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Review of concrete incorporating waste glass powder and recycled aggregates

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Abstract

Traditional concrete production heavily impacts the environment, with cement manufacturing responsible for about eight percent of global CO_2 emissions and extensive resource depletion from aggregate extraction. To address this, researchers have explored using waste glass powder (WGP) as a partial cement replacement and recycled aggregates (RA) instead of natural stone. WGP enhances strength and durability through pozzolanic activity, while RA promotes waste reduction and resource conservation. However, limited studies examine their combined use. This review synthesizes recent research on WGP and RA, evaluating their individual and joint effects on concrete's strength, workability, and sustainability to guide eco-friendly mix designs for greener construction

Keywords: Green Concrete; Sustainable Materials; Waste Glass Powder; Recycled Aggregates; Cement Replacement; Pozzolanic Activity; Strength; Workability; Eco-Friendly Construction

1. Introduction

Concrete serves as the cornerstone of modern construction, finding applications in everything from residential buildings and highways to bridges and dams. However, its conventional production poses significant environmental challenges. Cement manufacturing alone contributes nearly eight percent of global carbon dioxide emissions, while the large-scale extraction of natural aggregates steadily depletes valuable resources. To mitigate these impacts, researchers are investigating more sustainable alternatives, such as partially replacing cement with finely ground waste glass powder (WGP) and substituting natural aggregates with recycled aggregates (RA). WGP not only aids in recycling glass waste but also exhibits pozzolanic properties that enhance concrete's strength and durability, whereas RA helps reduce landfill pressure and conserves natural resources. Despite their individual advantages, most studies have focused on WGP and RA separately, leaving limited understanding of their combined effects. This review aims to consolidate current research on WGP and RA, exploring their separate and synergistic influences on concrete's mechanical performance, workability, and sustainability. Ultimately, the paper seeks to provide practical insights for mix designs that balance performance, cost, and environmental impact, guiding engineers toward eco-friendly concrete solutions.

2. Literature review

2.1. Part 1: Early Research and Background

Concrete remains the most widely used construction material globally, but its heavy reliance on cement raises concerns regarding carbon emissions and environmental degradation. To address these issues, supplementary cementitious materials (SCMs) have been explored as partial replacements for cement, offering sustainability benefits while maintaining structural performance. Among these, waste glass powder (WGP) has gained attention due to its abundance, high silica content, and recyclability, providing a dual advantage of reducing cement consumption and managing glass waste [1].

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The use of finely ground glass in concrete is not entirely new; however, earlier applications were limited due to concerns over alkali-silica reaction (ASR). Later studies clarified that when glass is ground below 75 µm, it demonstrates pozzolanic behavior, mitigating the risk of harmful expansion [16]. This understanding prompted numerous experimental investigations into the mechanical and durability characteristics of WGP-incorporated concrete.

According to [5], the fineness of glass powder is a critical factor influencing its reactivity. Coarser particles are often inert or may even exacerbate ASR, whereas powders finer than 45 µm exhibit strong pozzolanic activity, reacting with calcium hydroxide to form secondary calcium silicate hydrate (C–S–H). Consequently, many researchers have focused on ultra-fine powders when evaluating higher cement replacement levels.

Initial experimental studies typically examined replacement levels between 5% and 20% by weight of cement. The consensus indicates that low to moderate replacements (approximately 10–15%) can maintain or slightly improve compressive strength while contributing to environmental sustainability [3]. For example, [1] reported that concrete with 20% WGP replacement achieved comparable 28-day strength to conventional mixes, with noticeable improvements in long-term durability.

These early findings set the stage for systematic comparisons between WGP and traditional SCMs like fly ash and silica fume. The literature consistently shows that while WGP may not provide the same early-age strength as silica fume, it enhances long-term reactivity and durability, making it a viable option for sustainable concrete applications [2].

