

## Alkali-Carbonate Reaction Concrete Prism Test Samples – Macroscopic Petrography and Damage Evaluation through the Damage Rating Index Method

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### Abstract

Extensive research has been done regarding ACR since its discovery in the 1960s in Kingston, Ontario, Canada. ACR is a complex reaction mechanism that has drawn the attention of many researchers around the world, despite its scarce occurrence. More and more followers agree on the presence of ASR in ACR-susceptible or ACR-reactive rocks recently, especially since it was first suggested that ACR is possibly a different form of ASR in the 1990s.

In order to contribute to the above debate, several laboratory samples (Concrete prism test, CPT, CSA A23.2-14A) from different ACR-susceptible rocks in Canada and China were provided to the authors to add supplementary observations to already published work on the matter and to the current global ACR investigative program started earlier.

At the end of the 1-year testing period, prisms from the past study were cut in half in the length axis and polished using progressive diamond coated pads until mirror polish was obtained. Following DRI procedure, a 1cm square grid was drawn onto the surface for DRI determination according to the modified method. DRI was then measured on each of the 8 samples. As expected, high DRI values were obtained from the most ACR-susceptible aggregates from the Pittsburg quarry in Kingston, Ontario (also showing the highest expansions at 1-year) (i.e., Pit-16, Pit-15 and Pit-6, in that respective order) with lesser DRI values for other levels and the Chinese aggregate, the latter showing low to very low damage evaluated by DRI. DRI values obtained showed good correlations with expansions reached.

Abundant deposits of secondary reaction products, which are thought to correspond to calcite and brucite were identified mainly in the Pit-15, 16 and 6 (cracks in aggregates and cement paste). Increasing occurrences of the above features were found with increasing concrete prism expansion. It may play more than a secondary role in the expansion process of Kingston-bearing concretes. Even in renowned ACR reactive rocks (Pit 15, 16 and 6), ASR plays a significant yet secondary role (30%) in the overall reaction.

**Keywords:** ACR, ASR, DRI, Macroscopic petrography, Reaction mechanisms

### 1. INTRODUCTION

Alkali-carbonate reaction (ACR) is a complex reaction mechanism that has drawn the attention of many researchers around the world, despite its scarce occurrence. It usually involves dolomitic limestones that react promptly in concrete (within 3 years) forming extensive cracking and distress. More questions than answers often arose from past investigations, and still much debate about the basic mechanisms involved is going on.

Besides the fact that a recent review and a recent study are suggesting that ACR is obviously ASR [1] and some work on field concretes [2] susceptible to ACR but renowned to be ASR reactive, the current knowledge still opposes two to three main/distinct theories to explain the reaction/expansion mechanism(s) in ACR. The first one [3], introduced more than half a century ago, suggests that the clay mineral *illite* disseminated in the reactive limestone, although of non-swelling-type, is responsible for the deleterious expansion. It is suggested that the *dedolomitization* of dolomite rhombs, also present in the rock matrix, is contributing to the process by opening channels/access for moisture and ionic species into the rock, thus causing expansion of the above clay mineral [3]. The second theory, introduced almost 30 years ago by Tang et al. [4], states that the reorganization of the products of *dedolomitization* results in deleterious expansion around reacting dolomite crystals in the rock matrix. In addition to the above, the last theory that was first introduced almost 30 years ago, states that ACR is only a form of alkali-silica reaction (ASR) involving cryptocrystalline quartz disseminated in the rock matrix [5-7]. Since

then, other researchers have supported the idea [8]. Nevertheless, many questions on whether ACR, ASR or both are present in ACR-susceptible rocks are still unsolved and need to be further investigated. Amongst other work conducted in past years, Princic et al. [9] observed very interesting calcite rims around reportedly ACR case in Slovenia. Scaglione and Piercey [10] also reported lately that a specific dolomitic limestone aggregate in Missouri (USA) showed both classic ACR and ASR in the same rock. These will be discussed further in the present paper.

In order to contribute to the above debate, several laboratory (Concrete Prism Test - CPT) specimens incorporating different ACR-susceptible rocks from Canada and China were studied by the authors to add supplementary observations to already published work on the matter [11-12] and to the current global ACR investigative program mentioned in [13].

Research work has been conducted and data generated on those specimens accompanied by macroscopic petrographic characterization and DRI determination of the ACR-susceptible concrete specimens which showed valuable insights.

## 2. SCOPE OF WORK

As part of a global investigative program, CPT prisms from a past study [11-12] were analyzed by macroscopic petrography and Damage Rating Index (DRI) method to complement the already obtained results. Carbonate rocks (limestones and dolostones) from different levels of the Pittsburg quarry from Kingston (Ontario, Canada) and dolostones from a suspected case of ACR in China were tested for one year in the CPT and examined macroscopically on sawn polished sections for DRI determination through the use of a stereobinocular. A comparison of the damage features/reaction mechanism, including their extent/texture and the type and presence of reaction products, was conducted. Interpretation of the observations was then accomplished to better understand the reaction mechanisms involved and complement other ongoing research work.

This program aims to provide information on the following issues:

- Is expansion measured in the CPT test procedure related or not to ACR/ASR reaction in concrete and to what extent ?
- Which aggregate generates the most damage in concrete within the ACR susceptible selected aggregates ?
- Is there a correlation between the expansion measured and the DRI observations ?
- Is there a correlation between the petrographic observations and the results of other ongoing research works on ACR (global program) ?
- Which aggregates within the selected group show distinct signs of ACR/ASR or combination of the above ?

