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Review On Comparative Study on Investigating the Effect of Partially Replacing Fine Aggregate with Glass Waste Sand in Concrete Beam

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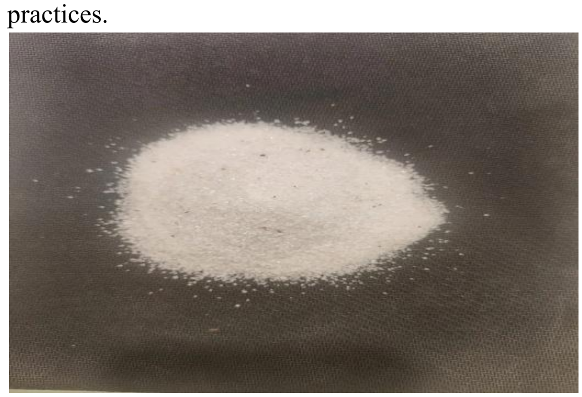
***Abstract*—The increasing depletion of natural fine aggregates and the accumulation of waste glass have necessitated the development of sustainable alternatives in concrete production. This study evaluates the potential of waste glass powder as a partial replacement material within the range of 5% to 25%, with emphasis on its influence on strength characteristics and environmental performance. Due to its high silica content, glass powder contributes to microstructural enhancement through filler effects and limited pozzolanic activity. At lower replacement levels (5%–10%), improved strength is observed due to enhanced particle packing and densification. However, at higher replacement levels, strength reduction may occur due to dilution effects and weaker interfacial bonding. In addition, the incorporation of glass powder improves durability by reducing permeability and water absorption, thereby enhancing resistance to harmful environmental agents. From a sustainability perspective, the use of waste glass powder reduces landfill disposal and conserves natural sand resources. Overall, the study highlights that controlled utilization of glass powder within the 5%–25% range can achieve a balance between mechanical performance and environmental sustainability, making it a viable alternative material in concrete.**

***Index Terms*—Waste glass powder; Partial replacement; Sustainable concrete; Strength properties; Durability; Pozzolanic activity; Microstructure; Environmental impact.**

I. INTRODUCTION

Concrete remains the most widely used construction material due to its strength, durability, and adaptability. However, the continuous extraction of natural resources, particularly river sand used as fine aggregate, has led to serious environmental concerns including resource depletion and ecological imbalance. This has created a need for sustainable alternative materials in concrete production.

At the same time, the accumulation of waste glass has emerged as a significant environmental challenge due to its non-biodegradable nature. Large quantities of waste glass are disposed of in landfills, contributing to environmental pollution. Recycling this waste into construction materials offers a promising solution for both waste management and sustainable construction practices.



Waste glass, when processed into fine powder, contains a high percentage of amorphous silica, which enables it to participate in limited pozzolanic reactions and act as a filler material. This contributes to improved particle packing and microstructural densification in concrete. Consequently, the incorporation of glass powder influences both strength and durability characteristics.

Previous research indicates that the performance of glass powder-based concrete is highly dependent on replacement level and particle size. Lower replacement levels tend to enhance strength and durability, while higher replacement levels may adversely affect mechanical performance due to reduced cementitious effectiveness.

In this context, the present study focuses on evaluating waste glass powder as a partial replacement material within the range of 5% to 25%, with particular emphasis on its effect on strength performance and environmental benefits, aiming to establish its suitability as a sustainable alternative in concrete.

II. LITERATURE REVIEW

This section reviews previous research on the use of waste glass powder as a partial replacement for fine aggregates in concrete. Various studies conducted by different researchers are briefly discussed, focusing on the effects of glass powder on the mechanical and durability properties of concrete. Special attention is given to parameters such as particle size, replacement percentage, and curing conditions. The influence of glass powder on workability, compressive strength, and microstructural behavior is also highlighted. The collected findings help in identifying key trends, benefits, and limitations, while also indicating areas where further investigation is needed.

X. Zhang & B. Shao, (2000) [1] This study investigates the mechanical properties of concrete with glass powder. The authors reported improved compressive strength at lower replacement levels. The filler effect enhanced particle packing. However, higher replacement levels reduced strength. The study highlighted improved tensile strength. Microstructural improvement was observed. The importance of particle size was emphasized. Environmental benefits include reduced cement usage. The study recommended optimal replacement levels. The authors concluded that glass powder improves mechanical performance.

