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Analysis of Mechanical and Environmental Effects of Utilizing Waste Glass for the Creation of Sustainable Ultra-High Performance Concrete

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ABSTRACT

Typically, waste glass industry contributes to various harmful environmental impacts. Glass manufacturing relies on considerably extreme temperature values. 22 million tons in Europe and 95 million tons of carbon dioxide are generated globally per annum. Meantime, scholars noted that million tons of waste glass produced worldwide yearly could cause elevated levels of water and air pollution due to the accumulation of waste glass in landfills. In this setting, researchers dedicated numerous efforts to create feasible strategies and active solutions to alleviate all these significant numbers. One of those solutions is the waste glass recycling. It is reported that recycling waste glass provides efficient air pollution and water contamination mitigation by roughly 20% and 50%, respectively. One sector that took into account this valuable idea is the concrete industry. Scientists discovered that substituting specific ratios of cement/ sand with waste glass (including 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%) in concrete could achieve substantial added values in terms of mechanical properties, such as better durability, abrasion resistance, flexural strength, compressive strength, and splitting tensile strength. Few, at the same time, found that adding waste glass into concrete could reduce facilities' cooling and heating loads due to the decline in the concrete's thermal conductivity. Nonetheless, the available literature lacks adequate proofs associated with this fact. Additionally, different peer-reviewed articles did not address the application of this concept on Ultra-High Performance Concrete (UHPC) but on regular concrete. To bridge this knowledge gap, this manuscript is guided to provide more databases on the influence of cement/ sand replacement with waste glass on concrete's thermal characteristics yet paying special attention on UHPC. A comprehensive review is implemented in this context to shed light on these aspects. Based on the thorough review carried out in this article, the outcomes revealed that employing waste glass in concrete and UHPC could attain multiple advantages, like (i) Enhancing variant UHPC and concrete's mechanical properties (containing split tensile strength, compressive strength, compaction, durability, flexural strength, bulk density, and shrinkage resistance), (ii) fostering thermal conductivity and thermal resistance, helping make the building of this new concrete mix more energy efficient, (iii) minimizing glass industry's adverse environmental effect, (iii) preserving natural resources, and (iv) reducing the overall budget of UHPC production. However, it is crucial to conduct further experimental and numerical analyses on waste glass replacement with concrete to offer more pieces of evidences and facts of the importance of waste glass replacement in boosting UHPC thermal performance in small and large-scale facilities.

1. INTRODUCTION

Over the last decades, construction experts recognized that concrete and UHPC consume a lot of natural resources and substances in different large and utility-scale infrastructure projects and massive buildings worldwide. For instance, concrete and UHPC needs coarse aggregate, fine aggregate, water, cement, mineral admixtures, and chemical admixtures. At the same moment, UHPC employed in various construction purposes, like utility-scale projects, infrastructure, and Vertical Construction (VC) facilities, may use welded wire fabric (such as wire mesh), reinforcing steel bars, and variant reinforcement fibers [1].

On the other hand, construction consultants and engineering professionals realized that UHPC manufacturing, mainly, and concrete preparation, generally, could bring a group of negative environment consequences and severe impacts that may harm air, water, and land qualities. In terms of facts and numbers, studies confirmed that each ton of Portland cement generation emits roughly 1 ton of carbon dioxide into the atmosphere, worsening problems of global warming and climate change. Also, it was reported that concrete consumes more than 8 billion tons of aggregates per annum, which could deplete the natural resources. Furthermore, diversified categories of waste materials, including kaolin, cement and quarry dust, bottom ash, fly ash, rice husk ash, slag, palm-oil fuel ash, bagasse, tires, sewer sludge, silica fume, glass, garnets, bentonite, and volcanic ash are generated from the construction or demolition of each project, resulting in the damage and deterioration of the global environment. Besides, most of those waste substances comprise a group of toxic or hazardous chemicals that may enter seas or lands with different percentages [2].

Using recycled waste products in UHPC would be better for the environment and the economy. For instance, numerous quantities of waste glass are produced daily, and most of it is disposed of in open areas and landfills. Waste glass is one type of waste that can be incorporated into concrete. Concrete has several advantageous qualities, including a high toughness, compressive strength, and other durable characteristics. However, concrete has a poor tensile strength and is a fragile substance. These flaws can be fixed by adding fibers, resulting in more ductile concrete with narrower fissures. Concrete's durability would be improved by reducing the entry of hostile species through cracks. The concrete mix can contain a variety of fibers, including rubber, asbestos, glass, and bamboo fibers. Several studies clarified the contributions of waste glass on concrete when cement/ sand is substituted using specific ratios connected with concrete mechanical properties [3]. Regarding environmental issues, using various recycled materials and recovered substances from garbage is considered quite useful and essential. Utilizing waste materials in concrete after they have been modified, such as waste glass, aggregate, ash, silica powder, and nanoclay, may have a variety of beneficial effects on concrete's durability, toughness, ductility, corrosion resistance, and various improvements in its thermal properties, in addition to promoting sustainability. Utilizing these recycled materials would also significantly impact reducing environmental waste and air pollution, both serious problems [4-7]. Environmentally friendly UHPC is a popular subject that has drawn the attention of many academics. Several scholars guided various experimental and numerical analyses to create environmentally friendly UHPC with more practical and functional advantages over traditional concrete. Also, they aimed to enable UHPC to be employed in a variety of engineering structures, demanding structural applications, and large-scale construction projects, including infrastructure, skyscrapers, tunnels, and bridges. There are some drawbacks to conventional concrete that prevent it from being widely used in many engineering projects, including significant requirements for repair and maintenance costs due to concrete cracking problems [8]. In comparison to regular concrete, UHPC is recognized for its greater robustness, more considerable value of toughness, large ductility, and effective resistance to fracture [9]. Furthermore, compared to traditional concrete, UHPC possesses significant compressive strength. The UHPC has also been the subject of numerous studies to improve its qualities. For instance, Azmee et al. [10] added ultrafine calcium carbonate to UHPC with more fly ash based on various curing conditions. Additionally, Bahedh and Jaafar [11] investigated the use of fly ash as a cement substitute based on an autoclaving method. Additionally, Jiao et al. [12] investigated how early-age shrinkage of UHPC dependent on more excellent volume mineral combinations was affected by relative humidity and ambient temperature. Further, several publications emphasized the significance of making UHPC green by substituting waste glass for part of the original materials (as demonstrated in the literature supporting this suggestion). This aspect would help to have a positive impact on the environment and achieve some beneficial properties in concrete [12-49]. Besides, UHPC is one of the significant developments that contribute to remarkable enhancements in the effectiveness and performance of buildings. However, the wide application of UHPC in the building industry is constrained by its high cost compared to regular concrete [16, 10]. Various researchers have advised using various alternative materials (with specific replacement percentages), such as glass and waste glass, to provide a lower rate of UHPC budget and a significant amount of building costs [50]. According to variant scholars, using waste glass in UHPC could promote sustainability, mitigate air and water pollution, and minimize its considerable cost. After water, concrete is one of the most ubiquitous building materials in the globe. Concrete production requires a lot of raw ingredients. Finding methods of replacing these substances with waste products recorded significant benefits and brought different positive environmental advantages. The volume of waste glass produced annually has constantly been increasing and has become a huge environmental problem. Million tons of waste glass are generated around the world each year.

Using waste glass in concrete production could be a workable solution to help reduce the adverse influences of waste glass on the global environment. Aggregates comprise most of the concrete volume and significantly contribute to the material's strength, workability, durability, and dimensional stability. The structural effectiveness of concrete will suffer if waste elements like waste glass are used as a partial aggregate substitute [3-6].

