Effect of Particle Size of Waste Glass on Compressive Strength and Modulus of Rupture of Concrete Mix

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Abstract

Glass is an inert material which could be used and recycled many times. Several tons of waste glass (WG) are generated annually worldwide due to the rapid growth of the population and improvement in the standard of living. In this study, the WG was used and supplied with three different particle sizes; 600µm, 2.36 mm and 4.75mm and partially weight replaced of fine aggregate at ratios 10%, 20% and 30%. The effectiveness of that changes on compressive strength and modulus of rupture at ages 28 and 90 days for concrete specimens produced were studied. The results showed that compressive and modulus of rupture at all ages increased along with addition of WG as glass powder (GP). Moreover, the specimens containing 30% of GP replaced has the best results, also it is found at this percentage of GP, more beneficial and capable to increased compressive and flexural strength up to 18.64% and 5.87 % respectively at 28-day compared to reference specimen. Besides, the test results revealed that at a replacement level 10% of 2.36mm fine glass (FG) has slightly improved the strength characteristics. While, the results demonstrated decreasing in that properties for the concrete specimens contained on coarse glass (CG) up to 4.75mm. The maximum negative effect on compressive strength and modulus of rupture recorded at the ratio 30% of CG where was the reduction in compressive strength 28.52% opposite 22.12% for modulus of rupture at age of 28-day. From that results, it can be concluded that the effect of FG was little compared to GP.

Keywords: Waste glass, Partial replacement, Compressive strength, Modulus of rupture.

1. Introduction

Management of waste has become a main issue of all over the world. Glass is not appropriate to add in garbage and also the chance recycled required investigated (Adaway, M., 2015). Also it is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing (Park, S., 2004). So it is an perfect material for recycling where contributes in energy saving, building unites manufacture, conserves ore materials, diminishing consumption energy, and the volume of waste (BSI, 2005).

In the recent years, the quantity of waste glass is piecemeal grows due to multiply use of glass products. Most waste glass have been dumped into landfill sites and it full have been undesirable because they are not biodegradable as a result environmentally less friendly. There is huge potential for using waste glass in the concrete construction sector and therefore the cost of concrete production will go down (Topu, I., 2004). When using crushed glass or cullet with duly sized and processed can get similar characteristics to that of gravel or sand. So, in construction applications it must be crushed and screened to produce suitable design gradation. Glass crushing equipment normally used to produce a cullet is similar to that in rock crushing, typically smaller and uses less energy compared to conventional aggregate or rock crushing equipment. Because it has been designed to reduce the size or density for transportation purposes and for use as a feedstock material. (Egosi, N. ,1992).

Fine aggregate is widely used in construction works so it is important construction material, where the concrete cost increases according to the fine aggregate cost. Therefore some alternative materials are required to reduce cost (Madhavi, T., 2013). Because of consumption of higher for fine aggregate in construction industry so it partially replacement with waste glass has been more appeal in structural concrete (Adaway, M., 2015). Newly, using waste glass as a construction material in concrete has been effort because of the potentially decreasing the cost of glass disposal and concrete production. An endeavor was place for a long time to test the use of the waste glass as aggregate in the concrete.

With no evident unanimity presently ready in literature, this research` will aim to explain the strength characteristics of concretes containing different three particle sizes of wastes glass as a partial substitution of fine aggregate by 10% interval up to 30% and make a comparison with control sample.

2. Materials Used

Cement: The cement used in all concrete mixtures was ordinary Portland cement type I complies with the requirement of IQS No.5/1984 as represented in Table 1 and 2.

Table 1: Chemical composition of cement used

Compound	Weight,%	IQS No.5/1984
CaO	64.10	–
SiO_2	20.88	–
Al_2O_3	3.74	–
Fe_2O_3	4.50	–
SO_3	2.10	2.80% max if $C_3A > 5$ 2.50% max if $C_3A < 5$
MgO	1.00	5.0% max
I.R	0.82	1.5% max
L.O.I	1.98	4.0% max
L.S.F	0.95	0.66-1.02
C_3S	21.30	–
C_2S	52.30	–
C_3A	6.20	5.0% min
C_4AF	9.30	–

Table 2: Physical properties of cement used

Property	Value	IQS No.5/1984
Fineness, m^2/Kg	338	≥230
Setting time, hrs:min		
Initial set.	2:35	≥00:45
Final set.	4:30	≤ 10:00
Compressive strength, MPa		
3-day	20.35	≥15.00
7-day	26.26	≥23.00
Autoclave expansion,%	0.14	≤ 0.80

Fine and Coarse Aggregate: Natural sand and gravel of maximum size 4.75mm and 20 mm respectively were used as fine and coarse aggregate (FA and CA). Table 3 and 4 denoted to the properties and gradation of aggregate used.

