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EFFECT OF GRADATION AND REPLACEMENT LEVEL ON ALKALI-SILICA REACTIVITY OF MINERAL FILLERS

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Mineral fillers are used in concrete for a number of reasons, which include achieving self-consolidation properties. Different fillers are available depending on the type of the original rock. Alkali-silica reaction might occur if the filler is produced from a reactive rock. The present research focuses on evaluating the applicability of the current accelerated mortar bar test, described in ASTM C1260 and CSA A23.2-25A, in evaluating their reactivity. Three different fillers are used: a calcium-carbonate filler, a carbonate silica filler with 27% SiO_2, and a siliceous filler produced from reactive aggregate. Two different gradations of the filler obtained from reactive aggregate are tested: 1) Gradation finer than 75 µm; 2) Gradation with 30% passing 150 µm sieve but is retained on 75 µm sieve and remaining 70% passing 75 µm. Results showed that the calcium-carbonate filler and the carbonate silica filler did not show any expansion higher than the non-reactive sand, while the filler obtained from reactive aggregate did not show expansion higher than the control at 14 days for both gradations, with the expansion showing at later age. This might be due to the high surface area of fillers and the reduced permeability affecting the rate of expansion. Hence, the need to extend the testing period beyond the 14-day specified in the standard to be able to see the expansion.

Keywords: Accelerated mortar bar test, Concrete prism test, ASR, Expansion, Permeability.

1 INTRODUCTION

Alkali-silica reaction (ASR) is a chemical reaction between the silica present in the aggregate and the alkaline pore solution of the concrete. This reaction leads to the formation of a hygroscopic gel that tends to swell in the presence of moisture. The swelling-gel exerts pressure on the concrete leading to cracks and deterioration (Lindgård *et al.* 2012). Many preventive measures are being implemented in order to avoid the damage associated with this reaction, such as the use of supplementary cementing materials and lithium-based compounds (Thomas *et al.* 2006). In addition to their fine size, supplementary cementing materials such as fly ash, slag, and silica fume act as an alkali diluent by substituting a portion of the cement and have a high alkali binding capacity due to their pozzolanic nature (Kandasamy and Shehata 2014).

Several test methods are available to evaluate the reactivity of aggregates. First, the concrete prism test (CPT), described in the American and Canadian standards (ASTM C1293/CSA A23.2-14A), specifies an expansion limit of 0.040% at 1 year above which the aggregate is considered reactive. The accelerated mortar bar test (AMBT), described in ASTM C1260 and CSA A23.2-25A, is another faster test method consisting of soaking mortar bar samples in an alkaline solution

and measuring expansion for 14 days with an expansion limit for this test equal to 0.10%. While these two tests are commonly used for testing the reactivity of aggregates, there is no standard test available to evaluate the reactivity of fillers.

Mineral fillers are one of the additives used in self-consolidating concrete (SCC) (Sinno and Shehata 2017) to maintain cohesiveness and stability of the mix (Uysal 2012). SCC is characterized as having high flowability properties and ability to be poured without vibration, while avoiding bleeding and segregation (Khayat 1999). Applications of SCC include its use in areas with congested reinforcement or in the repair of structural elements such as beams and slabs when reaching the repair area is inaccessible (Khayat 1999, Murthy *et al.* 2012). Some types of mineral fillers might have a potential to cause expansion due to alkali-silica reaction (Pedersen 2004). Hence the need of modified test methods to evaluate fillers' reactivity before using them.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Fine aggregates used in this study are of a non-reactive sand type having a fineness modulus equal to 2.64. The cement used is a Type GU cement of 0.99% Na_2O_e having a chemical composition as shown in Table 1.

Table 1. Chemical composition of Type GU cement.

Oxide	GU Cement (Mass %)
SiO_2	19.54
Al_2O_3	5.21
Fe_2O_3	2.16
CaO	62.39
MgO	2.39
SO_3	4.03
Na_2O_e	0.99
Loss on Ignition	2.36

Three mineral fillers are tested in this paper covering different ranges of silica content. The first is a calcium-carbonate filler composed of 94% calcium carbonate and 2.5% magnesium carbonate. The median diameter of this filler is 21 µm having 10% passing 150 µm sieve and retained on 75 µm sieve and the rest is finer than 75 µm. The second is a carbonate silica filler containing 27% SiO_2. This filler has a median diameter of 40 µm with 30% passing 150 µm sieve and retained on 75 µm sieve and the rest finer than 75 µm. These two fillers are commercially available and their particle size distributions are presented in Figure 1.

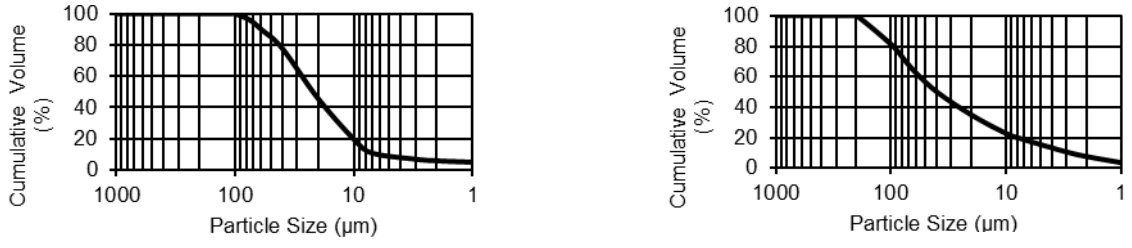


Figure 1. Particle size distribution of (a) carbonate filler and (b) carbonate silica filler.

