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Field Trials Using Recycled Glass as Natural Sand Replacement and Powdered Glass as Cementitious Materials Replacement in Concrete Pavement

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ABSTRACT

Laboratory investigations, using recycled glass as natural sand replacement and powdered glass as cementitious materials replacement, have resulted in concrete mixes properties well within current specification requirement. The major benefits of concrete mixes using crushed glass as natural sand replacement were lower drying shrinkage and significant lower chloride diffusion coefficients. The results of this investigation were presented at the second International Conference on Sustainable Construction Materials and Technologies, in Ancona, Italy, in 2010.

This paper, documents the results of a field concrete pavement trial, using crushed recycled glass as natural sand replacement, and powdered glass as cementitious material replacement. It was concluded that, partial natural sand replacement with crushed recycled glass and, partial replacement of cementitious materials with powdered glass, can meet the current concrete pavement specification requirements, with the exception of abrasion resistance which is lower. A protocol regarding the testing regime, has also been considered, in order to achieve not only daily concrete production consistency, but also, to address the potential health and environmental issues.

Keywords. Recycled glass sand, recyced powdered glass, pavement, premix concrete

LABORATORY TRIALS

Natural Sand Replacement

Laboratory trials, carried out with recycled crushed glass as natural sand replacement in concrete pavement, and, the results of the trials were presented at Ancona, Italy, conference in 2010 [Dumitru et al. 2010]. The trials were carried out with a clear and green glass with a size distribution between 3mm – 0.3mm, with a particle density (SSD) of 2.49 t/m^3, and with very low level of chloride and sulphates.

The recycled crushed glass was non-alkali silica reactive. The concrete trial mixes using 30%, 45% and 60% crushed glass, as natural sand replacement, have demonstrated that, the 45% natural sand replacement resulted in higher compressive strength at 28 days, when compared with the control mix using 100% natural sand. Results are presented in Figure 1. Drying shrinkage, AVPV (apparent volume of permeable voids – AS 1012.21) were also lower when compared with the control.

When assessed for durability, in terms of chloride diffusion coefficient as per NT443, the concrete mix using 45% natural sand replacement has performed better than other mixes as presented in Figure 2.