This paper summarizes and compares the results obtained from these laboratory investigations to some other research work conducted by the same authors.

## 3. MATERIALS AND METHODS

### 3.1 Materials and mix designs

As part of a past study [11-12], CPT specimens were cast incorporating ACR-susceptible aggregates following CSA A23.2-14A procedure (equal parts of 20-14mm, 14-10mm and 10-5mm, total cementitious materials content at 420 kg/m<sup>3</sup>, high alkali cement of 0,91% Na<sub>2</sub>O<sub>eq</sub>, 0.42 water/cement, 1.25% Na<sub>2</sub>O<sub>eq</sub> by NaOH addition) [14]. From those mixtures, the renowned ACR-reactive limestone from Kingston, Ontario was used. It is a dolomitic limestone from the Gull River formation exploited in the Pittsburg quarry ((Pit 16, Kingston, retrieved by a group led P.E. Grattan-Bellew in the 1990s and stocked at CANMET [11]) (typical ACR) [15]). Other dolomitic limestone aggregates from the same quarry (different levels, [11]) and from other locations around the world were also casted into prisms using the same procedure. More details on the mix designs are available from [11-12]. Concrete mixtures incorporated Pit-13, 14, 15, 16, 17, 6, 6 +CH-6 and CH-2 aggregates. "Pit" correspond to different stratigraphic levels within the Pittsburg quarry, while Pit-6 is a blend of all of the above other Pit aggregates). CH aggregate is a dolomitic limestone from China [11-12], while Pit-6 + CH is a 50/50 blend of Pit-6 and CH aggregates into the coarse fraction of the concrete [14].

### 3.2 Methods for assessment and analysis

#### 3.2.1 Expansion testing

All aggregates from the past studies [11-13] were cast into test prisms, 75 x 75 x 300 mm in size. After 24 hours in their moulds, the specimens were demoulded, their initial length determined, and then placed at 38°C and R.H. > 95%. Their length change was monitored regularly over a 52-week period for [11-12] and then for more than 6-7 years for [13] and ongoing. Specimens were then retrieved for analysis at the end of the 52 weeks testing period for [11-12] and only 1 prism at specific expansions (different expansion depending on the mix) for [13].

#### 3.2.2 The Modified DRI method [16]

At the end of the one-year testing period, the prisms from [11-12] were cut in half longitudinally and one side polished using abrasive magnetic pads (up to 3000 grit) and minimum water as a lubricant until mirror polish was obtained. This method ensure no or minimal polishing residues (slurry) stays in the concrete pores or cracks after final polishing.

The *Modified DRI method* is based on the original and revised DRI method by P.E. Grattan-Bellew and co-authors [17-19]. Since then, several authors used and modified the method slightly [16, 19-21]. The *modified DRI method* [16] consists in a count, under the stereomicroscope ( $\approx 16\times$  magnification), of the number of petrographic features of deterioration commonly associated to ASR (Table 3.1) on polished concrete sections on which a grid is first drawn (1 by 1 cm in size). The *DRI* thus represents the normalized value (to 100 cm<sup>2</sup>) of the frequency of these 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 (Table 3.1). A minimum of 200 cm<sup>2</sup> were examined for each sample. DRI was then measured on each of the eight samples. Polished slabs were then photographed macroscopically and microscopically to illustrate the different features identified. Table 1 incorporates a new feature selected for ACR as it occurs quite often especially when high levels of expansion are reached (Calcite Rim at the ITZ, CAR). In the present study, calcite or silica gel (as reactions products) were counted equally as RP in CA+RP and CP+RP counts.

Table 3.2: Petrographic features and weighing factors [16] and modifications with present study observations.

Features		Abbreviation	Weighting factor
Features quantified during DRI determination	Closed/tight crack in coarse aggregate particle	CCA	0,25
	Opened crack or network cracks in coarse aggregate particle	OCA	2
	Crack or network cracks in coarse aggregate with reaction product	CA+RP	2
	Crack in cement paste	CCP	3
	Crack in cement paste with reaction product	CP+RP	3
	Coarse aggregate debonded	CAD	3
Qualitative observations	Reaction Rim*	RR	--
	Void filled or lined with reaction products*	VCP+RP	--
	Calcite Rim in at the ITZ*	CAR	--

\* Only noted to gather evidence of reaction but not counted in the DRI number

## 4. RESULTS

### 4.1 Expansion of the selected aggregates in CPT (CSA A23.2-14A)

Figure 4.1 (borrowed from [12]) shows the expansion over time for all concrete prisms incorporating the dolomitic limestones and control ASR aggregate (Spratt limestone from Ottawa, Canada) (ACR vs ASR) investigated. As explained above, “Pit” samples are different levels within Pittsburg quarry except Pit-6 which is a blend corresponding to the regular aggregate from the quarrying operations. CH is a dolomitic limestone from China [11] and SP is the Spratt limestone renowned for ASR [22]. Each curve represents the mean expansion obtained from three prisms by mixture.

High variations in expansions were obtained at one year depending on the aggregate and level within the Pittsburgh quarry. It can be seen from the plot that some mixtures are still below the 0.040% expansion limit at one year (Pit-14, 17 and 18), while others are close to very close to the limit (Pit-13 and CH). The Spratt control mix is, as expected, very reactive at almost 0.28% expansion at one year. The Kingston control mix (Pit-16) is at approximately 0.61% expansion at one year, which is more than two times the expansion of the Spratt limestone at the same age.