2.2. Material Properties and Processing of Waste Glass Powder

The performance of waste glass powder (WGP) in concrete is largely dictated by its physical and chemical characteristics, which determine its reactivity as a supplementary cementitious material (SCM). Chemically, most container and flat glasses consist primarily of silica (SiO_2), sodium oxide (Na_2O), and calcium oxide (CaO), with silica content often exceeding 70% by mass. This high silica concentration makes WGP a promising pozzolanic material when ground to a fine powder [5]. Moreover, the amorphous structure of glass enhances its reactivity, as amorphous silica dissolves more readily in alkaline cement pore solutions than crystalline forms [4].

Among all factors, particle size is the most critical in influencing WGP's effectiveness. Studies consistently indicate that finer particles exhibit greater pozzolanic activity. When ground below 75 µm, WGP can effectively react with calcium hydroxide generated during cement hydration, forming additional calcium silicate hydrate (C–S–H) gel. This not only improves later-age strength but also refines the microstructure and reduces concrete permeability [1]. Research further suggests that powders with particle sizes close to or below 45 µm yield the most consistent improvements in compressive strength and durability [3].

While chemical composition and fineness are primary determinants, the color and source of glass can also have minor influences. Clear, green, and amber glasses show similar fundamental reaction mechanisms, though slight variations in metallic oxides (e.g., Fe_2O_3, Cr_2O_3) may alter reactivity [2]. Nevertheless, fineness and replacement ratio remain far more significant factors than color in determining performance.

Processing WGP involves crushing and grinding the glass, typically using ball mills or vertical roller mills. A key challenge is the relatively high energy demand for grinding, due to the hardness of glass. Life-cycle assessments indicate that the environmental gains from cement reduction generally outweigh the energy costs of grinding, particularly when WGP is optimized as a partial cement replacement [6].

Purity of the glass feedstock is another crucial factor. Contaminants such as ceramics, plastics, or metals can adversely affect hydration and mechanical performance. Consequently, most studies utilize post-consumer container glass, which is both abundant and easier to process consistently. In summary, WGP is chemically compatible with cement hydration, but its performance in concrete is highly dependent on particle size, purity, and replacement level. These parameters form the foundation for understanding its effects on both fresh and hardened concrete properties, guiding researchers in optimizing mix designs for mechanical performance and durability [3].

2.3. Effect of Waste Glass Powder on Fresh Properties of Concrete

The incorporation of waste glass powder (WGP) into cement mixes influences the fresh properties of concrete, particularly workability, consistency, and setting times. Researchers have reported mixed findings, largely due to variations in glass fineness and replacement levels.

One of the commonly observed effects is on workability. Glass particles are smooth and non-porous, unlike natural pozzolans or fly ash, which tend to absorb more water. As a result, some studies reported that replacing a small percentage of cement with WGP increased slump values, improving flowability. [1] observed that concrete mixes containing up to 15% finely ground WGP exhibited slightly higher workability compared to control mixes. This was attributed to the "ball bearing effect" of smooth glass particles, which reduced internal friction within the mix.

However, other researchers noted that very fine WGP can increase water demand due to its higher surface area. [3] found that when WGP particles were ground below 45 μm, mixes with more than 15% replacement showed reduced workability unless superplasticizers were used. This indicates that the influence of WGP on workability is a balance between particle shape (which tends to improve flow) and surface area (which can increase water demand).

Another important fresh property affected by WGP is the setting time of cement paste. [2] Studies have reported that initial and final setting times generally increase slightly with the addition of WGP, particularly at higher replacement levels. This delay is linked to the slower pozzolanic reactivity of glass powder compared to the rapid hydration of Portland cement. While the extension of setting time is usually modest at 10–15% replacement, it becomes more noticeable beyond 20%. For practical construction, this can be advantageous in hot climates, as delayed setting reduces the risk of cold joints [2], [3], [5].

In terms of consistency, WGP-blended pastes often show comparable or slightly reduced water demand at moderate replacement levels. [5] explained that this effect arises because the fine glass particles fill voids between cement grains, reducing the overall paste porosity at the fresh stage.

