INVESTIGATING THE ALKALI-SILICA REACTION OF RECYCLED CRUSHED MIXEDGLASS AS FINE AGGREGATE IN CONCRETE

Abdurrahmaan Lotfy, Lafarge Canada Inc., Toronto, Canada, abdurahman.lotfy@lafarge.com
Solomon Asantey, Fanshawe College, London Ontario, Canada, sasantey@fanshawec.ca
Amneh Kalloush, Fanshawe College, London Ontario, akalloush@fanshawec.ca

Abstract:

To strive for more sustainability contribution, the use of recycled crushed glass as aggregate in concrete has attracted much research interest. Many studies have been performed by mixing different sizes and percentages of glass to replace aggregate in concrete mixes. Test results have shown that concrete containing glass as an aggregate replacement has lower water absorption. However, the use of glass in concrete may result in alkali-silica reaction (ASR). This reaction causes extensive cracking and expansion within the aggregate particles, resulting in potential durability issues of hardened concrete. The objective of this research was to investigate the potential for alkali reactivity of concrete aggregates when using mixes containing different percentages of local recycled crushed glass. During the summer of 2014, trial tests were conducted by Lafarge Canada Inc. and Fanshawe College's Concrete Technology Research Group to assess the use of recycled glass as an aggregate in concrete. This paper presents the results of ASR testing on several mixes using different percentages of glass. The tests were completed based on the requirements of ASTMC1260–Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method). The expansion of the prepared test specimens increased as the replacement level of glass aggregate increased. The results demonstrate that even as low as 5% replacement of recycled glass as fine aggregate in concrete, the percentage expansion was excessive leading to considerable durability issues.

1 INTRODUCTION

Concrete is the world's most-widely used sustainable construction material (Jin and Chen 2013), and the use of innovative and sustainable materials in concrete production has attracted much research interest (Ling and Poon 2014). Durability and strength properties of concrete can be greatly improved if appropriate aggregates sources and type are carefully selected to suit a particular climatic, environmental and loading condition. Glass pieces are waste materials created by human activities every day. Theoretically, glass can be indefinitely recycled without any loss of quality (Sobolevet al. 2006).

Many recycling plant operators and environmentalists are aware of the serious environmental consequences of huge amount of glass supply surpluses, and are taking actions to resolve this issue (Meyer 2004, Meyer et al 1998). Growing public concerns and restrictive governmental policies regarding treatment and disposal of waste glass in landfills makes recycled glass pieces an attractive alternative source of aggregates in concrete production made with 100% GU cement.

The use of glass in concrete is known to result in alkali-silica reaction (Du and Tan 2014).The amorphous silicate structure of glass reacts with the alkaline pore structure of concrete and produces an alkali-silicone gel, which expands in the presence of moisture in the concrete degrading the concrete quality (Hamed et al). This reaction causes extensive cracking and expansion within the aggregate particles, resulting in potential durability issues of hardened concrete. For any recycled crushed glass source to qualify as an aggregate source, therefore, its potential to undergo an alkali-silica reaction needs to be closely investigated.

2 Research Objective

The overall objective of this research project was to assess the use of recycled glass from a local recycle plant (Try Recycling Inc., London ON). During the summer of 2014, tests were conducted by Lafarge Canada Inc. and Fanshawe College's Concrete Technology Research Group at Lafarge's Hamilton testing laboratory to assess the use of recycled glass from the local recycle plant as suitable aggregate in concrete. The specific objective of this research was to investigate the potential for alkali reactivity of concrete aggregates when using mixes containing different percentages of local recycled crushed glass in a concrete mix made with 100% GU cement. Therefore, the study was aimed at: (a) comparing alkali reactivity of a local source of recycled green glass particles; (b) investigating the optimal amount for utilizing a local recycled green glass as fine aggregates in a concrete mix with 100% GU cement.

3 Experimental Program

3.1 Materials

A quantity of recycled crushed mixes glass was obtained from Try Recycling site and transported to the Fanshawe College concrete laboratory in London, Ontario for cleaning and test preparation. Fig. 1 shows a sample of the recycled crushed mixed glass used for the investigation.