As a reference and for discussion below, mixtures used in a previous study [13] but updated at  $\approx 2500$  days (6-7 years) are shown in Figure 4.2. It shows the expansion curves over time for Spratt and Kingston (corresponds to Pit-16) limestones and reaction types (ACR vs ASR). The dashed (blue) curves are for the Spratt limestone and thick (red) curves for the Kingston limestone. Each curve represents the mean expansion obtained from three prisms until retrieval of one prism from Kingston SCMs mixtures for petrographic examination [13]. Therefore, the expansion of test prisms from Kingston mixtures incorporating supplementary cementitious materials (SCMs) is the mean of two prisms between 334 and 378 days of testing (50% FA = 334 days, 40% GGBFS = 341 days, 30% FA = 349 days and 70% GGBFS = 378 days) and the last measurement (still in progress). In fact, very similar expansion values were obtained on each SCM prism before retrieval of one prism, so it is believed that the mean was not affected significantly. The horizontal dashed (green) line is the non-reactive threshold of 0.040% expansion level.

It can be seen from the plot that most of Spratt + SCMs mixes are still below or close to the 0.040% expansion limit at  $\approx 2500$  days (except 30% FA). The expansion of the prisms from the Spratt control mixture has, as expected, levelled off at about 0.24% expansion (alkali leaching effects). The expansion of the test prisms from the Kingston control mixture has also levelled off but at about 0.62% at over 2500 days, which is more than 2.5 times the expansion of the Spratt limestone at similar age.

The Kingston control and SCMs mixtures show different expansive trends, with a slightly slower onset of expansion for the SCMs mixtures compared to the control; however, most of the Kingston + SCMs prisms eventually expanded more than the control specimens, i.e. 30% FA, 40% GGBFS and soon 50% FA. For Kingston 70% GGBFS, it seems that the high slag dosage largely reduced the expansion compared to the control specimens and other SCM mixtures but, still, the expansion is well over the 0.040% limit and more than 0,1% over that of the Spratt control mixture.

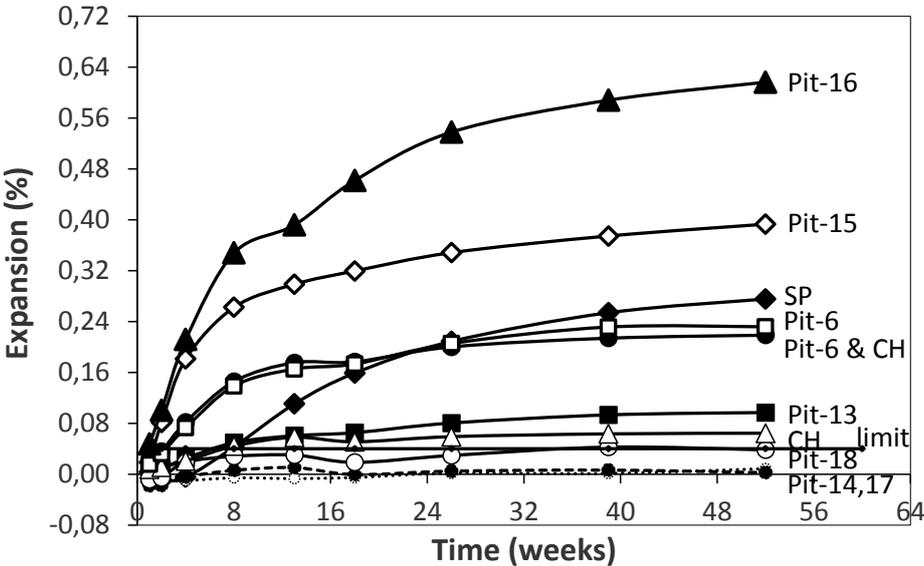


Figure 4.1: One year final concrete prism expansion results for the various aggregates investigated (Graph adapted from [12]).

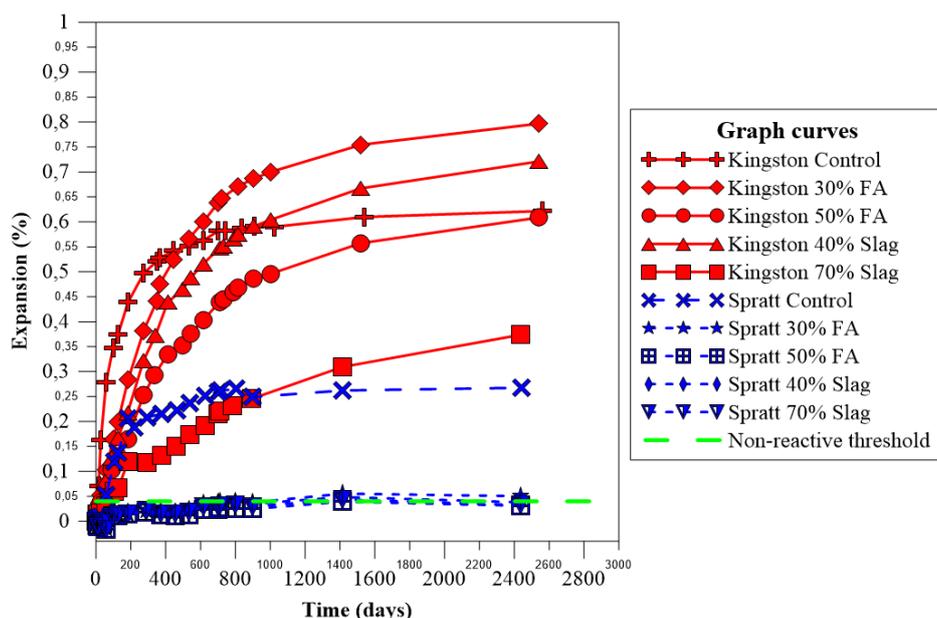


Figure 4.2: Expansion (%) as a function of time for concrete specimens made in accordance with CSA A23.2-14A and 28A, and incorporating Kingston (Pit-16) and Spratt reactive limestones (control, with fly ash (FA) or ground granulated blast-furnace slag (GGBFS)). Graph expanded from [13].

