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Strength and Durability of Mortars Containing Silica-Breccia

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Abstract: Silica-breccia, also known as Aplite, is a newly discovered supplementary cementing material (SCM) that has shown to have some pozzolanic effect when mixed with cement. Like any other SCM, pulverized silica-breccia reacts with the calcium hydroxide formed during portland cement hydration, creating additional cementitious products that modify the mixture structure and enhance its overall strength and durability performance. The objective of this study was to investigate the strength and durability of mortar samples incorporating silica-breccia. The strength and durability properties of other SCM's including fly ash, metakaolin, silica fume, and slag were also investigated for comparison. The strength and durability performance was evaluated based on the results of the pozzolanic activity index, compressive strength of hydraulic cement mortars, sodium sulfate attack, and the alkali-silica reactivity tests. The results showed that the replacement of cement by 10% silica-breccia increased the compressive strength and decreased the expansions due to sulfate attack and alkali-silica reactivity.

1. Introduction

The use of supplementary cementing materials (SCM's) such as ground granulated blast furnace slag, fly ash, metakaolin, and/or silica fume has become common in the production of concrete because of their superior effect in enhancing the mixture strength and durability. SCM's are incorporated to produce impermeable and dense concrete (Boddy et al. 2000). SCM's are classified as low reactive (limestone powder), cementitious (natural cement and hydraulic lime), pozzolanic (silica fume and class F fly ash), and both cementitious and pozzolanic (ground granulated blast-furnace slag and class C fly ash). The incorporation of one or more types of the SCM's, together with a low water-to-cement ratio (usually a superplasticizer is used in these mixes and sometimes with very high dosage to maintain adequate workability), has been proven to greatly improve the microstructure over that of concrete with ordinary water-to-cement ratio (Larbi 1993). Furthermore, the SCM particles have a very high surface area, which consume part of the mixing water to get their surface wet, results in a very little free water left in the mixture for bleeding. In addition, the SCM improves the concrete microstructure by means of either filler effect and/or chemical effect in the form of pozzolanic reaction (Mehta 1981).

At early ages, the filler effect of SCM is responsible for the improvement in densification of the microstructure. The SCM improves packing of the hydration products especially around the aggregate particles. At later ages, the chemical effect (pozzolanic reaction) adds to the improvement of the microstructure. The pozzolanic reaction of SCM is caused mainly by its reaction with the calcium hydroxide crystals (the main by-product from the hydration of normal cement) that previously nucleated around the SCM particles (Larbi 1993). The pozzolanic reaction produces more calcium silicate hydrate (C-S-H) gel, which is the main cementitious product from the hydration of normal cement. C-S-H effectively ties together the hydration products and the unhydrated cement particles leading to a more homogeneous and denser matrix. SCM that has higher pozzolanic activity is believed to be more effective in reducing the concrete porosity (Sadok et al. 2011).

Silica-breccia, or Aplite, is a recently discovered SCM that showed some pozzolanic effect when mixed with cement. Similar to other commercially available SCM's, pulverized silica-breccia reacts with the calcium hydroxide formed during portland cement hydration, creating additional cementitious products that modify the mixture structure and enhance its overall mechanical and durability performance. Recently, one of the largest deposits of silica-breccia was discovered in Finnvolldalen, Norway, yielding large volumes that make silica-breccia an economical choice for use in cement mixtures.

Over the past few years, a number of tests were performed on silica-breccia to investigate its reactivity when mixed with cement. The preliminary test results showed a noticeable improvement in compressive strength, expansion due to alkali-aggregate reaction, and pozzolanic activity with lime. Silica-breccia also proved to be beneficial for oil well cement industry. Tests on cement mixed with silica-breccia under elevated temperature and high pressure showed some resistance towards CO_2 attack as well as improvement in the mechanical and shrinkage properties.

The purpose of this study was to examine the feasibility of using a developed silica-breccia product as an alternative SCM in the production of mortar and concrete. The significance of this research project is the introduction of a new SCM that achieves comparable strength at relatively low costs compared to other commercially available SCM's. Furthermore, the study investigated the durability performance of the new material compared to other commercially available SCM's, when mixed with cement.

