Studies In Utilisation Of Ground And Coarse Waste Glass In Mortar And Concrete

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ABSTRACT

The reuse of waste glass poses a major problem in large municipal areas of the United States. Post-consumer glass is often mixed-color and commingled with plastics and metals, contaminated with other materials like ceramics and organic matter and partially broken. This reduces its value and complicates the ability to achieve the cullet specifications of bottle manufacturers or other markets such as the construction industry. Most of these markets make little use of the inherent chemical and physical properties of glass, therefore its market value is very low. A major research effort has been underway at Columbia University for a number of years, to develop new applications for waste glass as an aggregate for concrete. Extensive studies were undertaken to solve the alkali-silica reaction (ASR) problem. Specific products such as paving stones, concrete masonry blocks, terrazzo tiles, and precast concrete panels are close to commercial production. This paper discusses the various steps that need to be taken by recyclers to collect the glass, separate it from the other materials, clean it and crush it to obtain the appropriate grading to meet the specifications for specific applications. Glass is unstable in the alkaline environment of concrete and could cause deleterious alkali-silica reaction problems. This property has been used to advantage by grinding it into a fine glass powder (GLP) for incorporation into concrete as a pozzolonic material. In laboratory experiments it can suppress the alkali-reactivity of coarser glass particles, as well as that of natural reactive aggregates. It undergoes beneficial pozzolonic reactions in the concrete and could replace up to 30% of cement in some concrete mixes with satisfactory strength development. The drying shrinkage of the concrete containing GLP was acceptable.

Keywords

Waste Glass, Mixed-Color Cullet, Glass Concrete, Paving Stones, Precast Concrete, Architectural Concrete.

1. INTRODUCTION

Glass is produced in many forms, including packaging of container glass (bottles, jars), flat glass (windows, windscreens), bulb glass (light globes), cathode ray tube glass (TV screens, monitors, etc), all of which have a limited life in the form they are produced and need to be reused/recycled in order to avoid environmental problems that would be created if they were to be stockpiled or sent to landfill. It is the design goal of each MRF to effectively recover the maximum amount of recyclables from the incoming stream. A significant portion of the mixed-color container glass set out by the participating households is received broken. Glass breaks during the loading onto collection trucks, during transport, unloading at the MRF, and during processing. Although this breakage is unintentional, it is also inevitable due to the characteristics of glass. As much as 75% of the total glass may be broken, and at most MRFs the breakage percentage is typically 50%. Due to size and contamination, color sorting of this material into glass cullet suitable for glass bottle manufacturing can be costly. Therefore, MRFs are often forced to landfill this material as residue, unless alternative approaches are found. Container glass represents about 65 to 70% of the total commingled container stream (i.e. inclusive of plastics and metals). There is consequently a significant amount of potential residue if the broken glass cannot be recovered as a marketable product. The solution is to develop an alternate product that could be marketed even if not color-sorted. A simple automatic mixed broken glass beneficiation system was developed in the early 90's to size, clean and sell the contaminated broken glass material as a construction aggregate product. While this material does not have a strong market value, it does contribute to overall plant performance by reducing residue disposal costs. Many recycling operations realize that they gain little - or even have a loss of - income by processing glass. *Closed-loop recycling*, the process of collecting, sorting, transporting, beneficiating, and manufacturing glass back into bottles, is the most common form of glass recycling and has costs embedded in each step of the process. The growth and evolution of recycling in the United States and in many other parts of the world has resulted in a number of different methods for the collection and sorting of glass. Some glass is collected and sorted by color at drop-off centers. This often requires labor at the center to assure that the glass is properly color-sorted and free of ceramic contamination. Glass may also be collected as part of the commingled curbside collection programs common in many communities. The color sorting is then done at the MRF. Both of these collection methods incur labor and

DOI: http://www.researchpublications.org

transportation costs for color sorting and recycling of bottle glass. Because the glass is of mixed color, and much of it is broken, it cannot be easily recovered for closed-loop recycling. The disposal of the mixed broken glass (MBG) as a residue from the recycling process causes a significant cost to recyclers. If they are getting paid $20.00 per ton to process the recyclables, but have to pay $40.00 per ton to dispose of residual material in landfills, the losses they incur for disposing of the MBG will exceed the entire income they receive for taking in the glass. Also the labor cost for sorting the glass and transporting it to a glass recycler or beneficiator often equals or exceeds the price paid by the glass beneficiator. As the glass manufacturing industry consolidates and the number of glass beneficiators decreases, the cost of transportation increases, and the prices traditionally paid by the beneficiators decrease. Clearly, closed-loop glass recycling under such conditions is a break-even business at best and often results in financial losses for every bottle that is picked.

