A Literature Review on the Utilization of Waste Glass Powder in Concrete

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***Abstract** - The integration of recycled waste glass into Portland cement and concrete has garnered significant global interest due to rising disposal costs and environmental issues. Glass, being amorphous and rich in silicon and calcium, exhibits pozzolanic or even cementitious characteristics when finely ground, making it a potential substitute for cement in concrete applications. However, utilizing crushed glass as aggregates introduces challenges, such as expansion and cracking in concrete; nonetheless, concrete with 100% crushed glass can still be viable. The cement industry is a major contributor to global CO_2 emissions, with approximately 5% of such emissions attributed to its production processes. The burgeoning population increases the demand for construction, resulting in millions of tons of glass waste generated annually, much of which ends up in landfills, exacerbating environmental concerns. This review highlights the advancement in using waste glass as an alternative in concrete, noting its pozzolanic properties and potential for reducing cement consumption. It has been found that the mechanical properties of Waste Glass Powder (WGP) concrete are dependent on factors such as particle size and the replacement ratio of cement. The article compiles previous experimental results on the role of waste glass powder as a partial cement replacement, underscoring the importance of its size and chemical properties on mortar performance. Additionally, it discusses the development of a predictive model for the compressive strength of mortar using multi logistic linear regression (MLR) and artificial neural networks (ANN), with ANN demonstrating superior predictive capabilities.*

Key Words: Concrete; Cement replacement; Mechanical properties; Waste management; Waste Glass Powder (WGP)

1. INTRODUCTION

1.1 Concrete: - a widely used construction material, is composed of cement, sand, gravel, and water, sometimes with admixtures. Cement, which acts as a binding agent, constitutes 7–15% of concrete's volume, while aggregates account for 70–75%. In 2015, global aggregate usage reached 48.3 billion tons. Urbanization trends suggest that by 2050, over 60% of the population in many countries will live in urban areas, primarily in Africa and Asia, which will host 90% of the expected 2.5 billion new residents. The construction industry plays a vital role in sustainable infrastructure. However, concrete production, estimated at one ton per person annually, contributes significantly to CO2 emissions, causing environmental concerns related to climate change. To mitigate the cement industry's environmental impact, supplementary cementitious materials like Waste Glass Powder (WGP) are being explored. WGP exhibits pozzolanic properties and can be effectively used to replace cement, with optimal replacement levels at 10–40%. Concrete with 10–20% WGP shows enhanced resistance to chloride ion penetration, making it suitable for coastal structures. The problem of waste glass (WG), which is non-biodegradable and contributes to landfill issues, can be transformed into a resource through recycling. Although WG poses challenges in conversion to usable cullet—such as equipment wear and safety issues due to sharp edges—new methods like implosion technology provide safer alternatives. This review discusses the potential applications and effects of WGP as a cement substitute

1.2 Glass: - is a versatile material valued for its optical transparency, chemical inertness, and low permeability. Despite being theoretically recyclable, over 200 million tons of glass are landfilled annually due to limitations in quality for re-manufacturing, with soda-lime glass, primarily from beverage bottles, making up the bulk of waste. In Hong Kong, less than 10% of waste glass bottles are recycled. The construction industry presents opportunities for recycling waste glass, reducing landfill strain, preserving resources, and lessening carbon footprints. Early studies, beginning in 1963, demonstrated that waste glass could be transformed into useful aggregates. However, challenges arose with the use of glass cullet leading to decreased concrete workability and strength, along with alkali-silica reaction (ASR) expansion. Ground glass powder (GP), a solution to these challenges, offers improved workability with its finer particle size and angular shape, consisting of primarily SiO2, Na2O, and CaO, and can act as a reactive pozzolan in cement mixtures or even as a precursor for geopolymer production. GP's applications extend to creating lightweight aggregates and phase change materials, aligning with the construction industry's increasing focus on sustainability. This paper reviews the potential uses of GP in cement concrete, blocks, bricks, polymer composites, and other eco-friendly construction materials, emphasizing its versatility as a sustainable option.

