Incorporation of waste glass and bottom ash in concrete construction

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Abstract

This research investigated the effect of incorporating waste glass powder and raw bottom ash in concrete construction. Laboratory work was designed to identify the performance of concrete mixes using waste glass powder and raw bottom-ash as a partial substitute of cement. The performance of the prepared mixes was obtained in terms of workability, compressive strength. The first series of concrete mixes were prepared with 10%, 20% and 30% glass powder as a replacement of the cement content. The cement content of the second series were replaced with 10%, 15% and 20% raw bottom-ash. Further, a third series were carried out having 20 % of cement content replaced by 10% of glass powder and 10% of raw bottom ash.

Incorporation of glass powder or/and raw bottom-ash partially replacing cement content in concrete indicated a significant improvement in slump values. The ultimate compressive strength of 10% replacement of cement by glass powder showed the optimum content in which the strength was higher than the control mix. However, Incorporation of raw bottom-ash in concrete as a partial substitution of cement showed decrease in strength compared with the control mix.

Index Terms— Concrete, Glass Powder, Bottom Ash, Slump, Compressive strength.

1- Introduction

The Gaza Strip suffers from scarcity of land, where about two million inhabitants live in an area of not more than 360 km2. This resulted in very limited areas available for landfills making disposing solid wastes is a real issue in the Gaza Strip. Further, the flow of construction materials into the Gaza Strip, such as cement, is a very complicated process. This situation pushed the researchers to optimize solid waste recovery to reduce the solid waste quantities going to the current landfills. Glass waste and raw bottom ash represent materials of solid waste compositions that could be utilized as a cement-replacing material due to its pozzolanic reaction.

The quantities of waste glass in Gaza Strip have been increasing significantly without being recycled, increasing the risk to public health due to the scarcity of land area. A study conducted by United Nation Development Program in 2012 [1] showed that Gaza Strip produced about 37 ton per day of waste glass in 2012, anticipating this quantity to reach 72 ton per day in 2040.

Using waste glass in construction is one of the potential areas to both enhance the performance of concrete and to reduce the adverse social and environmental effects of disposing such solid wastes. Several studies showed that glass has a chemical composition that can be classified as cementitious materials that can be partially replace cement content in concrete mixes [2-5]. Grounding and milling of waste glass to micro sizes can improve the pozzolanic reaction between glass composition and the cement hydrates resulting in the production of calcium silicates hydrates [6-9]. Researchers replaced waste glass powder with a varying percent of cement content used in concrete mixes [4, 8-11]. They replaced the cement content by a wide range of glass powder contents ranging from 10% to 30 %. The effect of adding waste glass powder was studied on various mechanical properties of concrete, such as workability, compressive strength, flexural strength, tensile strength, etc.

Due to the slow pozzolanic reaction between silicic acid available in waste glass powder (WGP) and the cement hydrates, the improvement in mechanical properties of the concrete samples containing WGP was observed at higher concrete ages [4]. However, Rashad [7] reviewed past researches conducted on glass concrete and indicated that these researches were not conclusive in terms of workability and strength; the chloride resistance of glass concrete was similar to that of the control sample. Studies were conducted to investigate the potential of using glass culets as aggregates, fine or/and [4, 7, 11-13]. The results of these studies indicated the possibility of replacing natural aggregates with waste. However, the alkali-silica reaction and deleterious chemical constituents should be considered.

Aggarwal, et al. [14] and Andrade, et al. [15] studied the effect of use of bottom ash as a replacement of fine aggregates. The study found that the strength development for various percentages (0-50%) replacement of fine aggregates with bottom ash can easily be equated to the strength development of normal concrete at various ages.

Rafieizonooz, et al. [16] investigate concrete mixes by replacement of sand with bottom ash waste and cement with fly ash. Concrete specimens were prepared incorporating 0, 20, 50, 75 and 100% of bottom ash replacing sand and 20% of coal fly ash by mass, as a substitute for Ordinary Portland cement.

