Replacement of Natural Gravel with Waste Glass in Concrete

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Abstract. In this work, sheet glass waste was used as a replacing material instead of natural gravel. The mix proportion of cement - gravel - sand was (1:1.5:3) and natural gravel was subjected in each mix at different percentages (10%, 20%, 30%, 40%, and 50%) all the specimens made with natural gravel were repeated with the same specification but instead of natural gravel, sheet glass waste were subjected. Compressive strength for cubic specimens were tested after immersing for different period (1, 7, 14, 28) days and a comparisons made between the concrete of waste glass with the conventional concrete. Because of similarity of the strength of compressive results of both glass and gravel concrete, it was concluded that glass waste could replace natural gravel in concrete. It was obvious that all the percent's show this behavior, but still at a particular percent's glass concrete results were even better than gravel concrete. On the other hand glass concrete specimens were less absorbing than gravel concrete when studying the water absorption. Beside the maximum immersion time is the best to improve the properties to both series (glass, gravel).

Keywords: Materials, waste, glass, compressive, absorption.

1. Introduction
Waste glass is gradually increased due to growing use of glass products over the recent years. Waste glass consider environmentally less friendly because they are not biodegradable. The cost could be minimized by reusing waste glass in construction products [1]. The characteristics of gravel or sand are similar to Crushed glass (cullet). A proper design gradation for waste glass can be achieved after crushed and screened to use in construction applications [2]. Waste glasses can replace the aggregates in concrete [3, 4]. The major limitation in this application is damaging expansion by alkali-silica reaction (ASR). This chemical reaction causes decreasing in concrete life by weaken it due to initiation of crack upon expansion [5]. Although, dumped glass is positively contribute in improving mechanical performance of concrete [6].

N.N.M. Pauzi et.al. (2017) revealed that CRT could be an another of coarse aggregate. Concrete was prepared to have CRT as fully replacement of normal coarse aggregate. The CRT increased the density with decreasing in compressive strength and the shape of crushed affects the workability of concrete [7].

M. Liaqat et.al.(2018) utilized broken glass's waste as 10% to 40% by increasing in 10% by weight of coarse aggregates for M-20mix. These samples were prepared with W/C ratio of 0.5 and adding Alkali-silica reaction inhibitor agents. The specimens of concrete were tested for the strength of compressive and durability at different ages (3, 28 days), the results obtained were confront with those of conventional concrete showed that glass can be used as an alternate construction material to coarse aggregates up to 20% by weight for glass as coarse aggregate size up to 12mm in concrete without substantial change in strength [8].
2. Experimental Work

2.1. Materials Used

1. The Iraqi ordinary Portland cement was used and kept in dry place. The physical and chemical of cement properties are given in table(1) which conformed to Iraqi Standard Specification No.5/1984.

2. Iraqi sand was used as fine aggregate, zone 2 consistent with the requirement's of the Iraqi Standard Specification No.45/1984.

3. Tap water.

4. Sheet Glass waste (crushed to size 12mm).

5. Coarse natural Aggregates (Gravel) (size 12 mm).

| Table 1. Chemical composition & physical properties of Portland cement |
|---------------------------------------------------------------|
| **Chemical composition**                                      | **Physical properties**                        |
| Item   | Content | Spec Limit | Item   | Test result | Spec Limit |
| SiO₂   | 20.66   | -          | Fineness(m²/kg) | 310 | 230 |
| Al₂O₃  | 4.34    | -          | Autoclave exp    | 0.24 | 0.8% |
| Fe₂O₃  | 3.40    | -          | Compressive Strength (MPa) | 17.2 | 15.0 |
| CaO    | 63.71   | -          | 3-days age      | 26.0 | 23.0 |
| MgO    | 2.07    | 5.0 max    | 7-days age      | 75 min. | 45 |
| SO₃    | 1.17    | 2.8max     | Time of setting | I.R. | 1.03 |
| L.O.I. | 2.52    | 4.0 max    | Initial (min)   | 4.15 | 10 max |

Specification No.45/1984.
3. Tap water.
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5. Coarse natural Aggregates (Gravel) (size 12 mm).

3. Experimental Procedure

3.1. Specimens preparation

To evaluate the possibilities of replacing gravel in concrete by Sheet Glass waste, two main series of mixes were prepared. The first one include cement, sand and gravel while the second series include cement, sand and Sheet Glass waste instead of gravel. The proportion of mixing were (1:1.5:3) according to (Indian standard -IS 456-2000- M20). The percent of gravel (or Sheet glass waste in the second series) was altered as followed (10%, 20%, 30%, 40%, 50%); beside the gravel used in this research was (12 mm) in size and to resemble the gravel size, sheet glass waste was crushed in to (12 mm) in size too.

