Performance Evaluation of Eco-Friendly Ultra-High-Performance Concrete Incorporated with Waste Glass-A Review

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Abstract. The ultra-high-performance glass concrete (UHPGC) is an advanced UHPC innovative pioneer in sustainable concrete technology. UHPG technology can provide environmental benefits through the use of post-consumer glass. Economic benefits through the decrease in the amount of landfilled materials are undesirable as they are neither biodegradable nor environmentally friendly and could reduce the costs for UHPC. Compressive strength greater than 150 MPa and mini-slump spread diameter bigger than 250 mm can be achieved, depending on the UHPGC composition and curing temperature. The glass powder (GP) milled to the micro-scale is subjected to low pozzolanic reaction and works as a catalyst speeding clinker dissolution forming calcium silicate hydrate (C-S-H). These reactions have a good positive influence on both UHPC's mechanical and microstructural properties. This paper overviews previous studies carried out as partial or full replacement of sand or quartz sand (QS), quartz powder (QP), and silica fume (SF) by the use of milled waste glass (WG) in UHPC mixture. Nowadays, the sustainability of the construction sector must be a priority for the scientific community. So, the development of the used materials and methods to extend the lifetime of concrete structures is mandatory.

Keywords. Performance evaluation, eco-friendly, UHPC, Waste Glass.

1. Introduction
Recent advances in concrete technology have created new types of cementitious composites such as high strength concrete (HSC), self-compacting concrete (SCC), self-healing concrete, ultra-high-performance concrete (UHPC), etc. Usually, UHPC is described by the low W/C (water-cement ratio), excellent workability, advanced durability, and high mechanical properties. These properties depend mainly on the distribution of particle size, density, and optimum W/C ratio [1]. UHPC is one of the concrete types with a compressive resistance that exceeds 150 N/mm², a tensile strength over 7 N/mm², and little porosity. The positive characteristics are due to the mixture's increased homogeneity by replacing the coarse aggregates with fine sands and quartz powder. The mixture is also characterized by large quantities of cement, SF, small water-cement ratios (w/c), and the use of high-range water-reducing admixtures [2]. Because of these super mechanical properties of the UHPC, lighter construction structures with long spans, new design with a potentially cheaper cost and less resource consuming than steel, traditional concrete can be achieved. High cement contents are used to make UHPC mixtures. Also, SF (0.1-1 μm), superplasticizer, very fine quartz sand (0.15 - 0.60 mm),
and QP (smaller than 10 μm) without coarse aggregate. Fine QS substitutes coarse aggregate. The substituting quartz is optimally graded at 150–600 μm to reduce heterogeneity between the cement matrix and the aggregate. As a result, a dense microstructure is produced. This significantly improves UHPC performance [3],[4]. The population and industry are overgrowing. As a result, enormous waste is generated. Therefore, recycling wastes has turned critical universally. In theory, the best sustainability for reusing wastes is the closed-loop recycling technique [5]. With a growing understanding of the value of environmental preservation and the conservation of natural resources, concrete sustainability as a construction material has turned a concern to engineers and researchers. Using waste in concrete offers significant advantages such as reducing waste disposal costs, decreasing greenhouse gas pollution, and conserving raw materials. These advantages satisfy the increasing rigorous regulations of the environment and enhance concrete features. Glass has been researched as a replacement for fine aggregates, and even cement, among the various forms of solid waste. Because of its chemical compositions and physical features, WG well substitutes sand, powder sand, and SF, which are particularly important for areas that lack natural resources dealing with waste disposal [6]. Recycling of WG by converting it to fine aggregate or powder provides landfill areas and reduces the request for raw material for building[7]. The advantage of using WG as a replacement for QP or fine aggregates in concrete provides a potential environmental solution to the growing problem of effective GW management in some developing countries[8]. In sustainable construction development, and new materials are used. Also, waste materials could replace natural resources with alternative ways to conserve the environment. The replacement of QS with glass sand (GS) extracted by crushing WG cullets in the UHPC may reduce QS use to the lowest point as QS sources are minimal, expensive, and harmful to the environment. This replacement will significantly decrease the usual UHPC cost by decreasing the content of QS or reduce the QS transport costs when the local GS is used in the production of UHPGC. Besides, human carcinogenic and environmental hazards because of QS in UHPC can be reduced [9],[10]. QP causes short and long-term ecological harm because of its environmental diversity. This diversity is a concern for the environment. The "International Agency for Research on Cancer (IARC)" considers respirable QP carcinogenic to humans because it is a Group I carcinogen. Also, the U.S. National Toxicology Program listed respirable-sized small crystalline silica as a human carcinogen. Thus, work to substitute QP with other safe, harmless materials should be conducted. The substitution of QP with GP can intensely decrease the UHPC cost [9],[11]. In addition, replacing SF with fine glass powder (FGP) in UHPC mixing could save SF material limited in availability. The WG non-biodegradable can be reused, minimizing the quantity that must be processed or deposited in landfill [12].

