مجلة العلوم الهندسية
FES Journal of Engineering Sciences
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FJES
FES Journal of Engineering Sciences

Utilization of Waste Glasses as Supplementary Cementitious Materials

Yousif Hummaida Ahmed[1,*], Mohamed Ibrahim[2] and Duaa Soliman[2]

[1] *Civil Engineering Department, University of Khartoum, Khartoum, Sudan*
[2] *Civil Engineering Department, Al-Mughtaribeen University, Khartoum, Sudan*
* Corresponding author: Yousif Hummaida Ahmed (e-mail: y.hummaida@uofk.edu).

Article history: Received 19 March 2020, Received in revised form 4 November 2020, Accepted 11 November 2020

ABSTRACT Wastes of Glass are recognized as pozzolanic material. This study aims to investigate utilization of local glass wastes in Sudan as supplementary cementitious materials. Two glass wastes specimens having different colors are procured from a local source namely Sudanese Emirati Glass and Metal Company (SEGMAL). Then thy are ground to micro sizes producing two types of glass powders, clear white glass powder (W-GP) and colored glass powder (C-GP). The two Specimens are characterized using tests specified in American Society for Testing and Materials ASTM C311. These tests include chemical properties using X-ray Fluorescence (XRF), Loss on Ignition (LOI), Insoluble Residue (IR), also physical properties such as fineness, specific gravity, water requirement, and strength activity index (SAI). This study shows that at 7 days W-GP and C-GP produced SAI of 84% and 87% at 7-days respectively. These values are more than the 75% of SAI's requirements of ASTM C618. Both specimens have outperformed the control OPC mix at 28 days by producing SAI of 108.68% and 123.82% for GP-W and GP-C respectively.

Keywords*:* Waste Glass powder (GP); Pozzolana; Strength Activity Index (SAI).

1. Introduction

As developing countries make their way toward enhancing infrastructure and life quality, they face a lot of economic and environmental challenges. This situation leaves them with no choice but to create and follow sustainable development strategies and plans. While the short economic considerations are leading the normal construction practices, minimizing the negative environmental impacts and increasing the economic sustainability of construction are the guidelines of sustainable construction. Infrastructures designed and constructed in sustainable ways will minimize resource consumption and negative environmental impacts which will lead towards more feasible and sustainable developments.

Being non-biodegradable in nature, glass disposal as landfill has environmental impacts and could also be expensive. Sustainable construction practice means creation and responsible management of a healthily built environment considering resource efficiency and ecology [1].

Being versatile and economical, concrete became the prime construction material around the world, however, it has impacts on the environment [2]. Manufacturing of cement (key ingredient used for the production of concrete) is a major source of greenhouse gas emissions [3]. 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 byproducts have been used successfully as SCMs, including silica fume (SF), ground granulated blast furnace slag (GGBS) and pulverized fuel ash (PFA) commercially known as fly ash [3]. These materials are used to create blended cements which can improve concrete durability, early and long term strength, workability and economy [4]. Another material which has potential as a SCM, but had not yet achieved commercial success is waste glass [5]. Researches indicated that glass has a chemical composition and phase comparable to traditional SCMs [6]. The study aims to investigate compressive strength of mortars modified with glass powders.

2. Materials and Methods

2.1. Materials

A typical commercial Type I Portland cement (Atbara Cement) according to ASTM C150 [7] was used as a testing cement. Its relevant physical properties were found to be 97 and 180 minute as initial and final setting time respectively. Also, its Compressive strength 14.18, 33.52, and 36.76 N/mm^2 as at 3, 7 and 28 days respectively. River Sand passing sieve 600 microns and retained on 300 microns was used instead of standard sand.

Two types of waste GP were used, clear white glass powder (W-GP) and colored glass powder (C-GP). The glass plates wastes were obtained from The Sudanese Emirati Glass and Metal Company (SEGMAL) in Khartoum. The glass plates waste specimens had different colors. They were ground using ball mills at the Geological Research Authority (GRA) – Ministry of Minerals.

Specific gravity of W-GP and C-GP were assessed and found to be 2.6 and 2.56 respectively. Chemical composition of both W-GP and C-GP were examined by X-ray fluorescence (XRF). Also, Loss on Ignition (LOI) and Insoluble Residue (IR) tests were conducted.

The fine aggregate used was prepared according to graded sand requirements ASTM C778 [8].

Flow and compressive strength tests were carried out on mortar according to ASTM (C1437-99) [9] and ASTM C311 [10] specifications.

2.2. Loss on Ignition

Loss on Ignition (LOI) test is used in inorganic analytical chemistry. It consists of strongly heating and igniting a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change.

Loss on ignition was determined in accordance with the procedures outlined in ASTM C114 [11], except that the material remaining from the determination of moisture content was ignited to constant mass in an uncovered porcelain -not platinum- crucible at 750 ± 50°C (1382 ± 190°F).