## 4.2 DRI and macroscopic petrography on the selected samples

Table 4.1 shows the CPT specimens tested along with the DRI measured and expansion at one year (%). We can definitely observe that, in general, the higher the one-year concrete prism expansion the higher the DRI value. The highest DRI value were obtained for the Kingston Pit-15, Pit-16 and Pit-6. This is not surprising considering their renowned ACR reactivity (Pit-15 and 16 are the most reactive levels within first lift of the quarry [11] with Pit-16 being the most reactive; Pit-6 is a blend (quarry run) of all first lift including Pit-15 and 16.

Table 4.1: DRI and 1-year expansion measured on CPT samples tested.

Identification of CPT sample	DRI measured (Villeneuve et al. 2012)	1-year expansion (%)
CH	165	0.064
Pit-6 with CH	689	0.219
Pit-6	908	0.232
Pit-13	393	0.097
Pit-14	237	0.009
Pit-15	1124	0.393
Pit-16	1477	0.616
Pit-17	59	0.003

ACR damage features are associated to yellowish reaction products (mainly associated to secondary calcite) within cracks in both cement paste and coarse aggregate particles, with more commonly seen empty open cracks in the latter. Moreover, calcite rims at the ITZ are often seen around ACR “reacted” aggregate particles. Numerous cracks are also often seen in the cement paste compared to cracks in the aggregate particles, which are usually empty when there is only ACR. ASR damage features are most of the time linked to the presence of ASR gel (white to translucent) both in cracks of the cement paste and in the coarse aggregate particles and sometimes filling voids in the cement paste (although not counted in the latest modified DRI [16]). Reaction rims (also not counted in latest DRI procedure) are present in both types of reaction and then not associated to one specific reaction type.

Table 4.2 shows the DRI features details along with the total DRI number. It also shows different qualitative observations as signs of ASR/ACR in addition to Notes regarding the observations completed during DRI determination. First of all, it is interesting to observe that Pit-16, Pit-15, Pit-6 and Pit-6+CH-6, in that respective decreasing order, show the highest DRI values of all samples. They are the most ACR-susceptible rocks within the selection. It is also possible to realize that blending Pit-6 with the Chinese aggregate (50/50) lessens the damage generated by the reaction despite somewhat similar concrete prism expansions (this point will be discussed further in the section below). Focusing on the ASR/ACR signs and notes (other phenomena will be better described in Figure 4.3), also it is suggested that little reaction (at all, ACR or ASR) is observed in Pit-13 and Pit-17 specimens, while very little signs of reaction are found from the prism incorporating CH Chinese aggregate (ACR and ASR are both seen scarcely). Also, specimens Pit-6, Pit-15 and Pit-16 all show very similar percentages of what can be associated to ACR- or ASR-type features of damage. More signs of ACR are present compared to ASR signs (70/30%), determined visually. Pit-6 + CH interestingly show more ASR signs than ACR signs within the sample compared to only Pit-6 (discussed further below). Pit-14 sample show very little signs of ASR reaction only.

Table 4.2: DRI number details measured on CPT specimens tested and associated notes .

Identification	Pit-17	Pit-16	Pit-15	Pit-14	Pit-13	Pit-6 + CH	Pit-6	CH
<b>Dri number</b>	<b>59</b>	<b>1477</b>	<b>1124</b>	<b>237</b>	<b>393</b>	<b>689</b>	<b>908</b>	<b>165</b>
CCA	16	36	26	25	17	34	27	25
OCA	20	384	144	0	23	73	145	19
CA+RP	12	192	348	195	170	278	278	104
Debon	3	6	16	0	4	10	31	0
RAP	0	2	1	0	0	0	0	0
CCP	7	574	466	14	141	226	290	17
CCP+RP	0	283	123	3	39	69	136	0
RR	91	81	82	0	82	66	59	5
RPV	24	40	20	50	90	41	73	9
Signs of ASR (%)	0	30	30	2	10	90	30	2
Signs of ACR (%)	0	70	70	0	0	10	70	2
<b>Notes</b>	N/A	Gel in pores	Gel in pores	N/A		Some calcite rims but much more ASR signs	Much more ACR and some ASR signs	Especially in yellow aggregates

The bar chart in Figure 4.3 show the different proportions of the damage features and the DRI values associated for each sample tested. The Spratt 0.2% expansion (classic ASR) bar from the same figure was imported from [13] for comparison and discussion to the current study results. It is interesting to note that Pit-15, 16 and 6 samples show distinct difference in quantity of CA+RP and OCA as well as in the quantity of cracks in the cement paste in general (however not as same expansion level) compared to Spratt 0.2%. For similar expansion levels. Pit-6 and Spratt 0.2% show notable differences in almost all features but especially distinct differences in the quantity of CA+RP and CCP.

