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Ways to evaluate alkali-silica reactivity of mineral fillers

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Abstract

Mineral fillers used to attain specific properties in concrete might have the potential for alkali-silica reaction. This study investigates the potential reactivity of fillers using two standard test methods: 1) the Accelerated Mortar Bar Test (AMBT), and 2) the Concrete Prism Test (CPT). Modifications to the current AMBT were suggested to evaluate the alkali-silica reactivity of fillers. Three types of mineral fillers were investigated: two commercially available fillers - a carbonate filler and carbonate-silicate filler with 27 wt.% SiO_2 - and a siliceous filler produced from a reactive aggregate. Two different filler sizes were produced from the reactive aggregate to represent the sizes of the two commercially available fillers: 1) finer than 75 µm; 2) 30 wt.% passing 150 µm sieve - retained on 75 µm sieve and the remaining 70 wt.% finer than 75 µm. Concrete prisms cast with the siliceous filler showed expansion higher than that of prisms without filler for both filler gradations using the CPT. However, the 1-year expansions of all samples did not exceed the 0.040% ℓ/ℓ expansion limit and did not continue to expand between one and two years. With the AMBT, the coarser reactive filler showed higher expansion than the finer filler when used at 10 and 20 wt.% replacement levels taken from the aggregate finest portions. At 20 wt.% replacement level, the fine filler showed the same expansion as the non-reactive sand. The high surface area of the fine filler resulting in reduced permeability of the mortar as well as the high alkali level needed to trigger expansion in such large area of reaction sites could have caused the low expansion. It was concluded that the testing duration of the AMBT should be extended to 56 days instead of the standard 14 days to evaluate the potential expansion of mortars with fillers. Testing should be carried out at filler replacement levels of 10 and 20 wt.% of the aggregate finest portions. The max expansion should be compared to that of the non-reactive sand to reach a conclusion about the potential reactivity of fillers.

***Keywords**: accelerated mortar bar test; concrete prism test; expansion; mineral filler; permeability*

1. INTRODUCTION

Alkali-silica reaction (ASR) is a chemical reaction between the silica in the aggregate and the alkalis present in the concrete pore solution leading to the formation of an expansive gel [1–3]. The swelling of the gel causes cracks and deterioration in concrete [1]. Many preventive measures are available to prevent damage caused by ASR, such as the use of supplementary cementing materials (SCM) and lithium-based compounds [4].

Test methods are currently available to evaluate the reactivity of aggregates and the effectiveness of SCM in preventing the reaction. The first test is the Concrete Prism Test (CPT), described in [5–8], in which an aggregate is deemed reactive if an expansion higher than 0.040% ℓ/ℓ at 1 year is attained. The Accelerated Mortar Bar Test (AMBT), described in [9–11], is a quicker test method in which an aggregate is considered reactive when an expansion of 0.150% ℓ/ℓ is obtained at 14 days. For siliceous limestone aggregate from St. Lawrence Lowlands, Canada, a lower expansion limit of 0.100% ℓ/ℓ is applied. These two tests are commonly used for testing reactivity of aggregates, however, there is no current test method available to evaluate reactivity of mineral fillers.

Mineral fillers are used in self-consolidating concrete (SCC) to maintain cohesiveness and stability of the mix [12]. SCC is known to be highly flowable having the capacity to be poured without vibration, while avoiding bleeding and segregation [13]. SCC is used in areas with congested reinforcement or in structural elements where the repair area is hard to reach [13, 14]. Due to their high surface area, fillers were found to enhance the rate of cement hydration and the resistance to bleeding [15–17]. This is due to their micro-filling ability, improving the microstructure of the matrix and the interfacial transition zone [17].

Mineral fillers might be potentially reactive and can cause deleterious effects in concrete [15]. With the CPT, prisms cast with a Norwegian filler having a particle size of 0-125 µm expanded more than the

control sample with no filler, which contradicted the results obtained in AMBT [15]. It is believed that the pozzolanic reactivity of the filler used is utilized at temperatures higher than 38ºC leading to different results between the CPT and AMBT [15]. Also, the filler's size can significantly affect the expansion in concrete. A reactive filler with a particle size of 0-125 µm exhibited slightly lower expansion compared to fillers with a size of 0-20 µm when tested using the CPT. However, the same reactive filler, when tested using the AMBT, showed lower expansion with a smaller size of filler at 56 days, which was attributed to their higher pozzolanic activity [15]. In addition, a filler with 80 wt.% of its material passing 25 µm sieve and 20 wt.% between 25 µm and 75 µm used at 30 wt.% replacement of total aggregate showed lower expansion than the control sample with no filler when tested using the CPT. Same filler but with 10 wt.% replacement level showed higher expansion at 2 years [18].

Some mineral fillers might have the potential to cause ASR in concrete. Hence, there is a need for a test method to evaluate the alkali-silica reactivity of mineral fillers. This paper investigates if a modified version of the AMBT can be utilized for this purpose.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Mineral Fillers

Three mineral fillers were investigated in this study, namely: (1) calcium carbonate filler (CF), (2) carbonate-silicate filler (CSF), and (3) Springhill filler (SH).

The calcium carbonate filler (CF) is composed of 94 wt.% calcium carbonate and 2.5 wt.% magnesium carbonate. Its median diameter is 21 µm with 90 wt.% of its material finer than 75 µm and the rest having a size between 150 µm and 75 µm. The particle size distribution of this filler is shown in Figure 2.1(a).