2. Experimental Program

This research focused on developing a silica-breccia product having an acceptable pozzolanic activity that allows this product to be used widely as an alternative SCM in cement mixtures. Tests on other SCM's including fly ash (FA), silica fume (SF), slag (SG), and metakaolin (MK) were also conducted on counterpart specimens for comparison. The newly developed silica-breccia product was tested for effectiveness as an SCM, based on the Canadian Standard Association (CSA) test methods prior to acceptance. The research program was completed in the following two stages:

Stage 1: Investigate the Pozzolanic Activity Index for Different Silica-Breccia Samples

At this stage, different silica-breccia samples, having different genesis, different degrees of pulverization, and different burning temperature were tested for pozzolanic activity according to CSA test method (CSA A3004-E1), in order to select some successful samples for further investigation. Additional fly ash, silica fume, slag, and metakaolin samples were also tested under the same condition for comparison. During this stage, different techniques were applied to maximize the strength obtained from the pozzolanic activity test. The target was to achieve a minimum strength of 5.5 MPa after 7 days of an accelerated curing period as per CSA A3004-E1. These techniques included the following activities:

- Testing the pozzolanic activity index of silica-breccia samples having different particle sizes (<75, <45, and <20 µm).
- Testing the pozzolanic activity index of silica-breccia samples blended with calcite.
- Testing the pozzolanic activity index of silica-breccia samples burned at different temperatures (500, 700, and 900° C).

Stage 2: Investigate the Durability Performance for the Selected Silica-Breccia Samples

At this stage, selected silica-breccia samples from the first stage were tested for durability performance. The evaluation of the durability performance was based on the alkali-silica reactivity test and sulfate resistance test; the tests were performed according to CSA standards, CSA A23.2-25A and CSA 3004-C8, respectively. Additional fly ash, silica fume, slag, and metakaolin samples have been also tested; under the same conditions for comparison.

2.1 Materials

In this program, type GU Canadian Portland cement similar to ASTM Type I, with a specific gravity of 3.15, was used for mortar mixtures. Natural sand was used for production of mortar mixtures for alkali-silica reactivity and sulfate resistance tests. In addition, silica sand was included as fine aggregate for pozzolanic activity mixtures. The natural and silica sand each had a specific gravity of 2.70 and water absorption of 1%. The MK used was delivered from the Eastern United States by Advanced Cement Technologies, conforming to ASTM C618 Class N. The SG, and SF used in this investigation were similar to ASTM Type I. A high range water reducer admixture (HRWRA), similar to ASTM Type F (ASTM C494), was applied to control the water-to-binder ratios. The specific gravity, volatile weight, and pH of the HRWRA were 1.2, 62%, and 9.5, respectively. For the first set of tests, eleven silica-breccia (SB) samples with varying chemical properties were chosen. These eleven SB samples were initially used for the pozzonaic activity tests and are shown in Table 1.

The selection of the samples was done to obtain samples that had similar chemical compositions compared to FA, SG, SF, and MK. For example, Samples I501 and I601 have the highest percentage of SiO_2, I656 and I657 have the highest percentage of Al_2O_3, I548 and I625 have the highest percentage of Fe_2O_3, and I644 has the highest percentage of CaO. The grain size for the eleven chosen SB samples was kept constant at 75 µm. In addition, all these samples had a constant specific gravity of 2.7. The chemical properties of other SCM's as well as cement can be seen in Table 2. Table 3 shows the physical properties of cement and the used SCM's as well as a selected SB sample (sample # 6) ground to different particle size. Finally, the burned samples at 500, 700, and 900° C have the same chemical and physical properties as that of sample # 6 with 75 µm.

Table 1: Chemical Properties for the Eleven Selected SB (75 µm) Samples for Stage 1

