FEASIBILITY OF USING GROUND WASTE GLASS AS A CEMENTITIOUS MATERIAL

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ABSTRACT. The feasibility of using ground waste glass as cementitious material for concrete was investigated in this paper. The non-recyclable fluorescent lamp glass was collected from the recycling process of mercury containing lamps. The waste glass was ground and sieved to the size smaller than 150μm, 75μm and 38μm, respectively, to study the size effect on the pozzolanic behavior. With 30% cement replaced by ground glass, the normal strength concrete gained strength activity index 91%, 84%, 96% and 108% at 3, 7, 28 and 90 days respectively, exceeding 75% at all ages. The pozzolanic activity of ground glass was examined through lime tests. The glass having a particle size finer than 38 μm exhibited a satisfactory pozzolanic reaction. The expansion of glass concrete in highly alkaline solution was also tested. It was observed that small glass particle size led to a high reactivity with lime, a high compressive strength and a low expansion in concrete. While the glass concrete was directly comparable to fly ash concrete, it had difficulty to compete with concrete having same amount of silica fume.

Keywords: Glass concrete, Ground waste glass, Recycled fluorescent lamp, Cementitious material, Compressive strength, Pozzolanic behavior, Expansion, Grindability of Glass.

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INTRODUCTION

Electric utilities across Canada and North America have actively pursued electrical efficiency improvements through lighting initiatives. The demand side management and other re-lamping activity in Canada generated a sale of several millions of fluorescent lamps annually. The increasing use of high efficiency lighting systems proportionally produced large amount of lamp waste. In Canada, the estimated lamp waste was about 17,400 tonnes in 1992 alone.

Fluoresecnt and high intensity discharge (HIP) lamps contain mercury, lead, and other components of environmental concern. Of that 17,400 tonnes of lamp waste, there was an estimated 2.4 tonnes of mercury and 2.5 tonnes of lead. Processing of used fluorescent lamps to collect the mercury and lead is therefore important for protecting the environment. The fluorescent lamp recycling facility crushes the lamps, separates the metal caps and recovers mercury. The majority of the by-product from the processing is the lamp glass. For 55,000 tubes recycled, approximately 30 m^3 of waste glass will be generated. Because of the mercury contamination, the lamp glasses are finally sent to landfill. Similar to the mixed color bottle glass, the waste lamp glass awaits for the assessment of re-use.

Concrete is famous for reusing industrial by-products. However, the use of waste glass as coarse aggregate was not successful because of the marked strength regression and excessive expansion [1]. Recent studies have shown that if the glass was ground to a particle size of 300 µm or smaller, the alkali silica reaction (ASR) induced expansion could be reduced. Partial replacement of fine aggregates in concrete by crushed glass was possible [2-3].

This paper is to explore the feasibility of using finely ground glass as cementitious material to partially replace cement in concrete. The pozzolanic activity of the ground glass was studied by monitoring the reaction of glass with lime at 54 ^{0}C, the strength development of glass concretes with 30% cement replaced by glass and their expansion in highly alkaline solution. The particle size effect was evaluated. The results were compared with fly ash concrete and silica fume concrete.

EXPERIMENTAL

Fluorescent Lamp Glass

The chemical composition of lamp glass (RLF Canada, Quebec) was analyzed using a x-ray microprobe analyzer. It was a typical soda lime glass. Table 1 compares the glass with Class F fly ash and silica fume. In accordance to ASTM C618, the glass satisfies the basic chemical requirements for a pozzolan and exhibited a favored white color. However, it does not meet the optional requirement for the alkali content because of the high percentage of Na_2O in glass.

To obtain the required fineness, the glass was ground in a laboratory grinder (Lafarge Canada, Montreal). The grindability of the glass in terms of energy consumed per metric ton was measured and is shown in Table 2. It is seen that energy required for grinding the lamp glass is close to that for clinker, but less than that for slag with the same Blaine number.

The ground glass was then sieved to have 150 µm, 75 µm and 38 µm to study the size effect. 150 µm glass contains particles passing a #100 sieve (150 µm) and retained on a #200 sieve (75 µm). 75 µm glass particles passing a #200 sieve (75 µm) and retained on a #400 sieve (38 µm). 38 µm glass particles passing a #400 sieve (38 µm). The typical micrograph of 38 µm glass is shown in Figure 1.

