The Influence of Waste Glass Powder Fineness on the Properties of Cement Mortars

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ABSTRACT

There is now a significant world-wide interest to solve the environmental problems caused by industrial waste and other materials by including such materials in the manufacture of concrete. Utilization of waste glass in concrete production not only provides significant environmental benefits but also enhances performance of the concrete when used at optimum amounts. They may be used in the form of finely ground additive to replace part of the cement or as aggregates in concrete. Either way, their use in concrete would substantially reduce carbon dioxide emissions generated during the production process of Ordinary Portland cement. This study looked at the feasibility of waste glass inclusion as partial cement replacement in cementitious systems. Properties of concrete incorporating waste glass as partial substitution for Portland cement in amounts of 5%, 20% and 30% were investigated. The waste glass material used was obtained solely from green glass cullet ground to a fineness of 300 µm. The results obtained show clearly that glass powder enhances the compressive strength properties of the final concrete product if used at the right level of replacement. The level of replacement plus the size and distribution of the glass particles seem to be of key importance for the advantage of pozzolanic activity to become evident in the short-term.

Keywords: Cement replacement, Pozzolanic reaction, Fineness, Water absorption, Waste glass, Glass powder.

1. INTRODUCTION

Over the last decade growing concern about global environmental impact is forcing the Civil Engineering and construction industry to review its conventional cement and concrete production methods with a view to replace them with sustainable alternatives. Sustainable construction is in a large part implemented by recycling secondary materials and adapting them for use in concrete and to other market needs.

According to findings published by the University of Dunee (2005), 1.85 million tonnes of glass cullet, derived from Waste Glass (WG), are collected in the UK each year. The biggest proportion of glass cullet is returned for new glass production but the remaining surplus of WG needs alternative markets. Waste glass is not bio-degradable and therefore rational consideration for alternative utilization dictates a diversion of waste glass away from landfill disposal sites. Currently, the use of waste glass in the construction industry is in the form of fibreglass, abrasives, or as low-value filler, but its applications are constantly being revised in an effort to achieve most sustainable solutions. The reuse of WG in concrete has recently captured attention not only as secondary aggregate, but also as a substitute for Portland cement in concrete, Mukesh, C., et *al* (2004), Bignozzi, M. C., et *al* (2009). Extensive research funded by Waste and Resources Action Programme (WRAP) has been carried out on WG inclusion in Portland cement concrete by Byars, E. A.,et al (2004a and 2004b). The research findings indicate that WG can be used as aggregate or as partial Portland cement substitute in concrete. Poutos et *al* (2004) found that glass has an accelerating effect on the strength development of concrete when glass is used as an aggregate due to the thermal properties of glass. However, Byars, E. A. et al (2004a and 2004b), has pointed out that the main deficiency of incorporating WG aggregates, either in form of coarse or fine fraction, is the resultant Alkali-Silica Reaction (ASR) which undermines strength of concrete. Although mineral additives such as PFA or GGBS are also used in concrete mix to suppress Alkalis Silica reaction, the feasibility of long-term use of glass aggregates is questionable. As pointed out by Neville, A. M.(2006), ‘Glass is too valuable to be ‘thrown away’ as aggregate: glass should be recycled as glass.’ Closed-loop recycling is thought to be a more viable option in terms of sustainability and cost. Meanwhile demand for waste glass aggregate largely depends on location, transport costs and scarcity of natural aggregates.

The application of waste glass as finely ground additive (FGMA) in concrete represents a potential option for waste glass recycling. Use of powdered glass in concrete as alternative binder would help to decrease consumption of Portland cement. According to Neville, A. M.(2006), carbon dioxide emissions caused by production of Portland cement comprise 7% of global anthropogenic pollution. Work carried out on Glass concrete by Anderson, J. E. (2007), suggest

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that for every ton of cement clinker produced, 579 kg of CO_2 gas is emitted solely from chemical reaction, regardless of the process used or the fuel efficiency. Replacement of Portland cement with powdered glass in concrete would substantially reduce carbon dioxide emissions.

