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The influence of glass powder as a cement replacement material on Ultra-High-Performance Concrete

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الملخص العربى:

تم في هذا البحث دراسة تأثير استبدال جزء من محتوى الاسمنت بمسحوق الزجاج الناتج عن طحن مخلفات الزجاج على الخواص الميكانيكية ومتانة الخرسانة عالية الادائية. حيث تم استبدال جزء من الاسمنت وابخرة السيليكا بمسحوق الزجاج بنسب 10, 20 ,30 , 40 % وتم معالجة العينات معالجة قياسية في درجة حرارة الغرفة. و قد تم اجراء اختبار تعيين مقومة الانحناء لعينات من المونة الاسمنتية بأبعاد 25×25×280 مم وايضا اختبار مقاومة الخرسانة للاحتكاك والبري على مكعبات بأبعاد 70×70×70 مم. و قد اثبتت الدراسة كفاءه مسحوق الزجاج في تحسين خواص الخرسانة الميكانيكية ومتانتها، و من ثم يمكن انتاج خرسانة زجاجية عالية الادائية ذات متانة وخواص ميكانيكية فائقة وبذلك يمكن تقليل الاثار السلبية على البيئة الناتجة من صناعة الاسمنت وأيضا اعادة استخدام مخلفات الزجاج.

الكلمات الدلالية: خرسانة فائقة الادائية، مسحوق الزجاج ، مخلفات الزجاج.

Abstract:

This research studied the influence of adding glass powder resulted from grinding glass wastes (Particle size approximately 10 µm) on the mechanical properties of Ultra-High Performance Concrete (UHPC) when used as a partial replacement material cement and silica fumes. Cement and silica fumes were replaced partially by the exact percentages of 10, 20, 30, and 40% by glass powder. The specimens were normally cured in water at room temperature. After that, flexural strength was tested on prisms of 25×25×280 mm, and an abrasion test was held on cubes of dimensions 70×70×70 mm. The study proved the efficiency of glass powder to enhance the mechanical and durability properties of Ultra-High Performance Concrete. Therefore, using waste glass powder as cement replacement can help save the environment by reducing the amount of used cement in construction.

Keywords: Glass Powder, Glass wastes, green concrete, abrasion, flexural strength, UHPGC, UHPC.

1. Introduction

Conventional Concrete (C.C.) with typical cement content (200-450 kg/m^3) has low strength, durability, workability, and high fragility that may affect structural elements' performance and weight. Therefore, producing a new type of concrete such as Ultra-High Performance Concrete (UHPC) provides superior mechanical, durability, and ductility properties since it has higher cement content, silica fumes, quartz powder, quartz sand, and steel fibers. Nowadays, UHPC is used in precast and pre-stressed concrete for the construction of bridges and high-rise buildings.

Lately, many researchers tend to study new types of UHPC using eco-friendly materials as a replacement for cement [1]. Glass is one of the most suitable materials used for that purpose due to its high pozzolanic activity. Moreover, a vast amount of glass waste is dumped in landfills and not recycled due to expensive recycling costs [2]. Therefore, researchers tried to get benefits from non-recycled glass wastes and use those wastes as a replacement material for cement.especially, that glass has zero water absorption, but cement absorbs a portion of mixing water. Furthermore, glass has a high pozzolanic activity, which helps in increasing the strength of concrete. Therefore, why don't researchers get a new sort of green concrete, especially that glass has zero water absorption compared to cement and its high pozzolanic activity, which means a high degree of reaction over time [3].

Recently, manufacturing of Ultra-High-Performance Glass Concrete (UHPGC) with variable size of glass particles provides high workable concrete due to zero water absorption by glass particles. Moreover, the higher mechanical and durability properties of UHPGC improves concrete structures' behavior and design, as it approximately reduces sections by 60% compared to normal strength concrete. Also, it decreases glass wastes by replacing large quantities of cement and thus, reducing the cost. Moreover, the UHPGC has many other advantages, as stated by Soliman et al. [4], in the following points

- (i) It reduces the dimensions of concrete elements due to its higher mechanical properties compared to the conventional concrete;
- (ii) Consequently, it reduces the self-weight of structural elements by more than 60%;
- (iii) It extends the service life of the structure;
- (iv) It reduces the maintenance costs due to its superior durability properties.