Chem. Prop. %	# 6	I501	I548	I553	I581	I582	I601	I625	I644	I656	I657
SiO_2	82.10	90.66	58.72	65.20	85.49	78.44	92.60	50.60	17.50	68.40	67.10
Al_2O_3	8.78	5.09	11.49	9.92	7.17	8.40	3.60	15.80	7.58	17.10	18.11
Fe_2O_3	0.82	0.88	8.40	5.65	0.95	2.72	0.39	8.97	2.07	1.29	1.60
CaO	0.83	0.71	9.59	11.10	1.48	2.81	0.24	11.90	43.40	1.01	1.60
MgO	0.04	0.17	6.19	4.19	0.36	1.53	0.07	6.85	0.87	0.25	0.36
Na_2O	2.33	1.58	0.37	0.07	1.76	1.11	1.24	0.07	<0.01	5.71	5.89
K_2O	3.10	1.35	1.93	0.77	2.51	2.50	1.07	1.86	0.03	5.41	5.30
Cr_2O_3	<0.01	0.01	0.02	0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.01
TiO_2	0.03	0.05	1.14	0.78	0.10	0.32	0.13	1.16	0.65	0.14	0.18
MnO	0.02	0.02	0.13	0.10	0.03	0.06	0.02	0.13	0.05	0.03	0.04
P_2O_5	<0.01	0.01	0.18	0.11	0.02	0.05	0.01	0.19	0.08	0.04	0.05
SrO	0.01	0.02	0.04	0.04	0.03	0.04	0.02	0.04	0.09	0.06	0.07
BaO	0.03	0.05	0.05	0.02	0.06	0.05	0.02	0.07	0.03	0.17	0.17
L.O.I.	0.70	0.27	2.43	1.73	0.46	1.29	0.12	3.55	28.7	0.64	0.74
Total	98.80	100.90	100.70	99.69	100.40	99.32	99.40	101.00	101.00	100.30	101.00

Table 2: Chemical Properties for Other SCM's and Cement Used for Stage 1

Chemical Properties %	Cement	MK	SG	SF	FA
SiO_2	19.64	51-53	40.30	>85	52
Al_2O_3	5.48	42-44	8.40	-	23
Fe_2O_3	2.38	<2.2	0.50	-	11
FeO	-	-	-	<5	-
TiO_2	-	<3.0	-	-	-
C	-	-	-	<10	-
P_2O_5	-	<0.2	-	-	-
SO_4	-	<0.5	-	-	-
CaO	62.44	<0.2	38.71	<5	5
MgO	2.48	<0.1	11.06	<5	-
Na_2O	-	<0.1	-	-	-
C_3S	52.34	-	-	-	-
C_2S	16.83	-	-	-	-
C_3A	10.50	-	-	-	-
C_4AF	7.24	-	-	-	-
K_2O	-	<0.4	0.37	-	-
L.O.I.	2.05	<0.5	0.65	-	-

Table 3: Physical Properties for the Samples Studied in Stage 1

Physical Properties	# 6 (75 µm)	# 6 (45 µm)	# 6 (30 µm)	# 6 (20 µm)	Cement	MK	SG	SF	FA
Specific Gravity	2.70	2.70	2.70	2.70	3.15	2.56	2.89	2.27	2.26
Grain Size (µm)	75	45	30	20	45	60	45	30	75
Color	Greyish White	Greyish White	Greyish White	Greyish White	Grey	Pink	Greyish White	Black	Greyish Dark

2.2 Mixtures Design and Tests Procedure

Three different mortar mixtures were used for the three different tests (pozzolanic activity index, alkali-silica reactivity test, and sulfate resistance test). The mixture proportions of each mortar mixtures containing silica-breccia and different SCM's are described in detail as follows:

2.2.1 Pozzolanic Activity Index Test

The pozzolanic activity test involved mixing a small batch of mortar consists of hydrated lime, silica sand, and the mineral admixture. The amount of each material and the amount of water was specified as per CSA A3004-E1 standard. After mixing, the samples were stored in a moist room at 23 ± 2° C for 24 ± 2 hours. After this time the samples were removed from the moist room then sealed and stored at 55 ± 2° C for 7 days until the time of the test.

For the pozzolanic activity test the following considerations were taken:

- The mortar contained 1 part hydrated lime and 9 parts silica sand by mass, in addition to an amount of the mineral admixture equal to twice the mass of the lime multiplied by a factor obtained by dividing the density of the mineral admixture by the density of the lime.

- The amount of mixing water, measured in mL, was determined to be enough to produce a flow of 100 ± 5% in accordance with ASTM C109.
- A sufficient quantity of mortar was mixed to form at least three 50 x 50 x 50 mm cube specimens.

The mixture proportions for the eighteen different mortar mixtures, including fourteen selected SB samples and four other SCM's samples, are shown in Table 4.