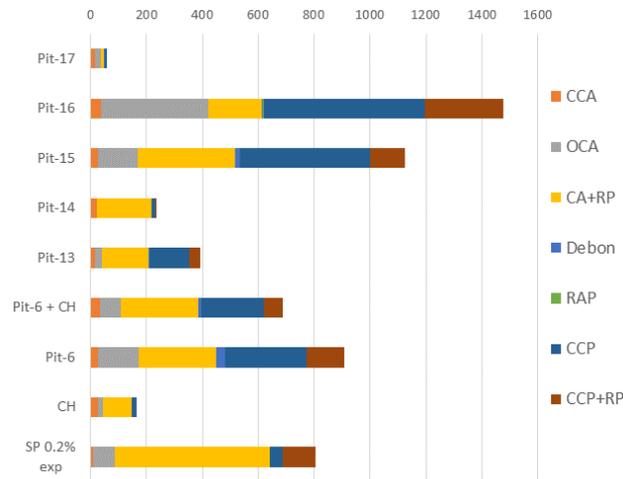
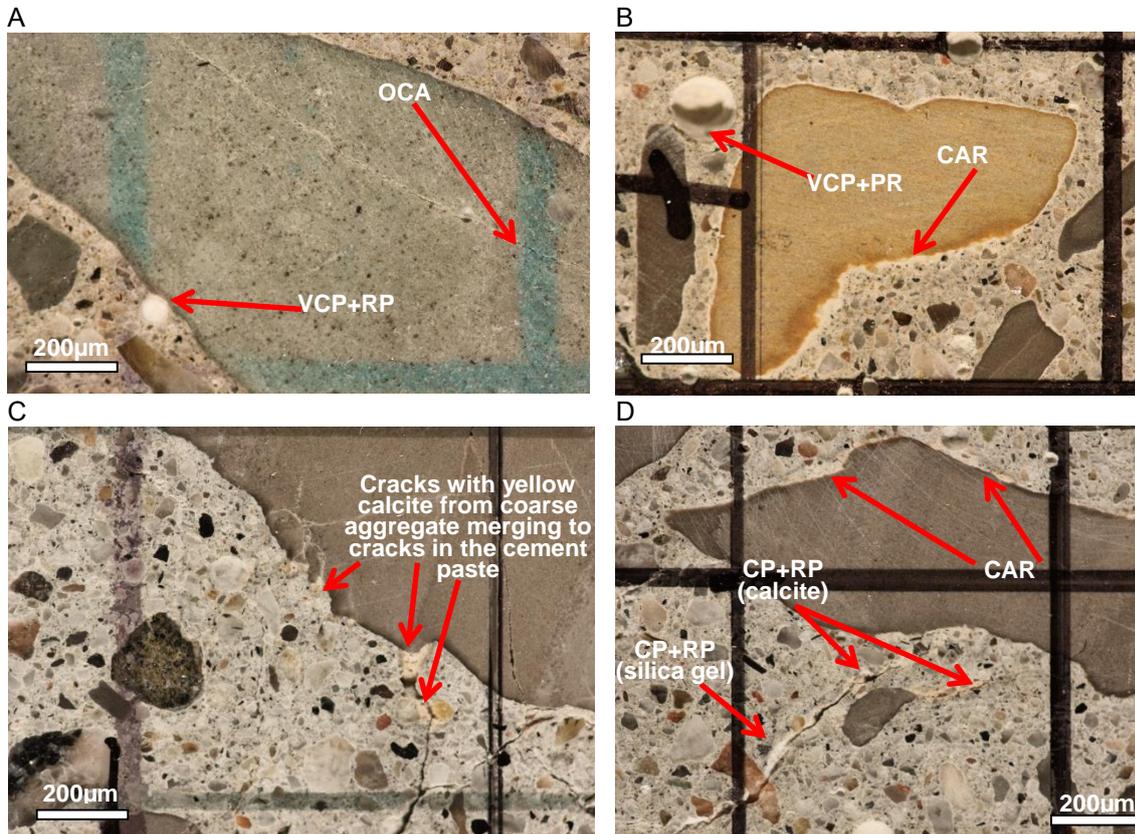


Figure 4.3: Bar chart of DRI results (CCA : Closed crack in aggregate particle; OCA: Open crack in aggregate particle; CA+RP: Crack in coarse aggregate particle with reaction products; Debon: Debonded aggregate particle; RAP: Reacted aggregate particle; CCP: Crack in the cement paste; CCP + RP: Crack in the cement paste with reaction products).

Figures 4.4 and 4.5 show micrographs of damage features identified in the different test specimens examined. Features and association to ACR or ASR reaction within the samples are described in the legend of the micrographs. What is most interesting to note is that Pit-6, Pit-15 and Pit-16 (especially high occurrences compared to aggregates from the other stratigraphic levels of the Pittsburgh quarry) show calcite rims at the ITZ and impregnation with secondary calcite of the paste besides cracks in the (cement) paste. The width of the above “impregnated” zone usually increases with increasing expansion. All samples show little to moderate signs of ASR (voids lined with gel and cracks filled with gel, both in coarse aggregate particles and in the cement paste). Spratt 0.2% (Figure 4.4 E and F) micrographs show moderate to high signs of ASR (CA+RP, CP+RP and VCP+RP, with silica gel only) compared to other samples of the present study.



