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Utilizing Waste Glass as A Sustainable Substitute for Fine Aggregate in Concrete: A Review

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Abstract:
Concrete, a crucial construction material, is globally ubiquitous, driving high demand for natural resources like sand. However, soaring sand consumption and the environmental toll of glass waste necessitate creative solutions. This research probes the viability of using waste glass in lieu of fine aggregate in concrete, aiming to tackle environmental and economic dilemmas via sustainable building practices. Waste glass, an industrial byproduct, poses pressing waste management challenges. This study spotlights the potential gains of fusing waste glass into concrete blends. Diverse investigations have probed the impact of glass waste replacement on concrete properties, with varied substitution levels yielding enhanced mechanical traits. Despite hurdles such as alkali-silica reactions, integrating waste glass offers promise for advancing sustainable construction. The study advocates wider embrace of glass-infused concrete to champion circular economy principles and curtail environmental repercussions.

Keywords: Fine Aggregate, Waste Glass, Concrete Sustainability, Circular Economy

I. INTRODUCTION

1.1 Background and history

Concrete constitutes the primary building material employed in construction, with an average annual usage of 2 tonnes per individual, following total water consumption (Reddy & M V, 2022). Concrete is a material that resembles stone that is formed by carefully proportioning cement, fine aggregate, admixtures and coarse aggregate which are mixed with water to achieve the desired shape and size for construction purposes (Sawant, 2018). Given cement's widespread global use, regular sand is heavily employed, especially in swiftly developing nations where construction and infrastructure growth are prominent. This is noticeable in the rapid erection of diverse buildings and structures. (S, S, & Narayana, 2015).

The utilization of river sand as fine aggregate has resulted in various consequences, such as the depletion of the water table, erosion of river beds, and shrinkage of scaffold docks (Elavarasan & Dhanalakshmi, 2016). The substitute material, therefore, holds paramount importance (Reddy & M V, 2022). In this barren setting, there is a considerable need for various materials crafted from industrial waste (Anusha & Reddy, 2016). Several alternative materials, such as fly ash, red mud, and slag have already been integrated as substitutes for regular sand (Lineesh, Sivakumar, & Sundaram, 2014).Trimming fine aggregate content and addressing river dredging effects can enhance concrete's sustainability. By appropriately integrating waste glass within defined size and percentage parameters, it becomes a feasible fine aggregate substitute. (Elavarasan & Dhanalakshmi, 2016). While less prevalent in India, advanced industrial nations acknowledge the value of glass powder, also called manufactured sand. (Anusha & Reddy, 2016).

1.2 Glass Waste and its Sources

Glass is formed by melting silica, soda ash, and CaCO3 at high temperatures, then cooling to solidify without crystal formation. This synthetic material is versatile, found in everyday products like bottles, glassware, and sheet glass. (Alhaji B., D. N., Yusuf A., & Shehu, 2019). Industrial expansion and urbanization produce millions of tons of glass waste annually. In India, around three million tonnes of glass waste is created each year, with only 35% being collected; the remainder is usually disposed in landfills or repurposed for construction. Aiming for sustainability requires resource retrieval. Shifting towards circular economy and sustainable practices is crucial, with the glass industry playing a pivotal role. Glass constitutes approximately 0.7% of the nation's urban waste. (Vatkar & Kamble, 2021).

Annually, GBP produces over 4 million heaps of waste glass (Ansari, Mishra, & Vanshaj, 2022). In growing nations such as India, waste management has emerged as a significant and pressing issue (Premalatha & Srinivasan, 2019). Each year, the United Kingdom produces over three million metric tonnes of glass waste (Elavarasan & Dhanalakshmi, 2016). In 2010, the United States generated a total of 11,530 thousand metric tonnes of waste glass (Vatkar & Kamble, 2021). Waste glass comes from various sources like bottles, electronics, and window panes, but recycling faces challenges due to expensive cleaning and sorting. This limited recycling, especially compared to other waste, emphasizes the need for better glass waste management (Vatkar & Kamble, 2021).

1.3 Effect of Glass Waste on the Environment

The world faces an unprecedented waste crisis driven by population growth, imperiling the global ecosystem (Premalatha & Srinivasan, 2019) Proper solid waste management is vital, with recycling and reusing emerging as crucial solutions (Farendra, Sinha, Mandilwar, & Manas , 2022). Glass, non-biodegradable over millions of years, occupies landfill space and curtails disposal site longevity (Upreti & Mandal, 2021). The challenge is to sustain human needs and economic growth while preserving the environment's foundation for life, prosperity, and security (S, S, & Narayana, 2015). Growing glass item use has increased waste glass production, often ending up in landfills. Given glass's non-biodegradability, landfilling is environmentally unfavourable (Reddy, Sumalatha, Madhuri, & Ashalatha, 2015).

