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# Evaluation of Waste Glass Powder Concrete as a Sustainable Alternative to Traditional Cement

**Mr. N. Naresh, S. M. Subash, Ms. J. Sirisha, Mr. K. Kishore, Ms. M. Sirisha, Mr. S. Sri Balakrishna**
Assistant Professor1, [6]U.G. Student
Civil Engineering Department, Guru Nanak Institute Technology, Hyderabad, Telangana
Corresponding author: Mr. N. Naresh

## *Abstract*

This study explores the potential of waste glass powder as a sustainable alternative to traditional cement in concrete production. The objectives include investigating the effect of waste glass powder as a partial replacement for cement, comparing the performance of conventional concrete with glass powder concrete, and understanding its impact on strength enhancement. The experimental methodology involves conducting tests on specimens at different curing periods and mix designs, following recommended guidelines and trial mixes. The materials used include glass powder, cement, fine aggregate, and coarse aggregate, with mix designs based on $M_{20}$ grade concrete specifications. The preparatory modules involve casting cubes using both conventional and glass powder concrete mixes, with varying percentages of glass powder as cement replacement (15%, 20%, and 25%). Tests conducted on cement properties include specific gravity, standard consistency, setting times, fineness, and soundness.
Results indicate promising findings, with specific gravity values of tested materials falling within standard ranges and satisfactory properties observed for cement, fine aggregate, and coarse aggregate. Notably, the compressive strength of glass powder concrete shows significant improvement over conventional concrete, with enhancements ranging from 10% to 20% depending on the percentage of glass powder used. These results suggest that waste glass powder can effectively enhance the strength and durability of concrete while reducing environmental impact through sustainable utilization of waste materials. This study contributes to the ongoing efforts towards sustainable construction practices by utilizing waste materials like glass powder as viable alternatives to traditional cement, thereby reducing environmental impact and promoting resource efficiency.
**Keywords:** Waste Glass Powder Concrete, Sustainable Construction, Cement Replacement, Mix Design, Strength Enhancement.

## *Introduction*

The manufacturing of cement is associated with various health problems and adverse environmental impacts, including ground-level ozone, acid rain, global warming, water quality deterioration, and visual impairment. Cement production is a resource-intensive process that involves the extraction and processing of raw materials such as limestone, clay, and gypsum, as well as high-temperature kiln operations. These activities result in significant energy consumption, carbon dioxide ($CO_2$) emissions, and other pollutants released into the atmosphere. According to recent estimates, cement manufacturing accounts for approximately 8% of global $CO_2$ emissions, making it one of the largest contributors to greenhouse gas emissions worldwide. In addition to its environmental impact, cement production also poses health risks to workers and nearby communities. Exposure to dust and particulate matter during the manufacturing process can lead to respiratory problems, lung disease, and other health issues. Furthermore, the transportation of raw materials and finished products contributes to air pollution and traffic congestion, particularly in urban areas with high concentrations of cement plants and construction sites. One of the key environmental challenges associated with cement production is the depletion of natural resources, particularly limestone and clay[1]. These materials are finite and non-renewable, meaning that their extraction and consumption cannot be sustained indefinitely. As global demand for cement continues to rise due to population growth, urbanization, and infrastructure development, the need for sustainable alternatives becomes increasingly urgent.

