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Effect of Using Windows Waste Glass as Fine Aggregate on Some Properties of Concrete

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Abstract

The main goal of this study is to investigate the effect of using waste glass (WG) on some mechanical properties of concrete at both fresh and hardened stages. In our study, we used local windows waste glass (WG) as partial replacement of fine aggregates with 0, 20, 25, and 30% percentages (by weight).

The experimental results obtained from testing specimens prepared from concrete mixes with water/cement ratio equal to 0.5, showed that the optimum percentage of fine waste glass to be used within the concrete mix was 20%. At this percentage of replacement the compressive strength obtained at 28-days age was 39 MPa compared with 30.32 MPa for reference concrete mix.

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

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تأثير استخدام النفايات الزجاجية للنوافذ كركام ناعم على بعض خواص الخرسانة

الخلاصة

ان الهدف الرئيس من هذا البحث هو دراسة تأثير استخدام مخلفات الزجاج على بعض الخواص الميكانيكية للخرسانة في كلتا حالتيها الطرية والصلبة. في هذه الدراسة تم استخدام مخلفات زجاج النوافذ المتوفرة محليا كبديل جزئي عن الركام الناعم في الخرسانة وبنسب استبدال (وزنية) 0 و 20 و 25 و 30 %.

أظهرت نتائج فحوصات النماذج المحضرة من خلطات خرسانية مع نسبة ماء/سمنت مساوية الى 0.5 ان نسبة الاستبدال المثلى هي 20 %. عند نسبة الاستبدال هذه بلغت مقاومة الانضغاط بعمر 28 يوم 39 ميكاباسكال مقارنة 30.32 ميكاباسكال للخرسانة الضابطة.

الكلمات الدالة : خرسانة، المواد المدوّرة، مخلفات الزجاج، الركام الناعم، الهطول، مقاومة الانضغاط، مقاومة الشد، مقاومة الانحناء.

Introduction

The growing environmental concern all over the world is one of the driving forces promoting the use of recycled materials such as building demolition waste in new concrete. The recycling of construction waste, including windows glass, is one of the important steps towards sustainable construction practices.

The first attempts to use waste glass as aggregates in concrete date back to several decades ago[1]. However, the early studies on this prospect revealed some problems that limited the use of glass in concrete mixes. Among these limitations stand 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.

Recently, the use of waste glass as aggregate in concrete has acquired a growing interest. This interest has been promoted by the increasingly need for getting rid of the large amount of waste glass accumulated from solid disposal waste stream.

Many researchers studied the possibility of using waste glass in normal concrete[2-6]. One of the advantages of using crushed glass as aggregate in concrete is that water absorption of glass is nearly zero which makes it very durable material. Moreover, glass has excellent hardness, and this gives the concrete high abrasion resistance. However, increasing the WG percentage in concrete also negatively affects other properties of the concrete, such as compressive strength, flexural strength, indirect tensile strength, and Schmidt hardness value[5].

Several researchers[7-10] have investigated the use of waste glass as substitute for fine aggregate.

Park et al.[7], showed that the mechanical properties of concrete like compressive, tensile and flexural strengths, as well as workability have decreased with increasing the glass content.

Liang et al.[8], 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 40 MPa can be obtained by using colored glass as aggregates beside other materials as partial replacement of cement.

Perkins[9], used processed glass as 100% replacement of fine aggregate and glass powder as partial replacement of binder with several proportions. He concluded that crushed glass is a suitable material for use as 100% replacement for fine aggregate and glass powder exhibits pozzolanic properties but is dependent upon fineness of the powder and finally that concrete containing glass as fine aggregate can achieve comparable strengths to that of natural sand aggregates.

Haider et al., in their study[10], showed that increasing the fractions of sand, replaced by waste glass, leads to reduce the compressive and tensile strength for both mortar and concrete.

In this experimental study, the effect of using locally available waste windows glass as partial replacement of fine 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 sand proportions (0, 20, 25, 30%) by weight.

Experimental Program

The slump and fresh density were measured for each concrete mix. Moreover, a total number of 54 hardened concrete specimens were prepared and tested including 18 cubes for compression, 18 cylinders for splitting tension, and 18 prisms for flexure.

Materials

The cement used in this study was ordinary Portland cement conforming to IQS/5/1984[11], and manufactured at Badosh cement plant. The cement was tested at Badosh cement factory labs and the chemical and physical properties are shown in Tables (1) and (2) respectively. As fine aggregate we used natural sand from Kanhash region with grading conforming to BS 882:1992[12], from medium gradient as shown in Table (3). The coarse aggregate used was natural gravel with grading according to BS 882:1992 as shown in Table (4).

The source of glass aggregate used in our research is the waste of windows Turkish-made glass, collected from local windows glass venders. After collecting it, the WG was cleaned, ground and sieved in order to obtain a grading similar to that of natural sand. 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 water used in present study was tap water.