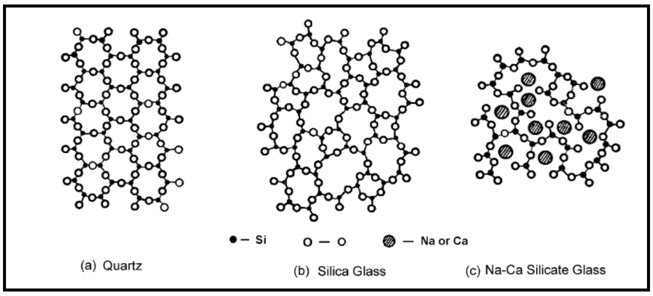

Fig. 1. Structure of quartz, silica glass and Na–Ca silicate glass.

Table-1 Physical properties of waste glass

Physical property	Waste glass
Specific gravity	2.19
Density (kg/m^3)	1672
Absorption (%)	0.39
Pozzolanic index (%)	80

Table -2 Amount of waste glass and the percentage of recycling in different countries

Country	Glass waste (tons)	% of recycling rate	Year
USA	11,500,000	27	2010
Canada	116,000	68	2009
Singapore	72,800	29	2010
Sweden	195,000 isolated	93	2010
	44,000 mixed	0	
Portugal	493,000	25	2001
Turkey	120,000	66	2004
Germany	3,200,000	94	2003
Jordan	35 building glass	0	2004

1.3 Cement: - is a crucial binding material in construction, with a global production rate of 2.8 billion tons annually, anticipated to exceed 4 billion tons due to rapid urbanization in various regions. Historically, ancient civilizations like Egypt and Greece used lime sediment before Joseph Aspdin developed Portland Cement in 1824. The production of cement involves primary materials such as silica, limestone, magnesium oxide, ferrous oxide, and alumina, leading to various cement types from Ordinary Portland Cement (Type 1) to highly sulfate-resistant cement (Type 5). Cement can be produced through wet or dry processes, with each method involving the precise preparation and burning of raw materials at high temperatures.

1.4 Challenges to Glass and cement industries:- High energy consumption, resource depletion, low glass waste recycling rates, and impacts to climate change are just a few of the major issues facing the glass and cement sectors. These problems have been made worse by the rising usage of glass. The cement industry also confronts comparable challenges, such as fuel prices, greenhouse gas emissions, and the depletion of raw materials; for every ton of cement produced, 1.5 to 1.7 tons of resources are used. Both businesses are always under pressure to address their environmental consequences due to these interrelated issues.

Table-3 Properties of waste glass cement and portland cement

	Normal Portland cement	Waste glass cement
Na_2O (%)	0.10	0.20
K_2O (%)	0.32	0.31
Total alkali (%)	0.31	0.40
SO_3 (%)	2.49	2.47
Free lime (%)	1.25	1.20
SiO_2 (%)	20.7	21.3
CaO (%)	65.2	65.1
Fe_2O_3 (%)	3.33	3.37
Al_2O_3 (%)	4.96	5.37
MgO (%)	0.57	o.61
C_3S (%)	62.7	55.6
Blaine (m^2/kg)	308	304
Fineness (−325) (%)	93.5	94.4
EN compressive strength		
2 day (MPa)	21.9	20.3
7 day (MPa)	39.6	36.5
28 day (MPa)	55.1	53.5

1.5 Waste glass as cementitious material:- non-biodegradable and non-recyclable waste glass (WG) poses a significant landfill burden, particularly in metropolitan areas where landfill space is limited. Utilizing WG in concrete production presents a viable solution due to its comparable physical and chemical properties to sand and cement. This approach not only protects the environment but also conserves natural resources and benefits the economy. WG, exhibiting pozzolanic characteristics, can replace cement in concrete; particle sizes influence its effectiveness, with 38 µm particles capable of substituting up to 30% of cement. Moreover, the pozzolanic behavior diminishes with larger glass particles, and using 20% finely ground WG can significantly mitigate alkali-silica reaction (ASR) expansion in concrete.