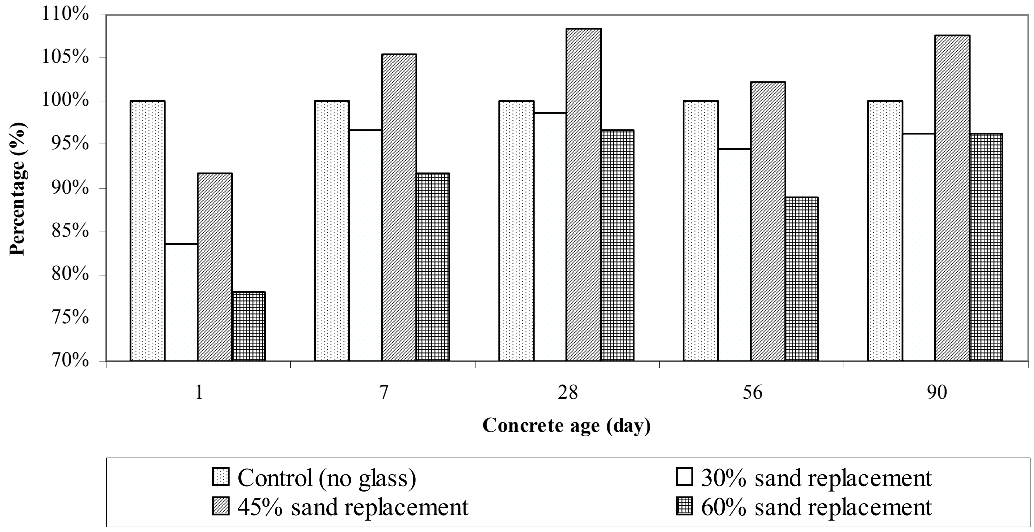

Figure 1. Compressive strength using glass sand replacement

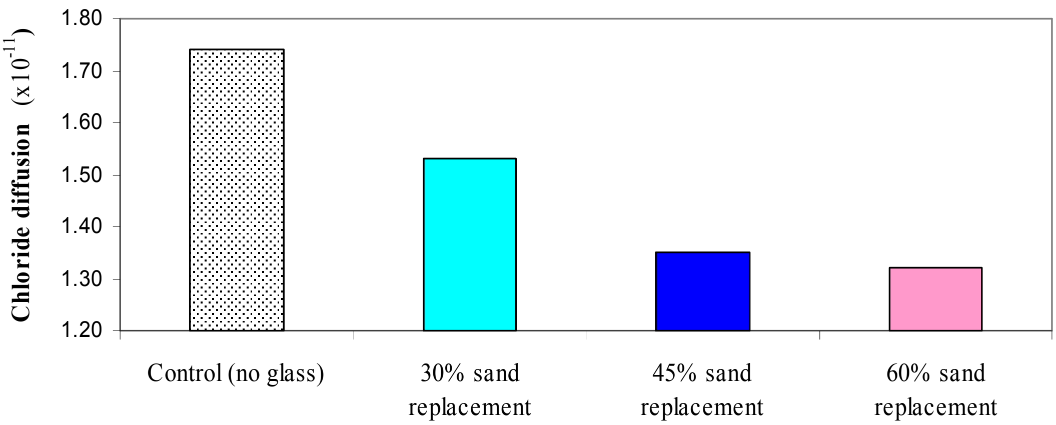

Figure 2. Chloride Diffusion Coefficient of laboratory concrete trials

Cementitious Materials Replacement

Powdered glass with a density of 2.48 t/m^3, a Fineness Index of $335m^2/kg$, and a mean diameter of 54.1 microns, has been used in the concrete pavement trials mixes (see Figure 3), using 7.5% - 15% replacement.

The finding of the trial mixes carried out, have concluded that:

- Setting time is up to 1-2 hours longer
- Air content is higher than control
- Compressive strength is lower at 28 days than control
- Abrasion resistance is lower

It is important to note that, the mixes using powdered glass as cementitious materials replacement, have met the design criteria for concrete pavement compressive strength and, for the field trial, a 15% cementitious materials replacement has been considered.

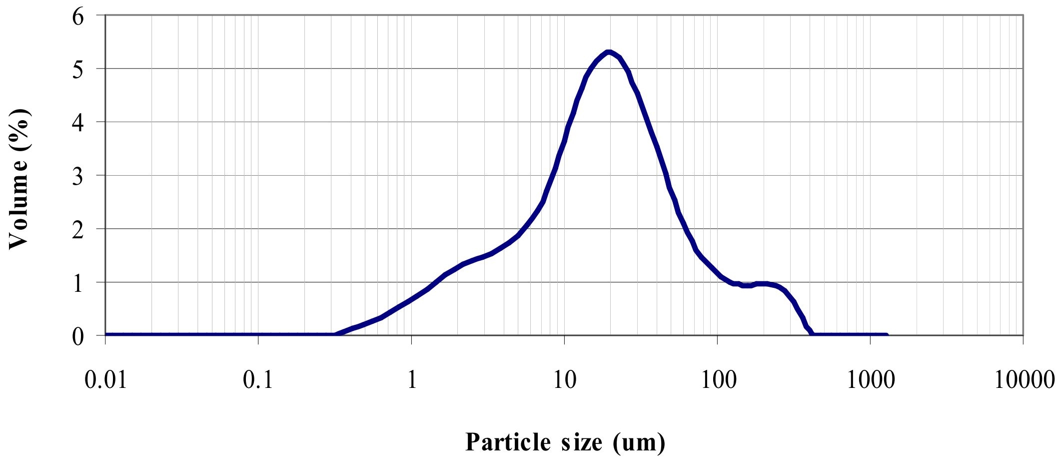

Figure 3. Particle Size Distribution of Glass Powdered

FIELD TRIALS

The field trials using recycled crushed glass, and powdered glass in concrete pavement, have been carried out at Boral's Dunmore Quarry, South of Sydney, using control mix cap, and a control mix between the glass sand concrete and the powdered glass concrete (Figure 4).

