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Incorporation of Recycled Glass-Derived Powders For Manufacturing High- Performance Fiber-Reinforced Concrete

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ABSTRACT

Concrete, as the most widely used material in the construction industry, plays a crucial role in modern infrastructure. However, its production is a major contributor to environmental challenges, particularly due to the high carbon footprint of cement manufacturing. To address this issue, researchers are exploring sustainable alternatives, including the use of supplementary cementitious materials SCMs to partially replace cement while maintaining or enhancing concrete performance. This study investigates the feasibility of incorporating recycled glass derived powders namely, glass powder and cullet powder as partial cement replacements in high-performance concrete HPC manufacturing. The research evaluates their effects on key properties such as workability, setting time, mechanical strength, and durability, with replacement levels of up to 25%, as suggested from the literature. Preliminary experimental results indicate that while these materials influence fresh and hardened concrete properties, their use remains within acceptable engineering limits. While this approach seems promising to mitigating the environmental impact of cement production is the incorporation of sustainable supplementary cementitious materials to reduce cement consumption, optimizing the dosage is crucial to maintaining desirable properties. The findings of this study highlight the potential of recycled glass as an eco-friendly SCM, contributing to reducing the environmental impact of concrete production while promoting circular economy principles in the construction industry.

Keywords: High Performance Concrete; Glass; Cullet; Powder; flow; compressive strength.

Graphical abstract

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1. Introduction

In today's world, where the environmental impact of human activities is under intense scrutiny, the need for sustainable solutions that reduce waste generation and preserve natural resources has become more critical than ever. Among the promising strategies for greener construction is the use of recycled concrete waste in concrete manufacturing [1], [2] a practice that holds significant potential for both innovation and environmental stewardship. The construction sector, unfortunately, remains a major consumer of raw materials and a significant contributor to global carbon emissions, making it essential to quantify and structure efforts toward more sustainable alternatives. As these initiatives gain momentum, the integration of fine particles derived from recycled glass into concrete production has emerged as a transformative approach. This strategy not only addresses the pressing issue of waste management but also provides a range of technical and environmental benefits, paving the way for more sustainable and durable infrastructure. In other hand, high-performance concrete HPC is well known for its exceptional strength and durability, is widely used in modern construction but requires a substantial amount of cement. Cement manufacturing, however, is among the leading sources of CO_2 emissions and contributes significantly to the depletion of finite resources. A promising approach to mitigating these environmental impacts is the incorporation of recycled materials, particularly glass waste, as a partial cement replacement. This substitution not only reduces the ecological footprint of concrete production but may also enhance specific mechanical and durability properties under certain conditions.

Several studies have investigated the feasibility of using glass powder as a supplementary cementitious material (SCM). Salahaddin et al. [3] achieved an ultra-high-performance concrete (UHPC) with a compressive strength of 220 MPa by incorporating glass powder. Additional research has demonstrated that replacing cement with glass powder in proportions up to 20% can maintain comparable compressive strength levels in UHPC at 28 days [4],[5]. Other studies suggest that glass powder can enhance compressive strength at similar replacement levels, with improvements of up to 20% at 28 days [6],[7],[8]. Moreover, in conventional concrete, a replacement rate of 22.5% has been found to increase 28-day compressive strength by approximately 20%, attributed to the pozzolanic reaction forming additional calcium silicate hydrates—the key binding agents in concrete [7]. On the other hand, the use of cullet powder as a cement substitute has yielded mixed results. Some studies report a reduction in compressive strength when cullet is used, while others have found that replacement levels up to 25% maintain acceptable mechanical properties for non-structural applications [9]. Beyond this threshold, particularly at 40% replacement, a significant decrease in compressive strength has been observed [9],[10]. Similarly, while glass powder exhibits positive effects at moderate replacement levels, its mechanical benefits diminish beyond 20%, with a pronounced decline in compressive strength beyond 30% [3],[6]. Furthermore, the physical properties of glass powder, particularly particle size, play a crucial role in the fresh-state behavior of concrete, influencing workability and setting characteristics [6]. Additionally, the use of cullet fines up to 40% as a cement substitute has been found to slightly reduce workability, necessitating adjustments in mix design [9],[10]. These findings underscore the importance of optimizing replacement levels to balance sustainability with mechanical performance.

