Effect of Using Windows Waste Glass as Coarse Aggregate on some Properties of Concrete

Dr. Abdelmaseeh Bakos Keryou
Technical College, Foundation of Technical Education/Mosul
Email: fabdelmaseeh@yahoo.com
Gailan Jibrael Ibrahim
Technical College, Foundation of Technical Education/Mosul

Received on: 1/7/2013 & Accepted on:6/3/2014

ABSTRACT

In this experimental study, local waste glass (WG) gathered from Turkey-made windows glass has been used as a partial replacement of coarse aggregates with 0, 20, 25, and 30% percentages of replacement by weight. Some mechanical and other properties of the concrete, produced this way have been studied at both fresh and hardened stages.

The experimental results obtained from testing the specimens prepared from concrete mixes with water/cement ratio equal to 0.5, showed that using WG resulted in decreasing the slump and fresh density due to angular grain shape, whereas the compressive, splitting, and flexural strengths noticeably enhanced. Tests revealed that with increasing the WG percentage the strengths gradually increase up to a given limit beyond which they decrease. The maximum effect was reached at 25% percentage of replacement. At this percentage the increases in the compressive, splitting tensile and flexural strengths at 28-day age were 30, 38 and 31 %, respectively. The results of this study indicate a considerable economical effect from using the optimum percentage of WG (25%) as partial replacement of coarse aggregate.

Keywords: Concrete, Recycled materials, Waste glass, Coarse aggregate, Slump, Compressive strength, Tensile strength, Flexural strength.

تأثير استخدام النفايات الزجاجية للنوافذ كركام خشن على بعض خواص الخرسانة

الخلاصة:

في هذه الدراسة التجريبية، استخدمت مخلفات الزجاج المحلي التي تم جمعها من زجاج النوافذ تركي المنشأ كبديل جزئي للركام الخشن وبنسب استبدال وزنية 0، 20، 25، و30% . تم دراسةبعض الخواص الميكانيكية وخواص اخرى للخرسانة المحضرة بهذه الطريقة في كلتا المرحلتين الطرية والمتصلبة.

أظهرت النتائج التجريبية المستحصلة من فحص النماذج المحضرة من خلطات خرسانية نسبة الماء الى الاسمنتفيها مساوية الى 0.5أظهرتان استخدام مخلفات الزجاج أدى الى نقصان الهبوط والكثافة الطرية بسبب شكل الحبيبات الزاوي بينما تحسنتبشكل ملحوظ مقاومة الانضغاط والانفلاق

غير المباشر (الشد) والانحناء. أظهرتالفحوصات انه بزيادة نسبة مخلفات الزجاج تزداد المقاومات باضطراد الى حد معين ثم تبدأ بالنقصان. كان التأثير الاعظم عند نسبة استبدال 25%. عند هذه النسبة بلغت الزيادات في مقاومة الانضغاط ووالانفلاق غير المباشروالانحناء بعمر 28 يوما 30 و38 و31% على التوالي. تشيرنتائج هذه الدراسة إلىمردوداقتصاديكبيرمن استخدام النسبة المثالية من مخلفات الزجاج (25%) كبديل جزئي عن الركام الخشن.

INTRODUCTION

The total annual domestic glass product and usage is growing up more and more. This rise in production and use of the glass in recent years is due to the increase in industrialization and the rapid improvement in the standard of living. Because of this process, the accumulating amounts of waste glass, including sheet or window glass, is a challenging problem, which requires effective and rational solutions. Therefore, from the economical and environmental points of view, the use of recycled waste glass in production of new concrete is acquiring an increasing interest in the recent years.

Several decades ago, attempts had been made to use waste glass in concrete [1,2]. However, the use of the glass did not have been widely used in concrete mixes until recently. The limited use was due to the well-known problem of Alkali-Silica Reaction (ASR), caused by the reaction between hydroxyl ions within the concrete and the silica that is contained in glass material.

Many researchers studied the use of waste glass in normal concrete [3-8]. Among the advantages of using crushed glass as aggregate in concrete is that water absorption of glass is nearly zero. This makes it very durable material. Moreover, glass has excellent hardness, and this gives the concrete high abrasion resistance.