Furthermore, research findings by Perkins, G. D. (2008), glass powder possess analogous technical characteristics to Portland cement. Glass is rich in silica and if finely grounded it exhibits pozzolanic properties. His work confirmed earlier works by Shayan, A., Xu, A. (2002), and Ye, L., Mai, W., Su, Z. (2004), who found that 30 - 70 % of cement in concrete mixtures can be replaced by glass powder without compromising the technical properties of the concrete. Other findings by Pereira de Oliveira, L. A., et al(2008), indicate that by reducing glass particle size, pozzolanic reactivity is enhanced and attacks like ASR reduces until risk of ASR is totally eliminated.

The main aim of the research presented is to assess the pozzolanic and sustainability potential of WG through a range of tests using finely ground waste glass as partial replacement for Portland cement in concrete.

2. EXPERIMENTAL DETAILS

2.1 Materials used

The following materials were used in the experimental investigations described.

2.2 Portland cement

The cement used was a commercial Portland cement type CEM II/A-V strength class 42.5N conforming to BS EN 197-1:2000. It is characterized by a normal rate of strength development was used in all six different mixes. The surface area of the cement was 350 kg/m^3.

2.3 Pozzolanic glass powder

The glass used in this study was derived from post-consumer glass sources. Fine glass powder with an average particle size of < 300 µm was used as cement replacement. The pozzolanic glass powder was obtained solely from unwashed green glass cullet ground to the desired size in the laboratory.

2.4 Natural aggregate

As aggregate for producing mortars, natural sand was used with maximum particle size 4.76 mm, a particle density of 2450 kg/m^3 and Modulus of Fineness of 2.97 which conforms to EN 196-1.

2.5 Mixture proportioning

One control mix and five experimental mixtures incorporating crushed glass powder, were produced in order to establish the effect of glass powder on the properties of mortar. The binder: fine aggregate: water weight ratio was 1: 3: 0.5 for all the mortar mixes. The control mixture contained the same material mix ratios, with no replacement. In the remaining three, mortar mixtures, glass powder was incorporated as 5%, 20%, 30%, cement replacement respectively, with the fine aggregate content and the water-cement ratio remaining constant. The mix proportions are shown in figure1 and Table1. Mortar mixes were produced using a standard concrete mixer and were water-cured for 3, 7 and 28 days at 20º C.

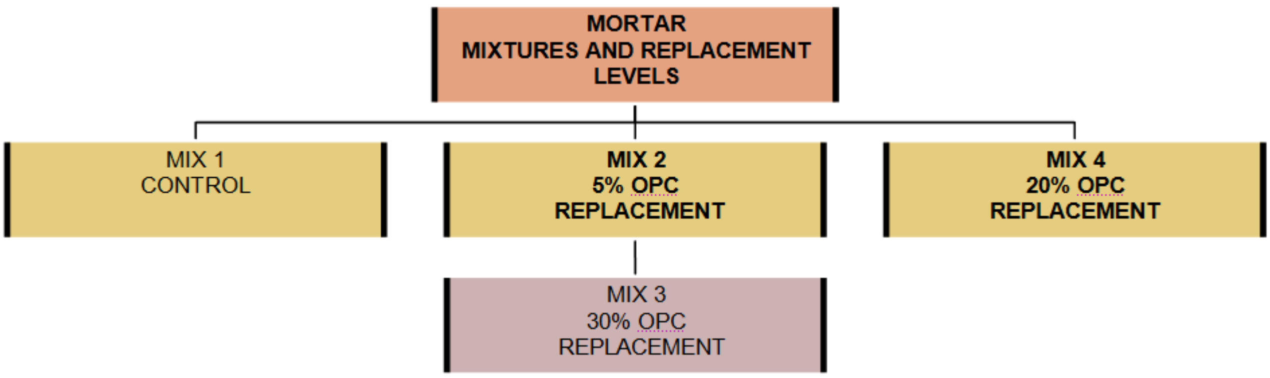

Figure 1 Experimental mortar mixtures

Table 1: Mix proportions for 10 cubes, 26 kg batch, w/c ratio 0.5

	Mix 1	**Mix 2**	**Mix 3**	**Mix 4**
Cement (kg)	5.772	5.4834	4.6176	4.0404
Glass aggregate (kg)	-	-	-	-
Glass powder (kg)	-	0.2886	1.1544	1.7316
Sand (kg)	17.342	17.342	17.342	17.342
Water (kg)	2.886	2.886	2.886	2.886

