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Mechanical Properties and Behavior of Sustainable Concrete

By

Dr. Zubaidah Abdullateef M. A. Al – Bayati

Civil Eng. Dept., College of Eng., Al – Mustansiria Univ., Baghdad, Iraq

Abstract:

The need to add value to wastes and the opening towards sustainability engineering, by the use of worn out materials as cement and aggregate replacement materials, both in mortars and concretes, with the purpose of promoting increased sustainability of building materials, were the grounds for this work that aims to produce a concrete mix with crushed glass residues.

This paper examines the possibility of using crushed glass from glass bottles as a replacement by weight in fine aggregate for a new concrete. Natural sand is partially replaced (10%, 20%, 30%, 40% and 50%) with crushed glass. Compressive strength, tensile strength (cubes and cylinders) and flexural strength up to 28 days of age are compared with those of concrete made with natural fine aggregates. Test results indicate that it is possible to manufacture concrete containing crushed glass with characteristics similar to those of natural sand aggregate concrete provided that the percentage of glass as fine aggregate is limited to 10-20% of sand weight.

د. زبيدة عبد اللطيف محمد علي

قسم الهندسة المدنية

كلية الهندسة /الجامعة المستنصرية

الخلاصة:

ان اساس هذا العمل جاء من خلال الحاجة الى اضافة القيمة الى المخلفات و التوجه المتفتح الى هندسة الاستدامة و ذلك عن طريق استعمال المواد المستهلكة كمواد بديلة عن السمنت و الركام في انتاج المونة و الخرسانة، و لغرض الرقي بمواد البناء المستدامة، و بهدف انتاج خلطة خرسانية باستعمال بقايا الزجاج المحطم.

يتحرى البحث الحالي عن امكانية استعمال الزجاج المحطم من القناني الزجاجية كنسبة إبدال وزنية من الركام الناعم لانتاج خرسانة جديدة. حيث تم ابدال جزء من الرمل الطبيعي بنسب من الزجاج المحطم (10%, 20%, 30%, 40% و 50%). يتم فحص و مقارنة مقاومة الانضغاط, مقاومة الشد, و مقاومة الانثناء للنماذج (الاسطوانية و المكعبة) مع تلك المصنعة من الركام التقليدي و لغاية عمر ٢٨ يوم. اشارت نتائج البحث الحالي الى امكانية تصنيع خرسانة حاوية على الزجاج المحطم و بخصائص مشابهة للخرسانة الحاوية على الركام التقليدي عندما تكون نسب الابدال بالزجاج بحدود ١٠ - ٢٠ بالمئة من وزن الرمل.

1. Introduction:

Following a normal growth in population, the amount and type of waste materials have increased accordingly. Many of the non-decaying waste materials will remain in the environment for hundreds, perhaps thousands of years. The non-decaying waste materials cause a waste disposal crisis, thereby contributing to the environmental problems. The problem of waste accumulation exists worldwide, specifically in the densely populated areas. Most of these materials are left as stockpiles, landfill material or illegally dumped in selected areas.

The use of waste materials in mortars and concrete can be an important step towards sustainability as the construction industry is significant and mortars worldwide use cement as their main binder. The use of alternative mortars with binders that are less pollutant and/or the use of residues could impact the mortar industry towards the production of mortars with less environmental impact. In order to achieve this, mortars and concrete must have adequate characteristics, implying that certain mechanical characteristics and water behavior must be achieved.

The most widely used fine aggregate for making concrete is the natural sand mined from the riverbeds. However, the availability of river sand for the preparation of concrete is becoming scarce due to the excessive nonscientific methods of mining from the riverbeds, lowering of water table, sinking of the bridge piers, etc. are becoming common treats [1]. The present scenario demands identification of substitute materials for the river sand for making concrete. Recently, some attempts have been made to use ground glass as a replacement in concrete [2, 3,4].

Glass from varying recycling processes is considered to be a material which could be used as binder and also as aggregate replacement. Glass which is most considered for recycling in terms of environmental protection is that from containers, architectural and end of life vehicle glass. This study outlines the use of such recycled glass as fine aggregate replacement and details workability and strength development of concrete containing glass as partial replacement of traditional materials.

Researches into new and innovative uses of waste materials are continuously advancing. These research efforts try to match society's need for safe and economic disposal of waste materials. The use of recycled aggregates saves natural resources and dumping spaces and helps to maintain a clean environment.