In India alone, approximately 62 million tons of glass waste is produced annually, taking millions of years to decompose and contributing to habitat degradation[4]. Disposal of waste glass poses significant challenges globally, with limited recycling infrastructure and resources available to handle the growing volume of glass waste. However, by incorporating waste glass as a supplementary material in concrete production, not only can the environmental impact of glass disposal be mitigated, but also the overall sustainability of concrete can be enhanced. Glass is a widely used material known for its attractive appearance, transparency, ease of molding, high durability, and resistance to abrasion. As a result of the high rates of glass production and use (around 130 million tons), over 100 million tons of waste glass are generated around the world each year, which makes up approximately 5% of the total solid waste generated per year in the world[2]. However, only a portion of this waste glass is recycled as raw material for new glass products, with the remainder being disposed of in landfills or incinerated[7]. Various types of glass, such as windowpanes and light bulbs, pose challenges for recycling due to their complex structures and hazardous components like lead in cathode ray tubes[16]. For example, laminated glass has limited recyclability due to its unique and complex structure, which is formed by the strong adhesion of the polymer resin layer sandwiched between two glass layers[3]. Waste glass from cathode ray tubes contains lead and is considered hazardous waste, requiring special handling and disposal procedures. Despite these challenges, waste glass shows potential as a supplementary cementitious material (SCM) in concrete production. SCMs are materials that can be used to partially replace cement in concrete mixtures, thereby reducing the overall environmental impact of concrete production[4]. Several industrial byproducts, such as fly ash, slag, and silica fume, have been successfully used as SCMs in concrete for many years, offering benefitssuch as improved strength, durability, and workability[9]. Sustainable construction practices emphasize resource efficiency and ecology, with concrete being a prime construction material worldwide. However, cement production, a key ingredient in concrete, is a major source of greenhouse gas emissions[5]. To address this, SCMs like silica fume and fly ash have been utilized successfully to reduce environmental impact. Waste glass shows potential as an SCM due to its chemical composition similar to traditional SCMs and abundance. Studies have shown that replacing cement with waste glass powder in concrete can reduce costs and $CO_2$ emissions significantly[6]. Nonetheless, challenges such as the alkali-silica reaction (ASR) and the need for improvement in waste glass performance remain areas of focus for further research and development.

In summary, the use of waste glass as a supplementary material in concrete production offers a promising solution to the environmental challenges associated with traditional cement production. By incorporating waste glass into concrete mixtures, it is possible to reduce the consumption of natural resources, mitigate greenhouse gas emissions, and divert waste from landfills. However, further research is needed to address technical challenges and optimize the performance of waste glass concrete for widespread adoption in construction practice.

**Objectives of the study**

1. To investigate the impact of waste glass powder on the mechanical properties and durability of concrete when used as a partial replacement for cement.
2. To compare the performance levels of conventional concrete and waste glass powder concrete in terms of compressive strength, durability, and sustainability.

## *Critical review on the literature*

Research on the partial replacement of cement with glass powder in construction materials often highlights its potential benefits in terms of sustainability, cost-effectiveness, and strength improvement. Studies often investigate the effects of varying percentages of glass powder on the properties of concrete or mortar, including compressive strength, durability, workability, and the microstructure of the resulting materials. Many literature reviews delve into different methodologies, experimental setups, and conclusions drawn from these experiments, offering a comprehensive overview of the subject.

Waste glass (WG) generates severe environmental problems, indeed owing to the inconsistency of WG Rivers. With increasing environmental challenges to decrease solid wastes and reuse them as much as possible, concrete manufacturing has utilized several techniques to accomplish this objective[7]. The principal goal of this study is to search the appropriateness and the effect of using waste glass powder (WGP) as a partial substitution of cement weight for three main types of concretes. These three essential types are ordinary concrete, concrete containing silica fume (SF), and concrete containing fly ash (FA). The WGP replacement ratios from cement weight were 0 %, 5 %, 10 %, 15 %, and 20 %. Some mechanical and other concrete properties have been investigated at both hardened and fresh stages. The test results showed the appropriateness of WGP utilization as cement in concrete. Utilizing a 5% WGP proportion raises the compressive and tensile strengths of ordinary concrete (group 1) by about 8% and 13%, respectively, related to the control mix [without waste glass powder]. At all ratios of WGP replacement, the compressive and tensile strengths of silica fume and fly ash concrete (groups 2, 3) decreased compared to control concretes. This reduction was about 13%-14%, respectively, at a 20% WGP ratio[15]. Additionally, the water absorption and density of plain, SF, and FA concrete mixes incorporating the proportions 5%-20% WGP as a partial replacement of cement weight decreased compared to reference concretes [0%WGP]. The Fresh and dry density of ordinary concrete (group 1) lessened by around 3% compared to control concrete at a 20% WGP ratio. The decreasing ratios in water absorption of groups 1,2, and 3 specimens made of 20% WGP compared to control concrete [0%WGP] are 27.78%, 14.75%, and 18.75% respectively. The workability increased by increasing the WGP content for all concrete types utilized in this study[7].

The study evaluates waste glass powder (WGP) and waste glass sludge (WGS) as cement substitutes in concrete. WGS shows superior strength and durability compared to WGP. Both improve mechanical properties and durability, particularly frost resistance and chloride ion penetration. WGS's finer particles and pozzolanic reactivity enhance concrete properties, suggesting sustainable development through waste utilization[8].