The carbonate-silicate filler (CSF) contains 27 wt.% SiO_2 and the rest is mainly calcium carbonate. This filler has a median diameter of 40 µm with 30 wt.% of its material passing 150 µm sieve and retained on 75 µm sieve and the rest passing 75 µm sieve. The particle size distribution of this filler is shown in Figure 2.1(b).
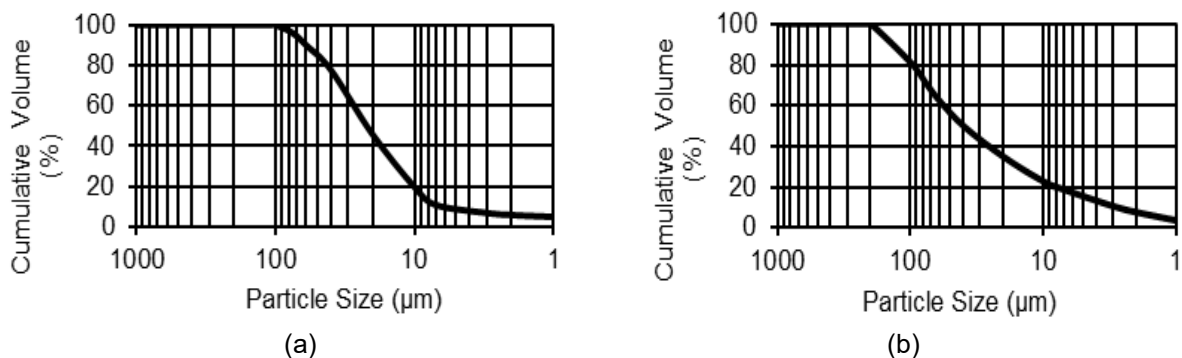

Figure 2.1: Particle size distribution of (a) CF and (b) CSF.

The third filler used is a siliceous filler obtained by crushing a highly alkali-silica reactive aggregate, Springhill, having an expansion of 0.22% ℓ/ℓ when tested using the CPT at one year and a 14-day expansion of 0.46% ℓ/ℓ using the AMBT [19]. The Springhill aggregate consists of coarse and fine materials. Crushing was completed on each material separately to obtain the following three types of fillers:

1. Filler finer than 75 µm (SH-F) obtained from pulverizing Springhill fine aggregate,

2. Filler finer than 75 µm (SH-C) obtained from crushing and pulverizing Springhill coarse aggregate.

   The above two fillers were produced to have the same maximum particle size close to the commercially available filler CF, and

3. Filler finer than 150 µm with 30 wt.% passing 150 µm sieve and retained on 75 µm sieve and the rest passing 75 µm (SH-C: 70/30) obtained from crushing and pulverizing Springhill coarse

aggregate. This filler was produced to have a gradation similar to that of the commercially available filler CSF.

2.1.2 Cement

A general use Portland cement (GU-PC) with 0.99 wt.% Na_2O_e was used with all the samples tested during this study. Its chemical composition is presented in Table 2.1.

Table 2.1: Chemical composition of Type GU-PC (wt.%).

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	Total	Na_2O_e
GU-PC	19.3	5.25	2.42	62.8	2.35	4.03	0.24	1.14	2.36	99.9	0.99

2.1.3 Aggregates

Two fine aggregates were tested in this research. The first fine aggregate (sand 1) used is a limestone natural concrete sand obtained from Caledon Pit, Ontario. The second fine aggregate (sand 2) is acquired from Precambrian granites and high-grade metamorphic gneiss and was obtained from a natural sand deposit located in Wakefield, Quebec.

In addition, a limestone non-reactive coarse aggregate for testing concrete prisms was obtained from an aggregate quarry near Hamilton, Ontario. The aggregates properties are presented in Table 2.2.

Table 2.2: Aggregates properties.

Aggregate	Sand 1	Sand 2	Non-reactive coarse Aggregate
Bulk relative density	2.538	2.659	2.726
Absorption (%)	1.30	0.81	0.81
Fineness modulus	2.64	2.43	-
14-day AMBT expansion (CSA A23.2-25A)	0.148	0.035	0.016[*]

[*]1-year CPT expansion (CSA A23.2-14A)

2.2 Experimental Details

2.2.1 Springhill Filler Preparation

SH filler was obtained by crushing Springhill aggregate which was received as a mix of coarse and fine materials. The coarse and fine aggregates were washed separately over 4.75 mm sieve and 75 μm sieve, respectively to remove dust, and then they were allowed to dry. To obtain SH-C and SH-C: 70/30, the coarse Springhill aggregate was crushed using the jaw crusher first until all passed 4.75 mm sieve; then processed using a pulverizer until enough filler materials passing 150 μm sieve/retained on 75 μm sieve, and passing 75 μm sieve were obtained. For SH-F filler, the fine aggregate was processed using a pulverizer until enough filler passing 75 μm sieve was achieved.

2.2.2 Accelerated Mortar Bar Test (AMBT)

For testing mineral fillers using AMBT (ASTM C1260) [9], the mineral filler was used as a partial replacement of the total aggregate; i.e., (sand 1 + filler) or (sand 2 + filler). According to the test method, the gradation of the total aggregate mass (990 g) is shown in Table 2.3.

Table 2.3: Grading required as specified in ASTM C1260 [9].

Passing	Retained on	Mass (%)
4.75 mm	2.36 mm	10
2.36 mm	1.18 mm	25
1.18 mm	600 µm	25
600 µm	300 µm	25
300 µm	150 µm	15

Two different replacement methods of total aggregate by filler were implemented:

1. Replacement from the aggregate finest portions: for 10 wt.% filler replacement, only 5 wt.% aggregate passing 300 µm and retained on 150 µm was used, and the remaining 10 wt.% would be filler. For 20 wt.% filler replacement, the whole aggregate with size between 300 µm and 150 µm in addition to 5 wt.% from the size between 600 µm and 300 µm were replaced by filler.