Fig.1. Recycled Glass

The cleaned crushed glass was then transported to Lafarge's concrete testing laboratory in Hamilton, Ontario for the ASR testing in accordance with ASTMC1260 - Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method). Lafarge GU cement was used. Chemical composition analysis was also performed on the cleaned crushed mixed glass. Table 1 provides the chemical composition of the cement as well as that of crushed glass passing sieve No. 4 (4.75mm) and retained on No.100(150 µm).

Table 1 Chemical composition of the cement and glass used

Chemical	GU Cement	Glass
SiO2 (%)	19.6	69.7
Al2O3 (%)	4.9	2.08
Fe2O3 (%)	3.1	0.6
TiO2 (%)	-	0.07
CaO (%)	61.4	11.13
MgO (%)	3	0.99
SO3 (%)	3.6	0.05
S2- (%)	-	-
Alkalis as Na2O (%)	0.7	12.93
LOI (%)	2.3	2.89
Blaine (cm2/g)	3870	-
+ 45 µm (%)	3	-
Density (g/cm3)	3.15	-
Bulk density (g/cm3)		2.718
SSD density(g/cm3)		2.731
Apparent density (g/cm3)		2.753
Absorption		0.47 %

The mixed crushed glass was graded in accordance with ASTMC1260 as shown in Table 2.

Table 2 Grading Requirements

Sieve Size		Mass (%)
Passing	Retained	
4.75mm (No. 4)	2.36 mm (No. 8)	10
2.36mm (No. 8)	1.18 mm (No. 16)	25
1.18mm (No. 16)	600 μm (No. 30)	25
600μm (No.30)	300 μm (No.50)	25
300μm (No.50)	150 μm(No.100)	15

3.2 Test Matrix

Seven mixes were tested using the accelerated mortar bar test. The control mix consisted of 100 % natural sand, and the six other mixes comprised of varying replacement levels of recycled glass. A Spratt aggregate mix was cast as a control of the testing procedure, in according with CSA23.2-25A clause 11. The replacement of aggregate was done by mass, and the gradations of the final blend met the requirements. Recycled crushed mixed glass was used to replace fine aggregate in proportions as shown in Table 3. The control mix consisted of 100 % natural sand, and the six other mixes comprised of varying replacement levels of recycled glass.

Table 3 Glass Replacement in Concrete Mixes

Concrete Test Mixes	
1	0 % Glass Replacement (Control mix)
2	5 % Glass Replacement
3	10 % Glass Replacement
4	15 % Glass Replacement
5	20 % Glass Replacement
6	30 % Glass Replacement
7	40 % Glass Replacement

Also referenced was A23.2-25A - Test method for detection of alkali-silica reactive aggregate by accelerated expansion of mortar bars. A Spratt aggregate mix was cast as a control of the testing procedure. This is according to CSA23.2-25A Clause 11.

3.3 Test Procedures

The concrete mixing and aggregate grading process followed the guidelines and steps outlined in ASTM C1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method). Three concrete mix test specimen were made for each cement-aggregate-glass combination and poured into 25x25x250mmmoulds as shown in Fig. 4.

Fig.4aThree Test Specimens

Fig.4bBar Specimen in Moist Cabinet

The specimen was left to cure in a moist cabinet (Fig. 4b) for 24 hours and an initial comparatory expansion reading was taken. The specimen was placed in a sealed storage container filled with water which totally immersed the specimen. The sealed container was then placed in an oven set at 80 ˚C for 24 hours. The container holding the specimen was then removed from the oven and mortar specimen were placed in a water container to cure. The mortar bars were then removed from the container one at a time, placed in the measuring gauge, while ensuring that the surfaces are dry. The initial (zero) expansion reading for each bar was taken immediately. After measuring the initial readings, the bars were placed in a container filled with Sodium Hydroxide solution, in accordance with the accelerated mortar bar test. The container was sealed and placed in an oven set at 80 ˚C for 14 days. Each bar was then placed in the measuring gauge and an expansion reading was taken. The test setup is shown is Fig.5

