Recycling of Waste Glass in Concrete as Partial Replacement of Cement or Fine Aggregate

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Abstract

In this paper, mixing of the recycled glass, which possesses a high SiO_2 (silicon dioxide) percentage, was utilized to produce a green concrete with remarkable properties. Waste glasses were utilized as cement or fine aggregate partial replacement with various contents (5%, 10%, 15% and 20%) via the weight of cement or fine aggregate. The compressive strength for three ages (7, 14, and 28) days and slump was measured for each concrete mix. Results evinced that the recorded compressive strength increased with the glass content up to10% and then decreased when using glass as replacement of cement, while when using glass as replacement for fine aggregate, the compressive strength decreased initially and then increased with the content of glass. The results of slump test manifested that the concrete workability increased with the content of glass whether the powder of glass employed as cement or fine aggregate replacement.

Keywords: Green concrete, Blended cement, Glass waste, Recycling materials, Fine aggregate replacement

Introduction

Concrete is a stone-like substance obtained via designing a cautiously proportioned mix of cement, gravel, sand or different aggregates and water to be hardened in the required structure shapes and dimensions. It's most broadly utilized as a man-made building substance and its need is rising daily. The construction community attention in utilizing the waste or re-cycled substances in concrete is rising due to the more stress given to the sustainable building. Glass is an inert substance that can be re-cycled and utilized several times without varying its chemical characteristic [1].

Shivacharan Singh et al. observed that the glass waste could be utilized separately as cement and tiny aggregate partial replacement. Also, it was depicted that the compressive strength of concrete, which produced with glass waste, was higher than the reference traditional concrete at the whole levels of cement and normal tiny aggregate replacement [2]. Aseel Basim et al. studied the influence of different waste glasses as cement partial replacement with various contents on the mechanical properties of concrete and found that the compressive strength enhanced with the increasing the content of glass up to 13% [3]. M. Iqbal Malik et al. found that the allowability of utilizing the powder of the waste glass as fine aggregates partial replacement was till (30%) by the weight. Also, it was obtained that the concrete compressive strength enhanced with the glass content, and the concrete mix workability increased with the increment in the content of waste gla [4]. Aseel B. et al. investigated the mechanical properties and the thermal conductivity of mortar cement made from glass waste at various ratios of glass to cement. It was concluded that the glass waste can be utilized ecologically and cost-effective cement substitution as in the production of mortar cement [5]. N. Tamanna et al. discussed the waste glass possibility in the concrete production and its pozzolanic characteristics in the cement in terms of sustainability and durability. It was found that the straight use of the waste glass as the aggregates of concrete possesses a negative influence upon the strength and workability of concrete. But, the glass ground powders revealed a very good pozzolanic reactivity and can be utilized as a cement replacement [6].

The purpose of this study is to recycle glass in the cement-based materials by using fine and coarse glass powders as partial replacement for centment or fine aggregate, respectively. This utilization of glass leads to a reduction in the crushing energy utilized. It's assumed that the glass particles normally present a pozzolanic activity useful to the concrete.

Materials

Natural sand, which was supplied from from Al-Akhedher in Karbala, was utilized. The fine aggregates grading with their content of sulfate in accordance with the Iraqi specification (no. 45/1984) [7] is listed in Table (1). For the utilized crushed gravel during the present investigation, Table (2) lists the coarse aggregates grading with their content in accordance with the Iraqi specification (no.45/1984) [7]. The existing normal Portland cement named Karasta being commercially employed in the present work. Table (3) indicates that the cement chemical and physical characteristics conform to the Iraqi specifications (I.Q.S.) no.5/1984 [8]. Broken glass was collected from different sources and then ground to fine powder with two groups; the first group is a powder with particle size range (4.75-0.075) mm and utilized as fine aggregate partial replacement, and the second group has particle size less than 0.075 mm and utilized as cement partial replacement. The analysis of the particle size of the second group is depicted in figure (1), and Table (4) explains the chemical analysis of this glass.