The pozzolanic properties of a coal combustion bottom ash were investigated by [17]. Plain pastes containing equal amounts of calcium hydroxide and bottom ash were prepared and analyzed at different ages for their strength and the calcium hydroxide consumption. At early ages, bottom ash does not react with calcium hydroxide. Its pozzolanic reaction proceeds slowly and accelerates gradually to become very interesting after 28 days and especially after 90 days.

The research of Jaturapitakkul and Cheerarot [18] investigates the potential of using bottom ashes as a pozzolanic material. They incorporated the bottom ashes as a replacement of Portland cement type I in mortars and concrete mixes. The results indicated that compressive strength of mixes having 20 to 30 % of bottom ash as cement substitute were significantly less than that of cement mortar.

The current research aims at investigating the incorporation of waste glass or/and bottom ash in concrete construction. This aim was achieved by conducting a laboratory work to identify the performance of concrete mixes using waste glass powder or/and raw bottom-ash as a partial substitute of cement. The performance of the prepared mixes was obtained in terms of workability, compressive strength.

2- Experimental Investigation

2.1 Materials

Waste glass is obtained from local factory for manufacturing glass. This waste glass is milled and the passing sieve 75µm is collected for the experimental work. The fineness of the waste glass powder is 3319.12 cm^2/kg using Blain Air Permeability according to ASTM C204 [19]. Specific gravity and PH of the waste glass is 2.60 and 10.26 respectively.

Cement CEM II AM 42.5N was utilized in the current study according to EN 197-1. Specific gravity and fineness of OPC was measured to be 3.14 and 3898.42 cm^2/kg according to ASTM C187 [20] and ASTM C786/C786M [21], respectively.

The natural coarse and fine aggregate and glass coarse aggregate were prepared according to the requirements ASTM C778 [22]; their gradations are shown in Tables 1 and 2.

Table 1 Gradation of natural coarse aggregates

Sieve opening (mm)	Coarse Aggregates % Passing			Sieve opening (mm)	Coarse Aggregates % Passing
	Type I	Type II	Grade III		
37.5	100	100	100	1.180	100
25	91.46	100	100	0.600	99.97
19	58.06	94.13	100	0.425	94.34
12.5	2.03	33.07	92.20	0.300	32.73
9.5	0.95	4.36	82.54	0.150	1.708
4.75	0.6	0.15	5.82	0.075	1.00
Pan	0.04	0.01	0.06	Pan	0.72

Table 2 Gradation of glass coarse aggregates

Sieve opening (mm)	% Passing	
	Grade 1	Grade 2
25	100	100
19	88.23	100
12.5	27.41	99.99
9.5	8.23	99.97
4.75	0.29	1.1627
Pan	0.01	0.01

The absorption and bulk specific gravity of the applied natural aggregates are presented in Table 3.

Table 3 Physical properties of aggregates

Aggregate type		Absorption capacity %	Bulk specific gravity (SSD)	Dry-rodded unit weight, kg/m3
Coarse	Type I	1.58	2.58	111
	Type II	0.97	2.63	111
	Type III	1.27	2.62	111
Fine		1.27	2.61	-

2.2 Mix proportions and preparation

The performed concrete mix was designed according to ACI 211.1 [23]. The obtained mix proportions are presented in Table 4.

Table 4 Mix proportions of concrete.

Materials		Quantity, kg/m^3
Cement		330
Coarse	Type I	540
	Type II	330
	Type III	350
Sand		660
Water		155
Water/cement ratio		0.47
Superplasticizer		2.31

The replacement of cement was conducted in three phases. The first phase was carried out by replacing 10%, 20% and 30% of cement by glass powder. In the second stage 10%, 15% and 20% of cement were substituted by bottom ash. The third stage comprised replacing 20 % of cement by 10% of glass powder and 10% of raw bottom ash in order to study the combined effect. In all test the weight of Type I, Type II, Type III coarse aggregate and sand was kept constant with 540, 330, 350 kg and 660kg per cubic meter respectively. Also the w/c ratio is set to be 0.47 and Superplasticizer 2.31 kg. Table 5 presents the details of the prepared specimens including the control mix, glass powder mixes, bottom ash mixes and glass powder-bottom ash mixes.