M.S. Shetty, (2005) [2] This standard reference provides fundamental knowledge on concrete materials. It discusses the role of supplementary materials in concrete. The book highlights the importance of particle size and grading. It explains the concept of pozzolanic reactions. The study emphasizes proper mix design for strength and durability. It provides guidelines for material selection. The book supports the use of alternative materials. Environmental benefits of sustainable materials are discussed. The author highlights the importance of quality control. This reference is widely used in concrete research and practice.

C. Riefler & H. Wang, (2005) [3] This study examines the pozzolanic characteristics of glass powder. The authors analyzed the chemical composition and reactivity of glass particles. It was found that glass powder contains a high percentage of amorphous silica. This contributes to its pozzolanic behaviour in cementitious systems. The study highlighted the importance of particle size in reactivity. Finer particles showed higher pozzolanic activity. The formation of C–S–H gel improves the microstructure. The study also reported improved durability properties. However, excessive glass powder reduces strength due to dilution. The research concluded that finely ground glass powder is beneficial for concrete performance.

A.M. Shayan & A. Xu, (2006) [4] This study evaluates the performance of glass powder as a pozzolanic material in concrete through field trials. The authors demonstrated that finely ground glass powder reacts with calcium hydroxide in cement. This reaction leads to the formation of additional C–S–H gel. The results indicated improved long-term strength development. Early-age strength was slightly lower due to slower pozzolanic activity. The study highlighted that glass powder enhances durability characteristics. Reduced permeability and improved resistance to chemical attack were observed. The authors emphasized the importance of particle fineness. The environmental benefits include reduced cement consumption and waste utilization. The study concluded that glass powder is a viable supplementary cementitious material for sustainable concrete.

R. Siddique, (2008) [5] This reference provides a comprehensive overview of waste materials in concrete. The author discusses the use of glass powder as a supplementary material. It highlights the pozzolanic nature of glass powder. The study reports improved microstructural properties. Strength enhancement is observed at lower replacement levels. Higher replacement levels reduce strength performance. Durability improvements include reduced permeability. Environmental benefits include sustainable waste management. The author emphasizes proper mix design. The study concludes that glass powder is a promising material for sustainable concrete.

R. Taha & A. Nounu, (2008) [6] This research evaluates the use of waste glass as both sand and cement replacement. The authors observed that glass powder improves workability. The study reported enhanced durability properties. Reduced water absorption and permeability were observed. At lower replacement levels, compressive strength improved. However, higher replacement levels reduced strength performance. The study highlighted the role of particle size and distribution. Glass powder contributed to better microstructural properties. Environmental benefits include reduced landfill waste. The authors concluded that glass powder is a sustainable alternative material.

J. Schwarz & N. Neithalath, (2008) [7] This study investigates the effect of fine glass powder on cement hydration. The authors reported that glass powder influences hydration reactions. The formation of additional C–S–H gel improves strength. Early-age strength was slightly reduced. However, long-term strength showed improvement. The study highlighted improved microstructural properties. Durability performance was enhanced due to reduced porosity. The authors emphasized the importance of particle size. Environmental benefits include reduced cement usage. The study concluded that glass powder is beneficial for long-term performance.

P. Turgut & E.S. Yahlizade, (2009) [8] This study investigates the use of waste glass in concrete blocks. The authors focused on strength and durability properties. It was observed that glass powder improves workability. The filler effect enhances microstructural properties. Strength improvement was noted at lower replacement levels. However, excessive glass content reduced strength. The study reported improved durability performance. Environmental benefits include reduced landfill waste. The authors emphasized optimal replacement levels. The study concluded that glass powder is suitable for eco-friendly construction materials.

M. Cyr, P. Rivard & M. Labrecque, (2009) [9] This study focuses on the mitigation of alkali–silica reaction (ASR) in concrete. The authors reported that glass powder reduces ASR expansion. The pozzolanic reaction consumes alkalis in the system. This improves the durability performance of concrete. The study observed improved microstructural properties. Strength performance was enhanced at lower replacement levels. However, excessive replacement reduced strength. The authors emphasized optimal replacement levels. Environmental benefits include improved durability and sustainability. The study concluded that glass powder helps in controlling ASR in concrete.