A number of research studies were performed. Some studied the effect of the irregular surface of the crushed concrete on the properties of concrete mixes. Others have been investigated the use of plastic materials and glass in a number of civil engineering applications through a large number of research studies. These have been conducted to examine the possibility of using plastics and glass powder in various civil engineering projects in the construction field [5, 6, 7]. Rindl[6] reported many uses of waste glass, which included road construction aggregate, asphalt paving, concrete aggregate, and many other applications. Shayan[7,8] studied the use of the waste glass aggregates in concrete. The chemical reaction that takes place between the silicarich glass particles and the alkali in the pore solution of concrete, alkali–silica reaction is the major concern regarding the use of glass in concrete. Zdenek et al.[9] reported that the particle size of ground glass used in concrete is proportional to the concrete strength. They also reported that the effect of alkali–silica reaction will be eventually eliminated if the particles sizes are small enough. However, it was concluded by Blumenstyk[10] that using glass from green bottles tends to mitigate alkali–silica reaction due to the existence of chromium oxide which gives glass its green color. Appropriate precautions must be taken to minimize the detrimental alkali–silica reaction effect on the stability of concrete by incorporating a suitable pozzolonic material such as fly ash, silica, or ground blast furnace slag in the concrete mix at appropriate proportions, as specified by Shayan[8]. Yang et al.[11] concluded in their research that the use of rubberized concrete should be limited to secondary structural components such as culverts, crash barriers, sidewalks, running tracks, sound absorbers, etc. Huang et al.[12] treated the rubberized concrete as a multiphase particulate- filled composite material, and built a model to predict the factors affecting the strength of the rubberized concrete. A parametric analysis was conducted using the finite element method. Based on their analysis, they concluded that the strength of rubberized concrete can be increased by reducing the maximum rubber chip size; using stiffer coarse aggregate; employing uniform coarse aggregate size distribution; and using harder cement mortar if it has a high strength or using softer cement mortar if it has high ductility. In addition, they concluded that rubber chip content should be limited to a certain range in order for it to be used in practice. Sukontasukkul and Chaikaew[13] used crumb rubber to replace coarse and fine aggregates in concrete pedestrian blocks. This has produced softer blocks that provided softness to the surface. In addition, crumb rubber blocks performed quit well in both skid and abrasion resistance tests. Krammart and Tangtermsirikul[14] investigated the use of municipal solid waste incinerator bottom ash and calcium carbide waste as part of the cement raw materials. They found that the chemical composition of the cement produced from raw materials containing the used wastes was similar to the control cement. They also noted the superiority of the newly produced cement over the control cements in the sodium sulfate solutions.

The waste materials considered to be recycled in Batayneh et al. [15] study they were consisted of glass, plastics, and demolished concrete. Such recycling not only helps conserve natural resources, but also helps solving a growing waste disposal crisis. Ground plastics and glass were used to replace up to 20% of fine aggregates in concrete mixes, while crushed concrete was used to replace up to 20% of coarse aggregates. To evaluate the effect of these replacements on the properties of the ordinary Portland cement mixes, a number of laboratory tests were carried out. The tests included workability, unit weight, compressive strength, flexural strength, and indirect tensile strength (splitting). The main findings of their investigation revealed that the three types of waste materials could be reused as partial substitutes for sand or coarse aggregates in concrete mixtures successfully.

Mageswari and Vidivelli[16] in Their study examined the possibility of using Sheet Glass Powder as a replacement in fine aggregate for a new concrete. Natural sand was partially replaced with Sheet Glass Powder. Concrete mechanical properties up to 180 days of age were compared with those of concrete made with natural fine aggregates. Fineness modulus, specific gravity, moisture content, water absorption, bulk density, percentage of voids and porosity (loose and compact) state for sand were also studied. Test results indicated that it is possible to manufacture concrete containing Sheet Glass Powder with characteristics similar to those of natural sand aggregate concrete provided that the percentage of Sheet Glass Powder as fine aggregate is limited to 10-20%, respectively.