This study aims to increase the applicability of using glass powder to replace cement in concrete mixes to achieve higher mechanical and durability properties and find a green type of concrete to replace the traditional ones.

2. Experimental Program

This research project aims to achieve hardened properties of Ultra-High Performance Concrete (UHPC) using glass powder as an alternative material for cement and silica fumes, by replacement values of 10, 20, 30, and 40% by weight. In addition, the properties of the materials were clarified according to the specified tests and certified datasheets. The experimental program consists of two phases: Phase (I) aims to evaluate the chemical and physical properties of raw materials, while Phase (II) aims to evaluate the mechanical properties of the modified concrete mixture to achieve an optimum mix for high abrasion resistance, flexural strength, and acceptable fresh properties. The tests performed to assess the mechanical properties of the UHPGC are the following: (i) Abrasion properties determined according to DIN 52108 [5]; and (ii) Flexural strength according to ASTM C293 [6].

2.1. Evaluating the Properties of Raw Materials

2.1.1. Properties of Glass Powder (GP):

Glass powder (GP) was the wastes of broken glass from EL NASR COMPANY FOR GLASS, Egypt, as shown in **Figure 1**. The glass is made from three main chemical components: silicon dioxide (SiO_2), calcium carbonate ($CaCo_3$), and sodium carbonate (Na_2Co_3) melted at a temperature of 1400 - 1600^{o}C. The glass was ground using a grinding machine to be a fine powder, as shown in **Figure 2**. XRF test was applied on a specimen of glass powder to determine its chemical composition, as presented in **Table 1**. In addition, the same specimen underwent a laser sieve analysis test to find that (D_{max} = 26.59 µm) and (D50 = 14.216 µm), according to **Figure 3.**

D_{50}: The portions of particles with diameters smaller and larger than this value are 50%.

D_{max}: The maximum particle size.

Figure 5: Glass wastes before grinding

Figure 2: Glass wastes after grinding to fine glass powder

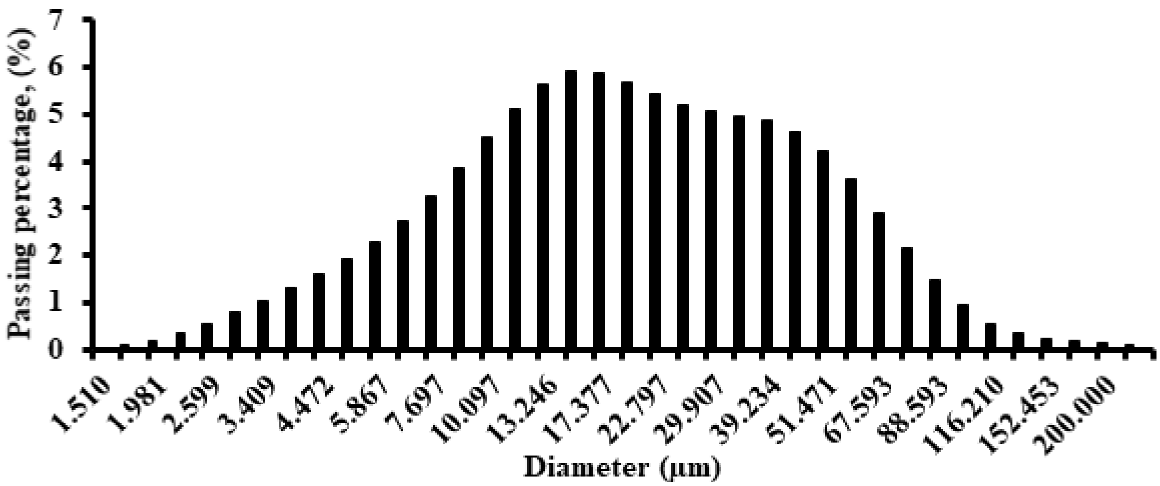

Figure 3: Laser scattering particle size

Table 1: Chemical composition of glass powder according to XRF test

Oxide content (%)										
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I**	Total
74.85	1.52	0.28	4.32	5.10	0.19	12.90	0.13	0.08	0.49	99.87