2. Replacement from the total graded aggregate: for 10 wt.% replacement level, 10 wt.% of the total mass of aggregate (99 g) was replaced by filler and the remaining 891 g would be aggregate distributed based on the gradation listed in Table 2.3.

The mixing procedure followed was based on the requirements described in ASTM C305 [20]. The water to cement ratio used was 0.47 for all the samples. Once mixing was complete, the flow of the mix was measured according to the procedure described in ASTM C1437 [21]. The samples were then placed in 25x25x285 mm mortar bar molds and cured for 24 hours in a curing room at a relative humidity (RH) > 95%. Then, they were demolded and soaked in water at 80ºC for 24 hours. After that, the samples were taken out, and zero measurements were obtained. They were then stored in a soaking solution of 1M NaOH in an oven at 80ºC. Three bars from each mix were cast and the average expansion is reported. Measurements were taken at 1, 3, 7 days and then every week until 56 days.

2.2.3 Concrete Prism Test (CPT)

Concrete prisms were cast using a water-to-cement ratio of 0.45 and coarse-to-fine aggregate ratio of 60:40 by mass as per CSA A23.2-14A [5]. The coarse and fine aggregates used were the non-reactive limestone aggregate and sand 2, respectively. The gradation of the coarse aggregate consisted of equal masses of sizes between 19.5 mm to 13.2 mm, 13.2 mm to 9.5 mm, and 9.5 mm to 4.75 mm. The cement content was 420 kg/m^3 and the alkalinity of the cement was boosted to 1.25 wt.% Na$_2$O$_e$ as per CSA A23.2-14A [5]. The filler was used as a percent replacement from the fine aggregate by mass. A high range water reducer was added to the samples cast with fillers to improve workability of the mix. The samples were placed in 75x75x285 mm molds and covered by wet burlap and plastic as means of curing for 24 hours at which time they were demolded. Zero measurements were then taken, and the samples were stored in buckets above water at 38ºC as required in CSA A23.2-14A [5]. Three prisms from each mix were prepared and the expansion results presented in this paper are the average of the three.

2.2.4 Alkali Leaching from Concrete Samples

Alkalis leached from three concrete prisms to the bottom of their bucket were measured at 1 year. The volume of the solution at the bottom of the bucket was measured and a sample solution was collected to test for concentrations of Na$^+$ and K$^+$ ions by flame photometry. The obtained concentrations were then converted to Na$_2$O$_e$ and expressed as percent of the sample's initial 1.25 wt.% Na$_2$O$_e$ content by mass of Portland cement.

2.2.5 Scanning Electron Microscopy Analysis

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) testing were completed on two mortar bar samples: one cast with (SH-C: 70/30) and the other with CSF, both at 20 wt.% replacement of the aggregate finest portions. Chunks obtained from the mortar bars were dried under vacuum in a desiccator at room temperature and impregnated with epoxy. Then, the specimens were polished using a 0.3 µm diamond grade and sputtered with carbon using Edwards Vacuum Coating

System Model # 306A. The polished samples were tested using a JEOL JSM6380 LV (SEM) operated at 20 kV in backscattered electron mode (BSE).

3. RESULTS

3.1 Effect of Replacement Level and Replacement Method on Workability of Mortars

The workability of mortars was evaluated using the flow test as per ASTM C1437 [21]. Figure 3.1(a) shows the effect of filler level on flow results. The mortars tested in Figure 3.1(a) contain sand 1 and carbonate filler, replacing the aggregate finest portions. For replacement levels higher than 15 wt.%, the filler replaced the whole finest portion of the total aggregate and part of the next coarser portion, as needed. As Figure 3.1(a) shows, the workability of mortars decreased with the increase of the filler's replacement level. At replacement levels of 30 wt.% and higher, a superplasticizer was needed to maintain workability.

Figure 3.1(b) shows a comparison of flow results between the two replacement methods of fillers. This test was done using sand 2 and different types of fillers at 20 wt.% replacement level. In general, the replacement method did not seem to affect the workability of mortars.
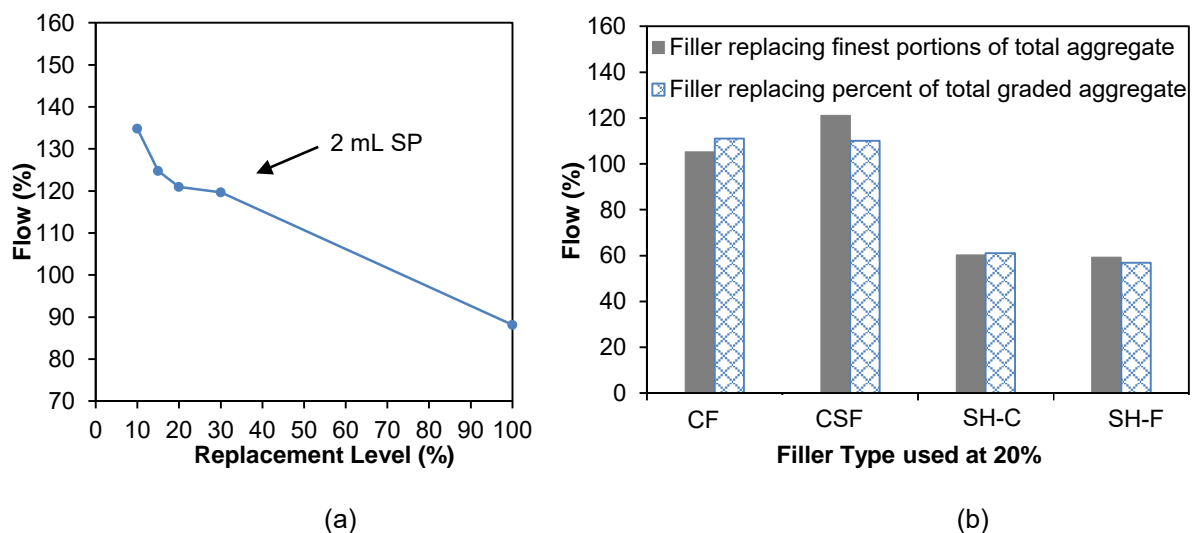