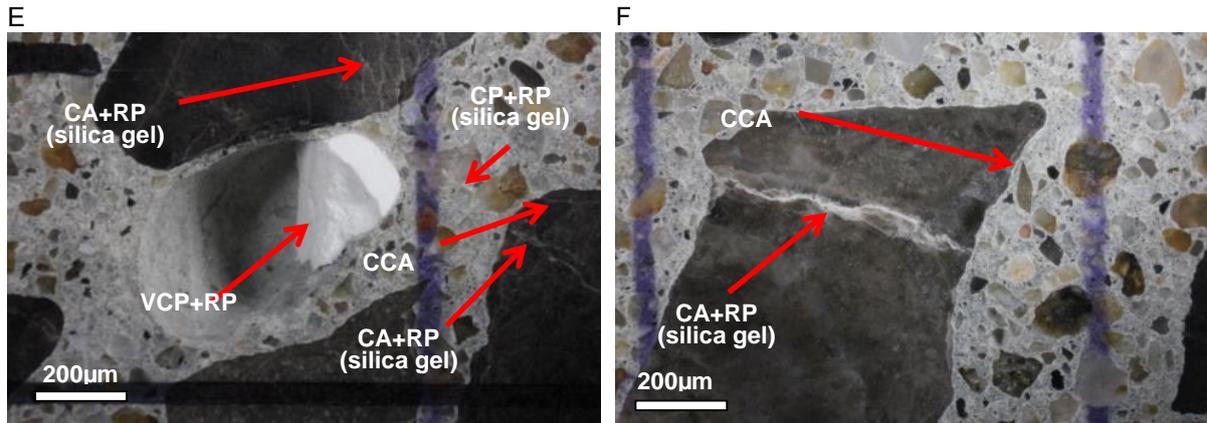
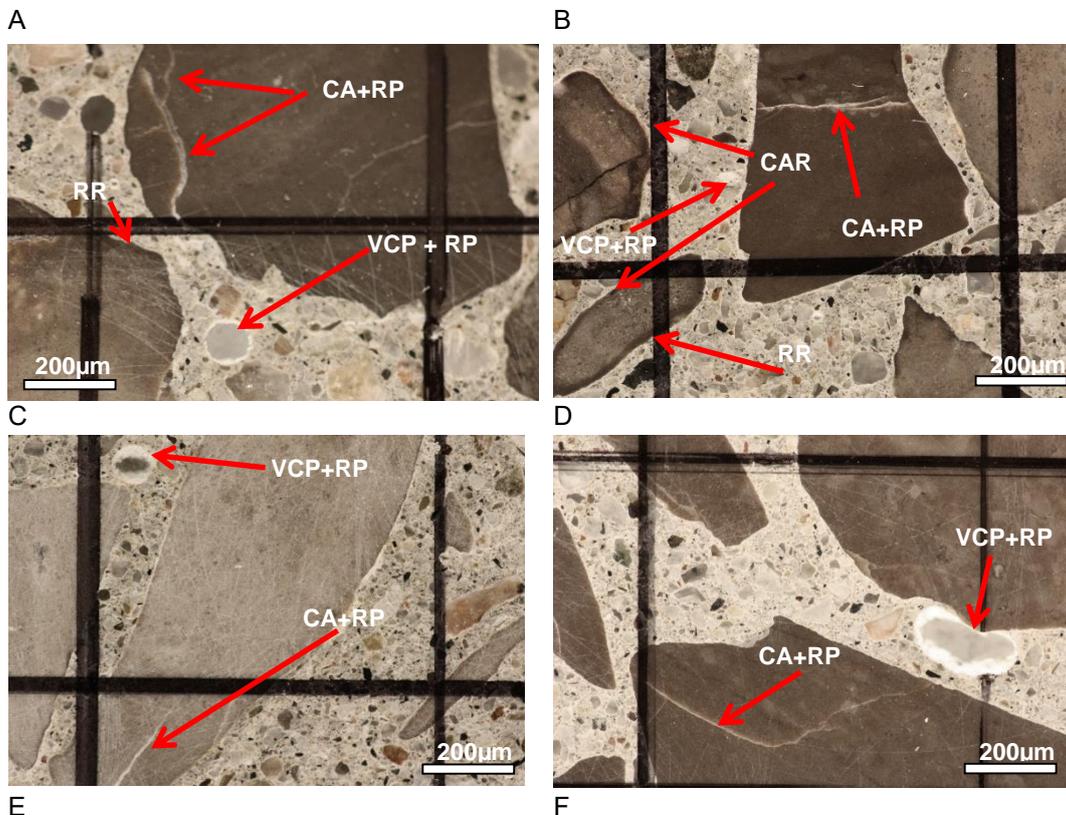


Figure 4.4: Petrographic features observed in the selected CPT specimens; **A**: Open crack in the coarse aggregate particle (OCA) and a void filled with silica gel (VCP+RP) in sample Pit-17; **B**: Calcite rim at the ITZ of a coarse aggregate particle (CAR) and a void lined with silica gel (VCP+RP) in sample CH; **C**: Crack in the cement paste with secondary calcite (yellow) originating from the coarse aggregate (CP+RP) in Pit-15 sample; **D**: Cracks in the cement paste with secondary calcite (yellow) originating from the coarse aggregate particle (CP+RP) and with silica gel (whiter below) and calcite rim at the ITZ in the cement paste (CAR) in Pit-16 sample. **E**: Cracks in the aggregates with reaction products (CA+RP, silica gel), in the cement paste with reaction products (CP+RP, silica gel), closed crack in the aggregate (CCA) and reaction product (RP, silica gel) in the sample Spratt 0.2% (from [13], **F**: Crack in the aggregates with reaction products (CA+RP, silica gel) and closed crack in the aggregate (CCA) in the sample Spratt 0.2% (from [13]. Please note that not all phenomena present are indicated in each of the micrographs to ensure emphasis is clearly given to the phenomena that the authors want to highlight.