J. Schwarz & M. S. Thomas, (2009) [10] This study evaluates the durability performance of concrete containing glass powder. The authors reported improved resistance to chloride penetration. Reduced permeability was observed due to microstructural densification. The pozzolanic activity contributed to improved durability. The study highlighted reduced water absorption. However, higher replacement levels reduced mechanical strength. The authors emphasized proper mix proportioning. Environmental benefits include reduced waste disposal. The study recommended optimal replacement levels. The authors concluded that glass powder enhances durability characteristics.

M. Cyr & A. Tagnit-Hamou, (2011) [11] This research investigates the use of waste glass in both powder and aggregate forms. The authors studied its influence on strength and durability properties. Glass powder showed pozzolanic activity due to its high silica content. The study reported improved microstructural properties at lower replacement levels. Strength enhancement was observed due to filler effects and secondary hydration. However, excessive replacement resulted in reduced mechanical performance. The durability properties such as resistance to chloride penetration were improved. The study also discussed mitigation of alkali–silica reaction. The authors emphasized the importance of controlling replacement percentage. Overall, the research confirmed the potential of glass powder in sustainable concrete applications.

M. Cyr & A. Clastres, (2011) [12] This study evaluates the pozzolanic properties of waste glass powder. The authors analyzed the chemical composition and reactivity of glass powder. It was found that glass powder contains a high percentage of amorphous silica. This contributes to its pozzolanic behaviour. The study reported improved microstructural properties. Strength enhancement was observed at lower replacement levels. However, higher replacement levels reduced strength performance. The study emphasized the importance of particle fineness. Environmental benefits include reduced cement consumption. The authors concluded that glass powder is a suitable supplementary material.

A. Ali & A. Al-Tersawy, (2012) [13] This study investigates the use of recycled glass in concrete. The authors observed that glass materials influence strength properties. At lower replacement levels, performance was satisfactory. However, higher replacement levels reduced strength. The study reported increased porosity. Durability characteristics were affected by replacement levels. The authors emphasized proper proportioning. Environmental benefits include waste reduction. The study highlighted limitations of high replacement. The authors concluded that controlled usage is necessary.

K.H. Tan & X. Du, (2013) [14] This study investigates the use of waste glass in mortar. The authors focused on mechanical and durability properties. The inclusion of glass powder improved workability. Strength properties were influenced by replacement levels. At lower percentages, strength was improved. However, higher replacement levels reduced strength. The study reported improved resistance to chloride penetration. Durability properties were enhanced due to reduced permeability. The authors emphasized optimal replacement levels. The study concluded that glass materials can improve concrete performance when used appropriately.

N. Patel & J. Pitroda, (2013) [15] This study investigates the use of glass powder as a cement replacement. The authors observed improved workability. Strength properties improved at lower replacement levels. However, higher replacement levels reduced strength. The study reported improved durability characteristics. Reduced water absorption was observed. The pozzolanic activity enhanced microstructure. Environmental benefits include reduced CO_2 emissions. The study emphasized optimal replacement levels. The authors concluded that glass powder is a viable alternative material.

H. Du & K.H. Tan, (2014) [16] This study investigates the influence of particle size on concrete performance. The authors reported that finer particles show higher pozzolanic activity. Improved microstructural properties were observed. Strength enhancement was noted at lower replacement levels. Coarser particles reduced performance. The study highlighted improved durability characteristics. Reduced permeability was observed. The authors emphasized the importance of grinding fineness. Environmental benefits include efficient waste utilization. The study concluded that particle size plays a critical role in performance.

J. Du & C.S. Tan, (2014) [17] This study focuses on concrete with high volumes of glass powder replacement. The authors investigated the mechanical properties and durability behaviour. It was observed that glass powder contributes to improved workability. The filler effect enhances the packing density of concrete. At moderate replacement levels, strength was comparable to conventional concrete. However, high replacement levels significantly reduced compressive strength. The reduction was attributed to lower cementitious content. The study reported improved resistance to permeability. Durability properties were enhanced in terms of reduced water absorption. The authors concluded that optimal replacement levels are necessary for balanced performance.

A. Rashad, (2014) [18] This review paper summarizes multiple studies on glass materials in concrete. The author analyzed the effect of glass powder on strength and durability. It was observed that glass powder improves microstructural properties. Strength enhancement occurs at lower replacement levels.

