Effect of Waste Glass Powder as a Supplementary Cementitious Material on the Concrete Mix Properties

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Abstract

Glass is a non-biodegradable material; therefore landfills do not provide an environment friendly solution for waste glass. Hence, there is a great need for proper management of waste glass. In this study, a new application of waste glass powder as a supplementary cementitious material to produce high performance concrete was investigated. Grinded glass was added to concrete mix as partial replacement of cement at (5, 10, 15) % by weight. It was evaluated as a pozzolanic material in conjunction with high range water reducing admixture superplasticizer (HRWR). The compressive strength at the ages of 7, 28, 90, 150, 240 days were tested. The study confirmed that the use of 10 % of grinding glass improved the compressive, flexure strength of concrete by about (30 , 11.64)%, respectively at 240 days compared to reference concrete and decrease the permeability of water under presser by about 29.4% at 240 days . At the end of 300 days of partial submerge in 3.5% NaCl solution, the half-cell potential of steel embedded in reference and glass concrete were (-356 and-340) mV respectively. The results indicated that there is a possibility to prepare high performance concrete using grinded glass.

Key words: Grinded glass; Pozzolanic material; Strength properties; permeability; half-cell potential.

1. Introduction

The term sustainability has a plethora of definitions; however, almost all the definitions provided by researchers have commonalities which are synonymous with the term "green." Green materials have the characteristics of less energy and resources and high performance ability. Concrete is one of the most vastly used building materials in the world [14].

On the other hand the production of cement is one of the major sources of CO_2 emissions in the world .An increase in cement content contribute with an increase in greenhouse gases emission, which is highly pertinent to global warming. Every ton of cement produced liberates about 1 ton of carbon dioxide [5], also the cement industry is responsible for almost 5% of the total global industrial energy consumption [20], this problems can be solved by the substitution of larger portions of the cement by supplementary cementitious materials, while maintaining its mechanical and durability properties [1].

Supplementary cementing materials (SCMs) improved the hydraulic activity for Portland cement through hydraulic activity; pozzolanic activity, or both. Chemical reaction between phases in the SCM and water are led to hydraulic activity, forming cementitious hydration products similar to those formed through hydration of Portland cement, while pozzolanic activity, which is characterized by the reaction between siliceous or alumino-siliceous material in the SCM with calcium hydroxide forming calcium silicate hydrate and other cementitious compounds. Calcium silicate hydrate is a more desirable hydration product and thus the pozzolanic reaction is considered to have a positive impact on the long-term properties of the hardened concrete [10].

The use of supplementary cementitious materials (SCMs) as a partial replacement of 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 fly ash [2], these materials are used to create blended cements which can improve concrete durability, early and long term strength, proved workability and economy [3].

Researches indicated that glass has a chemical composition and phase comparable to traditional SCMs [17]. The term glass contains several chemical diversities including soda-lime silicate glass, alkali-silicate glass and boro-silicate glass. In order to decrease environmental problems, glasses and its powder have been used as a construction material. The coarse and fine glass aggregates could cause ASR (alkali-silica reaction) in concrete, but the glass powder could suppress their ASR tendency, an effect similar to SCMs. Therefore, glass is used as a replacement of supplementary cementitious materials [12]. It also helps in ceramic and bricks manufacture and it preserves raw materials, decreases energy consumption and volume of waste sent to landfill.

2. Literature Review

Meena and Singh (2012) were conducted a series of tests to study the effect of 15% and 30% replacement of cement by silica fume, fly ash and glass powder on compressive strength and durability in the form of capillary absorption. They concluded that 30% of glass powder of size less than 100μm shows a pozzolanic behavior and could be included as cement replacement in concrete without any unfavorable effect [12].

Vijayakumar et al. (2013) examined the possibility of using Glass powder as a partial replacement of cement for new concrete. Glass powder was partially replaced as 10%, 20%, 30% and 40% and tested for its compressive, Tensile and flexural strength up to 60 days of age and were compared with those of conventional concrete; from the results obtained, it is found that glass powder can be used as cement replacement material up to particle size less than 75μm to prevent alkali silica reaction [19].

Raju and Kumar (2014) studied the strength of concrete containing waste glass powder as a partial replacement of cement for concrete in the range of replacement 5% to 40% , they tested for compressive strength and flexural strength at the age of 7, 28 and 90 days and compared with those of conventional concrete. Results showed that replacement of 20% cement by glass powder was found to have higher strength [16].