Turgut, and Yahlizade[17] in their paper, carried out a parametric experimental study for producing paving blocks using fine and coarse waste glass. Some of the physical and mechanical properties of paving blocks having various levels of fine glass and coarse glass replacements with fine aggregate are investigated. Test results showed that the replacement of fine glass by fine aggregate at level of 20% by weight has a significant effect on the compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving blocks as compared with the control sample because of puzzolanic nature of fine glass. The compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving block samples in the fine glass replacement level of 20% are 69%, 90%, 47% and 15 % higher as compared with the control sample respectively. It is reported in the earlier works that the replacement of fine glass by fine aggregate at level of 20% by weight suppress the alkali-silica reaction in the concrete. Test results showed that the fine glass at level of 20% has a potential to be used in the production of paving blocks. The beneficial effect on these properties of coarse aggregate replacement with fine aggregate is little as compared with fine glass.

The main objective of this paper is to present the results of experimental investigations on physical and mechanical properties of normal strength concrete that contains crushed glass powder as replacement ratios by weight of natural fine aggregate. Natural fine aggregate is substituted by weight by glass powder at rates varying from 10, 20, 30, 40 and 50 percentages. Workability, compressive, tension, and flexural strengths are evaluated and compared up to 28 days of curing age. The used glass throughout this study is based on crushing glass bottles.

2. Experimental Program

The glass bottles are first collected and manually washed to get rid of any residue and dirt, then left to dry. The bottles were crushed manually by means of a hummer in order to facilitate the insertion of glass lumps through the feeding openings of the crusher machine. The jam crusher was set up to give a finished product of about 4.75 mm maximum aggregate size and 0.15 mm minimum aggregate size. **Figure (1)** shows a sample of the crushed glass. Normal strength concrete mix is designed in accordance with ACI-211[18]. Six concrete mixtures are used, five mixes with different fine aggregate replacement ratios with crushed glass are considered. A new batch of concrete for each replacement ratio is used, in addition to one normal concrete batch with no replacement in fine aggregate. The number and classification of casted and tested samples for each concrete batch are shown in **Table (1).**

Figure (1) Crushed glass

Table (1) Classification of tested samples used in the present study

Mechanical Property of Concrete	Sample Type	No. of Samples	Testing Age (days)
Compressive strength	Cube 150 mm	3	7
		3	28
Modulus of rupture	Prism (100 x 100 x 500 mm)	3	28
Splitting tensile strength	Cylinder 150 mm diameter x 300 mm height	3	28
Modulus of elasticity	Cylinder 150 mm diameter x 300 mm height	2	28

3. Material Properties

3.1 Cement

Ordinary Portland cement, Type I, produced by United Cement Company (TASLIJA-BAZIAN) is used throughout this study. It is stored in air-tight plastic containers to avoid exposure to atmospheric conditions like humidity. Tables **(2)** and **(3)** show respectively the chemical composition and physical properties of the cement used in this research.

Test results indicate that the adopted cement conforms to the Iraqi Specification No.5/1984. [19]

Table (2) Chemical composition of cement

Item	Test result (%)	Limit of Iraqi Specification NO.5/1984
Lime (CaO)	63.26	---
Silica (SiO_2)	19.22	---
Alumina (Al_2O_3)	4.51	---
Iron Oxide (Fe_2O_3)	3.34	---
Magnesia (MgO)	2.62	≤5.0%
Sulfate (SO_3)	2.03	≤2.8%
Loss on Ignition (L.O.I.)	3.72	≤4.0%
Insoluble residue (I.R)	1.10	≤1.5%
Lime saturation Factor (L.S.F.)	0.88	0.66-1.02
Tricalcium Aluminates (C_3A)	6.59	---

Table (3) Physical properties of cement

Physical Properties	Test result	Limit of Iraqi Specification NO.5/1984
Specific surface area (m^2/kg)	407	≥230
Setting time (Vicat's apparatus) Initial setting time, (hrs: min.) Final setting, (hrs: min.)	 2:35 5:20	 ≥ 0:45 ≤10:0
Compressive strength 3days, MPa 7days, MPa	 20.8 26.0	 ≥15 ≥23

3.2 Fine Aggregate

Al-Ekhaider natural sand of 4.75 mm maximum size is used as fine aggregate. The grading of the original fine aggregate is shown in **Table (4)** and **Figure (2).** The results indicate that the fine aggregate grading is within the requirements of the Iraqi Specification No.45/1984 [2٠]. **Table (5)** shows that the specific gravity, sulfate content and absorption of fine aggregate are within the requirements of the Iraqi Specification No.45/1984[2٠].