2.3 Test methods used in experimental program

2.3.1 Particle Size Distribution

The particle size distribution of the Portland cement and ground glass were measured on a Malvern Mastersizer 2000 equipment.

Both powders were dispersed dry with the Scirocco dry powder disperser linked to the Mastersizer 2000 optical bench. The vibration feed was set at 30% and the air pressure was set at 2Bar. Three repeat measurements were carried out on each sample and an average of those three repeats is shown in Figure 2.

2.3.2 Preparation of specimens

The mixtures were prepared using a standard concrete mixer. 100 mm moulds were used for casting both the control and PC/Glass mortar mixtures. Concrete specimens were cast in two layers. Each layer was compacted manually using a compacting rod, subjecting each layer of mortar to 25 strokes.

2.3.3 Flow table test

The workability of the mixtures were assessed by means of a Flow table test method using a Jolting table operated in accordance with BS EN 12350-5:2000 specifications. The test specimens were then cast in 100mm moulds, demoulded after 24 hours and left to cure in water before testing.

2.3.4 Wet (fresh) density.

This was measured after moulding and compacting according to BS EN 12350-6:2000. The results are shown in Table 4.

2.3.5 Hardened density

Prior to the compression test, the hardened density of each specimen was measured in accordance with BS EN 12390-7:2000. The hardened density of concretes shown in Table 4 represents the mean value at each curing age.

2.3.6 Compressive strength

A standard compression testing machine was used to determine the compressive strength of the specimens at constant a displacement rate of 50 mm/min according to BS EN 12390-3:2000. Figure 3 shows the average of the compressive strengths of cube testing recorded for each testing age.

2.3.7 Water absorption

At 60 days of age water absorption test was carried out in order to assess the water absorption of the specimens. To ensure unidirectional flow during the test, four sides of the specimens from each mixture were coated with silicon rubber; they were placed in the oven for 48 hours at a temperature of 110º C. The dry specimens were subsequently weighed in air and then immersed with the uncoated side into water for an hour. Finally the specimens were removed from the water bath and weighed in order to measure the weight of water absorbed.

3. RESULTS AND DISCUSSION

3.1 Particle size distributions

The particle size result reveals clearly that even though both materials were ground below 300µ, the Portland cement particles has a greater proportion of fine particles whilst the glass powder used was very much coarser. This had a major impart on the properties investigated.