Sharma (2015) studied the effect of 5%, 10% and 15% replacement of cement by glass powder on compressive strength and durability. The particle size effect was evaluated by using glass powder of size 600μm-100μm.The results shows that maximum increase in strength of concrete occurred when 10% replacement also the pozzolanic behavior of waste glass appears, if they ground finer than 600μm. The early consumption of alkalis by glass particles helps in the reduction of alkali-silica reaction hence enhancing the durability of concrete [18].

Jain et al. (2016) used glass powder in the range of 5% to 20% as replacement of cement and concrete cube, cylinder and beam strength compared with conventional concrete, and concludes that replacement of cement by glass powder in concrete generally decreases the ultimate strength in 28 days curing of concrete **[9].**

The aim of this study focuses on the feasibility of using grinded glass of locally available construction waste for establishing economically-friendly and affordable green environment through evaluate its pozzolanic activity and check the suitability as partial replacement of cement to produce high performance concrete.

3. Methodology

The materials used in this study are locally available except the admixture.

Ordinary Portland cement conforming to IQS No. 5/1984 was used. **Tables. 1 and 2** represent the chemical and physical properties of the used cement respectively.

Natural sand of zone **(1)** conforming to IQS No.45/1980 was used as fine aggregate. **Tables .3 and 4** show the gradation of the used fine aggregate and its chemical and physical properties .Crushed river gravel with 20 mm maximum size and properties conforming to Iraqi standards No.45/1984, **Table. 5** was used as coarse aggregate.

High range water reducing admixture (HRWR) super-plasticizer, known as (PC2000) complies with ASTM C 494 type G was used. Water/cement ratio was increased in order to increase the mechanical property and durability of concrete, it ranged from 0.5 to1.5% of the cement weight. The properties of this admixture are listed in **Table .6.**

The waste glass was collected from recycled clear glass bottles, cleaned and then crushed using Jet mills machine. The grinded glass was sieved to the desired particle size, **Fig. 1.** the chemical and physical properties of waste glass are summarized in **Tables .7** and **.8** respectively.

X-ray diffraction test indicated that the glass powder has amorphous pattern **Fig.2**. The high peak represents silica **Table .8** which is potentially pozzolanic when particle size is less than 75µm **[4].**

All the tests were carried out at the room temperature for one year, at the laboratory of concrete in the building research directorate. Each mixture consisted of cement (400 kg/m^3) ; sand (750kg/m^3); gravel (1035 kg/m3) and a w/c ranged between (0.41-0.50) and 1.2% HRWR by weight for reference mix and 1.4% for glass-concrete in order to achieve 50 MPa compressive strengths at 28 days. The slump was kept within the range (80-90) mm.

Fig. 1. Glass powder

Table.1 Chemical properties of cement

Compound composition	Abbreviation	Percent by weight	Limit of IQS No.5/1984
Lime	CaO	62.73	-
Silica	SiO_2	20.41	-
Alumina	Al_2O_3	4.91	-
Iron oxide	Fe_2O_3	3.21	-
Magnesia	MgO	2.60	≤ 2.85%
Sulfate	SO_3	2.80	≤ 5%
Loss on ignition	L.O.I	3.17	≤4%
Insoluble residue	I.R	1.05	≤ 1.5
Lime saturation factor	L.S.F	0.93	0.66-1.02
Main compounds % by weight			

Name of compounds	Abbreviation	Percent by weight
Tri calcium silicate	C_3S	49.57
Di calcium silicate	C_2S	21.36
Tri calcium aluminate	C_3A	7.58
Tetra calcium alumino ferrite	C_4AF	9.75
Free lime	-	1.12

Table. 2 Physical properties of cement

Physical properties	Limits of cement	Limits of IQS No. 5/1984
Fineness Blaine m^2/kg	359.7	≥ 230
Initial setting time (h:min)	1:35	≥ 00:45
Final setting time (h:min)	4:40	≤ 10:00
Compressive strength(MPa)		
3 days	28	≥ 15
7 days	34	≥ 23

Table. 3 Gradation and Aggregate

Sieve size (mm)	Percentage passing %	Limit of IQS No.45/1984, zone (1)
10	100	100
4.75	97	90-100
2.36	77.9	60-95
1.18	51.6	30-70
0.6	30.3	15-34
0.3	10.9	5-20
0.15	2	0-10

Table. 4 Physical and chemical properties of fine aggregate

Properties	Values	Limits of IQS No.45-1980
Sulfite % (SO_3)	0.18	≤ 0.5%
Fineness modulus	3.3	---
Absorption %	1.5	----