2.3 Insoluble residue

This test method determines insoluble residue in cement is obtained by treatment with diluted hydrochloric acid 1:9 in order to minimize the precipitation of soluble silica. The residue from this treatment is treated with a boiling solution of sodium carbonate in order to re-dissolve traces of silica which may have been precipitated. After ignition the residue is determined gravimetrically. Insoluble residue was determined in accordance with procedures outlined in test methods BS EN 196-2:2005 [12].

2.4 Flow Test and Water Requirement

The Standard Test Method for Flow of Hydraulic-Cement Mortar covers the determinations of flow of hydraulic-cement mortars, and of mortars containing cementations materials other than hydraulic cement according to the ASTM (C1437-99) [9] . A layer with about 25 mm thickness was placed in the mold and the layer was tamped 20 times using a rod of 10 mm diameter. Then the mold was filled with mortar as specified for the first layer. The mortar was cut off to plan surface flush with the top of the mold by drawing the edge of the trowel with a sawing motion across the top of the mold. The mold was removed after 1 minute, then the table was dropped 25 times in 15sec using crank arm. Then the diameter of the mortar was measured along the three lines scribed on the table. Then the diameter was recorded to the nearest millimeter. The samples were tested, control mix and two test mixes contain (80%OPC+20%GP) of W-GP and C-GP. The proportions for control mixture and test mixtures are summarized in Table I. Flow table is shown in Fig.1.

2.5 Compressive strength test

Compressive strength test measures the maximum amount of compressive load a material can bear before failing completely. In each case a set of three cubes were tested and average value of the results were reported. Compressive strength test was carried out as per ASTM C109 [13].

Experimental set up for compression test is shown in Fig.2. Maximum load was noted for each specimen.

3. RESULTS AND DISCUSSION

3.1 Chemical analysis of glass powders:

3.1.1. XRF results

The chemical composition of glass powders samples was examined using XRF technique. Results are shown in Table II. Results shows that the percentages of (SiO_2 + Al_2O_3 + Fe_2O_3) equal to 90.122% for C-GP and 90.049% for W-GP. These are greater than the 70% specified by ASTM C618. This agreed with the fact that glass is principally composed of silica. The percentage of SO_3 is equal to 0.389% for C-GP and 0.112% for W-GP. These are less than the 4% specified by ASTM C618 [14]. According to these results GPs can be classified as class N pozzolans.

3.1.2 Loss on Ignition (LoI)

LoI for GP-C has a value equal to 0.7%, and for GP-W has a value equal to 1%, these values comply with ASTM C618-99 [14] (LOI less than 5%). This was well expected because glass manufacturing involves treating glass raw materials in high temperatures up to 1600 degree centigrade.

Table III: Proportions of control mixture and test mixtures asper the ASTM C311

Control Mixture	Test Mixtures (80%OPC+20%GP)
500 g of Portland cement.	400 g of Portland cement
1375 g of graded standard sand.	100 g of GPs
242 mL of water.	1375 g of graded standard sand
	242 mL of water required for flow ±5 control mixture.

Fig1: Flow table

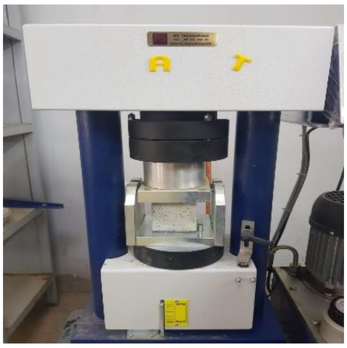

Fig 2: Compressive strength test set up

3.1.3 Insolube Residue (IR)

IR for C-GP has a value equal to 17.1%, and for W-GP has a value equal to 41.9%. This indicated that C-GP contains more active silica than W-GP, which may be due to the difference in fineness of the GPs.

3.2. Flow test

As per ASTM (C1437-99) [9] a constant water to cement to water ratio was set for preparing mortars for flow test. Minor increase in mortar flow was achieved with 20% of cement replaced by GPs. This may be due to the fineness of the GPs and their clarity.

3.3 *Compressive strength test*

Compressive strength results of cement mortars were less than 42.5 N/mm^2 due to the use of non-standard sand،which does not affect the final results because the same non-standard sand was used to prepare both types of the GP mortars for the compressive strength test. Compressive strength test was carried out on mortar by replacing 20% of cement by GPs. Lower average compressive strengths, compared to control mortar were obtained at 7 and 14 days. At 28 days average compressive strengths obtained for both W-GP and C-GP exceeded average compressive strength of control mortar. Fig.3 shows compressive strength at 3, 7, and 28 days. Fig.4 illustrates compressive strength development with age.

Values of SAIs for GP-C and GP-W mortars at age of 7 and 28 days are equal and they comply with the requirement of ASTM C618 [14] (75% at minimum). These values are in agreement with (Nassar, Soroushian 2012) [15]. Fig.5 shows SAIs at 3, 7, and 28 days.