Processed glass – container and architectural glass of fraction size 5mmdust.

• Glass powder – a much finer material which is collected in the air filtration system whilst producing the processed glass. The glass powder is being used for partial binder replacement in proportions of 10%, 20% and 30% binder replacement whereas the processed glass is being used for 100% replacement of fine aggregate. The coarse aggregate component of the concrete is standardised at 10mm crushed limestone. Each of the materials has been analysed to establish chemical composition and size. The particle size of the processed glass was established by sieve analysis and a comparison made between it and the natural sand being used in comparative mixes.

2. COARSE AND FINE AGGREGATE IN CONCRETE

The influence of physical properties of glass aggregate such as grading on the properties of the concrete mix is well known. Glass, due to its silica-rich nature and amorphous structure is susceptible to chemical attack under the high alkali conditions provided by the hydrated cement phase in the concrete. This chemical attack on glass could produce extensive formation of AAR gel which is expansive and could cause premature cracking in the concrete, if appropriate precautions are not put in place in the formulation of the concrete mix. The nature of the glass reactivity has important implications in its utilization in concrete. For Instance, some natural aggregates cause excessive expansion in concrete when used as a small Proportion of total aggregate content, and some other ones when used at 100% of the total aggregate. The reactivity of aggregate is assessed by accelerated mortar bar testing (AMBT), conducted in 1M NaOH at 80oC, according to ASTM C1260 or an Australian method RTA T363. The AMBT results obtained at ARRB have shown that the larger the content of glass in mortar bars, the higher the expansion. The criteria for this test, according to the RTA Test Method T363, are that expansion values smaller than 0.10% at the age of 21 days are associated with non-reactive aggregate (smaller than 0.15% for sand), and expansions greater than 0.10% at 10 days associated with reactive aggregates. Expansions smaller than 0.10% at 10 days but exceeding 0.10% at 21 days indicates slowly reactive aggregate. Based on these criteria, use of up to 30% glass in the concrete may not cause deleterious effects, particularly if the alkali content of the concrete is low (below 3 kg Na2O equivalent per cubic meter). At higher alkali contents of concrete further expansion may result. In addition to the glass content of mortar bars, the particle size also has an effect on the expansion. Glass particle sizes below 0.30 mm would not cause deleterious expansions, whereas fractions above 0.60 mm would cause significant deleterious expansions. Therefore, the magnitude of expansion would depend on the interaction of glass content, particle size and alkali content of the concrete. These results have shown that glass can react and produce AAR gel, and that once the particle size is sufficiently reduced, it can act as a pozzolonic material. It is well known that the reactivity of aggregate and its consequent expansion can be suppressed by incorporating appropriate amounts of supplementary cementitious materials such as silica fume and Fly ash. Fine glass powder can also act in a similar manner. It is evident from the strength results that these mixes easily meet and exceed the requirements of the 32 MPa concrete, while incorporating large quantities of waste glass. For non-structural applications, where lower strength (e.g. 25 MPa) is required, the same mix without the water reducer or superplasticiser could be used to achieve the required strength.