The mix design for the trials, has used 45% replacement of natural sand with recycled crushed glass, and approximately 15% powdered glass replacement of cementitious materials. Although the laboratory trials have demonstrated that 30% recycled glass has performed better, the 45% replacement of natural sand with recycled glass has been chosen in order to assess the field performance of a concrete pavement using large quantities of recycled crushed glass.

Details of the mix designs are presented in Table 1, the mix using cement and fly ash.

The pavement design was a typical concrete road pavement used in main roads in New South Wales, with a lean mix subbase, two coat seal and, proper anchor trench steel, as shown in Figure 5 .

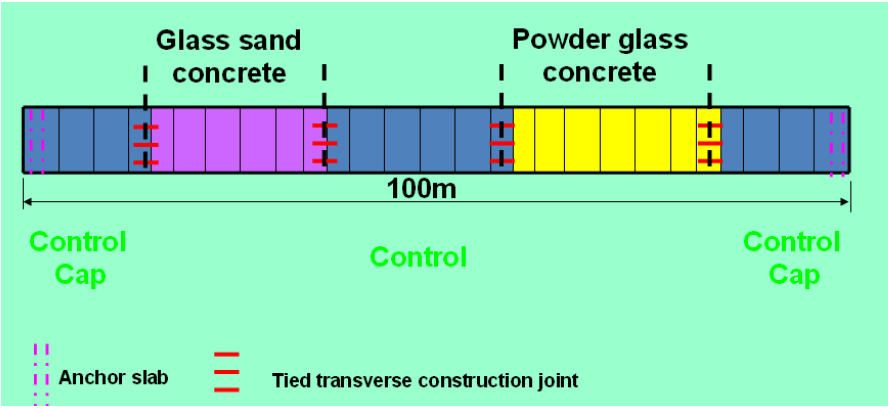

Figure 4. Field trials plan

Table 1. Concrete Mix Design used for Field Trials

Mix		Control	Glass Sand 45%	Glass Powder 15%
CEMENTITIOUS	kg/m^3	395	397	337
Glass Powder	kg/m^3	-	-	**60**
COARSE Sand (DSS)	kg/m^3	664	367	664
Glass Sand	kg/m^3	-	**292**	
10mm Dunmore	kg/m^3	325	327	325
20mm Dunmore	kg/m^3	749	755	749
WATER (incl. Admix.)	kg/m^3	185	175	185
AEA-940	ml/m^3	300	200	300
POZZ-300RI	ml/100kg	200	200	200

Figure 5. Anchor trench steel / formwork for field trials

Recycled Crushed Glass as natural Sand Replacement

The 35MPa mix using 45% recycled crushed glass, has a slightly lower slump than the control, with the air content also slightly lower than control. The compressive strength of the mixing, using recycled glass as natural sand replacement, has been measured in cylinders taken from concrete delivered in five trucks, with all results higher than the design 35MPa. At 91 days, the compressive strength was almost 55MPa, well within the specification requirements.

The results for compressive strength at 28 and 91 days are presented in Figure 6.