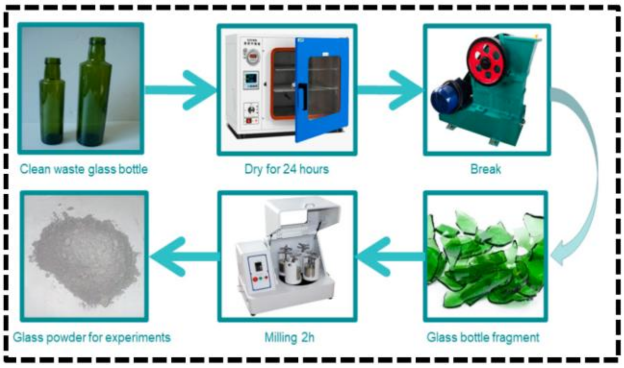

Fig. 2. Preparation Process of waste glass powder for concrete"

Table-4 Chemical Composition of cement and different colored glass.

Chemical	Cement (%)	Clear glass (%)	Brown glass (%)	Green glass (%)	Crushed glass (%)	Glass powder (%)
SiO_2	20.2	72.42	72.21	72.38	72.61	72.20
Al_2O_3	4.7	1.44	1.37	1.49	1.38	1.54
CaO	61.9	11.50	11.57	11.26	11.70	11.42
Fe_2O_3	3.0	0.07	0.26	0.29	0.48	0.48
MgO	2.6	0.32	0.46	0.54	0.56	0.79
Na_2O	0.19	13.64	13.75	13.52	13.12	12.85
K_2O	0.82	0.35	0.20	0.27	0.38	0.43
SO_3	3.9	0.21	0.10	0.07	0.09	0.09
TiO_2	-	0.035	0.041	0.04	-	-
Loss on ignition	1.9	-	-	-	0.22	0.36

2. LITERATURE REVIEW:

- **Hassani et al. (2023)** Hassani et al. reviewed many previous studies and concluded that waste glass powder can improve both compressive strength and durability of concrete. They emphasized that fine glass powder performs better because it has higher reactivity and forms more binding compounds inside concrete.

- **Matos et al. (2023)** Matos et al. reported that waste glass powder works as a filler material in concrete. It fills the tiny voids between cement particles, making the concrete structure denser, stronger, and less porous. This also helps in improving overall durability.

- **Zhang et al. (2023)** Zhang et al. highlighted the environmental benefits of using WGP. They stated that replacing cement with glass powder reduces cement consumption, which in turn lowers carbon dioxide (CO_2) emissions. This makes concrete production more eco-friendly and supports sustainable construction practices.

- **Eixeira et al. (2023)** Teixeira et al. found that the optimum replacement level of cement with waste glass powder is around 10% to 30%. Within this range, concrete shows a good balance between strength, workability, and durability. Beyond this limit, performance may start decreasing.

- **Sivasuriyan et al. (2025)** Sivasuriyan et al. explained that waste glass powder reacts with cement to form additional calcium silicate hydrate (C-S-H) gel. This gel is responsible for increasing strength and reducing permeability in concrete.

3. AIM & OBJECTIVES

3.1 Aim & Objectives:

- a comprehensive review on how different dosages of waste glass affect fresh, physical, mechanical, and durability properties.
- A Review of prior research on the impact of waste glass ratios on mortar properties. Examination of glass composition's role in mortar properties.
- The paper aims to provide insights into the factors influencing compressive strength when using waste glass in mortar.

