{tot}), i.e the summation of the length of all cracks over the whole area analysed as proposed by Rivard et al. [24], was obtained with ImageJ, an open source image processing program. The pictures were first converted to 8 bits images (shades of grey), scaled (with a measuring tape placed on the barrier before taking the pictures) and reversed to make cracks appear white. A median filter was applied to facilitate cracks detection. The cracks were traced semi-automatically with the Simple Neurite Tracer plugin (Figure 1). To better match the internal damage assessed with DRI, only the upper portion of the barrier section was considered (Figure 1), since the cores were extracted from that part. The L_{tot} (cm/cm^2) is then automatically calculated by ImageJ for a selected surface area.

Table 1: Petrographic features along with the weighing factors used for DRI determination.

Petrographic features		Acronyms	Weighing factor	
			[9]	[10]
Crack in the particles (> 1 mm)	*Closed (without reaction products)*	CCA	0.75	0.25
	Opened or in a fine network (without reaction products)	OCA	4	2
	Opened or in a fine network (with reaction products)	CA + RP	2	2
Crack in the cement paste	*Without reaction products*	CCP	2	3
	With reaction products	CCP + RP	4	3
Debonded aggregate (> 1 mm)		Debon	3	3
Reacted aggregate particle (> 1 mm)		RAP	---	2
Reaction rim (> 1 mm)		RR	0.5	---
Reaction products in voids of the cement paste		RPV	0.5	---

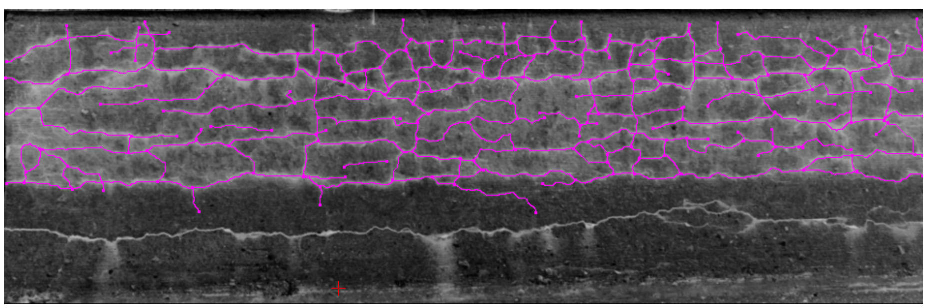


Figure 1: Example of crack tracing using the Simple Neurite Tracer plugin in ImageJ.

RESULTS

Figure 2 showcases the field conditions of a treated (silane) and an untreated barrier section approximately 25 years after treatment. Furthermore, the conditions of the barriers can be compared to the barrier section sheltered from rain (i.e. under the deck of an adjacent bridge). It can be noticed that the field conditions are the best under the bridge deck, which is somewhat surprising because this barrier is still in contact with splashing water from cars during rainy days. It can also be noted that a longitudinal crack appears in the bottom part of all barriers, which is thought to be associated to combined effects of freezing and thawing and rebar corrosion.

Figure 3 displays the full results of the internal damage assessment of the six median barriers obtained with the DRI using Villeneuve et al.'s [10] procedure (weighted average of two cores per barrier section). One can notice a significantly lower damage degree of all treated barriers compared to the control (exposed) one, and this result is even more significant for the barrier treated twice. According to the DRI damage classification for ASR provided by Sanchez et al.

[20], the control barrier is considered “highly damaged”, whereas all treated barriers are “marginally damaged”. Moreover, the cores extracted from the barrier section sheltered from rain shows by far the least damage amongst all, with a “negligible internal damage” due to ASR. Typical microtextural characteristics of ASR affected concrete at the three damage degrees mentioned above are illustrated in Figure 2.