Several researchers have investigated the use of waste glass as substitute for coarse aggregate. Shayan [8] used waste container glass in the form of coarse and fine particles as replacement for the corresponding size ranges of natural aggregate materials. He concluded that there is a great potential for the utilization of waste glass in concrete in several forms, including coarse aggregate

Liang et al. [9] used colored glass as coarse and fine aggregates in order to achieve a high performance and aesthetic level of concrete. They proved that high compressive strength concrete with the value above 40MPa can be obtained by using colored glass as aggregates beside other materials as partial replacement of cement.

To pçu and Can baz[10]found that using waste glass (gathered from colored soda bottles) as partial replacement for coarse aggregate (with proportion up to 60%) did not have a significant effect upon the workability of the concrete and only slight reduction was reported in its strength.

Verdugo [11] studied the practicality, versatility and feasibility of utilizing recycled glass as a concrete aggregate in the form of: fine aggregates, coarse aggregates and fine glass powders. He considered the results promising as strength tests showed that the concrete mixes in question have moderate to high strengths, and hence that the concrete derived from recycled glass could be effectively applied to a multitude of services including structural applications.

Abdullah A. Siam [12] investigated the possibility to improve the compressive strength of concrete over a range of glass percentages as replacement for fine and coarse aggregates. He found that the optimum value of coarse waste glass to be used within the concrete mix with a water-cement ratio of 0.4 was determined as about 0.265.

In this experimental study, the effect of using locally available waste windows glass as partial replacement of coarse aggregate on the mechanical properties of concrete was investigated. The specimens of concrete were tested for compressive strength, splitting tensile strength, modulus of rupture and slump at two ages (7 and 28 days) with various glass to coarse aggregate proportions (0, 20, 25, 30%) by weight.

Experimental program

The experimental program was conducted on concrete specimens. The fresh concrete specimens were tested for slump and density. Moreover, a total number of 54 hardened concrete specimens were prepared and tested including 18 (150 mm) cubes for compression, 18 (100x200 mm) cylinders for splitting tension, and 18 (100x100x400 mm) prisms for flexure.

Materials

The cement used in this study was ordinary Portland cement conforming to IQS/5/1984[13] and manufactured at Badosh cement plant. The cement was tested at Badosh cement Factory Labs. The chemical and physical properties are shown in Tables (1) and (2), respectively. Natural sand was used as fine aggregate. It was from kanhash region with grading conforming to(IQS 45:1984) [14] from medium gradient as shown in Table (3). The coarse aggregate used was natural gravel with suitable grading according to (IQS 45:1984) [14] as shown in Table (4).

The source of glass aggregate used in this research was the waste of windows Turkey-made glass, collected from local windows glass venders. The thickness of the glass was 4mm. After collecting it, the WG was cleaned, crushed and sieved in order to obtain a grading similar to that of natural coarse aggregate. The summary of sieve analysis data for WG is given in Table (5). The particles shape of crushed WG was angular as it seems from Figure (1). The physical properties of fine aggregate, coarse aggregate, and the crushed WG are shown in Table (6).Tap water was used for mixing and curing of concrete.

Table (1): Chemical properties of cement

Component	Value	Specification limit according to IQS/5/1984
SiO_2 (%)	21.38	
Insoluble residue (%)	0.27	Max 1.5 %
Al_2O_3 (%)	5.9	-
Fe_2O_3 (%)	2.4	-
CaO (%)	62.31	-
MgO (%)	3.77	Max 5 %
SO_3 (%)	2.3	Max 2.8 %
Loss of ignition (%)	1.22	Max 4 %
Total	99.28	

Table (2): physical properties of cement

Property	Value	Specification limit according to IQS/5/1984
Fineness by Blaine (cm^2/g)	2738	Min 2300 (cm^2/g)
Initial setting time(minute)	160	Min 45 (minute)
Final setting time(hr : min)	3.67	Max 10 (hr)
Soundness(%)	0.14	0.8 (%)
Compressive strength (mortars) 3-day(MPa)	24.68	Min 15 (MPa)
Compressive strength (mortars) 7-day(MPa)	33.32	Min 23 (MPa)