Table 1 Chemical compositions of soda lime glass, Class F fly ash and silica fume (wt%)

OXIDE	SODA LIME GLASS	CLASS F FLY ASH	SILICA FUME
SiO_2	72.8	40.71	96.5
Al_2O_3	1.4	17.93	0.5
Fe_2O_3	-	29.86	2.0
($SiO_2 + Al_2O_3 + Fe_2O_3$)	74.2	88.50	99.0
CaO	4.9	2.80	0.80
MgO	3.4	1.09	0.90
SO_3	-	1.27	0.2
K_2O	0.3	1.56	2.0
Na_2O	16.3	0.73	0.40
P_2O_5	-	0.17	-
TiO_2	-	0.85	-
B_2O_3	1.0	-	-
Color	white	grey	dark
Fineness	75µm <glass<150µm 38µm <glass<75µm glass<38µm	90%<45µm (Mean=11µm)	99%<45µm (Mean= 0.15µm)

Concrete with 30% Ground Glass

The mixture proportions of concrete with 30% cement replaced by glass, fly ash and silica fume are shown in Table 3. The hybrid batches with 15% ground glass and 15% silica fume were also prepared to investigate if the highly reactive silica fume could promote the pozzolanic activity of the ground glass in concrete (Table 4). As a control, concrete with 15% silica fume alone was also tested.

Table 2 Energy consumed in grinding the lamp glass

BLAINE, m²/kg	GRINDABILITY, Kilo Watts Hour/Metric Ton (kWh/mt)		
	Lamp Glass	Blast Furnace Slag	Cement Clinker
350	41	60	45
400	55	80	55
500	80	115	-
550	96	130	-
600	112	150	-

The materials used were CSA type 10 (ASTM type I) cement, river sand and crushed limestone with maximum aggregate size of 10 mm. For all the batches, water to cementitious (cement + mineral additive) ratio was 0.75, and the coarse to fine aggregate ratio 65 to 35. The target strength was 25 MPa at 28 days. No other additives were used. Five cylinders from each batch were tested at 3, 7, 28 and 90 days respectively to obtain compressive strength of the concrete. The strength activity index at a given age is defined in accordance with ASTM C618 [4] as the percent compressive strength with respect to the control.

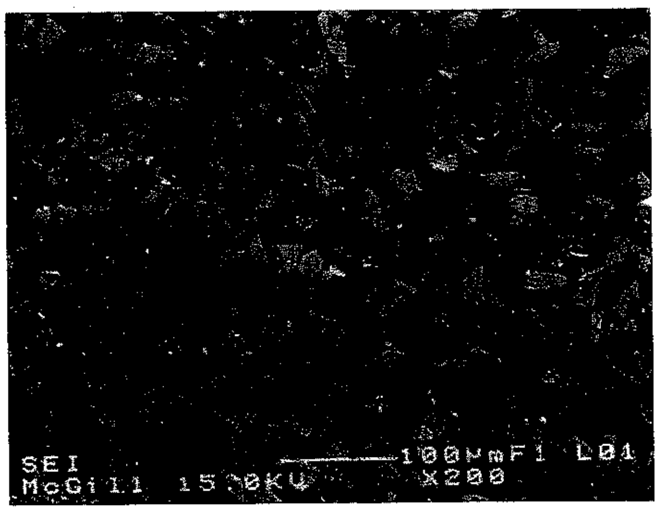

Figure 1 Particle size and shape of ground lamp glass (passing 38 μm)

Table 3 Mixture proportions for concretes containing 30% mineral additives, (kg/m^3)

MATERIAL	S.G.	CONTROL CONCRETE	SILICA FUME	FLY ASH	150 μm GLASS	75 μm GLASS	38 μm GLASS
Cement	3.15	300	210	210	210	210	210
Silica-fume	2.20	-	62.7	-	-	-	-
Fly Ash	2.60	-	-	74.3	-	-	-
Glass	2.40	-	-	-	68.6	68.6	68.6
Coarse Agg.	2.60	1269	1269	1269	1269	1269	1269
Fine Agg.	2.60	681	681	681	681	681	681
Water	1.00	225	204.7	213.2	208.9	208.9	208.9

Table 4 Mixture proportions for hybrid glass - silica fume concretes, (kg/m^3)