**According to ASTM C114 [7]

2.1.2. Properties of Sika Fumes- HR

Sika Fumes-HR is a new generation of concrete additives in powder form based on sika silica **fume** technology. It contains extremely fine reactive silicon dioxide of an approximate size of 0.1µm, as shown in **Figure 4**. As well as, its bulk density was 300 kg/m^3. It was recommended to use Sika Fume-HR to improve the internal cohesion and water retention towards incredibly soft mix and improved pumping properties. Sika Fume-HR was added by dosage 10% of cement weight, according to ASTM C494 [8] and ASTM C1017 [9]

Figure 4: Sika Fumes –HR

2.2. Concrete Mix

Ultra-High Performance Concrete (UHPC) requires a precise mixing procedure and high-quality control. A detailed description for the steps of mixing is clarified, as well as procedure of flexural and abrasion tests. Five mixtures were prepared using six materials such as Portland cement, water, quartz sand, sika fumes-HR, sika Visco-flow10, and glass powder. The mixtures were prepared with different replacement percentages and constant water binder ratio (w/b = 0.2). Constant water, quartz sand, and sika Visco-flow10 were used. In each mixture, cement and sika fumes-HR are replaced by glass powder with the same ratio for both 0, 10, 20, 30, and 40%.

Test Matrix and Experimental Program

2.3. Test Matrix

Mixture constituents in kilogram for binders and liter for water and superplasticizer per cubic meter of mortar are shown in **Table 2**

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Table 2: Test Matrix for Cubic Meter of Mortar

Mixture ID	Cement	Sika fumes-HR	Quartz sand	Sika Visco-flow 10	Water	Glass powder
Control	1080	108	950.86	10.8	237.6	0
10%	972	97.2	950.86	10.8	237.6	118.8
20%	864	86.4	950.86	10.8	237.6	237.6
30%	756	75.6	950.86	10.8	237.6	356.4
40%	648	64.8	950.86	10.8	237.6	475.2

2.4. UHPGC Properties

3.2.1. Flexural Strength

Testing specimens determined the flexural properties of the UHPGC according to ASTM C293[6] . Prisms of 40×40×160 mm for mortar were cast. The prisms were filled with mortar then compacted on vibrating tables. Specimens were cured and placed in water tanks at room temperature. A flexural strength test was conducted after 28 days of curing. **Figure 5** shows the flexure test setup.

Figure 5: Typical specimen under flexural testing

3.2.2. Abrasion Test

Cubes of dimensions 70×70×70 mm were tested under abrasion. The machine was cleaned, and sand spread on the primary disk, the specimen was put between the jaws, the used load was 5.0 N. The dimensions and the weight of specimens were measured before testing then each specimen was subjected to abrasion for 500 m (tested for 11 minutes continuously), as shown in **Figure 6**. The weight was measured again to get the weight loss. The test was held according to DIN 52108 [5].

Figure 6: Typical specimen under abrasion testing

Results and Discussion

2.5. Flexural Strength Test Results

All specimens were cured under normal conditions for 28 days. The flexural specimens were tested under three point loading test, as shown in **Figure 7**. All specimens were failed due to tension at the bottom face, as shown in **Figure 7**. The prism specimens provided a flexure strength value of 18.22, 20.1, 27.88, 17.43, and 14.39 MPa for control mix, 10%, 20%, 30%, and 40% cement replacement, respectively. Therefore, the highest flexure strength was 27.88 MPa, corresponding to 20% of glass-cement replacement, as clarified in **Figure 8**. This behavior is attributed to the pozzolanic activity of grass powder with the calcium hydroxide to increase CSH gel. The flexural strength varies by changing the precentages of replacement by 0, 10, 20, 30 and 40% to be 18.2, 20.1, 27.9, 17.4 and 14.4 MPa.