3. RECYCLING OF GLASS

Post-consumer glass containers have traditionally been disposed of either in domestic refuse, which ends up in landfill, collected in designated collection spots for reuse/recycling, or collected from kerbside and then transported to collection sites. The major aim of environmental authorities is to reduce, as far as possible, the disposal of post-consumer glass in landfill and diversion to economically viable glass product streams. Glass is a unique inert material that could be recycled many times without changing its chemical properties. In other words, bottles can be crushed into cullet, then melted and made into new bottles without significant changes to the glass properties. Most of the glass produced is in the form of containers, and the bulk of what is collected post consumer is again used for making containers. The efficiency of this process depends on the method of collecting and sorting glass of different colours. If different colour glass (clear, green, amber) could be separated, then they could be used for manufacturing similar colour glass containers. However, when the glass colours get mixed, they become unsuitable for use as containers, and are then used for other purposes, or sent to landfill. Rindl (1998) reported the many non-container uses of glass cullet, which included road construction aggregate, asphalt paving, concrete aggregate, building applications (glass tiles and bricks, wall panels, etc), fibre glass insulation, glass fibre, abrasive, art glass, agricultural fertiliser, landscaping, reflective beads, tableware, hydraulic cement, among other applications. The utilisation of glass in concrete is of particular interest for the work reported here. A major concern regarding the use of glass in concrete is the chemical reaction that takes place between the silica-rich glass particles and the alkali in the pore solution of concrete, i.e., alkali-silica reaction (ASR). This reaction can be very detrimental to the stability of concrete, unless appropriate precautions are taken to minimise its effects. Such preventative actions could be achieved by incorporating a suitable pozzolonic material such as fly ash, silica fume, or ground blast furnace slag in the concrete mix at appropriate proportions. The susceptibility of glass to alkali implies that coarse glass or glass fibres could undergo ASR in concrete, possibly with deleterious effects. However, it would be expected that fine ground glass (i.e. glass powder), would exhibit pozzolonic properties such as those of the materials named above, and would be an effective ASR-suppressant, preventing ASR damage to concrete in the presence of reactive aggregates. Rindl (1998) presented a summary of work conducted by other researchers or organisations. For example, he quotes from Boral company, Lilesville, North Carolina that ground soda-lime glass of < 100 mesh was effective against ASR, and from Clean Washington Centre that glass as fine aggregate (rather than powder) can weaken the concrete matrix due to ASR. He quoted work by Samtur (1974) on this issue, which indicated that fine glass powder (< 200 mesh, or < 75 □m particle size), could act like a pozzolonic material to reduce the tendency of reactive aggregate to undergo ASR. Pattengil (1973) had apparently also found similar effects. The work of Phillips and Cahn (1973) has been quoted to have shown that up to 35% glass cullet could be used in concrete in combination with low alkali cement, without detrimental effects. Recently, New York State Energy Research and Development Authority (NYSERDA), sponsored research on the utilisation of recycled glass for concrete masonry blocks, and it was shown that waste glass can be used as both coarse aggregate and as additive, provided that certain conditions are met (NYSERDA, 1997). Another project dealt with the use of recycled glass and fly ash in precast concrete and encouraging results were obtained (NYSERDA, 1998). Bazant et al. (1998) found that glass particle size of around 1.5 mm caused excessive expansion,

whereas particles < 0.25 mm caused no expansion in laboratory tests on concrete. Jin, Meyer and

Baxter (2000) found that glass particles of around 1.2 mm caused the largest mortar bar expansion in the particle size range of 0.15 – 4.75 mm. They found that the largest expansion resulted when glass particles formed 100% of the aggregate, and that green glass containing more than 1.0% chromium oxide had a beneficial suppressive effect on ASR. Carpeneter and Cramer (1999) also reported that powdered glass was effective in reducing ASR expansion in accelerated mortar bar tests, similar to the effects of fly ash, silica fume and slag. This is in agreement with the present authors' unpublished results Shayan and Xu, (1998), where it was shown that glass powder could suppress the ASR expansion caused by natural reactive aggregates and coarse glass particles. From the above it appears that glass could be used in concrete in three forms; as coarse and fine aggregate, and in powder form. The coarse and fine glass aggregates could cause ASR in concrete, but the glass powder could suppress their ASR tendency, an effect similar to supplementary cementitious materials (SCMs). On a market price basis, it would be much more profitable to use the glass in powder form as a cement replacement material (i.e., as an SCM), than as aggregate. This would be a value-added material, produced from contaminated, mixed-colour glass chips which are not useable for packaging purposes. Although such material could also be used as abrasive grit, although the volume used for this application is not very high compared to that of SCMs. In the following sections data are presented in relation to the utilisation of glass in concrete

in the three forms mentioned above.