| (a) | (b) |

Figure 3.1: Flow results of mortars containing (a) sand 1 and CF replacing the aggregate finest portions, (b) sand 2 and different fillers at 20 wt.% replacement level.

Moreover, the flow was within the expected or targeted range when the two investigated commercially available fillers were used. However, for samples cast with SH filler, the workability was found to be much lower compared to the other two fillers. This could be due to the particle shape or surface properties of SH fillers. The addition of a superplasticizer is recommended with samples containing SH or similar fillers at replacement levels of more than 10 wt.%. At 10 wt.% replacement level, the flow of sand 2 and SH-C filler replacing the total graded aggregate (not shown in the figure) was acceptable with a value of 103%.

3.2 Effect of Mineral Fillers on Expansion of Mortar Bars

The effect of the replacement method on expansion of mortars was studied for samples cast with CSF using the AMBT. Expansion results are presented in Figure 3.2 and Figure 3.3 for samples cast with sand 1 and sand 2, respectively. Expansion of mortars was measured until 56 days. Reasons for extending the test duration (the standard duration is 14 days) will be explained in Section 3.3.
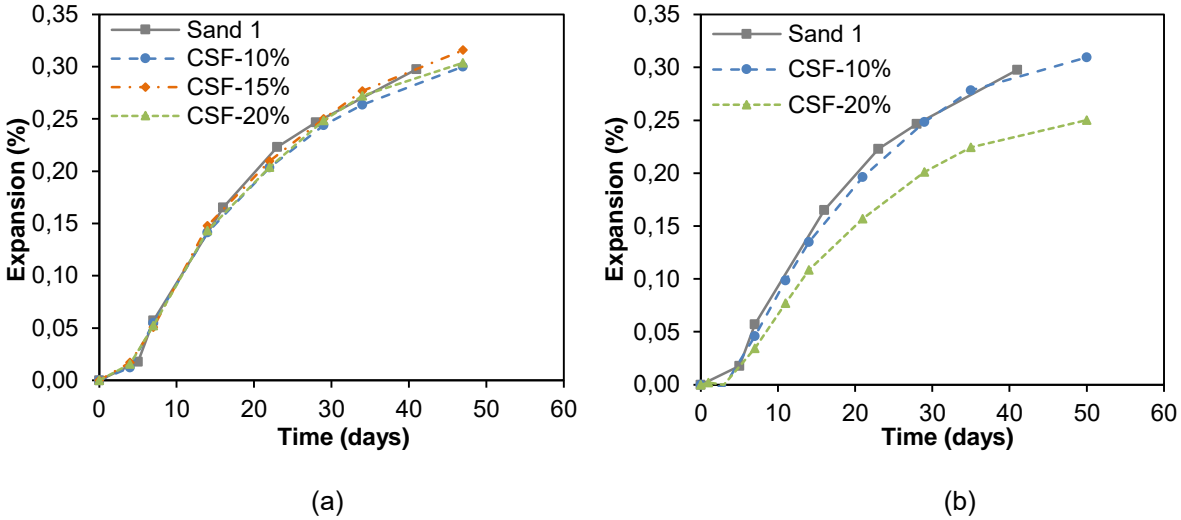
(a)

(b)

Figure 3.2: Expansion of mortar bars containing sand 1 and CSF replacing (a) the aggregate finest portions, (b) percent of the total graded aggregate.
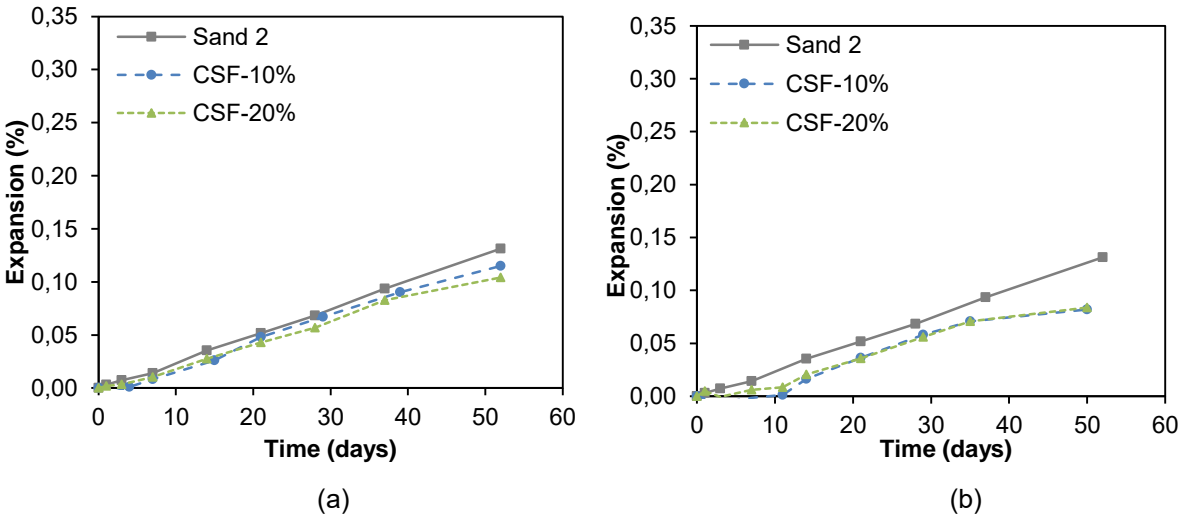