MATERIAL	S.G.	15% SILICA FUME	HYBRID 150 μm GLASS-SF	HYBRID 75 μm GLASS-SF	HYBRID 38 μm GLASS-SF
Cement	3.15	255	210	210	210
Silica-fume	2.20	31.4	31.4	31.4	31.4
Fly Ash	2.60	-	-	-	-
Glass	2.40	-	34.3	34.3	34.3
Coarse Agg.	2.60	1269	1269	1269	1269
Fine Agg.	2.60	681	681	681	681
Water	1.00	214.8	206.8	206.8	206.8

Lime - glass tests were conducted following ASTM C593 [4] for pozzolanic material. Five batches of samples with different mineral additives were prepared. Respectively, they contained the Class F fly ash, silica-fume, 150 μm glass, 75 μm glass, and 38 μm glass. Both fly ash and silica fume batches were used as control for comparison. Mortar bar tests in accordance with ASTM C1260 [4] was conducted to monitor the possible expansion in glass concrete. For the five batches containing mineral additives, 30% by volume of the portland cement was replaced by the silica fume, fly ash, 150 μm glass, 75 μm glass and 38 μm glass respectively. Non-reactive river sand was used in all batches.

RESULTS

Strength Development in Glass Concrete

The comparison of concrete containing 30% ground glass with control concrete is shown in Figure 2. Glass concrete had lower strengths than the control at the ages of 3, 7, 28 and 90 days, except concrete containing 38 μm glass at 90 days.

It seemed that there existed a competition in strength development between the 30% 38 μm glass in glass concrete and the same amount of cement in control concrete. The size effect was obvious. The smaller the particle size of the glass, the higher the strength of glass concrete.

Figure 3 compares 38 μm glass concrete with silica fume concrete and fly ash concrete at the same percent of cement replacement. The 38 μm glass concrete exhibited a strength higher than the fly ash concrete at all ages, but only half as that of silica fume concrete. The strength activity indexes of all the five concrete containing 30% mineral additives are presented in Figure 4.

ASTM C618 recommends that a pozzolan have a minimum strength activity index of 75%. Therefore, the 150 μm glass did not always satisfy the criteria. Nevertheless, 75 μm and 38 μm glasses were suitable. Silica fume concrete showed a superior performance. It was the submicron particle size and the high silica content in silica fume that played a critical role in strength development.

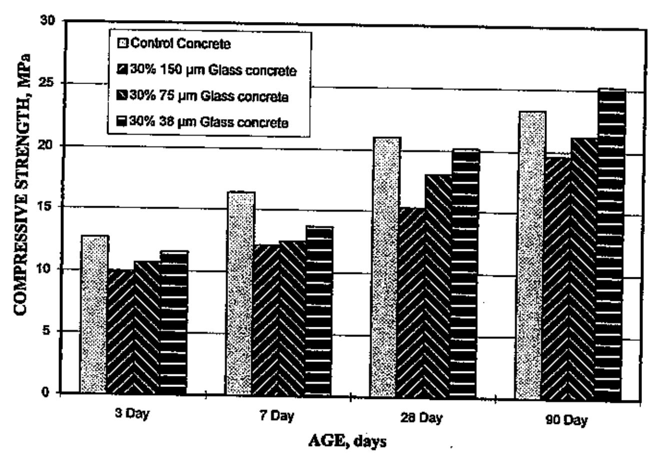

Figure 2 Compressive strength of glass concrete

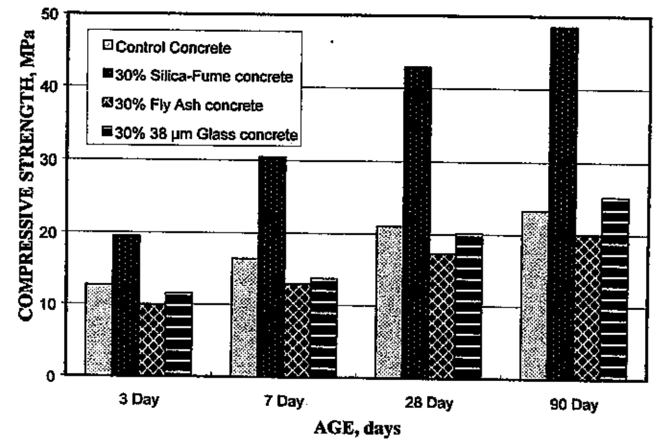

Figure 3 Comparison of glass concrete (38 μm) with fly ash and silica fume concrete