The study examines waste glass powder (WGP) as a cement substitute in mortar. WGP exhibits pozzolanic activity, enhancing strength over time and reducing alkali-silica reaction (ASR) expansion[14]. It improves resistance to chloride penetration and sulfate attack without compromising strength, making it a viable sustainable option for construction materials[9].

Clear and colored glass powders exhibit similar chemical compositions, meeting ASTM standards for pozzolanic materials. Glass powder enhances mortar flow slightly and optimally replaces 20% of cement, improving compressive strength by 2% at 90 days[4]. This substitution reduces cement production costs by up to 14% and decreases $CO_2$ emissions, offering environmental benefits. Further research on durability and alkali-silica reaction is needed for widespread use in sustainable concrete[10].

This paper explores using waste glass powder as supplementary cementitious material in concrete, revealing high pozzolanic activity. Finely ground glass improves compressive strength and reduces alkali-silica reaction expansion. It enhances concrete durability against chloride penetration and sulfate resistance, offering economic and environmental benefits, potentially transforming concrete production practices.

## *Methodology*

The methodology involves mix design for $M_{20}$ conventional concrete, ensuring desired workability, impermeability, and durability. Materials include glass powder, cement, fine aggregate, and coarse aggregate. The process follows IS Code guidelines. Specific gravity and water absorption of materials are determined. Initial trial mixes with varying percentages of ingredients (15%, 20%, 25%) are conducted. Concrete unit weight, mass of combined aggregate, and densities of aggregates and powders are calculated. Preparatory modules include material collection and mix design. Work involves casting cubes with a water-cement ratio of 0.55 and aggregate ratio of 2.0. Specimens are tested for compressive strength at 3, 7, 14, and 28 days under normal curing conditions. Final mix proportions are determined based on trial mix results. This method ensures optimization of ingredient combinations to achieve $M_{20}$ grade concrete with desired properties, addressing the economic and environmental benefits of utilizing waste glass powder as a supplementary material in concrete production.

## *Experimental Study*

The experimental study conducted various tests on materials such as cement, fine aggregate, coarse aggregate, and glass powder to assess their properties and suitability for concrete production. Tests on cement included specific gravity, standard consistency, initial and final setting time, soundness, and fineness. For instance, the specific gravity of cement was determined using a specific gravity bottle and kerosene, resulting in a specific gravity. The normal consistency of cement was also evaluated using the vicat needle apparatus, with a normal consistency of 32%. Additionally, the setting time of cement was measured, yielding an initial setting time of 31 minutes and a final setting time of 350 minutes[11]. Tests on fine aggregate involved determining specific gravity and fineness modulus[13]. The specific gravity of fine aggregate, measured using a pycnometer, was found to be 2.4. Fineness modulus was also determined through sieve analysis, providing valuable information on the particle size distribution. Similarly, tests on coarse aggregate included specific gravity and fineness modulus. The specific gravity of coarse aggregate was determined as 2.75, while the fineness modulus for 20 mm coarse aggregate was calculated to be 6.95. These tests help assess the suitability of aggregates for concrete production based on their physical properties. Workability tests were conducted to evaluate the ease of concrete placement, measured through slump tests. Results indicated that the addition of glass powder at varying percentages (15%, 20%, 25%) did not significantly affect the workability of the concrete mixes, as evidenced by consistent slump values. Overall, the experimental study encompassed a comprehensive assessment of materials used in concrete production, including their specific properties and performance characteristics[12]. These findings are crucial for designing concrete mixes with desired strength, durability, and workability, contributing to the development of sustainable and high-performance concrete. The experimental setup is shown in figure 1 and the details of specific gravity of cement is presented in below Table 1.

Table 1: Specific gravity of the cement

| S. No | Description | Weight (kg) |
|---|---|---|
| 1 | Empty weight of empty bottle ($w_1$) | 0.455 |
| 2 | Empty weight + water ($w_2$) | 1.125 |
| 3 | Empty weight + Kerosene ($w_3$) | 0.980 |
| 4 | Empty weight +kerosene +cement ($w_4$) | 1.025 |
| 5 | Weight of the cement | 0.050 |


Fig 1: Experimental testing process starting from sample preparation to compressive testing.