Table (3): Sieve analysis of fine aggregates

Sieve size (mm)	Percentage of passing (%)	Specification limit according to (IQS 45:1984) (%) [6]
		Medium
5	100	100
2.36	67	65-100
1.18	58	45-100
0.6	49	25-80
0.3	12	5-48
0.15	1	0-15
Fineness modulus	3.1	

Table (4): Sieve analysis of coarse aggregates

Sieve size (mm)	Percentage of passing (%)	Specification limit according to (IQS 45:1984) (%) [6]
20	100	100
14	100	100
10	90	85-100
5	24	0-25
2.36	1	0-5

Table (5):Summary of sieve analysis data for coarse waste glass

Sieve Size (mm)	% Passing
20	100
14	97
10	93
5	70
2.36	33
1.18	14
0.6	4
0.3	2
0.15	1
0.075	0

Figure (1): Particle shape of coarse WG after sieve analysis

Table (6): Physical properties of the aggregates

Type of aggregate	Specific Gravity	Bulk Density(kg/m³)	Absorption (%)
Fine aggregate	2.6	1743	2.07
coarse aggregate	2.67	1687	1
WG	2.5	1564	0.17

MIX DESIGN

Throughout the experimental program of this research, the ACI method [15] was adopted as reference for mix design of glass-free concrete or control mix. The proportions of control mix by weight were (1 : 1.96 : 2.73 : 0.5) (cement: sand : gravel : W/C). Table (7) shows the concrete mixes tested in this research.

Table (7): Ingredient content of concrete mixes (kg/m^3).

Description	Cement	Fine aggregate	Coarse aggregate	Coarse waste glass	Water
Control mix	367	719	1002	0	185
20 %	367	719	802	200	185
25%	367	719	751	251	185
30%	367	719	701	301	185

TESTING PROCEDURES

The slump and fresh density tests were conducted according to BS EN 12350 -2:2000 [16] and BS EN12350-6:2000 [17], respectively.

The compressive strength tests were conducted according to BS EN 12390-3:2002 [18] and BS EN 12390-1:2000 [19], at 7 and 28 days.The (150mm) concrete cubes were maintained in water at temperature 23±2ºC up to the required age.

The tensile splitting strength test was conducted according to BS EN 12390-6:2000 [20] and BS EN 12390-1:2000 [19], at 7 and 28 days. The (200x100) mm concrete cylinders were cured by placing them in water at temperature 23±2ºC up to the required age.

The flexural strength test was conducted, in according with BS EN 12390-5:2000 [21] and BS EN 12390-1:2000 [19], at 7 and 28 days. The (100×100×400) mm concrete prisms were cured the same way as for the compressive and tensile splitting tests.

RESULTS AND DISCUSSIONS

Table (8) and Figure(2) show the results of slump tests. It is obvious that the slump decreased with the increase of waste glass percentage. This may be attributed to the fact that as the WG percentage increases, additional cement paste attaches to the surface of the waste glass, which results in less available cement paste necessary for the fluidity of the concrete. Moreover, the WG aggregate has sharper and more angular grain shapes compared to the rounded shapes of gravel, which results in less fluidity.

Table (8): results of slump test with various WG contents.

Type	Ratio of WG by weight (%)	Slump (mm)
CM	……	120
CAR	20	110
CAR	25	102
CAR	30	92