Environmental problems have been taking into consideration the difficult situations in modern construction industries. Reusing and recycling wastes are considered as one of the most important methods to reduce waste. Indeed, a few articles on fresh and hardened features and durability of UHPGC consisting of WG as a partial or full replacement of SF, QP, and QS can serve the market. This research presents a review of the feasibility of sustainable reuse of WG and GP crushed into fine aggregate size as a replacement for sand in the production of UHPGC and reviewed the past outcomes of this topic to be a standard reference for further studies.

2. Recycle waste glass

More than a million tons of WG are generated worldwide per year. When the glass becomes a WG, it is disposed of in landfills. This disposal is harmful because glass does not decompose in the environment [13]. Glass is commonly considered a solid substance consisting of non-crystalline silica, calcium oxide, sodium oxide, etc. The used raw materials make the chemical composition vary significantly in each glass use[14]. Per year, thousands of tons of end-use glass are obtained separately from municipal waste worldwide. Owing to its amorphous nature and its high silica content, recycled glass has been used as a fine aggregate and supplementary cementing materials (SCMs) in concrete [15]. According to “The United States Environmental Protection Agency (U. S. EPA),” the US generate 11,500,000 million tons of WG a year. Therefore, reusing or recycling WG is required to
prevent contamination generated by storing or disposing WG in landfills or dumping sites. Glass is considered non-biodegradable in comparison to other solid waste substances, that can produce a considerable menace to the environment [8]. Because glass is 100% recyclable, its waste can be recycled endlessly with the properties of purity and quality remain [16]. However, there is less glass recycling in developed countries than other solid waste materials. Despite the growing attempts to recycle WG, more than 50% of collected WG in some parts of the world are deposited in landfills [8] [17].

In practice, only some glass types are reusable to new glass because other glass types are impure, expensive, or mixed in colors. The development of new recycling options for WG is required, for example, employing WG in concrete and constructing materials [18]. Because of the glass's outstanding hardness, substantial studies are conducted to recycle glass as a small aggregate for concrete. Crushed pieces of glass that have been used as aggregates are usually angular in form and can have certain elongated and smooth pieces. The angularity degree, flat number, and the elongated particles depend on the crushing degree [19]. This deposition is non-biodegradable waste in landfills. This means it harms the environment. Because of the low recycling rate, landfill areas for modern landfills are rare. Generally, in solid waste management systems, WG is a problem. In the construction industry, such as the industry of the cement and concrete could be a very effective and useful solution for the influence of glass waste on the environment because of the physical features and the chemical composition of glass with similar features of the composition of sand, as Table (1) shows [20].

### Table 1. Colored glasses and cement chemical composition [20].

| No. | Chemical | Cement % | Clear glass% | Brown glass % | Green Glass % | Crushed glass % | Glass powder % |
|-----|----------|----------|--------------|---------------|---------------|-----------------|----------------|
| 1.  | SiO₂     | 20.2     | 72.42        | 72.21         | 72.38         | 72.61           | 72.20          |
| 2.  | Al₂O₃    | 4.7      | 1.44         | 1.37          | 1.49          | 1.38            | 1.54           |
| 3.  | CaO      | 61.9     | 11.50        | 11.57         | 11.26         | 11.70           | 11.42          |
| 4.  | Fe₂O₃    | 3        | 0.07         | 0.26          | 0.29          | 0.48            | 0.48           |
| 5.  | MgO      | 2.6      | 0.32         | 0.46          | 0.54          | 0.56            | 0.79           |
| 6.  | Na₂O     | 0.19     | 13.64        | 13.75         | 13.52         | 13.12           | 12.85          |
| 7.  | K₂O      | 0.82     | 0.35         | 0.2           | 0.27          | 0.38            | 0.43           |
| 8.  | SO₃      | 3.9      | 0.21         | 0.1           | 0.07          | 0.09            | 0.09           |
| 9.  | TiO₂     | -        | 0.035        | 0.041         | 0.04          | -               | -              |
| 10. | Loss on ignition | 1.9 | - | - | 0.22 | 0.36 | |