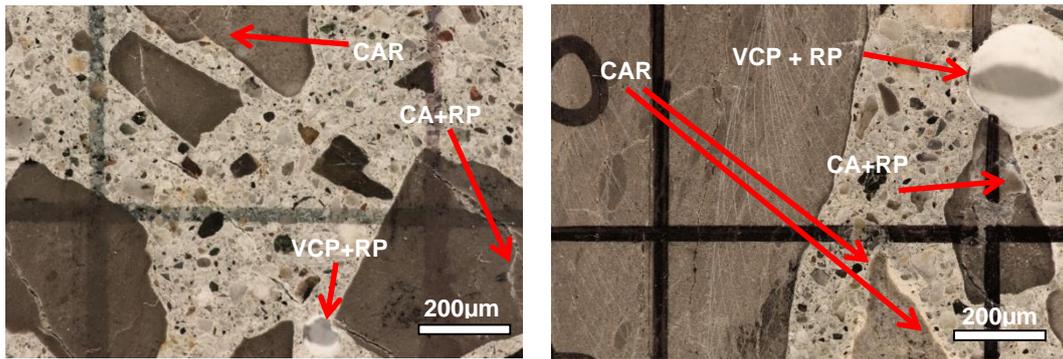


Figure 4.5: Petrographic features observed in the selected CPT specimens; **A:** Reaction rims at the interior edge of a coarse aggregate particle (RR), a pore lined with silica gel ((VCP + RP) and some white cracks (filled with silica gel) in a coarse aggregate particle (CA+RP) in specimen Pit-6; **B:** Calcite rims at the ITZ of two coarse aggregate particles (CAR), a crack in a coarse aggregate particle with reaction products (likely calcite in this case, yellowish) (CA+RP), a void filled with silica gel (VCP+RP) and a reaction rim (RR) in specimen Pit-6+CH; **C:** Crack in a coarse aggregate particle filled with silica gel (CA+RP) and void lined with silica gel (VCP + RP) in specimen Pit-13; **D:** A crack filled with silica gel in a coarse aggregate particle (CA+RP) and void lined with silica gel in the cement paste (VCP+RP) in specimen Pit-14; **E:** Yellowish calcite rim at the ITZ of a coarse aggregate particle (CAR), a crack in coarse aggregate particle with reaction products (CA+RP) and a void lined with silica gel (VCP+RP) in specimen Pit-15; **F:** A calcite yellowish rim at the ITZ around a coarse aggregate particle (CAR), a void lined with silica gel (VCP+RP) coming from a nearby coarse aggregate particle showing a crack lined with silica gel (CA+RP) in sample Pit-16. Please note that not all phenomena present are indicated in each of the micrographs to ensure emphasis is clearly given to the phenomena that the authors want to highlight.

Figure 4.6 shows two micrographs taken from a polished slab obtained from a field (core) sample from MTO's (Ontario DOT) experimental sidewalk in Kingston, Ontario, incorporating a blend from the first lift of renowned Pittsburg quarry (Kingston, Ontario). The three pictures (A being a larger view of the slab, B a close up of A with the same picture with a treatment to enhance visibility of the calcite rim, side by side) display the same calcite rim showed previously at the ITZ of coarse aggregate particles.

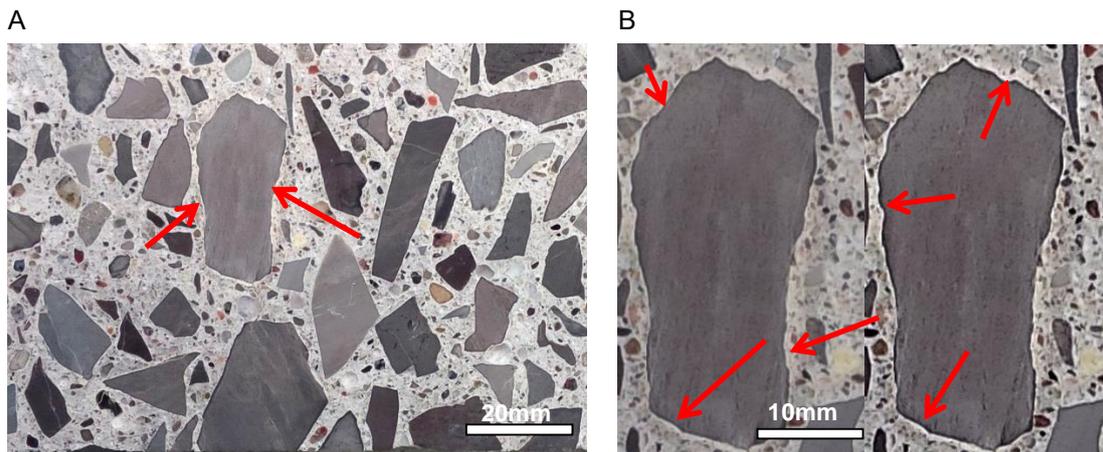


Figure 4.6: Pictures of a polished slab sample (Slab 1, Core 1A) of the MTO's experimental sidewalk in Kingston, Ontario, incorporating Pittsburg quarry-run aggregate (blend of the full height of the first lift of the quarry including the different levels mentioned above (Pit-13 to Pit-17) renowned for ACR). **A:** Picture showing a coarse aggregate particle with a yellowish rim at the ITZ, **B:** Two close-up views of the aggregate particle shown in A where, on the left, there is no treatment on the picture and on the right, there is a brightness treatment to enhance the presence of the calcite rim (white/yellow all around the particle) at the ITZ.