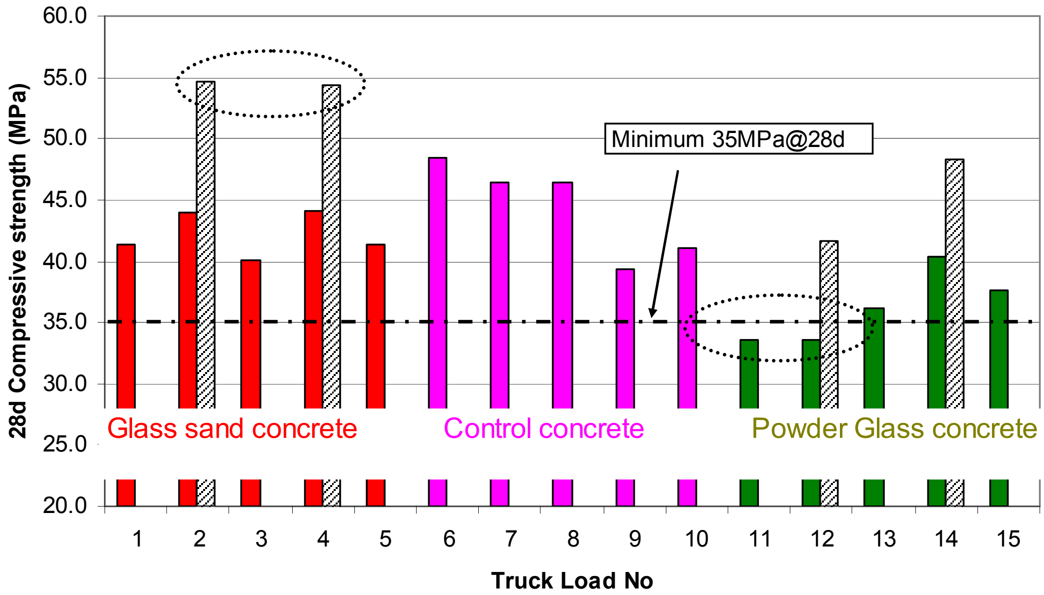

Figure 6 Concrete compressive strength in cylinders from field trials at 28d (colour) and 91d (diagonal line)

The flexural strength, of the concrete using crushed glass, was lower than 4.5MPa requirements at 28 days, but it was as high as 6MPa at 91 days.

As expected, the concrete shrinkage at 21 days was very low at around 420 microstrain and, was less than 600 microstrain at 56 days. The results are lower than the control, as presented in Figure 7.

Interesting results were obtained for compressive strength, on cores drilled from site at age of 28 days.

The data, as presented in Figure 8, show that all results of concrete cores are above the minimum requirements of 35MPa, with some compressive strength as high as 45MPa, the average of 6 cores being almost 40MPa, slightly higher than the control mix.

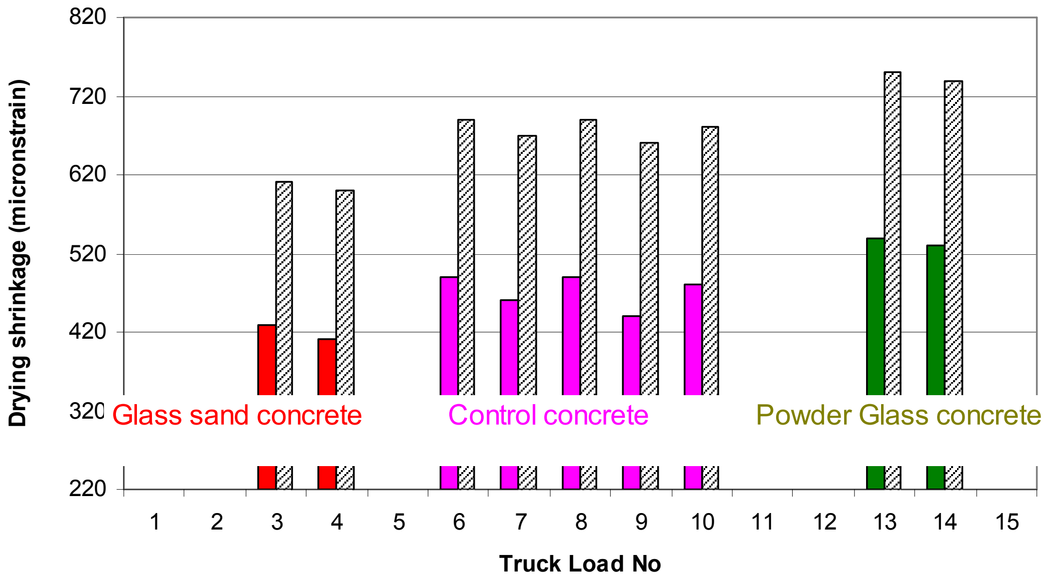

Figure 7 Concrete drying shrinkage of concrete from field trials at 21d (colour) and 56d (diagonal line)

