International Journal of Scientific Research in Computer Science, Engineering and Information Technology
ISSN : 2456-3307 (www.ijsrcseit.com)
doi :https://doi.org/10.32628/IJSRCSEIT

Waste Glass Powder as Partial Replacement of Cement Analysis

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Article Info

Publication Issue :
Volume 5, Issue 1
January-February-2019
Page Number : 627-632

Article History
Received: 01/01/2019
Accepted: 26/01/2019
Published: 25/02/2019

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

I. 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. ustainable 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 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 ofASR 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 pozzolansin concrete, are fineness, chemicalcomposition, 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, 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. This research examined the potential of waste glass powder to produce sustainable concrete. Experimental work was carried outon 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.

II. 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. pecific 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 Table 1, Table 2. For the flow test sand grading was prepared as per EN 196-1 (EN, 2005).

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

Table 2. Grading of sand used for mortar compressive strength test (ASTM, 2013).

Sieve No	Sieve opening (mm)	% Cumulative pass
16	1.19	100
30	0.60	75
50	0.3	25
100	0.15	0

2.2 Flow test on mortar

The standard test method for flow of hydraulic cement mortar, determines how much a mortar sample flows when it is unconfined and consolidated. Mortar is placed inside 2-inch high conical brass mold. The top and bottom diameter of the mold was 2.75 inch and 4 inch respectively. After filling, compacting and removing the mold, the mortar is vibrated at 1.67 Hz as the flow table rises and drops ½ inch, 25 times in 15 seconds. The mortar changes from a 4-inch conical shape to a "pancake". The change in diameter of the mortar was measured and expressed in mm as per ASTM C1437 (ASTM, 2015b). Experimental set up for flow test is shown in Fig. 1. A constant water to binder ratio (0.5) was used with different glass contents in mortars.

Figure 1. (a) Mortar sample in brass mold, and (b) mortar sample turned to pancake shape

2.3 Strength evaluation

2.3.1 Mix details and preparation of mortar

As with flow, test on mortar is also carried out for compressive strength. The mass ratio of sand to (cement + glass powder) was fixed at 2.75 according to ASTM C109 (ASTM, 2016c) for all batches. A water binder ratio of 0.485 was used and kept constant for every mixes. The mix proportion for the mortar is given in Table 5. The same mix details was used for the preparation of mortar with superplasticizing admixture (1% by weight of cement). As the flow test results with different levels of glass addition did not give any significant difference, the water to binder ratio for mortar with admixture remained unchanged. The mortar was prepared and placed in the 50 × 50 × 50 mm steel mold as per ASTM C109 (ASTM, 2016c). Material within the mold is kept in a moist condition for 24 h and then after demolding the specimens were placed in curing tank. After a specified period of curing, strength test of the specimens was conducted shortly after taking those out from storage water as per ASTM C109.

2.3.2 Concrete mix proportion and preparation

Trial mix design were conducted to obtain the target strength of 35 MPa at 28 days with a workability of 100–125 mm as per American Concrete Institute ACI 211.1 (ACI, 2009). The glass powder replacement in cement was varied (0–25%). Mix proportion of concrete is shown in Table 6. Firstly, stone chips and sand were dry mixed for a minute. Appropriate quantity of glass powder was blended with cement in a separate container and then incorporated into the aggregate matrix (mixed earlier). Measured quantity of water was added to the matrix and thoroughly mixed for 5 more minutes. After mixing, workability of the concrete was determined using slump test. It was confirmed that the slump values of concrete at different glass replacement level remained within the target slump range of 100–125 mm without changing the water content. The concrete was placed, compacted and surface finished with a smooth steel trowel in cube mold. The material was kept within the mold for 24-h in moist condition before demolding. After demolding the concrete was placed under fresh curing water in tank for specified period before testing. No admixtures was used in concrete compressive strength tests.

2.3.3 Compressive strength test

The compressive strength of a material is the uni-axial compressive stress reached when the material fails completely. A set of three cubes were tasted in each case and the average value of these three was reported. Compressive strength test of mortar and concrete were done as per ASTM C109 (ASTM, 2016c) and ASTM C39 (ASTM, 2016b). Experimental set up for compression tests in mortar and concrete are shown in Fig. 2. Ultimate load is noted for each specimen. Compressive loading for mortar and concrete was maintained as 900–1800 N/s and 20–50 psi/s. Both mortar and concrete samples were tested for compressive strength at 7, 14, 28, 56, 90, 180 and 365 days.

(a) Mortar test setup (b) Concrete test setup

Figure2.Compressivestrengthtest.

III. RESULT AND DISCUSSION

3.1 Chemical composition of glass powder and cement

The chemical composition of glass powder samples (clear and colored) are determined using a XRF technique. The results obtained are compared with other pozzolanic materials in Table 7. According to ASTM C618 (ASTM, 2015a), (SiO2 + Al2O3 + Fe2O3)'s minimum requirement for a standard pozzolana is 70% which is comparable with the results obtained for the waste glass samples. The standard also sets maximum limit of SO3, Loss on Ignition (LoI) and Moisture content as 4%, 10% and 3% respectively. As shown in Table 7, the SO3 contents of the glass samples were found well below the acceptable limit and LoI and moisture content was negligible. Therefore, the glass powder samples are expected to show pozzolanic behavior in cementitious system.