CM: Control Mix, CAR: Coarse Aggregate Replacement

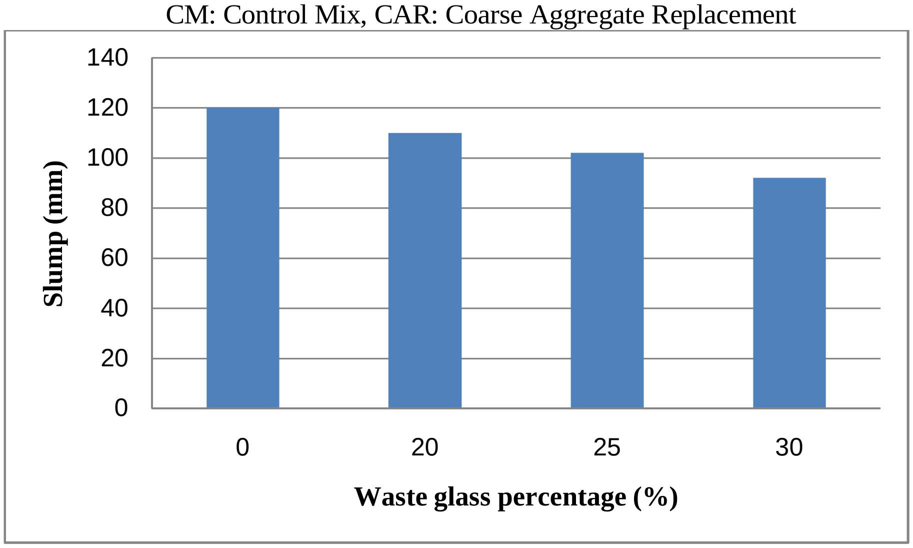

Figure (2): Relationship between slump and WG content.

Table (9) and Figure(3) show the values of fresh density (unit weight) versus WG percentages. It is clear that, as expected, the density of concrete with WG decreases with increasing percentages of WG due to the difference between density of WG and natural coarse aggregate. However, the decrease in density is not significant within the WG percentages used.

Table (9): density of fresh concrete with various ratios of waste glass

Type	Ratio of glass by weight(%)	Density (Kg/m^3)	Percent of reduction (%)
CM	……	2400	-
CAR	20	2388	0.5
CAR	25	2380	0.8
CAR	30	2372	1.2

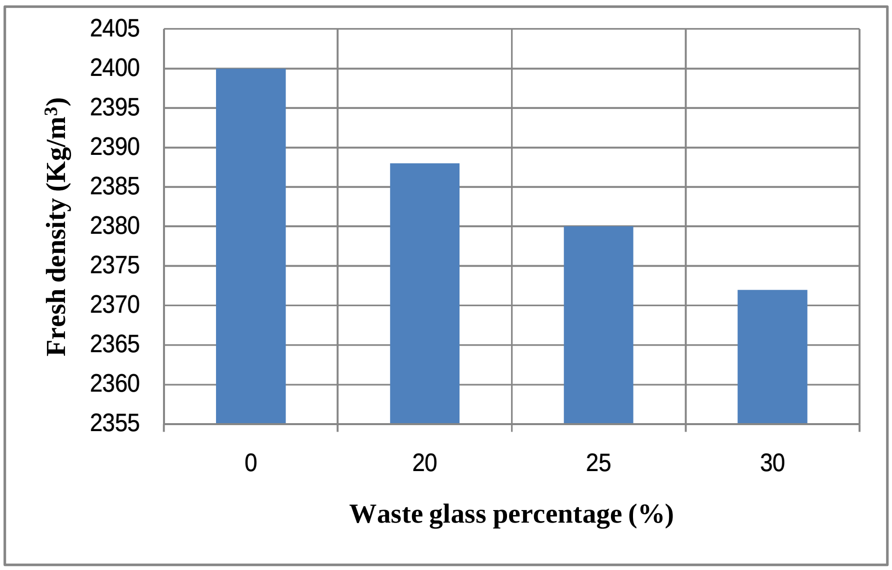

Figure (3): Relationship between fresh density and WG content

Table (10) and Figure (4) show the results of compressive strength of concrete mixes with different WG percentages at 7 and 28 days ages. It seems, from the figure, that using WG in concrete improved the compressive strength of the concrete at both ages (7 and 28 days). The maximum effect was reported at WG/coarse aggregate percentage of 25%, where the increases in compressive strength at 7 and 28 days reached 20.5% and 30%, respectively. This can be explained, again, by the fact that the particle shape of the crushed WG aggregates was more edged and angular compared to the rounded shape of the natural coarse aggregates, resulting in best interlocking effect and higher friction forces inside the concrete mix. The drop in compressive strength beyond 25% percentage of replacement may be explained by the fact that with increasing the WG content the compressive strength of concrete will decrease due to the smooth surface and the friability of the WG particles compared to those of natural coarse aggregate.