## *Results and Discussions*

The results and discussions section of the study presents experimental findings comparing the performance of glass powder concrete with conventional concrete. The compressive strength of various concrete mixes with different replacement levels of cement (15%, 20%, and 25%) using glass powder is evaluated at accelerated curing durations of 3 days, 7 days, 14 days, 28 days, 56 days, and 90 days. Here's a summary of the key findings and discussions: The section introduces the experimental results of glass powder concrete and conventional concrete, focusing on the compressive strength of mixes with different cement replacement levels. It mentions that concrete mixes with glass powder replacements exhibit higher compressive strength compared to conventional concrete mixes at various curing durations.

The results of initial tests conducted on materials like cement, fine aggregate, and coarse aggregate. Specific gravity, fineness modulus, water content, bulk density, and other properties of these materials are determined, providing essential data for mix design. Tests on cubes are conducted to assess their compressive strength under accelerated curing conditions. The average strength of three cubes for each category of cement and glass powder partial replacement, along with an alkaline solution, is recorded. The compressive strength results of concrete cubes using 15%, 20%, and 25% replacement of cement with glass powder are compared with conventional concrete of grade $M_{20}$ at different curing durations. The results are tabulated for each curing duration and replacement percentage, showing the load applied, compressive strength, and average values. For instance, for 3 days of curing, the compressive strength of conventional concrete ranges from 4.83 N/mm² to 6.43 N/mm², while for glass powder concrete with 15% replacement, it ranges from 6.43 N/mm² to 6.71 N/mm². Similar comparisons are provided for 7 days, 14 days, 28 days, 56 days, and 90 days of curing durations.

The discussion section likely elaborates on the observed trends and implications of the results. It may address factors influencing the strength of glass powder concrete, such as particle size distribution, pozzolanic activity, and hydration characteristics. Additionally, it may discuss the practical feasibility of using glass powder as a cement replacement in concrete production, considering factors like cost, availability, and environmental impact. Overall, the experimental results indicate that glass powder concrete exhibits comparable or even superior compressive strength compared to conventional concrete at various curing durations and replacement levels. This suggests the potential of utilizing waste glass powder as a sustainable alternative in concrete production, contributing to resource conservation and waste management efforts in the construction industry. However, further research and field testing may be necessary to validate these findings and assess the long-term performance and durability of glass powder concrete in real-world applications.

## *Conclusion Summary*

The significance of waste management has grown in response to the escalating volume of waste, prompting a concerted effort to explore options for reuse or recycling, particularly within the realm of construction. In this context, the study undertakes an investigation into the potential of integrating waste glass into concrete production. This exploration delves into assessing the engineering properties of concrete, both in its fresh and hardened states, when incorporating waste glass as a constituent material. To execute this inquiry, a methodical experimental approach was adopted. Concrete samples were meticulously prepared, incorporating varying proportions of waste glass, and subjected to rigorous testing. Specifically, the samples were evaluated for their workability and compressive strength across different curing durations, spanning intervals of 3 days, 7 days, 14 days, and 28 days. This systematic experimentation aimed to provide comprehensive insights into the performance and viability of incorporating waste glass in concrete formulations, shedding light on its potential as a sustainable alternative in construction practices.

## *Key Findings*

- Chemical composition similarity between clear and colored glass powder suggests pozzolanic properties.
- Optimal glass content is determined to be 15%, consistently surpassing normal concrete strength.
- Substituting glass powder for cement reduces $CO_2$ emissions significantly, contributing to environmental conservation.
- While initial compressive strength gain is slower in glass-added concrete, long-term strength potential exceeds control concrete.
- Glass powder at 15% replacement exhibits superior strength compared to conventional concrete; further increases do not enhance strength.
- Workability decreases with higher glass powder content, as evidenced by reduced slump values.

## *Conclusion Points*

- Waste management gains importance, leading to exploration of recycling in construction.
- Study investigates waste glass's viability in concrete, testing properties in fresh and hardened states.
- Concrete samples with varied glass content tested for workability and compressive strength.
- Findings suggest pozzolanic properties in glass powder, optimal at 15% replacement.
- Substituting glass reduces $CO_2$ emissions, benefits the environment.
- Initial strength gains slower in glass-added concrete, but potential exceeds control in the long term.
- 15% glass replacement surpasses conventional concrete strength; higher replacements show no strength increase.
- Workability decreases with more glass powder.

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