PREVENTIVE MEASURES AGAINST EXPANSION IN CONCRETE CONTAINING REACTIVE RECYCLED CONCRETE AGGREGATE

Medhat H. Shehata[1*], Waleed Mikhaeel[1], Mohamed Lachemi[1] and Chris Rogers[2]

[1]Department of Civil Engineering, Ryerson University, ON, Canada

[2]Post Office Box 185, Beeton, Ontario, Canada

Abstract

This study presents an investigation into various approaches to mitigate expansion in concrete containing reactive coarse RCA. The concrete prism test was used to evaluate the different mitigation approaches. One of the investigated options was blending the reactive RCA with non-reactive natural aggregate at a blending ratio of 70% to 30% of total coarse aggregate, respectively. While blending alone was not effective in maintaining the 2-year expansion below the 0.04% limit, the addition of moderate levels of common SCM's were found to be effective in mitigating the expansion. The study also developed the level and type of SCM blends that mitigated the expansion in concrete with 100% reactive RCA. Some ternary blends, including a blend containing 20% low-calcium fly ash and 30% slag, were found to be effective in mitigating the expansion. Lithium nitrate used with moderate levels of SCM's reduced the expansion in concrete prisms with 100% RCA; however, the expansion was slightly above 0.04% at 2 years.

Keywords: recycled concrete aggregate, alkali silica reaction, preventive measures, concrete prism test

1 INTRODUCTION

Many structures in North America and around the world are now approaching the end of their service life. It is of interest from the economic and sustainability standpoints to reuse the concrete debris generated from these structures as Reclaimed or Recycled Concrete Aggregate (RCA) in new concrete. In Ontario, Canada, current Provincial specifications permit the recycling of RCA as granular base in pavements but not into new concrete construction. There are challenges associated with the use of RCA in concrete including the durability of the new concrete. One of such durability issues is the alkali reactivity of RCA In an earlier study Shehata et al. [1] found that RCA produced from concrete affected by alkali-silica reaction (ASR) caused expansion and damage when used in new concrete.

Many highway and hydraulic structures in North America have been reported to be affected by ASR. In Ontario alone, as early as the beginning of the 1980's, it was reported that more than 130 highway structures were affected by ASR [2]. It is anticipated that most of these structures will be demolished as they approach the end of their service life. So, it is important to develop practical and feasible preventive measures against alkali reactivity of RCA to enable the use of ASR-affected RCA in new concrete. While RCA identified as reactive could be prohibited from use in concrete, the development of practical preventive

* Correspondence to: mshehata@ryerson.ca

measures against ASR in concrete with reactive RCA will help promote the use of RCA from unknown multiple sources. Such RCA could be contaminated with reactive particles and hence the use of preventive measures could serve as a "safeguard" against any possible deterioration. It should be noted that stockpiles of RCA are usually from different and often unknown sources. A practical approach would be a measure that prevents ASR and has positive effects on other concrete properties.

The use of supplementary cementing materials (SCM's) as preventive measures against ASR in concrete containing natural aggregates is well known. Much research has shown that the use of the right amount and type of SCM reduces the reaction and expansion to a very low level [3,4]. The efficacy of these materials in mitigating ASR is attributed, mainly, to their ability to bind and retain alkalis in their hydration products, and hence reduce the alkalinity of the concrete pore solution [5,6]. Field observations of structures have confirmed the efficacy of SCM in providing good mitigation [7]. Lithium salts have been reported by various researchers to be effective, when used in appropriate dosages, in counteracting ASR [8,9,10,11]. Lithium nitrate has been found to be the most effective salt as it does not raise the alkalinity of the pore solution as is the case with lithium hydroxide [9].