3. The use of waste glass to partially replace quartz sand and QP in UHPC

Waste glass provides comparable alternatives as a substitute for the traditional concrete aggregates and utilizes crushed granular WG as fine aggregate and sand powder in concrete. It saves the environment and decreases the need for raw material extraction [21]. The relevant legislation has recently promoted the use of unconventional aggregates in Europe and has provided environmental benefits, such as the safeguarding of non-renewable raw materials and the off landfill disposal. Recycled glass has already been used as concrete aggregates [22] using ground glass sand (GS) as partially or entirely replacing QS in UHPC. The particle-size distributions (PSD) of the QS used in UHPC mixtures are about 150-600 μm with a d50 of 250 μm. Different studies were conducted on the replacement ratios from 0% - 100% for the QS [23]. The concrete sand glass powder density (SGP) is higher than that of the standard concrete. SGP is available as waste in large amounts and can be utilized in concrete manufacturing. This will go a long way toward decreasing waste in our environment [24]. Recently, there have been some attempts to use WG, in concrete, as supplementary cementitious materials (ASCMs) as alternatives. There are other attempts to utilize ultrafine fillers, according to its chemical composition and PSD. The use of WG as fine aggregate makes concrete resist chloride penetration by glass ground to a particle size finer than (38 μm). This makes the concrete resistant and durable when the crushed WG is used as fine aggregate. The chemical composition of the recycled glass is given in Table (2) [9].
Table 2. Chemical compositions of high-sulfate resistance cement (HS), GP, SF, quartz sand, and QP.

| No. | Composition % by mass | Cemen | Quartz sand | Quartz powder | Silica fume | Glass powder |
|-----|-----------------------|-------|-------------|--------------|-------------|-------------|
| Chemical compositions % | SiO$_2$ | 22    | 99.8        | 99.8         | 99.8        | 73          |
|  | Al$_2$O$_3$ | 3.5   | 0.14        | 0.11         | 0.11        | 1.5         |
|  | Fe$_2$O$_3$ | 4.3   | 0.04        | 0.9          | 0.9         | 0.4         |
|  | CaO      | 65.6  | 0.17        | 0.38         | 0.4         | 11.3        |
|  | TiO$_2$  | 0.2   | 0.2         | 0.25         | -           | 0.4         |
|  | SO$_3$   | 2.3   | --          | 0.53         | -           | -           |
|  | MgO      | 1.9   | 0.01        | 0.2          | 0.2         | 1.2         |
|  | Na$_2$O  | 0.07  | --          | 0.25         | 0.2         | 13          |
|  | K$_2$O   | 0.8   | 0.05        | 3.5          | 0.5         | 0.5         |
|  | Na$_2$O$_{soil}$ | 0.9   | --          | --           | -           | -           |
|  | ZnO      | 0.09  | --          | --           | 0.25        | -           |
|  | Loss on ignition | 1     | 0.2         | 0.32         | 3.5         | 0.6         |

Physical properties

| Unit weight | 3.21 | 2.7 | 2.73 | 2.20 | 2.6 |
| Blaine surface area ($m^2/kg$) | 430 | - | - | 20.0000.1 | 380 |
| Average particle size, $d_{50}$ | 11 | 250 | 13 | 5 | 12 |
| Largest particle size, $d_{max}$ | - | 600 | - | - | 100 |

4. The use of waste glass to partially replace silica fume (SF) in UHPC

There are three main functions of ultra-fine silica fume with high amorphous silica in UHPC. The first is filling voids in the larger granular class. The second is the enhancement of the mixing lubrication because it has perfect spherical particles. The third is the production of secondary hydrates when the pozzolanic reactions happen with the primary hydration products [25]. Also, the silica surface functions as a nucleation center to form C-S-H phases produced by the alite and belite hydration [26]. Typically, SF is 20-25% of the whole binder elements in UHPC. About 18% of SF quantity is needed to react cement hydration. The tests of the construction showed that the highest compressive strength can be obtained when the SF content is 30%. This strength increases the density of the concrete mixtures. The high content of SF (30%) is mission obstructions of UHPC for the increase of the consumption of the concrete market because of its low resources and high prices. Even though SF improves the rheology of concrete, the high SF particle surfaces raise the demand for water and influence the fluidity of mixtures. The increased SF content increases the viscosity which needs a large quantity of superplasticizers[12],[27]. The substitution of SF in UHPC mixing with fine GP (FGP) reduces the cost and is environmentally friendly. WG is not a biodegradable substance and is not reusable. It minimizes the buried quantity. Replacing SF with FGP will also significantly reduce the price of traditional UHPC. Using FGP increases UHPC workability and enhances the quality of concrete[12]. The SF is not only one pozzolanic substance, it also has a positive impact on the cementitious material structure. Also, different studies report that GP can have a similar effect. Their experiments show that alkali silica reaction can happen if the particle size is about 0.075 mm - 2.00 mm. Yet if the WG is milled to powder, a reaction of pozzolanic than that of alkali silica, could happen. Also, a positive GP influence on the hydration of cement is reported [1].