The concrete was prepared according to the Standard Method of making and curing test specimens in laboratory, [24]. After 24 hours, the hardened concrete was removed from the 10 cm cubic molds and placed for curing in a water tank at temperature ranging from 21 to 25 C^0 until the date of testing.

Table 5: Glass and Bottom ash Content of the Mixes

Mix		Cement kg	Glass Powder kg	Bottom Ash kg
Control Mix		330	--	--
Glass Powder Mix	10%	297	33	--
	20%	264	66	--
	30%	231	99	--
Bottom Ash Mix	10%	297	--	33
	15%	280.5	--	49.5
	20%	264	--	66
10% Glass +10% Bottom Ash		264	33	33

2.3 Testing program

The slump test according to ASTM C143/C143M [25] was carried out to obtain the effect of various glass and bottom ash contents on the workability of concrete specimens. The cubic compressive strength based on ASTM C39/C39M [26] was performed; a single test result was obtained by averaging three companion cubes.

The testing program comprised three series. In the first phase, the compressive strength was tested for concrete specimens replacing cement by 10 %, 20 % and 30 % glass powder. The strength of these concrete specimens was obtained at the ages of 7-days, 14-days, 28-days and 60-days.

The second phase represents concrete specimens in which cement was replaced by 10%, 15% and 20 % raw bottom-ash. Strength results of these specimens were obtained at the ages of 14-days and 28-days. The third phase included concrete specimens with 20 % of cement replaced by 10 % glass powder and 10 % raw bottom-ash. The strength of phase 3 concrete specimens was obtained at the ages of 7-days, 14-days, 28-days and 60-days.

3- Results and Analysis

3.1 Workability

The workability of the tested concrete specimens was measured using the slump test. Figure 1 represents the slump values of the concrete specimens having cement content partially replaced by 0%, 10 %, 20 % and 30 % glass powder. The slump results showed that the workability of the specimens improved as the glass powder content replacing cement is increased. The maximum improvement was reached at the partial replacement of cement of 30 % glass powder. This can be attributed to the mechanical effect of the smooth glass powder particles. It is believed that the existence of such smooth fine particles would improve the movement of aggregate particles on each other resulting in improving the overall workability of the specimens. Further, the absorption capacity of the glass powder particles is less than that of cement particles. It results in providing more free water for the lubrication effect of the mixing water. These findings agree very well with [27, 28].

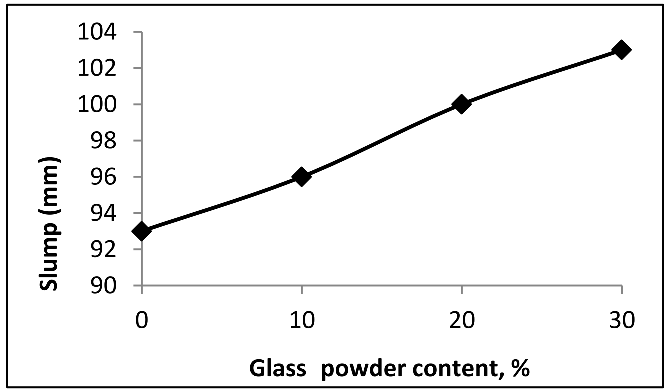

Figure 1. Slump with glass powder contents

The workability of utilizing raw bottom-ash as a partial substitution of cement in terms of slump is indicated in Figure 2. The results of slump show that the investigated contents of raw bottom-ash have a slight improvement on the slump values of specimens. There was no adverse effect on slump with partial substitution of cement by raw bottom-ash added up to 30 % replacement. This could be attributed to mechanical lubricant action of the bottom ash particles, which allows the aggregate particles move more freely around each other [17].

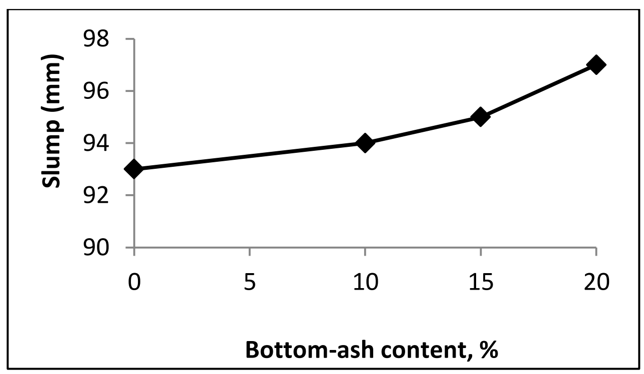

Figure 2. Slump with bottom-ash contents.