Table (1): Sieve analysis and sulfate content of fine aggregate

Sieve opening (mm)	**Accumulative passing (%)**
10	100
4.75	94
2.36	85.6
1.18	76.9
0.60	46.3
0.3	10.8
0.15	1.1
0.075	0.5
Property	**Result**
SO_3, %	0.4

Table (2): Sieve analysis and sulfate content of the gravel

Sieve opening (mm)	**Accumulative passing (%)**
14	97
10	62
5	10
0.075	0.037

Table (3): Chemical and physical properties of the used cement

Oxide	**%**	**I.O.S.5: 1984 [7] Limits**
CaO	66.11	_
SiO_2	21.93	_
Al_2O_3	4.98	_
Fe_2O_3	3.10	_
MgO	2.0	< 5.0
K_2O	0.75	
Na_2O	0.35	
SO_3	2.25	< 2.8
Physical properties	**Test results**	**I.O.S.5: 1984 Limits**
Setting Time:		
Initial hrs.; min	2; 05	≥ 45 min
Final hrs.; min	4; 00	≤ 10 hrs

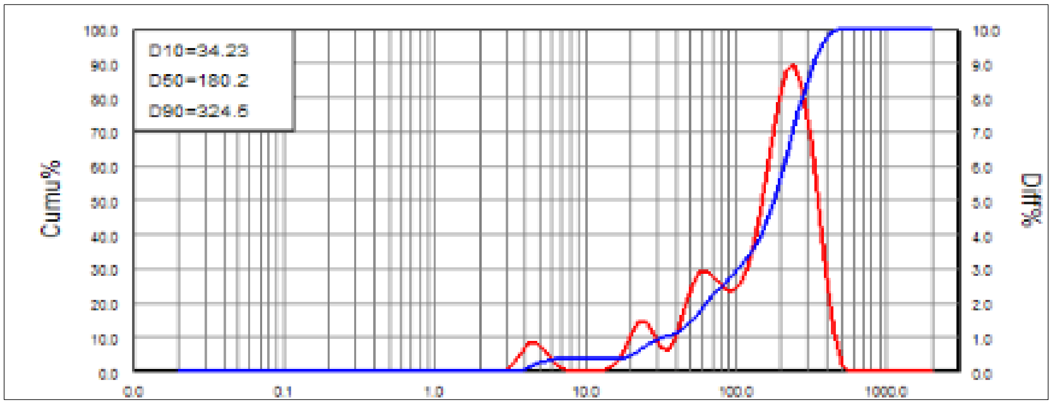

Figure (1): Particle size analysis of glass powder

Table (4): Chemical analysis of glass

Element	Content %
Si	57.41
Ca	4.78
Al	1.68
Fe	0.80
K	0.59
Mg	2.55
Pb	0.571
Cu	0.157
Ag	0.096
Mn	0.067

Specimens and Compressive Strength Test

The utilized kinds and dimensions of specimens were cubic with (150 x 150 x 150 mm) for the test of compressive strength in accordance with the (BS 1881-Part 101) [9]. The compressive strength test was conducted in accordance with the (BS 1881-Part 116) [10]. The curing ages were (7, 14 and 28 days). Three cubes were made for every mix at the limited age.

Slump Test

Workability with respect to slump for the concrete was done utilizing the waste glass as a replacement of cement and fine aggregate; it is applied to identify the new concrete workability. This test was done in accordance with ASTM C143 [11] for each concrete mix.

Proportion of Mix

The mix of concrete was suggested to be 1:1.5:3 mix with (0.45) ratio of water to cement, and nine kinds of concrete mix were employed in the present work. The constant parameters for the whole mixes are the water/cementitious (0.45) and the gravel (1200 Kg/m3), the details and symbols of mixes are listed in Table (5).