The third filler is produced from reactive aggregate and is obtained by crushing a highly reactive coarse aggregate with an expansion of 0.22% at 1 year and 0.46% at 14 days using the CPT and AMBT respectively. This filler was crushed and used in two different gradations: the fine filler with all particles passing 75 µm sieve and the coarse filler having 70% passing 75 µm sieve and 30% passing 150 µm sieve and retained on 75 µm sieve. The crushing procedure is explained in next section.

2.2 Experimental Procedure

2.2.1 Crushing of filler obtained from reactive aggregate

Coarse aggregate was crushed using the jaw crusher until all passed 4.75 mm sieve. Then, the crushed aggregate was sieved on the different fine sieves, and each portion, starting with the coarser size, was crushed using the pulverizer and sieved again until all what is on the sieve passed. This is done for all the different sieve sizes until enough filler passing 150 µm sieve and retained on 75 µm sieve and passing 75 µm sieve is obtained.

2.2.2 Sample preparation

The gradation of the mortar bars is as specified in the ASTM C1260. Each set of mortar bars required 990 g of fine aggregate and 440 g of cement. The gradation of the fine aggregate is shown in Table 2.

Table 2. Grading requirements as per ASTM C1260.

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

The fillers were tested at 10% and 20% replacement levels taken from the finest portion of sand. As an example, for 10% replacement level (RL), 10% from the fine aggregate passing 300 µm sieve and retained on 150 µm sieve was replaced by filler leaving 5% sand of this size. The required masses of the sand and fillers are shown in Table 3.

Table 3. Sample preparation for different replacement levels.

Passing	Retained on	Masses required (g)		
		Control	10% RL	20% RL
4.75 mm	2.36 mm	99	99	99
2.36 mm	1.18 mm	247.5	247.5	247.5
1.18 mm	600 µm	247.5	247.5	247.5
600 µm	300 µm	247.5	247.5	198
300 µm	150 µm	148.5	49.5	0
Filler		0	99	198

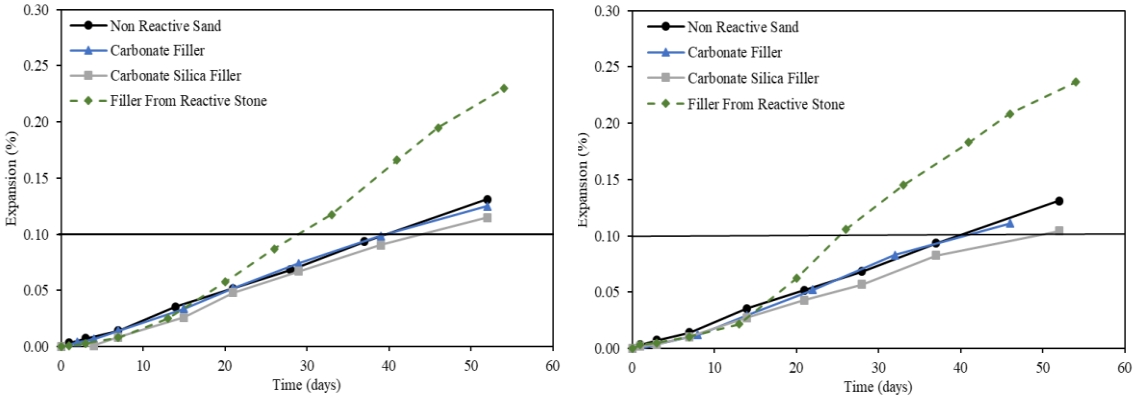
For the filler produced from reactive aggregate, the amount of filler obtained from the table is divided into 30% passing 150 µm sieve and retained on 75 µm sieve and the rest 70% is passing 75 µm sieve to reach the coarse gradation.

2.2.3 Mixing and placing of mortar bars

A water to cement ratio of 0.47 was used for all the samples which were mixed using the procedure described in ASTM C305. Upon finishing the mixing, the mortar bars were cast in molds of 25 x 25 x 285 mm dimension and cured for 24 hours. The following day, they were put in water preheated at 80ºC as required by the standard. Twenty-four hours later, the samples were soaked in 1M NaOH solution and measurements were taken for the next 56 days.

3 RESULTS AND DISCUSSIONS

The expansion of mortar bars was measured and the average of three mortar bars for each set was used in this study. Figure 2 presents the expansion data of the carbonate filler, carbonate filler with silica content and filler obtained from reactive aggregate with the coarse gradation at 10% and 20% RLs. The horizontal line shows the 0.10% limit specified in ASTM C1260 and CSA A23.2-25A.