The alkali-silica reactivity of natural aggregates and ways to mitigate it have been studied in detail. However, there are limited studies on the reactivity of RCA. A study, in the United States, on RCA produced from a section of Interstate I-95 near Gardener, Maine, showed that ASR-affected RCA caused high expansion in the new concrete. The expansion was higher than that produced in concrete containing the aggregate originally used in the concrete which was a fine-grained quartzite coarse aggregate [12]. A later study conducted by Shehata et al. [1] showed similar results. The research of Shehata et al. [1] was conducted on a reactive RCA produced from test blocks (0.6 x 0.6 x 2 m) placed outdoors in 1991 using CSA Type 10 cement (a General Use Portland cement) and a highly expansive alkali-reactive siliceous limestone coarse aggregate from the Spratt quarry in Ottawa, Ontario. The blocks were part of an exposure site in Kingston, Ontario, Canada [13].

In terms of preventive measures, Shehata et al [1] reported that the levels of SCM required to mitigate the expansion was much higher than those required to mitigate the expansion in concrete containing the same reactive natural aggregate used in the blocks. Indeed, the only practical level of SCM that maintained the expansion below 0.04% at 2 years was a ternary blend of 5% silica fume and 25% Type CI fly ash. Lithium nitrate used up to a dosage of 2.5 Li/(Na+K), ratio based on alkalis from PC alone, ignoring those from the RCA, was not enough to limit the concrete prism expansion to less than 0.04% at 2 years.

This paper covers an investigation on the efficacy of different preventive measures to counteract ASR in concrete containing alkali-silica reactive coarse RCA (nominal maximum size of 19.0 mm). One of the main options investigated was blending the reactive RCA with non-reactive natural stone, and using moderate levels of SCM to counteract the expansion. Such levels are within the levels commonly used in concrete in North America. Combinations of SCM/lithium nitrate were also investigated as preventive measures for concrete with 100% RCA. Finally, the paper presents the results covering the effects of different ternary blends of SCM including slag and low-calcium fly ash on mitigating the expansion in concrete with 100% RCA.

2 MATERIALS AND METHODS

2.1 Materials and mixture proportions

The RCA used in this study was obtained from the Ontario Ministry of Transportation outdoor exposure site in Kingston, Ontario, Canada. The construction of the concrete outdoor exposure site is described in Ref. [13]. After 12 years of exposure, the block (a spare) was removed and crushed into aggregate. At that time, the concrete block had experienced severe expansion (linear expansion of 0.19 %) and cracking. The concrete block was broken into boulder-size pieces using a backhoe ram and a laboratory jaw crusher was used to produce coarse (19.0 mm to 5.0 mm) and fine (passing 5.0 mm Sieve) RCA. The reactive aggregate used to produce the concrete block was a dolomitic limestone from the Spratt quarry in Ottawa, Ontario, Canada. The non-reactive aggregate used in this study was 19.0 mm crushed, quarried dolomite of Silurian age (Amabel Formation) from the Niagara Escarpment. The concrete prism expansion value for this aggregate was 0.027% which was lower than the maximum specified limit of 0.04% for non-reactive aggregate.

Figure 1 shows a backscattered electron image of an RCA particle prior to being used in concrete prisms. The image shows an RCA particle with cracks filled with reaction product, and cracked residual mortar around the original aggregate particle (Spratt). Table 2 shows the physical properties of the RCA as well as Spratt aggregate. In addition to the alkalis content of RCA determined by XRF, the water soluble alkalis were determined by a simple leaching test and was found to be 0.16% Na_2O_e. In this leaching test, coarse RCA particles were leached in distilled water at a solid-to-liquid ratio of 1:10. The alkalis contributed to the distilled water after 28 days were calculated and expressed as % by mass of RCA.

A high-alkali GU Portland cement (PC) and five different SCM's were used in the study. The chemical analysis of the PC and SCM's are listed in Table 2. Lithium nitrate ($LiNO_3$) solution was also used as a preventive measure in certain mixtures.