(a)

(b)

Figure 3.3: Expansion of mortar bars containing sand 2 and CSF replacing the (a) aggregate finest portions, (b) percent of the total graded aggregate.

With both sands, the expansion of mortar bars cast with 10 wt.% and 20 wt.% CSF was the same as the control sample containing no filler, as shown in Figure 3.2(a) and Figure 3.3(a), for sand 1 and sand 2, respectively, where the CSF replaced the aggregate finest portions. When the total graded aggregate was replaced with 20 wt.% CSF, the expansion was lower than that of the control samples for both sands. The difference in expansion between the samples with no filler and that with filler is outside the expected range of within-laboratory precision of 8.3% of the mean expansion stated in ASTM C1260 [9]. Reasons for this difference in expansion between the two replacement methods will be explained in Section 4.

In addition, the CSF did not show any expansion higher than sand 2 at 10 wt.% and 20 wt.% replacement levels although the CSF does contain 27 wt.% SiO_2. As for the calcium carbonate filler, CF, it did not show any expansion higher than sand 2 when used at 10 and 20 wt.% replacement of aggregate finest portions. These results are listed in Table 3.1.

Table 3.1: Expansion of mortar bars containing sand 2 and CF replacing aggregate finest portions.

Time (days)	14	28	56
Sand 2	0.035	0.068	0.131
CF-10%	0.034	0.074	0.125
CF-20%	0.034	0.072	0.115

Moving to the SH filler, both SH-C and SH-F fillers showed the same expansion when using the same replacement method, as shown in Figure 3.4. In addition, SH-C and SH-F fillers did not show any expansion higher than the control sample with no filler. This behaviour was found despite the fact that the SH filler was obtained from a highly reactive aggregate.
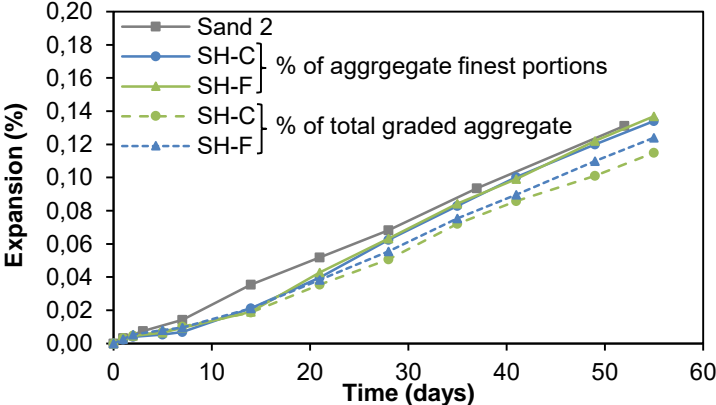
Figure 3.4: Expansion of mortar bars containing sand 2 and SH filler at 20 wt.% replacement level.

The behaviour of coarser SH filler - 70 wt.% passing 75 µm sieve and 30 wt.% passing 150 µm sieve and retained on 75 µm sieve (SH-C: 70/30) - was different as will be presented in Section 3.3. This gradation was selected since it is closer to the gradation of one of the commercial mineral fillers used here and available in the market. This will allow studying the behaviour of mineral fillers produced from reactive aggregates and of a gradation similar to some commercially available fillers.

3.3 Effect of Mineral Fillers' Size on AMBT Expansion

The effect of fillers' size on expansion of mortar bars was studied for samples cast with sand 2 and SH filler at 10 wt.% and 20 wt.% replacements from the aggregate finest portions. This replacement method was used since it showed higher expansion compared to the replacement from total graded aggregate due to the reasons explained in Section 4. The non-reactive sand 2 was used as this sand has very low expansion when tested using the AMBT. Figure 3.6(a) shows the 14-day expansion of SH filler using both gradations: (1) 100 wt.% passing 75 µm sieve (SH-C) and (2) 30 wt.% passing 150 µm sieve and retained on 75 µm sieve and the rest passing 75 µm (SH-C: 70/30). At 14 days, both fillers expanded less than sand 2. At 28 days, samples cast with SH-C filler did not show any expansion higher than sand 2 as opposed to samples cast with SH-C: 70/30 filler which expanded slightly more than sand 2 as shown in Figure 3.6(b). The difference in expansion between the samples with no filler and that with the coarser filler at 10 wt.% and 20 wt.% replacements is outside the expected range of within-laboratory precision of 8.3% of the mean expansion stated in ASTM C1260 [9] for samples made with the same materials. In other words, the difference between expansions is beyond the variability of the test when the same material is tested under the same lab conditions.