2. PROPERTIES OF UHPC AND PRODUCTION TECHNIQUES

Compared to regular concrete, (UHPC) is the more long-lasting option. The high concentration of tiny particles and low water-to-binder proportion (W/B) of about 0.2 contribute to its superior performance. Further, Ultra-High Performance Concrete (UHPC) is a novel composite material that shows promise as a replacement for concrete in challenging conditions. UHPC is characterized by several beneficial properties and advantageous merits that make it more functional and feasible compared with traditional concrete, making UHPC more applicable and convenient for different complex and demanding structural applications. For instance, UHPC has a longer lifespan. It is estimated that UHPC may last for over seventy-five years. Knowing that conventional concrete may last between fifteen and twenty-five years before it may require replacement. Besides, UHPC has lighter weight. Structures made out of UHPC have between twenty-five and thirty-three less weight. This fact can indicate that this novel type of concrete would demand a lower volume of construction materials. As its name suggests, UHPC has more considerable strength, corresponding to a compressive strength of roughly 27.6 MPa. When it is cured, UHPC would have a compressive strength of about 207 MPa. In some cases, some UHPC mixes may reach a compressive strength of 345 MPa. In the meanwhile, the UHPC's tensile strength reaches around 117 kPa. This innovative concrete category is featured with its substantial resistance to severe environmental degradation conditions. Conventional concrete begins to degrade after about twenty-eight freeze-thaw cycles. As previously mentioned, facilities built using UHPC will require fewer construction materials, and the carbon footprint of those structures would be lower than those that use traditional concrete. Besides, UHPC has exceptional levels of flexibility, enabling it to be adopted in facilities that require more complicated architectural design taking into account durability and strength aspects. Ductility is another critical property of UHPC. This practical classification of concrete can sustain more deformation amounts until failure occurs. Because UHPC has a higher rate of density than regular concrete, it can have more resistance to challenging environmental conditions recognized by significant humidity. Besides its remarkable humidity resistance, UHPC proved its potential to resist higher thermal loading or fire attacks compared with normal concrete due to more steel fibers and polypropylene content. Additionally, it is reported by some scholars that UHPC has higher impact resistance, abrasion resistance, diffusion, toughness, chemical reluctance, adhesiveness features, lower requirements of maintenance, and remarkable cost-effectiveness and economic profitability. Primary production techniques adopted to manufacture UHPC include [51]:

A. Removing of coarse aggregates,
B. Employment of specific graded and fine aggregates considering lower portions,
C. Implementation of silica fume content and robust superplasticizer (which comprises a large-rate water reducer),
D. Application of curing process at high-temperature values.

Generally, four curing techniques can be adopted to prepare the UHPC, comprising the following approaches [52]. Figure 1 represents significant benefits and properties of UHPC.

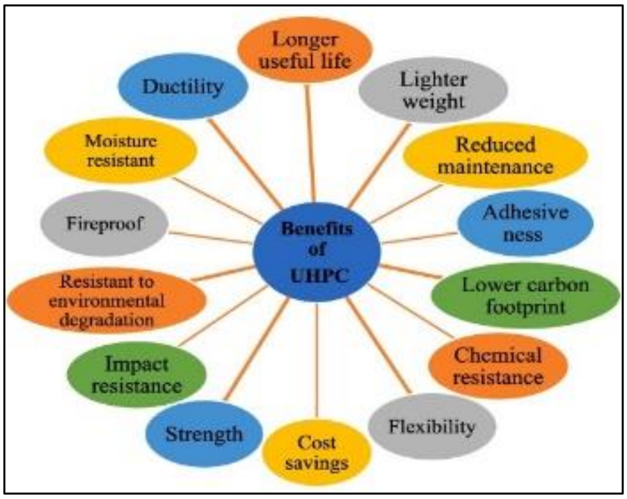

Figure 1. Significant benefits and properties of UHPC [1]

Figure 2 illustrates a comparison of the strength of UHPC and regular concrete.

Figure 3 describes a sample of Steel Fibers (utilized as 1.5% in UHPC).

Figure 4 represents some UHPC tests, including (a) post-cracking strength and (b) strain capacity under different cement types.

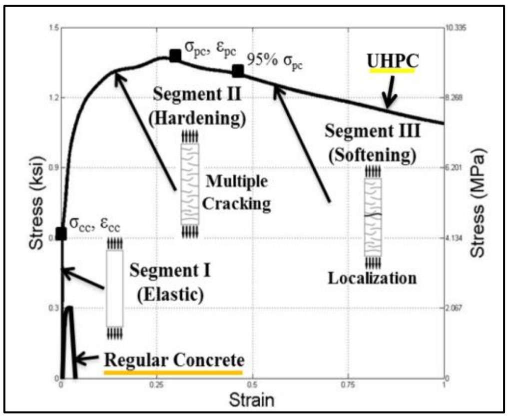

Figure 2. A comparison of the strength of UHPC and regular concrete [53]

Figure 3. Sample of Steel Fibers (utilized as 1.5% in UHPC) [53]

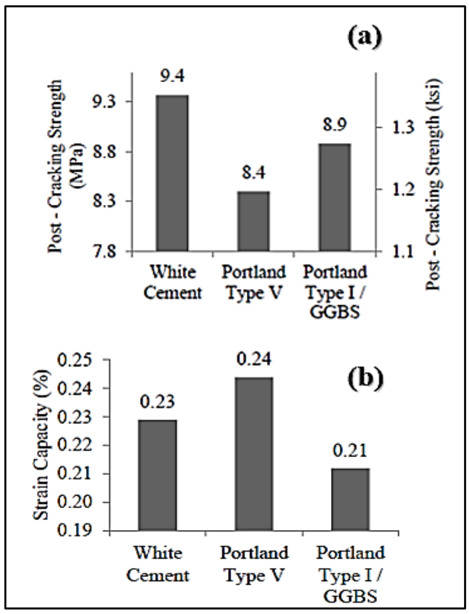

Figure 4. UHPC tests: (a) post-cracking strength and (b) strain capacity under different cement types [53]

Figure 5 depicts the impact of glass/ silica powder on (a) the compressive strength and (b) the post-cracking strength of UHPC.

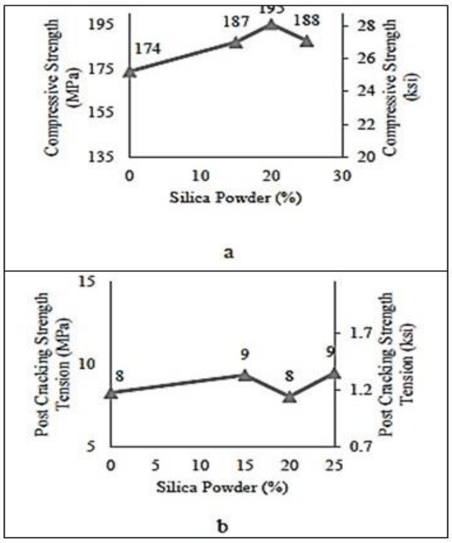

Figure 5. Impact of glass/ silica powder on (a) the compressive strength and (b) the post-cracking strength of UHPC [53]

Table 1. Primary UHPC mix design and appropriate ratios [53]

No.	Category	Ratio of UHPC	Density (kg/m^3)
1	Silica Fume	0.25	194
2	Fine Sand (I)	0.26	245
3	Cement	1.0	775
4	Fine Sand (II)	1.03	975
5	Water	0.22	165

Table 1 describes the primary UHPC mix design and appropriate ratios.

Figure 6 represents critical UHPC tests employed to assess fresh, hardened, and durability properties.

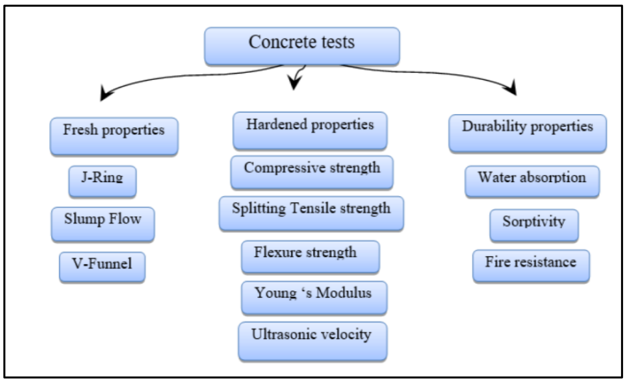

Figure 6. Critical UHPC tests employed to assess fresh, hardened, and durability properties [54]

3. WASTE MATERIALS UTILIZED IN UHPC

Over the last decades, variant construction professionals and civil engineers investigated some vital approaches and more effective mechanisms to make concrete and UHPC more sustainable and environmentally friendly, reducing their adverse impact on nature and mitigating pollution. From reviewing different old and latest peer-reviewed articles, it can be observed that the dominant materials used in replacing part or overall cement/ sand in UHPC include broad types of substances that are replaced using certain ratios to optimize the strength, toughness, and other properties of UHPC, as indicated in Table 2.

Table 2. Various types of waste materials used in UHPC

No.	Author(s)	Waste Materials Used in UHPC	Properties Assessed	Replacement Ratio
1	Esmaeili and AL-Mwanes [55]	Waste Glass	Compressive Strength	N/A
2	Alani et al. [56]	Waste Plastics	Compressive Strength	20% and 40%
3	Ahmad et al. [57]	Waste Plastics from Electronic Waste (E-waste)	Hardness, and compressive, tensile, and flexural strengths	25%
4	Norhasri et al. [58]	Nano metaclay	Morphology, Workability, and Strength	1%, 3%, 5%, 7%, and 9%
5	Amin et al. [59]	Waste Aggregate	Compressive Strength	10%, 20%, and 30%
6	Cheah et al. [60]	Pulverized Fuel Ash (PFA)	Flexural and Compressive Strengths	50% Cement Replacement
7	Wu et al. [61]	Silica Fume	Flexural and Tensile Strengths	5% to 25%
8	Abdellatief et al. [62]	Metakaolin	Chloride-Ion Permeability Resistance	15% to 25% Metakaolin
9	Koh et al. [63]	Cement Kiln Dust (CKD)	Compressive Strength	70% Reduction of Superplasticizer
10	Wang et al. [64]	Demolished Concrete	Auto-Shrinkage and Compressive Strength	19% of Fine Aggregate and 50% of Cement
11	Chinnu et al. [65]	Agricultural Waste	Hardness, Durability, Strength	N/A

4. WORKABILITY OF UHPC COMPRISING WASTE GLASS

Several authors and construction professionals reported in their articles that replacing some ratio of cement or sand with waste glass would enhance the workability of UHPC [55, 66, 67]. The workability of concrete or UHPC can be described by the potential and capability of concrete to be flexibly and successfully placed, mixed, finished, and consolidated, considered lower losses in its homogeneity aspects. In addition, UHPC/ concrete workability is associated with fresh concrete properties that indicate its quality, impact strength, and appearance. It also considers its cost-effectiveness regarding finishing operations and labor expenses [68-70]. Figure 7 indicates the slump flow testing results depending on the waste glass replacement ratio in concrete.