5. Properties of ultra-high-performance waste glass concrete (uhpgc)

5.1. Fresh UHPGC properties

In Table (3), the UHPGC new properties are given. They include a unit weight, a mini-slump flow, and an air content compared to a reference of UHPC. The slump flow diameters do not increase with the
increases of GS contents such as (190, 200), by 50 QS to 50 GS, and (210) mm to the concrete reference, 0QS to 100GS mixtures. This increase is because of the substitution of QS particles with the GS particles characterized by low water absorption [23]. When recycled glass content is increased, the slump flow, flow ratio, and V-funnel increase too [7]. The new features of the concrete mixtures, compared with the reference of UHPC mixture, entail that more FGP replacement raises flow capacity due to the low absorption of water of the FGP particles. The specific surface area SF is 22000 m2/kg, two times bigger than that of the FGP (10000 m2/kg) [28]. Also, in the reference counterpart mixture, the addition of more FGP substitution increases the capacity of flow because of the low absorption of water. The smooth surface of the FGP particles had also contributed to that capacity. So, the entire net surface blend area of the SF and FGP is reduced when FGP substitutes SF. The required water for the particle surfaces' lubrication is positively correlated with the net particle surface area. However, it is negatively correlated with the increase of the slump flow. All UHPGC mixtures with FGP slump had improved more than UHPC mixtures reference [12].

5.2. Compressive strength

Compressive resistance can be attained by up to 220 (MPa), with a good economic gain obtained using glass powder in the lie of SF and QP. The obtained UHPC mechanical strength is GP outcome [14]. GP functions as a chemical activator material more than pozzolanic material. It serves as an inert substance in early hydration points. Occasionally, a GP can minimize the volume of water for the usual consistent mixture in concrete. This possibly relies on the specific surface and the distribution of the particle size. Also, the GP amorphous silica defects could react with CH and produce a low basicity C-S-H in a later hydration stage. In this level of basicity, alkalis can be used in the creation of new hydration phases. Thus, the concrete microstructure and compression resistance could increase dramatically and give UHPC very high mechanical features [14]. The compressive resistance to the UHPC mixture with (50%) FGP substitution of (50SF/50FGP) increases the compressive strength of (3%) at 56 days and (6%) and 91 days of Normal Curing (NC), in comparison with the reference counterparts[12]. The partial replacement of SF by other finely sized SCMs such as FGP is thus a promising solution. The compressive resistance of the 28 days can be increased by replacing the nanosilica with the addition of WGP. The positive effect of WG powder on UHPC compressive resistance is due to increasing pozzolanic activity because of the increased amounts of amorphous substances. Hence, the optimal WGP amount for the 28 days compressive resistance will be related to SF replacement at different levels [27]. The addition of GP increases the drying shrinkage by raising the pozzolanic activities [14]. The concrete mixture compressive resistance is 0%, 30%, 50%, 70%, and 100% FGP following various curing ages, NC, and high curing (HC). Also, the replacement of 30% and 50% of the SF with FGP produces higher FC levels under NC at various ages. Regardless of SF replacement quantity in UHPC mixing, the compressive strength increases by about (10-16) % in the samples exposed to HC two days compared to NC 91 days because there is a pozzolanic reaction from the SF and FGP in the mixture. This reaction makes a denser C-S-H microstructure in the cement mixture, developing the strength very quickly [12]. The increase of compressive resistance is due to the pozzolanic reaction that has occurred. As a result of this reaction, an additional gel is produced,