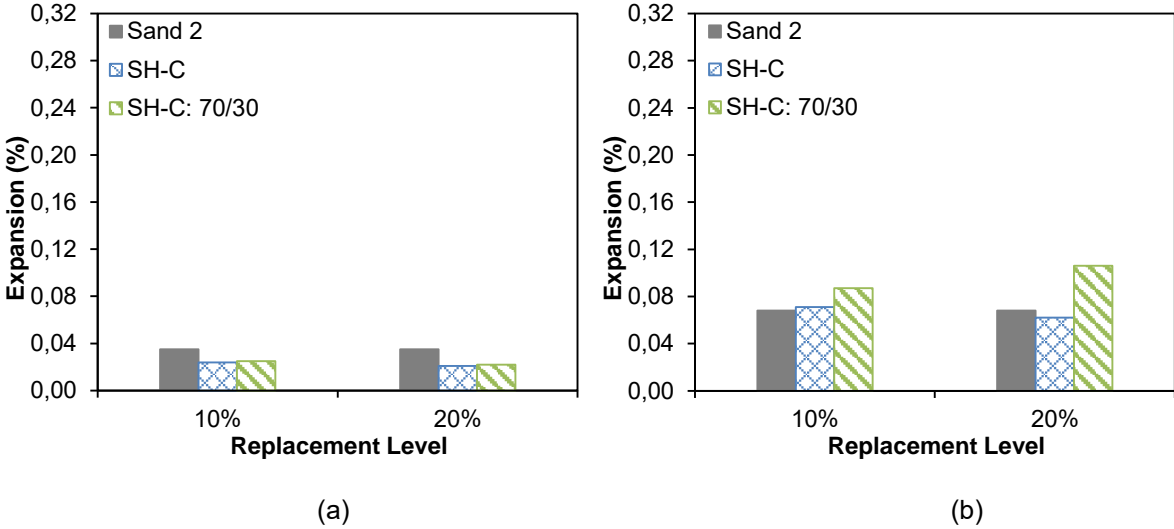(a)   (b)

Figure 3.5: Expansion of mortar bars containing sand 2 and SH filler at: (a) 14 days and (b) 28 days.

Measurements were taken until 56 days and results are shown in Figure 3.6. Extending the testing period to 56 days was adopted as shorter period of time was not enough to trigger expansions of samples with SH fillers. In fact, the expansion at 14 days for samples with fillers was lower than that of control samples, likely due to reduced permeability of the bars with fillers.
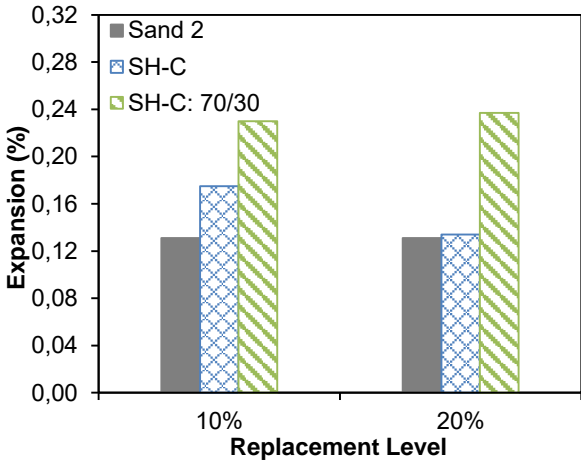

Figure 3.6: Expansion of mortar bars containing sand 2 and SH filler at 56 days.

At 20 wt.% replacement level, the filler finer than 75 μm did not show any expansion higher than sand 2 at 56 days. The coarser filler showed higher expansion compared to the control at 56 days. At 10 wt.% replacement level, the expansion of the coarser filler was higher than that of the fine filler, both showing higher expansion than sand 2. At 20 wt.%, not much increase in expansion was obtained with sand 2 and SH-C: 70/30 compared to 10 wt.% replacement level. The reasons behind the lower expansion observed in the finer filler compared to the coarser filler will be explained in Section 4. In summary, it is clear from Figure 3.6 that the coarser filler showed higher expansion than finer filler and testing at 10 wt.% might be the adequate level to evaluate the reactivity of this type of fillers. Indeed, the expansion at 56 days of samples with 10 wt.% coarse reactive filler was double that of the aggregate without filler.

3.4   Testing Reactive Mineral Fillers using CPT

Concrete prims cast with the non-reactive limestone coarse aggregate and SH fillers replacing part of the fine aggregate (sand 2) were tested at different replacement levels. The expansion results up to 2 years are presented in Figure 3.7.
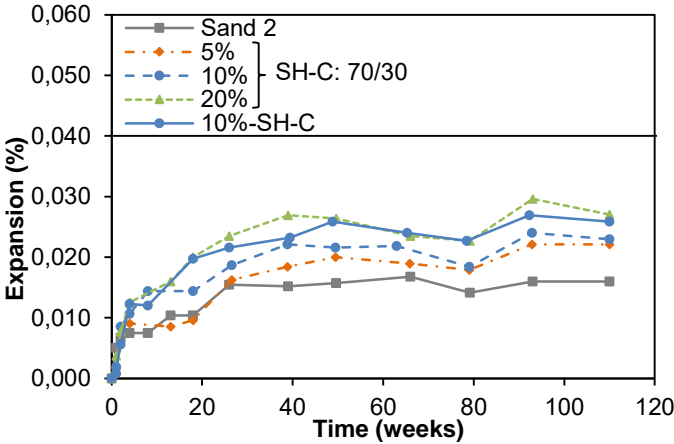

Figure 3.7: CPT expansion of prisms cast with sand 2 and SH filler at different replacement levels.