2.1 Methods for assessment and analysis

Concrete Prism Test (CPT)

The concrete prism test (CPT) according to CSA A23.2-14A was used to evaluate the efficacy of the different preventive measures. A volume of dry-rodded coarse aggregate of 0.69 vol.% of unit volume of concrete was used as it was found to produce workable and homogeneous mixtures. This ratio lies within the limit of CSA A23.2-14A. The dry-rodded density of coarse aggregate is the bulk density of an aggregate sample compacted in a standardized manner as per ASTM C 29. The determined value for the RCA used in this study was 1385 kg/m^3. Hence, 1 m^3 of concrete contains 0.69 m^3 of dry-rodded RCA or $0.69 \times 1385 = 956$ kg. The RCA was not washed to prevent any leaching of alkalis from its residual mortar. This was to make sure that the effect of alkalis contributed from RCA is considered in the investigation.

Lithium nitrate was tested with SCM at different dosages. The high alkali Portland cement (HAPC) with 0.96% Na_2O_e was used without boosting the alkalis to 1.25% Na_2O_e. The dosage of lithium is expressed as a ratio of Li/(Na+K) in the system. Alkalis from RCA or SCM's were not used is the calculation. In other words, the source of Na and K ions considered in the calculations were only from the Portland cement.

Electron micro probe analysis (SEM)

A polished section of RCA particle was prepared and sputter coasted with carbon in an Edwards Vacuum Coating System Model # 306A using ultra pure Carbon, Grade UF4S. The sample was polished using a diamond grade of 0.3 μm for final polishing. Oil was used as a cooling agent, to avoid leaching of alkalis. Polished sections were studied in a JEOL JSM6380 LV scanning electron microscope operated at 10^{-4} Torr and 20kV in backscatter mode (BSE).

3 RESULTS

Various binary blends containing one type of SCM plus PC were investigated earlier [1] and found ineffective in mitigating the expansion of concrete with the same RCA investigated in this study, although the same levels were effective in concrete with the virgin alkali-reactive Spratt aggregate [1]. The only preventive measure that was proven effective was a ternary blend containing 5% silica fume and 25% Type CI fly ash. More ternary blends were investigated in this study and the results confirmed that 5% silica fume and 25% or higher levels of Type F or CI fly ash (CaO < 20%) were effective in mitigating the expansion, as shown in Figure 2. It is worth noting that to mitigate expansion in concrete with the Spratt virgin aggregate, ternary blend of 5% silica fume and only 15% low-calcium fly ahs (F-Ash) was needed [14]. The higher levels of SCM required to mitigate the expansion in concrete with RCA compared to that with virgin reactive aggregate Spratt is believed to be due to alkalis contributed from the residual mortar or RCA [1]. Hence, higher levels of SCM were required to bind this high level of alkalis which were available to the pore solution of the new concrete.

Another type of ternary blends was investigated in this study: Type F fly ash and slag. The results are presented in Figure 3 which show that ternary blend of (20% Type F fly ash + 30% slag) was effective in meeting the expansion limit of 0.04% at 2 years. Figure 3 also includes the expansion curves of binary blends containing the same fly ash or slag used in binary blends. It is clear that 20/30 F-Ash/slag produced less expansion that 50% slag. This is expected since the low-calcium fly ash is more effective in mitigating the expansion [1]. Indeed 20% F-Ash produced less expansion than 30% slag, as shown in Figure 3.

Another type of preventive measure that was investigated in this study was the use of lithium nitrate with SCM. Lithium nitrate alone was not effective in mitigating the expansion as found earlier [1]. The expansions results of lithium/SCM are presented in Figure 4 which shows improvement in the performance of any cementing blend with the addition of lithium. However, the expansion values were still above 0.04%. It should be noted that the lithium dose is usually expressed as ratio of Li ion to (Na+K) ions in the system. In concrete prisms with natural aggregates, the source of (Na + K) ions are Portland cement and the alkalis added to raise the alkali content to 1.25% Na_2O_e by mass of PC. In this study the (Na + K) used to calculate the Li are those from the PC, ignoring alkalis from the RCA. Also, in the concrete prisms with lithium, the alkali content was not boosted to 1.25% Na_2O_e by mass of PC. Figure 4 also shows that the effect of lithium was more noticeable when used with SCM of low efficacy (i.e. CH or high calcium fly ash). Figure 4 clearly shows that increasing the level of lithium beyond a certain value does not reduce the expansion, especially when the expansion values are relatively low such as those encountered with ternary blends. .