Table 4: Mixture Proportions for the Pozzolanic Activity Test Mixtures in Stage 1

Sample	W/B	Hydrated Lime (gm)	HRWRA (mL)	Flow (mm)	Silica Sand (gm)	SCM (gm)	Water (mL)
I501	0.585	53.51	-	214	481.59	138.72	113.42
I548	0.590	53.51	-	206	481.59	138.72	113.42
I553	0.570	53.51	-	207	481.59	138.72	113.42
I581	0.585	53.51	-	211	481.59	138.72	113.42
I582	0.575	53.51	-	214	481.59	138.72	113.42
I601	0.570	53.51	-	210	481.59	138.72	113.42
I625	0.600	53.51	-	209	481.59	138.72	113.42
I644	0.570	53.51	-	210	481.59	138.72	113.42
I656	0.590	53.51	-	205	481.59	138.72	113.42
I657	0.585	53.51	-	206	481.59	138.72	113.42
SB # 6 <20 µm	0.600	53.24	-	205	479.13	138.01	114.75
SB # 6 <30 µm	0.580	53.79	-	207	484.07	139.43	112.07
SB # 6 <45 µm	0.590	53.51	-	210	481.59	138.72	113.42
SB # 6 <75 µm	0.590	53.51	-	212	481.59	138.72	113.42
FA	0.650	53.96	1.50	209	485.68	117.10	111.19
MK	0.800	48.99	3.80	205	440.89	120.41	135.52
SG	0.600	52.42	-	210	471.80	145.46	118.73
SF	0.800	50.46	4.40	205	454.11	109.97	128.34

2.2.2 Alkali-Silica Reactivity Test

The alkali-silica reactivity test involved mixing a mortar batch for moulding at least three bar specimens (25 x 25 x 127 mm). After 24 hours of mixing, the specimens were removed from the mould and the initial length was measured by means of a standard length comparator. The change in the length of the specimens was then measured after 24 hours submergence in water at 80° C ± 2° C. The samples were then submerged in a preheated sodium hydroxide (1N NaOH) for a period of 14 days at 80° C ± 2° C. The rate of expansion at 2, 7, and 14 days was calculated as specified in the CSA standards, CSA A23.2-25A. For the alkali-silica reactivity test the following considerations were taken:

- The mortar contained 1 part binding material (cement and SCM) and 2.25 parts graded sand by mass.
- The water to binder ratio was kept constant (0.44) as specified in CSA standards, CSA A23.2-25A.
- A sufficient quantity of mortar was made to mold at least three (25 x 25 x127 mm) prism specimens.

The mixture proportions for the nine different mortar mixtures, including control, four selected SB samples and four other SCM's samples, are shown in Table 5.

Table 5: Mixture Proportions for the Alkali-Silica Reactivity Test Mixtures in Stage 2

Sample	W/B	Replacement Level %	Cement (gm)	Graded Sand (gm)	SCM (gm)	Water (mL)
Control	0.44	-	97.81	266.63	-	135.56
FA	0.44	30	66.92	260.60	39.97	132.50
MK	0.44	20	77.55	264.24	23.86	134.35
SG	0.44	30	68.11	265.23	31.81	134.85
SF	0.44	8	89.44	265.02	10.79	134.75
SB # 6 <20 µm	0.44	10	87.74	265.76	11.37	135.12
SB # 6 <30 µm	0.44	10	87.74	265.76	11.37	135.12
SB # 6 <45 µm	0.44	10	87.74	265.76	11.37	135.12
SB # 6 <75 µm	0.44	10	87.74	265.76	11.37	135.12

2.2.3 Sulfate Resistance Test

In this test, the change of length of six mortar bars (25 x 25 x 127 mm) representing each tested specimen was monitored as specified in CSA standard, CSA 3004-C8. The mortar bars were cured at a 35° C water bath until their companion cubes reached a minimum strength of 20.0 ± 1.0 MPa. The companion cubes were made from the same specimen batch and were tested at different times until their strength reaches 20.0 ± 1.0 MPa. The mortar bars were then stored in a sodium sulfate solution (Na_2SO_4) for up to one year with measurements taken at the specified intervals. The reading increments included 1, 2, 3, 4, 8, 13, and 15 weeks after the placement of the bars in the sulfate solution. Subsequent readings were taken at 4, 6, 9, and 12 months. For the sulfate resistance test the following considerations were taken:

- The mortar consisted of 1 part binding material (cement and SCM) and 2.75 parts graded sand by mass.
- The water to binder ratio was kept almost constant (around 0.45) as specified in the CSA standards, CSA 3004-C8; however, the flow table test was performed after mixing to maintain the same flow diameters for all mortars, according to ASTM C230 standard.
- A sufficient quantity of mortar was made to pour at least six (25 x 25 x 127 mm) prism specimens and about 21 (50 x 50 x 50 mm) companion cube specimens.
- The percentages of cement replacement by SCM's were chosen based on the optimum replacement levels from the literature.

The mixture proportions for the nine different mortar mixtures, including control, four selected SB samples, and four other SCM's samples, are shown in Table 6.

Table 6: Mixture Proportions for the Sulfate Resistance Test Mixtures in Stage 2

Sample	W/B	Repl. Level %	Cement (gm)	HRWRA (mL)	Flow Table (mm)	Graded Sand (gm)	SCM (gm)	Water (mL)
Control	0.49	-	1100	-	215	3020	-	530
FA	0.46	30	750	-	205	2960	320	500
MK	0.49	20	870	5.00	208	3000	220	530
SG	0.46	30	880	-	208	3010	220	500
SF	0.49	8	1000	4.00	205	3000	90	530
SB # 6 <20 µm	0.47	10	1000	-	211	3010	100	520
SB # 6 <30 µm	0.49	10	1000	2.50	209	3010	100	530
SB # 6 <45 µm	0.49	10	1000	-	205	3010	100	530
SB # 6 <75 µm	0.45	10	1000	-	207	3010	100	500

3. Discussion of Test Results

3.1 Pozzolanic Activity Tests

The first stage of testing involved investigating sample # 6 and 10 other SB samples with different chemical properties and comparing the results with those obtained from MK, SG, SF and FA samples. The results of the pozzolanic activity test in this stage are shown in Table 7. From this table, it can be seen that sample # 6 produced the highest compressive strength after 7 days compared to any sample tested. The other samples that were chosen based on chemical composition fared poorly when compared to sample # 6, with some samples having strength less than 1 MPa.

Table 7: Results for Pozzolanic Activity Tests for First Stage of Silica Breccia Testing

SB Sample	# 6	I501	I548	I553	I581	I582	I601	I625	I644	I656	I657
7-days Strength (MPa)	1.95	1.17	0.38	0.41	1.03	0.59	0.5	0.23	0.37	1.25	1.11
28-days Strength (MPa)	2.04	1.19	0.43	0.48	1.12	0.63	0.75	0.31	0.49	1.29	1.16

According to the CSA standards, the successful samples should reach a minimum of 5.5 MPa after 7 days. From these results, only sample # 6 was selected for further investigations which involve burning or grinding the material. Moreover, comparing SB samples to the other SCM's shown in Table 8, all SB samples showed very low strength compared to any other SCM's.

Table 8: Results for Pozzolanic Activity Tests for Different SCM's

SCM	FA	MK	SG	SF
7-Days Strength (MPa)	4.82	14.50	9.93	12.93
28-Days Strength (MPa)	4.93	17.00	10.65	13.10

After the first stage of testing, sample # 6 was chosen to be burned at 500, 700, and 900° C to study the effect of burning on the 7-days compressive strength of the pozzolanic activity index test. The results of the pozzolanic activity for the burned samples are shown in Table 9. It was observed that burning the sample reduced the compressive strength compared to that obtained without burning the same sample. All temperatures produced almost similar 7-days compressive strengths; therefore, the difference in the burning temperature was not a factor.

Table 9: Results for Silica-Breccia (SB # 6) Burned at Varying Temperatures

Burning Temperature	W/B	Flow Table (mm)	7-days Compressive Strength (MPa)
500˚ C	0.60	206	0.99
700˚ C	0.58	208	0.87
900˚ C	0.59	206	1.11

Further testing of sample # 6 involved grinding the sample down to various sizes including 45, 30 and 20 µm. The results from this investigation are shown in Table 10. It can be seen that the grinding process increased the compressive strength of sample # 6 from 1.95 MPa to 6.83 MPa when the particle size reduced from 75 to 20 µm, respectively. Moreover, mixing 10% calcite with SB showed to decrease the compressive strength of all ground samples. For example, the strength of the 20 µm SB sample decreased from 6.83 to 5.59 MPa when 10% calcite was added to the mixture.