4. EFFECTS OF GLASS POWDER (GLP) ON MORTAR STRENGTH

The particle size distribution of the glass powder (GLP) used is as follows:

Particle size : <5 □m 5-10 □m 10-15 □m >15 □m % : 39.0 49.0 4.4 7.6

The specific surface area of the GLP was 800 m2/kg, which is around double that of most Australian GP cements (~ 400 m2/kg). The effects of cement or sand replacement by GLP on the strength of mortar cubes (aggregate to cement ratio of 2.25 and water/cement ratio of 0.47) are shown in Figures 1 and 2. In the case of cement replacement, the reduction in the 28 days strength, may, to some extent, be a short-term effect because in such short periods the pozzolonic effects would not become evident. Fly ash also exhibits a similar effect when it replaces an equal mass of cement.

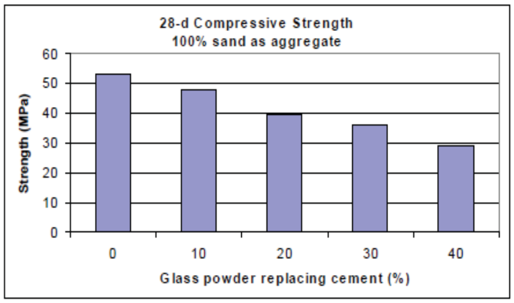

Fig. 1Effect of glass powder replacing cement on strength of mortar made with 100% sand.

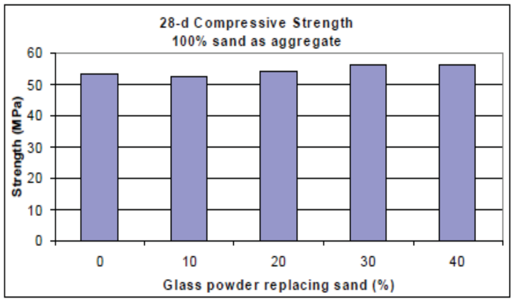

Fig. 2 Effect of glass powder replacing on the strength of mortar made with 100% sand.

Longer-term strength development was studied in comparison with silica fume. This series consisted of control specimens in which the fine aggregate was a reactive greywacke and other specimens that contained either of 10% silica fume (SF), 20% GLP or 30% GLP, each replacing corresponding amounts of the cement. In one case 30% GLP replaced the aggregate. Figure3shows the strength development of each combination over 270 days.

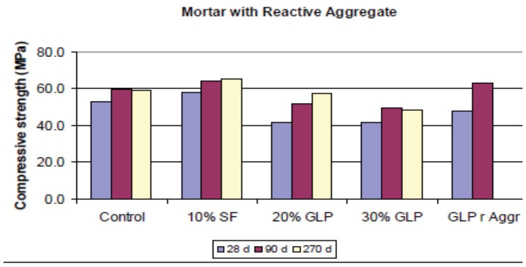

Fig. 3 Strength development of mortar with reactive aggregate.

These results indicate that 10% SF replacement produces higher strength than the GLP replacements, but they also show that mortar specimens containing GLP continue to develop further strength with time, indicating pozzolonic reactivity. It should be noted that when 30% sand was replaced by GLP, the 90-day strength was the same as that of the SF-bearing specimens. To verify the positive effect on strength of aggregate replacement by glass powder two additional tests were conducted on mortar cubes, cured for up to 270 days. In one set of specimens 20% cement was replaced by glass powder and in the other set, in addition, 10% of aggregate was also replaced by glass powder. Figure 4 confirms that this replacement is beneficial, probably due to improvement in the particle packing, as well as the pozzolonic reaction. It should be noted that the strength achieved with 30% glass powder replacing 20% cement and 10% aggregate exceeds that of the silica fume-containing mix. The apparently larger effect of SF on strength gain compared to glass powder, is exaggerated in these tests, because those with SF have 90% cement, whereas those with glass powder have 80 and 70% cement. For a comparison based on similar cement contents, mortar strength tests were conducted on two further sets of specimens that contained crushed, graded glass as the fine aggregate (80% glass + 20% natural sand), and in which 30% of the cement was replaced by other materials. In one set 30% of cement was replaced by glass powder, and in the other set by a mixture of 10% silica fume plus 20% pulverised basalt powder (non-pozzolonic). This made the cement content of the two sets the same. Figure 5 shows the strength results for the two sets to be very similar. It should be noted that the strength results presented in Figures 3 and 5 are not comparable due to completely different aggregates in the mortar mixes. Therefore, it is confirmed that the reduced strength observed in Figure 3 for the mix containing glass powder, is due to the lower cement content rather than the nature of the glass powder. In the case where glass powder replaces aggregate, without reduction in the cement content, the resulting strength is greater than those of specimens containing SF. The above indicates the favourable effects of glass powder on strength development of mortar specimens containing it.