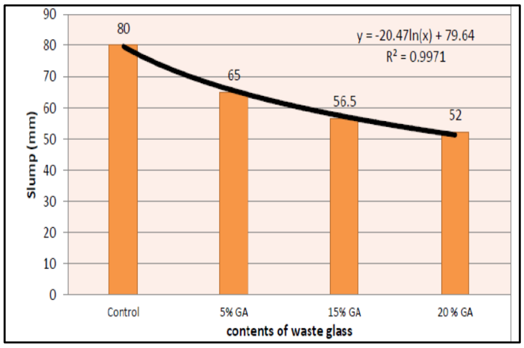

Figure 7. Workability/ slump flow characteristics depending on the waste glass replacement ratio in concrete [71]

The results illustrated in Figure 7 are obtained according to the concrete mixes clarified in Table 3.

Table 3. Ratios and densities of concrete mixes using waste glass [71]

Mixes	The density of Cement (kg/m^3)	Water-to-Cement Ratio	Fine Aggregate Density (kg/m^3)	The density of Fine Aggregate Glass (kg/m^3)	The density of Coarse Aggregate (kg/m^3)
Reference (Control)	363.3	0.55	812.2	00.0	979.0
5% Waste Glass	363.3	0.55	771.6	40.6	979.0
15% Waste Glass	363.3	0.55	690.4	121.8	979.0
20% Waste Glass	363.3	0.55	649.8	162.4	979.0

5. IMPACT OF WASTE GLASS ON UHPC'S MECHANICAL PROPERTIES

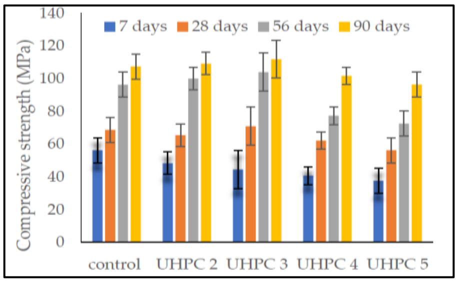

Figure 8. Variation of Compressive strength with different UHPC specimens, considering the N-curing process [54]

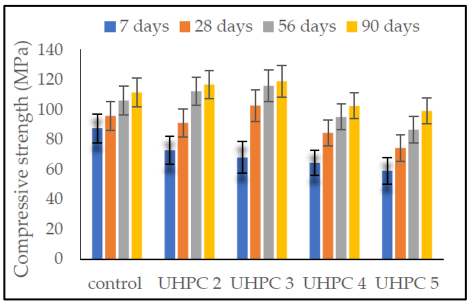

Figure 9. Compressive strength variation with some UHPC specimens, considering the H-curing process [54]

To explore the mechanical and fracture characteristics when waste glass is partially substituted in the UHPC, Jiao et al. [12] carried out an analysis selecting different replacement ratios of glass sand and river sand (with a size of between 0.05 and 2.0 mm) in Ultra-High Performance River Concrete (UHPRC) and UHPC. Also, Jiao et al. [12] relied on experimental analysis. They computed the new specimens' compressive strength and other mechanical and fracture characteristics. Their experimental investigation showed that recycled waste glass provided a successful strategy for conserving resources and protecting the environment. Additionally, it improved the fluidities and performance of UHPRC and UHPC. Besides, the compressive strength potential of UHPRC and UHPC was increased using waste glass. For both forms of concrete, a maximum compressive strength value was attained by using glass sand at a ratio of 75%. The tensile stress values were unaffected by substituting some UHPRC and UHPC. Figure 8 describes variation of compressive strength with different UHPC specimens, considering the N-curing process.

Also, Figure 9 expresses compressive strength variation with some UHPC specimens but considering the H-curing process.

Further, Figure 10 indicates the splitting and flexural tensile strengths of some UHPC specimens after ninety days.

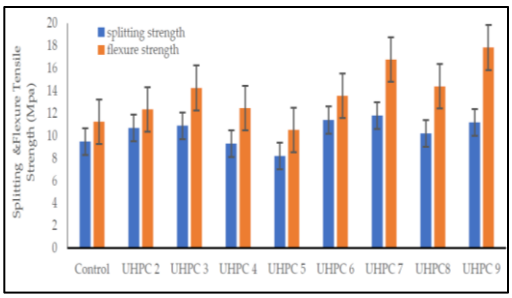

Figure 10. Splitting and flexural tensile strengths of some UHPC specimens after ninety days [54]

It is visible from the viewpoint of Figure 9 that the flexural strength of the specimen (UHPC-9) has the most significant value compared with all models. The flexural strength of this UHPC sample reaches around 18 MPa. More results on the mechanical properties that take into account the impact of waste glass on UHPC are represented in Figures 11 and 12.

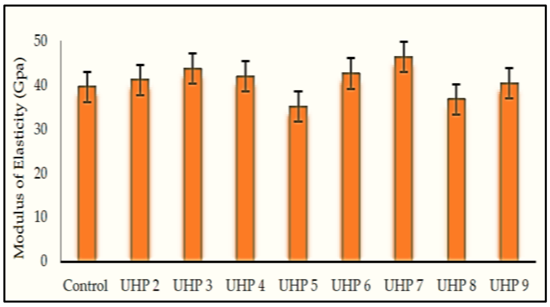

Figure 11. Variation of modulus of elasticity considering variant waste glass replacement ratios for a test duration of ninety days [54]

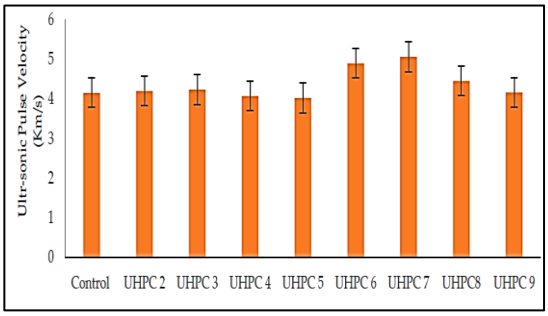

Figure 12. Variation of ultrasonic pulse velocity with different waste glass ratios depending on a test duration of ninety days [54]

Figures 8 to 12 were obtained based on the glass powder replacement ratios of 10 specimens (control and nine samples) with other materials mixed and used, illustrated in Table 4. The type of concrete used in the work [54].

Table 4. Mixes and densities of materials used in UHPSCC [54]

Specimen Type	Cement (C) (kg/m^3)	Density (kg/m^3)		
		Glass Powder	Lime Powder	Polypropylene
Reference	900	0	0	0
UHPSCC-2	810	90	0	0
UHPSCC-3	720	180	0	0
UHPSCC-4	630	270	0	0
UHPSCC-5	540	360	0	0
UHPSCC-6	810	0	90	0
UHPSCC-7	720	0	180	0
UHPSCC-8	630	0	270	0
UHPSCC-9	540	180	360	900