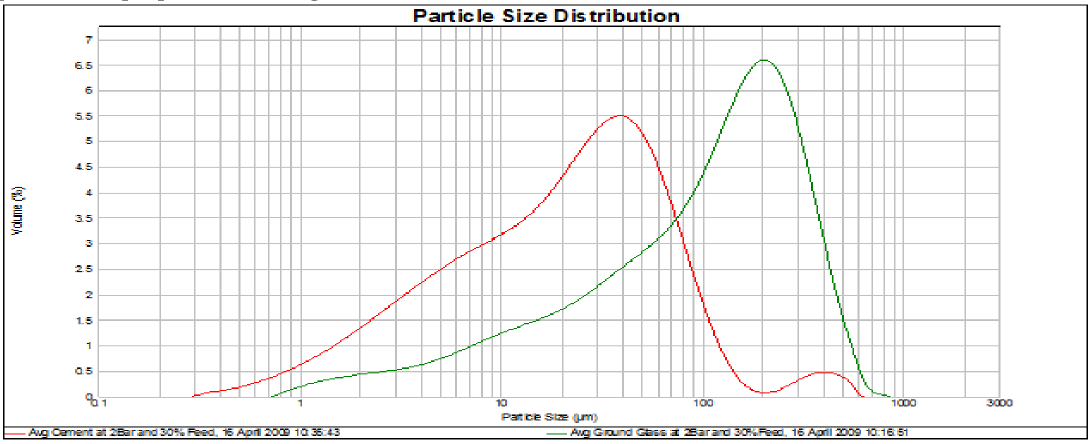

Figure 2 Particle size distribution for cement and ground glass

3.2 Flow table test and visual inspection

The results of Flow table tests and visual inspection are shown in Table 2 and 3, respectively. The result show that with the inclusion of higher content of glass, the workability of the mortar mixtures tend to decrease in proportion to increased glass powder content in a mixture. The control mixture showed the highest workability level. Only Mix 2 containing 5% ground glass visually appeared to have improved consistency due to lower replacement amount and its workability compared favorably with the control mix. Mix 3 visually appeared to be of good consistency but achieved lower Flow-table value. The consistency of Mix 4 was clearly adversely affected by larger amounts of glass.

Table 2: Flow table values of mortar mixes

Mixture	Mix 1 Control	Replacement level		
		Mix 2 5% Glass	Mix 3 20% Glass	Mix 4 30% Glass
Table Flow (mm)	200	195	185	175

Table 3: Visual inspection of fresh mortar mixes

Mixture	Mix 1	Mix 2	Mix 3	Mix 4
Visual inspection	Consistent and homogenous	Consistent and homogenous	Rich mix, good texture, consistent	Very dense, heavy and grainy mix

3.3 Fresh densities of mixtures

Fresh density values of the mortar mixtures suggest a tendency to decrease only if the amount of glass content greatly increases. As can be seen, the fresh densities of Mix 2 and 3 are comparatively similar to that of the control mix at 5% and 20% cement replacement. The density values was affected only after 30% cement replacement with glass powder but all are within the known density values for glass and cement mortars (2000-2500 kg/m^3).

Table 4: Effect of Glass Content on the Fresh Density of Mortar Mixes

Mixture	Mix 1 Control	Replacement level		
		Mix 2 5% OPC	Mix 3 20% OPC	Mix 4 30% OPC
Fresh density (kg/m^3)	2220	2260	2220	2180

3.4 Hardened densities of mixtures

The densities of the cube specimens were determined at curing ages of 3, 7, and 28 days from their mass and volume. As was mentioned by Shayan & Xu [2006] the fluctuating values in dry densities arise because of 100% compaction is not usually achieved. Only the hardened density values of Mix 2 with 5% OPC replacement is slightly higher compared with control mix. Higher density of these mixes can be attributed to better particle parking. The remaining mixtures achieved considerably lower density values at later curing ages, Mix 4 with 30% OPC representing the least density value.

Table 5: Effect of Glass Content on the Hardened Density of Mortar Mixes

Curing Age	Mix 1 Control	Replacement level		
		Mix 2 5% OPC	Mix 3 20% OPC	Mix 4 30% OPC
	Hardened density (kg/m^3)			
3 days	2158	2200	2145	2100
7 days	2190	2195	2198	2170
28 days	2185	2225	2200	2155

3.5 Compressive strength

The compressive strength results are shown in Figure 3 below. It is evident that with incorporation of larger amount of glass powder compressive strength has a tendency to decrease. Pozzolanic reactions offset this trend at later stage of hardening and helped to improve the compressive strength at 28 days.

It is important to note that the lower compressive strength of the PC/Glass(pozzolanic) mixtures can be attributed to the coarser particle size of the glass powder used. This has obviously diminished the pozzolanic reactivity of the particles and therefore the associated benefits in terms of increased compressive strength and improved durability performance.
To assess the pozzolanic potential of the Glass powder used, the compressive strength ratio between samples containing glass powder and the control mortar with the cement (CEM II 42.5 N) mix is compared to ascertain the pozzolanic activity index.