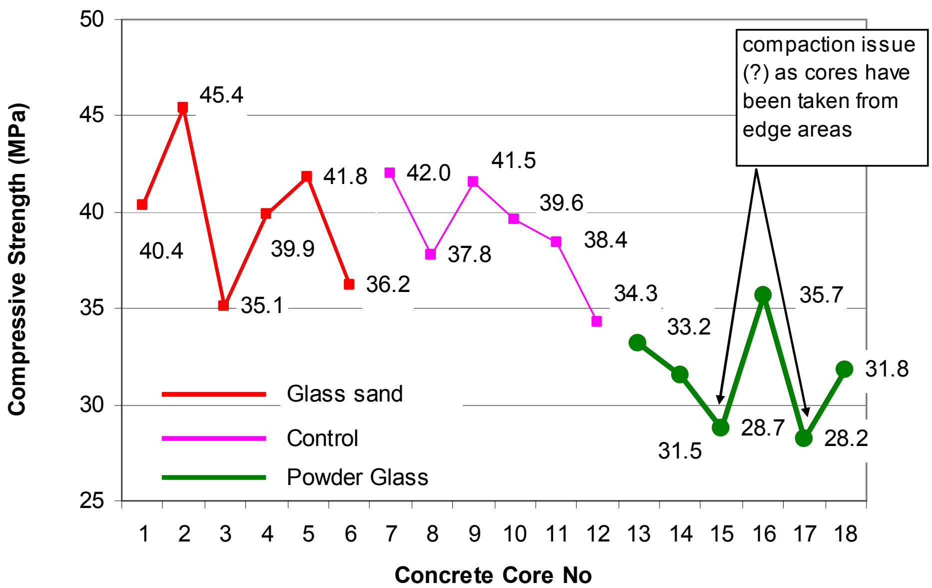

Figure 8. Compressive strength @28d of cores from field concrete

Powdered Glass as Cementitious Material Replacement

The results are a true reflection of the laboratory trials. About 15% cementitious material was replaced with powdered glass, with a fineness index of 335m^2/kg, resulting in lower compressive strength in cylinders and cores, presented in Figures 6 and 8, respectively. However, at 91 days, the compressive strength was higher than 45MPa in concrete cylinders. Some lower results in cores, as presented in Figure 8, are due to compaction issue, as the cores were taken from the concrete edge areas.

The concrete shrinkage at 21 and 56 days are higher than control, as presented in Figure 7.

ASSESSMENT OF FIELD TRIAL AREA AFTER ONE YEAR IN SERVICE

Visual inspection, carried out after one year in service, has concluded that the pavement is in a good condition, with some aggregate loss of about 20-30% for both areas, using glass as natural sand replacement and powdered glass as cementitious materials replacement.

As expected, the abrasion resistance is lower than the control for both trials, being obvious that the control performed better, as presented in Figures 9 and 10.