Further, Chu et al. [72] looked at the role and major advantages of replacing waste glass in UHPC. They estimated a few mechanical properties, including workability, bending strength, and compressive strength. According to their investigation, the performance and strength of UHPC may suffer if the waste glass is substituted with some ratios. As a result, additional ingredients, like waste glass powder, can be added to improve the strength and other mechanical characteristics of UHPC. Chu et al. [72] employed various replacement percentages of waste glass in UHPC based on experimental analysis. Results also showed that cement content was lowered to 365 kg/m^3 by replacing 18.8% with waste glass. Furthermore, the findings indicated that the compressive strength had surpassed 150 MPa. Moreover, to boost the sustainability rate and environmental rating of UHPC, Tagnit-Hamou and Soliman [73] conducted an analytical study to examine the crucial role of waste glass replacement. Tagnit-Hamou and Soliman used an experimental analysis in which they substituted quartz powder for cement in the UHPC and mixed between 10% and 20% waste glass and quartz powder. To support their findings, they calculated some factors linked to the mechanical characteristics of UHPC. The inclusion of waste glass and quartz powder in the UHPC greatly boosted its compressive strength, functionality, and workability, based on the findings of their experimental studies. Also, employing waste glass and quartz powder in UHPC can produce added environmental benefits, such as a smaller negative environmental effect and a better sustainability rate. To better understand how UHPC performs when waste glass is used in place of some of the cement, Ahmad et al. [74] conducted an experimental analysis studying three samples of UHPC in which (10, 20, and 30%) of the cement were substituted with waste glass. The researchers examined the mechanical properties of UHPC specimens, including mechanical compressive strength, split tensile strength, and punching strength. Their experimental tests confirmed that the new concrete's mechanical performance had improved but its workability had decreased. A study was conducted by Mosaberpanah et al. [66] to determine how the substitution of waste glass in UHPC affected the material's mechanical, shrinkage, and rheological properties. They substituted waste glass for cement to reduce consumption of cement and increase the sustainability and performance of UHPC. They ran a test as an experiment. For 28 days of mechanical stress testing, they made various specimens of UHPC, replacing 0% to 20% of the cement with waste glass with a maximum particle size of 63 micrometers. The results of the tests showed that adding a further quantity of waste glass had enhanced the mechanical characteristics of UHPC, notably its compressive strength. In a study conducted by Karim et al. [75], the researchers examined the effects of waste glass powder used as a cement substitute on the compressive strength and mechanical characteristics of UHPC. One hundred seventeen concrete cubes were formed, and compressive pressures were applied. Their test findings showed that adding waste glass powder in place of cement up to 5% of the time improved compressive strength. Mariaková et al. [76] conducted a study to examine the effects of 100% replacement of silica powder (sand) with waste glass. Two types of waste glass powder—jewelry grinding and municipal waste glass milling—were used to replace the waste glass. The new UHPC's mechanical characteristics were evaluated and contrasted with UHPC containing sand (silica powder). The testing findings affirmed that when 100% of silica powder was replaced by waste glass, the flexural strength, compressive strength, and bulky density decreased. Safarizki and Gunawan [77] examined the use of waste glass in Portland concrete by substituting it with sand and its effects l features of Portland concrete. They aimed to establish the ideal replacement rate for preserving Portland concrete's highest and best mechanical qualities. They created a sample of Portland concrete and substituted waste glass for sand in amounts of 30%, 20%, 15%, and 10%. The test findings confirmed that because waste glass powder absorbs a significant quantity of water, higher waste glass replacement percentages with sand reduce Portland concrete stiffness, ductility, performance, and mechanical qualities, including compressive strength, declined. The concrete compressive strength results indicated an optimum value of roughly 22.8 MPa having a variation of approximately 15% in waste glass powder quantity. Thus, the employment of waste glass powder could be efficient and practical as a substitute for sand in concrete, partially using 15% of waste glass. Also, Figure 13 indicates some results in the literature identifying the splitting tensile strength characteristics when the waste glass is substituted in concrete.

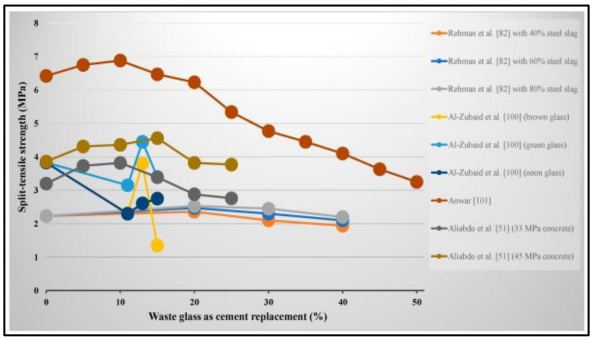

Figure 13. Splitting tensile strength evaluation by some authors [78]

It can be noted from Figure 13 that the splitting tensile strength ranges from roughly 2 to 7 MPa in most of the authors' work [79-82]. Table 5 illustrates some advantages related to recycled waste glass for concrete with its replacement percentage.

Table 5. Recycled waste glass advantages for concrete with its replacement percentage

No	Research Publication: Author(s), (Year)	Type of Properties	Percentage of Waste Glass Replacement
1	Sikora et al. [83]	Thermal and Mechanical Properties (Compressive strength, density; thermal diffusivity, thermal conductivity)	100% of waste glass fine aggregate
2	Sun et al. [84]	Mechanical properties (Flexural strength, density, compressive strength)	0%, 10%, 20%, and 30% of waste glass fine aggregate
3	Guo et al. [85]; Mehta and Ashish [86]; Qaidi et al. [87]; Mohajerani et al. [88]; Chung et al. [89]; Siddika et al. [90]; Harrison et al. [91]; Abdelli et al. [92]; Esmaeili and AL-Mwanes [55]; Khan et al. [93]	Mechanical properties (Durability, compressive strength, carbonation resistance, workability, concrete density)	Varied (A review)
4	Yang et al. [94]	Mechanical properties (Compressive strength, fire resistance)	10%, 20% and 30% of waste glass fine aggregate
5	Islam et al. [95]	Mechanical properties (Compressive strength, workability)	0% to 25% of waste glass fine aggregate
6	Tamanna et al. [96]	Mechanical properties (Flexural strength, density, compressive strength, workability)	20%, 40% and 60% of waste glass fine aggregate
7	Mohammadyan and Ghaderi [97]	Mechanical and thermal properties (Flexural strength, tensile strength, compressive strength, workability, water absorption, permeability; Conductivity	20% of waste glass fine aggregate
8	Salem et al. [98]	Mechanical properties (Density, voids)	5, 10, 15 and 20% of waste glass fine aggregate
9	Sudharsan and Saravanaganesh [99]	Mechanical properties (Density, compressive strength, water absorption)	0, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20% of waste glass fine aggregate
10	Letelier et al. [100]	Mechanical properties (Flexural strength, density, compressive strength)	10, 20 and 30% of waste glass powder
11	Kim et al. [101]	Mechanical properties (Compressive strength, density, water absorption, flexural strength)	0, 50, and 100% of waste glass fine aggregate

No	Research Publication: Author(s), (Year)	Type of Properties	Percentage of Waste Glass Replacement
12	Li et al. [102]	Mechanical properties (water permeability, flexural strength, splitting tensile strength)	0, 10, 15, 20, and 25%) of waste glass fine aggregate
13	Jiao et al. [12]	Mechanical properties (Splitting tensile strength, flexural strength, compressive strength)	0, 25, 50, 75, and 100% of waste glass fine aggregate
14	Hama et al. [103]	Mechanical properties (Compressive strength)	0%, 10%, and 15% of waste glass fine aggregate
15	Keerio et al. [104]	Mechanical properties (Water absorption, workability, compressive strength)	10%, 20%, 30 and 40% of waste glass fine aggregate
16	Ahmad et al. [105]	Mechanical properties (Chemical resistance to acids, workability, tensile strength, compressive strength)	10%, 20% and 30% of waste glass fine aggregate
17	Lu et al. [106]	Thermal and Mechanical Properties (Compressive strength, water absorption, permeability; Thermal conductivity)	50% of waste glass fine aggregate
18	Ibrahim [107]	Mechanical properties (Water absorption, workability, compressive strength, tensile strength)	0, 5, 10, 15, and 20% of waste glass fine aggregate

Furthermore, Figure 14 indicates the number of publications discussing waste glass utilization in concrete over the years [79].

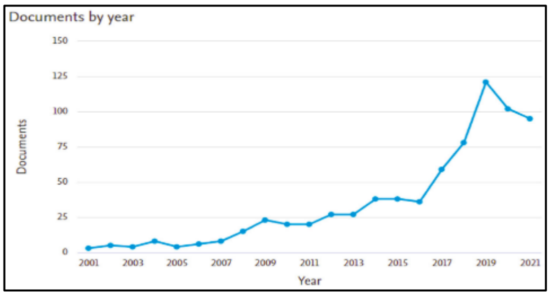

Figure 14. Growth in the number of articles discussing waste glass use in concrete over the years [79]

It is inferred from Figure 14 that over the years, the number of academic publications related to the investigations and assessments of waste glass in concrete has been increasing.

6. IMPACT OF WASTE GLASS ON UHPC'S DURABILITY

Besides the substantial impact, beneficial mechanical properties, and positive effects of integrating waste glass into the UHPC, several researchers investigated the impact of waste glass on the durability of UHPC. For instance, Tahwia et al., [108], Mostafa et al. [109], Soliman and Tagnit-Hamou [110] reported that replacing some ratios of cement, sand, or other UHPC components would achieve enhancements in the UHPC mechanical properties and durability. The durability of UHPC can be described as the UHPC capability and potential to offer practical resistance to weathering, degradation, abrasion, and severe chemical circumstances to provide optimum and superlative mechanical properties. Those aspects are vital to helping UHPC offer better serviceability, significant quality, and damage under challenging working conditions throughout the lifespan of UHPC. Figure 15 represents some examples and layouts of concrete degradation and deterioration due to a lower level of durability than UHPC.