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	N. A.*
Fe_2O_3 (%)	2.4	N. A.
CaO(%)	62.31	N. A.
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 Blain	2738	Min 2300 (cm^2/g)
Initial setting time	160	Min 45 (minute)
Final setting time	3.67	Max 10 (hr)
Stability	0.14	0.8 (%)
Compressive strength (mortars) 3-days	24.68	Min 15 (MPa)
Compressive strength (mortars) 7-days	33.32	Min 23 (MPa)

Table 3. Sieve analysis of fine aggregates

Sieve size (mm)	Percentage of passing (%)	Specification limit according to (B.S882:1992) (%) [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	
Bulk density (kg/m^3)	1743	

Table 4. Sieve analysis of coarse aggregates

Sieve size (mm)	Percentage of passing (%)	Specification limit according to (B.S 882:1992) (%)
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 fine waste glass

Sieve Size (mm)	% Passing
20	100
14	100
10	100
5	99
2.36	83
1.18	51
0.6	31
0.3	14
0.15	5
0.075	1
Bulk density(kg/m^3)	1564

Fig.1. Particle shape of fine WG after sieve analysis

Mix Design

Throughout the experimental program of this research, the ACI method[13], was adopted as reference for mix design of glass-free concrete or control mix. The proportions of control mix were (1 : 1.956 : 2.73 : 0.5) (cement: sand : gravel : W/C). Table (6) shows the concrete mixes tested in this research.

Table 6. Mix proportions of concrete waste glass (kg/m^3)

Description	Cement	Fine aggregate	Fine waste glass	Coarse aggregate	Water
Control mix	367	718	0	1002	185
20 %	367	574.4	143.6	1002	185
25%	367	538.5	179.5	1002	185
30%	367	502.6	215.4	1002	185

Testing Procedures

The slump and fresh density tests were conducted according to BS EN 12350-2:2000[14] and BS EN 12350-6:2000[15], respectively.

The compressive strength tests were conducted at 7 and 28 days according to BS EN 12390-3:2002[16] and BS EN 12390-1:2000[17]. The (150×150×150) mm concrete cubes were maintained in water at temperature 23±2ºC.

The tensile splitting strength tests were conducted at 7 and 28 days ages according to BS EN 12390-6:2000[18] and BS EN 12390-1:2000[17]. The (200x100) mm concrete cylinders were cured by placing them in water at temperature 23±2ºC.

The flexural strength tests were conducted at 7 and 28 days according to BS EN 12390-5:2000[19] and BS EN 12390-1:2000[17]. The (100×100×400) mm concrete prisms were cured the same way as for the compressive and tensile splitting tests.

Results and Discussion

Table (7) 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 both edged and angular grain shapes of the fine waste glass aggregates, hence increasing the friction forces inside the concrete mix during mixing or handling.

Table 7. Results of slump test with various WG contents

Type	Ratio (%)	Slump (mm)
CM	……	120
SR	20	105
SR	25	96
SR	30	85

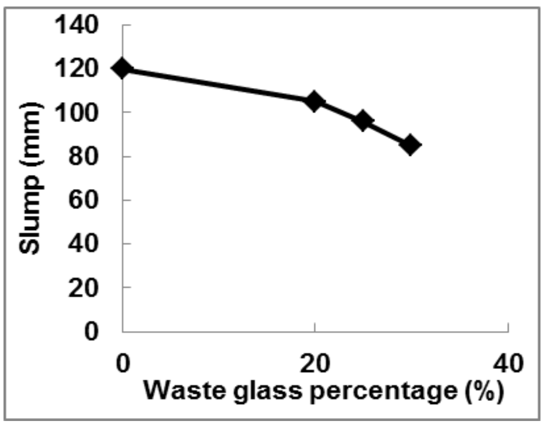

Fig. 2. Relationship between slump and WG content

Table (8) 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 fine aggregate. However, the decrease in density is not significant within the WG percentages used.

Table 8. Results of density test with various WG contents

Type	WG content (%)	Density kg/m^3
CM	……	2400
SR	20	2380
SR	25	2373
SR	30	2360

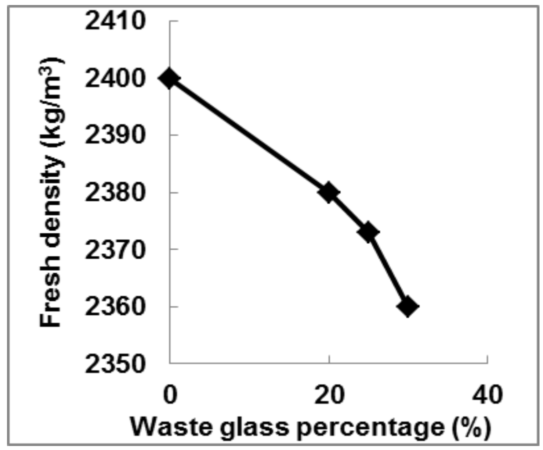

Fig. 3. Relationship between fresh density and WG content

Table (9) 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 increased the compressive strength of the concrete at both ages (7 and 28 days). The maximum effect was reported at WG/sand percentage of 20%, where the increases in compressive strength at 7 and 28 days reached 32.8% and 28.5%, 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 sand, resulting in best interlocking effect and higher friction forces inside the concrete mix.