Table 3 Properties of natural used

Property	CA	FA
Specific gravity	2.72	2.66
Absorption capacity (%)	0.72	0.98
Unit weight (kg/m3)	1686	1739

Table 4 Gradation of fine aggregate used

Sieve size, mm	37.5	20	10	4.75			
IQS No.45/1984 (5-20) mm	100	95-100	30-60	0-10			
CA	100	99.31	55.09	8.75			
Sieve size, mm	**10**	**4.75**	**2.36**	**1.18**	**0.60**	**0.30**	**0.15**
IQS No.45 /984, Zone 2	**100**	**90-100**	**75-100**	**55-90**	**35-59**	**8-30**	**0-10**
FA	**100**	**100**	**95.17**	**86.45**	**49.62**	**22.03**	**6.68**

Waste Glass : Locally available waste glass is collected and converted into three categories on the bases of its particles size; glass powder (GP) up to 600µm, fine glass (FG) up to 2.36mm and coarse glass (CG) up to 4.75mm. Table 5 demonstrated the chemical composition and some properties of WG used.

Table 5: Chemical composition and some properties of WG used

Compound	Weight,%
CaO	8.31
SiO_2	72.40
Al_2O_3	1.72
Fe_2O_3	1.35
MgO	2.19
SO_3	0.73
Na_2O	13.75
K_3O	0.23
Property	
Specific gravity	2.54
Absorption capacity (%)	0.14
Unit weight (kg/m3)	1563

Water: Tap water was used for mixing and curing of concrete.

Mixture Design and Experimental Procedure

The concrete mix design was proposed according to ACI 211.1-95 standard for control mix for the target strength of 25 MPa at 28-day with slump (75-100) mm. The ratio of cement, sand and gravel is (1:1.55:2.53) and water-cement ratio is 0.47 which is constant for all mixes to determine the effect of various levels to WG on the compressive and flexural strength of concrete mix. The experimental work starts by cast cubes and prisms for trial mix without replacing of WG in the ratio of 0% was grad WG0. Then, three groups of concrete mixes were prepared in laboratory. First group was sand replacement by GP particles (600µm). While, in the second group, FG particles (2.36mm) was replaced. Whereas third group includes replacement of CG particles (4.75mm). The rates of replacing to WG were 10%, 20% and 30% for each group and compared with the control mix (WG0). As a result, a total of ten mixtures were produced including control mixture without any replacement to WG. The details of mixes are given in Table 6.

Table 6 Replacement proportions and slump test Results

Mix code	GP %	FG %	CG %	Slump mm
WG0	-	-	-	78
GP10	10	-	-	84
GP20	20	-	-	91
GP30	30	-	-	98
FG10	-	10	-	80
FG20	-	20	-	83
FG30	-	30	-	87
CG10	-	-	10	79
CG20	-	-	20	68
CG30	-	-	30	52

After the mixing process, slump test was carried out to measure the workability. Then, the fresh mixes were fed into the cubes and prisms of steel moulds with dimensions of 100mm and 100x100x400mm respectively to evaluated the compression and flexion at age of 28 and 90 days. Twelve specimens were created for each percentage replacement of glass, with six cubes samples being used for 28 and 90 days compressive strength tests and six prisms samples being used for 28 and 90 days modulus of rupture tests. Totally 120 specimens were cast and tested for the compressive and flexural strength at desired age.

3. Results and Discussion

3.1. Slump

The results obtained are presented in Table 6 and Fig.1. An initial slump of 78mm was obtained for the control concrete mix, while mixes containing WG as GP and FG exhibited slump ranging from (2-26)% higher than that of the control mix as illustrated in Fig.2. This increase may be attributed to the fact that fine particle size has a large volume as a result mixture with more consistent. On the other hand, in response to the addition of WG as CG, the slump demonstrates a decreasing trend ranging from (10–41)% compared to slump of conventional mix. This may be returned to harsh texture of coarse size to WG due to sharp edges and angular shapes (Keryou, 2014) or due to the loss of effective water from specimen through rapid transportation caused by more voids produced by equivalent waste glass component in lieu of natureal sand being heavier than the later (Singh, 2015). Although the disparity in the resulting values for slump test, but all the concrete mixes were workable and some of which overrides the allowed levels of (75-100)mm. On the other hand, no isolation or bleeding observed` during the processing, according to research that indicated that less than 50% replacement for fine aggregate had a little unfavorable effects on the fresh properties fresh (Taha, B., 2009).