Table (4) Grading of fine aggregate

Sieve size (mm)	Passing %	Limits of Iraqi specification No.45/1984 , zone 3
4.75	96	90-100
2.36	89	85-100
1.18	81	75-100
0.600	67	60-79
0.300	27	12-40
0.150	3	0-10

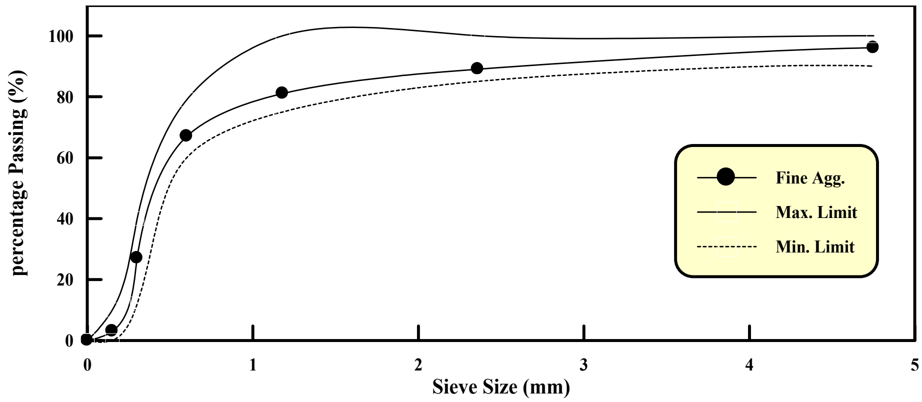

Figure (2) Grading curve for original used fine aggregate

Table (5) Physical properties of fine aggregate

Physical properties	Test results	Limits of Iraqi specification No.45/1984
Specific gravity	2.73	-
Sulfate content	0.08%	≤0.5%
Absorption	0.70%	-

3.3 Coarse Aggregate

Crushed gravel with maximum size of (14mm) is used throughout the tests. The crushed river coarse aggregates are washed, then stored in air to dry the surface, and then stored in a saturated dry surface condition before using. The specific gravity and absorption are (2.66) and (0.66%) respectively. Grading of the coarse aggregate is shown in **Table (6).** The obtained results indicate that, the coarse aggregate grading is within the requirement of the Iraqi specification No. 45/1984[2·].

Table (6) Grading of coarse aggregate

Sieve size (mm)	Passing%	Iraqi specification No. 45/1984
14	98	90-100
10	71	50-85
5	10	0-10
pan	-	-

3.4 Crushed Glass

The crushed glass used in this study is bottles sieved after is being crushed in the laboratory. The gradation of the used crushed glass is shown in **Table (7)** and **Figure (3).**

Table (7) Grading of crushed glass

Sieve size(mm)	Retained%	Passing%
4.75	2.91	97.09
2.36	12.93	87.07
1.18	22.92	77.08
0.600	36.52	63.48
0.300	79.54	20.46
0.150	93.23	6.77

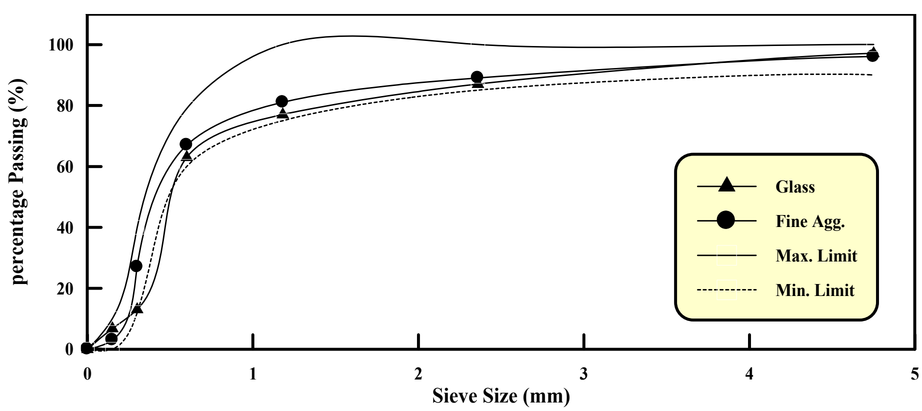

Figure (3) Grading curve for crushed glass

4. Mix Design

Before mixing, all quantities are weighed and placed in clean container, saturated dry surface crushed gravel, sand, crushed glass and cement are mixed for 5 minutes in a horizontal rotary mixer with (0.19 m^3) capacity. The water is then added gradually to the mix. The total mixing time is (8-10 minutes). After casting all specimens are left in the laboratory until they are demolded after 24 hours, and then placed in water bath for (28) days with almost constant laboratory temperature. After (28) days, they are taken out of the water and left to dry for (24) hours and then tested in accordance with the standard specifications.