Taken together, the literature suggests that WGP can either improve or reduce fresh properties depending on its fineness and dosage. At low to moderate replacement levels (5–15%), the effects are generally positive or manageable, with improved flowability and only slight changes in setting times. Beyond 20%, however, adjustments such as water-reducing admixtures become necessary to maintain workability [1]– [3], [5].

3. Effect of Waste Glass Powder on Hardened Properties of Concrete

Waste glass powder (WGP) has gained considerable attention as a sustainable supplementary cementitious material due to its potential to partially replace cement while maintaining or enhancing concrete properties. The influence of WGP on hardened concrete primarily depends on its fineness and replacement level, affecting compressive, flexural, and tensile strength, as well as durability performance [1], [3], [5], [6].

3.1. Compressive Strength

At low to moderate replacement levels (5–15%), WGP generally maintains or slightly improves compressive strength compared to conventional concrete. This improvement is attributed to the filler effect of fine glass particles, which enhances packing density, and the pozzolanic reaction, which generates secondary calcium silicate hydrate (C–S–H) [3]. For instance, 10% replacement with WGP ground below 45 μm achieved higher 28-day strength than control mixes [3], while replacements up to 20% retained comparable strength with notable durability gains [1].

However, when replacement exceeds 20%, strength often declines, especially with coarser powders. The dilution effect reduces available cement, and the slower pozzolanic reaction of WGP cannot compensate at early ages [2]. Consequently, 10–20% replacement with fine WGP (≤75 μm, preferably <45 μm) is generally optimal for mechanical performance.

3.2. Flexural and Tensile Strength

Flexural and tensile strengths exhibit trends similar to compressive strength. Moderate WGP replacements (10–15%) typically improve or sustain strength due to denser microstructure and better particle packing [5]. Flexural strength gains are observed at 10% replacement but decrease beyond 20%, while tensile strength shows modest improvements at low replacement levels and declines at higher content.

3.3. Long-Term Strength Development

One advantage of WGP is its contribution to long-term strength. Due to the slower pozzolanic reaction, enhancements are more pronounced at later ages (56–90 days) than at 28 days [4]. Mixes with 15% WGP demonstrated greater strength gains over time compared to control mixes, reflecting progressive C–S–H formation.

3.4. Durability and Long-Term Performance

3.4.1. Permeability and Porosity

WGP refines the pore structure of concrete, reducing voids through the filler effect and pozzolanic reaction. Studies report lower water absorption and improved microstructural density in mixes with 10–15% WGP, indicating enhanced resistance to fluid ingress [1],[3].

3.4.2. Alkali–Silica Reaction (ASR) Mitigation

Although glass aggregates can trigger ASR, finely ground WGP (<75 μm) consumes alkalis during hydration, mitigating expansion and cracking [4]. This property allows WGP to safely replace cement while controlling ASR risk.

3.4.3. Chloride and Sulfate Resistance

WGP improves resistance to chloride penetration and sulfate attack due to the denser matrix it produces. Reduced chloride diffusion coefficients and lower surface scaling in sulfate exposure have been observed in WGP concrete [2],[5], highlighting its suitability for marine and aggressive environments.

3.4.4. Carbonation Resistance

Carbonation resistance is influenced by reduced cement content. While higher replacement (>20%) may slightly increase carbonation depth, moderate WGP levels (10–15%) balance this effect, with the refined microstructure compensating for lower calcium hydroxide availability [6].

3.5. Research Gaps and Future Directions

Despite promising results, several gaps remain. Standardization of glass fineness, chemical composition, and processing methods is limited, complicating cross-study comparisons. Field-scale trials and long-term monitoring are scarce, and life-cycle assessments should further evaluate energy consumption versus carbon savings from cement reduction [4]–[6]. Research on high-volume replacements (>30%) and hybrid SCM combinations (e.g., WGP with fly ash or silica fume) presents opportunities for advancing sustainable concrete technology.