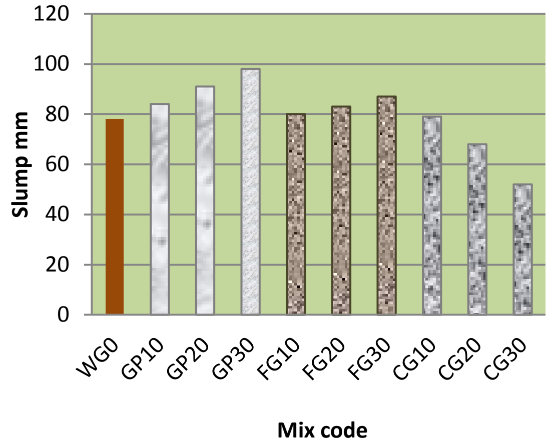

Figure 1: Variation of slump for all mixes

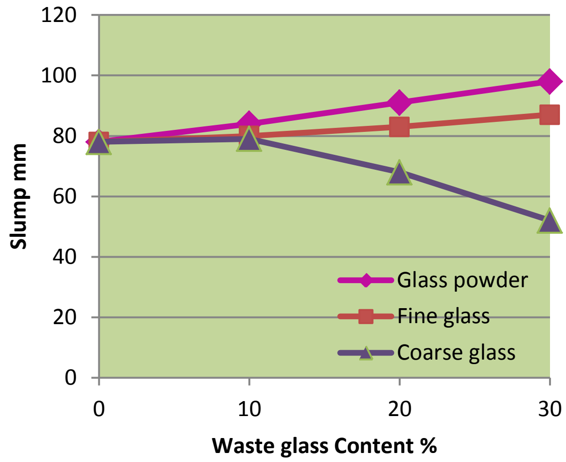

Figure 2: Variation of slump for WG mixes with respect to control mix

3.2. Compressive Strength:

Table 7 and Fig. 3 show the values of compressive strength test for specimens cured at age 28 and 90 days. This results reveal that using WG in concrete as GP improved the compressive strength of the concrete specimens at all ages. The maximum effect was reported at percentage of 30%, where the increase in compressive strength at 28-day 18.64% higher than that of traditional specimen. While, the increasing achieved 2.02% higher at only replacement level of 10% to FG. This may be returned to the nature of angular of glass particles than the rounded sand (Adaway,2015). In addition to the great surface area which allows to highest bonding with the cement paste as a result to that stronger concrete matrix. On the contrary, using WG in concrete as FG at level 20 and 30% showed slightly reduction in the compressive strength at all ages. Accompanied, gradual considerable reduction in the compressive strength with the increase in rate of WG used as CG as represented in Fig.4 and

5. The maximum effect was recorded at percentage of 30% for FG and CG, where the reduction in compressive strength at 28-day 7.01% and 28.52% lower than that of conventional sample respectively. This may be attributed to the lesser volume of equivalent waste glass as compare to natural sand since former is heavier the later (Singh, 2015) or due to the great reaction between the alkali in cement and the reactive silica in glass (Johnson,1974).

Table 7: Results of compressive strength and modulus of rupture tests

Mix code	Compressive strength, MPa		Modulus of rupture, MPa	
	28-day	90-day	28-day	90-day
WG0	30.68	33.18	4.43	4.68
GP10	32.77	34.71	4.46	4.75
GP20	34.23	35.97	4.57	4.87
GP30	36.40	37.26	4.69	5.01
FG10	31.30	33.20	4.44	4.71
FG20	30.01	31.80	4.36	4.58
FG30	28.53	29.89	4.20	4.19
CG10	29.47	31.34	4.29	4.47
CG20	27.65	29.15	4.04	4.15
CG30	21.93	23.03	3.45	3.51

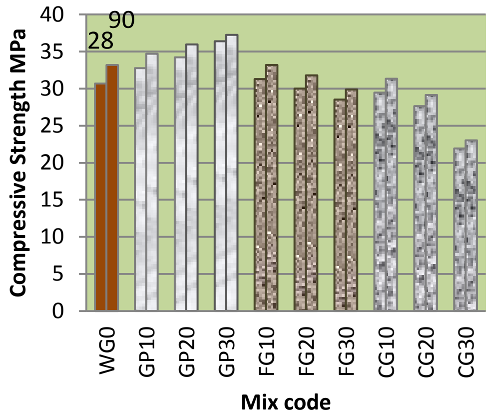

Figure 3: Variation of compressive strength for all mixes

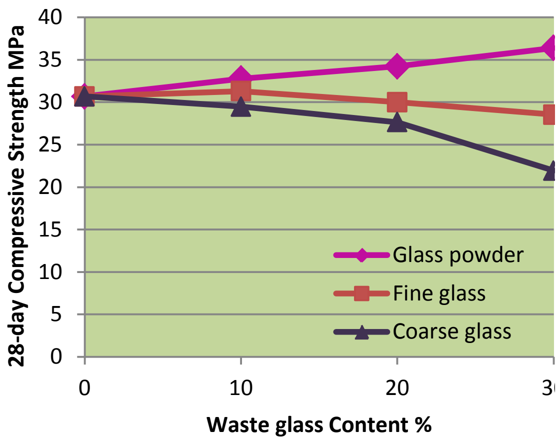

Figure 4: Variation of 28-day compressive strength for WG mixes with respect to control mix