4. METHODS

4.1 Effect of using glass powder in concrete:

a. **Slump test:** Vasudevan Gunalaan and Kanapathy pillay Seri Ganis [2013] studied slump property in his research and resulted that compared to control mix, by using waste glass powder will give another benefit which is the workability of concrete which is much higher. R.Vandhiyan et al[2013] investigated that the workability was reduced due to the replacement and it reduced with increase in replacement, this is due to the increase in the surface area of the glass powder and also the angular shape of the glass particles. Kumarappan N. [2013] presented that there is a systematic-increases in the slump as the glass powder in the mix increases. The slump ranged from around 40mm for the reference mix (i.e. 0% glass powder) to 160mm at 40% glass powder. Khatib J.M. et al [2012] in his study showed that there was a systematic increase in the slump as the glass powder content in the mix increases. Jangid Jitendra B. and Saoji A.C. [2012] resulted that the workability decreases as the percentage glass powder in the mix increases. . Chikhalikar S.M. and Tande S.N. [2012] studied the properties of SFRC (Steel Fibre Reinforced Concrete) containing waste glass as pozzolona and concluded that the 20% replacement of cement by waste glass powder gives better workability to SFRC. Nassar Roz-Ud-Din and Soroushian Parviz [2012] utilized milled waste glass in his experimentation and resulted that slump is observed to slightly increase with the introduction of milled waste glass. This could be attributed to the low water absorption of glass. The slump of recycled aggregate concrete mixes (at both levels of w/cm ratio) is higher than that of corresponding control mixes.

b.

Fig. 3. Process of slump cone test of waste glass powder concrete"

c. **Compressive strength:** Many studies have explored the impact of waste glass powder as a partial replacement for cement in concrete. Notably, Gunalaan and Seri Ganis (2013) found that a 20% replacement of glass powder significantly improved compressive strength at 28 days of curing compared to lower ratios of 10% and 15%. Meanwhile, Vandhiyan et al. (2013) reported that a 15% replacement resulted in a 29% increase in strength at 7 days, though this decreased to 23% by 28 days, with optimal strength at 10% replacement. Kumarappan (2013) also found that up to 10% replacement yielded higher compressive strength than control mixes. Further, Vijayakumar et al. (2013) suggested up to 40% replacement could enhance strength over 28 and 60 days. In contrast, Nwaubani and Poutos (2013) observed that increased glass content generally reduced compressive strength, though this effect diminished with prolonged curing time, emphasizing particle size distribution as a critical factor. Khatib et al. (2012) noted similar findings, where maximum strength occurred at around 10% glass powder and declined with greater amounts. Research by Patel Dhirendra (2012) indicated moderate declines in compressive strength at 28 days, while Jangid and Saoji (2012) confirmed strength increases up to 40% replacement, peaking at 20%. Chikhalikar and Tande (2012) demonstrated up to a 30% strength increase with fiber-reinforced concrete containing waste glass, with the peak at a 20% replacement. Dali and Tande (2012) reported up to 25% strength increments at 20% replacement. In experimental work, Khmiri et al. (2012) found that sieve sizes lower than 40 μm could lead to a compressive strength index of over 82%. Patil and Sangle (2012) concluded that 20% glass powder addition significantly enhanced strength. Bajad et al. (2011) demonstrated that 20% replaced glass powder maintained peak strength even under sulfate attack. Lastly, studies by Wang and Hou (2011) and Oliveira et al. (2010) suggested effective cement replacement rates of 10% and 30% respectively, focusing on the pozzolanic activity and favorable strength properties. Overall, optimal results generally indicate that partial replacement of cement with waste glass powder leads to improved concrete characteristics, particularly around the 10% to 20% range.

d. **Split tensile strength:** In the study of split tensile strength, Vijayakumar G. et al. (2013) found that glass powder concrete enhances tensile strength compared to conventional concrete, while Vandhiyan R. et al. (2013) reported only a marginal improvement. Chikhalikar S.M. and Tande S.N. (2012) identified that Steel Fibre Reinforced Concrete (SFRC) reaches its peak tensile strength at a 20% cement replacement with waste glass powder. Furthermore, Dali J.S. and Tande S.N. (2012) concluded from their experiments on concrete with mineral admixtures that a 20% replacement is optimal, irrespective of whether the concrete experiences alternate wetting and drying conditions. Regarding water absorption, Malik M. Iqbal et al. (2013) demonstrated in their research on using Waste Glass as a partial fine aggregate replacement that the percentage of water absorption decreases with higher waste glass content, with the lowest absorption observed at a 40% waste glass mix. Conversely, Nwaubani Sunny O. and Poutos Konstantinos I. (2013) indicated that water absorption rises with increased glass powder content, yet moderate substitutions (5% and 20% glass powder) yielded values comparable to the control mix. Finally, Nassar Roz-Ud-Din and Soroushian Parviz (2012) found that the introduction of milled waste glass as a partial cement replacement significantly reduces water absorption in both low and high water/cement ratio mixes.