Higher replacement levels lead to reduced strength. Durability properties such as resistance to chemical attack are improved. The study highlighted the importance of particle fineness. Environmental benefits include waste reduction and sustainability. The author emphasized proper mix design. The study concluded that glass powder is a promising material for concrete.

H. Wang & Z. Li, (2015) [19] This study evaluates the influence of glass powder on compressive strength and durability. The authors reported improved strength at lower replacement levels. The pozzolanic reaction contributed to microstructural improvement. However, higher replacement levels reduced strength. The study observed improved resistance to chloride penetration. Durability characteristics such as reduced permeability were enhanced. The importance of particle size was highlighted. Environmental benefits include reduced cement consumption. The study emphasized optimal replacement levels. The authors concluded that glass powder improves concrete performance.

A. Rashad, (2015) [20] This review paper summarizes various studies on waste glass in concrete. The author highlighted the pozzolanic behaviour of glass powder. Strength enhancement occurs at lower replacement levels. Higher replacement levels reduce performance. The study discussed durability improvements. Reduced permeability and improved resistance to chemical attack were observed. The author emphasized particle size importance. Environmental benefits include sustainability. The study recommended optimal replacement levels. The author concluded that glass powder is a promising material.

S. Afshinnia & P. Rangaraju, (2015) [21] This study investigates the combined use of ground glass powder and crushed glass aggregate in concrete. The authors focused on evaluating the influence of glass powder on mechanical and durability properties. It was observed that finely ground glass powder contributes to improved particle packing. The pozzolanic nature of glass powder enhances the formation of secondary calcium silicate hydrate (C–S–H) gel. This leads to densification of the concrete microstructure. At lower replacement levels, compressive strength showed noticeable improvement. However, higher replacement levels resulted in a reduction in strength due to dilution effects. The study also reported improved resistance to chloride ion penetration. The presence of glass powder reduced permeability and enhanced durability performance. Overall, the research concluded that glass powder can be effectively utilized as a supplementary material in concrete with controlled replacement levels.

S.P. Singh & R. Srivastava, (2016) [22] This research focuses on the application of waste glass powder in concrete. The authors studied its effect on strength and durability. It was observed that glass powder improves workability. The filler effect contributes to better packing density. Strength properties improved at lower replacement levels. However, higher replacement levels reduced mechanical performance. The study reported improved resistance to environmental exposure. Durability characteristics were enhanced. The authors emphasized proper mix proportioning. The study concluded that glass powder is a sustainable alternative material.

J. Du & K.H. Tan, (2016) [23] This study investigates the behaviour of high-performance concrete incorporating glass powder. The authors focused on strength and durability characteristics. It was observed that glass powder improves particle packing due to its fine size. The pozzolanic reaction contributes to microstructural densification. At lower replacement levels, compressive strength improved significantly. However, higher replacement levels resulted in strength reduction. The study reported improved resistance to water penetration. Durability characteristics were enhanced due to reduced porosity. The authors emphasized optimal replacement levels. The study concluded that glass powder can be effectively used in high-performance concrete.

S. Park, H. Lee & Y. Kim, (2017) [24] This study focuses on durability aspects of concrete with glass powder. The authors reported improved resistance to environmental exposure. Reduced permeability and water absorption were observed. The study highlighted improved chloride resistance. Microstructural densification was achieved. However, excessive replacement reduced strength. The authors emphasized proper mix design. Environmental benefits include sustainability. The study recommended optimal replacement levels. The authors concluded that glass powder enhances durability.

M. Rahman & N. Kazi, (2017) [25] This study evaluates both strength and durability properties of concrete. The authors reported improved compressive strength at lower replacement levels. The pozzolanic reaction enhanced microstructure. However, higher replacement levels reduced strength. The study observed improved durability characteristics. Reduced permeability and water absorption were reported. The authors emphasized optimal replacement levels. Environmental benefits include reduced CO_2 emissions. The study recommended controlled usage. The authors concluded that glass powder is a sustainable material.

M. Islam & N. Kazi, (2017) [26] This study evaluates the use of glass powder as a cement replacement. The authors observed improved workability at certain replacement levels. Strength properties improved at lower replacement percentages. Higher replacement levels reduced strength performance. The study reported improved durability characteristics. Reduced permeability and water absorption were observed. The pozzolanic activity of glass powder enhanced microstructure. Environmental benefits include reduced CO_2 emissions. The study emphasized optimal replacement levels. The authors concluded that glass powder is a sustainable material for concrete.