Table (10): results of compressive strength of concrete containing WG.

Type	Ratio of glass by weight (%)	Compressive strength at 7-day (MPa)	Compressive strength at 28-day (MPa)
NC	……	27.2	30.3
CAR	20	30.0	35.5
CAR	25	32.8	39.4
CAR	30	26.5	34.4

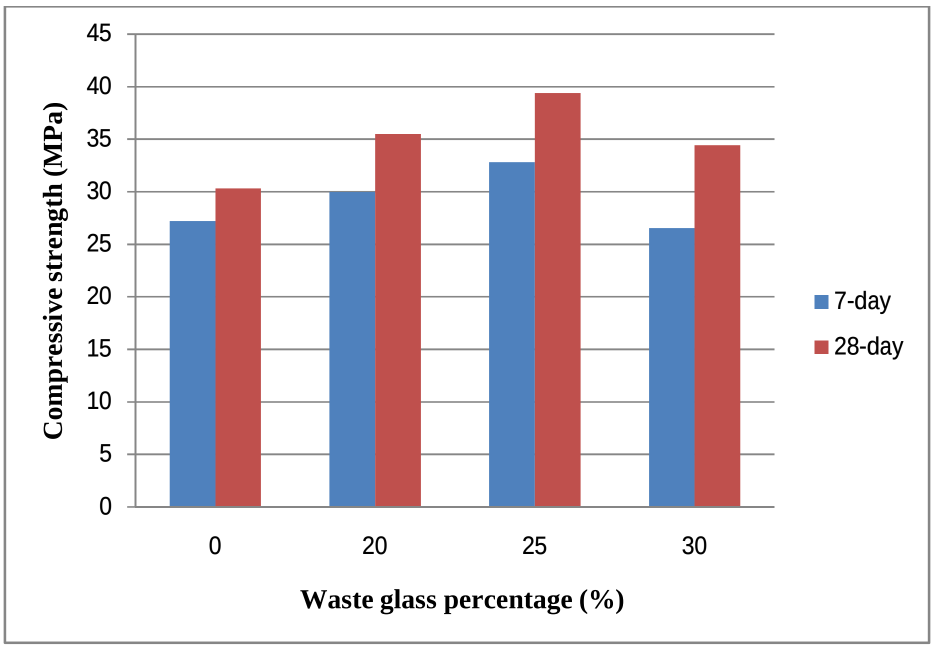

Figure (4): Relationship between compressive strength and WG content.

The results of splitting tensile strength tests are shown in Table (11) and Figure (5). It is clear that the use of WG increased the values of tensile strength compared to control mix. The maximum effect was at percentage of 25%. The increases in compressive strength at 7 and 28 days were 81% and 38%, respectively.Again, the reason behind this increase is the edged and angular shape of the crushed WG aggregates which enhances the interlocking effect and yields higher friction forces inside the concrete mix. Also, the drop in compressive strength beyond 25% percentage of replacement may be explained the same way as was done for the compressive strength.

Table (11): results of splitting tensile strength of concrete containing WG.

Type	Ratio (%)	Splitting tensile strength at 7-days(MPa)	Splitting tensile strength at 28-days (MPa)
NC	……	2	3.2
CAR	20	3.2	3.6
CAR	25	3.6	4.5
CAR	30	2.9	3.5