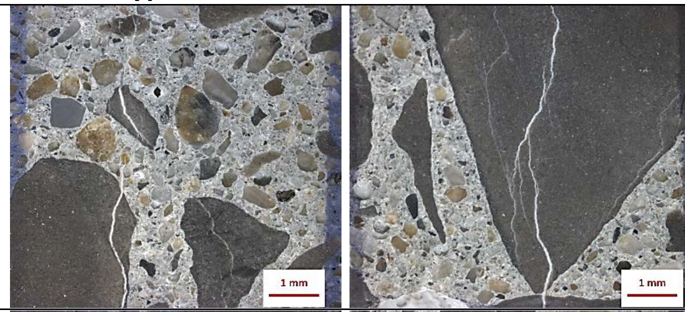
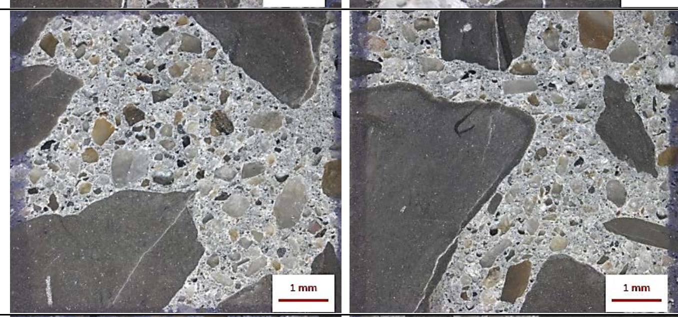
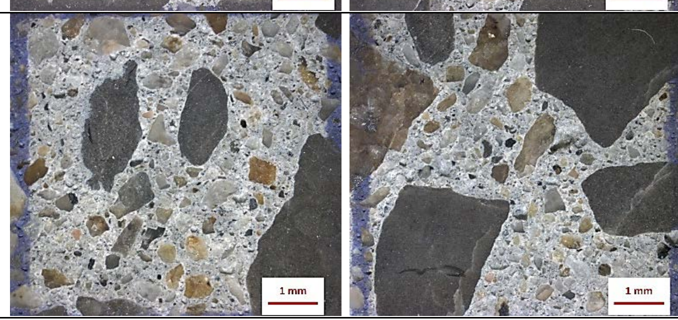
Field Condition	**Typical microtextural characteristics**
 Control	
 Silane	
 Sheltered	

Figure 2: Comparison of the field condition of the control, the silane treated and the sheltered barrier sections, along with typical microtextural characteristics observed at ≈15x.

Figure 4 shows a good correlation between the surficial and internal conditions of the barrier sections assessed in this study. However, this correlation is based on only six barriers, which is not enough to provide appropriate conclusions based on the correlation coefficient. According to the L_{tot} measured, the silane-treated barriers still show less visual cracking compared to the other treated barriers.

CONCLUSION

The results obtained in this study indicate that, more than 25 years after their first treatment, all treated median barrier sections show significantly lower visual (external) and internal damage than the control (exposed) median barrier section. Among all assessed barrier sections, the one sheltered from direct rain fall under a bridge deck was significantly less affected by ASR than the others. Furthermore, the silane-treated section still shows less visual cracking than the oligosiloxane/polysiloxane-treated sections.

A new crack mapping assessment method was developed in this study using image analysis. Based on the results obtained by comparative condition assessments with image analysis and DRI, this tool is promising and encourages further development as it is much less time-consuming, easy to apply and does not require to extract cores from the concrete element.