H. Du & K.H. Tan, (2017) [27] This study investigates the feasibility of using waste glass powder as a cement replacement in concrete. The authors focused on strength development and durability characteristics. It was observed that glass powder improves workability due to its smooth texture. The pozzolanic reaction contributes to the formation of secondary C–S–H gel. This enhances the microstructure of concrete. At lower replacement levels, compressive strength showed improvement. However, higher replacement levels reduced strength due to dilution of cement content. The study reported reduced permeability and improved durability. The particle size of glass powder was identified as a critical factor. The authors concluded that controlled replacement levels can achieve sustainable and durable concrete.

M. Tamanna & S. Tuladhar, (2018) [28] This study evaluates the mechanical and durability performance of concrete containing glass powder. The authors observed improved particle packing due to the filler effect. Strength enhancement was noted at lower replacement levels. The pozzolanic activity contributed to microstructural densification. However, excessive replacement reduced strength performance. The study reported improved resistance to water penetration. Durability characteristics such as reduced permeability were observed. The importance of particle fineness was emphasized. Environmental benefits include reduced waste disposal. The study concluded that glass powder can enhance concrete performance when used optimally.

M. Zahid & S. Ahmed, (2026) [29] This study evaluates the mechanical properties of concrete incorporating glass powder. The authors reported improved compressive strength at lower replacement levels. The filler effect enhanced particle packing. However, higher replacement levels reduced strength. The study highlighted improved tensile strength. Microstructural improvement was observed. The authors emphasized optimal replacement levels. Environmental benefits include reduced cement consumption. The study recommended controlled usage. The authors concluded that glass powder improves mechanical performance.

A. Summary of Literature Review

The reviewed studies collectively indicate that waste glass powder is a promising sustainable material for concrete due to its high silica content and potential pozzolanic reactivity. The incorporation of finely ground glass powder improves microstructural properties through filler effects and secondary C–S–H formation. Most studies report that lower replacement levels, typically between 5% and 15%, enhance compressive and tensile strength due to improved particle packing and densification. However, higher replacement levels beyond 20% tend to reduce strength due to the dilution of cementitious content.

Durability performance is significantly improved with the use of glass powder, as it reduces permeability, water absorption, and chloride ingress. The effectiveness of glass powder is strongly influenced by particle size, with finer particles providing better performance. From an environmental perspective, the utilization of waste glass powder reduces landfill waste and conserves natural resources such as river sand. Overall, the findings confirm that glass powder can be effectively used within the 5% to 25% range when properly optimized.

B. Research Gap

From the literature review, the following observations were made:

1. Limited Studies on Structural Behaviour of RC Beams: Most existing research focuses on compressive strength and durability of concrete with glass powder, while very few studies investigate the flexural and shear performance of reinforced concrete beams, especially when glass powder is used as a fine aggregate replacement.
2. Lack of Shear Capacity and Failure Mode Evaluation: There is insufficient experimental data on shear strength, crack propagation, and failure mechanisms of beams incorporating glass powder. The influence of glass powder on diagonal cracking, shear resistance, and ductility behaviour remains unclear.
3. Inadequate Research on Load–Deflection and Flexural Performance: Limited work has been carried out on load–deflection behaviour, stiffness, energy absorption, and ultimate flexural capacity of beams with varying percentages of glass powder, indicating a need for detailed structural-level investigation.

III. CONCLUSION

The review of literature indicates that waste glass powder is a promising sustainable material for use in concrete. Its high silica content contributes to pozzolanic activity and improved microstructural properties. Most studies show that partial replacement in the range of 5% to 15% enhances compressive and tensile strength. However, higher replacement levels beyond this range tend to reduce strength due to dilution of cementitious content.

The incorporation of glass powder also improves durability by reducing permeability, water absorption, and chloride ion penetration. The performance of concrete is highly influenced by factors such as particle size, fineness, and mix proportion. Finer glass powder particles generally result in better strength and durability characteristics.

From an environmental perspective, the use of waste glass powder helps reduce landfill waste and conserves natural resources. It also contributes to lowering the carbon footprint of concrete production. Overall, glass powder can be effectively utilized as an eco-friendly material in concrete when used within optimal limits.

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