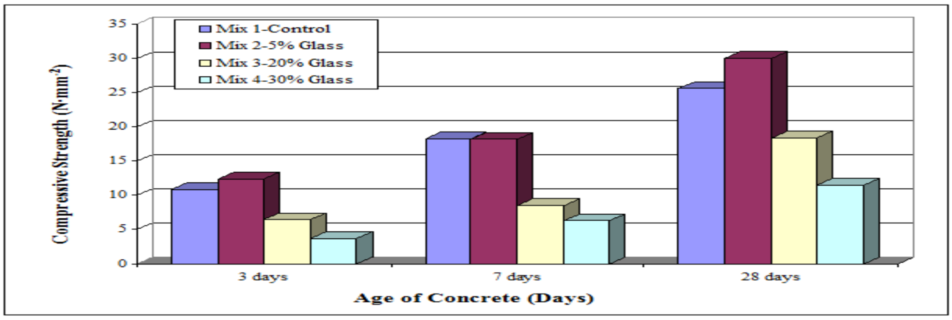

Figure 3 Compressive strength of waste glass mortar mixes

Bignozzi et *al*.(2009) have established that the activity index at 28 days must be greater than or equal to 75% to ensure pozzolanic activity of the addition. Mix 2 with 5% of OPC replacement exceeded pozzolanic activity of control mix at 28 days and achieved strength activity index of 114%, whereas Mix 3 with 20% OPC replacement achieved 72% of required pozzolanic activity.

3.6 Water absorption test

Water absorption of concrete is an important factor in classifying its durability. Generally concrete of low water absorption will afford better protection to reinforcement within it. Taha et *al*., [2008] had noticed that glass by nature is an impermeable material, so it could be assumed that the presence of glass particles in concrete can reduce the permeability of the concrete mix. However the values obtained from this study suggest similar water absorption for the 100% PC mortar and that containing 5% glass replacement, while the mixtures with higher glass contents were clearly more absorbent. As explained earlier, the particle size results shown in Figure 1 provide an important explanation of the influence of particle size on the observed trends for this study. The performance seems to depend on the form and fineness of the waste-glass powder used. The glass particles are evidently coarser than the concrete therefore pozzolanic activity correspondingly reduced to a lesser level than would otherwise be expected.

Table 9: Water absorption values

Mixture	Mix 1 Control	Replacement level		
		Mix 4 5% OPC	Mix 5 20% OPC	Mix 6 30% OPC
Water absorption (%)	0,45	0,46	1,25	0,82

4. CONCLUSIONS

In the present study glass powder obtained from post consumer green glass cullet ground to particle size of 300 µm was utilized as partial cement replacement. The main conclusions drawn are:

- The amount of incorporated waste glass largely influenced properties of the cement mortar. It is evident from these results that ground glass could enhance the properties of the final concrete product if used at the right level of replacement.
- The fineness of the particles used have also been shown to have very important influence. It must be at least as fine as the cement powder for the advantage of pozzolanic activity to become evident in the short-term.
- Increasing the amount of glass in mortar causes a general decrease of compressive strength, but the decrease becomes less evident with prolonged curing time. The particle size distribution of waste glass used was the key factor influencing the strength development.
- Flow table tests have demonstrated that with the inclusion of higher content of glass workability tend to decrease regardless of glass replacement form. Only Mix 2 containing 5% ground glass as cement replacement visually appeared to have improved consistency due to lower replacement amount and its workability compared favorably with the control mix. Control mix contained highest workability level.
- Similarly, the wet density values were observed to decrease as the amount of glass incorporated into the mortar increases. Fluctuating values of hardened densities of mixtures resulted because of varying degrees of compaction.
- Water absorption increased with increased glass powder content. Moderate substitution levels such as Mix 2 with 5% of glass powder and Mix 3 with 20% of glass powder content achieved similar values to that of control mix.
- Finally, the environmental drivers must not be overlooked as waste glass incorporation into concrete on an appropriate selective basis would provide solution to problems encountered in waste management. When used

as finely ground powder to substitute Portland cement, this constitutes a positive response to global environmental problems such as high carbon dioxide emissions generated by Portland cement production. In addition it would reduce extraction of natural materials such as limestone.

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