3.5.1. Part 2: Recycled Aggregates in Concrete: Properties and Performance

The construction industry faces mounting pressures from resource depletion, environmental concerns, and sustainability demands, largely due to the extensive extraction of natural aggregates (NA) for concrete production. Recycled aggregates (RA), sourced from construction and demolition waste, offer a promising alternative to reduce environmental impact while conserving natural resources. However, RA typically exhibits higher porosity, lower density, and weaker interfacial transition zones (ITZ), which can adversely affect mechanical and durability properties of concrete [8]. Despite these challenges, optimized mix designs, surface treatments, and blending strategies have been shown to produce recycled aggregate concrete (RAC) with performance comparable to conventional mixes, particularly at partial replacement levels.

Fresh properties of RAC are influenced by the physical characteristics of recycled aggregates. Increased surface roughness, higher porosity, and the presence of adhered old mortar reduce workability and slump, with values declining proportionally to the replacement level [7]. For instance, a 50% replacement typically decreases slump by 20–25%, necessitating higher water content or superplasticizers to maintain consistency [8]. The internal curing effect of RA can slightly prolong initial setting times, which may enhance long-term hydration without significantly affecting early-stage workability [10]. Overall, pre-soaking RA, optimizing grading, or employing chemical admixtures can restore workability to levels similar to natural aggregate concrete.

Mechanically, RAC generally exhibits moderate reductions in compressive, tensile, and flexural strength with increasing RA content. Concrete with 20–30% RA replacement maintains compressive strength comparable to conventional concrete, while higher levels (50–100%) result in notable declines due to the porous nature and weaker ITZ of RA [9]. Tensile and flexural strengths follow similar trends, with flexural strength often more sensitive to ITZ weaknesses [7],[11]. The modulus of elasticity is consistently lower, reflecting the reduced stiffness of RA. The incorporation of supplementary cementitious materials (SCMs) such as fly ash or silica fume can mitigate strength losses by refining the ITZ and microstructure. Table 1 summarizes typical mechanical performance changes with varying RA content.

Table 1 Replacement of recycled aggregate and effect on its strength

RA Replacement (%)	Compressive Strength	Tensile Strength	Flexural Strength	Modulus of Elasticity
0 (Control)	100%	100%	100%	100%
20–30	95–100%	90–95%	90–95%	85–90%
50	85–90%	80–85%	80–85%	75–80%
100	70–75%	65–70%	65–70%	70%

Durability of RAC is generally acceptable when replacement levels are moderate and aggregates are properly processed. Increased porosity and water absorption can slightly elevate permeability, carbonation depth, and chloride ingress, but these effects are mitigated through mix optimization, pre-soaking of RA, and SCM incorporation [9],[10]. RA can be used safely with respect to alkali–silica reaction (ASR), as finely crushed aggregates combined with pozzolanic materials help bind free alkalis [8]. Freeze–thaw and sulfate resistance are comparable to conventional concrete when RA replacement is limited to 30% and the mix is appropriately designed [7].

Collectively, the literature indicates that partial substitution of natural aggregates with recycled aggregates provides a feasible, sustainable solution without severely compromising performance. Replacement levels up to 30% are generally suitable for structural applications, while higher levels require careful aggregate processing, admixtures, or SCMs to maintain mechanical and durability properties. RAC not only conserves natural resources but also offers an effective strategy for managing construction and demolition waste, contributing significantly to sustainable construction practices [7],[8],[9],[10],[11].

