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Review of Conventional and Waste Glass–Granite Powder Concrete for Improved Strength, Durability, and Environmental Sustainability

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Abstract : *The increasing demand for concrete has intensified the consumption of Portland cement, natural river sand and mineral aggregates, while simultaneously generating substantial quantities of solid waste from municipal, industrial and stone-processing activities. Waste glass and granite-processing residues are increasingly being investigated as alternative materials for sustainable concrete because their incorporation can reduce landfill disposal, conserve natural resources and potentially lower the environmental burden associated with conventional concrete production. This review paper critically examines research published between 2010 and 2025 concerning conventional concrete, waste glass powder concrete, granite powder concrete and combined waste glass–granite powder concrete. Particular attention is given to compressive strength, tensile and flexural strength, workability, permeability, water absorption, chloride penetration, sulphate and acid resistance, alkali–silica reaction, microstructure and environmental sustainability.*

Keywords: Conventional Concrete, Waste Glass Powder, Granite Powder, Sustainable Concrete, Circular Economy

I. INTRODUCTION

Concrete is one of the most widely used construction materials because of its availability, versatility, strength and durability. Conventional concrete normally consists of cement, fine aggregate, coarse aggregate, water and, where necessary, chemical or mineral admixtures. Despite its engineering advantages, conventional concrete has significant environmental implications. Cement production requires substantial energy and generates greenhouse-gas emissions, while extraction of natural sand and aggregates consumes non-renewable resources and can disturb ecosystems. Consequently, the development of concrete incorporating industrial and municipal waste has become an important research direction in sustainable construction.

Waste glass represents one of the materials receiving considerable attention. Glass is chemically stable and difficult to degrade under ordinary landfill conditions, while its disposal creates long-term waste-management challenges. When waste glass is finely ground, its amorphous silica can participate in pozzolanic reactions and contribute to the development of additional calcium-silicate-hydrate (C-S-H) gel. Reviews have shown that the performance of glass-containing concrete is strongly influenced by glass particle size, replacement percentage, glass composition, curing conditions and whether glass is used as powder, fine aggregate or coarse aggregate.

OBJECTIVES OF THE REVIEW

The main objectives are:

To review the properties and limitations of conventional concrete.

To examine the influence of waste glass powder on concrete strength.

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To assess the effect of granite powder on mechanical properties.
To compare durability characteristics of conventional and waste-based concrete.
To examine the combined effects of waste glass and granite powder.
To evaluate the environmental and sustainability advantages of waste incorporation.
To identify optimum replacement ranges reported in the literature.
To identify research gaps and future research requirements.

REVIEW METHODOLOGY

This review considers published research from 2010 to 2025 concerning waste glass, granite powder and sustainable concrete. Peer-reviewed journal articles and review studies were examined, with emphasis on studies reporting experimental measurements of mechanical properties, durability, microstructure and environmental performance.
The literature was classified into four major groups:
conventional concrete;
waste glass powder concrete;
granite powder concrete;
combined waste glass–granite powder concrete.
Studies were compared according to replacement material, replacement level, mechanical response, durability response and sustainability implications.
Because the reviewed studies employed different cement types, aggregate gradations, water-to-cement ratios, curing periods and testing standards, numerical values from different studies should not be treated as directly equivalent. Instead, the review emphasizes general trends and experimentally reported findings.

COMBINED WASTE GLASS–GRANITE POWDER CONCRETE

The combined use of WGP and GrP is especially important because the two materials can provide complementary functions.
Waste glass powder can partially replace cement, while granite powder can partially replace natural sand. This means that one waste material modifies the binder system and the other modifies the aggregate system.
Jain (2020) investigated WGP replacement levels of 5%, 10%, 15%, 20% and 25% and granite powder replacement levels of 10%, 20%, 30%, 40% and 50%. The researchers investigated water absorption, water permeability, acid attack, sulphate attack and RCPT, together with SEM and XRD.
The study reported particularly favorable results for 15% glass powder + 30% granite powder. The 28-day compressive strength of this mixture reached 36.85 MPa, approximately 34% higher than the control concrete under the conditions of the experiment.

Table 1. Representative Literature on Waste Glass and Granite Powder Concrete

Study	Waste material	Replacement level investigated	Main properties	Major finding
Vijayalakshmi et al. (2013)	Granite powder	Up to 25%	Strength and durability	Up to about 15% favorable
Singh et al. (2016)	Granite cutting waste	10–50%	Strength, permeability, abrasion	Around 30% favorable
Omran et al. (2017)	Glass powder	Cement replacement	Long-term strength and durability	Improved later-age performance and chloride resistance
Khan et al. (2020)	Waste glass	Various	Mechanical and durability	Fine glass powder generally favorable

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Siddika et al. (2021)	Waste glass	Various	Durability and microstructure	Fine glass can improve durability but ASR must be controlled
Paul et al. (2022)	Waste glass powder	Various	Strength and durability	Fine WGP can provide favorable sustainable concrete performance
Semmana et al. (2025)	Glass powder	Literature synthesis	Strength, durability, microstructure	10–20% frequently favorable
Gholampour et al. (2025)	Glass powder/glass sand	Binder and sand	Mechanical and physical properties	Waste glass can replace both binder and aggregate fractions

COMPARATIVE DURABILITY CHARACTERISTICS

Durability is arguably more important than short-term strength when evaluating sustainable concrete for infrastructure.