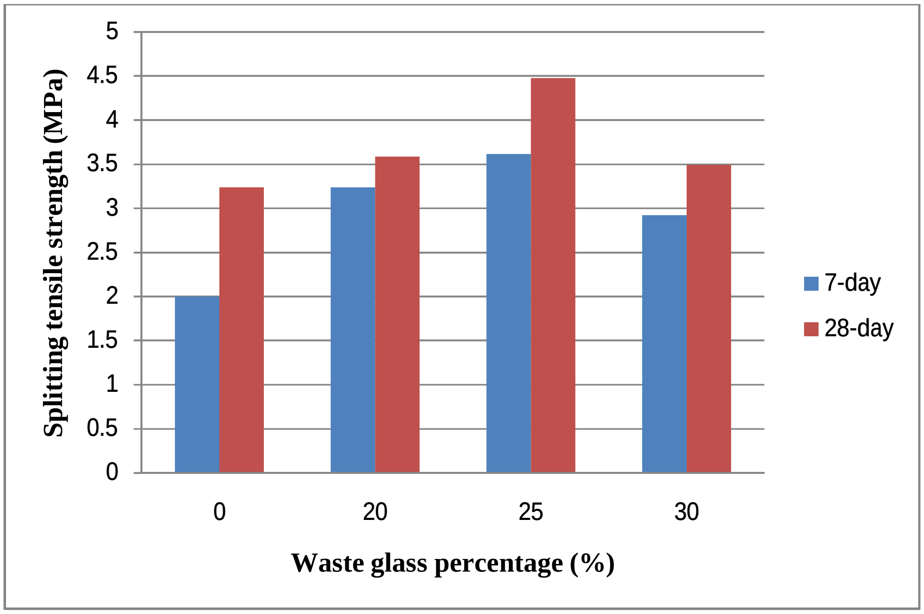

Figure (5): Relationship between splitting tensile strength and WG content

The results of flexural strength tests with several WG contents at 7 and 28 days ages are presented in Table (12) and Figure (6). The effect of using WG on flexural strength is similar to that on the splitting tensile strength. The 25% WG content resultedin maximum enhancement in flexural strength. With this content, the increases in flexural strength at 7 and 28 days were 44% and 31%, respectively. Here again, the same discussion and reasoning for explaining the increase and then the decrease in compressive and splitting tensile strength may be driven.

Table (12): results of flexural strength of concrete containing WG.

Type	Ratio of glass by weight (%)	Flexural strength at 7-day (MPa)	Flexural strength at 28-day(MPa)
NC	……	5.0	6.2
CAR	20	5.9	6.7
CAR	25	7.2	8.1
CAR	30	5.5	6.6

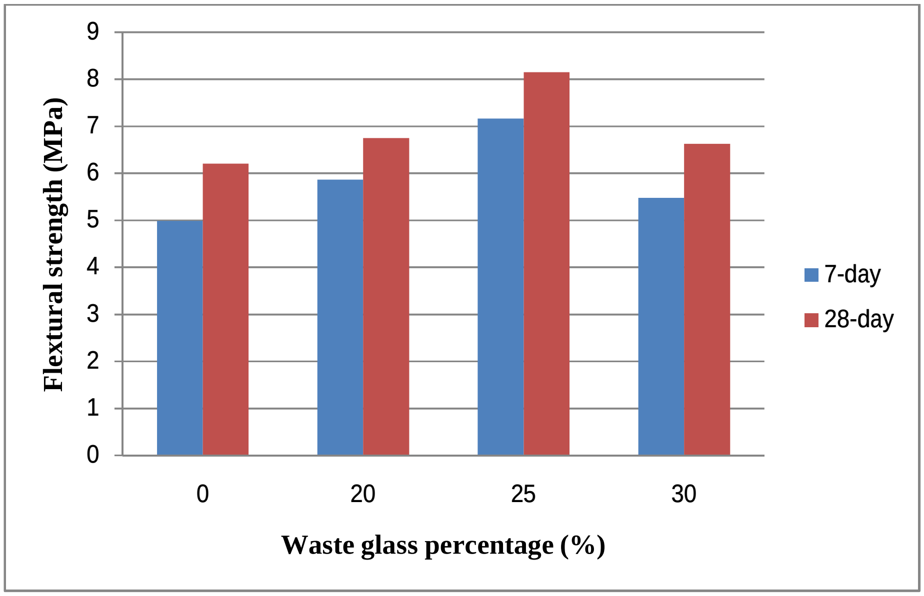

Figure (6): Relationship between flexural strength and WG content.