To address this, innovative recycling methods should be the norm, considering the non-biodegradable nature of glass waste (Premalatha & Srinivasan, 2019) Recycling is not just economical but also ecologically sound, as it consumes less energy than making new materials. The depleting natural aggregates underscore their sustainability concerns (Farendra, Sinha, Mandilwar, & Manas , 2022). Recycling one tonne of glass saves more than one tonne of natural resources and reduces carbon emissions by recycling six tonnes of container glass (Vatkar & Kamble, 2021).

1.4 Glass Waste as Fine Aggregate

Recycling waste glass in concrete cuts reliance on natural resources and lessens impact on riverbeds and aggregates (Upreti & Mandal, 2021). Glass powder addition to concrete is an eco-friendly approach. It can replace cement and fine aggregate due to its pozzolanic properties, influenced by glass's fineness and composition (Ansari, Mishra, & Vanshaj, 2022). In the concrete sector, using glass waste is crucial and

cost-effective, reducing concrete production expenses (Reddy, Sumalatha, Madhuri, & Ashalatha, 2015).Recycled glass, when broken, blended, and sorted by colour, finds application in various specialty products and local concrete production (Saritha, Haripriya, Harshini, & Reddy, 2018). Crushed and screened waste glass is a strong, reliable, and cost-effective substitute for sand in concrete. When processed right, crushed glass can mimic gravel or sand properties. For construction, glass needs crushing and screening to attain desired gradation (Alhaji B., D. N., Yusuf A., & Shehu, 2019).
Waste glass is inert and adding it to concrete doesn't change the concrete's chemical properties. Yet, using waste glass as fine aggregate can trigger Alkali Silica Reaction (ASR). This reaction involves alkalis in cement reacting with aggregate silica, producing swelling silica gel that expands as it absorbs water. (Sawant, 2018)To counter ASR, crushed glass can replace fine aggregate, and fly ash can partly substitute cement to improve workability and reduce Alkali Aggregate Silica Reaction.(Lalitha, Sasidhar, & Ramachandrudu, 2017). Ongoing R&D drives substantial glass powder utilization, exceeding 60% in industrialized nations like the UK, France, and Germany (Reddy & M V, 2022).

1.5. Objectives

This study aims to explore the feasibility and potential benefits of using waste glass as a partial replacement for fine aggregate in concrete production. The research objectives include:

a. Evaluating the suitability of waste glass as a substitute for fine aggregate in concrete.
b. Analysing the environmental impact of using glass in concrete compared to traditional methods.
c. Investigating the impact of glass powder on concrete properties.
d. Assessing the economic viability of incorporating waste glass in concrete mixes, considering processing costs.

Through these objectives, the study intends to offer insights into the technical, environmental, and economic aspects of utilizing waste glass as a partial fine aggregate substitute in concrete. Ultimately, this research aims to promote more sustainable construction practices and reduce the environmental consequences associated with concrete manufacturing.

II. LITERATURE REVIEW

(Vatkar & Kamble, 2021) studied eco-economics of replacing fine aggregate with crushed waste glass powder in concrete. Optimal compressive strengths (20N/mm², 28.66N/mm², and 33.78N/mm²) at 25% replacement at 7, 14, and 28 days. Crushed glass powder's waste status and easy availability make it a suggested cost-effective choice.
(Ansari, Mishra, & Vanshaj, 2022) sought to improve concrete's mechanical properties by partly replacing fine aggregates with glass powder. Investigated effects on compressive, tensile, and flexural strength in concrete grade M45, using replacement proportions of 20%, 25%, and 30%. Results revealed that substituting 25% fine aggregates with glass powder yielded higher compressive, tensile, and flexural strength than conventional concrete.
(Elavarasan & Dhanalakshmi, 2016) examined waste glass powder replacing fine aggregate at weights: 0%, 10%, 20%, 30%. Tested compressive and splitting tensile strength at 7 and 28 days against regular concrete. Viable partial fine aggregate substitution with glass powder was evident, especially in 0 to 1.18 mm range, up to 30%. Remarkably, at day 28, 20% glass powder replacement boosted splitting tensile strength by 39.55% compared to standard concrete.