## 5. DISCUSSION

From the experimental data presented in the previous section (Figure 4.1 + Table 4.1 and 4.2), it is possible to mention that Pit-14, Pit-17, CH, and to a lesser extent Pit-13, show no significant signs of ASR nor typical signs of ACR. Those rocks are considered very marginally reactive compared to other rocks examined in the present study based on DRI observations, even if some showed 0,097% expansion at 1-year. However, it is interesting and important to note that Pit-6 specimen show at least 30% of ASR signs (defined earlier) within a blend of the first lift of the Pittsburg quarry. It emphasizes that even within the quarry that was the “cradle” of ACR, rock compositions vary a lot within the spectrum of carbonate lithologies present and that ASR reactive rocks are present. Surprisingly, Pit-6 stone mixed 50/50 with CH Chinese ACR-susceptible stone showed mainly signs of ASR in proportions. It suggests that the Chinese aggregate CH “dilutes” the reactivity within the whole coarse aggregate portion to show only signs of ASR from Pit-6 aggregate. This also suggests that most of the Pittsburg quarry lithologies from the first lift are indeed ASR reactive, at least to a certain degree. Thus, it is not surprising [7] that identified the presence of petrographic signs of ASR from the petrographic examination of MTO sidewalk sections since those had been manufactured from the “blend” from the Pittsburg quarry-run. Only some specific levels within that quarry are then ACR reactive. Figure 4.1 and 4.2 show very different regimes of expansion (and ultimate expansion levels) over time for known alkali-carbonate (Kingston, Pit-16) and alkali-silica (Sp) reactive aggregates. Then, all high to very high expansions at one year seems related to ACR aggregates in Table 4.1. As expected, Pit-15 and 16 followed by Pit-6 show the highest damage in DRI along with the most signs of ACR (70% of all the reactivity signs present). However, there is 30% proportion of ASR signs within these specimens, which is again reflected in the overall DRI numbers.

From the data presented in Figure 4.3 and in Table 4.2, there is an increased occurrence of cracks in the cement paste (CCP and CCP+RP) and debondings (Debon) in Pit-15, Pit-16 and Pit-6 compared to other aggregates tested and especially Sp 0.2%. This suggests that there is possibly much more reaction occurring near the border (outer portions) of ACR-reactive aggregate particles than from the interior (center) portion of those particles [13]. In all limestones examined that showed both reaction signs, CCA+RP and CCP+RP were attributed to about 70% calcite and 30% silica gel (similar to [13] observations) in opposition to limestone specimens showing only ASR signs (Spratt 0.2% in Figure 4.3 for instance) that were only attributed to silica gel. The above observations and suggestions were previously mentioned by [13] on different ACR reactive samples compared to renowned ASR-reactive samples.

For Pit-15, Pit-16 and Pit-6 that contain a larger proportion of alkali-carbonate reactive lithologies, the emphasis is given on the following features mentioned in Figures 4.4, 4.5 and 4.6 (and from the examination of field specimens – work in progress): 1) the yellowish products in the interfacial zone between the aggregate particles and the cement paste (i.e. calcite rims - CAR) which were also reported by the authors of this study from thin section examination [13] and by [25] from SEM observations; 2) the presence of calcite (and possibly brucite) filling cracks and impregnating the cement paste in the vicinity of those cracks also observed by [13 and 25]. The fact that the extent in the occurrence of the above features, likely resulting from the dedolomitization process, increases with increasing expansion suggests that this phenomenon actually plays a significant role in the overall reaction mechanism and perhaps in the expansion process of the Kingston aggregate bearing concretes, as stated by [4]. The above was again mentioned on different samples in [13].

It is suggested again that a combination of reaction mechanisms (other mechanism + ASR as a secondary reaction contributing to damage at a later stage in the overall damage generation) would be responsible for the renowned deleterious expansion generated by the alkali “carbonate” reactive Kingston limestone. This is the topic of on-going investigations by the authors. Not to mention again, the inefficacy of SCMs (Figure 4.2) on the long term to reduce enough or control expansion due to ACR and even increase the final expansion compared to control.

## 6. CONCLUSION

The present contribution aims at documenting the behaviour and characteristics of ACR-susceptible rocks mainly from Pittsburg quarry in Kingston, Ontario along with an ACR-susceptible aggregate from China by macroscopic petrography and DRI determination. Different levels within the above-mentioned quarry were evaluated in CPT [14] and a test specimen was subjected to petrographic examination through the DRI method at the 1-year period. Considering what was presented above, it can be concluded that:

- The expansion of concrete specimens incorporating aggregates from different lithologies of the Pittsburg (Kingston) quarry, varies from 0.009 to 0.616 % at one year. Damage values determined by the DRI method correspond quite well to expansion attained. From data of the present study and other investigations, confirmed cases of alkali-carbonate reactive aggregates show a very different regime of expansion in the CPT and much higher ultimate levels of expansion compared to solely ASR reactive aggregates (e.g. Spratt limestone).
- Increased occurrences of cracks in the cement paste (with and without secondary products) and debondings (CAD) for Pit-15, Pit-16 and Pit-6 concrete samples compared to Spratt 0.2% show that there is much more reaction occurring near the border of the Kingston aggregate particles and the paste (ITZ).
- Even in renowned ACR reactive rocks (Pit 15, Pit-16 and Pit-6), ASR plays a significant but secondary role (30%) in the overall reaction, however, likely at a later stage (unpublished data).
- Abundant deposits of secondary reaction products, which are thought to correspond to calcite and brucite, were identified mainly in the Pit-15, Pit-16 and Pit-6. The fact that increasing occurrences of the above features were found with increasing concrete prism expansion suggests that this phenomenon, likely related to dedolomitization, may play more than a secondary role in the expansion process of Kingston-bearing concretes, as stated amongst others by [13].

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