The effects of partially replacing cement by glass waste powder on concrete properties

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Abstract

The cement production causes different types of pollution in addition to the high amount of energy needed for the manufacturing process, starting by the site extraction and ending by the factory production; at the same time millions of tons of glass waste are dumped yearly at landfills. This research verifies the possibility of partially replacing cement by glass waste powder (GWP) in new concrete mixes. For this purpose, two different concrete mixes having compressive strengths of 25 MPa and 32 MPa were made with 0%, 10%, 15%, 20% and 25% of GWP as a partial replacement of cement. The properties of fresh concrete mixes were determined by the slump, air content and flow table tests. Concerning the tests on hardened concrete, the compressive strength test was carried out on cylindrical specimens at 7, 14 and 28 days in addition to the water absorption and the tensile strength tests at 28 days. As a result, the partial replacement of cement by GWP showed no clear effect on the properties of the fresh concrete mixes. Whereas, 10% GWP in 25MPa concrete mix gave higher compressive and tensile strengths at 28 days and increased the moisture content; and 15% GWP in 32 MPa concrete mix gave the higher compressive strength at 28 days but decreased the tensile strength and the moisture content.

Keywords: recycled glass, environment, compressive strength, fresh concrete properties, cement production, sustainability

Kulcsszavak: újrahasznosított üveg, környezet, nyomószilárdság, friss beton tulajdonságok, cementgyártás, fenntarthatóság

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1. Introduction

Lebanon suffers from specific and deep-rooted problems affecting waste collection, waste treatment and disposal of municipal solid waste. Since 1997, the waste sector in Lebanon has operated under an emergency municipal solid waste management plan, which ended in July 2015. This culmination in the current national trash crisis was mainly triggered by the premature closure of Lebanon's largest sanitary landfill located in Naameh in July 2015. These problems have led to significant social, economic, and environmental difficulties. In Lebanon, open dumping, and open burning of municipal waste is a common and widely accepted practice. As the case of Lebanon, most of the developing countries are facing shortage of post consumer's disposal waste sites that is becoming a very serious problem. For this reason, regenerating and using waste products as resources is necessary to prevent environmental pollution. According to GMI (Green Med Initiative), Lebanon produces around 2.04 million tons of municipal solid waste per year and glass represents 3.5% of this amount [1].

In Lebanon, the cement industry is the largest source of carbon dioxide emission; in addition, cement factories are also responsible for the emission of Nitrogen Oxide, Sulfur Monoxide, and Carbon Monoxide in the atmosphere. High concentrations of these pollutants in the atmosphere have detrimental effects on the human body and also cause environmental problems such as ozone depletion, water quality deterioration and acid rain [2].

One of the possible solutions that might minimize the environmental impacts of cement production and glass waste dumped at landfills, is to partially replace cement by glass waste powder in new concrete mixtures. On the one hand, it helps reducing the toxic gases resulting from the manufacturing process of cement and on the other hand, it valorizes glass waste instead of being dumped in landfills. Since glass is mainly composed of silica, when it is milled down into micro size particles, it is expected to undergo pozzolanic reactions with cement hydrates, forming secondary Calcium Silicate Hydrate (C-S-H) that provide strength for the concrete mix.

To study the mechanical properties of concrete when neon glass, brown glass, and green glass partially replace cement, [3] chose a design compressive strength of 35 MPa to be achieved at 28 days, with three different replacement ratios of cement by each type of glass (11%, 13% and 15%). Their results have pointed out that the compressive strength increases proportionally with curing process because the hydration process is continuous until getting the full strength of concrete; the highest compressive strength that appeared at 28 days was

31.75 MPa with 13% replacement of cement by neon glass. The results of splitting tensile strength tests showed that the splitting tensile strengths of the three different types of glass were greater than that of the control concrete mix, especially for green glass where the higher value was recorded at 13% replacement. The results also showed that the splitting tensile strength increased gradually at 11% and 13% for neon, green, and brown glass but decreased at 15% for all the three types of glass.

[4] tested four different replacement ratios of cement by glass waste powder (5%, 10%, 15%, 20% and 25%) in order to achieve a target compressive strength of 35 MPa. The difference in compressive strengths between the control mix and the mix with 25% glass replacing cement at 180 and 365 days were further reduced and provided similar mean compressive strengths. At the age of 180 and 365 days, the 20% replacement of cement by glass gave 10% and 14% respectively higher strengths than the control concrete mix. The results revealed that an increase in the replacement ratio of glass resulted in a slight increase in the mortar flow while a minor effect on concrete workability was noted. In addition, the results have shown that the compressive strength was decreasing with the addition of glass powder in recycled glass mortar and concrete, but gave better strength compared to control samples at later age.