CONCLUSIONS AND RECOMMENDATIONS

Windows waste glass was used as a partial replacement of coarse aggregate. The following observations and conclusions can be drawn based on the experimental results reported in this study:

1. The slump of WG concrete decreased with increasing the waste glass content due to the edged and angular grain shapes of the coarse waste glass aggregates.
2. The fresh density of WG concrete decreased with increasing the WG percentagesdue to the difference between the density of WG and that of natural coarse aggregate.
3. The best effect on the mechanical properties was observed at 25% WG percentage. The increases in compressive, splitting tensile and flexural strengths at 28-day age were 30, 38 and 31 %, respectively.
4. The results obtained from this study permit to formulate a general conclusion that using recycled WG as a partial replacement gives a dual economical effect. It enhances the mechanical properties of the concrete and at the same time helps to get rid of the accumulated quantities of waste recycled glass.

As future related researches, we recommend conducting further studies to reveal the effect of using the recycled WG as a partial replacement of fine aggregate or as glass powder to partially replace cement and finally, as partial replacement of cement, coarse and fine aggregates together.

REFERENCES

[1]C.D. Johnston, "Waste Glass as Coarse Aggregate for Concrete". Journal of Testing and Evaluation 1974. Volume 2, No. 5: pp. 344-350.

[2]Schmidt, A., and Saia, W.H.F.,"Alkali-Aggregate Reaction Tests on Glass Used for Exposed Aggregate Wall Panel Work", ACI, Mat.J.,Vol.60, 1963, PP.1235-1236.

[3]Zhu H, Byars E. Potential for use of waste glass in concrete. Concr (London) 2005;39(Compendex):41–5.

[4]Shayan A, Xu A. Performance of glass powder as a pozzolanic material in concrete: a field trial on concrete slabs. Cem Concr Res 2006;36(Compendex): 457–68.

[5]Dhir RK, Dyer TD, Tang MC. Alkali-silica reaction of concrete containing glass – Interaction with reactive aggregates. In: 2005 international congress – global construction: ultimate concrete opportunities, July 5, 2005–July 7, 2005, Dundee, Scotland, United Kingdom: Thomas Telford Services Ltd; 2005.

[6]Meyer C. Recycled glass – from waste material to valuable resource. In: Recycling and reuse of glass cullet, Scotland, UK; 2001.

[7]Topçu I, Canbaz M. Properties of concrete containing waste glass. Cement and Concrete Research, Vol.34, pp. 267-274, July, 2004

[8]Shayan A. Value-added utilisation of waste glass in concrete. IABSE Symposium in Melbourne 2002.

[9]Liang H, Zhu H, Byars E. Use of waste glass as aggregate in concrete. 7th UK CARE Annual General Meeting. UK Chinese Association of Resources and Environment, Greenwich, 15 Sept. 2007.

[10]Topçu I, Canbaz M. Properties of concrete containing waste glass. Cement and Concrete Research, Vol.34, pp. 267-274, July, 2004.

[11]Verdugo C. D. The practicality, versatility and feasibility of utilizing recycled glass as a concrete aggregate. University of Florida.

[12]Abdullah A. S. Properties of Concrete Mixes with Waste Glass. M. Sc. Thesis, The Islamic University of Gaza, 2007.

[13]Iraqi standard specification,(1984), " Portland cement",No.5.

[14]Iraqi standard specifications (45 : 1984),"Aggregates from Natural Source for Concrete",1984.

[15]ACI Committee 211, 1991, Standard practice for selecting proportions for normal, heavyweight and mass concrete. American Concrete Institute, USA.

[16]BS EN 12350-2:2000, testing fresh concrete "Slump test", British Standard Institution.

[17]BS EN 12350-6:2000, testing fresh concrete "density", British Standard Institution.

[18]BS EN 12390-3:2002, testing hardened concrete "Compressive strength of test specimens, British Standard Institution.

[19]BS EN 12390-1:2000, "Shape, dimensions and other requirements for specimens and moulds", British Standard Institution.

[20]BS EN 12390-6:2000, testing hardened concrete "Tensile splitting strength of test specimens", British Standard Institution.

[21]BS EN 12390-5:2000, testing hardened concrete "Flexural strength of test specimens", British Standard Institution.