This study explores the potential of integrating fine particles derived from recycled glass into high-performance concrete as part of a sustainable construction strategy that maximizes durability while reducing cement demand. By incorporating recycled glass waste into HPC, the objective is to enhance the material's longevity, lower carbon emissions, and contribute to circular economy principles in the construction sector. This research aims to provide insights into the optimal replacement levels of glass-derived powders, ensuring a balance between sustainability and mechanical performance while advancing the transition toward environmentally responsible concrete production.

2. Materials and Methods

The experimental study compose of description of the used materials as well an indication of the physico-chemical characteristics, as well the formula used for manufacturing concrete.

2.1. Material

2.1.1 Materials Used for Control Concrete Manufacturing

The materials used in this study were carefully selected to ensure the production of high-performance fiber-reinforced concrete with consistent and reliable properties. These materials served as the basis for manufacturing the control formulation, which was used as a reference to evaluate the effects of glass powder and cullet powder replacements.

Cement: The cement used for manufacturing the test specimens is CPA type CEM I 42.5 SR, produced by the industrial group CEMEX Buñol from Elkem, Spain. This cement complies with the European standard NF EN 197-1 and is known for its high early and long-term strength, as well as its sulfate resistance, making it particularly suitable for high-performance applications.

Aggregates: The fine aggregates consist of a blend of three different fractions sourced from a local quarry. This mixture is designed to replicate the properties of standardized sand, providing consistent granulometry and enhancing the mechanical performance of the concrete mixtures.

Admixture: A high-range water-reducing admixture (superplasticizer) was used to improve the workability and maintain the desired consistency without increasing the water-to-cement ratio. Specifically, Sika Viscocrete 20HE was selected for its ability to enhance flowability, improve mechanical strength, and minimize segregation.

Fibers: Metallic fibers measuring 10 mm in length were incorporated into the concrete mixtures. These fibers are recommended for high-performance concrete due to their effectiveness in improving tensile strength, crack resistance, and overall durability.

Water: Normal tap water was used for all mixtures to ensure consistency in hydration and setting times throughout the experiments.

These materials formed the foundation for the control formulation, against which the effects of recycled glass powder and cullet powder were compared. The goal was to assess how these eco-friendly substitutions influence the mechanical and durability properties of high-performance concrete.

2.1.2 Glass-Derived Powders

In the process of recycling glass waste supposed to end up in landfills, these materials will be recovered, promoted, and transformed into useful materials. The process started by undergoing grinding in an industrial pendular mill equipped with pendulums sporting rollers at their ends. These pendulums swing vigorously, applying intense pressure against a grinding ring. The secret lies in the star-shaped center that spins rapidly, generating the necessary force. Through this remarkable dance of motion and pressure, the waste glass is transformed into a finely ground product. It is a simple yet effective way to turn waste into something valuable and useful. This process is applied to two types of glass waste, namely the glass powder and cullet powder, which differ in origin since the glass powder is derived from bully glass waste. In contrast, the cullet powder comes from crushed glass fragments after manufacturing defects when processing to the usual treatment for recycling glass or from the or discarded glass that has not undergone complete remelting and refining. Concerning the difference, it was noticed that they have the same colors, but the difference appears in the structure because the cullet is softer and encourages the formation of small cullet balls, as it appears in Fig.1.

The Glass Powder and the Cullet have been supplied following an industrial grinding and screening treatment from a recycling platform by the company FCC ámbito, Molaris (Sagunto, Spain).

a - Glass Powder b - Cullet

Fig 1. The Glass Powder and The Cullet Powder

2.2. Characterization

The characterization of the recycled glass-derived powders is essential for assessing their suitability as supplementary cementitious materials. This characterization included analyses of particle size distribution, density, specific surface area, and bulk density. The particle size distribution was determined using laser granulometry, following the procedure outlined in ISO 13320, which is the standard for laser diffraction methods. The apparent density was measured in accordance with EN 196-6, while the specific surface area was evaluated using the Blaine air permeability method, based on EN 196-6 as well. Although chemical parameters were not directly measured, they were compiled from a reviewed bibliography based on representative literature data. The results of the laser granulometry analysis for both the glass powder and the cullet powder are presented in Fig 2, while Table 1 summarizes their key physical characteristics.