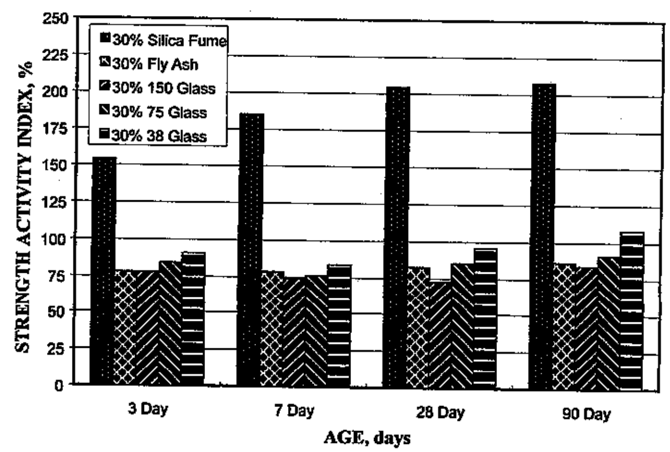

Figure 4 Strength activity index

Silica fume was used to promote the strength gain in glass concrete by mixing silica fume with glass in glass concrete. In hybrid batches, the 15% ground glass was competing with the same amount of cement in the control batch in the presence of 15% silica fume. The results of the compressive strength tests are shown in Figure 5. In the early age (3-day and 7-day) tests, all hybrid batches had lower strengths than the control, 15% silica fume concrete.

As hydration progressed, the hybrid concrete developed strength close to the control, but had never exceeded it, even at 90 days. The activity indexes of hybrid batches were computed as the strength ratio of hybrid concrete to the 15% silica fume concrete. At the ages of 3-day and 7-day, the activity indexes were about the same as or even lower than that of the 30% glass concrete without silica fume, indicating a low activity of glass at early ages even in the presence of the silica fume.

The activity index of concrete containing 15% 38 μm glass was 95% at 28 days and 96% at 90 days. The former was slightly higher than that in 30% glass concrete, while the latter was lower. Size effect of ground glass in hybrid concrete was not as apparent as that observed in glass concrete without silica fume at a late age. The hybrid concrete with 150 μm glass had exhibited an increased activity index, which was close to that with 38 μm glass. It implies that the activity of ground glass has not been substantially enhanced by the highly reactive silica fume and the strength gain in hybrid concrete is attributed mainly to silica fume, not to ground glass.

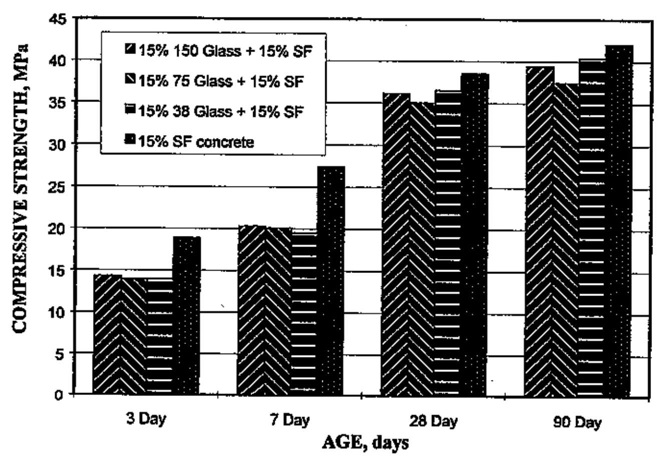

Figure 5 Compressive strength of concrete with mixed glass and silica fume

Pozzolanic Reaction

Pozzolanic reaction of ground glass was examined through the compressive strength development in lime – glass mixture. The lime - silica fume and lime - fly ash mixtures were also tested at the same condition as control. The strengths for each mixture are shown in Table 5. As recommended by ASTM C593, a satisfactory pozzolanic material should have a minimum compressive strength 4.1 MPa when mixed with lime after 7 days curing at 54 ^{0}C, and after an additional 21 days curing at 23 ^{0}C in water.

The 38 μm glass satisfied the minimum strength requirement at 7-day test, and attained an increase in strength after additional 21 days curing in water. The strength of 150 μm glass mixture was far below the limit because of the coarse size of the glass. The 75 μm glass performed marginally. Its 7-day strength was slightly lower than the threshold value, while its additional 21-day curing in water enhanced the strength to a satisfactory level. As controls, both lime - fly ash and lime - silica fume mixtures exhibited high pozzolanic activity. The relatively low percentage of components, $SiO_2 + Al_2O_3 + Fe_2O_3$, in glass (Table 1) made the ground glass less reactive. The size effect of the ground glass on the pozzolanic activity was observed. The smaller the particle size, the more the reaction of the glass with the lime.