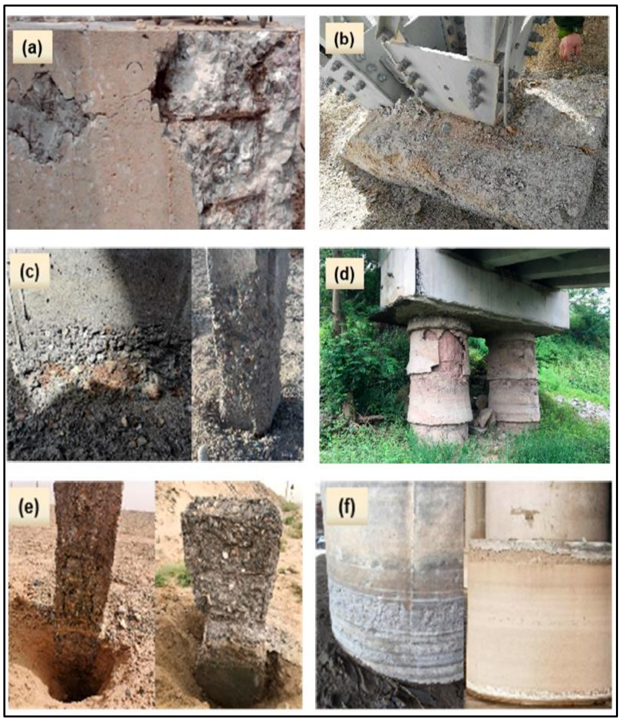

Figure 15. Some illustrations of concrete deterioration in China: (a) Reinforced Concrete (RC) column in a coastal region, (b) transmission tower with RC foundation, (c) RC column, (d) RC bridge pier, (e) RC boundary monument, and (f) RC bridge pier [111]

7. PROSPECTS AND CONCLUSIONS

According to the comprehensive review led in this paper, the major process implemented in this work can be summarized in the following paragraphs.

This study was managed to bridge a knowledge gap reflected in the identification of waste glass beneficial impacts on UHPC's thermal performance, energy efficiency, and thermal conductivity when it is added into it using different replacement proportions. Also, this article addresses the environmental consequences of waste glass. In addition to causing a number of environmental problems, throwing glass bottles and other trash out into the wild is also illegal. Reinforcing concrete with recycled glass has positive long-term effects on the environment, as it helps lessen human activity's impact on natural areas and water supplies. This paper attempts to provide a complete assessment of the substantial contributions and crucial relevances of integrating waste glass into Ultra-High Performance Concrete (UHPC). Based on the thorough review adopted in this work, the critical findings of this research can be listed in these following points:

Using waste glass with different replacement ratios of cement/ sand could:

(i) Enhance variant UHPC and concrete's mechanical properties (containing split tensile strength, compressive strength, compaction, durability, flexural strength, bulk density, and shrinkage resistance),

(ii) Foster thermal conductivity and thermal resistance, helping make the building of this new concrete mix more energy efficient, (iii) minimizing glass industry's adverse environmental effect,

(iii) Preserve natural resources,

(iv) Reduce the overall budget of UHPC production. However, it is crucial to conduct further experimental and numerical analyses on waste glass replacement with concrete to offer more pieces of evidences and facts of the importance of waste glass replacement in boosting UHPC thermal performance in small and large-scale facilities.

In addition to these research findings, it was found that studies have shown that replacing cement/sand with waste glass at a ratio of 5%-100% results in the best mechanical qualities for UHPC. The recycled glass used in place of sand and cement typically ranges in size from 0.05 to 2.0 mm. The amounts of cement and sand replacement increased the UHPC's compressive strength, durability, splitting tensile strength, and workability, making it suitable for demanding construction projects. Furthermore, the literature outcomes indicated that the majority of published studies examined how using waste glass altered the mechanical properties of UHPC. Many studies have been conducted, but just a few have focused on quantifying the reduction in carbon and other greenhouse gas (GHG) emissions that result from using recycled glass in UHPC.

REFERENCES

[1] Amran, M., Huang, S.S., Onaizi, A.M., Makul, N., Abdelgader, H.S., Ozbakkaloglu, T. (2022). Recent trends in Ultra-High Performance Concrete (UHPC): Current status, challenges, and future prospects. Construction and Building Materials, 352, 129029. https://doi.org/10.1016/j.conbuildmat.2022.129029

[2] Mirza, J., Huseien, G.F., Shah, K.W., Kirgiz, M.S. (2020). Reduction in ecology, environment, economy and energy in concrete industry using waste materials. Journal of Advanced Composite Materials, Construction, Environment, and Nano Technology, (2).

[3] Bawab, J., Khatib, J., Jahami, A., Elkordi, A., Ghorbel, E. (2021). Structural Performance of Reinforced Concrete Beams Incorporating Cathode-Ray Tube (CRT) Glass Waste. Buildings. 11(2): 67. https://doi.org/10.3390/buildings11020067

[4] Khatib, J., Jahami, A., El Kordi, A., Sonebi, M., Malek, Z., Elchamaa, R., Dakkour, S. (2021). Effect of municipal solid waste incineration bottom ash (MSWI-BA) on the structural performance of reinforced concrete (RC) beams. Journal of Engineering, Design and Technology. https://doi.org/10.1108/JEDT-01-2021-0068

[5] Raydan, R., Khatib, J., Jahami, A., El Hamoui, A., Chamseddine, F. (2022). Prediction of the mechanical strength of concrete containing glass powder as partial cement replacement material. Innovative Infrastructure Solutions, 7(5). https://doi.org/10.1007/s41062-022-00896-8

[6] Jahami A, Khatib J, Raydan R. (2022). Production of low-cost, high-strength concrete with waste glass as fine aggregates replacement. Buildings. 12(12): 2168. https://doi.org/10.3390/buildings12122168

[7] Khatib, J., Jahami, A., Baalbaki, O. (2019) Flexural characteristics of reinforced concrete beams containing lightweight aggregate in the tensile zone. Fifth International Conference on Sustainable Construction Materials and Technologies, Kingston University, London, UK. http://dx.doi.org/10.2139/ssrn.3523048

[8] Gardner, D., Lark, R., Jefferson, T., Davies, R. (2018). A survey on problems encountered in current concrete construction and the potential benefits of self-healing cementitious materials. Case Studies in Construction Materials, 8: 238-247. https://doi.org/10.1016/j.cscm.2018.02.002

[9] Imam, A., Sharma, K.K., Kumar, V., Singh, N. (2022). A review study on sustainable development of ultra high-performance concrete. AIMS Materials Science, 9(1): 9-35. https://doi.org/10.3934/matersci.2022002

[10] Azmee, N., Abbas, Y. M., Shafiq, N., Fares, G., Osman, M., Iqbal Khan, M. (2021). Enhancing the microstructure and sustainability of ultra-high-performance concrete using ultrafine calcium carbonate and high-volume fly ash under different curing regimes. Sustainability, 13(7): 3900. https://doi.org/10.3390/su13073900

[11] Bahedh, M.A., Jaafar, M.S. (2018). Ultra high-performance concrete utilizing fly ash as cement replacement under autoclaving technique. Case Studies in Construction Materials, 9. https://doi.org/10.1016/j.cscm.2018.e00202

[12] Jiao, Y., Zhang, Y., Guo, M., Zhang, L., Ning, H., Liu, S., 2020. Mechanical and fracture properties of Ultra-High Performance Concrete (UHPC) containing waste glass sand as partial replacement material. Journal of Cleaner Production, 277. https://doi.org/10.1016/j.jclepro.2020.123501

[13] Wei, H., Zhou, A., Liu, T., Zou, D., Jian, H. (2020). Dynamic and environmental performance of eco-friendly Ultra-High Performance Concrete containing waste cathode ray tube glass as a substitution of river sand. Resources, Conservation and Recycling, 162, 105021. https://doi.org/10.1016/j.resconrec.2020.105021

[14] Tahwia, A.M., Essam, A., Tayeh, B.A., Abd Elrahman, M. (2022). Enhancing sustainability of Ultra-High Performance Concrete utilizing high-volume waste glass powder. Case Studies in Construction Materials, 17. https://doi.org/10.1016/j.cscm.2022.e01648

[15] Aslam, F., Zaid, O., Althoey, F., Alyami, S. H., Qaidi, S. M., de Prado Gil, J., Martínez-García, R. (2022).