3.2 Compressive Strength of Glass Powder Samples

The compressive strength of specimens with partial substitution of cement by glass powder contents was obtained at several ages. Table 6 and Figure 3 show the compressive strengths of specimens with cement replaced by 10 %, 20 %

and 30 % glass powder at age of 7-days, 14-days, 28-days and 60-days.

Table 6. Compressive strength of specimens with glass powder

Glass powder specimens	Compressive strength, kg/cm^2			
	7-days	14-days	28-days	60-days
0 %	235	303	338	414
10 %	216	265	337	418
20 %	186	234	278	293
30 %	143	167	231	270

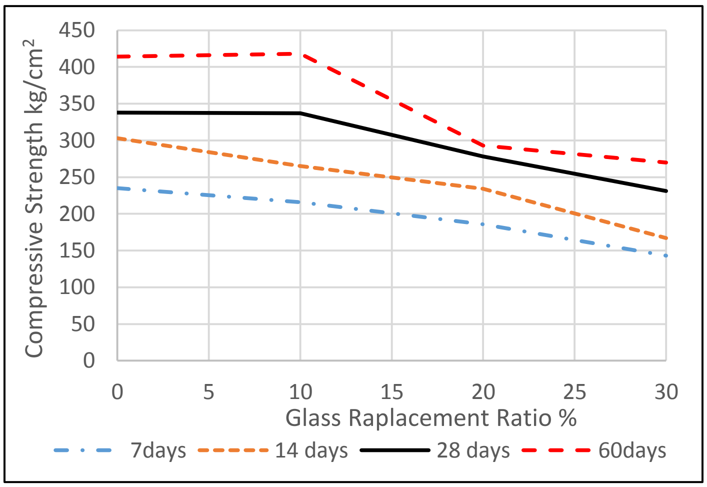

Figure 3: Compressive strength with several replacement ratios of glass powder at 7,14,28 and 60 days

The compressive strength of the specimens with glass powder replacing 10%, 20% and 30% of cement with glass powder at 7-days achieved 91.91%, 79.14% and 60.85% of the control mix (without glass powder) respectively. At 14-days age, the 10%, 20% and 30% glass powder specimens showed strength of 87.45%, 77.22% and 55.11% of the control mix respectively. The 28-days strength of the 10%, 20% and 30% glass powder specimens indicated 99.70%, 82.24% and 68.34% of the control mix respectively. At 60-days age, the 10%, 20% and 30% glass powder specimens revealed strength of 100.96%, 70.77% and 65.21% of the control mix respectively. The results indicated that in general the strength is adversely affected by increasing the glass powder content.

Figure 4 presents the compressive strength results for all glass powder contents with respect to specimen age. The results showed that the development of the compressive strength continues with the age of the specimens with all glass powder contents. The 10% glass powder specimen showed that it started to compensate the early strength reduction at age 28-days. Further, at age of 60-days the strength of the glass powder specimen became slightly higher than that of the 0% glass powder specimen. This can be attributed to the fact that the hydration process of glass powder as a cementitious material is slow at the beginning and gets faster later [28-30]. It can be concluded that replacement of 10% of the cement content by glass powder gives the optimum compressive strength without scarifying the ultimate strength.

The failure mode for the control mix and for all specimens with glass powder is normal mode; pyramid failure. Figure 5 shows a photo of the failure mode of concrete specimens with 10% of glass powder replacement after 60 days.