Table (5): Symbols, content, and quantity of mixes

Mix symbol	Cement (Kg/m^3)	Sand (Kg/m^3)	Waste glass (Kg/m^3)
Control	400	600	0
GC5	380	600	20
GC10	360	600	40
GC15	340	600	60
GC20	320	600	80
GS5	400	570	30
GS10	400	540	60
GS15	400	510	90
GS20	400	480	120

Results and Discussion

1- Results of the compressive strength test

Compressive strength test was carried out beyond 7, 14 and 28 days of curing. The outcomes shown in the figure (3) were the average of three specimens, and for the mixes of concrete with the glass powder as a partial replacement of cement, the outcomes revealed that the compressive strength first increased with the content of glass till 10% and then decreased. The fine powder of glass enhances the concrete properties through the pozzolonic effect due to the presence of SiO2, so if water is mixed with the cement, the hydration will take place making two outputs; Calcium Silicate Hydroxide (CSH) gel and Calcium Hydroxide (CH), in the existence of silica. SiO2 will react with the (CH) to make more aggregate binding (CSH) gel which reduces the permeability and enhances the paste to aggregate bond in concrete in comparison with the traditional concrete [12]. The decrease in the compressive strength value is attributable to the possibility of agglomerate formation in concrete paste. However the behavor of glass is due to the high silica content of glass it is likely to under go a potentially detrimental alkali-silica reaction which causes the detrimental effect in concrete production. Being amorphous and containing relatively large quantities of silicon and calcium, glass is in theory pozzolanic or even cementitious in nature when it is finely ground [6].

Figure (4) elucidates the outcomes of the concrete compressive strength test with the glass coarse powder as a partial replacement of sand. These results exhibited a decrease in the strength values followed by an improvement when the glass content increased this change belonged to the compaction condition of concrete paste which effects the bonding and strength properties, also the coarse particles being normally harmful to concrete owing to the Alkali-Silica Reaction (ASR) [13]. The reduction in compressive strength can be also attributed to the following two reasons: first the poor paste-aggregate bond because of the smooth texture of glass aggregate piece, second the friability of waste glass and its relatively low resistance to aggregate fracture [14]

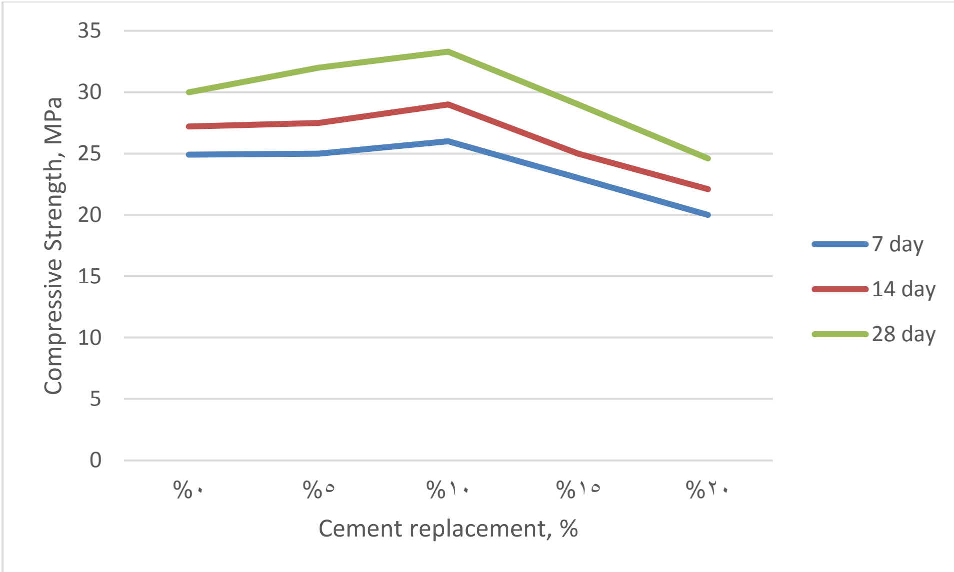

Figure (3): Results of the test of compressive strength for the mixes of concrete with the powder of glass as a partial replacement of cement