[5] took the waste bear bottles and soda lime glass and transformed them into powder of 75 μm diameter to study the pozzolanic reaction of glass powder for up to 60% cement replacement and its influence on the microstructure of cement paste, which has not been investigated before. The design compressive strength in this study was 48 MPa and four percentages of cement were replaced by glass waste powder (15%, 30%, 45% and 60 % by weight of cement). As a result, the rate and the total heat generated during the hydration consistently decreased with higher glass powder content due to the dilution of cement in the mix. Concerning the compressive strength at 28 days, the 30% replacement of cement by glass waste powder gave 49 MPa (the highest compressive strength), whereas its compressive strength was 55 MPa at 91 days. The results have revealed that this increase in later age strength was not observed for concrete in which more than 30% cement is replaced by glass waste powder. Therefore, there is an upper limit for cement replacement level, beyond which no further pozzolanic reaction of Glass Waste Powder (GWP) can occur; this replacement level is lower than 30%.

[6] has summarized in her research entitled "Performance of lamp glass waste powder (LGWP) as supplementary cementitious material (SCM) – viscosity and electrical conductivity" the experimental results of a laboratory test series carried out on cement mortar specimens, in which two different lamp glass waste powders were used as cement component: the incandescent light bulb borosilicate glass waste cullet powder (LGWP1) and the fluorescent lamp tube glass waste cullet powder (LGWP2). Patricia had demonstrated that Portland cement substitution with lamp glass waste powders at a level of 30% is possible without any strength loss, moreover, the addition of superplasticizer admixture led to an increase in compressive strength by 15-17% in comparison to the control mortars.

[7] substituted the cement with waste glass powder at levels of 20% or 30% per mass. It was demonstrated that the waste glass powder addition improves the workability of fresh pastes and can be effectively used as cement replacement for compressive strength. It was also demonstrated that the particle size of the waste glass powder (specific surface area) has a stronger influence on the effectiveness of the cement replacement than the chemical composition. The effectiveness of the cement replacement increases as the specific surface area increases.

The results in the literature review showed promising results in terms of the effect of partial replacing the cement by glass waste powder in new concrete mixes and motivated the researchers to undergo an experimental study to analyze the GWP generated in Lebanon and evaluate its effects on the fresh and hardened properties of concrete.

2. Experimental plan

In this study, two different concrete mixes having compressive strengths of 25 MPa and 32 MPa were performed with different replacement ratios of cement by glass waste powder, with reference to the absolute volume method [8]. These two compressive strengths were taken in order to try if possible to not limit our uses only by the 25 MPa concrete mix in all the structural elements of a real life project, especially in high-rise buildings where there is a need to increase the compressive strength of some beams and columns in some stories instead of enlarging there sections, which the architect might not agree on. The different percentages of cement that were replaced by the glass waste powder were the following: 0%, 10%, 15%, 20% and 25%. This resulted in 10 different concrete mixes that were prepared and tested in the laboratory. The maximum replacement ratio was limited by 25% due to the crushing method of the glass that takes a lot of time to give the wanted particles size.

The tests conducted on fresh concrete included the slump test, flow table test, and the air content test. Concerning the hardened concrete tests, the compressive strength test was performed to obtain the compressive strength; the concrete specimens were crushed at 7, 14 and 28 days with three specimens at each age; therefore, nine specimens were tested for the compressive strength [9], and one additional specimen was tested for the indirect tensile strength test [10]. In total 50 cylinders of 150 mm diameter and 300 mm height were prepared for each concrete mix. Furthermore, the water absorption test was conducted to evaluate the effect of inclusion of glass powder on the porosity of concrete [11].

3. Materials

3.1 Cement

The ordinary Portland cement used is fabricated by Holcim (Liban) S.A.L, according to the Lebanese specifications LIBNOR (NL 53:1999) for the cement PA-L, 42.5. The specific gravity and the density were found to be 3.15 and 1551 kg/m^3 respectively [8].

3.2 Glass

The chemical analysis by Energy Dispersive X- Ray Fluorescence Spectrometer (ARL-9800 XP) of the glass waste powder and Portland cement showed in *Fig. 1*, indicates that the waste glass collected from Golden Glass Company located at Al-Badawi / North Lebanon, has a high percentage of silica and has almost the same content of ordinary Portland cement but with different percentages. The glass was crushed using the Los Angeles machine in order to minimize the particles size to less than 75 µm (see *Fig. 2*). Crushing 8 kg of glass waste into the Los Angeles machine took six hours and resulted in approximately 3 kg of glass powder of less than 75 µm particles size.

The density of the GWP was determined to be 1200 kg/m^3, by dividing the mass of the glass powder filled in a cylinder by its volume; in addition, using the Chatelier apparatus, the specific gravity of the GWP was calculated to be 2.75 [8].