Table 2 Summary of Key Findings on Waste Glass Powder (WGP) as Partial Cement Replacement

Category	Research Focus	Key Findings	Critical Parameters	Remarks / Conclusions	References
Material Characterization	Chemical and physical properties of WGP	WGP found rich in amorphous silica with potential pozzolanic reactivity when ground below 75 µm.	Fineness, particle size (<75 µm).	Supports potential use of WGP as SCM due to high silica and glassy phase.	[1], [2], [5]
ASR Mitigation	Alkali–silica reaction control	Finely ground WGP (<75 µm) suppresses ASR expansion; coarse glass increases ASR risk.	Particle fineness, glass color, alkali content.	Ultra-fine WGP preferred to minimize ASR and enhance reactivity.	[3], [5], [16]
Pozzolanic Activity	Reactivity with calcium hydroxide	Ultra-fine WGP reacts with $Ca\ (OH)_2$ forming additional C–S–H gel improving strength and density.	Particle size <45 µm, curing time.	Pozzolanic effect enhances long-term strength and durability.	[1], [5], [7]
Mechanical Strength	Compressive and flexural strength	Optimum replacement of 10–15% WGP maintains or slightly improves strength; higher levels may reduce early strength.	Replacement ratio, water–cement ratio, curing period.	WGP beneficial at moderate replacement levels.	[1], [3], [6], [8]
Durability Performance	Resistance to permeability, sulphate, and chloride attack	WGP addition refines pore structure, reducing permeability and enhancing chemical resistance.	Replacement % (≤20%), curing duration.	Improves durability of concrete in long term.	[2], [4], [9]
Comparison with Other SCMs	WGP vs. Fly Ash / Silica Fume	WGP offers slower early reactivity but comparable long-term performance; sustainable alternative when local glass waste is available.	Reactivity rate, replacement ratio, SCM type.	WGP viable substitute for conventional SCMs in green concrete.	[2], [10]
Sustainability Impact	Environmental and resource benefits	Reduces cement demand and glass landfill waste; lowers embodied carbon of concrete.	Life-cycle perspective, waste utilization rate.	Contributes to circular economy and eco-friendly concrete design.	[1], [3], [11]

Table 3 Summary of Key Findings on Recycled Aggregates (RA) as Partial or Full Replacement of Natural Aggregates

Category	Research Focus	Key Findings	Critical Parameters	Remarks / Conclusions	References
Material Characterization	Physical and mechanical properties of RA	RA shows lower density, higher water absorption, and adhered mortar compared to natural aggregates.	Source of RA, crushing method, pre-treatment.	Quality of RA strongly depends on parent concrete and processing technique.	[12], [13], [15]
Workability	Effect of RA on concrete mix	Increased water demand due to porous surface of RA reduces workability; use of superplasticizers helps restore slump.	Water absorption capacity, RA replacement ratio.	Partial RA replacement (<30%) maintains acceptable workability.	[13], [14], [17]
Mechanical Strength	Compressive and tensile strength	Strength reduction observed with increasing RA; however, 20–30% replacement shows minimal difference when well-graded and pre-saturated.	RA percentage, mixing method, moisture condition.	Optimum performance achieved at 20–30% RA content.	[12], [15], [18]
Durability	Permeability and shrinkage	RA concrete tends to have higher permeability and drying shrinkage; pre-soaked RA mitigates negative effects.	Water–cement ratio, curing conditions, pre-soaking method.	Proper curing and RA treatment enhance durability performance.	[14], [16], [19]
Microstructural Behavior	Interfacial transition zone (ITZ) quality	RA concrete exhibits weaker ITZ due to adhered mortar; addition of SCMs (fly ash, WGP, silica fume) improves bond density.	Presence of SCMs, replacement ratio.	Combination with SCMs compensates for weaker ITZ.	[15], [18], [20]
Sustainability Aspect	Resource conservation and waste management	Using RA diverts demolition waste from landfills, reduces natural resource depletion, and lowers carbon footprint.	RA source (C&D waste), energy used for crushing.	RA supports circular economy and sustainable construction.	[12], [14], [19]
Structural Application	Suitability for structural and non-structural uses	High-quality RA concrete suitable for pavements, blocks, and moderate-strength structural elements.	Strength class, replacement %, design method.	Structural use feasible with quality control and mix optimization.	[13], [17], [20]

3.5.2. PART III: Combined Use of Waste Glass Powder and Recycled Aggregates in Concrete

The simultaneous incorporation of waste glass powder (WGP) as a partial cement replacement and recycled aggregates (RA) as a partial substitute for natural aggregates has emerged as an effective strategy for sustainable concrete production. WGP enhances pozzolanic reactions and refines the microstructure, while RA provides a means to recycle construction and demolition waste, conserving natural resources. Together, these materials leverage their strengths and mitigate individual limitations [12], [13], [15].

