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Incorporation of Recycled Glass for Durable Concrete

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ABSTRACT

Laboratory investigations were carried out to assess the potential of the crushed recycled glass as natural sand replacement using ratios of 30%, 45% and 60%. Replacement of cementitious materials in concrete was also considered using cement replacement ratios of 7.5%, 15% and 25% of powder glass. The effects of glass sand replacement and cementitious materials replacement with powder glass on fresh and hardened concrete properties were assessed. It was concluded that with the incorporation of 45% of crushed glass as a natural sand replacement, the compressive and flexural strengths have marginally increased, while the indirect tensile strength marginally decreased. The concrete with glass as the natural sand replacement had lower shrinkage and significant lower chloride diffusion coefficient. Concretes with powder glass as cementitious materials replacement showed lower compressive strength and marginally higher drying shrinkage than the control mix, but meeting the concrete mix design requirements.

INTRODUCTION

In 2001, the Roads and Traffic Authority (RTA) in New South Wales, Australia, commissioned a project with the aim of assessing the greenhouse gas emissions resulting from its activities. The scope of the RTA project was to develop a better understanding of the greenhouse gas emission, and also, to develop abatement and mitigation strategies, indicators and bench-marks for further auditing of emissions across all its activities. The direct greenhouse gas emission from RTA activities with a known Global Warming Potential (GWP) described in terms of CO_2 equivalent emissions are presented in Figure 1.

Under the Sustainability Concept, a joint partnership project was agreed between RTA, Department of Environment, and Climate Change and Water (DECCW) and Boral in order to assess the technical and economic performance of recycled glass as a partial sand and cementitious materials replacement in concrete. The potential environmental benefits of this project were:

- Enhance economic viability and sustainability of domestic kerbside recycling.
- Reduce greenhouse gas emissions.
- Keep in excess of 100,000t of glass out of New South Wales landfill.
- Conserve energy and material resources.

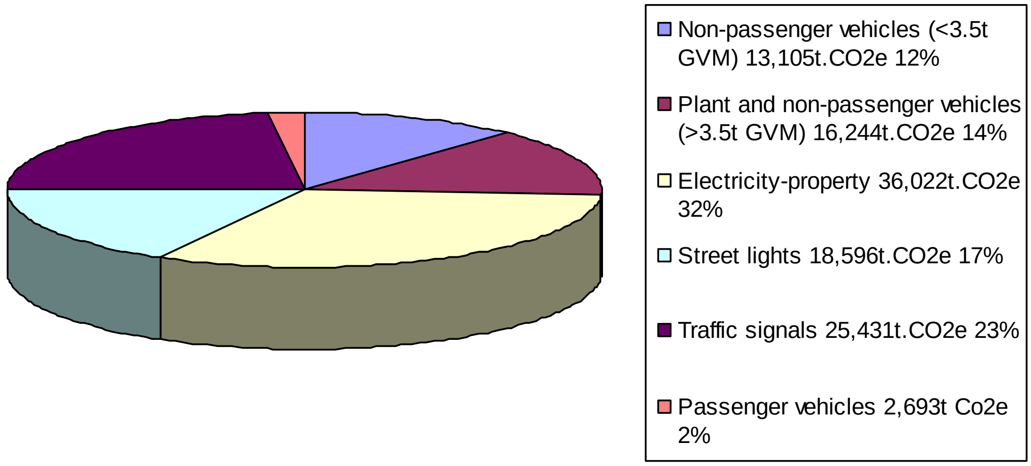

Fig.1. RTA Direct Greenhouse Gas Emissions by Activity

BRIEF REVIEW OF PUBLICATIONS ON RECYCLED CRUSHED GLASS AS NATURAL SAND AND CEMENTITIOUS MATERIAL REPLACEMENT

There is a large number of documentation available on the potential for glass waste to be used in concrete. It is important to mention some of these, which include work carried out in United Kingdom [University of Dundee 1998], raising relevant issues related to glass types, colour sensitivity, grading effect and also the risk for the potential alkali silica reaction (ASR) when using recycled glass in concrete.

Work on the potential impact of ASR in glass concrete has also been carried out by Columbia University [Meyer and Baxter 1998] and [Meyer 1999] concluding that different glasses cause different expansion and the fact that the technical know-how to control potential ASR in glass concrete is available.