Evaluating the influence of fly ash and waste glass on the characteristics of coconut fibers reinforced concrete. Structural Concrete. https://doi.org/10.1002/suco.202200183
[16] Hendi, A., Mostofinejad, D., Sedaghatdoost, A., Zohrabi, M., Naeimi, N., Tavakolinia, A. (2019). Mix design of the green self-consolidating concrete: Incorporating the waste glass powder. Construction and Building Materials, 199: 369-384. https://doi.org/10.1016/j.conbuildmat.2018.12.020
[17] Jiang, X., Xiao, R., Bai, Y., Huang, B., Ma, Y. (2022). Influence of waste glass powder as a supplementary cementitious material (SCM) on physical and mechanical properties of cement paste under high temperatures. Journal of Cleaner Production, 340. https://doi.org/10.1016/j.jclepro.2022.130778
[18] Jiang, Y., Ling, T.C., Mo, K.H., Shi, C. (2019). A critical review of waste glass powder-Multiple roles of utilization in cement-based materials and construction products. Journal of Environmental Management, 242: 440-449. https://doi.org/10.1016/j.jenvman.2019.04.098
[19] Li, S., Zhang, J., Du, G., Mao, Z., Ma, Q., Luo, Z., Duan, Y. (2022). Properties of concrete with waste glass after exposure to elevated temperatures. Journal of Building Engineering, 57, 104822. https://doi.org/10.1016/j.jobe.2022.104822
[20] Lu, J.X., Poon, C.S. (2018). Use of waste glass in alkali activated cement mortar. Construction and Building Materials, 160: 399-407. https://doi.org/10.1016/j.conbuildmat.2017.11.080
[21] Lu, J.X., Duan, Z.H., Poon, C.S. (2017). Fresh properties of cement pastes or mortars incorporating waste glass powder and cullet. Construction and Building Materials, 131: 793-799. https://doi.org/10.1016/j.conbuildmat.2016.11.011
[22] Małek, M., Łasica, W., Jackowski, M., Kadela, M. (2020). Effect of waste glass addition as a replacement for fine aggregate on properties of mortar. Materials, 13(14): 3189. https://doi.org/10.3390/ma13143189
[23] Mallum, I., Lim, N.H.A.S., Omolayo, N. (2021). Sustainable utilization of waste glass in concrete: A review. Silicon, 1-16. https://doi.org/10.1007/s12633-021-01152-x
[24] Najaf, E., Abbasi, H. (2022). Using recycled concrete powder, waste glass powder, and plastic powder to improve the mechanical properties of compacted concrete: cement elimination approach. Advances in Civil Engineering, 2022. https://doi.org/10.1155/2022/9481466
[25] Nodehi, M., Mohamad Taghvaee, V. (2021). Sustainable concrete for circular economy: A review on use of waste glass. Glass Structures & Engineering, 1-20. https://doi.org/10.1007/s40940-021-00155-9
[26] Ramakrishnan, K., Pugazhmani, G., Sripragadeesh, R., Muthu, D., Venkatasubramanian, C. (2017). Experimental study on the mechanical and durability properties of concrete with waste glass powder and ground granulated blast furnace slag as supplementary cementitious materials. Construction and Building Materials, 156: 739-749. https://doi.org/10.1016/j.conbuildmat.2017.08.183
[27] Yoo, D.Y., You, I., Zi, G. (2021). Effects of waste liquid–crystal display glass powder and fiber geometry on the mechanical properties of ultra-high-performance concrete. Construction and Building Materials, 266. https://doi.org/10.1016/j.conbuildmat.2020.120938
[28] Liu, T., Wei, H., Zou, D., Zhou, A., Jian, H. (2020). Utilization of waste cathode ray tube funnel glass for Ultra-High Performance Concrete. Journal of Cleaner Production, 249, 119333. https://doi.org/10.1016/j.jclepro.2019.119333
[29] Jaramillo-Murcia, D.C., Abellán-García, J., Torres-Castellanos, N., García-Castaño, E. (2022). Properties analysis of ultra-high-performance concrete with recycled glass and limestone powders. ACI Materials Journal, 119(5).
[30] Esmaeili, J., AL-Mwanes, A.O. (2021). A review: Properties of eco-friendly ultra-high-performance concrete incorporated with waste glass as a partial replacement for cement. Materials Today: Proceedings, 42, 1958-1965. https://doi.org/10.1016/j.matpr.2020.12.242
[31] Abellán-García, J., Núñez-López, A., Torres-Castellanos, N., Fernández-Gómez, J. (2019). Effect of FC3R on the properties of ultra-high-performance concrete with recycled glass. Dyna, 86(211): 84-93. https://doi.org/10.15446/dyna.v86n211.79596
[32] Abellán, J., Fernández, J., Torres, N., Núñez, A. (2020). Statistical optimization of ultra-high-performance glass concrete. ACI Materials Journal, 117(1): 243-254. https://doi.org/10.14359/51720292
[33] San Ha, N., Marundrury, S.S., Pham, T.M., Pournasiri, E., Shi, F., Hao, H. (2022). Effect of grounded blast furnace slag and rice husk ash on performance of ultra-high-performance concrete (UHPC) subjected to impact loading. Construction and Building Materials, 329. https://doi.org/10.1016/j.conbuildmat.2022.127213
[34] Abellán-García, J. (2022). Tensile behavior of recycled-glass-UHPC under direct tensile loading. Case Studies in Construction Materials, 17. https://doi.org/10.1016/j.cscm.2022.e01308
[35] Abellán-García, J., Redondo-Mosquera, J. D., Sánchez-Angarita, D., Redondo-Pérez, M., Gómez-Espitia, J. C. (2022). Development of High-Volume Recycled Glass Ultra-High-Performance Concrete. Available at SSRN 4234008. http://dx.doi.org/10.2139/ssrn.4234008
[36] Bameri, M., Rashidi, S., Mohammadhasani, M., Maghsoudi, M., Madani, H., Rahmani, F. (2022). Evaluation of mechanical and durability properties of eco-friendly concrete containing silica fume, waste glass powder, and ground granulated blast furnace slag. Advances in Materials Science and Engineering, 2022. https://doi.org/10.1155/2022/2730391
[37] Dong, W., Li, W., Tao, Z. (2021). A comprehensive review on performance of cementitious and geopolymeric concretes with recycled waste glass as powder, sand or cullet. Resources, Conservation and Recycling, 172. https://doi.org/10.1016/j.resconrec.2021.105664
[38] Khan, M.N.N., Saha, A.K., Sarker, P.K. (2020). Reuse of waste glass as a supplementary binder and aggregate for sustainable cement-based construction materials: A review. Journal of Building Engineering, 28. https://doi.org/10.1016/j.jobe.2019.101052
[39] Paul, D., Bindhu, K.R., Matos, A.M., Delgado, J. (2022). Eco-friendly concrete with waste glass powder: A sustainable and circular solution. Construction and building materials, 355.