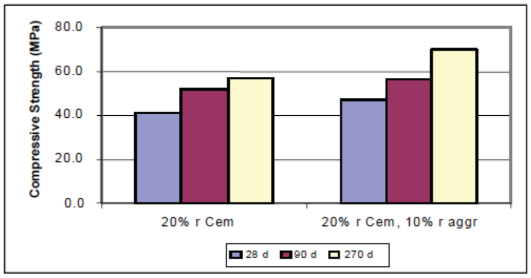

Fig. 4 Strength development of reactive aggregate with additional Glass Powder.

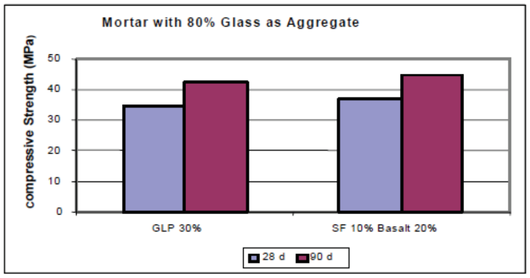

Fig. 5 Comparison between SF and mortar with GLP with 30% reduction in cement content.

5. EFFECT OF GLASS POWDER ON MORTAR EXPANSION

As shown in Figures 2 and 3 coarse sand size particles of glass can cause deleterious AAR expansion, particularly at high glass contents in the accelerated mortar bar test. Therefore, six sets of mortar bars were made to contain 80% glass particles in the aggregate phase as the reactive component. The control set contained the aggregate and plain cement, and in the other five sets the cement was replaced by 5% SF, 10% SF, 10%, 20% and 30% GLP. Figures 10 and 11 show the expansion results for these combinations and indicate that both SF and GLP are effective in suppressing AAR expansion when used in sufficient amounts (10% SF and >20% GLP).

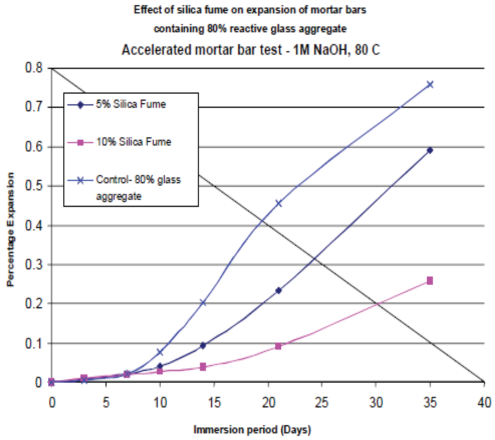

Fig. 6 Effects of SF on expansion of mortar

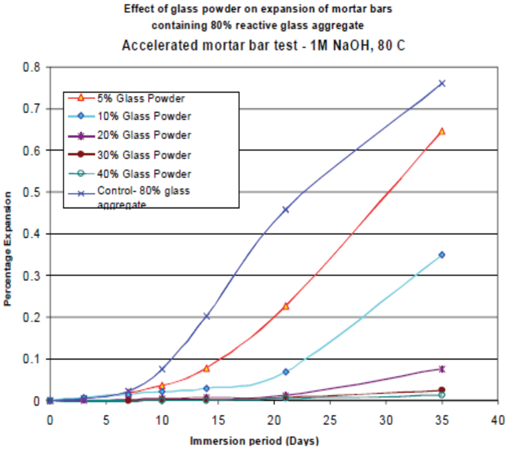

Fig. 7 Effects of GLP on expansion of

bars containing reactive aggregate.

mortar bars containing reactive aggregate.