| Table 3. The fresh concrete properties [23]. |
|---------------------------------------------|
| Reference | Series 1 | Series 2 |
|           | ISC (Q/GS) | 100% substituting with various GS and granulomere (d50=275) | 100% substituting with GS and optimum granulomere (d50=275) |
| property  | 0/100 | 0/100 | 0/100 | 0QS/100GS | 50QS/50GS |
| Slump flow (mm) | 190 | 175 | 210 | 170 | 210 | 200 |
| Air void % | 3.8% | 5.5 | 4.6 | 5.2 | 4.6 | 4.3 |
| Unit weight (kg/m3) | 2363 | 2292 | 2297 | 2300 | 2297 | 2306 |
| Temperature (˚C) | 32 | 32 | 31 | 31 | 31 | 32 |
and thus the strength is improved. The increase of GP content could raise the active silica in the concrete microstructure depleting calcium hydroxide due to the pozzolanic reaction. The remaining free silica could weaken the concrete structure and strength.

5.3. Flexural strength
Glass sand aggregates substitute sand. About (5%, 10%, 15%, and 20 %) of glass sand flexural strength are added in comparison with the reference counterpart (10.5 MPa) by (2.9%, 7.6%, 9.5%, and 14.3%) [29]. Also, there is a slight increase in the concrete flexural strength when 25% of glass sand is added from green glass (1.5%) compared to the plain concrete[30]. The reduction of flexural strength for specimens is 25% and 30% of GP. This may be attributed to the depletion of calcium hydroxide due to the pozzolanic reaction. The free silica remaining part in a concrete microstructure could weaken the concrete elements' strength and bond.

5.4. Durability
UHPC is more durable than NC and HPC because of the reduced water-cement rate (w/c) by about 0.20%, and at the same time, it includes more fine materials. The durability of UHPC is good regarding the permeability of water and chloride-ion, and the resistance of the following: chemical attack, freeze-thaw, alkali-silica reaction, and abrasion resistance for the previously mentioned causes [31]. The UHPGC dense matrix prevents the ingress of detrimental materials (chloride-ion) through functioning as a sealing layer to make the concrete more durable. The mean of the total Coulombs passes by using the resistance to chloride-ion penetration (RCP) test is 5.0 and 3.0 Coulombs at 28 and 91 days, respectively. According to ASTM, C1202, these results are within the “negligible” classification. This chloride-ion penetration rate is lower than high-performance concrete (HPC) and the traditional UHPC. The low UHPGC corrosion rate is partly because the material significantly resists conducting an electric current. The UHPGC resistivity is extremely high, about 3466 kΩ.cm [32]. The mechanical abrasion test (ASTM, C779) produces a mean relative volume-loss index (1.35 mm). The mass loss following 56 freeze-thaw cycles when the decline of the salt is very low (12 g/m²) (BNQ NQ 2621-900). The samples of 28- and 91 days are exposed to the operations of chloride-ion penetration (ASTM, C-1202) test producing only 10 Coulombs, which are very low. However, when freeze-thaw cycles are 1000, the dynamic modulus elasticity (ASTM, C-666) is 100% [33].

5.5. Drying shrinkage
The addition of nano-silica and WGP to UHPC increases the drying shrinkage. Because of the hydration reaction, cement usually shrinks, silicon powder responds to Ca(OH)₂ formed through cement while hydrating. This develops the shrinkage because of the increase in the pozzolanic activities, that increases the chemical shrinkage. This shrinkage results from excluding gel water and higher drying shrinkage of nano-silica, which perform better in terms of concrete than the reference counterpart. The reason for this performance is a higher quantity of finer C-S-H with more gel water released in the drying shrinkage[27],[34]. Also, the addition of GP raises the drying shrinkage through the increase in the pozzolanic activities [14].

5.6. Microstructure analysis
In the specimens of the reference UHPC mixture, HC is treated using 50QS/50GS in UHPGC. As the ASR test is completed, the microstructure analysis under the "scanning electron microscope" (SEM) is conducted. Several processes are conducted on UHPGC specimens, such as epoxy impregnation, polishing, and carbon coating, to facilitate SEM analysis. Figure (1) shows “a backscattering-scanning-electron (BSE).” Pictures (a)and (b) show that the reference mixture counterparts; pictures c and d display 50QS/50GS. The pictures show a low w/c, a significant unreacted cement quantity, QP, and SF particles. Cracks are not visible, and pores appear as portlandite (Ca(OH)₂) crystals[23],[35]. Some entrapped or entrained globular air pores in the concrete matrix, most of which are a side effect of the superplasticizer in the mixture of UHPC. There is a clear interfacial transition zone (ITZ) of the
reference mixture in the figure, which is very thin or could not appear at all, as in Figure (1). This figure (c and d) does not show ASR gel or micro-cracking ring around the (GS) particles in the mixture. As a result, there is no worry about ASR problems with the UHPC, which contains GS. There should be free water for the occurrence of the ASR in any concrete. As the permeability of this UHPC is low, ASR would not be expected as an issue if there is a GS use [9]. Pictures e and f in figures (2) reveal the microstructure of 0QP/100GP following HC. In the 0QP/100GP BSE, glass powder particles are not separated from the surrounding (C-S-H) phase. This could form a thin hydration rim as there is a GP pozzolanic reactivity. In the reference UHPC mixture, the QP particles are separated from the surrounding (C-S-H) phase, as in Figure (2b) [9],[35].