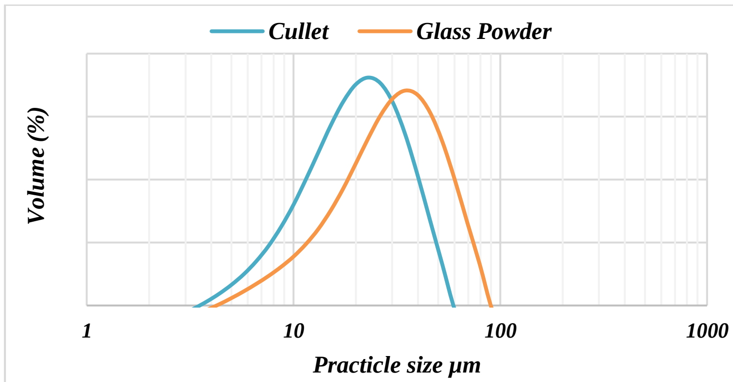

Fig 2. The laser particle size curve

Table 1. Physical characteristics of Glass powder and Cullet

	Glass Powder	Cullet
Apparent Density	1350 kg/m^3	1150 kg/m3
Volume weighted mean D50	28.40 µm	19.35 µm
Specific surface area	0.56 m²/g	0,74 m²/g

It was noticed that the fineness of its materials was within the range of additions (lower than 100µm); it is also noted that the apparent density is comparable to that of cement and those of conventional SCMs.

Regarding the chemical composition of these powders, literature consistently highlights that materials derived from glass waste, such as cullet and glass powder, are predominantly composed of SiO_2, often-exceeding 70% of the total content. They also contain notable amounts of Na_2O reaching 16% sometimes, as well as CaO below 13%, which influence their reactivity in cementitious systems. Additionally, smaller proportions of MgO within a maximum of 5% and traces of other oxides contribute to their overall chemical behaviour and potential as a supplementary cementitious material [9],[11-13].

2.3. Concrete Formulation

Following preliminary testing based on a formulation inspired by previous research conducted at the ICITECH laboratory particularly the work of Serna et al. [14]; the mix design was optimized in accordance with the specifications of EN 196-1, which governs the preparation and testing of cementitious mortars. This optimized formulation served as the control mix, from which a series of modified mixtures were developed by incorporating three different cement replacement rates (10%, 18%, and 25%) using either glass powder or cullet powder, in order to evaluate their influence on the performance of fiber-reinforced high-performance concrete.

Table 2. Formulation table with quantities needed for each mixture (Kg)

Concrete mixtures	Control	Glass Powder			Cullet		
		10 %	18 %	25 %	10 %	18 %	25 %
Cement	975	875	800	730	875	800	730
Glass Powder	-	100	175	245	-	-	-
Cullet	-	-	-	-	100	175	245
Sand fine 0,4	305	305	305	305	305	305	305
Sand medium 0,8	565	565	565	565	565	565	565
Sand gross 3	225	225	225	225	225	225	225
Water	175	175	175	175	175	175	175
Superplastisizer	25	25	25	25	25	25	25
Fibers	160	160	160	160	160	160	160

As shown in Table 2, the total binder content was adjusted proportionally to maintain a consistent paste volume, while the aggregate composition (fine, medium, and coarse sand) and superplasticizer dosage were kept constant across all mixtures. The fiber content was uniformly maintained at 160 kg/m³, ensuring comparability of mechanical performance and rheology across all mixes. These controlled variables support a reliable comparison of the impact of glass-derived powders on fresh and hardened concrete properties. The inclusion of detailed mix proportions contributes to clarity, reproducibility, and alignment with established testing standards, forming a robust foundation for subsequent experimental evaluation.

3. Results and Discussion

Concrete testing was carried out in two phases, beginning with fresh-state assessments to evaluate workability, as well the setting time for each formula. Then, after the curing period, destructive tests were conducted to analyze the compressive strength of mortars incorporating recycled glass fines, in comparison to control samples without glass additions. These tests were performed at 28-days cure period, following standardized procedures for defining concrete strength classes. To assess the mechanical contribution of these additions, six specimens per mix were demolded and subjected to compressive strength tests, providing a comprehensive evaluation of their performance.