All the samples cast with SH filler showed slightly higher expansion than the control sample with the highest expansion obtained with SH-C: 70/30 filler at 20 wt.% replacement level and SH-C filler at 10 wt.% replacement level. However, none of the samples with SH filler showed expansion higher than 0.040% ℓ/ℓ, which is the expansion limit - at one year - as per CSA A23.2-14A [5]. The difference in expansion between the samples with no filler and that with SH-C: 70/30 filler at 20 wt.% replacement level and SH-C filler at 10 wt.% replacement level is outside the expected range of within-laboratory precision of 40% of the mean expansion stated in CSA A23.2-14A [5]. It should be noted, however, that the expansion values are low in all cases.

Alkalis leached from the concrete prisms to the bottom of the bucket were measured, and results are shown in Figure 3.8. With a higher replacement level of filler, the alkali leaching was decreased, likely due to reduced permeability. The lowest alkali leaching (11%) corresponds to the samples cast with 20 wt.% SH-C: 70/30 filler as in Figure 3.8, and SH-C filler at 10 wt.% replacement level (not shown in the figure). The low alkali leaching from samples with filler could have helped to trigger ASR in these samples.
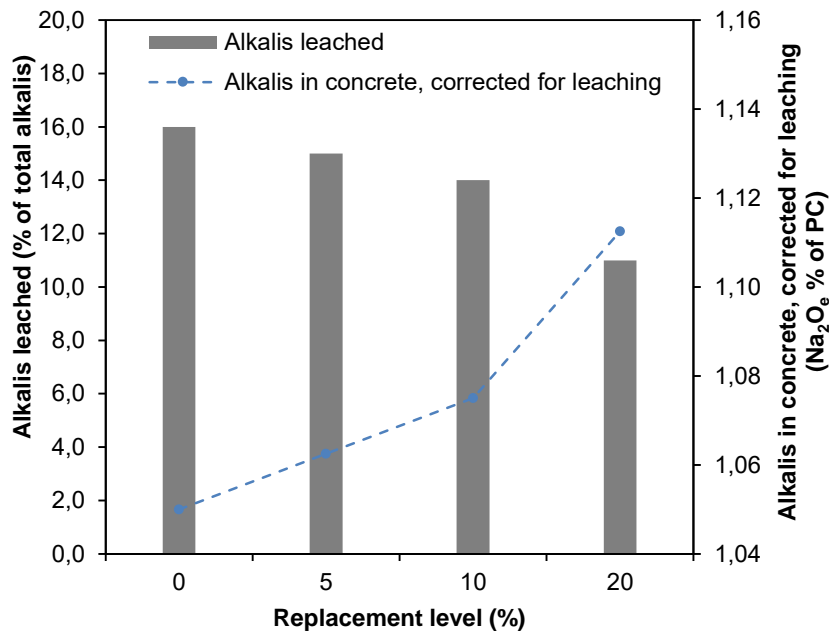
Figure 3.8: Alkalis leached and alkalis corrected for leaching in concrete prisms cast with SH filler.

3.5 Scanning Electron Microscopy Analysis

Microscopy study was performed on mortars cast with CSF and SH-C: 70/30 filler at 20 wt.% replacement level taken from aggregates finest portion. The results did not show any sign of alkali-silica gel in the CSF suggesting that the silica in this filler is not reactive. For the SH-C: 70/30 filler, evidence of ASR product - as per EDS Spectra - was found in the sample as shown in Figure 3.9 showing deposits of ASR gel in a void. The sample thickness or depth was about 10 mm as the collected mortar chunk was impregnated in epoxy and polished. Using an accelerating voltage of 20 kV is likely to result in the EDS picking up signal from deeper part of the sample, in addition to the surface. The fact that the spectra reflects a typical composition of ASR product suggests the presence of an appreciable amount of ASR gel in this void. It should be noted that the sample was not oven-dried or completely dried prior to surface polishing. Rather, the sample was kept in a desiccator at room temperature for 2 weeks. Perhaps this is the reason for the presence of thin deposits at the surface of the sample, suggesting that the sample dried under the high-vacuum used in the operation of the microscope.
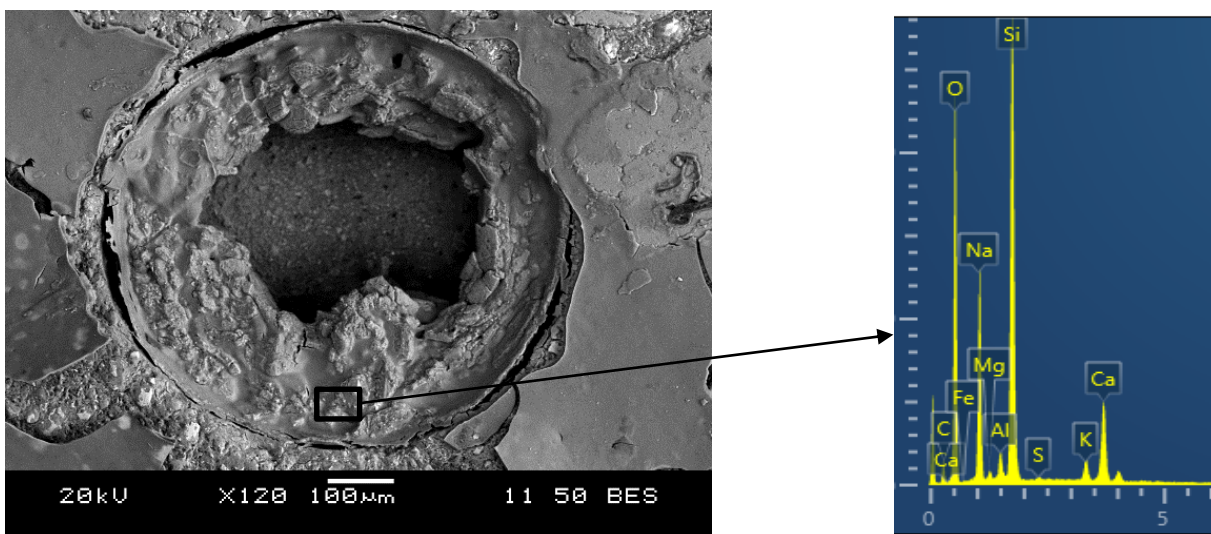

Figure 3.9: SEM-EDS results of mortars cast with SH-C: 70/30 filler at 20 wt.% replacement from aggregate finest portions.