Figure 1. BSE, SEM images for reference mixture (a,b) and (50QS/50GS) (c,d)[23],[35]

Figure 2. BSE, SEM specimens under hot curing (HC) for 2 days: ( pictures a and b) reference, (pictures c and d) 80C/20GP, and (pictures e and f) 0QP/100GP[36], [35].

5.7. Water absorption
The concrete permeability to water may allow the chemical compounds, such as chloride ions, for example, the concrete's permeability. It eventually contributes to corrode steel rebars and fibers. UHPC is famous for having a lower porosity and denser microstructure than NC and HPC. This prevents permeability [37]. This permeability is usually influenced by W/C rate, SCMs, and pore diameter and connectivity. The permeability coefficient of concrete significantly decreases by reducing the W/B rate [31]. Past works show that the absorbed water quantity in concrete is low when there is RGS. Thus, the glass is permeable with deficient water absorption. Thus, RGS in concrete decreases
the whole water absorption demand [5]. The water absorption is tested for mixtures and percentages, which decreased if the WG content increases. The lowest absorption is in the concrete mix containing 40% WG. The absorption for all elements is depicted in Table (4). Also, there is a negative correlation between WG content and water absorption [24].

| No. | Mix.     | Water absorption at 28 days |
|-----|----------|----------------------------|
| 1.  | Without GP | 1.7                        |
| 2.  | GP 10%    | 0.81                       |
| 3.  | GP 20%    | 0.71                       |
| 4.  | GP 30%    | 0.63                       |
| 5.  | GP 40%    | 0.52                       |

6. Conclusions
Various researchers’ investigations of the effect of glass reused on properties of (UHPC) show that WG and GP could be successfully utilized to partially replace SF, QP, and QS in a mixture in the UHPC. Also, they are used in the construction industry, which turns significantly common:

- An ideal UHPC mixture is possibly formed through substituting quartz sand with glass-sand up to 50%. This mixture could be in approximate flowability and compressive resistance similarity relative to the reference counterpart. This similarity is because UHPC is very low in terms of permeability. This prohibits the ingress of the alkali.
- The substitution of QP with GP makes UHPC highly strong and slump flowing. Thus, the compressive resistance and concrete microstructure could significantly improve.
- Because of the positive alkali-silica reaction influence on the compositions with GP, macroporosity is removed. Also, there are big pores at the micro-scale (670 μm). The highest pore concentrations at nano-scale (60 μm) are reported in all compositions of UHPC.
- At the later ages, after 28 days, the pozzolanic impact of WG in concrete is more evident in the concrete color.
- The (SEM) examination revealed poor contact bonds between the crushed glass sand and cement matrix, as evidenced by the increase in the voids as the glass content increased in the concrete mixtures.
- The sustainable and eco-friendly concrete could be obtained from WG sand mixed with natural sand in concrete mixes about 50% natural sand substitution for structural application. However, if the glass sand content percentage is less than 25, better results will be achieved. These results show that the recycled WG could produce sustainable concrete to prevent the harm of WG in landfill sites.
- GP milled to tiny particles (micro-scale) is subjected to the pozzolanic reaction and functions as a catalyst. This increases the dissolution speed of clinker phases. It also quickly forms sub-basic hydrate (C-S-H) calcium silicate. A favorable impact on UHPC's microstructural and mechanical features can be gotten from these reactions.
- The recycling and reuse of WG in concrete are sustainable to improve and preserve the environment. These recyclings are efficient for eliminating pollution by reducing waste, extending landfill lifetime, and conserving natural resources. When the GP substitutes QP, more sustainable UHPCG can be obtained. The transportation cost could decrease when UHPC is made from locally available GP.

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