https://doi.org/10.1016/j.conbuildmat.2022.129217
[40] Guo, P., Bao, Y., Meng, W. (2021). Review of using glass in high-performance fiber-reinforced cementitious composites. Cement and Concrete Composites, 120. https://doi.org/10.1016/j.cemconcomp.2021.104032
[41] Luo, B., Deng, C., Luo, Y. (2022). Mechanical properties and microstructure of UHPC with recycled glasses after exposure to elevated temperatures. Journal of Building Engineering, 62. https://doi.org/10.1016/j.jobe.2022.105369
[42] Orouji, M., Najaf, E. (2022). Effect of GFRP rebars and polypropylene fibers on flexural strength in high-performance concrete beams with glass powder and microsilica. Case Studies in Construction Materials. https://doi.org/10.1016/j.cscm.2022.e01769
[43] Mariaková, D., Vlach, T., Pavlů, T. (2019). Glass waste powder utilization in high performance concrete. Acta Polytechnica CTU Proceedings, 21: 24-27. https://doi.org/10.14311/APP.2019.21.0024
[44] da Cunha Oliveira, J.V., da Silva Morais, C.R., de Andrade Meira, F.F.D. (2021). Ultra-High Performance Concrete made from the insertion of glass residues as supplementary cement material. Research, Society and Development, 10(7). https://doi.org/10.33448/rsd-v10i7.16988
[45] Mohamed, M.A.M., Elgabbas, F., El-Nemr, A., Khalaf, M.A. (2021). The influence of glass powder as a cement replacement material on Ultra-High-Performance Concrete.
[46] da Cunha Oliveira, J.V., de Andrade Meira, F.F.D., de Lucena, K.F.M. (2021). Highlights on the properties of the soda-lime-silicate glass residue that enable its use as filler in Ultra-High Performance Concrete. Research, Society and Development, 10(3). https://doi.org/10.33448/rsd-v10i3.13801
[47] Qaidi, S., Najm, H.M., Abed, S.M., Özkılıç, Y.O., Al Dughaishi, H., Alosta, M., Milad, A. (2022). Concrete containing waste glass as an environmentally friendly aggregate: A review on fresh and mechanical characteristics. Materials, 15(18): 6222. https://doi.org/10.3390/ma15186222
[48] Hamada, H., Alattar, A., Tayeh, B., Yahaya, F., Thomas, B. (2022). Effect of recycled waste glass on the properties of high-performance concrete: A critical review. Case Studies in Construction Materials. https://doi.org/10.1016/j.cscm.2022.e01149
[49] Lu, J.X., Ali, H.A., Jiang, Y., Guan, X., Shen, P., Chen, P., Poon, C.S. (2022). A novel high-performance lightweight concrete prepared with glass-UHPC and lightweight microspheres: Towards Energy Conservation in Buildings. Composites Part B: Engineering, 247. https://doi.org/10.1016/j.compositesb.2022.110295
[50] Faried, A.S., Mostafa, S.A., Tayeh, B.A., Tawfik, T.A. (2021). Mechanical and durability properties of Ultra-High Performance Concrete incorporated with various nano waste materials under different curing conditions. Journal of Building Engineering, 43. https://doi.org/10.1016/j.jobe.2021.102569
[51] Sbia, L.A., Peyvandi, A., Lu, J., Abideen, S., Weerasiri, R.R., Balachandra, A.M., Soroushian, P. (2017). Production methods for reliable construction of ultra-high-performance concrete (UHPC) structures. Materials and Structures, 50(1): 1-19. https://doi.org/10.1617/s11527-016-0887-4
[52] Yuan, C., Xu, S., Raza, A., Wang, C., Wang, D. (2022). Influence and mechanism of curing methods on mechanical properties of manufactured sand UHPC. Materials, 15(18): 6183. https://doi.org/10.3390/ma15186183
[53] Alkaysi, M. (2016). Strength and Durability of Ultra-High Performance Concrete Materials and Structures (Doctoral dissertation). Civil Engineering. The University of Michigan.
[54] Ghareeb, K.S., Ahmed, H.E., El-Affandy, T.H., Deifalla, A.F., El-Sayed, T.A. (2022). The novelty of using glass powder and lime powder for producing UHPSCC. Buildings, 12(5): 684. https://doi.org/10.3390/buildings12050684
[55] Esmaeili, J., AL-Mwanes, A.O. (2021). Performance evaluation of eco-friendly ultra-high-performance concrete incorporated with waste glass-A review. In IOP Conference Series: Materials Science and Engineering, 1094(1). IOP Publishing. https://doi.org/10.1088/1757-899X/1094/1/012030
[56] Alani, A.H., Bunnori, N.M., Noaman, A.T., Majid, T.A. (2019). Durability performance of a novel ultra-high-performance PET green concrete (UHPPGC). Construction and Building Materials, 209: 395-405. https://doi.org/10.1016/j.conbuildmat.2019.03.088
[57] Ahmad, F., Qureshi, M.I., Ahmad, Z. (2022). Influence of nano graphite platelets on the behavior of concrete with E-waste plastic coarse aggregates. Construction and Building Materials, 316. https://doi.org/10.1016/j.conbuildmat.2021.125980
[58] Norhasri, M.M., Hamidah, M.S., Fadzil, A.M. (2019). Inclusion of nano metaclayed as additive in ultra high performance concrete (UHPC). Construction and Building Materials, 201: 590-598. https://doi.org/10.1016/j.conbuildmat.2019.01.006
[59] Amin, M., Tayeh, B.A., Agwa, I.S. (2020). Effect of using mineral admixtures and ceramic wastes as coarse aggregates on properties of ultrahigh-performance concrete. Journal of Cleaner Production, 273. https://doi.org/10.1016/j.jclepro.2020.123073
[60] Cheah, C.B., Tiong, L.L., Ng, E.P., Oo, C.W. (2019). The engineering performance of concrete containing high volume of ground granulated blast furnace slag and pulverized fly ash with polycarboxylate-based superplasticizer. Construction and Building Materials, 202: 909-921. https://doi.org/10.1016/j.conbuildmat.2019.01.075
[61] Wu, Z., Khayat, K.H., Shi, C. (2019). Changes in rheology and mechanical properties of Ultra-High Performance Concrete with silica fume content. Cement and Concrete Research, 123. https://doi.org/10.1016/j.cemconres.2019.105786
[62] Abdellatief, M., AL-Tam, S.M., Elemam, W.E., Alanazi, H., Elgendy, G.M., Tahwia, A.M. (2023). Development of ultra-high-performance concrete with low environmental impact integrated with metakaolin and industrial wastes. Case Studies in Construction Materials, 18. https://doi.org/10.1016/j.cscm.2022.e01724
[63] Koh, K.T., Park, S.H., Ryu, G.S., An, G.H., Kim, B.S. (2018). Effect of the type of silica fume and filler on mechanical properties of Ultra High Performance Concrete. In Key Engineering Materials, 774: 349-354. Trans Tech Publications Ltd.

https://doi.org/10.4028/www.scientific.net/KEM.774.349
[64] Wang, X., Yu, R., Shui, Z., Song, Q., Liu, Z., Liu, Z., Wu, S. (2019). Optimized treatment of recycled construction and demolition waste in developing sustainable Ultra-High Performance Concrete. Journal of Cleaner Production, 221: 805-816. https://doi.org/10.1016/j.jclepro.2019.02.201
[65] Chinnu, S.N., Minnu, S.N., Bahurudeen, A., Senthilkumar, R. (2021). Recycling of industrial and agricultural wastes as alternative coarse aggregates: A step towards cleaner production of concrete. Construction and Building Materials, 287. https://doi.org/10.1016/j.conbuildmat.2021.123056
[66] Mosaberpanah, M.A., Eren, O., Tarassoly, A.R. (2019). The effect of nano-silica and waste glass powder on mechanical, rheological, and shrinkage properties of UHPC using response surface methodology. Journal of Materials Research and Technology, 8(1): 804-811. https://doi.org/10.1016/j.jmrt.2018.06.011
[67] Salahaddin, S.D., Haido, J.H., Wardeh, G. (2022). The behavior of UHPC containing recycled glass waste in place of cementitious materials: A comprehensive review. Case Studies in Construction Materials, 17. https://doi.org/10.1016/j.cscm.2022.e01494
[68] Shen, W., Shi, C., Khayat, K., Yuan, Q., Ji, Y., Zeng, R., Chen, Z. (2021). Change in fresh properties of high-strength concrete due to pumping. Construction and Building Materials, 300. https://doi.org/10.1016/j.conbuildmat.2021.124069
[69] Rostami, J., Khandel, O., Sedighardekani, R., Sahneh, A. R., Ghahari, S. (2021). Enhanced workability, durability, and thermal properties of cement-based composites with aerogel and paraffin coated recycled aggregates. Journal of Cleaner Production, 297. https://doi.org/10.1016/j.jclepro.2021.126518
[70] Al-Maliki, A.A.K., Aswed, K.K., Abraheem, A.K. (2020). Properties of concrete with magnetic mixing water. In AIP Conference Proceedings, 2213(1). AIP Publishing LLC. https://doi.org/10.1063/5.0000330
[71] Abdallah, S., Fan, M. (2014). Characteristics of concrete with waste glass as fine aggregate replacement. International Journal of Engineering and Technical Research (IJETR), 2(6): 11-17.
[72] Chu, S.H., Li, L., Shen, P.L., Lu, J.X., Poon, C.S., 2022. Recycling of waste glass powder as paste replacement in green UHPFRC. Construction and Building Materials, 316. https://doi.org/10.1016/j.conbuildmat.2021.125719
[73] Tagnit-Hamou, A.R.E.Z.K.I., Soliman, N.A. (2017). Sustainable ultra-high-performance glass concrete for infrastructures. Proceedings of International Structural Engineering and Construction, 4(1).
[74] Ahmad, J., Martínez-García, R., de-Prado-Gil, J., Irshad, K., El-Shorbagy, M.A., Fediuk, R., Vatin, N.I. (2022). Concrete with partial substitution of waste glass and recycled concrete aggregate. Materials, 15(2): 430. https://doi.org/10.3390/ma15020430
[75] Karim, F., Bakar, B.A., Keong, C.K., Aziz, O. (2016). Influence of cement and glass powder on the compressive strength of Ultra-High Performance Concrete. International Journal of Engineering Trends and Technology, 35: 243-246.
[76] Mariaková, D., Jirkalová, Z., Laiblová, L. (2019). Waste glass as a replacement for fine fraction in high-performance concrete. In IOP Conference Series: Materials Science and Engineering 660(1). IOP Publishing. https://doi.org/10.1088/1757-899X/660/1/012033
[77] Safarizki, H.A., Gunawan, L.I. (2020). Effectiveness of glass powder as a partial replacement of sand in concrete mixtures. In Journal of Physics: Conference Series, 1625(1). IOP Publishing.
[78] Qin, D., Hu, Y., Li, X. (2021). Waste glass utilization in cement-based materials for sustainable construction: A review. Crystals, 11(6): 710. https://doi.org/10.3390/cryst11060710
[79] Rehman, S., Iqbal, S., Ali, A. (2018). Combined influence of glass powder and granular steel slag on fresh and mechanical properties of self-compacting concrete. Construction and Building Materials, 178: 153-160. https://doi.org/10.1016/j.conbuildmat.2018.05.148
[80] AL-Zubaid, A.B., Shabeeb, K.M., Ali, A.I. (2017). Study the effect of recycled glass on the mechanical properties of green concrete. Energy Procedia, 119: 680-692. https://doi.org/10.1016/j.egypro.2017.07.095
[81] Anwar, A. (2016). The influence of waste glass powder as a pozzolanic material in concrete. Int. J. Civ. Eng. Technol, 7(6): 131-148.
[82] Aliabdo, A.A., Abd Elmoaty, M., Aboshama, A.Y. (2016). Utilization of waste glass powder in the production of cement and concrete. Construction and Building Materials, 124: 866-877. https://doi.org/10.1016/j.conbuildmat.2016.08.016
[83] Sikora, P., Horszczaruk, E., Skoczylas, K., Rucinska, T. (2017). Thermal properties of cement mortars containing waste glass aggregate and nanosilica. Procedia Engineering, 196: 159-166. https://doi.org/10.1016/j.proeng.2017.07.186
[84] Sun, J., Wang, Y., Liu, S., Dehghani, A., Xiang, X., Wei, J., Wang, X. (2021). Mechanical, chemical and hydrothermal activation for waste glass reinforced cement. Construction and Building Materials, 301. https://doi.org/10.1016/j.conbuildmat.2021.124361
[85] Guo, P., Meng, W., Nassif, H., Gou, H., Bao, Y. (2020). New perspectives on recycling waste glass in manufacturing concrete for sustainable civil infrastructure. Construction and Building Materials, 257. https://doi.org/10.1016/j.conbuildmat.2020.119579
[86] Mehta, A., Ashish, D.K. (2020). Silica fume and waste glass in cement concrete production: A review. Journal of Building Engineering, 29. https://doi.org/10.1016/j.jobe.2019.100888
[87] Qaidi, S.M., Dinkha, Y.Z., Arbili, M.M., Haido, J.H., Tayeh, B.A. (2022). Properties of sustainable green concrete containing waste glass as eco-friendly aggregate: A review. In AIP Conference Proceedings, 2660(1). AIP Publishing LLC. https://doi.org/10.1063/5.0108686
[88] Mohajerani, A., Vajna, J., Cheung, T.H.H., Kurmus, H., Arulrajah, A., Horpibulsuk, S. (2017). Practical recycling applications of crushed waste glass in construction materials: A review. Construction and Building Materials, 156: 443-467. https://doi.org/10.1016/j.conbuildmat.2017.09.005
[89] Chung, S.Y., Abd Elrahman, M., Sikora, P., Rucinska, T., Horszczaruk, E., Stephan, D. (2017). Evaluation of the effects of crushed and expanded waste glass aggregates on the material properties of lightweight concrete using image-based approaches. Materials, 10(12): 1354.