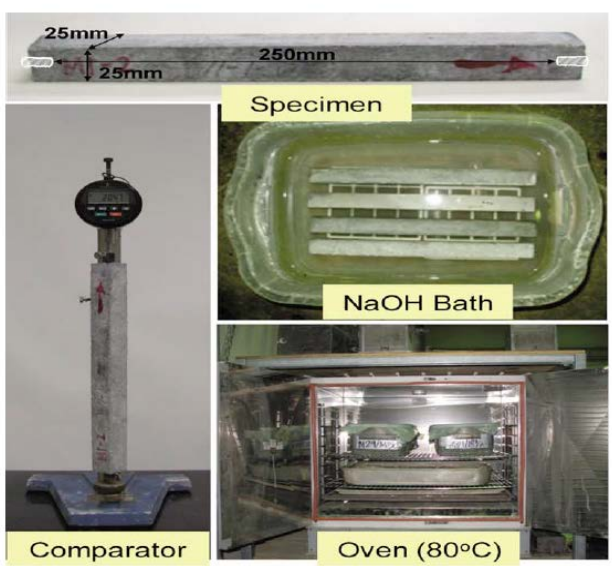


Fig.5. Test setup

4 Results and Discussions

Fig. 6 shows the expansion results from the accelerated mortar bar test, which shows that the expansion is severely increased as the glass replacement is increased from the 0% (control mix) to 40%.

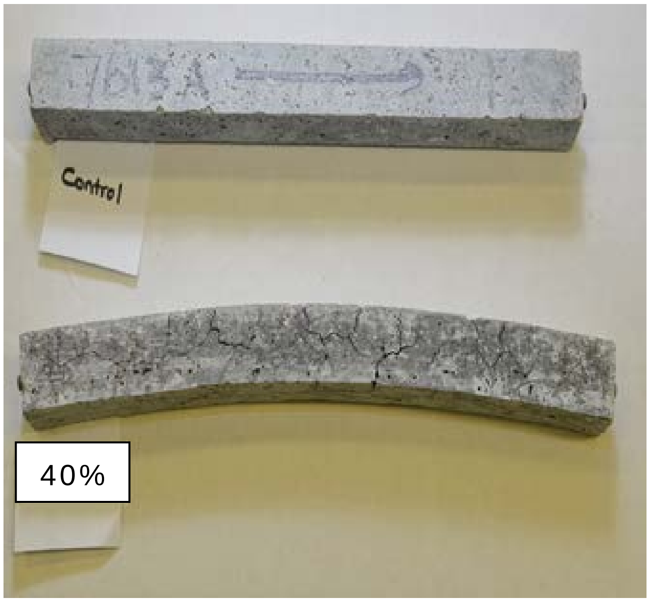


Fig.6. Specimens after 14-days.

The Spratt aggregate expansion (control mix) was within the limits outlined in CSA A23.2-25A. The 14 day average expansion was 0.392 %. The range to be acceptable by CSA23.2-25A is 0.3% - 0.5% at 14 days.

Table 4 shows the average expansion of all seven mixes at 14 days and the difference between the mixes and the 0% glass mix. The difference and percentage differences of the mixes compared to the 0% glass mix are provided in Table 4. Table 4 and Fig. 7 show that a 5% and 40 % replacement of glass aggregate increases the expansion by 0.227% and 0.493%, respectively, compared to the control mix (0% glass), which exceed the 14 days limits. The CSA limit for expansion at 14 days is 0.15%, while the ASTM C1260 limit is 0.2% expansion at 14 days. From Table 4, it is clear that the addition of glass aggregate in concrete severely increases expansion. Any addition of glass into concrete makes the concrete expansive and structurally unusable.