Table.5 Gradation of coarse aggregate

Sieve size (mm)	Percentage passing %	Limit of Iraqi standards No. (45/1984)
20	100	100
10	23.5	0-25
5	1.15	0-10

Table. 6 Properties of HRWR

Chemical content	Poly-carboxylate based
Color, appearance	Brown liquid
pH	0.5±6
Density	1.03±0.02 g/cm3
Chloride content (%)	Without chloride ion

Table. 7 Chemical properties of waste glass powder

Oxide composition	Oxide content %	ASTM C618 class C limitation
SiO_2	59.98	Min 50%
Al_2O_3	4.9	
Fe_2O_3	1.7	
SO_3	0.34	
CaO	10.0	
MgO	4.37	
L.O.I	-	
Total	81.29	

Table. 8 Physical properties of glass waste

Physical properties	Glass	ASTM C618 class C limitation
Fineness: Amount retained when wet-sieved on 45 µm (No. 325) sieve, %	10	Max 34
Specific gravity	2.33	

3.1 Detection and Monitoring the Corrosion by Half –Cell Potential

The electrochemical potential of the reinforcing steel was measured relative to a copper-copper sulfate electrode (CSE) according to ASTM C 876-99. **Table. 9** shows the relationship between half-cell potential and corrosion of steel embedded in concrete.

Table. 9 Relationship between half – cell potential and corrosion of steel in concrete

(ASTM C 876-99).

Half-cell potential (mV)	Interpretation
> -200	Low probability of corrosion
-200 to -350	Uncertain corrosion activity
< -350	high probability of corrosion

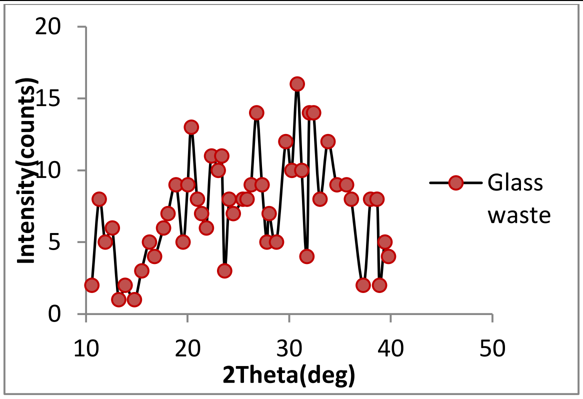

Fig. 2 X-ray analysis for waste glass

4. Results and Discussion

4.1Compressive Strength

The results of the compressive test for the SCM-C glass mixes are given in **Fig.3,** results show that the compressive strength for SCM-C glass increased until10% by weight cement percentage(10 G) and then beganed this percent to decline until cement percentage reached 15% by weight (15 G)but it still higher than that of the reference concrete at all curing ages.

For waste glass when grounded to a very fine powder, SiO_2 react chemically with alkalis in cement and form cementitious product (by producing C-S-H gel) that contribute to the strength development and durability, this is because voids are effectively filled and provide rise to dense concrete microstructure. However, beyond 15% the dilution effect takes over and the strength starts to drop **[2].**

The maximum increase in compressive strength was 30% for 10 G as compared to reference concrete at 240days curing age.

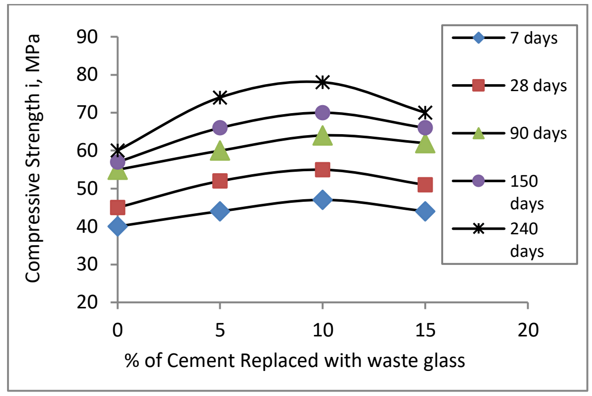

Fig. 3 Effect of waste glass powder on compressive strength as compared with reference concrete

4.2Flexural Strength

The flexural strengths test results for 10G-concrete are plotted in **Fig. 4.** The flexural strength for reference concrete was improved by the replacement of 10% by weight glass waste as well as it tend to increase with increasing curing age from150 to 240 day.

