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# Waste glass powder as partial replacement of cement for sustainable concrete practice

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**Abstract**

Million tons of waste glass is being generated annually all over the world. Once the glass becomes a waste it is disposed as landfills, which is unsustainable as this does not decompose in the environment. Glass is principally composed of silica. Use of milled (ground) waste glass in concrete as partial replacement of cement could be an important step toward development of sustainable (environmentally friendly, energy-efficient and economical) infrastructure systems. When waste glass is milled down to micro size particles, it is expected to undergo pozzolanic reactions with cement hydrates, forming secondary Calcium Silicate Hydrate (C–S–H). In this research chemical properties of both clear and colored glass were evaluated. Chemical analysis of glass and cement samples was determined using X-ray fluorescence (XRF) technique and found minor differences in composition between clear and colored glasses. Flow and compressive strength tests on mortar and concrete were carried out by adding 0–25% ground glass in which water to binder (cement + glass) ratio is kept the same for all replacement levels. With increase in glass addition mortar flow was slightly increased while a minor effect on concrete workability was noted. To evaluate the packing and pozzolanic effects, further tests were also conducted with same mix details and 1% super plasticizing admixture dose (by weight of cement) and generally found an increase in compressive strength of mortars with admixture. As with mortar, concrete cube samples were prepared and tested for strength (until 1 year curing). The compressive strength test results indicated that recycled glass mortar and concrete gave better strength compared to control samples. A 20% replacement of cement with waste glass was found convincing considering cost and the environment.


*Keywords:* Waste glass; Recycling; Supplementary cementitious material; Environment; Sustainability



## 1. Introduction

As of 2005, the total global waste glass production estimate was 130 Mt, in which the European Union, China and USA produced approximately 33 Mt, 32 Mt and 20 Mt, respectively (IEA, 2007; Rashed, 2014). Being non-biodegradable in nature, glass disposal as landfill has environmental impacts and also could be expensive.

Sustainable construction practice means creation and responsible management of a healthy built environment considering resource efficiency and ecology (Plessis, 2007). Being versatile and economical, concrete became prime construction material over the world, however, it

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has impacts on the environment (Naik, 2008). Manufacturing of cement (key ingredient used for the production of concrete) is a major source of greenhouse gas emissions (Imbabi et al., 2012). The use of supplementary cementitious materials (SCMs) to offset a portion of the cement in concrete is a promising method for reducing the environmental impact from the industry. Several industrial by-products have been used successfully as SCMs, including silica fume (SF), ground granulated blast furnace slag (GGBS) and fly ash (Islam et al., 2011; Imbabi et al., 2012). These materials are used to create blended cements which can improve concrete durability, early and long term strength, workability and economy (Detwiler et al., 1996). Another material which has potential as a SCM, however, has not yet achieved the same commercial success is waste glass (Rashed, 2014). Researches indicated that glass has a chemical composition and phase comparable to traditional SCMs (Ryou et al., 2006; Binici et al., 2007; Nassar and Soroushian, 2012). It is abundant, can be of low economic value and is often land filled (Byars et al., 2003). Milling of glass to micro-meter scale particle size, for enhancing the reactions between glass and cement hydrates, can bring major energy, environmental and economic benefits when cement is partially replaced with milled waste glass for production of concrete (Rashed, 2014). Studies also focused on used of waste glass as aggregate in concrete production (Rashed, 2014; Taha and Nounu, 2009). Study on durability of concrete with waste glass pointed better performance against chloride permeability in long term but there is concern about alkali-silica reaction. Deleterious chemical constituents include sulfides, sulfates, and alkalis (which add more alkali to concrete) creates higher risk of ASR over the life of the concrete. A good pozzolan functions both to mitigate ASR and to consume the lime to greatly reduce efflorescence (Matos and Sousa-Coutinho, 2012; Rashed, 2014). Utilization of waste glass in ceramic and brick manufacturing process is discussed in a recent study (Andreola et al., 2016).

The properties influence the pozzolanic behavior of waste glass and most pozzolans in concrete, are fineness, chemical composition, and the pore solution present for reaction (Imbabi et al., 2012; Rashad, 2015). The pozzolanic properties of glass were first notable at particle sizes below approximately 300 μm, and below 100 μm, glass can have a pozzolanic reactivity at low cement replacement levels after 90 days of curing (Shi et al., 2005). This size can be achieved by using a grinding operation with the help of "Ball Mill" which is generally used in cement industry to grind cement clinker. Several researches show that, at the higher age recycled glass concrete (15% to 20% of cement replaced) with milled waste glass powder provides compressive strengths exceeding those of control concrete (Nassar and Soroushian, 2011). However, a review study by Rashed (2014) showed that previous studies with glass addition were not conclusive considering workability and strength while the chloride resistance of glass added concrete was found to be similar with control condition. To reduce this impact, this research examined the potential of waste glass powder to produce sustainable concrete. A further study was conducted on the performance of glass in mortar and concrete. Mortar samples were prepared to evaluate the flow and strength properties. Furthermore, compressive strength of concrete cube samples were also determined by crushing it. In addition, the study discussed the packing and pozzolanic effect of glass by using superplasticizer in selected mortar samples.

## 2. Materials and methods

### 2.1. Materials

CEM I of strength class 42.5N was used in this research. The percentage of clinker and gypsum in the cement was 95–100% and 0–5% respectively, while the specific gravity and fineness of OPC was found to be 3.15 and 99.3% (#200 sieve) according to ASTM C187 (ASTM, 2011) and ASTM C786 (ASTM, 2016d), respectively.

Specific gravity and fineness of clear and colored waste glass powders (prepared by ball mill) were 3.01 & 0.9% (#200 sieve) and 3.02 & 0.9% respectively as per ASTM standard mentioned above. Chemical composition of both glass powders were examined using a XRF-1800 Sequential X-ray fluorescence spectrometer. 20% binder was added to 80% glass powder to keep the material in position during test. Then the whole mixture was pressed using 140 kN pressing force. The chemical composition of glass powder is compared with other pozzolanic materials in the discussion. As the results of fineness, specific gravity and chemical composition test of color and clear glass powder were found similar, further experimental work with mortar and concrete was conducted with clear glass power.

The fine aggregate used for the study was prepared according to graded sand requirements ASTM C778 (ASTM, 2013). Properties of fine aggregate are shown in Tables 1 and 2. For the flow test sand grading was prepared as per EN 196-1 (EN, 2005).

To evaluate the pozzolanic effect more clearly, mortar strength tests were carried out using superplasticizers. The water reducing admixture used in mortar work is based on polycarboxylate ether chemistry. Properties of admixture are given in Table 3. For concrete work the coarse aggregate size and amount was selected as per ASTM C33 (ASTM, 2016a). Physical properties of aggregates used in concrete work are shown in Table 4.

Table 1
Physical properties of fine aggregate.

| | |
|---|---|
| Bulk specific gravity (SSD) | 2.55 |
| Absorption capacity (%) | 1.66 |
| Fineness modulus (FM) | 2.65 |
| Field moisture content | 0.68 |