Of extreme importance is the work carried out by University of Sheffield, United Kingdom [Byars et al. 2004] on this subject. The reports have concluded that:

- All products made with glass as an aggregate were found to have equivalent properties as products without glass.
- Glass can react in concrete and the reactivity increases with cement alkali content and particle size above 1mm. Particle size less than 1mm may reduce the potential for ASR.
- The ASR reactivity can be virtually reduced to zero by using fly ash, ground-granulated blast furnace slag or metakaolin.
- Colour effects of glass were unclear.

In Australia, work on waste glass as natural sand and pozzolanic material replacement in concrete was carried out [Shayan 2002; Shayan and Xu 2005] concluding that there is great potential for the utilisation of waste glass as fine and coarse aggregates but also as glass powder. The University of New South Wales [Sorrell 2005] has carried out a feasibility assessment of generating glass fines for markets, concluding that cullet glass is suitable for fine aggregates (< 1.18 mm) in concrete, although the minimal size is uncertain.

WASTE GLASS AS NATURAL SAND REPLACEMENT IN CONCRETE

Physical properties of recycled crushed glass

The glass as natural sand replacement in concrete trials was a crushed product with a size distribution between 3mm ~ 0.3mm. The clear and green glass was very clean with no materials passing 150 and 75 micron fractions. Other physical properties are presented in Table 1.

Table 1. Physical properties of recycled crushed glass sand

Properties	Results
Particle density SSD* t/m^3	2.49
Water absorption (%)	0.1
Sodium sulphate soundness (% Loss)	1.0
Sugar content	Not detected
Organic impurities other than sugar	Pass
Chloride as Cl^- (%)	0.007
Sulphate as SO_3 (%)	0.02

* SSD – Saturated Surface Dry

The crushed glass has also been tested for ASR [VicRoads RC376.03] in different combinations with results at 10 and 21 days presented in Table 2.

Table 2. ASR Accelerated Mortar Bar Test

Material/Mix	Expansion % (average of 3 specimens)	
	10 days	21 days
100% Agg /100% SL	0.003	0.029
80% Agg/20% GS/100% SL/0% FA	0.003	0.025
60% agg/40% GS/100% SL/0%FA	0.003	0.023
100% Agg/0% GS/80% SL/20% FA	-0.003	0.003
80% Agg/20% GS/80% SL/20% FA	-0.004	0.004
60% Agg/40% GS/80% SL/20% FA	-0.007	0.001
80% Agg/40% GS/60% SL/40% FA	-0.007	0.00
60% Agg/40% GS/60% SL/40% FA	-0.011	0.004

Agg – Basalt aggregate, SL – cement, FA – fly ash, GS – glass sand

The classification for test method considers aggregates as non-reactive if the expansion is < 0.15% for fine aggregate. Therefore, none of the combinations tested were reactive. However, the positive impact of fly ash on expansion is noted, which is well in line with current knowledge on the ASR and previous work by University of Sheffield, United Kingdom [Byars et al. 2004].

The ASR reactivity [RTA T364] was also assessed on concrete prisms covering a period of 2 years, replacing 30%, 45% and 60% of natural sand with crushed glass. None of the results were above 0.03%, the expansion limit for reactive aggregates classification, over 12 months.

Laboratory concrete trials

Three concrete trial mixes (in triplicate) were carried out against a control concrete mix using only natural products by replacing 30%, 45% and 60% of the natural coarse sand with recycled glass sand. The results are presented in Table 3. The mixes contain cement, fly ash, coarse aggregates (20/10mm) and coarse sand.

Table 3. Recycled Crushed Glass in Concrete

Properties	Control 100% natural product	Natural sand replaced by glass sand		
		30%	45%	60%
Slump (mm)	65	65	60	70
Plastic density (kg/m^3)	2317	2296	2314	2279
W/(C + FA)	0.47	0.46	0.44	0.45
Air Content %	5.2	6.2	5.6	6.6
Bleeding %	1.1	1.9	1.4	1.4
Initial/Final setting (hr:min)	5:30/7:20	7:05/9:00	7:20/9:35	7:30/10:15
28d compressive strength (MPa)	39.0	38.5	42.3	37.7
28d flexural strength (MPa)	4.71	4.70	5.00	4.89
28d indirect tensile strength (MPa)	4.89	4.45	4.41	4.43
28d modulus of elasticity (GPa)	31.4	31.9	31.7	28.3
56d drying shrinkage (με)	650	610	590	570
AVPV* value (%) @ 28d	15.7	16.2	13.6	13.4
Abrasion resistance (mm) @ 28d	1.95	2.48	2.95	6.49
Chloride diffusion ($\times 10^{-11}$)	1.74	1.53	1.35	1.32