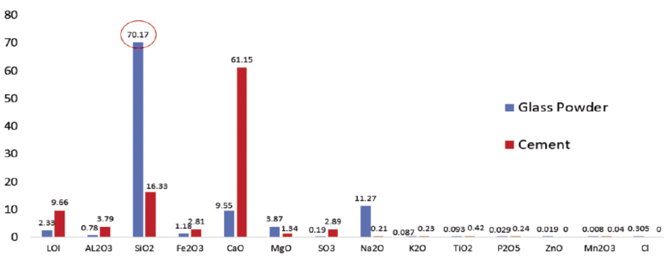

Fig. 1 Comparison between the chemical composition of the glass waste powder and Portland cement
1. ábra Az üveghulladék por és a portlandcement kémiai összetételének összehasonlítása

Fig. 2 Glass particles reduced from 30 mm to less than 75 µm
2. ábra Üveg részecskék porítása 30 mm-es méretről kevesebb mint 75 µm-re

3.3 Aggregates

The used fine aggregates (sand) have a fineness modulus of 2.89, specific gravity of 2.77, and water absorption of 3.09%. While the coarse aggregates used have a specific gravity and absorption of 2.46 and 2.41 respectively [8].

4. Experimental results and discussion

4.1 Fresh concrete properties

The partial replacement of cement with glass powder showed no clear effect on the results of the slump test in both, 25 MPa and 32 MPa concrete mixes. The slump results were very close and within the target values (25 mm-75 mm). The 20% GWP in 25 MPa concrete mix, resulted in the highest level of slump (75 mm), showing an advantage of improving the workability when partially replacing cement with waste glass powder. This partial replacement was however not efficient for the compressive strength (*Fig. 3*). On the other hand, the results represented in *Fig. 4* show that the GWP at 10% and 15% resulted in the highest slump in the concrete mix of 32 MPa (75 mm).

Similarly, the results of the air content test showed no clear effect of the glass powder on the air content in fresh concrete for both concrete grades, as the obtained results were close to the calculated air content for non-air entrained concrete, and within the percentage of air calculated for the control mixes see *Fig. 3* and *Fig. 4*.

The results of the flow table test showed an increase in the flow percentage when the percentage of glass waste powder increase in the 25 MPa concrete mix (*Fig. 3*), while as shown in *Fig. 4*, no clear effect was recorded for 32 MPa concrete mix.

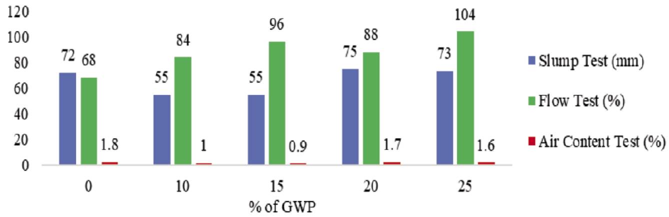

Fig. 3 Results of slump, flow table and air content tests (25MPa Concrete Mix)
3. ábra Roskadás-, terülés- és légtartalom vizsgálat eredményei (25 MPa beton keverék)

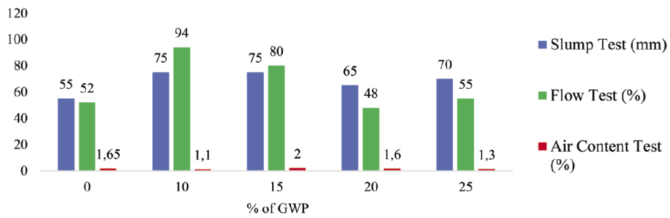

Fig.4 Results of slump, flow table and air content tests (32MPa Concrete Mix)
4. ábra Roskadás-, terülés- és légtartalom vizsgálat eredményei (32 MPa beton keverék)

4.2 Hardened concrete properties

For the 25 MPa concrete mix, the results show that the compressive strength of the concrete cylinders at 7, 14 and 28 days decrease with the increase of the % of GWP. However, for a replacement ratio of 10%, an average compressive strength of 25.6 MPa was achieved, exceeding by that the designed compressive strength at 28 days (*Fig. 5*). For the 32 MPa concrete grade, the results showed similar trends, except that a higher compressive strength was observed with a replacement ratio of 15% compared to 10%.Therefore, the use of 15% GWP as a replacement of cement represent the optimal replacement ratio without affecting the compressive strength of the design mix at the age of 28 days (*Fig. 6*).