4.   DISCUSSION

Two replacement methods of aggregates with fillers were studied in this research to understand their effect on expansion. Replacing the aggregates finest portion - in the AMBT - with filler showed higher expansion than replacing the total graded aggregates. A possible reason behind the difference in expansion between the two replacement methods is that when mineral fillers replace part of the whole aggregates, the amount of small particles increases leading to lower permeability of the bars, and hence lower penetration of the alkaline soaking solution resulting in less expansion.

In terms of testing the reactivity of fillers using the AMBT, the mortars cast with the carbonate-silicate filler did not show any expansion higher than mortars with no filler. This could lead to the conclusion that the silica content might not be enough to cause expansion or is not reactive. Another possible reason could be that the filler is fine enough to the level that does not cause expansion. In case of the SH siliceous filler produced from reactive aggregate, the lower expansion in the sample with the finer filler compared to the coarser filler at 10 and 20 wt.% replacement levels could be a result of the reduced permeability due to finer gradation of the total aggregate with the fine filler hindering the alkalis in the host solution from penetrating the sample. Moreover, the larger surface area of the finer filler might slow the expansion due to a required large amount of alkalis needed to trigger expansion, particularly at relatively high level of replacement, 20 wt.%. In other words, at high level of filler, the reduced permeability coupled with a larger surface area of reactive particles might slow down the reaction and expansion.

Using the CPT, concrete prisms cast with the siliceous filler showed slightly higher expansions compared to the concrete prisms without fillers. In the CPT, the alkalis are relatively limited and are available inside the samples, unlike the case with the AMBT. The relatively low expansion of prisms with filler - compared to the results obtained using the AMBT - could be due to the limited alkalis in the prisms which might not be enough to trigger a high level of reaction with the reactive filler. Many studies have shown that some aggregates have a pessimum effect [15, 22–25]. This pessimum effect depends on many factors such as the reactive silica content, the alkali level, and the aggregate size. In a study by Pedersen, a siliceous filler exhibited a pessimum effect when tested using the CPT, showing an increase in expansion up to 5 vol.% replacement level, after which there is no further increase [15]. In this paper, the pessimum effect was not observed with the SH siliceous filler, within the replacement levels tested here. While the expansion obtained for prisms cast with filler was still lower than the 0.040% ℓ/ℓ expansion limit of the CPT, the issue is if such filler is used in concrete with an aggregate that marginally meets the 0.040% ℓ/ℓ expansion limit. In such a case, the expansion of the CPT might exceed the limit, and, more importantly, the use of filler in concrete may cause cracking to the structures. In addition, external sources of alkalis from de-icers and/or release of alkalis from alkali-bearing aggregates could increase the concrete pore solution alkalinity, which could potentially trigger the expansion in the concrete cast with reactive fillers [18, 26]. In summary and based on the materials tested here, the AMBT could be used to test the reactivity of mineral fillers. Some modifications to the standard AMBT test should be considered, including:

1)   Increasing the testing duration to 56 days instead of 14 days,

2)   Using superplasticizer to maintain workability, if needed,

3)   Replacing part or the whole finest portion(s) of total aggregate with filler, and

4)   Testing the filler at 10 wt.% and 20 wt.% replacement levels with control sand of an expansion < 0.10% ℓ/ℓ at 14 days in the AMBT.

If the expansion of any of the samples with filler at any of the replacement levels is greater than 8.3% of the expansion of non-reactive sand at 56 days (both tests should be done at the same lab under the same conditions), the filler is deemed to be reactive and should not be used in concrete without appropriate preventive measures. If the filler is to be used, the efficacy of preventive measures should be evaluated using the CPT.

5.   CONCLUSIONS

Based on the materials tested in this paper, the following conclusions are drawn:

1)   The standard AMBT could be adopted to test the reactivity of fillers. However, the testing duration should be increased to 56 days, and the expansion of samples cast with fillers should be compared to that of a non-reactive control sample.

2) Replacing the aggregate finest portions with filler gives higher expansion in the AMBT compared to replacing the total graded aggregate. Both methods showed the same effect on workability.

3) Using the AMBT adopted here, commercially available carbonate or carbonate-silicate filler did not show excess expansion, compared to samples with no fillers, when used at partial replacements of 10 wt.% or 20 wt.% of the total aggregate.

4) Samples cast with the reactive siliceous filler having 30 wt.% of its material between 150 μm and 75 μm and the rest finer than 75 μm expanded more than the control sample at 10 wt.% and 20 wt.% replacement levels at 56 days.

5) Samples cast with reactive siliceous filler finer than 75 μm showed higher expansion at 56 days than samples with no filler at 10 wt.% replacement level, but not at 20 wt.%. The lack of excessive expansion at 20 wt.% of this fine filler is likely due to the low permeability of the mortar and larger area of reactive silica sites requiring a high level of alkalis to trigger the reaction.

6) With the CPT, samples cast with the reactive siliceous filler showed slightly higher expansion compared to the control sample.

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