3.1. The Influence of Glass Powder and Cullet Powder on the Concrete Workability

The experimental process was carried out in strict accordance with established norms and standards to evaluate the influence of glass and cullet powders on the workability (flowability) of fiber-reinforced high-performance concrete in the fresh state. Specifically, the workability was assessed using the reversed Abram’s cone method, in accordance with the NF EN 12350-2 standard (commonly known as the slump test). Following standardized protocols, a detailed study was conducted, ensuring that the results align with industry benchmarks. These findings offer valuable insights into the impact of recycled glass powders on concrete rheology, enriching the existing body of knowledge within the framework of applicable standards. The results are presented in the following Table 3 and Fig 3.

Table 3. Flow cone test results for different concrete formulations

Formulation		Spreading Measures (Slump Cone) mm
Control		800
Glass Powder	10%	790
	18%	780
	25%	750
Cullet Powder	10%	780
	18%	760
	25%	700

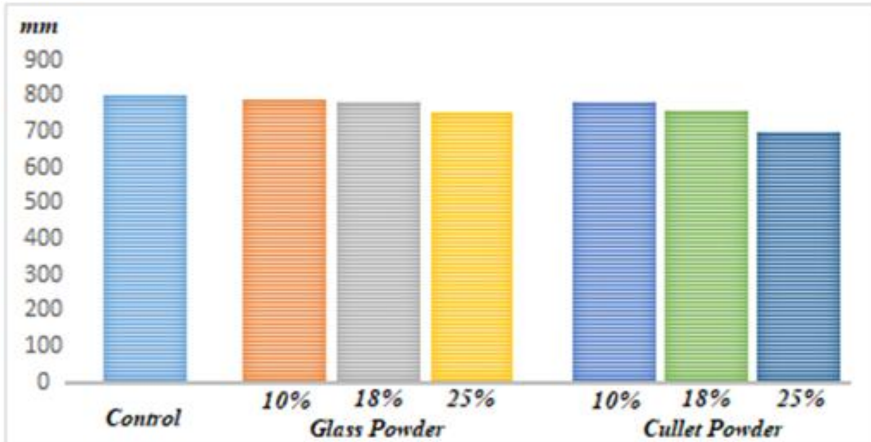

Fig 3. Workability test results when using different replacement rate of glass and cullet powders (mm)

The flow measurements obtained from Abram's cone test indicate that the workability of concrete is slightly influenced by the increasing replacement of cement with recycled glass-derived materials. As the substitution level rises, a gradual reduction in workability is observed, with higher replacement rates leading to a stiffer and less fluid mix, as evidenced by the lower flow values. These findings align with the work of Gimenez-Carbo et al. [9], who also reported a decline in workability with increased glass content.

Moreover, a notable difference was observed between the effects of glass powder and cullet fines. The incorporation of cullet fines resulted in a more pronounced reduction in workability since it has a workability decrease of around 12.5% at a replacement level of 25%, whereas when using glass powder the reduction was only by around 6%. Also, it has been observed that the mix is significantly more viscous for the cullet compared to mixtures containing glass powder. This variation can be attributed to differences in particle shape, texture, and packing density, which influence the overall rheology of the concrete.

It is also observed that the incorporation of recycled glass-derived materials, namely glass powder and cullet powder, did not compromise the stability of the mixture. Throughout the tests, the concrete mixes exhibited no signs of segregation, bleeding, or other instability issues, indicating that these materials can be effectively integrated into the formulation without negatively affecting the homogeneity and cohesion of the mix. As it appears on the fig. 4.


Fig 4. The tests in the fresh state of the concrete using the slump cone (Abrams cone)

3.2. The Influence of Glass Powder and Cullet Powder on the Concrete Sitting time Properties

The incorporation of Recycled Glass-Derived Powders, namely glass and cullet powders, as partial cement replacements may have a noticeable impact on the setting time of mortars. To evaluate this effect, setting time tests were conducted using the Vicat apparatus, following the standardized procedure outlined in ASTM C191. As shown in Table 4 and Fig. 5. Upon an initial observation, it can be noticed that the setting time varies depending on both the replacement rate and even the type of glass-derived material used.