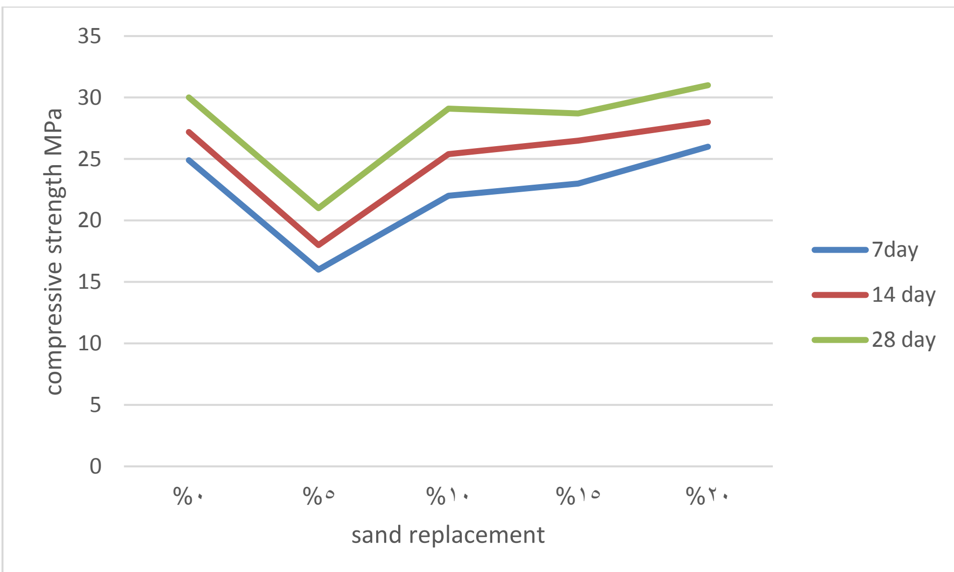

Figure (4): Results of the test of compressive strength for the mixes of concrete with the powder of glass as a fine aggregate partial replacement

Table (6) evinces the value of compressive strength for all concrete mixes. However, the maximum compressive strength recorded for the mixes of concrete with the fine powder of glass as cement partial replacement was 33.3 MPa at 10% glass content, while the maximum compressive strength recorded for the mixes of concrete with the coarse powder of glass as fine aggregate partial replacement was at 20% glass content.

Table (6): The results of compressive strength test.

Age of curing	Compressive Strength (MPa) for mixes with cement replacement					Compressive Strength (MPa) for mixes with fine aggregate replacement				
	0%	5%	10%	15%	20%	0%	5%	10%	15%	20%
7 days	24.9	25	26	23	20	24.9	16	22	23	26
14 days	27.2	27.5	29	25	22.1	27.2	18	25.4	26.5	28
28 days	30	32	33.3	29	24.6	30	21	29.1	28.7	31

2-Results of slump test

Workability is a concrete property which determines the ease in concrete blending and compaction. The workability results with respect to the slump for the mixes of concrete are displayed in the figure (3). It was noticed that the slump of concrete produced by utilizing the waste glass as a replacement of cement was raised with the level of replacement. Such rise was owing to the rising of the waste glass content with its hydrophobic in nature [Shivacharan S]. These mixes would possess more ingredients powdered form and therefore less resistance owing to their smoother surface, and that leads to the higher workability. For the concrete produced by utilizing the waste glass as fine aggregate replacement, the slump raised with the replacement, and such increment in the workability may be due to the waste glass non-water absorbent nature in comparison with the natural sand. Nevertheless, the increase in the slump value recorded a greater value for mixes with the cement replacement compared to the concrete mixes with the fine aggregate replacement which ascribed to the larger surface area of the powder of glass when employed as replacement for cement with smooth nature which led to less water absorption by the surface of glass. [2, 4 and 15] studies fully agreed with the result concluded in this study.