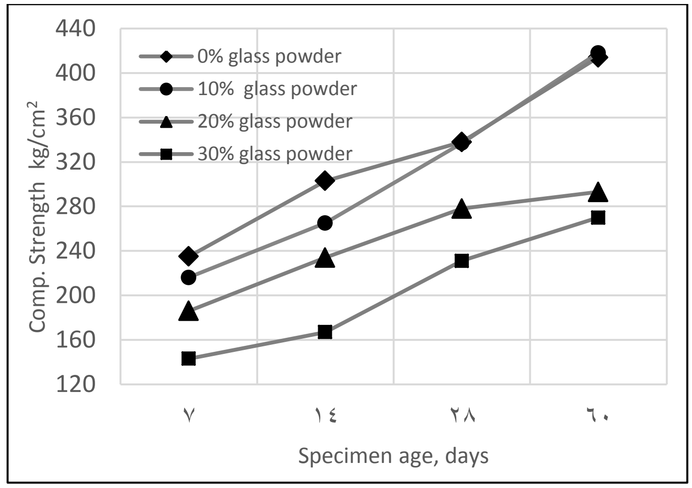

Figure 4: Compressive strength for glass powder contents with respect to specimen age

Figure 5: Failure Mode of concrete specimens with 10% of glass powder after 60 days

3.3 Compressive strength of Bottom Ash Samples

The compressive strength of the specimens with raw bottom-ash replacing 0%, 10%, 15% and 20% of cement content is presented in Figures 6 and 7.

The 14-days compressive strength of the specimens with 10%, 15% and 20% of cement substituted with raw bottom ash achieved 71.28%, 67.65% and 65.34% of the control mix respectively. At age 28-days, the compressive strength of the specimens with 10%, 15% and 20% of raw bottom-ash reached 69.52%, 67.45% and 66.27% of the control mix respectively.

These results indicate that the incorporation of original bottom ash has a negative influence on the compressive strength, which agrees well with [18]. Jaturapitakkul and Cheerarot [18] found out that original bottom ash should not be used as a pozzolanic material.

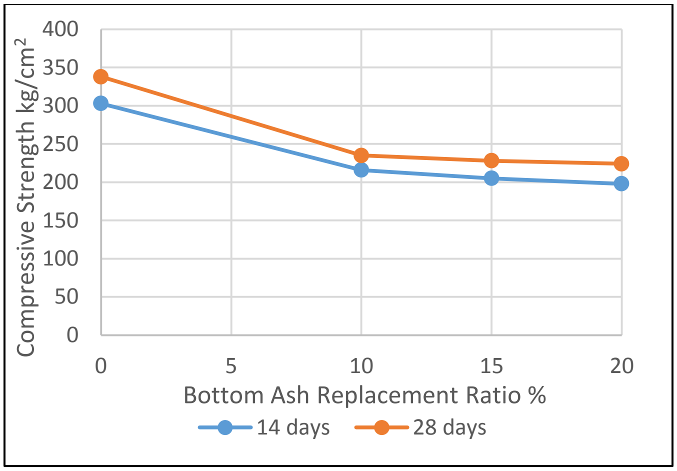

Figure 6: Compressive strength with several replacement ratios of raw bottom-ash at age of 14, 28-days

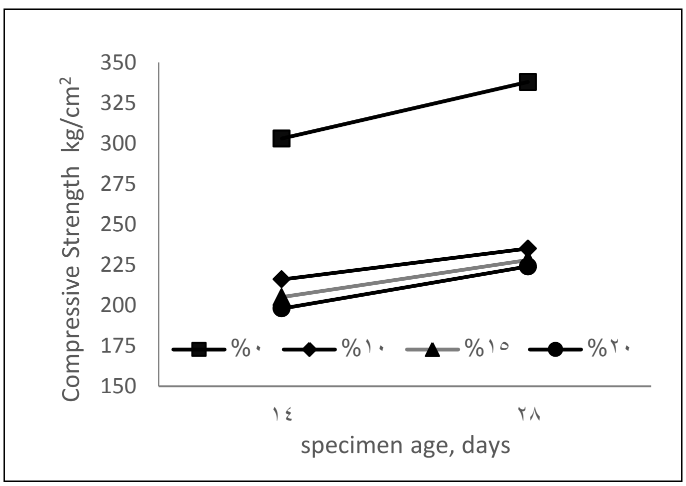

Figure 7: Compressive strengths of bottom ash contents at 14-days and 28 days age