Table 9. Results of compressive strength of concrete containing WG

Type	Ratio (%)	Compressive strength at 7-days (MPa)	Compressive strength at 28-days (MPa)
CM	……	27.223	30.322
SR	20	36.136	38.959
SR	25	30.651	33.638
SR	30	27.570	31.935

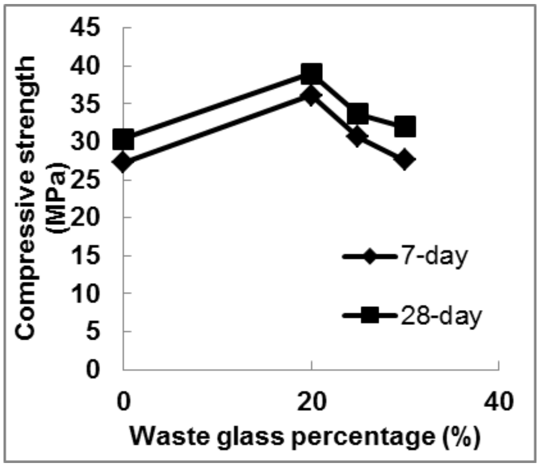

Fig. 4. Relationship between compressive strength and WG content

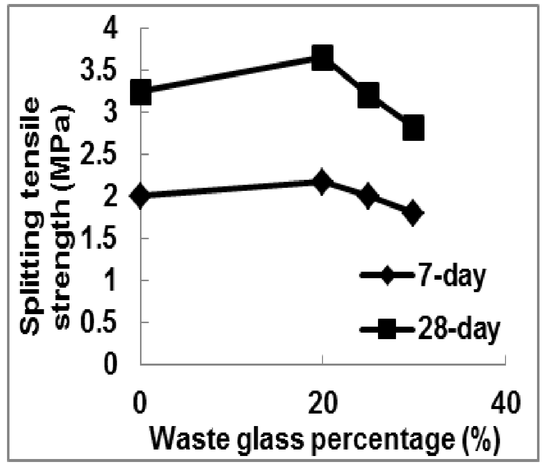

Fig. 5. Relationship between splitting tensile strength and WG content

The results of splitting tensile strength tests are shown in Table (10), Figure (5). It is clear that the use of WG increased the values of tensile strength compared to control mix at percentage of 20%. The increases in compressive strength at 7 and 28 days were 8.4% and 12.7%, respectively. However, at 25% percentage no significant change was reported. At higher content of WG (30%) the splitting tensile strength at 7 and 28 days ages dropped by about 10% and 13% respectively, compared to reference glass-free mix.

Table 10. 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)
CM	……	2	3.240
SR	20	2.168	3.652
SR	25	2.003	3.209
SR	30	1.802	2.822

The results of flexural strength tests with several WG contents at 7 and 28 days ages are presented in Table (11) and Figure (6). The effect of using WG on flexural strength is similar, but more significant, compared to that on the splitting tensile strength. The 20% WG content leaded to maximum enhancement in flexural strength. With this content, the increases in flexural strength at 7 and 28 days were 23.6% and 21.7%, respectively. No significant change in flexural strength was noticed at 25% percentage. For mixes with WG content of (30%) the flexural strength at 28 days age dropped by about 10.8%, whilst the drop was not significant at 7 days age.

Table 11. Results of flexural strength of concrete containing WG

Type	Ratio (%)	Flexural strength at 7-days (MPa)	Flexural strength at 28-days (MPa)
CM	……	4.984	6.206
SR	20	6.158	7.554
SR	25	5.199	6.537
SR	30	4.829	5.534

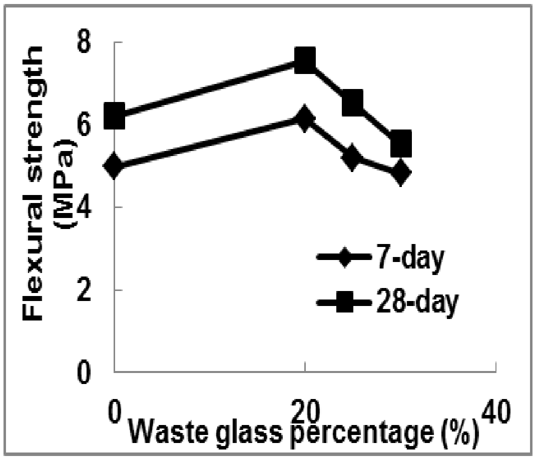

Fig. 6. Relationship between flexural strength and WG content

Conclusions and Recommendations

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

1- The slump of waste glass concrete decreased with increasing the waste glass content due to the edged and angular grain shapes of the fine waste glass aggregates.

2- The fresh density of waste glass concrete decreased with increasing the waste glass percentages due to the difference between density of WG and natural fine aggregate.

3- The best effect on the mechanical properties was observed at 20% WG percentage. The increases in compressive, splitting tensile and flexural strengths at 28-day age were 28.5, 12.7 and 21.7%, respectively.

4- It is not clear enough what would be the effect of using waste glass percentages less than 20% on the properties of the concrete. Therefore, extended study may be recommended to reveal the effect of using WG as replacement of fine aggregate with percentages of replacement say 5, 10, and 15%.

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