Table 5 Compressive strength of lime-pozzolan mixtures, Mpa

TIME	SILICA-FUME	FLY ASH	150 μm GLASS	75 μm GLASS	38 μm GLASS
At 7 Days	6.69	5.52	2.70	3.84	4.23
After additional 21 Days	-	-	-	4.20	4.69

Alkali-Silica Reaction Induced Expansion

The expansion of the mortar bars versus time is given in Fig. 6. From the graph, it was evident that all the batches had an expansion that was less than that of the control. This shows that not only was the glass not expansive as was expected due to the possible ASR, but it actually helped reduce the expansion as compared to the control. This is an indirect indication of pozzolanic activity.

There was also a correlation between the effectiveness of a pozzolan, its particle size, and the expansion of the corresponding mortar bar. Indeed, silica-fume had the lowest expansion followed by fly ash, 38 μm glass, 75 μm glass and 150 μm glass. While both of 150 μm glass and 75 μm glass had expansion close to each other, the 38 μm glass reduced the expansion to almost half of them. All of the pozzolans had an expansion below 0.1% and therefore, according to ASTM C 1260 specifications, the expansion was within an acceptable limit. Again, the size effect of glass was observed. The finer the particle size, the less the expansion.

CONCLUSIONS

The use of ground waste glass as a high volume cement replacement in concrete seems feasible, if the glass can be ground sufficiently fine. The strength activity indexes of the concrete with 30% cement replaced by 38 μm glass were 91%, 84%, 96% and 108% at 3, 7, 28 and 90 days respectively, exceeding the 75% as recommended by ASTM C618. The compressive strength of lime-glass mixture was higher than the threshold limit of 4.1 MPa. The expansion of the mortar bar with 30% cement replaced by the 38 μm glass was reduced to half of that in control. The lime activity, the strength development and the reduction in expansion were indicative of a pozzolanic activity.

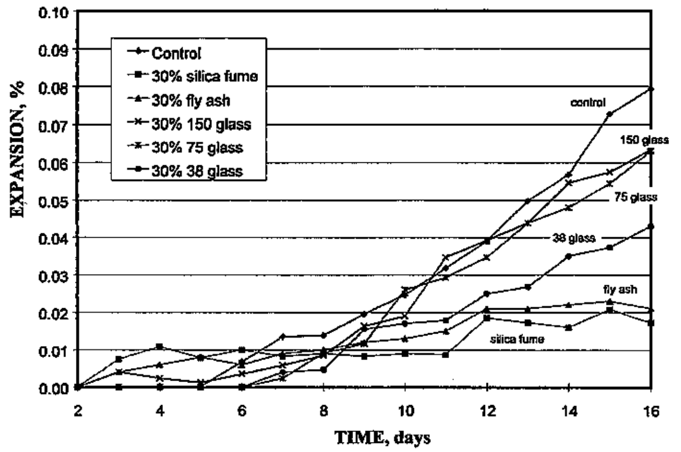

Figure 6 Expansion of glass concrete in highly alkaline solution

Glass concrete had a higher early strength and a higher late strength than fly ash concrete did. The high early strength could be attributed to the high alkali content in soda-lime lamp glass. Nevertheless, the high alkali content in mixture did not deteriorate the strength of the concrete at a late age. Instead, a gradual increase in strength was observed.

The concrete with 38 μm glass attained a 120% increase in strength from the age of 3-day to 90-day. This rate was higher than 102%, the strength increase in fly ash concrete during the same period of time. The presence of silica fume in hybrid concrete with 15% silica fume and 15% glass did not significantly promote the pozzolanic activity of ground glass in concrete.

Size effect of ground glass on the performance of concrete was observed. A smaller particle size of the ground glass resulted in a higher activity of glass with lime, a higher compressive strength in concrete as well as a lower expansion. It is expected that if the glass can be ground even finer, its pozzolanic activity can be remarkably improved.

Further research is necessary to study the effect of high Na_2O content on the alkali aggregate reaction when reactive aggregates are used in concrete. The optimal particle size distribution of glass needs also to be determined to trade off the cost and performance in glass concrete.

ACKNOWLEDGMENT

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