Table 4. The influence of the replacement rate of glass and cullet powders on setting time

Formulation	Control	Glass Powder			Cullet		
		10 %	18%	25%	10 %	18 %	25 %
Initial setting time	5h45mn	6h00mn	6h45mn	6h55mn	5h40mn	5h30mn	5h00mn
Final setting time	8h20mn	8h30mn	9h00mn	9h30mn	8h10mn	7h55mn	7h45mn

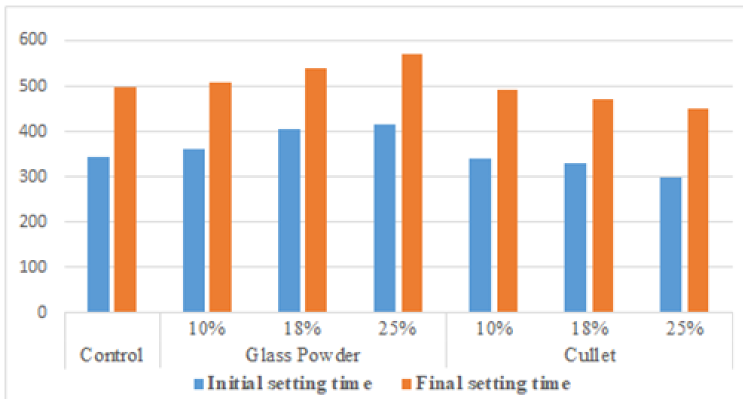

Fig 5. Influence of glass and cullet powders on setting time

Based on the initial and final setting time measurements, it is evident that increasing the percentage of glass powder in the concrete mix leads to a progressive delay in the setting process. Higher replacement levels further extend both the initial and final setting times, indicating a slower hydration reaction. In contrast, the use of cullet fine results in a slight reduction in setting time, thereby accelerating the overall hardening process of the mixtures. This suggests that while glass powder may act as a setting retarder, cullet fine has a more neutral or slightly accelerating effect on cement hydration.

3.3. The Influence Of Glass Powder and Cullet Powder On The Compressive Strength

The final stage of the experimental program involved evaluating the compressive strength of the concrete mixtures, a critical parameter in assessing their mechanical performance. The tests were conducted in accordance with EN 12390-3, which specifies the method for determining the compressive strength of hardened concrete. Standard cubic specimens with dimensions of 150 × 150 × 150 mm³, as defined in EN 12390-1, were used. For each mixture, three specimens were prepared and tested to ensure accuracy, repeatability, and statistical relevance. After demolding at 24 hours, the specimens were stored in a wet curing room at 20 ± 2 °C and ⩾95% relative humidity until the age of 28 days, following the curing conditions recommended by EN 12390-2. All tests were performed under controlled laboratory conditions to ensure the reliability and consistency of the results. The fig 6 presents a visual representation of the compressive strength test in progress, showcasing the use of a compression testing machine during the experiment.

Fig 6. Compressive Strength Test of Concrete Specimens Using a Compression Testing Machine.

The results are summarized in Table 5 and illustrated in Fig 7, these findings provide valuable insights into the influence of these recycled glass-derived materials, namely the glass and cullet powders, on the strength evolution of the mixtures. By analyzing these findings, the potential for incorporating recycled glass-derived powders as partial cement replacements in high-performance concrete can be assessed with regard to maintaining or enhancing structural integrity.

Table 5. Influence of Glass and Cullet Powders on the Compressive Strength MPa

Formulation	**Control**	**Glass Powder**			**Cullet**		
		10 %	**18%**	**25%**	**10 %**	**18 %**	**25 %**
Compressive strength	121 (±3)	120 (±4)	119 (±5)	115 (±4)	119 (±2)	111 (±3)	99 (±4)