(a) (b)

Figure 2. Expansion data of the fillers at (a) 10% RL and (b) 20% RL.

As shown in Figure 2, the carbonate filler and the carbonate silica filler did not show any expansion higher than the non-reactive sand. At 14 days, the expansion was 0.035% for the non-reactive sand compared to 0.034% and 0.026% for the carbonate and carbonate silica fillers. Both fillers had an expansion below the limit of 0.10% specified in the standard. It can be concluded that the silica present in the carbonate silica filler might not be enough to cause expansion or it might not be reactive. When the expansion was measured for 56 days, no expansion higher than the non-reactive sand was obtained. A similar behavior was observed at 20% RL as shown in Figure 2-b). In addition, the filler obtained from reactive aggregate showed expansion higher than the non-reactive sand for 10% and 20% RLs at 56 days. The expansions at 10% and 20% RLs were almost the same with 0.23% and 0.24% respectively. This might be due to the reduced permeability of the increased amount of fine materials at 20% RL hindering the alkalis in solution to reach inside the core which will block further expansion.

Expansion data for the filler obtained from reactive aggregate at 14 days was presented in Figure 3 for the two different gradations.

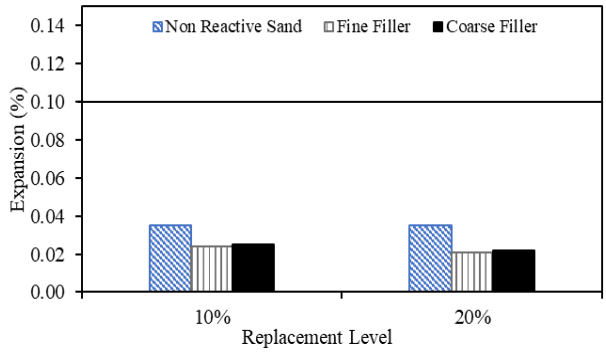


Figure 3. Expansion data of the filler obtained from reactive aggregate at 14 days.

The filler obtained from reactive aggregate did not show any expansion higher than the non-reactive sand at 14 days. The filler with both gradations had an expansion below 0.10% limit specified at 14 days. Measurements were taken for 56 days as shown in Figure 4.

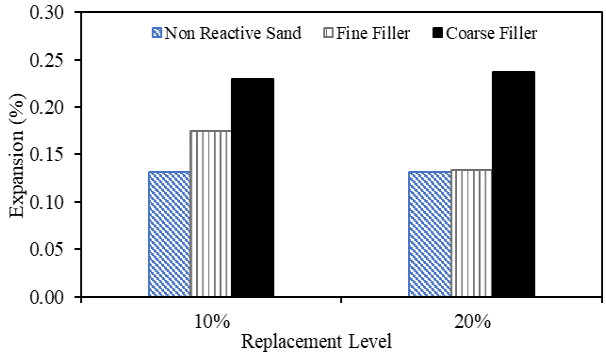


Figure 4. Expansion data of the filler obtained from reactive aggregate at 56 days.

For the filler finer than 75 µm at 20% RL, no expansion higher than the non-reactive sand was observed. However, with the same filler but coarser gradation, an expansion of 0.24% compared to 0.13% for the non-reactive sand was obtained after 56 days. The difference in expansion between the same filler with different gradations might be due to the fact that the larger surface area might result in very low disruptive expansion or it might slow the expansion due to the required large amount of alkali needed to trigger the expansion. The latter reason could be the explanation of why the expansion took place at later age. Moreover, the reduced permeability due to the filler's fine size might hinder the alkalis in solution to reach inside the core.

At 10% RL, the expansion of the coarse filler was 0.23% at 56 days as compared to 0.13% for the non-reactive sand. In addition, the expansion of the finer filler at 10% RL, was lower than the coarse filler at the same RL. This might also be due to the reduced permeability.

In order to better understand whether the filler either lost reactivity when grinded to small size, or its permeability was reduced due to the addition of the filler, concrete prisms were tested using the concrete prism test. At the end of this test, any modifications needed in order to use the

accelerated mortar bar test to evaluate fillers, such as extending the testing period to beyond, 14 days will be assessed. At the time of writing this paper, concrete prism tests were still ongoing.

4 CONCLUSION

Potentially reactive fillers need to be tested for expansion due to ASR before implementing them in concrete. With the carbonate silica filler studied in this research, no expansion was observed higher than the control. This might be due to the fact that the size of the filler might have affected its reactivity or the silica present in the filler is not reactive. In addition, the filler obtained from a reactive aggregate did not show any expansion above 0.10% limit at 14 days. At 56 days, the fine filler did not show any expansion higher than the control at 20% RL. However, the coarser filler showed expansion higher than the non-reactive sand at both replacement levels. This suggests that the larger surface area might affect the fillers reactivity and reduce the permeability of the samples. The expansion was not observed at 14 days as specified in the standard, hence the testing period was extended to 56 days. Concrete prims are being monitored to understand whether grinding to very fine size affects reactivity of the filler or the permeability of the mortar bars.

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