These results indicate the efficiency of 20% and 30% GLP in suppressing AAR expansion to be better than 10% SF. Due to the large soda content of the glass (around 13%), it is important to find out whether or not the GLP itself could cause long-term mortar bar expansion, or trigger the expansion of reactive aggregates if present in the specimen. Long-term mortar bar expansion testing, conducted at 38oC, 100% RH, were undertaken in combination with non-reactive and reactive aggregates, and with the same levels of cement replacement as mentioned above. Expansion values less than 0.1% at 1 year indicate innocuous combinations. Figure 8 shows that the GLP itself does not cause any expansion when the aggregate is nonreactive. Moreover, Figure 9 shows that when the aggregate is reactive, the presence of even 30% GLP does not trigger the reactivity of the very susceptible aggregate used. Even when the cement is not replaced, and GLP has replaced the aggregate, still the 30% GLP does not cause deleterious mortar bar expansion. The data indicate that GLP could be used without fear of harmful effects.

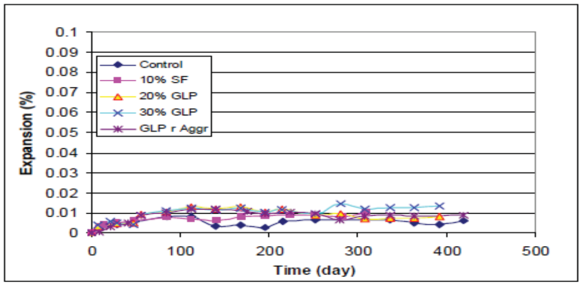

Fig. 8 Expansion curves for mortar bars containing non-reactive aggregate

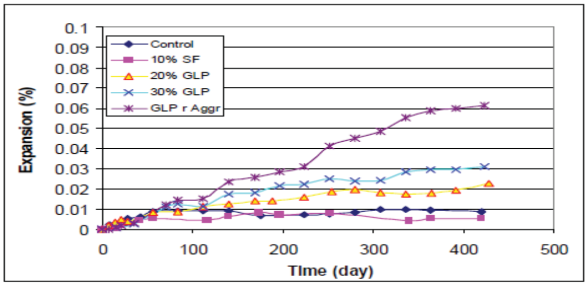

Fig. 9 Expansion curves for mortar bars containing reactive aggregate and 30% GLP.

6. GLASS POWDER IN CONCRETE

The efficiency of glass powder was also assessed in concrete expansion tests. A very reactive aggregate was employed in the concrete prism test conducted according to the RTA T364 test method (similar to ASTM C1293). Deleterious expansions are considered to be above 0.03% or 0.04% in one year. Figure 14 shows that even 40% GLP, which has the potential to release more alkali than 30% GLP, has effectively suppressed the enormous expansion of the very reactive aggregate in the concrete (80% reduction). For less reactive aggregates, the expansion would have been completely suppressed. This confirms the beneficial effects of GLP in improving the durability properties of concrete.

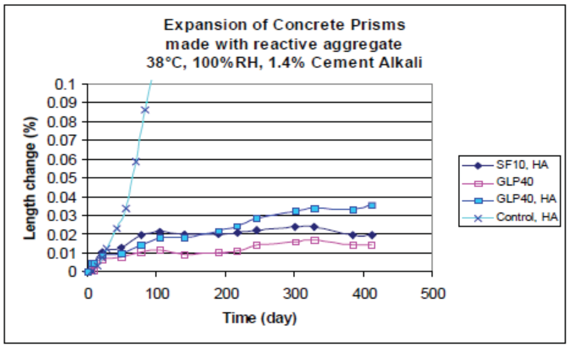

Fig. 10 Expansion curves for concrete prisms containing a very reactive coarse aggregate in combination with the materials indicated.