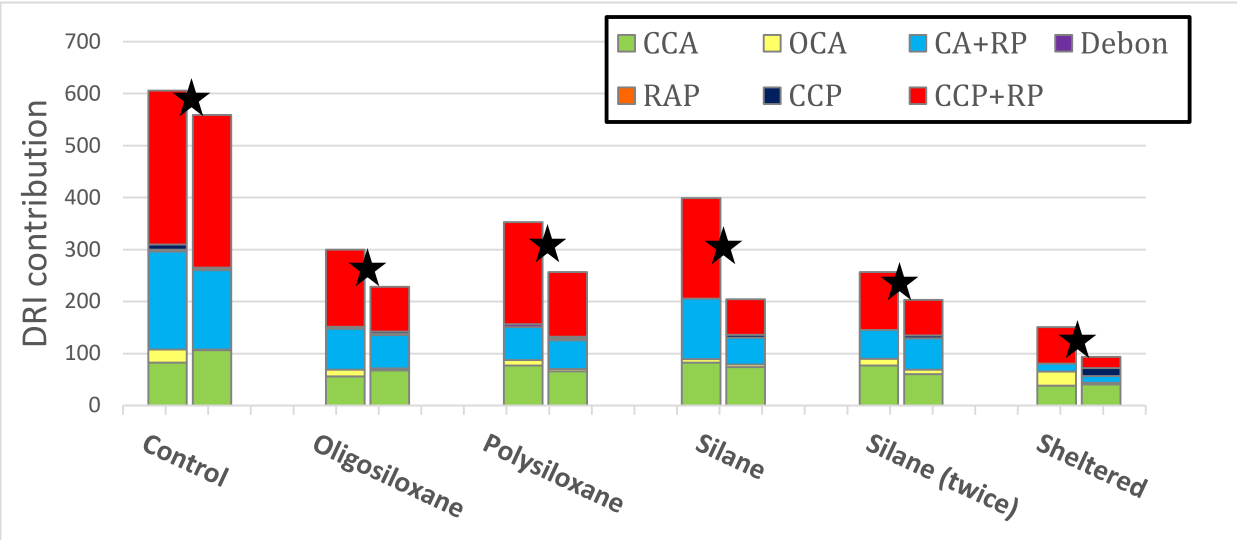


Figure 3: Internal damage assessment of all cores (two per section) displayed as DRI bar charts showing the contribution of each petrographic features; the black star indicates the average DRI values for each set of cores from the different barrier sections. The acronyms are defined in Table 1.

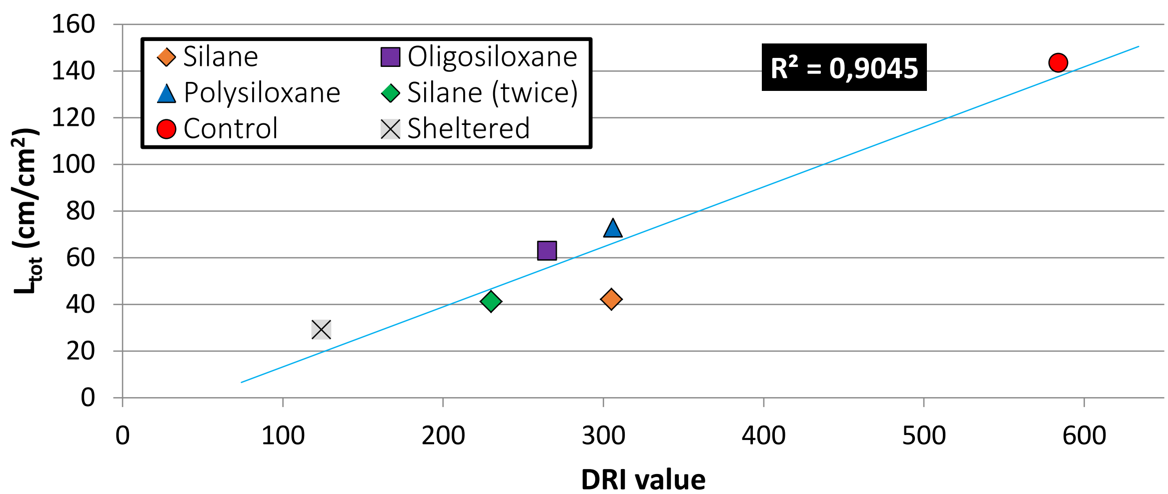


Figure 4: Comparison of the crack mapping in the form of total length of cracking determined by image analysis and the internal damage determined by DRI.

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