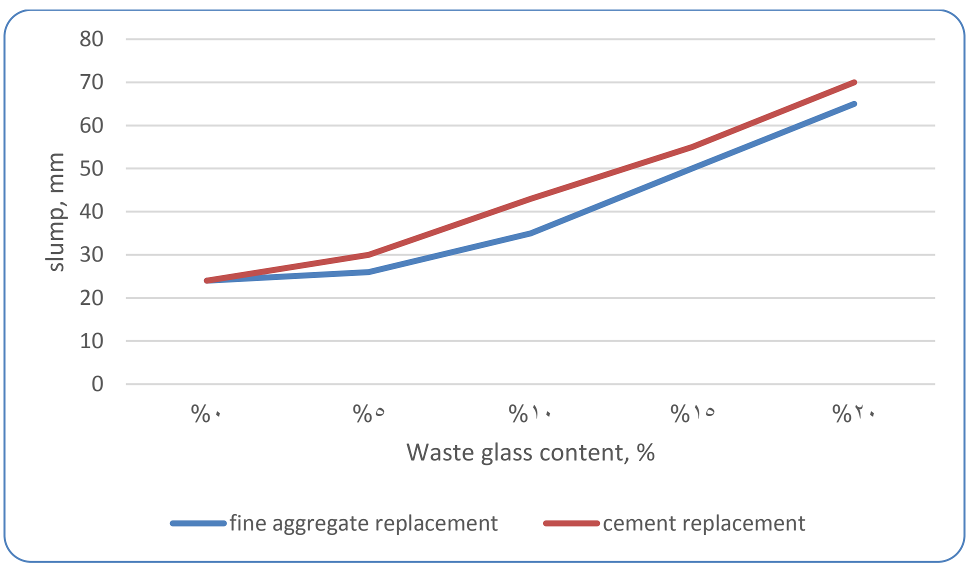

Figure (5): The results of slump test

Conclusions

The following conclusions are drawn from the acquired experimental results:

1- The results manifested that the glass powder mixed cement achieved a remarkable improvement in the compressive strength for concrete compared with the plain concrete.

2- The concrete workability develope with the glass replacement content either for cement or fine aggregate.

3- Fine glass powder as replacement of cement elucidated a greater effect on the concrete mixes compressive strength and slump compared to the coarse glass powder as a replacement of fine aggregate.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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إعادة تدوير مخلفات الزجاج في الخرسانة كبديل جزئي للأسمنت أو الركام الناعم

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الخلاصة

في هذا البحث، تم استخدام خليط الزجاج المعاد تدويره، والذي يحتوي على نسبة عالية من SiO_2 (ثاني أكسيد السيليكون) ، لإنتاج الخرسانة الخضراء ذات الخصائص الرائعة. تم استخدام مخلفات الزجاج كإسمنت أو استبدال جزئي للركام الناعم بمحتوى مختلف (5٪ ، 10٪ ، 15٪ و 20٪) من وزن الأسمنت أو الركام الناعم. تم قياس مقاومة الانضغاط لثلاثة اعمار (7 ، 14 ، 28) يوما والهطول لكل خلطة خرسانية. أوضحت النتائج أن مقاومة الانضغاط المسجلة تزداد مع محتوى الزجاج بنسبة تصل إلى 10٪ ثم تنخفض عند استخدام الزجاج كبديل للأسمنت، بينما عند استخدام الزجاج كبديل للركام الناعم، تنخفض مقاومة الانضغاط في البداية ثم تزداد مع محتوى الزجاج. أظهرت نتائج اختبار الهطول أن قابلية تشغيل الخرسانة تزداد مع زيادة محتوى الزجاج سواء كان مسحوق الزجاج المستخدم كبديل للإسمنت أو بديل للركام الناعم.

الكلمات الدالة: الخرسانة الخضراء، الأسمنت المخلوط، مخلفات الزجاج، مواد معادة التدوير، استبدال الركام الناعم.