Table 10: Results of 20, 30, and 45 µm SB # 6 With and Without 10% Calcite

Sample	W/B	Flow Table (mm)	7-Days Compressive Strength (MPa)
SB # 6 <20 µm	0.60	206	6.83
SB # 6 <30 µm	0.58	207	2.54
SB # 6 <45 µm	0.59	210	2.38
SB # 6 <20 µm + 10% Calcite	0.60	205	5.59
SB # 6 <30 µm + 10% Calcite	0.59	215	1.97
SB # 6 <45 µm + 10% Calcite	0.58	214	1.03

3.2 Alkali-Silica Reactivity Test Results

As concluded from stage 1, only sample # 6 that was ground to the four different sizes, was selected for further testing. As a result, only nine mixtures were tested for durability including control (not including any SCM's), four SB samples, and four other SCM's. Table 11 shows the rate of expansion resulted from the alkali-silica reactivity test for the nine tested mixtures at different intervals up to 14 days. A maximum expansion of 0.1% at 14 days is allowed for the sample to be qualified as an alternative supplementary cementing material, as per CSA A3004-E1. It is clear from the table that all SB samples exhibited expansions higher than 0.1%. Meanwhile, SB <30 µm sample had an expansion smaller than the control sample. In addition, SF and SG samples had higher expansions than FA and MK, which may be attributed to the relatively low replacement levels used in the mixtures of slag and silica fume.

It should be mentioned that the expansion results for the SB samples were previously expected because of its natural silica content. However, higher replacement levels (more than 10%) might be useful in decreasing the expansion rates. The optimum behavior in terms of expansions and overall durability was obtained by using MK with 20% replacement of cement.

Table 11: Expansion Rates for Samples Tested for Alkali-Silica Reactivity Test in Stage 2

Sample	Expansion Rate % (2-Days)	Expansion Rate % (7-Days)	Expansion Rate % (14-Days)
Control	0.083	0.113	0.156
FA	0.065	0.094	0.099
MK	0.078	0.078	0.093
SG	0.078	0.105	0.149
SF	0.080	0.109	0.134
SB # 6 <20 µm	0.076	0.098	0.206
SB # 6 <30 µm	0.059	0.088	0.155
SB # 6 <45 µm	0.080	0.123	0.192
SB # 6 <75 µm	0.087	0.119	0.167

3.3 Sulfate Resistance Test Results

The compressive strengths of the companion cubes for the nine mortar mixtures were continuously monitored until obtaining a minimum strength of 20.0 ± 1.0 MPa. At this time, an initial reading for each prism sample was measured, before the submergence in the sulfate solution. The change of length of the mortar bars was periodically reported and the rate of expansion was calculated compared to the initial length. The rate of expansion was calculated as the average expansion of the six mortar bars every week until a period of 8 months as seen in Figure 1.

It is clear from the graph that the 20% MK mortar exhibited the minimum expansions after 8 months. This result matches the results for the compressive strength of the companion cubes at 28 days. It can also be seen that the minimum expansion between SB mortars was SB <20 µm, which had an expansion less than the control mortar. However, the difference between the expansions of SB samples was not significant. It can be concluded that all mortar samples are acceptable in terms of maximum expansions after 8 months as all expansions were below 0.1%, as per CSA A3004-E1.