Figure 8 shows the average 7, 14 and 28 days compressive strength of concrete mixes having combined action of both glass powder and raw bottom ash as a replacement of cement. A concrete mix was prepared using 10% replacement of cement with glass powder in addition to 10% cement replacement with bottom ash. The average compressive strength of these mixes at 7,14 and 28 days achieved 81.27%, 75.24% and 76.33% of the control mix (without glass powder and bottom ash) respectively. The compressive strength of the 28-days compressive strengths of the control mix with the 10% glass powder mix, 10% bottom ash mix and 10% glass powder and 10% bottom ash mix were 338 kg/cm2 , 265 kg/cm2 , 235 kg/cm2 and 258 kg/cm2, respectively. These results indicated the existence of 10 % glass powder reduces the adverse effect of the existence of bottom ash content. The 28 days compressive strength of the 10 % bottom ash mix improved from 235 kg/cm2 to 258 kg/cm2 when replacing 10% of cement by glass powder.

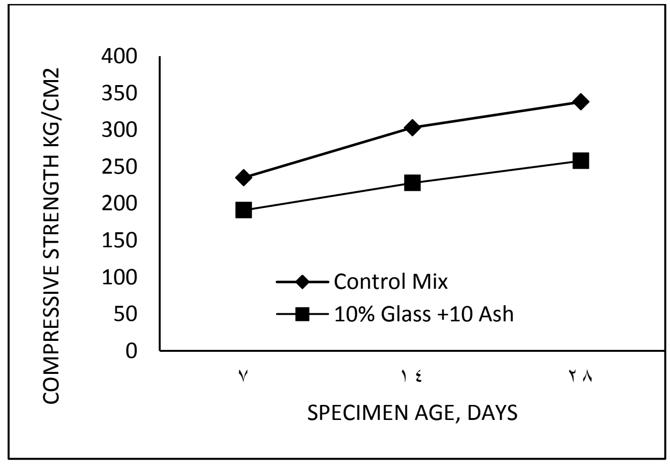

Figure 8: Compressive strengths of 10% bottom ash and 10% glass contents, at 28-days age

4- Conclusions

This research investigated the potential of incorporating waste glass powder and raw bottom as a substitute of cement in concrete construction. The performance of the prepared mixes was obtained in terms of workability, compressive strength. The first series of concrete mixes were prepared with 10%, 20% and 30% glass powder as a replacement of the cement content. The cement content of the second series were replaced with 10%, 15% and 20% raw bottom-ash. Further, a third series were carried out having 20 % of cement content replaced by 10% of glass powder and 10% of raw bottom ash. The following conclusions are achieved:

1- The slump results showed that the workability of the specimens improved as the glass powder content replacing cement is increased. The maximum improvement was reached at the partial replacement of cement of 30 % glass powder.

2- The slump results indicated that incorporating raw bottom-ash as a replacement of cement has a slight improvement on the slump values of specimens. There was no adverse effect on slump with partial substitution of cement by raw bottom-ash added up to 30 % replacement.

3- The compressive strength results showed that the development of the compressive strength continues with the age of the specimens with all glass powder contents. The 10% glass powder specimen showed that it started to compensate the early strength reduction at age 28-days. Further, at age of 60-days the strength of the glass powder specimen became slightly higher than that of the 0% glass powder specimen. It can be concluded that replacement of 10% of the cement content by glass powder gives the optimum compressive strength without scarifying the ultimate strength.

4- The 14-days compressive strength of the specimens with 10%, 15% and 20% of cement substituted with raw bottom ash achieved 71.28%, 67.65% and 65.34% of the control mix respectively. At age 28-days, the compressive strength of the specimens with 10%, 15% and 20% of raw bottom-ash reached 69.52%, 67.45% and 66.27% of the control mix respectively. The 14 and 28 days compressive strength of mixes with cement replaced by raw bottom ash indicate a negative influence on the compressive strength.

5- The compressive strength of concrete mixes having both glass powder and raw bottom ash as a replacement of cement indicated that the existence of glass powder reduces the adverse effect obtained when replacing cement by only bottom ash.

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