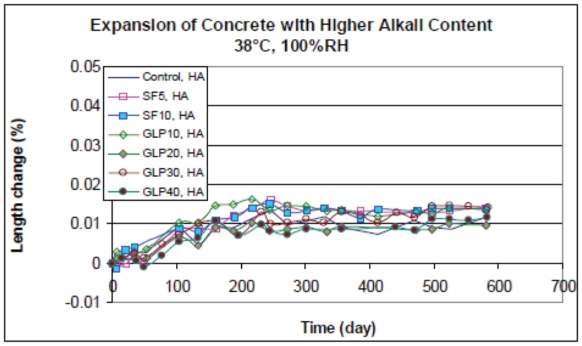

Fig. 11 Concrete expansion curves for the combination of various amounts of GLP and silica fume in the presence of 5.8 kg Na2O equivalent./m3.

7. EFFECTS OF GLASS POWDER ON CONCRETE SHRINKAGE AND STRENGTH

Concrete specimens corresponding to those represented in Figure11 but of lower alkali content were employed for determining the drying shrinkage of concrete containing various amounts of GLP and SF. Long-term data presented in Figure 12 show that the drying shrinkage of the various mixtures are not excessive and they easily meet the requirements of AS 3600, being values less than 0.075% at 56 days.

The strength properties of the concrete mixes represented in Figure 16 are given in Figure 12. It is seen that although the mixes containing GLP have lower initial strength values, due to significantly lower cement content, they keep developing strength with time under moist-curing conditions, and approach the strength of the control mixes. Particularly when GLP replaces sand, the strength is significantly greater than that of the control mixture. The continued strength development clearly indicates the beneficial pozzolonic reaction of the GLP in concrete.

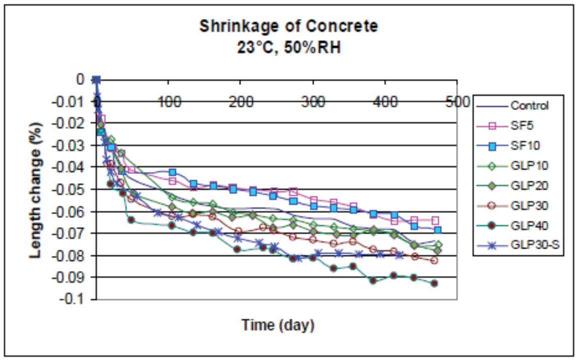

Fig. 12 Drying shrinkage of the various concrete mixtures containing low alkali contents (no additional alkali).

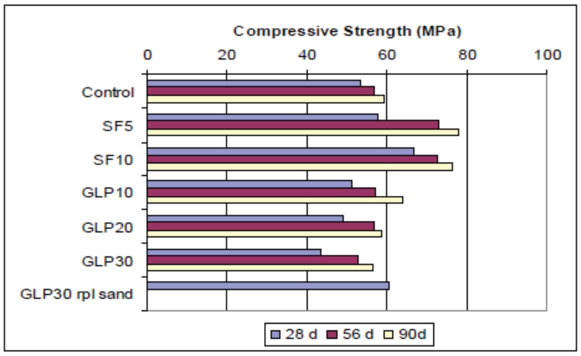

Fig. 13 Strength of concrete cylinders containing glass powder and silica fume, compared to the control cylinders.

8. MICROSTRUCTURE OF MORTAR PHASE CONTAINING GLP

The mortar specimens containing GLP, which had 270 days of moist curing were examined by scanning electron microscopy (SEM). These mortar specimens would also represent similar concrete of the same history. Figure 18 shows the dense microstructure that has developed in mortar incorporating 30% GLP, and illustrates the consumption of fine glass particles by their pozzolonic reaction with cement. In both cases fracture surfaces of the mortar specimens were indicative of a compact micro structure.

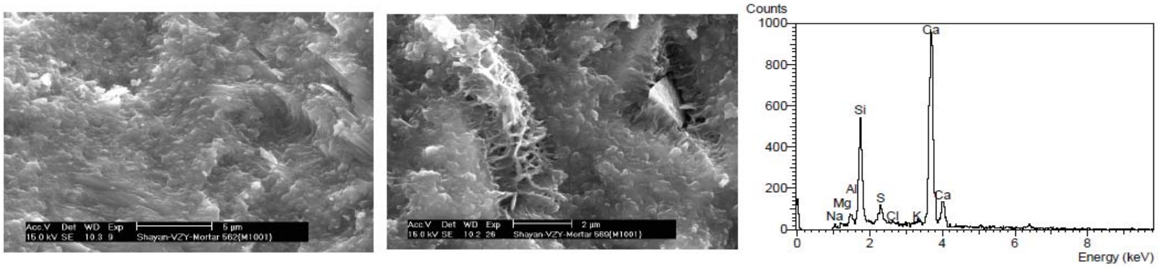

Fig. 14 SEM views of the fracture surface of mortar specimen containing 30% glass powder showing its dense microstructure, and pozzolonic reaction with cement.