Figure 7: Typical prim specimen under flexure failure

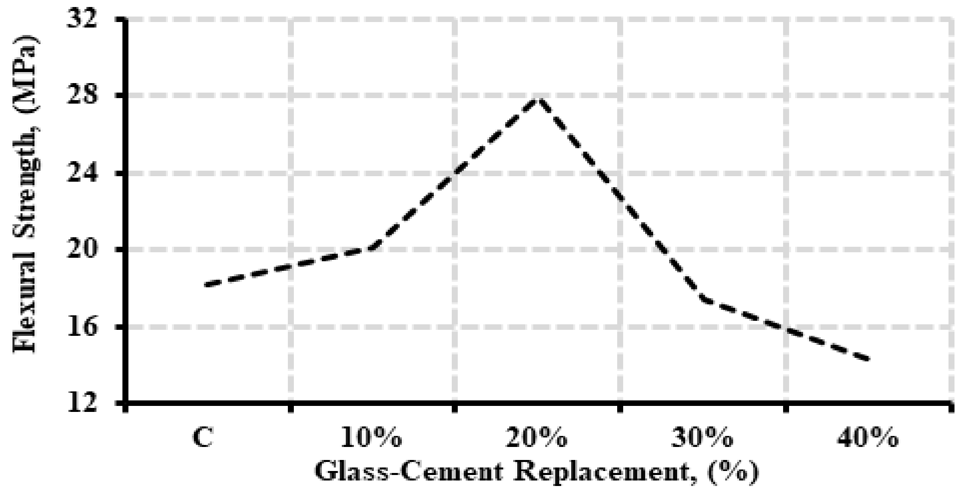

Figure 8: Average Flexural strength values of prism specimens at various cement replacements; 0, 10, 20, 30, and 40%.

2.6. Abrasion Test Results

The abrasion test results after 28 days showed that the control, 20%, and 30% replacement specimens had the most abrasion resistance as their specimens had the lowest height loss due to the high strength and compaction. The height loss of the specimens control, 10, 20, 30 and 40% glass-cement replacement was detected to be 0.34, 0.68, 0.32, 0.31 and 0.51 respectively.

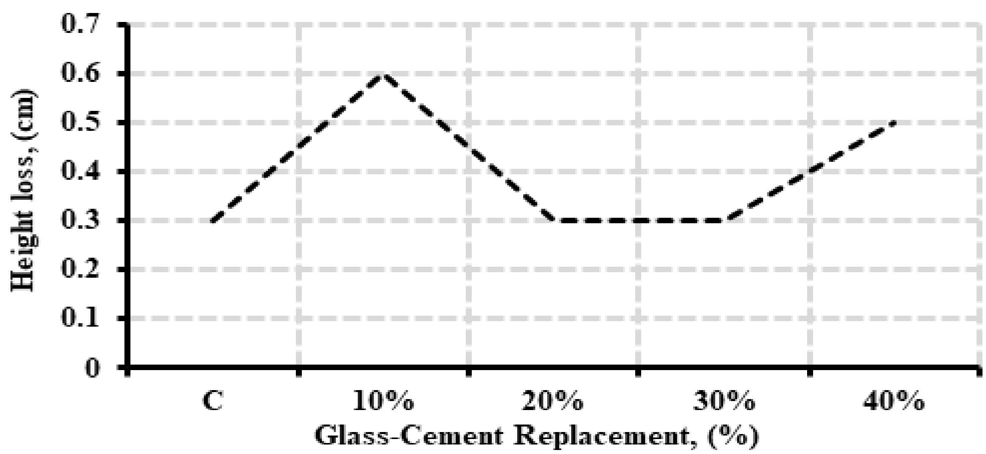

Figure 9: The influence of glass-cement replacement on height loss during abrasion testing

Finally, the observed optimum mixture was the 20% of glass cement replacement as it gives the highest flexural strength, and resistance to abrasion. **Figure 9** shows the height loss of cube specimens for various mixtures at 0, 10, 20, 30, and 40% cement replacement by glass powder.

Conclusions and Recommendations

This paper presented the preliminary results of a study conducted to characterize Ultra-High Performance Glass Concrete (UHPGC). Based on the test results presented herein, the following conclusions are drawn:

- Green concrete was produced using glass wastes, and this type of concrete is rescuing the environment against the harms caused by glass wastes and its non-decomposition and the harms of Co2 emissions due to cement manufacturing.
- The 20% glass-cement replacement specimen shows the best flexural resistance that reached 27.9MPa.
- The minimum height loss resulting from abrasion 20% and 30% of cement replacement by glass powder.
- The experimental study presented is limited to transparent glass powder used in this study and should not be extended to other colors or types of glass.

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