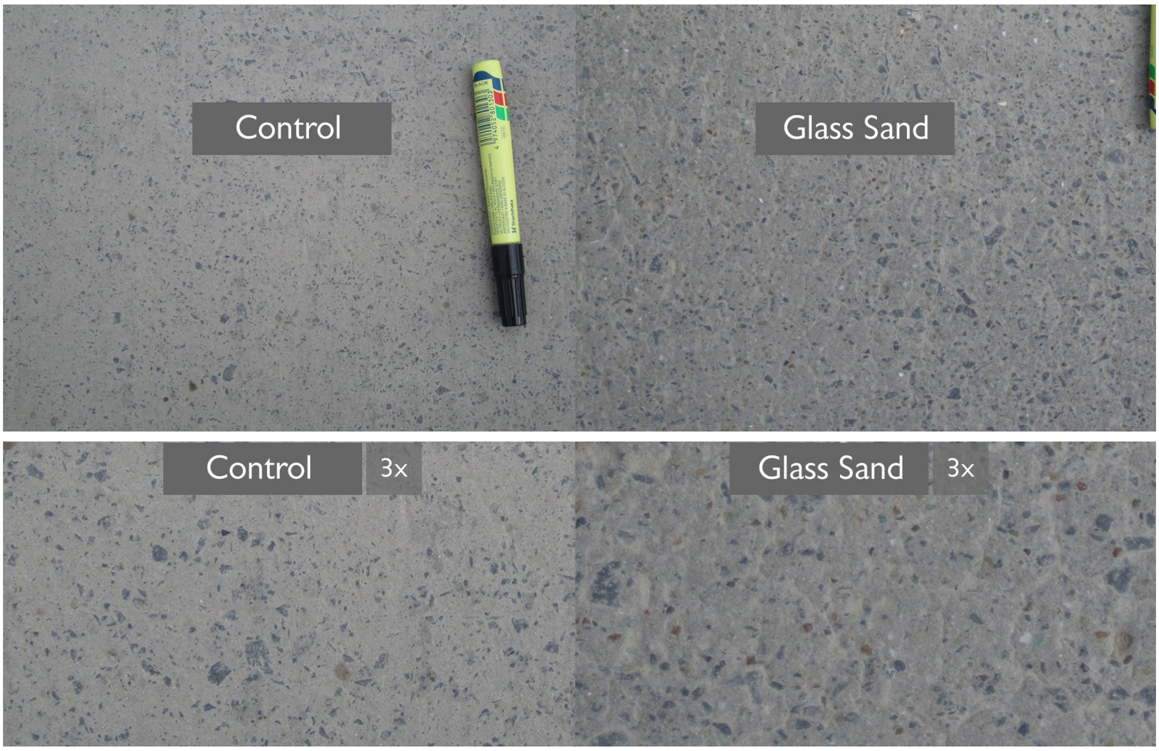

Figure 9. Side-by-Side Comparison of Surface Wear in IWP – Control vs Glass Sand (1x & 3x)

Figure 10. Side-by-Side Comparison of Surface Wear in IWP – Control vs Powdered Glass (1x & 3x)

Concrete cylinders tested at 365 days from crushed glass area, showed compressive strengths of 62.9MPa and, 50.8MPa for powdered glass area.

With regard to the visual inspection carried out, it is important to note that:

- Wheels and windborne grit from the quarry are prematurely accelerating abrasion.
- With coarse aggregate now exposed, the rate of abrasion is slow.
- Compressive strength does not correlate well with wear resistance.

The monitoring will continue on annual basis.

Based on the good results obtained in the field trials, glass sand is currently being used in production at 20-25% of the total sand content. After approximately 5 months, the results, before and after using glass, indicate no statistical differences at 28 days between concrete , with and without glass for 20, 25, 32 and 40MPa grade.

A protocol, regarding the testing regime for glass sand and powdered glass/natural sand blends has been introduced for concrete production. The protocol also covers health and technical aspects including dust, grading, chloride, lead, sulphur trioxide, sugar, setting time, etc.

CONCLUSIONS

- Recycled sand glass can be used to partially replace natural sand in concrete, producing concrete with at least equivalent fresh and hardened properties;
- The drying shrinkage, chloride diffusion coefficient and AVPV (apparent volume of permeable voids), decreases with the increase in replacement percentage of natural sand;
- Abrasion resistance of concrete with recycled glass is lower, and this is a major hurdle to be addressed in concrete pavement;
- Powdered glass with a Fineness Index of 335m^2/kg can be used to partially replace up to 15% of cementitious materials in concrete pavements;
- The compressive strength of the concrete pavement has achieved the minimum 35MPa as per specification requirements. Flexural strength has achieved the required 4.5MPa at 91 days;
- Drying shrinkage at 56 days is slightly higher than the control;
- Abrasion resistance is lower and setting time is longer when compared to control mix.

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