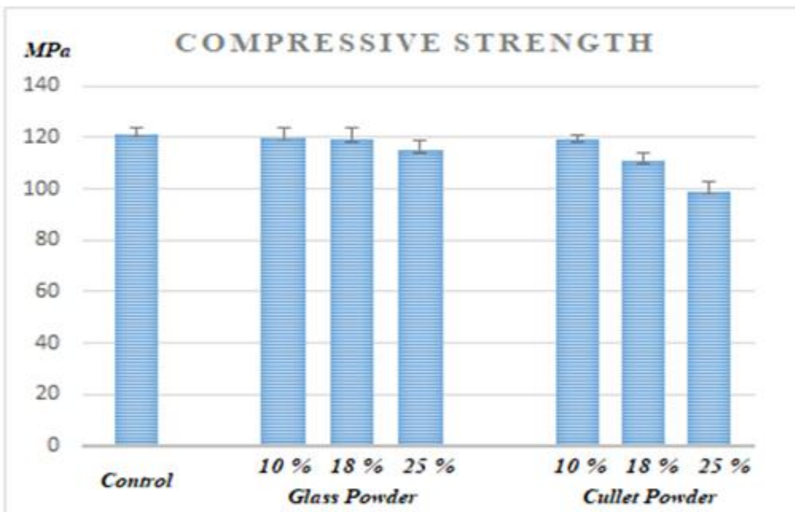

Fig 7. Influence of Glass and Cullet Powders on the Compressive Strength MPa

The compressive strength results presented in Table 5 reveal the influence of glass powder and cullet powder as partial cement replacements in high-performance concrete. The data suggest a slight reduction in compressive strength as the replacement percentage increases, with a more pronounced decline observed beyond an 18% substitution rate. However, the variations in strength are within an acceptable tolerance range, indicating that the reduction is not drastic but rather a gradual decline. This trend is consistent with the findings reported by Jiang et al. [14], who reported similar behavior with a gradual decrease in compressive strength when incorporating 10% to 40% glass powder as a cement replacement. Notably, this reduction was more pronounced in high-performance concrete mixes (45–80 MPa), where the sensitivity to glass powder substitution tends to be greater than in conventional concrete.

To evaluate whether the differences among mixtures are statistically meaningful, basic comparisons were made based on the mean values and associated standard deviations. The analysis revealed that concerning the glass powder series, the compressive strength values at 10% (120 ± 4 MPa) and 18% (119 ± 5 MPa) are very close to the control (121 ± 3 MPa) and fall within overlapping standard deviation ranges, indicating that these differences are not statistically significant. However, at 25% replacement (115 ± 4 MPa), the reduction becomes more consistent and likely meaningful.

In the case of cullet powder, a clearer reduction is observed. While the 10% replacement (119 ± 2 MPa) remains close to the control, the 18% (111 ± 3 MPa) and especially the 25% (99 ± 4 MPa) mixtures show noticeable decreases in strength beyond the expected variability, suggesting a statistically significant reduction in performance at higher substitution rates.

These observations suggest that recycled glass-derived powders can be effectively used as supplementary cementitious materials, provided that the replacement rates are carefully optimized. In particular, moderate incorporation levels (⩽18%) do not significantly affect compressive strength, making them a viable option for sustainable mix designs. However, higher replacement levels should be approached with caution, as they may lead to a notable reduction in mechanical performance and risk compromising the performances of high-performance concrete.

4. Conclusion

This experimental study investigates the incorporation of recycled glass-derived powders, specifically glass powder and cullet powder, as partial cement replacements in high-performance fiber-reinforced concrete (HPC). The effects of these materials on fresh-state properties, setting behavior, and compressive strength were systematically assessed.

Workability: The flowability of fresh concrete, measured by the reversed Abrams cone method (EN 12350-2), decreased with increasing replacement levels. Mixtures with cullet powder exhibited lower workability than those with glass powder, suggesting higher viscosity and reduced workability.

Setting Time: Glass powder prolongs both initial and final setting times in proportion to its dosage, reflecting a delay in the hydration process. In contrast, cullet powder exhibits a slight accelerating effect, marginally reducing the setting time.

Compressive Strength: A gradual reduction in compressive strength was observed with higher replacement levels, particularly beyond 18%. While all mixtures maintained strength values above 99 MPa, cullet-based mixes exhibited a more pronounced decrease. Based on standard deviations, the differences at low-to-moderate replacement levels (≤18%) were not statistically significant compared to the control, while higher substitution rates showed meaningful performance drops.

From a practical engineering standpoint, these results highlight the potential for using recycled glass-derived materials in concrete, since mixtures incorporating up to 18% glass-derived powders are deemed suitable for structural HPC applications, as they maintain mechanical performance within the range required for structural applications requiring high mechanical strength. In contrast, formulations with higher replacement levels, especially those containing cullet powder, are more appropriate for non-structural or secondary structural components, where lower mechanical demands may be acceptable. Moreover, it is important to consider the source of the glass waste, as its chemical composition, physical properties, and fineness can significantly influence the behavior of cementitious mixtures. Therefore, comprehensive material characterization and preliminary mix testing are essential to ensure consistent and reliable performance.