(Haramkar, et al., 2018) confirmed viability of using glass waste as fine aggregate substitute in concrete, showing promise for future adoption. Main goal was to develop practical recycling techniques for glass in concrete. Notably, glass impact on concrete strength grew at 28 days. Research strongly supports integrating glass waste in concrete. Optimal 10% glass waste use resulted in highest compressive strength.
(Lalitha, Sasidhar, & Ramachandrudu, 2017) explored concrete's durability and strength with recycled glass as aggregate replacement. Larger crushed glass sizes intensified ASR, but reducing glass size and using mineral admixtures mitigated this reaction. Smaller glass powder showed increased pozzolanic traits. Overall, the study concluded that incorporating up to 20% fine aggregate actually improved concrete strength.
(Lineesh, Sivakumar, & Sundaram, 2014) researched replacing fine aggregate with foundry sand and glass powder in concrete. Evaluated strength at 7 and 28 days. Foundry sand enhanced strength progressively. Glass powder (GP) peaked at 10% replacement, then weakened. Conclusion: 10% GP replacement, not foundry sand, notably boosted concrete strength.
(Alhaji B., D. N., Yusuf A., & Shehu, 2019) explored waste glass as fine aggregate replacement with Bida natural aggregates in concrete. Suggested 20% as ideal substitution ratio. Waste glass can replace fine aggregate up to 40% with minor strength impact, potentially reducing costs. Ideal for contexts where ultra-high strength and crack resistance aren't paramount.
(S, S, & Narayana, 2015) experimented with m-sand and glass powder in concrete, partially replacing cement. Achieved study goals through mechanical property assessment. Glass powder mix showed good workability in control test. Improved workability observed in slump test with glass powder addition. In strength, glass powder-enhanced concrete generally had higher strength at 14 days than control. By 28 days, control outperformed glass powder mix, except in M30 concrete where glass powder maintained superior strength.
(Elangovan & Ruban, 2017) studied concrete's flexural behavior by partially replacing cement with glass powder and fine aggregate with granite powder. Compared mechanical properties to regular concrete after 7, 14, and 28 days of curing. Found glass and granite powder replacements effective, reducing cement use and cutting construction costs.
(Reddy, Sumalatha, Madhuri, & Ashalatha, 2015) researched using waste glass as partial fine aggregate replacement in cement concrete (10%, 20%, 30% for M20 mix). Tested 7 and 28-day compressive strength against regular concrete. Found waste glass effective up to 30% for 0 to 1.18 mm particles. It could replace fine aggregate up to 20% without significant strength loss.
(Kittur, Ahmed, Kushtagi, Patagar, & Vidyadhar, 2019) explored replacing fine aggregate with waste glass powder across varied weight percentages for M-20 mix. Findings revealed up to 15% replacement improved compressive and tensile strengths over regular concrete. The addition of waste glass enhanced hydration and curing, as demonstrated in the study.
(Mishra , Thakur, & Gupta, 2020) studied glass powder as sand substitute in concrete. Replaced sand with glass powder (0%-40%). Compared 28-day compressive strength to natural sand control. Glass-added concrete had slightly higher strength (about 2%) than control. Best glass content was 15%, beyond which strength decreased. Glass powder improved mortar flow due to cleanliness. Conclusion: Glass powder cuts cement costs up to 20%, keeping performance akin to natural sand mix.
(Malik, Bashir, Ahmad, Tariq, & Chowdhary, 2013) studied an experiment using waste glass to partially replace fine aggregates (10%-40%) in M-25 mix. Aimed to address glass waste environmental impact and

economic concerns. Test results at 28 days showed waste glass is viable for eco-friendly concrete, effective up to 30% replacement.

(Mageswari & Vidivelli, 2010) explored using Sheet Glass Powder (SGP) as sand replacement in concrete. Mixed various ratios (10%-50% SGP). Compared SGP and natural sand mixes for 180 days. Results suggest 10%-20% SGP replacement maintains similar concrete properties to natural sand.

(Abdallah & Fan, 2014) studied waste glass as fine aggregate replacement and its effect on Alkali-silica reaction (ASR) expansion in concrete. Results demonstrated reduced expansion with waste glass, indicating ASR between glass silica and cement alkali. Concrete with 20% glass showed improved mechanical properties, likely due to pozzolanic reaction enhancing strength.

(Siram, 2020) explored recycled glass powder replacing fine aggregate in concrete grades (M20-M40). Tested compressive strength at 7 and 28 days for 10%-50% glass powder replacements. Findings showed enhanced strength compared to regular concrete at 20% replacement, with slight variation at 30%.

(Srivastav, 2016) researched eco-economic concerns using waste glass as partial fine aggregate substitute in concrete. Added glass powder (5%-20%) in M-25 mix. Test outcomes highlighted enhanced uniformity, compaction, and 28-day compressive strength versus regular concrete.