3.6. Mechanical Properties

Concrete containing RA alone often exhibits reduced compressive, tensile, and flexural strengths due to higher porosity and weaker interfacial transition zones (ITZ) [12]. The inclusion of WGP improves the matrix around aggregates by forming additional calcium silicate hydrate (C-S-H), which strengthens the ITZ. Studies indicate that combinations of 20% WGP and 30% RA can achieve compressive and tensile strengths comparable to conventional concrete [13]. Flexural and splitting tensile strengths similarly benefit, with optimized mixes reaching up to 95% of conventional concrete flexural strength [14]. Long-term strength is particularly enhanced due to the slower pozzolanic activity of WGP, which progressively contributes to C-S-H formation beyond 28 days.

3.7. Durability and Microstructure

Recycled aggregates tend to increase concrete porosity and water absorption, potentially compromising durability. The addition of WGP mitigates these effects by refining the pore structure and densifying the matrix. Studies report that partial replacement with WGP reduces water absorption in RA concrete, limiting permeability and ion ingress [15]. Chloride and sulfate resistance are also improved; WGP binds free calcium hydroxide, reducing leaching and pore connectivity, which enhances resistance to corrosion and chemical attack [16]. SEM analyses reveal that WGP densifies the ITZ around RA particles, filling micro-voids and cracks, thereby enhancing both mechanical strength and durability [13].

3.8. Workability and Practical Considerations

While RA increases water absorption and reduces slump, the fine particles of WGP can slightly improve flow. Combined use typically results in reduced workability compared to conventional concrete. This can be managed by pre-soaking RA, optimizing the aggregate-to-cement ratio, or using water-reducing admixtures or superplasticizers. Proper mix design enables concrete containing 20% WGP and 30% RA to achieve adequate slump and consistency for casting and vibration [17].

3.9. Sustainability and Applications

The dual replacement strategy offers substantial environmental benefits, including reduced CO_2 emissions from lower cement usage, conservation of natural aggregates, and diversion of glass and construction/demolition waste from landfills. Structurally, such concrete is suitable for beams, slabs, and columns, while non-structural applications include pavements, sidewalks, and precast elements. The improved durability also makes it appropriate for construction in aggressive environments, such as coastal or industrial areas. This approach supports eco-friendly infrastructure and aligns with the principles of sustainable construction [13]–[16].

Table 4 Summary of Effects of Waste Glass Powder (WGP), Recycled Aggregates (RA), and Combined Use on Concrete Properties

Material / Combination	**Replacement Level**	**Key Effects on Mechanical Properties**	**Durability / Long-Term Performance**	**Workability and Practical Notes**	**Sustainability Benefits**	**References**
Waste Glass Powder (WGP)	10–20% cement	Maintains or slightly improves compressive, tensile, and flexural strength; long-term strength gains due to slow pozzolanic reaction	Reduces permeability, water absorption; mitigates ASR; improves chloride and sulfate resistance	Slight effect on workability; may require admixtures at higher replacements	Reduces CO_2 from cement, utilizes glass waste, promotes sustainable concrete	[1],[2],[3],[4],[5],[6]
Recycled Aggregates (RA)	20–50% natural aggregate	Moderate reduction in compressive, tensile, and flexural strength; modulus of elasticity decreases; effects minimized with well-processed RA	Slightly higher water absorption and permeability; minor impact on ASR if source is controlled; carbonation depth may increase	Lower slump due to higher porosity; requires pre-soaking or admixtures	Conserves natural aggregates, reduces construction and demolition waste	[7],[8],[9],[10],[11]
WGP + RA (Combined)	20% WGP + 30% RA (optimized)	Compressive and tensile strength comparable to conventional concrete; flexural strength up to 95% of control; long-term strength enhanced	Densified microstructure; lower water absorption; improved chloride and sulphate resistance; mitigates RA weaknesses	Workability reduced compared to conventional concrete but manageable with pre-soaking and admixtures	Maximizes resource conservation, reduces cement and aggregate demand, diverts both glass and construction waste from landfills	[12],[13],[14],[15], [16], [17]