*AVPV – Apparent Volume of Permeable Voids

As noted in Table 3, for a constant slump of 65±5mm, concrete with glass sand had marginally lower W/(C+FA) ratios. The air content and bleeding are slightly higher for all mixes using crushed glass as natural sand replacement. In addition, the setting time becomes much longer and it increases with the amount of glass sand added to the mix.

The properties of hardened concrete vary with the different replacement percentages. A better performance of the 45% natural sand replacement mix is noted. The compressive strength results (Figure 2) shows that when 45% of natural sand is replaced, the W/(C+FA) ratio dropped slightly, resulting in about 8% higher compressive strength at 28 days when compared with control. This trend continues to 56 and 90 days. However, there are no major differences in any of the mixes when compared with control for flexural/indirect tensile strength and modulus of elasticity. It is also noted that the abrasion resistance is a major issue with all mixes using crushed glass not performing well when compared with control.

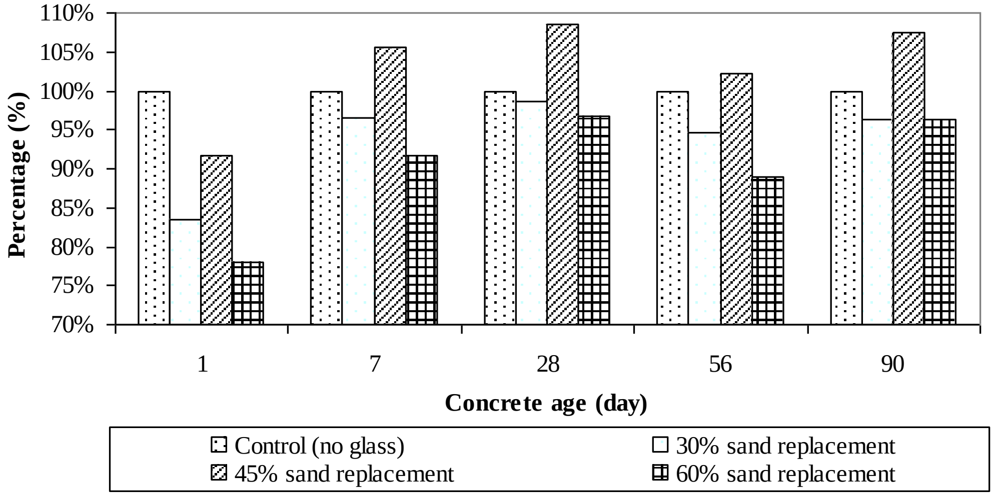

Fig.2. Comparison of Compressive Strengths at Ages

The drying shrinkage was monitored and the trend is represented in Figure 3. It is noted that both results for 56 and 90 days are lower for all mixes using crushed glass.