Table 4: Average Expansion of 7 Mixes at 14 days and Difference Between each mix and 0% Glass mix

Mix	14 Days Expansion (%)	Difference with 0% Glass (%)	Percentage Difference with 0% Glass
0% Glass	0.179	0	0
5% Glass	0.227	0.049	27.1
10% Glass	0.289	0.061	61.5
15% Glass	0.369	0.081	106.6
20% Glass	0.366	-0.003	104.9
30% Glass	0.479	0.113	168.1
40% Glass	0.493	0.014	175.7

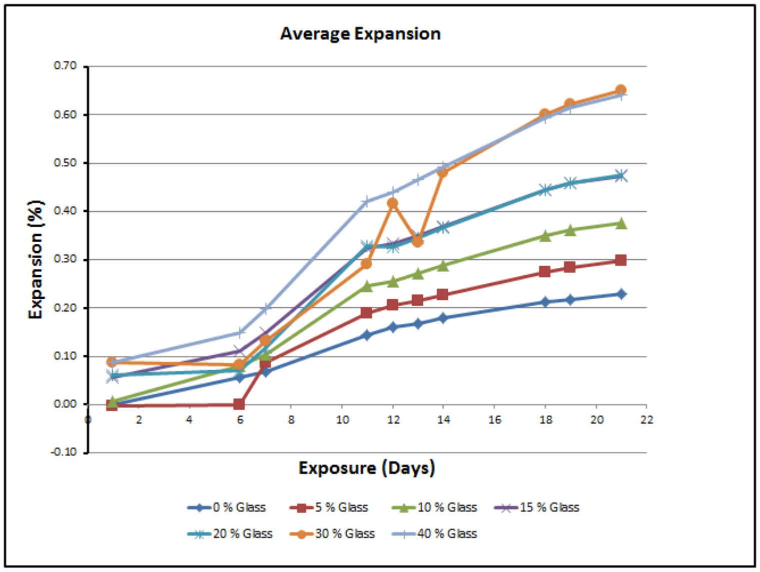
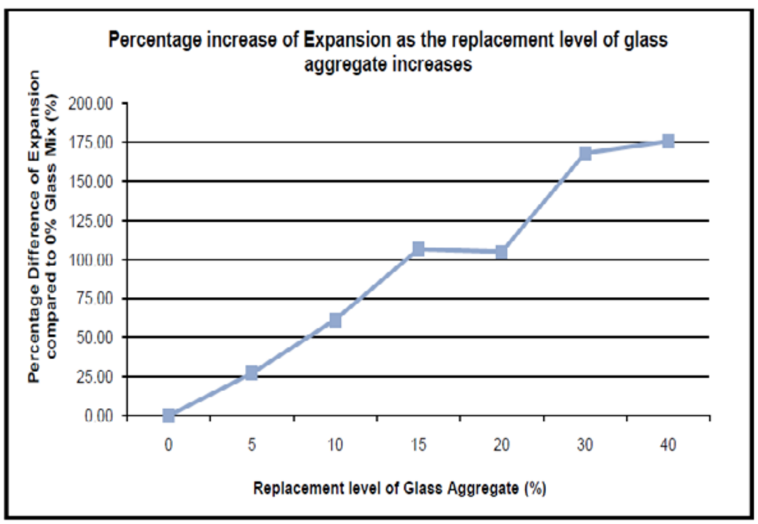


Fig.7: Percentage increase of expansion as the replacement level of

Fig. 8 represents the percentage increase of expansion as the replacement level of glass increases. As can be seen, even at a 5% replacement of glass, the expansion increases by 27% at day 14.A 40 % replacement of glass aggregate increases the expansion by 175%.



5 Conclusions and Future Work

The use of crushed glass as fine aggregate in concrete is known to result in Alkali-Silica reaction. This reaction causes extensive cracking and expansion within the aggregate particles, resulting in potential durability issues of hardened concrete. The results of this investigation demonstrate that even as low as 5% replacement of recycled glass as fine aggregate in concrete mix with 100% GU cement, the percentage expansion was excessive, leading to considerable durability issues. It is therefore recommended that for structural works involving load-bearing elements such as beams, slabs, columns, walls etc. this source of crushed mixed glass not be used.

Further investigation is suggested to explore the use of recycled crushed glass in concrete mixes with supplementary cementing materials (SCM) such as fly ash, slag and silica fume as well as in non-structural works such as countertops, roadway bases and non-load bearing landscaping blocks. Economic and environmental benefits could potentially result from the use of re-cycled crushed mixed glass.

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