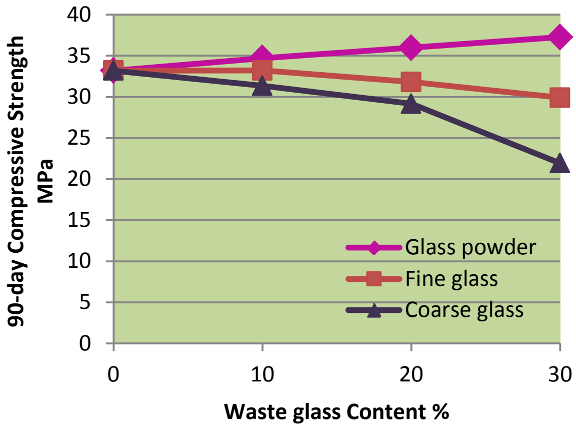

Figure 5: Variation of 90-day compressive strength for WG mixes with respect to control mix

3.3. Modulus of Rupture

The results of modulus of rupture tests with different WG contents and particle sizes at 28 and 90 days are presented in Table 7 and Fig.6. The effect of using WG on modulus of rupture is similar to that on the compressive strength. Where up to 30% GP substitution, flexural strength recorded maximum enhancement as apparent in Fig. 7 and 8. The increases in flexural strength at 28-day was 5.87% higher compared to WG0 specimen. Also, samples containing 10% of FG indicates slightly higher modulus of rupture than that of reference sample, where was achieved 0.23% at 28-day. This increasing can be attributed to the puzzolanic reaction of fine particle size. So that, as the partical size of waste glass reduces it helps in enhancing strength of concrete (Aphale, A., 2016) .After 10% of FG, it can be seen that the reduction in flexural strength increases with rising the level of sand replacement. However, at the different percentage of CG replacement, modulus of rupture is affected, especially at high levels of replacement. The maximum negative effect on modulus of rupture recorded at the ratio 30% of CG where was 22.12% at age of 28-day. The reason of this deterioration may be returned to the lack of coherence between the components of the concrete mixture with broken glass (Abbas, 2011) as a results to the extremely poor shape, poor surface characteristics and high friability of glass particles (Ammash, 2009).

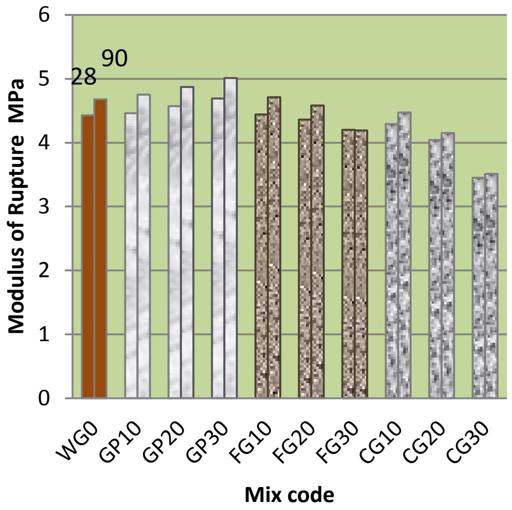

Figure 6: Variation of modulus of rupture for all mixes

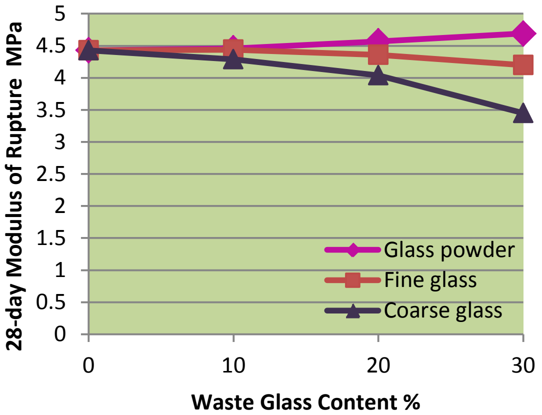

Figure 7: Variation of 28-day modulus of rupture for WG mixes with respect to control mix