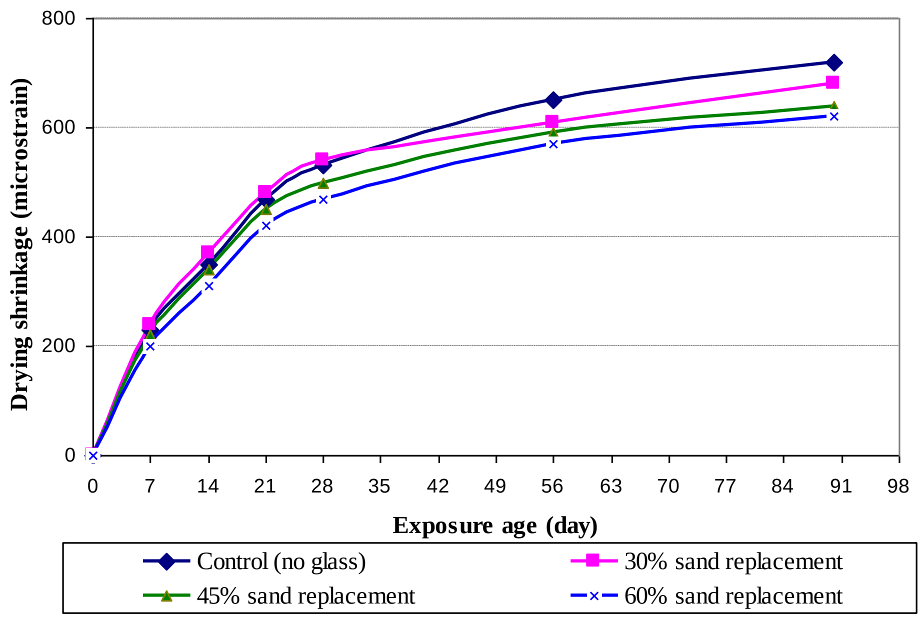

Fig.3. Comparison of Drying Shrinkage

The apparent volume of permeable voids – AVPV [AS1012.21] is up to 21% lower for the concrete mix using 45% natural sand replacement.

With regard to the durability performance, three concrete cylinders from each concrete mix were tested for the chloride diffusion [NT Built 443 1995] at age of 28 days. All concrete cylinders have been immersed in the salt solution for 35 days.

The results, in terms of chloride diffusion coefficient, show a better performance for all mixes using crushed glass as natural replacement (Figure 4).

Based on data available, it was found that the concrete mix using 45% crushed glass performs better than other mixes and it was chosen to be used in the field trial.

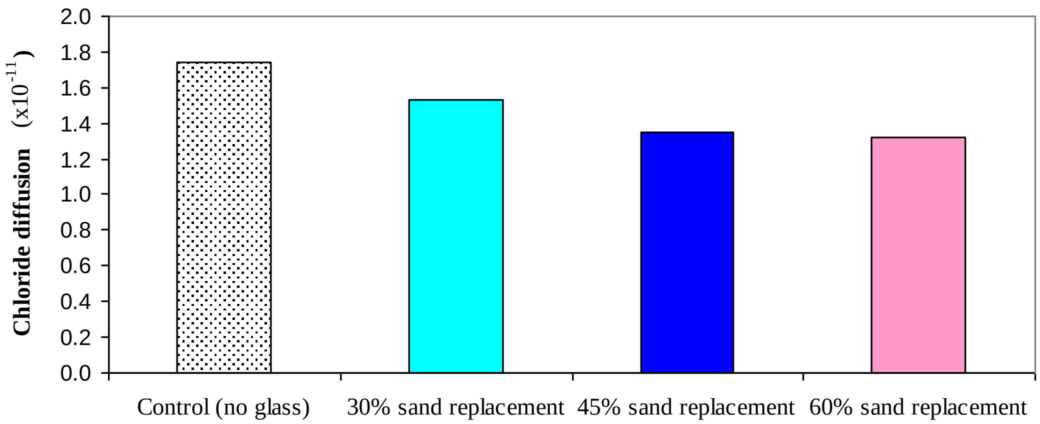

Fig.4. Comparison of Chloride Diffusion Coefficient

POWDER GLASS AS CEMENTITIOUS MATERIAL REPLACEMENT

Physical properties of powder glass

The properties of powder glass used in the concrete trial mixes are listed in Table 4 and a graphical representation of the particle size distribution is presented in Figure 5.

Table 4. Physical properties of recycled powder glass

Properties	Results
Density t/m^3	2.48
300 micron passing (%)	99.1
45 micron passing (%)	85
Fineness index (m^2/kg)	335
Mean diameter (micron)	54.1

When powder glass is used as a supplementary material, there is a concern that the sodium content of glass is too high and would compromise the quality of cement with respect to ASR. In order to address these concerns, chemical analyses were conducted on powder glass with the purpose of assessing the alkali released potential. The results are presented in Table 5.

The results show that, the powder glass does have a total equivalent alkali content of 10.7%, but these are “bound”-like alkalis within the glass. Only 0.23% equivalent acid soluble alkalis or only 0.6% available alkalis [AS 3583.12] means that the alkalis in glass are essentially acid insoluble and virtually non-reactive. However, glass is more susceptible to caustic attack on silica. Therefore, depending on the fineness/particle size of the glass, glass can either act as an ASR-susceptible aggregate or – if fine enough – as an ASR-mitigation agent. For higher reactivity of the silica, a pozzolanic-type effect can be expected.