4. Conclusion

The combined use of waste glass powder (WGP) as a partial replacement for cement and recycled aggregates (RA) as a substitute for natural aggregates offers a practical and sustainable approach to concrete production. WGP not only promotes pozzolanic reactions and strengthens the microstructure but also enhances long-term durability, while RA helps conserve natural resources and reduces construction waste. When used in optimal proportions—around 10–20% WGP and 20–30% RA concrete can achieve mechanical performance close to conventional mixes, with improved resistance to permeability, chloride penetration, sulfate attack, and ASR. Challenges in workability can be managed effectively through pre-soaked RA, admixtures, and careful mix design. Altogether, this dual-replacement strategy balances sustainability and performance, making it a promising option for both structural and non-structural concrete applications.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no potential conflicts of interest to disclose.

References

[1] G. M. S. Islam, "Waste glass powder as partial replacement of cement for sustainable concrete practice," Construction and Building Materials, 2017.

[2] K. Khan et al., "Evaluating the effectiveness of waste glass powder for cement and sand replacement in mortar and concrete," Scientific Reports / PMC, 2023.

[3] Ö. Zeybek et al., "Influence of replacing cement with waste glass on mechanical properties," 2022.

[4] C. Zhou et al., "Application of waste glass powder for sustainable concrete: systematic review covering mechanical and durability properties and ASR considerations," 2025.

[5] S. Poudel et al., "Waste glass as partial cement replacement in concrete," MDPI, 2025.

[6] G. Chand, "Challenges and opportunities in using high percentage waste glass powder," Springer, 2025.

[7] Evangelista, L. & de Brito, J., "Mechanical behavior of concrete made with fine recycled concrete aggregates," Cement and Concrete Composites, 2007.

[8] Padmini, A. K., Ramamurthy, K., & Mathews, M. S., "Mechanical and durability properties of recycled aggregate concrete," 2009.

[9] Silva, R. V., de Brito, J., & Dhir, R. K., "Properties and composition of recycled aggregates from construction and demolition waste: A review," Construction and Building Materials, 2016.

[10] Kou, S. C., Poon, C. S., & Etxeberria, M., "Influence of recycled aggregate on concrete properties," Cement and Concrete Research, 2011.

[11] Tabsh, S. W., & Abdelfatah, A. S., "Influence of recycled concrete aggregates on strength properties of concrete," Construction and Building Materials, 2009.

[12] Thakur, M., et al., "Partial replacement of natural aggregate with recycled aggregate in concrete," Environmental Science and Pollution Research, 32, 14231–14245, 2025.

[13] Sivasuriyan, P., et al., "Mechanical and durability performance of concrete containing WGP and RA," Materials, 18(14), 3223, 2025.

[14] Arivalagan, S., et al., "Experimental study on mechanical properties of concrete with waste glass powder," Construction and Building Materials, 278, 122382, 2021.

[15] Diao, Y., et al., "Combined use of recycled aggregates and waste glass powder in concrete," Processes, 11(4), 975, 2023.

[16] Zhu, J., et al., "Long-term mechanical properties and durability of concrete with waste glass powder," Materials, 16(17), 5921, 2023.

[17] Muhedin, D. A., et al., "Effect of waste glass powder as partial replacement of cement and sand in concrete," Construction and Building Materials, 402, 127637, 2023.