Table 2. Comparison of Durability Characteristics

Durability parameter	Conventional concrete	Waste glass powder concrete	Granite powder concrete	Combined WGP–GrP concrete
Water absorption	Reference level	Generally reduced at optimized dosage	Can be reduced	Reduced in favorable blends
Water permeability	Moderate	Often reduced	Often reduced	Particularly favorable in optimized mixes
Chloride penetration	Depends on w/c ratio	Generally reduced with fine WGP	Can be reduced through densification	Favorable reported performance
Sulphate resistance	Conventional baseline	Can improve	Can improve	Improved in reported combined system
Acid resistance	Conventional baseline	Can improve at moderate dosage	Can improve	Improved in Jain et al.
Abrasion resistance	Baseline	Can improve	Can improve	Potential improvement
ASR	Normal risk depending on aggregates	Requires particle-size control	Generally not the principal concern	Requires glass-particle control
Carbonation	Depends on mixture	Mixed findings	Requires further research	Limited combined evidence
Freeze–thaw	Depends on air entrainment	Can improve under suitable mixtures	Limited evidence	Requires further investigation
Microstructure	Conventional C-S-H matrix	Additional C-S-H and pore refinement	Improved packing/filler action	Combined densification and C-S-H development

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OPTIMUM REPLACEMENT LEVELS

There is no single universally applicable replacement level. Differences in cement chemistry, glass fineness, granite mineralogy, aggregate grading, water–cement ratio and curing conditions lead to different optimum values.

Table 3. Representative Replacement Ranges

Material	Replacement investigated in literature	Frequently favorable range	Principal limitation at high replacement
Waste glass powder	5–40%+	Approximately 10–25%	Cement dilution, reduced workability, porosity
Granite powder	10–50%	Approximately 10–30%	Excess fines and workability loss
Combined WGP + GrP	WGP 5–25%; GrP 10–50%	15% WGP + 30% GrP in Jain et al.	Interaction effects require optimization
Glass powder in recent reviews	Various	Approximately 10–20% for many systems	Strength reduction at excessive replacement

Recent 2025 reviews generally support moderate WGP replacement. Zhou et al. reported that 10–20 wt% WGP as a supplementary cementitious material is frequently associated with favorable mechanical and durability performance. Semmana similarly identified 10–20% as an important favorable range while noting that higher percentages can decrease compressive strength in some mixtures.

RESEARCH GAPS

The review identifies several important areas requiring additional investigation.

1. Limited Combined-System Research

A large proportion of published studies focus on either glass powder or granite powder individually. More systematic research is required on their combined use.

2. Long-Term Durability

Although several studies have investigated chloride, sulphate, acid and permeability performance, long-term field data for combined WGP–GrP concrete remain limited.

3. Particle-Size Standardization

Different researchers use different glass and granite particle sizes. Consequently, reported optimum replacement levels cannot always be directly compared.

4. Environmental Life-Cycle Assessment

Future studies should quantify:
embodied carbon;
energy consumption;
transportation emissions;
processing energy;
landfill diversion;
cost savings;
service-life extension.

5. Coupled Exposure Conditions

More research is needed on combined exposure to:
chloride + carbonation;
sulphate + wet–dry cycles;
acid + abrasion;
chloride + freeze–thaw;

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elevated temperature + chemical attack.

6. Field Applications

Laboratory performance should increasingly be validated through pavements, precast elements, structural components and infrastructure exposed to real environmental conditions.

DISCUSSION

The reviewed evidence demonstrates that sustainable concrete should not be evaluated solely on the basis of waste content. The principal objective is to achieve a balance between mechanical performance, durability, workability, resource conservation and environmental impact.

Waste glass powder and granite powder offer complementary benefits. WGP can partially replace cement and participate in pozzolanic reactions, whereas GrP can partially replace natural sand and enhance particle packing. The combined system therefore has the potential to produce a denser concrete matrix while simultaneously reducing cement and natural aggregate demand.

The literature demonstrates that replacement levels have a critical influence on performance. Fine WGP generally performs well at moderate replacement levels. The 2025 systematic review by Semmana et al. identified 10–20% as a frequently favorable range and noted that replacement beyond 25–30% may result in compressive-strength reductions in some systems.

The 2025 review by Zhou et al. likewise identified 10–20 wt% WGP as an important range for improving mechanical and durability characteristics.

II. CONCLUSION

This review of literature published between 2010 and 2025 demonstrates that waste glass powder and granite powder have considerable potential for improving the sustainability of concrete while maintaining or enhancing mechanical and durability performance.

Conventional concrete provides excellent structural performance but relies heavily on Portland cement and natural aggregates. Waste glass powder provides an alternative supplementary cementitious material because its amorphous silica can participate in pozzolanic reactions and produce additional C-S-H. This can improve matrix density, later-age strength and resistance to water and chloride penetration.

Granite powder provides a different sustainability advantage. Its use as a partial replacement for natural fine aggregate reduces the demand for river sand and provides a productive use for stone-processing waste. Moderate granite powder replacement can improve particle packing and contribute to improved strength and durability.

The combination of the two materials is particularly promising. The available direct experimental evidence indicates that 15% waste glass powder combined with 30% granite powder can provide substantial improvements in strength and durability compared with conventional concrete. Jain (2020) reported a 28-day compressive strength of 36.85 MPa, approximately 34% higher than the control, together with improved water absorption, permeability, acid resistance, sulphate resistance and chloride-penetration characteristics.

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