9. CONCLUSIONS

The data presented in this paper show that there is great potential for the utilisation of waste glass I concrete in several forms, including fine aggregate, coarse aggregate and glass powder. It is considered that the latter form would provide much greater opportunities for value adding and cost recovery, as it could be used as a replacement for expensive materials such as silica fume, fly ash and cement. The use of glass powder in concrete would prevent expansive ASR in the presence of susceptible aggregate. Strength gain of GLP-bearing mortar and concrete is satisfactory. Microstructural examination has also shown that GLP would produce a dense matrix and improve the durability properties of concrete incorporating it. It has been concluded that 30% GLP could be incorporated as cement or aggregate replacement in concrete without any long-term detrimental effects. Up to 50% of both fine and coarse aggregate could also be replaced in concrete of 32 MPa strength grade with acceptable strength development properties.The test results show that the replacement of FG by FA at level of 20% by weight has a significant effect on the compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving blocks as compared with the control sample because of puzzolanic nature of FG. The compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving block samples in the FG replacement level of 20% are 69%, 90%, 47% and 15 % higher as compared with the control sample respectively. It is reported in the earlier works the replacement of FG by FA at level of 20% by weight suppress the alkali-silica reaction (ASR) in the concrete. The test results show that the FG at level of 20% has a potential to be used in the production of paving blocks. The beneficial effect on these properties of CG replacement with FA is little as compared with FG.

Word abbreviation-(ASR- Alkali Silica Reaction, GLP- Glass powder, MRF-Material Recovery Facility, MBG-Mixed Broken Glass, AMBT-Accelerated Mortar Bar Testing, AAR-Alkali Aggregate Reaction, SF-Silica Fume, SEM-Scanning Electron- Microscopy)

10. ACKNOWLEDGEMENT

The author wishes to express her sincere thanks to the Guide and Head of the civil engineering department, Prof A.V.Patil sir, for his kind support & valuable guidance.

11. REFERENCES

[1] Research into Concrete Blocks with Waste Glass by P. Turgut, E. S. Yahlizade

[2] Development of Concrete Containing Waste Glass G. D. Perkins, University of Glamorgan, Pontypridd, CF37 1DL

[3] Design of Green Engineered Cementitious Composites for Improved Sustainabilityby Michael D. Lepech, Victor C. Li, Richard E. Robertson, and Gregory A. Keoleian

[4] Concrete manufacture withun-graded recycled aggregatesA.E. Richardson, K. Coventry and S. GrahamUniversity of Northumbria, Newcastle upon Tyne, UK

[5] Optimization of pozzolanic reaction of ground waste glass incorporated in cement mortars L.A Pereira de Oliveira, J.P. Castro Gomes & P. SantosUniversity of Beira Interior, Covilhã, Portugal

[6] Utilization of solid wastes (waste glass And rubber particles) as aggregates in Concrete Yunping Xi, Yue Li, Zhaohui Xie, and Jae S. LeeUniversity of Colorado, Boulder, CO 80309, USA

[7] Use of selected waste materials in concrete mixes Malek Batayneh *, Iqbal Marie, Ibrahim Asi Faculty of Engineering, Civil Engineering Department, The Hashemite University, Zarka 13115, Jordan

[8] CONCRETE WITH WASTE GLASS AS AGGREGATEC Meyer Columbia UniversityN EgosiRRT Design and Construction C AndelaAndela Products LtdUnited States of America

[9] USE OF WASTE GLASS AS AGGREGATE IN CONCRETE Liang, Hong1; Zhu, Huiying2; Byars, Ewan A