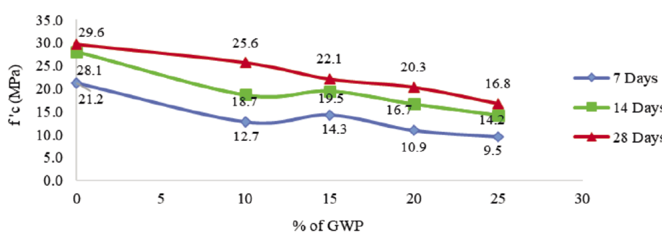

Fig. 5 Evolution of the compressive strength of 25 MPa concrete mix for 7, 14 and 28 days
5. ábra 25 MPa-os betonkeverék nyomószilárdságának alakulása 7, 14 és 28 napos korban

Concerning the tensile strength test, the 10% replacement of cement by GWP in 25 MPa concrete mix increased the tensile strength of the control mix by 0.4 MPa (from 2.4 MPa to 2.8 MPa). In contrary, the tensile strength test of 32 MPa concrete mix, showed no values above 3 MPa (the tensile strength of the control mix), where the results obtained showed a decrease in the tensile strength when the percentage of replacement of cement by GWP increased (see *Fig. 7*).

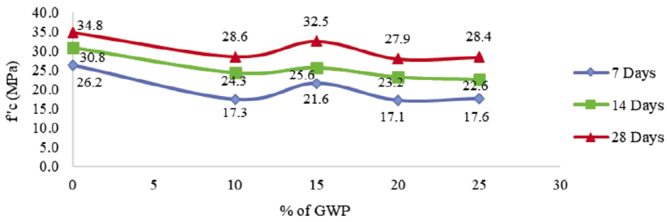

Fig. 6 Evolution of the compressive strength of 32 MPa concrete mix for 7, 14 and 28 days
6. ábra 32 MPa-os betonkeverék nyomószilárdságának alakulása 7, 14 és 28 napos korban

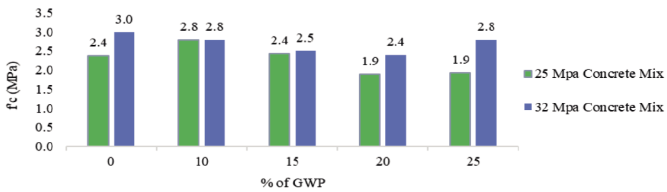

Fig. 7 Results of the tensile strength test of 25 and 32 MPa concrete mixes
7. ábra A 25 és 32 MPa-os beton keverékek húzószilárdság vizsgálatának eredményei

In terms of durability, the water absorption of the 25 MPa concrete mix with 10% GWP increased by 17.8% compared to the control mix. Consequently, construction in cold regions are not encouraged for such concrete use. On the contrary, for the 32 MPa concrete mixes, the water absorption increased when GWP content increased; the concrete mix with 15% GWP has lowered the water absorption of the control mix (32 MPa) from 2.69% to 2.64%, whereas 10% GWP increased this percentage to 3.18% (*Fig. 8*).

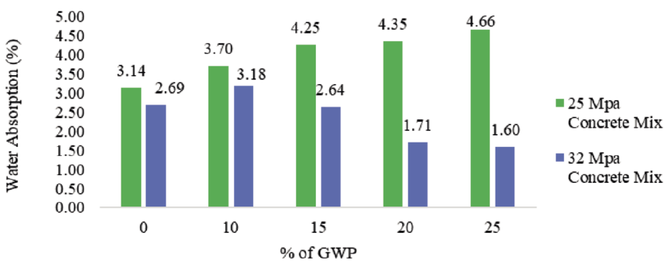

Fig. 8 Results of water absorption test of 25 and 32 MPa concrete mixes
8. ábra A 25 és 32 MPa-os beton keverékek vízfelvétel vizsgálatának eredményei

5. Conclusions and outlook

In conclusion, this research had revealed that reusing 10% and 15% of Glass Waste Powder in 25 MPa and 32 MPa concrete grades respectively has no clear effect on the air content in fresh concrete, but provides a very good workability, as the given slump values were within the target range that was 25mm-75mm in both concrete mixes. Concerning the flow table test, the flow percentage increased from 68% to 84% and from 52% to 80% in 25 MPa and 32 MPa concrete grades respectively.

In term of strength, the results showed that the concrete with Glass Waste Powder averagely has lower compressive strength compared to the control mix at 7, 14 and 28 days in both concrete grades. However, the 10% and 15% of Glass Waste Powder that replaced the cement in 25 MPa and 32 MPa concrete mixes respectively, exceeded the target compressive strength of 25 MPa by 2.4% and 32 MPa by 1.6%.

Therefore, reusing waste materials such glass in new concrete mixes could be a possible solution to save thousands of tons of waste glass from being dumped yearly at landfills and to minimize the environmental effects of cement production and solid waste crisis that Lebanon is suffering from.

However, to standardize the usage of GWP in concrete, there is a need to additionally conduct microscopic and hydration studies for the qualitative assessment and quantitative analysis of hydration and pore fillers according to the physical properties and the chemical compositions of waste glass powder.

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