Details of the adopted concrete mixes in the current research work are given in **Table (8)**. It is found that, the used mixture produces good workability and uniform mixing of concrete without segregation.

Table (8) Details of concrete mixes

Parameter	Concrete mix number					
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Water/cement ratio	0.4	0.4	0.4	0.4	0.4	0.4
Water (kg/m^3)	178	178	178	178	178	178
Cement (kg/m^3)	445	445	445	445	445	445
Fine aggregate (kg/m^3)	532	478.8	425.6	372.4	319.2	266
Coarse aggregate (kg/m^3)	1240	1240	1240	1240	1240	1240
Crushed glass (kg/m^3)	0.0	53.2	106.4	159.6	212.8	266

5. Results and Discussion

The compressive strength of hardened concrete specimens is carried out in accordance with BS1881-116[21] using (150mm) cubes loaded uniaxially by the universal compressive machine. Test results are presented in **Figure (4)**, the Figure shows the variation of compressive strength with the five different replacement ratios of fine aggregate with crushed glass for two curing ages 7-days and 28 days. The general behavior of the curves seems to be similar for both curing ages. It can be noted from the Figure that there is a gradual drop in compressive strength with the increasing content of glass as a partial replacement of fine aggregate.

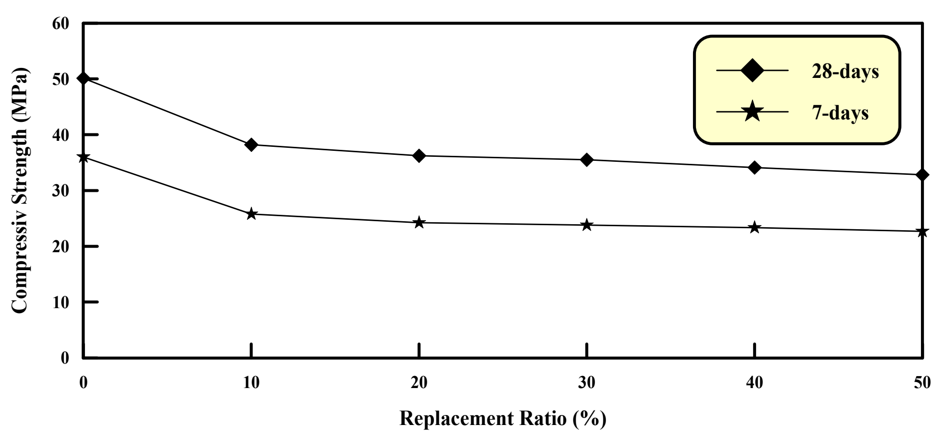

Figure (4) Relationship between compressive strength & percentage of glass content

The flexural strength (modulus of rupture) tests are made on (100 × 100 × 500 mm) prism specimens loaded at third points in accordance with ASTM-C78[22]. The following equation is used to estimate the flexural strength:

$$f_r = \frac{PL}{bd^2} \qquad \text{.................... (1)}$$

where:

f_r : modulus of rupture (MPa)

P: maximum applied load (*N*)

L: span length (mm) [in this work, L=300mm]

b: average width of specimen (mm)

d: average depth of specimen (mm)

The tested specimens result values are given in **Figure (5)**, which present the loss in flexural strength with increasing in the percentage of replacement ratio in a linear way. The loss in modulus of rupture looks to be more significant at the initial stages of replacement.