https://doi.org/10.3390/ma10121354
[90] Siddika, A., Hajimohammadi, A., Mamun, M.A.A., Alyousef, R., Ferdous, W. (2021). Waste glass in cement and geopolymer concretes: A review on durability and challenges. Polymers, 13(13): 2071. https://doi.org/10.3390/polym13132071
[91] Harrison, E., Berenjian, A., Seifan, M. (2020). Recycling of waste glass as aggregate in cement-based materials. Environmental Science and Ecotechnology, 4. https://doi.org/10.1016/j.ese.2020.100064
[92] Abdelli, H.E., Mokrani, L., Kennouche, S., de Aguiar, J.B. (2020). Utilization of waste glass in the improvement of concrete performance: A mini review. Waste Management & Research, 38(11): 1204-1213. https://doi.org/10.1177/0734242X20941090
[93] Khan, F.A., Shahzada, K., Ullah, Q.S., Fahim, M., Khan, S.W., Badrashi, Y.I. (2020). Development of environment-friendly concrete through partial addition of waste glass powder (WGP) as cement replacement. Civil Engineering Journal, 6(12): 2332-2343. https://doi.org/10.28991/cej-2020-03091620
[94] Yang, S., Lu, J.X., Poon, C.S. (2021). Recycling of waste glass in cement mortars: Mechanical properties under high temperature loading. Resources, Conservation and Recycling, 174. https://doi.org/10.1016/j.resconrec.2021.105831
[95] Islam, G.S., Rahman, M., Kazi, N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. International Journal of Sustainable Built Environment, 6(1): 37-44. https://doi.org/10.1016/j.ijsbe.2016.10.005
[96] Tamanna, N., Tuladhar, R., Sivakugan, N. (2020). Performance of recycled waste glass sand as partial replacement of sand in concrete. Construction and Building Materials, 239. https://doi.org/10.1016/j.conbuildmat.2019.117804
[97] Mohammadyan-Yasouj, S.E., Ghaderi, A. (2020). Experimental investigation of waste glass powder, basalt fibre, and carbon nanotube on the mechanical properties of concrete. Construction and Building Materials, 252. https://doi.org/10.1016/j.conbuildmat.2020.119115
[98] Salem, Z.T.A., Khedawi, T.S., Baker, M.B., Abendeh, R. (2017). Effect of waste glass on properties of asphalt concrete mixtures. Jordan Journal of Civil Engineering, 11(1).
[99] Sudharsan, N., Saravanaganesh, S. (2019). Feasibility studies on waste glass powder. International Journal of Innovative Technology and Exploring Engineering, 8(8): 1644-1647.
[100] Letelier, V., Tarela, E., Osses, R., Cárdenas, J.P., Moriconi, G. (2017). Mechanical properties of concrete with recycled aggregates and waste glass. Structural Concrete, 18(1): 40-53. https://doi.org/10.1002/suco.201500143
[101] Kim, I.S., Choi, S.Y., Yang, E. I. (2018). Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate. Construction and Building Materials, 184: 269-277. https://doi.org/10.1016/j.conbuildmat.2018.06.221
[102] Li, A., Qiao, H., Li, Q., Hakuzweyezu, T., Chen, B. (2021). Study on the performance of pervious concrete mixed with waste glass powder. Construction and Building Materials, 300, 123997. https://doi.org/10.1016/j.conbuildmat.2021.123997
[103] Hama, S.M., Mahmoud, A.S., Yassen, M.M. (2019). Flexural behavior of reinforced concrete beam incorporating waste glass powder. In Structures, 20: 510-518. Elsevier. https://doi.org/10.1016/j.istruc.2019.05.012
[104] Keerio, M.A., Abbasi, S.A., Kumar, A., Bheel, N., Tashfeen, M. (2020). Effect of silica fume as cementitious material and waste glass as fine aggregate replacement constituent on selected properties of concrete. Silicon, 1-12. https://doi.org/10.1007/s12633-020-00806-6
[105] Ahmad, J., Aslam, F., Martinez-Garcia, R., de-Prado-Gil, J., Qaidi, S., Brahmia, A. (2021). Effects of waste glass and waste marble on mechanical and durability performance of concrete. Scientific reports, 11(1): 1-17. https://doi.org/10.1038/s41598-021-00994-0
[106] Lu, J.X., Yan, X., He, P., Poon, C.S. (2019). Sustainable design of pervious concrete using waste glass and recycled concrete aggregate. Journal of Cleaner Production, 234: 1102-1112. https://doi.org/10.1016/j.jclepro.2019.06.260
[107] Ibrahim, K.I.M. (2021). Recycled waste glass powder as a partial replacement of cement in concrete containing silica fume and fly ash. Case Studies in Construction Materials, 15, e00630. https://doi.org/10.1016/j.cscm.2021.e00630
[108] Tahwia, A.M., Heniegal, A.M., Abdellatief, M., Tayeh, B.A., Abd Elrahman, M. (2022). Properties of ultra-high performance geopolymer concrete incorporating recycled waste glass. Case Studies in Construction Materials, 17: e01393. https://doi.org/10.1016/j.cscm.2022.e01393
[109] Mostafa, S.A., Faried, A.S., Farghali, A.A., El-Deeb, M.M., Tawfik, T.A., Majer, S., Abd Elrahman, M. (2020). Influence of nanoparticles from waste materials on mechanical properties, durability and microstructure of UHPC. Materials, 13(20): 4530. https://doi.org/10.3390/ma13204530
[110] Soliman, N.A., Tagnit-Hamou, A. (2017). Using glass sand as an alternative for quartz sand in UHPC. Construction and Building Materials, 145: 243-252. https://doi.org/10.1016/j.conbuildmat.2017.03.187
[111] Wu, L., Xiang, Z., Jiang, H., Liu, M., Ju, X., Zhang, W. (2022). A review of durability issues of reinforced concrete structures due to coastal soda residue soil in China. Journal of Marine Science and Engineering, 10(11): 1740. https://doi.org/10.3390/jmse10111740