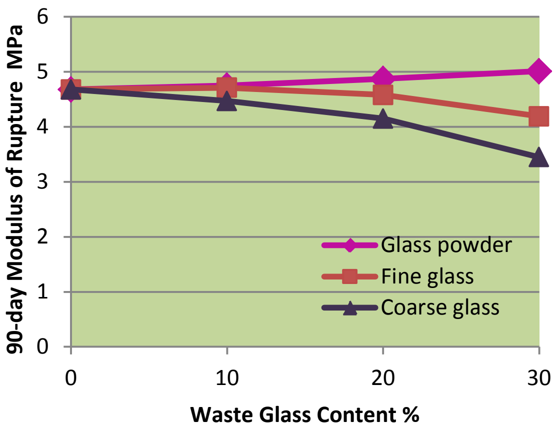

Figure 8: Variation of 90-day modulus of rupture for WG mixes with respect to control mix

4. Conclusion

1. All mixes that containing WG considered workable and some of them exceeded the tolerance levels of (75-100) mm such as CG20 and CG30 mixes. No isolation or bleeding observed `during the processing.
2. The mixes containing WG as GP and FG exhibited higher slump compared to control mix while the CG mixes demonstrated decreasing in slump.
3. There is a gradual increase in the strength of concrete with the addition of WG used as GP. At the replacement of 30% of FA by GP meets maximum strength as compare to that of normal concrete. Also, it is found at this percentage of GP, more beneficial and capable to increased compressive and flexural strength up to 18.64% and 5.87 % respectively at 28-day compared to conventional specimen.
4. The replacement of FG by FA at level 10% by weight has a considerable effect on the comparison and flexion properties. After this percentage, can be noted decreasing in that properties.
5. The presence of WG in the mixes as CG leads to decrease in compressive and flexural strength as the percentage of glass is increased. However, up to 20% of substitution, the reduction is not significant. While, the maximum negative effect on compressive strength and modulus of rupture was at the ratio 30% of CG, where was the reduction in compressive strength 28.52% opposite 22.12% for modulus of rupture at age of 28-day.
6. The GP can be used as a partial replacement of FA. Where, the finer glass particle size exhibits comparatively better results than coarser glass particle size.
7. The effect of replacement of FG was little compared with GP.

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تاثير المقاس الحبيبي لنفايات الزجاج على مقاومة الانضغاط ومعامل التصدع للخليط الخرساني

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الخلاصة

يعتبر الزجاج مادة خاملة يمكن استخدامها وإعادة تدويرها مرات عديدة. وتتولد سنويا في جميع انحاء العالم أطنان عديدة من نفايات الزجاج بسبب النمو السريع للسكان وتحسن مستوى المعيشة. وفي هذه الدراسة استخدمت نفايات الزجاج وجهزت بثلاث مقاسات حبيبية مختلفة : 600مايكرون, 2,36ملم و4,75 ملم واستبدلت جزئيا من وزن الركام الناعم بنسب 10٪، 20٪ و 30٪. تمت دراسة فاعلية تلك التغييرات على قوة الانضغاط ومعامل التصدع في عمر 28 و 90 يوم للنماذج الخرسانة المنتجة. أظهرت النتائج زيادة في مقاومة الانضغاط ومعامل التصدع لجميع الأعمار مع زيادة نفايات الزجاج المضافة كمسحوق للزجاج. علاوة على ذلك، فإن العينات الحاوية على 30٪ من مسحوق الزجاج لديها أفضل النتائج، كما تبين أنه عند هذه النسبة من مسحوق الزجاج هنالك اكثر فائدة وقدرة على زيادة مقاومة الانضغاط والانثناء تصل إلى 18,64٪ و 5,87٪ على التوالي بعمر 28 يوم مقارنة بالنموذج المرجعي. الى جانب ذلك، اظهرت نتائج الفحص تحسن طفيف في خصائص المقاومة عند نسبة تعويض 10 ٪ من 2,36 مم الزجاج الناعم. في حين أظهرت النتائج انخفاض في تلك الخصائص لنماذج الخرسانة الحاوية على الزجاج الخشن بمقاس يصل إلى 4,75 مم. وسجل أقصى تأثير سلبي على مقاومة الانضغاط ومعامل التصدع عند نسبة 30٪ من الزجاج الخشن حيث بلغ النقصان في مقاومة الانضغاط 28,52% مقابل 22,12% لمعامل التصدع. من تلك النتائج، يمكن الاستنتاج بأن تأثير تعويض الزجاج الناعم كان قليل مقارنة بمسحوق الزجاج.