Finally, this research represents the initial phase of a broader investigation focused on the development of sustainable high-performance concrete. While the results related to fresh and mechanical properties are promising, long-term durability remains a critical consideration for HPC. Future work will focus on optimizing performance through durability assessments including shrinkage, chloride penetration, and sulfate resistance, as well as conducting a life cycle assessment (LCA) to evaluate environmental impact. These efforts will support the safe, efficient, and sustainable integration of recycled glass materials into high-performance concrete technologies.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. Ismail AY, Al-Luhybi AS, Mohammad KI. Prediction of compressive strength of concrete incorporating fine recycled aggregate using regression analysis. *Alger J Eng Technol*. 2024;9(2):114–26. https://doi.org/10.57056/ajet.v9i2.168
2. Douidi O, Tafraoui A, Makani A, Serna P. The use of recycled concrete powder as supplementary cementitious materials for manufacturing concrete. *Commun Sci Lett Univ Zilina*. 2024;26(2):D27–37. https://doi.org/10.26552/com.C.2024.019
3. Salahaddin SD, Haido JH, Wardeh G. The behavior of UHPC containing recycled glass waste in place of cementitious materials: A comprehensive review. *Case Stud Constr Mater*. 2022;17:e01494. https://doi.org/10.1016/j.cscm.2022.e01494
4. Tagnit-Hamou A, Soliman N, Omran A. Green ultra-high-performance glass concrete. Ames (IA): Iowa State University Digital Press; 2016.
5. Soroushian P. Strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement. *Constr Build Mater*. 2012;29:368–77. https://doi.org/10.1016/j.conbuildmat.2011.10.061
6. Jiang Y, Ling TC, Mo KH, Shi C. A critical review of waste glass powder—multiple roles of utilization in cement-based materials and construction products. *J Environ Manag*. 2019;242:440–9. https://doi.org/10.1016/j.jenvman.2019.04.098
7. Jurczak R, Szmatuła F, Rudnicki T, Korentz J. Effect of ground waste glass addition on the strength and durability of low strength concrete mixes. *Materials*. 2021;14(1):190. https://doi.org/10.3390/ma14010190

8. Khan MI, Abbas YM, Abellan-Garcia J, Castro-Cabeza A. Eco-efficient ultra-high-performance concrete formulation utilizing electric arc furnace slag and recycled glass powder–advanced analytics and lifecycle perspectives. *J Mater Res Technol*. 2024;32:362–77. https://doi.org/10.1016/j.jmrt.2024.07.171
9. Gimenez-Carbo E, Soriano L, Roig-Flores M, Serna P. Characterization of glass powder from glass recycling process waste and preliminary testing. *Materials*. 2021;14(11):2971. https://doi.org/10.3390/ma14112971
10. Wilson W, Soliman NA, Sorelli L, Tagnit-Hamou A. Micro-chemo-mechanical features of ultra-high performance glass concrete (UHPGC). *Theor Appl Fract Mech*. 2019;104:102373.
11. Borek K, Czapik P, Dachowski R. Recycled glass as a substitute for quartz sand in silicate products. *Materials*. 2020;13(5):1030. https://doi.org/10.3390/ma13051030
12. Rao AU, Shetty PP, Bhandary P, Tantri A, Blesson S, Yaragal SC. Assessment of fly ash and ceramic powder incorporated concrete with steam-treated recycled concrete aggregates prioritising nano-silica. *Emerg Mater*. 2024;7(2):443–72. https://doi.org/10.1007/s42247-024-00639-8
13. Arab BA, Mehaddene R. Strength of glass powder-based high-performance concrete during the time. *Alger J Eng Technol*. 2023;8(1):108–16. https://doi.org/10.57056/ajet.v8i1.99
14. Serna P, Llano-Torre A, Martí-Vargas JR, Navarro-Gregori J. Fibre reinforced concrete: improvements and innovations. RILEM Bookseries, Volume 30. Cham (Switzerland): Springer; 2021. https://doi.org/10.1007/978-3-030-58482-5