We are of the opinion that the powder glass used in this project had a grading that it would not qualify as a fine aggregate and would not be a pozzolan either. However, it can possibly be used in concrete as a filler or "micro-aggregate". It may fill a grading gap between the fine sand and the cementitious component. This product is fine enough not to be susceptible to ASR (judging by the data available), even though it may not be fine enough to give much pozzolanic reaction.

Table 5. Total Alkalis in Powder Glass

Properties	% Total	% Acid Soluble	% Available Alkalis
SiO_2	74.80	0.21	--
CaO	10.10	0.35	--
Na_2O	10.38	0.22	0.53
K_2O	0.48	0.02	0.04
Total equivalent alkalis	10.70	0.23	0.57

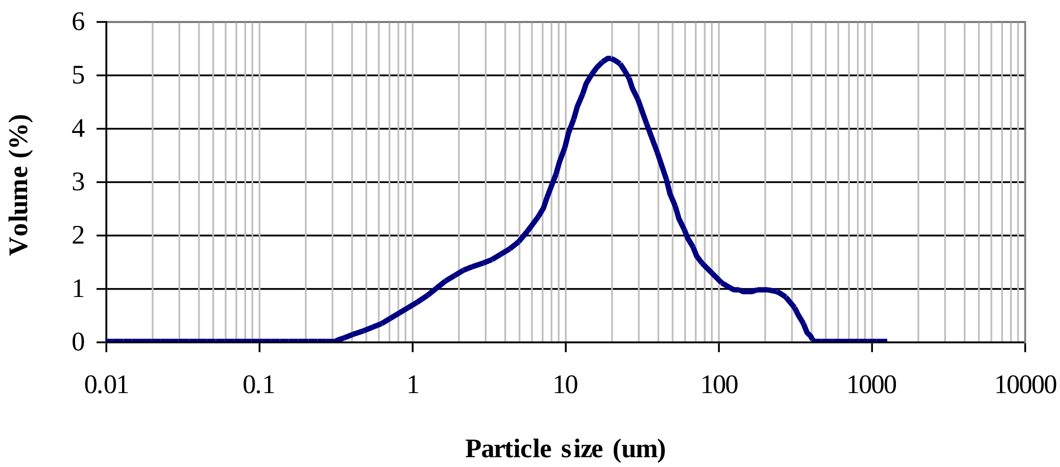

Fig.5. Particle Size Distribution of Glass Powder

Laboratory concrete trial mixes

Two sets of concrete trial mixes using powder glass as cementitious material replacement have been carried out against a control mix design for hand placed concrete pavement.

- **Replacement of 15% and 25% of cementitious materials with powder glass:**

The concrete trial mixes using the powder glass have confirmed some of the data where natural sand replacement with crushed glass sand took place, such as:

- Air content and bleeding are higher than control.

- Setting time is up to 1-2 hours longer than control.
- The compressive strength and flexural strength are lower than control.
- Drying shrinkage is higher than control.
- Abrasion resistance is much higher for all mixes using powder glass.

- **Replacement of 7.5% and 15% of cementitious materials:**

Due to lower results obtained in the first set of trials, a second trial was carried out, with results as follows:

- Air content is much higher than control for both mixes using 7.5 and 15% cementitious material replacement with powder glass.
- Compressive strength is also lower with results at 28 days at about 11.2% lower for 7.5% replacement and 18.8% less for 15% replacement.

It is interesting to note that both mixes using powder glass have met the mix design strength requirement at 28 days. For the field trial a 10% cementitious material replacement with powder glass has been considered.

CONCLUSIONS

-- Crushed glass sand can be used to partially replace the natural sand to produce concrete with at least equivalent mechanical properties. The optimum replacement percentage is 45%. For a constant slump of 65±5mm, the concrete trial mix with 45% replacement of natural sand achieved higher compressive strength and flexural strength and similar modulus of elasticity at age of 28 days.

-- The drying shrinkage, apparent volume of permeable voids, and chloride diffusion coefficient decrease with the increment of replacement ratios of glass sand. The alkali silica reaction results show that the glass sand used in this project is acceptable as an aggregate. Data from this project indicates that better durability can be achieved when crushed glass sand is used in concrete mixes.

-- The powder glass with fineness index > 335 m^2/kg can be used to partially replace the cementitious materials. Base on the data from this project, the replacement ratio of 10% has been recommended as the maximum to achieve the economic and environmental benefits.

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