3.2 work

3.2.1 Flow test

As per EN 196-1 (EN, 2005), a constant water to binder ratio (0.5) was maintained for preparing mortar samples for the flow tests. Minor increase in mortar flow was achieved with amount of cement replaced with glass powder as shown in Fig. 3. The increase in mortar flow with the addition of glass powder might be the effect of glass material which is cleaner in nature. Review by Rashed (2014) showed that previous studies indicated increase in workability with glass addition. As there was minor difference between the flow results at different glass replacement levels, it is expected that the flow with admixture will give similar trend. However, there should be a vertical shift between flow with and without admixture.

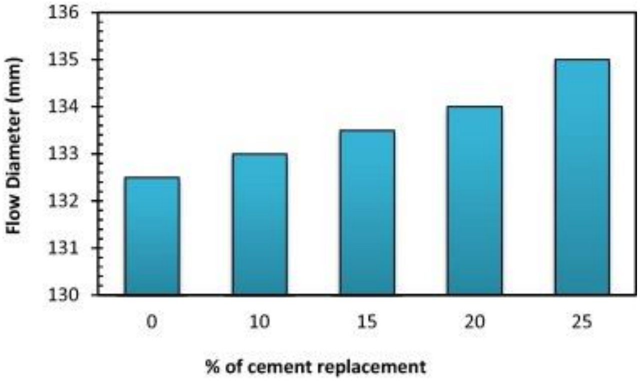

Figure 3. Glass quantity vs flow in cement mortar.

3.3 Concrete compressive strength

For compressive strength test concrete samples was prepared without any admixture. Compressive strengths of recycled glass concrete (0–25% glass addition) at different ages are shown in Fig. 6. Target compressive strength of 35 MPa at 28 days was achieved for all samples up to 0–20% glass addition while that for 25% addition was slightly lower. With the addition of glass, lower mean compressive strengths compared to the control concrete (0% glass) are obtained at 7, 14, 28 and 56 days age. With further progression of reaction at the age of 90 days, recycled glass concretes with 10, 15 and 20% glass addition provided mean compressive strengths exceeding the control concrete and 10% cement replacement gave the highest value among them. 25% glass addition gave slightly lower (approximately 2%) compressive strength than control concrete.

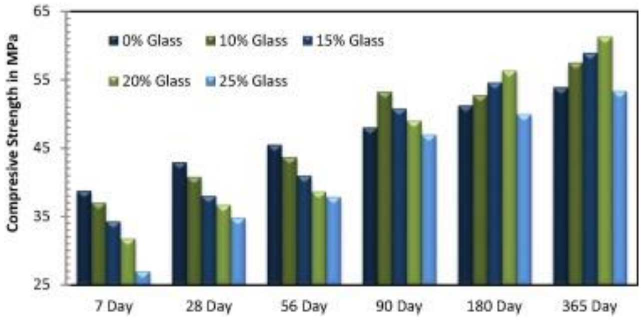

Figure 4. Compressive strength of concrete specimens at different age and glass replacement level

Except 10% glass addition, 90 day test results indicated that the differences in compressive strengths between recycled glass and control concretes were not significant. This indicate the optimum reaction period of glass replaced concrete (Nassar and Soroushian, 2011, Omran and Tagnit-Hamou, 2016).The difference in compressive strength between the control and 25% glass replaced concrete at 180 and 365 days were further reduced and provided similar mean compressive strengths. At these stage 10, 15 and 25% cement replacement gave higher compressive strength than the control concrete while compressive strength with 20% cement replacement was found to be greatest. At 180 and 365 days the 20% glass added concrete gave 10% and 14% higher strengths respectively than control concrete. The results show that compressive strength gain in glass added concrete occurs at a lower rate than that in controlled concrete, but in long-term recycled glass concrete has the potential to exceed control concrete strength (Nassar and Soroushian, 2011).

IV. CONCLUSIONS

The chemical composition of clear and colored glass powders are very similar and the materials could be declared as pozzolanic material as per ASTM standard. Being cleaner in nature, the flow of glass replaced mortar was found to be increased slightly with glass powder content. The optimum glass content is 20% considering mortar and concrete compressive strength at 90 days. In this age the compressive strength was found slightly higher (2%) than the control concrete specimen. In general, considering the similar performance with replaced material, glass addition can reduce cost of cement production up to 14%. In addition, production of every six ton glass powder concrete results in the reduction of each ton CO2 emission from cement production and save the environment significantly by reducing green-house gas and particulate production. Generally, the high surface area of milled waste glass changes the kinetics of chemical reaction toward beneficial pozzolanic reaction utilizing the available alkalis before production of a potential ASR gel. However, further research on durability and ASR aspects of glass replaced concrete is required to suggest this material for sustainable concrete practice.

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