A practical approach to promote the use of reactive RCA in concrete was investigated, which entailed blending the RCA with non-reactive natural coarse aggregate. This approach is practical as it is expected to have positive effects on concrete properties, other than resistance to ASR, including reducing shrinkage, enhancing compressive strength and reducing slump loss. Figure 5 shows the expansion curve for concrete prisms containing RCA used at 70% by mass of total coarse aggregate with the other 30% being a non-reactive dolomite. Figure 5 also includes the expansion of concrete prisms with Spratt aggregate used at 70%

by mass of coarse aggregate with the non-reactive aggregate forming the other 30%. For comparison, the expansion curves for concrete with 100% RCA and that with 100% Spratt are also included in the graph.

The reduced expansion of concrete with 70% RCA, compared to that with 100% RCA, made it possible for moderate levels of SCM's to mitigate the expansion. As shown in Figure 6, 25% low or intermediate calcium fly ash, or 50 % slag were able to maintain the expansion below 0.04% at 2 years. It should be noted that the two fly ashes investigated here had alkali contents < 2.0% Na_2O_e. Same types of fly ash with higher alkali content may not necessarily have the same efficacy in mitigating the expansion. While the effective level of slag (50%) seems high, this is the level normally required to mitigate expansion in concrete with natural highly reactive aggregate [15,16]. Indeed, the recommended level of slag required for "strong preventive action" as per CSA A23.2-09-27A is 50%. While ternary blends were not investigated with concrete containing 70% RCA, it is reasonable to assume that blends that were effective in mitigating the expansion in concrete with 100% RCA provide the same level of mitigation, if not better, when used with 70% RCA.

4 DISCUSSION

The CPT results presented in this paper show that blending reactive RCA with non-reactive natural stones is a viable option for using reactive RCA in concrete. For both natural reactive aggregate and reactive RCA, diluting the reactive aggregate content in the mix produces less expansion, as shown in Figures 5. Looking at the 4 curves in Figure 5, one would notice that the expansion curves for diluted RCA and Spratt are not identical as those for 100% RCA or 100%. Indeed, the diluted RCA produced less expansion than diluted Spratt, unlike the undiluted aggregates where the expansion values were the same. A possible reason for this is the reduced alkalis content in the mix with diluted RCA compared to that with 100% RCA. It should be noted that the mass of reactive constituents in concrete with RCA are less than those in concrete containing the same mass of natural aggregates due to the presence of residual mortar in RCA. Hence, one would expect the RCA to produce less expansion. However, concrete with RCA contains more alkalis due to those contributed from RCA. When RCA or reactive aggregate was used at 100%, the reduced quantity of reactive constituents in the case of concrete with RCA was offset by the increased alkali contribution from the RCA resulting in similar expansion. When the aggregates were diluted, however, the contributed alkalis from RCA were not high enough to raise the expansion to be similar to that of diluted Spratt. Indeed, the expansion of concrete with 70% Spratt was 0.15% at one year which is about 75% of that of concrete with 100% Spratt. On the other hand, the expansion of concrete with 70% RCA at one year is about 50% of that with 100% RCA.

The Spratt aggregate as well as the RCA used in this study do not exhibit the "pessimum effect" phenomenon. Aggregate that exhibits a pessimum effect produce higher expansion when used in a particular level, which is known as pessimum level. For this type of aggregate, blending the reactive aggregate with non-reactive aggregate may not be beneficial in terms of mitigating the expansion. RCA containing natural reactive aggregate with pessimism effects should be carefully examined prior to use.