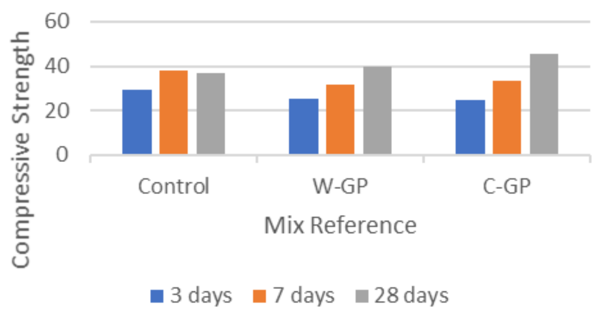

Figure 3 compressive strength at 3, 7, and 28 days

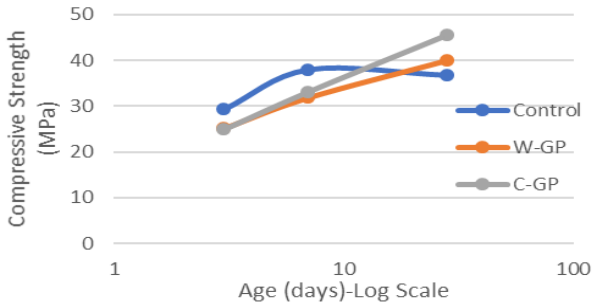

Figure 4 Compressive strength development with age

Table IV XRF results

C-GP Chemical composition		W-GP Chemical Composition	
SiO_2	89.665	SiO_2	89.937
CaO	9.367	CaO	9.763
Fe_2O_3	0.457	K_2O	0.133
SO_3	0.389	Fe_2O_3	0.112
K_2O	0.070	TiO_2	0.035
TiO_2	0.030	SrO	0.008
CuO	0.007	Ag_2O	0.007
MnO	0.006	CuO	0.005
SrO	0.006		
Ag_2O	0.002		

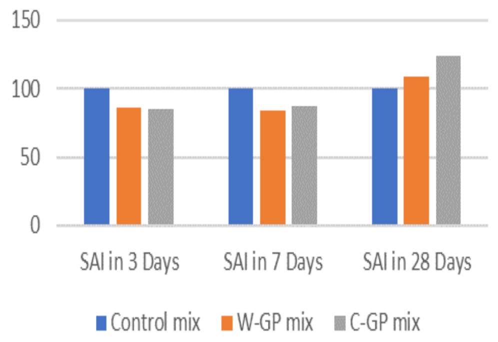

Figure 5 SAIs in 3, 7 and 28 days

4. Conclusion

1. The percentages of (SiO_2 + Al_2O_3 + Fe_2O_3) for Clear Glass Powder (W-GP) and Colored Glass Powder (C-GP) are greater than the 70% specified by ASTM C618 [14] . In addition, the percentage of SO_3 for W-GP and C-GP are less than the 4% specified by ASTM C618 [14] and the material could be declared pozzolanic material. Aslo the IR perecentage are found in GPs 17% and 42% for C-GP and W-GP respectively,
2. The flow of mortars modified with C-GP and W-GP increased slightly this may be due to the fineness of GPs. Hydraulic flows of mortars modified with W-GP and C-GP are found to be 22% and 22.6 respectively.
3. The values of Strength Activity Indexes (SAIs) for W-GP mortar and C-GP mortar are complying with the requirement of ASTM C618 [14] (75% at minimum) at 7 days. While it exceeded these values for 28 days, 123% for C-GP and 108.78% for W-GP. The compressive strength of W-GP and C-GP mortars increased more remarkably between 7 and 28 days compared to control mixes. This indicates that the pozzolanic activity of GPs is high and could be utilized to produce high strength concrete.
4. However, further research using dosages other than 20% and durability studies on concrete mixes contain GPs, as well as shrinkage and creep are recommended for future studies.

Acknowledgment

The financial support and laboratory provided by Al-Mughtaribeen University is well acknowledged. Thanks also go to the Geological Research Authority (GRA) – Ministry of Minerals for providing glass grinding facilities.

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Dr Yousif Hummaida Ahmed (PhD, DIC, Bsc), PhD in Engineering from Imperial College/ University of London (1996) Awarded Dr Shawki Saad Scholarship. Specilization Concrete durability & hazardous waste management technologies. Former Head of Civil Engineering Department, Faculty of Engineering, University Of Khartoum, Sudan. Currently Chairman of the Governmental Council for Registering and Classifying Engineering Works Contractors.

Duaa Khalid Hassan Soliman, date of birth 1\5\1996). Bachelor of science in civil engineering first class (2018) from Al-Mughtaribeen University (Khartoum, Sudan). She worked as a Teaching Assistant at Al-Mughtaribeen University (2019 − present). Also associated civil engineer at the General Administration for Projects and Engineering Affairs, Khartoum, Sudan (2016-2019).

Mohamed Altaib Alshaikh Ibrahim (DoB 1993) Bachelor in Civil Engineering from Al-Mughtaribeen University (Khartoum, Sudan) (2018). He worked as a Teaching assistant at Al-Mughtaribeen University (2019–present).