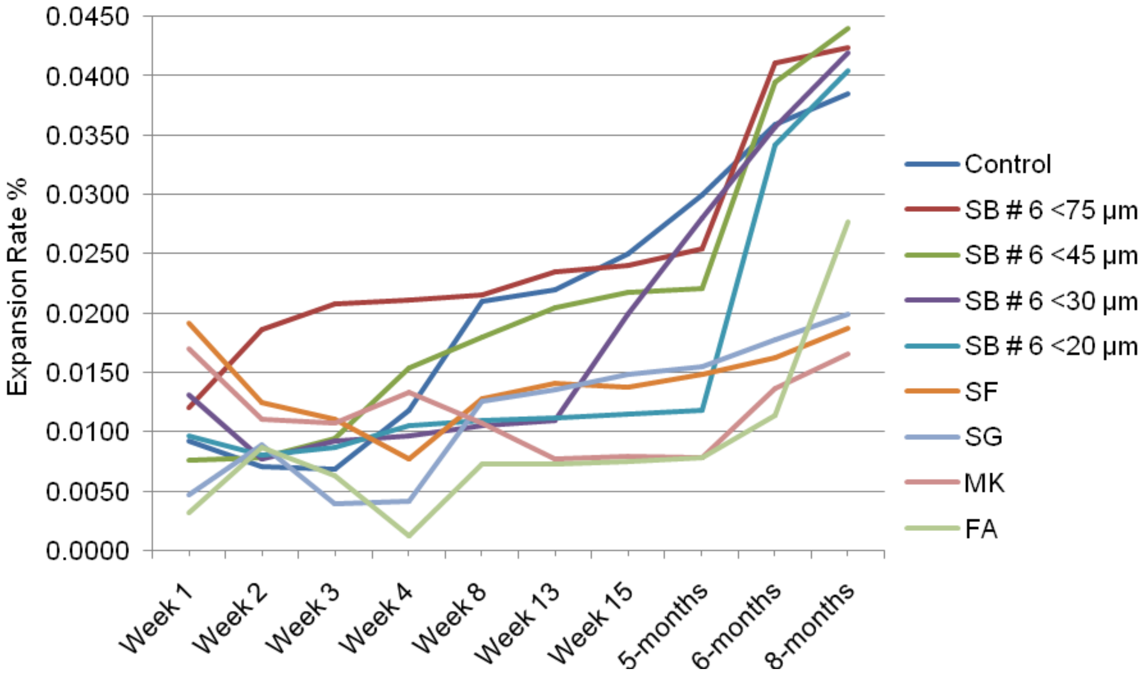

Figure 1: Rate of Expansions for Sulfate Resistance Test

4. Conclusions

In this paper, the pozzolanic activity test for SB samples was conducted to investigate the ability of SB to be used as an alternative SCM in concrete. Various samples were tested based on the chemical composition of those similar to existing SCM's used, their particles size, and burning them at different temperatures. Further tests were conducted to investigate the durability performance of selected SB samples. The evaluation of the durability of mortars containing SB was performed based on the alkali-silica reactivity and sulfate resistance tests. The following conclusions and recommendations can be drawn from the results discussed in the paper; summarized as follows:

- SB with a particle size <75 µm showed unacceptable pozzolanic activity regardless of its chemical composition.
- Burning SB at various temperatures reduced the pozzolanic activity of all tested samples.
- Grinding SB to a finer particle size (from 75 to 20 µm) greatly improved the pozzolanic activity and the durability performance of the sample. SB with a particle size <20 µm reached a 7-days strength of 6.83 MPa under the pozzolanic activity index test while SB with a particle size <75 µm obtained only 1.95 MPa.

- Mixing calcite with SB sample showed to reduce the pozzolanic activity of SB; this was even shown for the 20 µm SB sample where the compressive strength of the pozzolanic activity test was reduced from 6.83 to 5.59 MPa when adding 10% calcite.
- SB samples showed higher expansions in alkali-silica reactivity and sulfate resistance tests compared to FA, MK, SG, and SF. However, SB <30 µm showed lower expansion than the control mixture in both alkali-silica reactivity and sulfate resistance tests.
- All tested mortars in the alkali silica reactivity test had expansions higher than the maximum allowed expansion (0.1%) specified in CSA A23.2-25A after 14 days, except those with MK and FA.
- All mortars tested in the sulfate resistance test had expansions lower than the maximum allowed expansion (0.1%) specified in CSA A3004-C8 after 8 months.
- The mortar with the best strength and durability performance was the one containing 20% MK replacement. However, FA had approximately the same expansions as MK in both alkali-silica reactivity and sulfate resistance tests.
- It is recommended to grind the SB to a fineness of about 20-30 µm to obtain acceptable results of the strength and durability. However, different replacement levels should also be investigated to optimize the use of SB in mortar and concrete production.

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