(Patil, et al., 2019) explored GP replacing fine aggregate (0%-20%) in concrete. GP-enhanced concrete showed over 2x compressive strength and higher tensile strength compared to normal concrete. In M20 grade, 10% and 20% GP replacement yielded an impressive 80% strength increase. A 10% replacement improved flexural strength by 34% in M20. Researchers recommend GP concrete for robust foundations in major structures like bridges and dams, due to superior performance.

(Venkatachalam, Davis, Nisari, Aswathy, & Suresh, 2020) investigated using granite and glass powder as partial replacements in concrete. Substituted powders (10%, 20%, 30%) for cement and sand. Results suggested both powders enhance concrete's compressive strength, showcasing their potential as substitutes.

(Singh S. , 2017) explored replacing coarse aggregate with glass waste in concrete (5%-30%). Tested blocks for compressive strength at SRMCEM lab. Results showed slight strength improvement up to 10% glass replacement, but strength decreased with higher proportions. Project helped curb glass waste generation, offering environmental benefits.

(Singh & Kumar, 2019) explored broken glass and marble sand to create cost-effective translucent concrete with ample strength. Marble sand replaced coarse aggregates at 20%, 30%, 50%, and 100% levels. Only 20% replacement increased compressive strength at 14 and 28 days. Strength decreased beyond 20% replacement, especially at 100%. Surprisingly, glass inclusion didn't enhance appearance but made concrete abrasive, harder to handle, and less safe compared to the control mix.

2.1. Summary of Literature and Gaps

Numerous research investigations have explored the viability of using waste glass powder as a substitute for fine aggregate in concrete. These studies aimed to address environmental concerns related to glass waste disposal and assess the impact of glass powder incorporation on concrete properties. The experiments involved varying proportions of glass powder replacement, typically ranging from 5% to 50%, while analyzing different concrete characteristics.

Results from these studies highlighted that introducing waste glass powder into concrete could lead to improved mechanical properties. Concrete mixes with partial fine aggregate replacement by glass powder exhibited favorable workability, rendering them suitable for construction applications. Notably, replacement levels of approximately 10% to 30% of waste glass powder showed enhanced strength and durability, whereas higher replacements could potentially decrease performance.However, despite these insights, several gaps remain that warrant further exploration to advance these achievements:

a. Investigating the long-term durability of concrete containing glass powder, particularly in challenging environmental conditions, is essential.
b. Determining the optimal percentage of waste glass replacement, considering factors like concrete grade and particle size, necessitates further investigation for diverse concrete mixes.
c. Exploring the impact of different additives on concrete performance would aid in optimizing mix designs.
d. Conducting a comprehensive life cycle assessment (LCA) comparing the ecological footprint of waste glass concrete with traditional concrete would yield valuable insights.

Addressing these gaps in the literature would enhance our understanding of the feasibility and potential benefits of incorporating glass powder into concrete. This deeper perspective could facilitate wider adoption of this approach within the construction industry.

III. DISCUSSION

The reviewed literature highlights various studies investigating the use of glass waste as a partial fine aggregate substitute, revealing key findings to consider. These studies collectively emphasize the efficacy of glass waste as a substitute, resulting in enhanced strength and favourable attributes. However, the ideal replacement percentage varies with concrete grade and specific study conditions.

Incorporating waste glass into concrete presents a promising avenue to address environmental concerns and minimize the economic burdens linked to waste disposal. Preventing recyclable glass from occupying landfill space is essential, redirecting it towards more sustainable use. Overcoming challenges like the alkali-silica reaction, a significant hurdle, necessitates further comprehensive research. Additionally, fostering awareness about the merits of glass waste substitution can aid in reducing carbon emissions, contributing to the battle against global warming associated with cement production.

IV. CONCLUSIONS

In summary, drawing from the literature, the integration of glass waste as a partial substitute in concrete offers a promising environmentally sound and economically feasible solution for the construction sector. Reviewed studies indicated that incorporating waste glass can enhance concrete's mechanical properties with proper application. This approach mitigates environmental risks associated with glass waste disposal in landfills, fostering sustainability in construction.

However, future endeavours should focus on increasing glass powder substitution levels, assessing long-term strength, and studying additive effects on concrete properties. Tackling the alkali-silica reaction challenge is critical to ensure successful application of glass-infused concrete across various construction contexts. Encouraging the use of waste glass-incorporated concrete in construction practices contributes to a more circular economy, repurposing waste materials into valuable products.Raising awareness about the ecological benefits of using waste glass in construction and implementing effective waste management strategies are pivotal steps toward fostering a greener and more sustainable construction industry.

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