The maximum flexural strength was 8.38MPa at 240days curing .This can be attributed to the fact that waste glass serves as a filler material. Similar observation was reported by Jain, et al. **[9].**

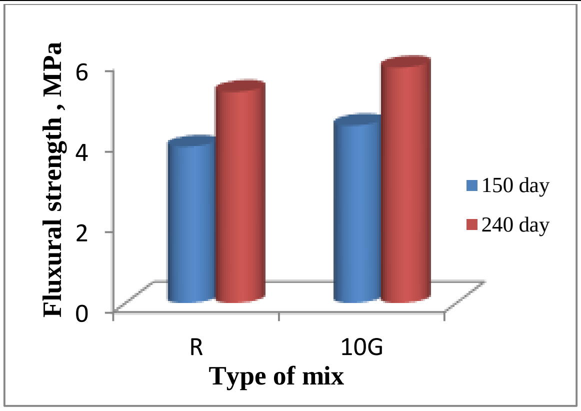

Fig. 4 Effect of 10% waste glass powder on flexural strength as compared reference concrete

4.3 Permeability

The results for water absorption test or the porosity test for 10G–concrete and reference concrete at 150 and 240 day curing ages was plotted in **Fig. 5.**

The results indicated that the percentage of water absorption for 10G– concrete was less than that of reference concrete at all curing age and it decreased with increasing curing age from 150 to 240 day.

The maximum reduction of water absorption was 32.6% as compared with reference concrete. This may be attributed to the pozzolanic reaction for glass waste which can refine the pore structures, decreasing the connectivity and increasing the tortuosity for water transport, due to more fineness property of particles than cement and the capacity of the pozzolanic towards fixing $Ca(OH)_2$ generated during the reactions of hydration of cement **[6][11].**

These results are in agreement with the finding reported by Hongjian, et al. **[7]. Fig. 6** Shows the water penetration depth for 10G–concrete and reference concrete at150 days curing age. This figure shows that the depth of water penetration for glass -modified concrete was less than that for reference concrete. Blended glass waste as replacement of cement content Improved the pore structure in the transition zone led to reducing water permeability .The results are in agreement with those obtained by Menadi, et al**. [13]** who reported that using a pozzolanic materials reduced the water depth penetration

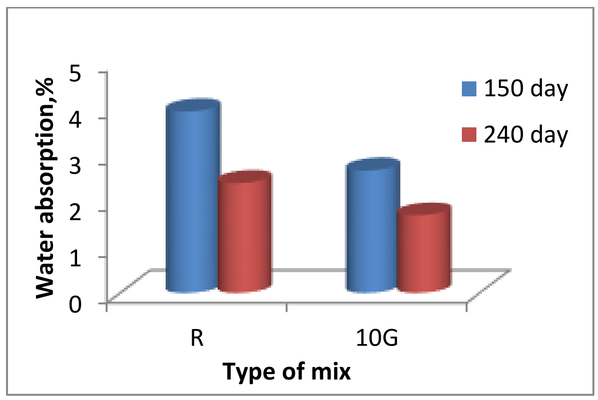

Fig. 5 Water absorption test

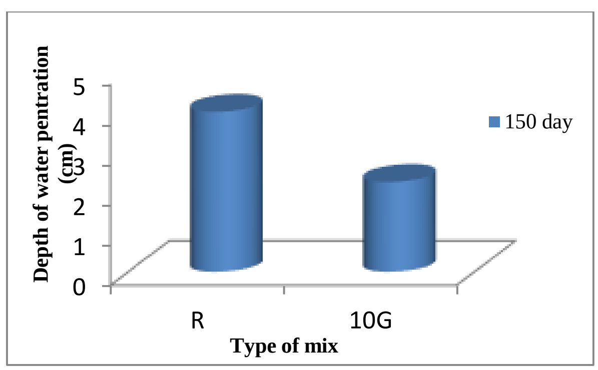

Fig. 6 water penetration for the concrete mixes

4.4 Half–cell potential

Half-cell potentials of steel results for 10G - concrete and reference concrete embedded in 3.5% NaCl solution are presented in **Fig. 6.** It is obvious that the potential of steel was shifted towards negative potential at the beginning of exposure period. The highly negative potential is not an indicative of high corrosion activity. It may be due to the higher moisture content of concrete after 28 days curing in tap water. The half -cell potential of steel increased with increasing moisture content of concrete **[8].** The steel potential for 10G- concrete was (-316 mV) at 150 days curing which was lower than reference concrete (-338 mV) which was lower than reference concrete (-338 mV). This behaviour may be proposed on the basis of the better adsorptive capacity resulting in a barrier film difficult to break or penetrate by the corrosive chloride ions **[15],** then results are fluctuated and shifted to a more negative potential. At the end of 300 days of exposure the average potential in the reference concrete was -356 mV, while the average potential for 10G-concrete was 340 mV. It can be noted that all the 10G- concrete of steel potential was significantly below the threshold value stated by ASTM C876, **Table .9**.