e. **Water absorption test** Malik M. Iqbal et al. (2013) investigated the use of waste glass as a partial replacement for fine aggregates in concrete, finding that water absorption decreased with increased waste glass content, with the lowest absorption at 40% waste glass. Nwaubani Sunny O. and Poutos Konstantinos I. (2013) explored the effect of waste glass powder fineness on cement mortars, noting that water absorption rose with higher glass powder content, though moderate substitutions (5% and 20% glass powder) showed values similar to the control mix. Lastly, Nassar Roz-Ud-Din and Soroushian Parviz (2012) examined the strength and durability of recycled aggregate concrete with milled glass as a partial cement replacement, concluding that water absorption was significantly reduced with milled waste glass in both low and high water/cement ratio mixes.

5. CONCLUSION

a. The following conclusions can be drawn:

- A large quantity of waste glass (WG) is produced annually, significantly impacting landfills, especially in urban areas.
- WG is primarily sent to landfills without recycling, contributing to energy consumption and CO2 emissions from glass and cement industries, exacerbating global warming.
- The concrete industry offers a sustainable solution by using waste glass as a substitute for cement, resulting in improved concrete characteristics compared to traditional mixes.
- Key properties enhanced through waste glass in concrete include compressive strength, flexural strength, workability, and split tensile strength.
- The level of cement replacement by waste glass powder (WGP) presents challenges, with varying optimal levels identified in research.
- There is a lack of literature on using WGP as both cement and fine aggregate replacement in concrete, suggesting a need for further research on its effects on concrete properties.
- Glass can partially replace cement in concrete, enhancing workability. Improvements observed in strength parameters: compressive, flexural, and split tensile strength. Increased durability indicated by results from water absorption and sorptivity tests.
- Utilization of waste glass addresses disposal challenges related to limited landfill space and rising disposal costs. This approach provides economic benefits while mitigating waste disposal issues.

6. LIMITATIONS AND FUTURE RESEARCH

- Alkali-silica reaction (ASR) poses risks due to glass particles reacting with cement alkalis, leading to expansion, cracking, and durability issues.
- The effectiveness of waste glass powder (WGP) is dependent on particle fineness; coarser particles may behave as inert materials, negatively impacting concrete strength.
- High replacement levels of WGP can reduce the workability of fresh concrete, complicating handling and compaction.
- Studies indicate that only 10-30% of cement can be effectively replaced with WGP; exceeding this range can diminish mechanical properties.
- The absence of universal standards for WGP use in construction hinders its widespread adoption. Waste glass quality varies based on its source (bottles, windows, mixed waste), which can affect concrete performance.
- The energy-intensive process of grinding waste glass into fine powder can elevate costs, potentially offsetting economic benefits.
- Future studies should investigate chemical additives or supplementary materials to control or eliminate alkali-silica reaction in WGP concrete.
- Expanded research on nano-sized or ultra-fine glass powder is needed, as it may enhance reactivity and concrete strength.
- Further studies on combining WGP with other waste materials like fly ash, silica fume, and GGBS could improve performance and durability.
- Research should explore the application of WGP in structural components such as beams, columns, and high-rise structures for reliability.
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- Long-term field studies (10–20 years) are necessary to assess real-life performance under varying environmental conditions.
- Research should explore the application of WGP in structural components such as beams, columns, and high-rise structures for reliability.

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