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The use of silica-breccia as a supplementary cementing material in mortar and concrete

Assem A.A Hassan *, Ahmed A. Abouhussien, Justin Mayo

Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5, Canada

HIGHLIGHTS

- Silica-breccia as a newly discovered supplementary cementing material is introduced.
- The durability of Silica-breccia mortar samples is investigated.
- The fresh and mechanical properties of Silica-breccia concrete samples are investigated.
- Silica-breccia with a particle size <20 μm can be qualified as a supplementary cementing material.
- The addition of 10% Silica-breccia slightly enhanced the mechanical properties of concrete.

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ABSTRACT

Silica-breccia (SB), 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 SB 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. The objective of this study was to investigate the effectiveness of using SB as a supplementary cementing material in mortar and concrete. The first part of the investigation included testing the pozzolanic activity index, sodium sulfate attack, and alkali-silica reactivity on mortar samples containing SB. The second part was designed to test the fresh properties and mechanical performance of concrete samples containing SB. The investigation also involved testing other SCM's including fly ash, metakaolin, silica fume, and slag for comparison. The results showed that pulverized SB with a particle size less than 20 μm can be qualified as an alternative SCM. Replacement of cement by 10% SB slightly enhanced the mechanical and durability performance of mortar and concrete samples. The results also showed that the addition of SB improved the mixture workability and proved to enhance the fresh properties of self-consolidating concrete mixture.

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 in concrete to produce impermeable and dense mixture. 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 materials (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 concrete microstructure over that of concrete with ordinary water-to-cement ratio [1].

SCM particles have a 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 [2]. At early ages, the filler effect of SCM is responsible for the improvement in densification of the microstructure by means of improving packing the hydration products especially around the aggregate particles [3]. At later ages, the pozzolanic reaction adds to the improvement of the microstructure by producing more cementitious products. The pozzolanic reaction is a reaction of the SCM with calcium hydroxide crystals which is the main by-product from the hydration of normal cement [1]. This reaction

* Corresponding author. Tel.: +1 709 864 7473; fax: +1 709 864 4042.
E-mail address: ahassan@mun.ca (A.A.A Hassan).

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produces more calcium silicate hydrate (C–S–H) gels (the main cementitious product from the hydration of normal cement). The C–S–H gels effectively tie 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 [2].

Silica-breccia (SB), also known as Aplite, is a recently discovered SCM that showed some pozzolanic effect when mixed with cement. Similar to other commercially available SCM's, pulverized SB 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 SB was discovered in Finnvolldalen, Norway, yielding large volumes that make SB an economical choice for use in cement mixtures.

Over the past few years, a number of tests were performed by Stantec Inc., Statoil Canada Ltd., and University of Stavanger on different SB products to investigate their relativities when mixed with cement [4,5]. 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 SB under elevated temperature and high pressure showed some resistance towards CO_2 attack as well as improvement in the mechanical and shrinkage properties.

There is very limited information available in the literature on the performance of SB in concrete or mortar. The purpose of this study was to examine the feasibility of using a developed SB product as an alternative SCM to be used in mortar or concrete. The study investigated the strength and durability performance of the new material compared to other commercially available SCM's, when mixed with cement. The pozzolanic activity index, sodium sulfate attack, and the alkali-silica reactivity tests were conducted on mortar samples. On the other hand, the compressive strength, strength development, flexural strength (FS), modulus of elasticity (ME), and splitting tensile strength (STS) tests were conducted on concrete samples containing SB. The study also included evaluating the fresh properties of concrete mixture containing SB and the feasibility of using this product in the production of self-consolidating concrete (SCC).

2. Experimental program

The research program was divided into two parts; the first part focused on testing the strength and durability performance of cement blended with SB in mortar samples. The second part of the research program dealt with testing the fresh and mechanical properties of concrete samples containing SB as a SCM. Tests on other SCM's including fly ash (FA), silica fume (SF), slag (SG), and metakaolin (MK) were also conducted in both parts of the research program for comparison. The details of each part were as follows:

Part 1: Testing the strength and durability of mortar samples containing SB.

Different SB products were tested for effectiveness as an alternative SCM based on the Canadian Standard Association (CSA) test methods [6,8]. The program was completed in the following two stages:

Stage 1: Investigation on the Pozzolanic Activity Index of Different SB samples

In this stage, different SB samples having different genesis, different degrees of pulverization, and different burning temperatures were tested for pozzolanic activity according to CSA test method (CSA A3004-E1), in order to select some successful samples for further investigation (Tables 1 and 2). Additional FA, SF, SG, and MK samples were also tested under the same condition for comparison (Table 3). After evaluating the results of the pozzolanic activity index, Sample # 6 was shown to have the highest pozzolanic activity index among all tested samples. For this reason, this sample (sample # 6) was chosen for investigating the effect of burning temperature, degrees of pulverization, and the effect of mixing SB with calciteon maximizing 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 [6]. The detailed activities in this stage were as follows:

- Testing the pozzolanic activity index of 11 SB types with particle size <75 μm (Table 1) in addition to the other SCM's (FA, SF, SG, and MK) samples.
- Testing the pozzolanic activity index of selected SB sample (sample # 6 with particle size <75 μm) burned at different temperatures (500, 700, and 900°°C).
- Testing the pozzolanic activity index of selected SB sample (sample # 6) having different particle sizes (<75, <45, <30, and <20 μm).
- Testing the pozzolanic activity index of selected SB samples (sample # 6 with different particle sizes) blended with calcite.

Stage 2: Investigation on the Durability Performance of the Selected SB Samples.

In this stage, selected SB samples (sample # 6 with different particle sizes) from the first stage were tested for their durability performance based on the alkali-silica reactivity (CSA A23.2-25A) and sulfate resistance (CSA 3004-C8) tests [7,8]. Additional FA, SF, SG, and MK samples were also tested under the same conditions for comparison.

Part 2: Testing the fresh and mechanical properties of concrete samples containing SB.

This part was designed to investigate the effect of SB on the fresh and mechanical properties of concrete mixtures. Because the results of the first part of this investigation indicated enhanced workability of SB mixture compared to other SCM's mixtures, self-consolidating concrete (SCC) was chosen in this part to clarify the effect of SB on the improvement of the fresh properties of SCC mixture. The mechanical properties tests in this part included the compressive strength, strength development, FS, ME and STS tests. On the other hand, the fresh properties tests of SCC mixtures included slump flow, time to reach 500 mm diameter of the slump flow (T_{500}), J-ring, and air content tests. Control SCC mixture with no SCM's in addition to SCC mixtures containing SF, SG, and MK were also included for comparison.

2.1. Materials

Type GU Canadian Portland cement similar to ASTM Type I, with a specific gravity of 3.15, was used in this investigation. Silica sand was chosen for the pozzolanic

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