In addition to reducing reactivity, blending RCA with natural coarse aggregate has many other beneficial effects on concrete properties. Due to the presence of residual mortar in RCA and its porous nature, concrete made with RCA usually exhibits higher shrinkage [17]. In addition, the strength of RCA could vary depending on the source; this could reduce the strength of the new concrete. Fresh properties including slump retention are also affected by the presence or RCA. Limiting the amount of RCA in concrete is a practical approach to produce concrete of consistent and adequate properties. Hence, blending reactive RCA with natural aggregate could be one of the recommendations for incorporating RCA in concrete, regardless of its reactivity. The optimum level of RCA would vary depending on the source of RCA and the performance requirements of the concrete. However, the authors believe that 70% RCA is perhaps on the high side of the recommended range of RCA to be used in concrete. In addition, SCM's are commonly used in concrete due to their beneficial effects on concrete properties [18]. Hence, blending RCA with non-reactive aggregate, and using SCM in appropriate amounts as a mitigation strategy for counteracting ASR fits well with current construction practice.

While the levels of Type F and CI fly ash required to mitigate expansion in concrete with 70% reactive RCA is in line with the levels currently used by the construction industry, the level of slag (50%) may be higher than is acceptable for some applications. In such cases, possible mitigation approaches would be a lower level of RCA or the use of ternary blends of slag and silica fume, or slag and Type F fly ash.

5 CONCLUSIONS

For the materials investigated in this study, the following conclusions are drawn:

- Ternary blends of silica fume and low or intermediate calcium fly ash were effective in mitigating the expansion in concrete containing reactive RCA. Ternary blends of 20% Type F fly ash and 30% slag were also effective in mitigating the expansion. The fly ash investigated had $Na_2O_e < 2.0\%$.
- Blending the reactive RCA with non-reactive coarse aggregate produced a reduction in expansion that exceeded the level of reactive aggregate dilution. In other words, blending RCA with 30% non-reactive natural aggregate produced a 50% reduction in expansion. This helped reducing the expansion below the specified limit using moderate levels of SCM. .
- Practical levels of SCM's (25% Type F or CI fly ash and 50% slag) were effective in mitigating the expansion in concrete with reactive RCA blended with 30% non-reactive natural aggregate.
- Adding lithium nitrate to SCM reduced the expansion of concrete with reactive RCA. The reduction was greater for SCM that are less effective in counteracting the expansion. However, the levels of lithium and SCM investigated here were not enough to reduce the expansion to less than 0.04% at 2 years
- The results obtained in this study are applicable to reactive RCA containing Spratt aggregate. Preventing expansion in concrete with RCA from different sources may require different levels of SCM.

6 Acknowledgments

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7 REFERENCES

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Table 1: Properties of RCA and Spratt aggregates		
	RCA	Spratt
Dry Bulk Relative Density	2.33	2.66
Absorption	5.1%	0.60%
Total Na_2O_e determined by XRF	0.56%	-

Table 2: Major oxide composition of the Portland cement and SCM's determined by XRF (wt.%)						
Main Oxide	[1]HAPC	[2]SF	[3]SG	[4]F- LA	[5]CI-LA	[6]CH-LA
CaO	62.8	0.27	43.2	4.43	17.0	28.7
SiO_2	19.6	96.2	34.4	55.7	40.2	33.3
Al_2O_3	5.35	0.35	7.4	27.4	21.4	18.2
Fe_2O_3- total	2.29	0.10	0.94	5.59	9.92	6.45
MgO	2.43	0.91	9.30	1.56	4.23	5.32
SO_3	4.10	0.25	0.83	0.26	2.46	2.59
K_2O	1.13	0.51	0.58	2.29	1.04	0.33
Na_2O	0.21	0.21	0.57	0.44	1.36	1.94
TiO_2	0.31	0.13	0.44	0.67	1.39	1.45
P_2O_5	0.11	0.13	0.00	0.31	1.10	0.88
Na_2O_e	0.96	0.55	0.95	1.95	2.10	2.16
[7]Fineness	n.a.	n.a.	n.a.	26.7	14.9	n.a.