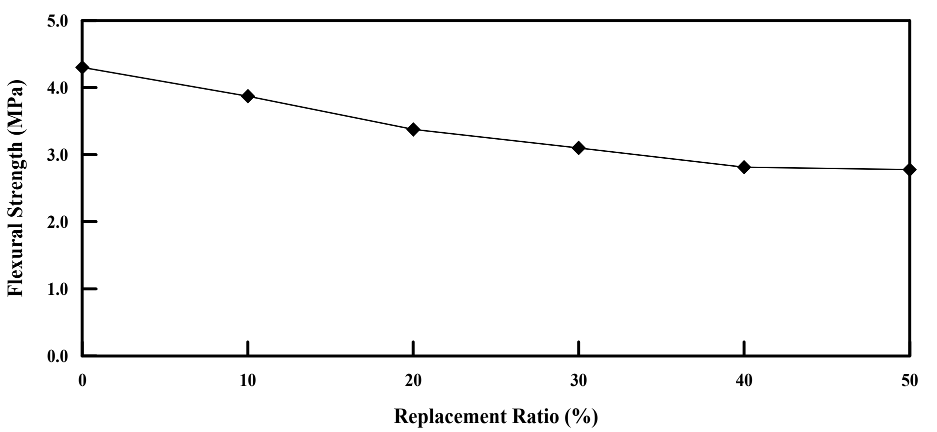

Figure (5) Relationship between flexural strength & percentage of glass content

The indirect tensile strength (splitting tensile strength) tests are carried out in accordance with ASTM-C496 [23] by subjecting a (150×300) mm concrete cylinder to a compressive load at a constant rate (75kN/min) along the vertical diameter until failure. The splitting-tensile (indirect tensile) strength is computed as:

$$f_t = \frac{2P}{DL\pi} \qquad \text{.................... (2)}$$

where:

f_t : tensile strength, MPa.

P: load at failure, N.

L: length of specimen, mm.
d: diameter of specimen, mm.

Figure (6) shows the variation in tensile strength values with the increasing replacement ratio of crushed glass content.

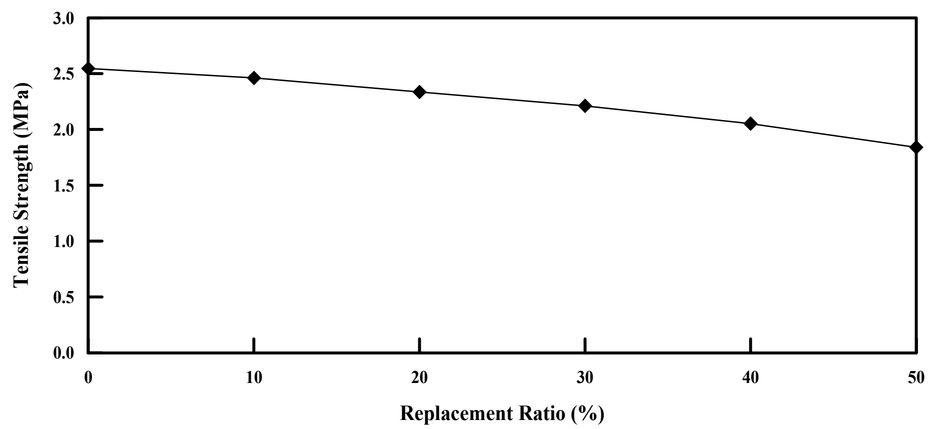

Figure (6) Relationship between tensile strength & percentage of glass content

Figure (7) shows that there is a decrease in the slump with the increase in the crushed glass content. For a 50% replacement, the slump has decreased to 35.38% of the original slump value with 0% crushed glass content. This decrease in the slump value is due to the shape of glass particles, i.e., the glass particles have sharper edges than the fine aggregate.

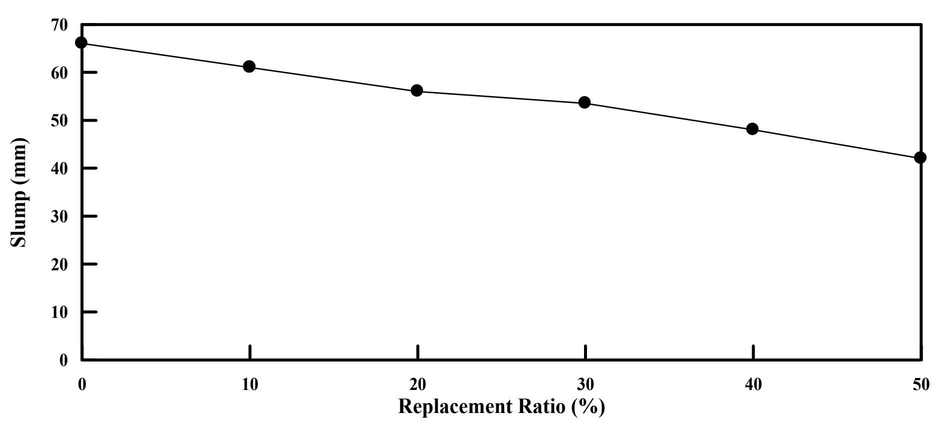

Figure (7) Workability versus percentage of glass content

A comparison among the different replacement levels of glass in term of compressive strength is shown in **Figure (8).** As can be seen from the Figure that the reduction in strength ranges between 0% and 10% replacement ratios are quite considerable, while the reduction in strength among other replacement ratios are relatively low.