After collecting and crushing the glass sheet into the proper size; the molds were covered with mineral oil to keep the mixture from sticking with the mold. For three layers of each 50 mm, the concrete was casted. Each layer was compressed by a table vibrating used for 1–1.5min while waiting for no air bubble's emerged to the surface of the concrete mold. Later cubic specimen's of concrete were obtained with dimensions of (10×10×10) cm. some of the specimens were included gravel at different percent (10%, 20%, 30%, 40%, 50%); other specimens carrying the same percent but instead of gravel, crushed sheet glass were took place.
3.2. Absorption of water
The test of water absorption was determined according to ASTM C642-97[9]. After 24 hours from casting, all the specimen's were de-molded. Each specimen was marked and then completely immersed in clean tap water at different periods (1, 7, 14, and 28) days. After each period the specimens were took out of water and allowable to drain the surface water by placing them on metal wire-mesh. After that, the dry surface specimen's were weighed after obtaining the saturated weight content. At 100 °C, the specimens were placed in the oven and let them to dry and to ensure complete drying the specimens were let too dry for 48 hours. Another weighing was taking after cooling the specimens in to room temperature (the procedure above enable to calculate the water absorption according to the specification (B.S. 1881: part 122)).

3.3. Density
Densities were calculated for each specimen of concrete cubes (in g/cm$^3$); by weighing these cubes and divide their weight by the volume of these cubes (10×10×10) cm$^3$.

3.4. Compressive strength
The test of compression was determined according to ASTM C109/C109M-05. The strength of compressive of hydraulic cement mortars (Using 2” or [50mm] cubic samples) [10]. The cubic specimen's were tested by using the hydrostatic compression test machine with ultimate capacity reach of 800kN and the maximum load of compression that each specimen having the dimensions of (10×10×10) cm had been recorded. Finally the compressive strength was calculated.

4. Results and Discussion
The aim of this work were to prove if it’s possible to replace the gravel with glass or not by selecting different percent to know which one is suitable and which must be avoided.

4.1. Density
Beside shiny appearance and smoothness of the cubic specimens of glass concrete, The studying of dry densities showed a close values for both gravel concrete and glass concrete even after 28 days, except for 20% glass concrete which represent the most denes specimen among all the specimens which may be explained as the suitable arrangement of glass as aggregate and cement- sand mixture. As shown in Figure (1).
4.2. Water absorption
In general when studying the water absorption of specimens; it was obvious that the water content decrease as sheet waste glass content increases after each immersion period time especially for a long period (after 28 days). This can be explained that the porosity generate due the packing of the gravel; while the porosity is limited in the case of crushed sheet glass in concrete due to its flakes nature which make the alignment more packed and more arranged with less porosity unlike the gravel concrete. This behaviour is clearly shown in the Figures (2) and (3) after 14 and 28 days. It can be noticed that the highest in water content is the 50% gravel concrete after 14 days; while the glass concrete in general after each period and at any percent is lower in water content than gravel concrete.
4.3. Compressive strength

Two factors played the major role in determine the compressive strength of the specimens. The first one is the percentage of the replacing the gravel by glass and the second one is the immersion period. It was found that the influence of the first factor on the compressive strength of all percentages (10%, 20%, 30%, 40% and 50%) glass are close values when compare it with gravel concrete, since glass concrete is quite brittle just like conventional concrete (gravel concrete) [11].

When studying the immersion period (the second factor) it is clearly shown that the compressive strength influence by this factor. To show the effect of the percentages variation and the immersion period on the compressive strength each percentages have been studied separately to show the suitable immersion period for that percentages and which one should be avoided.

In general for the lowest percentage (10%) glass the compression strength was high on each immersion period due to the good arrangement of the crushed sheet glass with the cement-sand mixture; beside the lowest percent is the lowest influence in improving the strength of concrete.

As the percentage becomes increased the behaviour becomes different as the immersion period change, especially for 40% and 50% glass (the higher percentages) the proper immersion period was after 28 days (the longest period of immersion) and this was reflected on the final strength which made them the higher strength even than the ordinary concrete (gravel concrete). This was proven by measuring then comparing the values of the compressive strength of the specimens which become higher and their cross section showed more uniformity in structure for the glass concrete.

A remarkable notice that the close values of densities of the specimens of the gravel concrete and glass waste concrete with results of compressive referred to the possibilities of replacing gravel with glass waste, especially that at specific percentages glass concrete was higher in compressive strength even than gravel concrete.
Figure 4. The effect of replacing 10% gravel by 10% glass on compressive strength during different times in concrete

Figure 5. The effect of replacing 20% gravel by 20% glass on compressive strength during different immersion times in concrete
Figure 6. The effect of replacing 30% gravel by 30% glass on compressive strength during different immersion times in concrete.

Figure 7. The effect of replacing 40% gravel by 40% glass on compressive strength during different immersion times in concrete.
5. Conclusions
The immersion period control the properties of concrete beside percent of aggregate (or the replacing material). The similarity in results of density and strength of compressive between concrete include natural aggregate and glass waste create the possibility of utilizing the waste of glass in concrete as aggregate. The amount of water absorption depends on the sheet glass waste percent in concrete.

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