[1]HAPC: High-Alkali GU Portland Cement
[2]SF: Silica Fume
[3]SG: Slag
[4]Fly Ash Type F (CaO < 8 wt.%)
[5]Fly Ash Type CI (8 wt.% <CaO < 20 wt.%)
[6]Fly Ash Type CH (CaO> 20 wt.%)
[7]Fineness (%retained on 45-µm sieve)

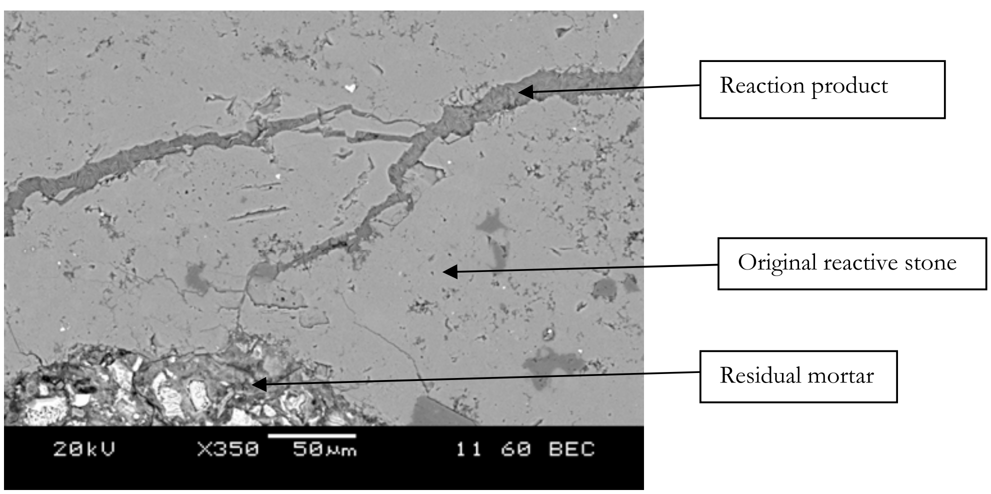

Figure 1: Back Scattered Electron Image showing RCA particle with crack filled with reaction product

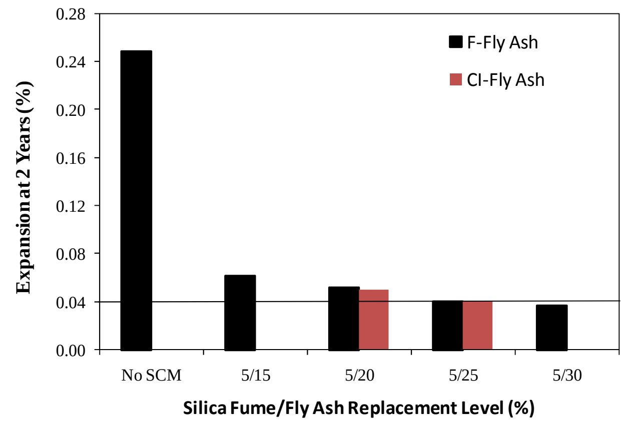

Figure 2: Effects of ternary blends Containing silica fume low or intermediate calcium fly ash on the 2-year expansions of concrete prisms