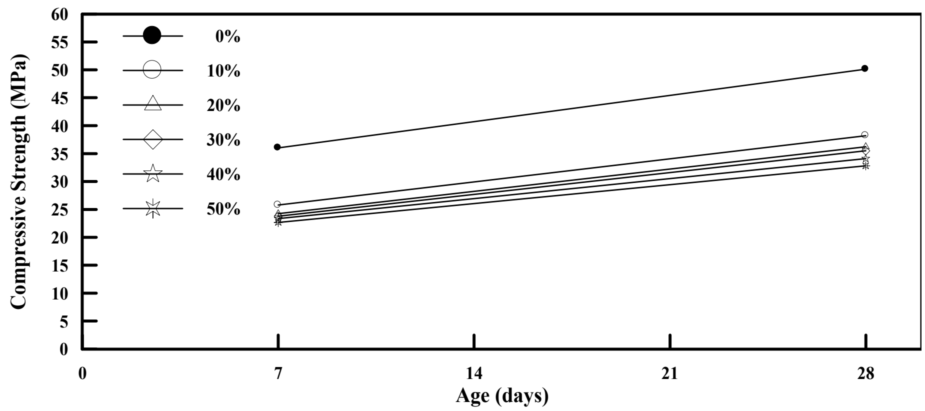

Figure (8) Comparison among compressive strengths with different glass content

Figure (9) shows that the addition of the crushed glass led to a reduction in the strength properties. For a 50% replacement, the compressive strength shows a sharp reduction up to 34.53% of the original strength. With 10% replacement the compressive strength shows a 23.75% reduction. Similar behavior, but in a lower effect, is observed for both the tensile and flexural strengths of the tested samples. This reduction in strength is due to the fact that the strength of the crushed glass particles is lower than that of the natural aggregate.

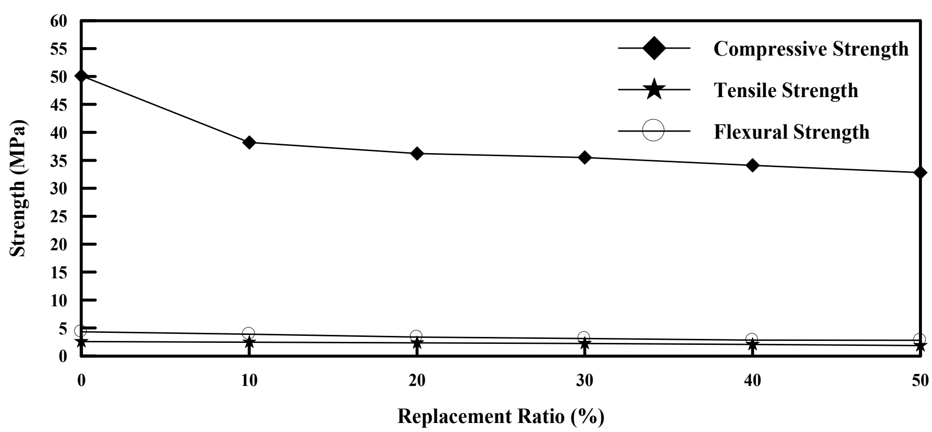

Figure (9) Comparison among concrete strengths with different glass content

6. Conclusions

The tests carried out in this study were primarily designed to provide an indication of relative advantages and disadvantages of the use of crushed glass particles in concrete mix. This would provide an overview of the reuse of waste materials in the construction industry.

The reduction in strength is about 23.75, 3.38, and 10.0% in terms of compressive, tensile, and flexural respectively when a replacement ratio of 10% is used, and this can be considered a relatively low decrease in strength values.

When up to 50% of crushed glass is used in concrete, the strength of the concrete exhibited lower compressive, splitting-tensile and flexural strengths than that of normal concrete using natural aggregates. The reduction is about 34.53, 27.73, and 35.47% respectively. Therefore, it is recommended that concrete with recycled glass materials of lower strength with high replacement ratio be used in certain civil engineering applications, especially in non-structural applications, where lower strength is required. This will contribute to cutting down the cost of using non-structural concrete.

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