This pozzolanic reaction reduces the porosity and permeability of cement paste making it stronger and significantly more durable **[15].** Use of superplasticizer in concrete lead to reduce the water content and this leading to low permeability thereby reducing the penetrability of the aggressive ions.

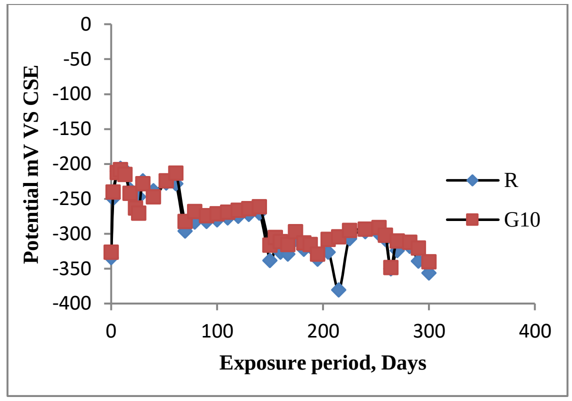

Fig. 7 Potential versus time behavior for 10G– concrete as compared with reference concrete

5. Conclusion

This study concluded the performance of glass waste powder as supplementary cementitious materials to produce high performance concrete in conjunction with high range water reducing admixture and minimizing the threat of this type of solid wastes for environmental protection.

This study confirmed that the use of grinded waste glass improved:

- The compressive strength results for specimens with waste glass reveal that it increased up to 10% replacement of cement and further increasing of percentage leads to decrease in compressive strength of concrete. A significant improvement in compressive strength for 10% replacement of cement by 30% at age 240 days.

- The use 10% by weight of waste glass and as partial replacement of cement improve:
  1. Flexural strength for reference concrete .It increased by 11.64 at age 240 days.
  2. Improving water absorption at the age of 240 days. It decreased by 29.41%.
  3. The depth of water penetration at the age of 150 days, it decreased slightly by 43.75%.
  4. Reducing the corrosion of steel reinforcement by about 4%.

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تأثير مخلفات مسحوق الزجاج كمادة اسمنتية تكميليه على خصائص الخلطة الخرسانية

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الخلاصة:-

يعتبر الزجاج مادة غير قابل للتحلل وان عملية الطمر لا توفر حلا ولاتعد مخلفات الزجاج صديقه للبيئه وبالتالي دعت الحاجة الى اعاده استخدام مخلفات الزجاج. تهدف هذه الدراسة إلى التحقيق في جدوى استخدام النفايات الزجاجية المواد الاسمنتية التكميلية لإنتاج الخرسانة عالية الأداء.تم إضافة الزجاج المطحون إلى المزيج الخرساني كبديل جزئي للأسمنت وبنسبة (5، 10، 15)٪ وزنيا. تم تقييمها على أنها مادة بوزولاني بالاقتران مع مجموعة عالية من مياه خفض الخليط الملدن المتفوق . تم اختبار قوة الانضغاط في عمر 7و 28و90و150و 240 يوم. وأكدت الدراسة أن استخدام 10٪ من الزجاج المطحون ناعما يحسن من قوة الانضغاط وقوة الانحناء للخرسانة بنحو (30، 11.64)٪ على التوالي عند عمر 240 يوم مقارنة بالخرسانة المرجعية كما ساهم بتقليل نفاذية الماء تحت الضغط بنحو 29.4٪ عند 240 أيام. في نهاية عمر 300 يوم من الغمر جزئيا في محلول كلوريد الصوديوم 3.5٪ كان جهد نصف الخلية للخرسانة المسلحه (المرجعية والخرسانة الزجاجية) (-356 و 340) ملي فولت على التوالي. وهذا يعني أن هناك إمكانية لإعداد الخرسانة عالية الأداء باستخدام الزجاج المطحون .

الكلمات المفتاحية: زجاج مطحون،مادة بوزولونية ، خصائص القوة ، النفادية ، جهد نصف الخلية