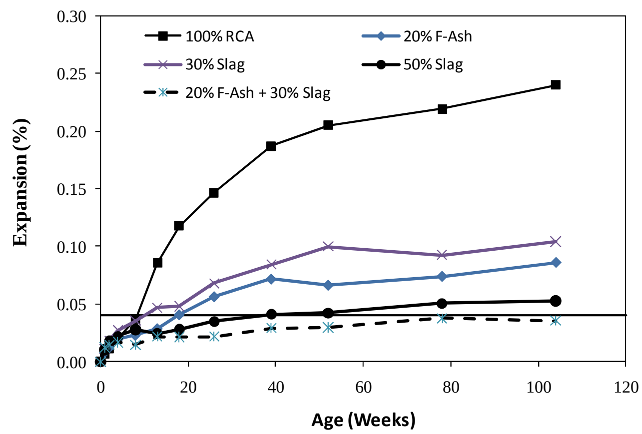

Figure3: Effect of binary and ternary blends of Type F fly ash and slag on the 2-year expansion of CPT

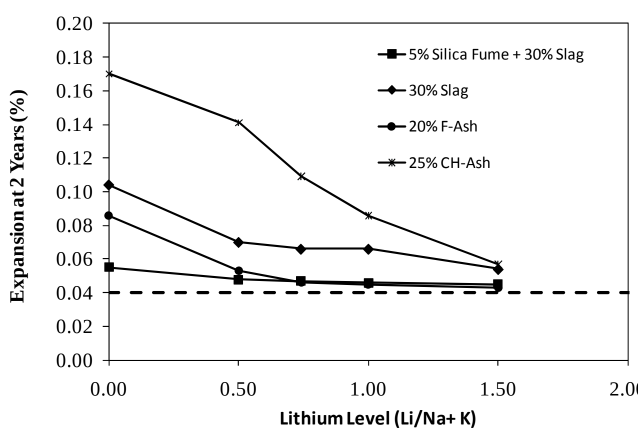

Figure 4: Effect of lithium nitrate addition on the expansion of concrete with RCA and various SCM blends

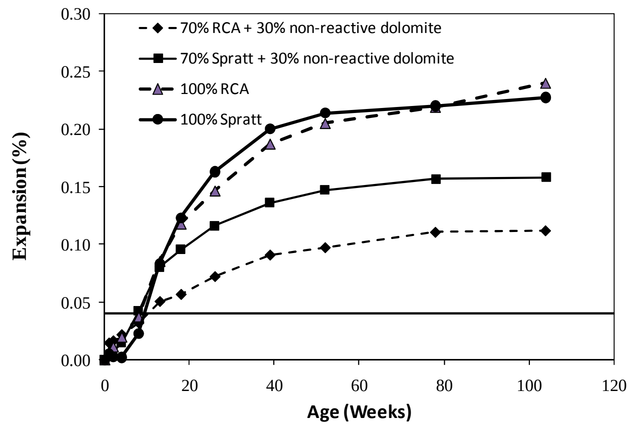

Figure 5: Expansion of concrete prisms containing different reactive/non-reactive RCA and Spratt Blends.

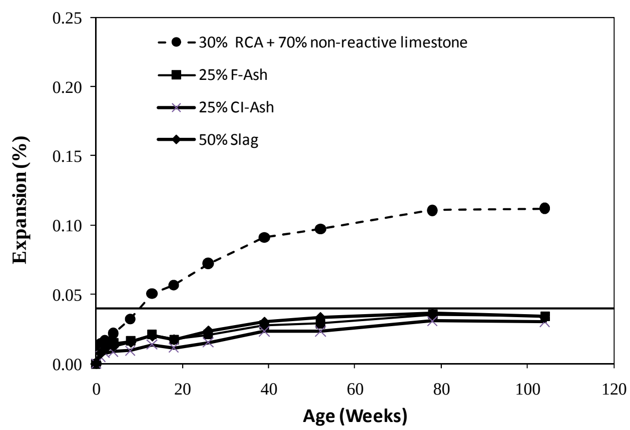

Figure 6: Effects of different SCM on the 2-year expansion of concrete with 70% RCA