Educational Administration: Theory and Practice
2024, 30(5), 13922-13930
ISSN: 2148-2403
https://kuey.net/
Research Article

An Experimental Analysis For Utilization Of Waste Glass Fiber As An Additive In Concrete For Eco-Friendly Construction

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Citation: Hariram Sahu[1], Dr. Bhagyashree Naik, (2024) An Experimental Analysis For Utilization Of Waste Glass Fiber As An Additive In Concrete For Eco-Friendly Construction, *Educational Administration: Theory and Practice, 30(5),* 13922-13930
Doi: 10.53555/kuey.v30i5.6120

ARTICLE INFO

ABSTRACT

This study investigates the utilization of waste glass fibers as an additive in concrete for eco-friendly construction. An experimental analysis evaluates the mechanical properties (compressive, flexural, tensile strength, and modulus of elasticity), durability characteristics (water absorption, chloride penetration, freeze-thaw resistance, and sulfate resistance), and environmental performance (carbon footprint, energy consumption, and leaching potential) of concrete containing varying percentages of waste glass fibers as partial replacement for fine aggregates. The results demonstrate improved mechanical strength, enhanced durability, and reduced environmental impact with the incorporation of waste glass fibers, highlighting its potential as a sustainable and high-performance concrete solution. This research contributes to waste management and promotes a circular economy in the construction industry.

Keywords: Waste glass fibers, concrete, mechanical properties, durability, environmental performance, sustainable construction, circular economy.

1.1 Introduction

Because of the significant role sector plays in the production of greenhouse gases and the depletion of resources on a worldwide scale, it is absolutely necessary to investigate more environmentally friendly building materials and methods. Glass fibre is a material that is frequently used for reinforcing in a variety of sectors; nevertheless, the collection and disposal of waste glass fibre presents considerable environmental issues. Making use of discarded filaments of glass according to concrete also is an innovative strategy that might enhance tangible outcomes and promote the growth belonging to a new economic at the same time.

1.1.1 The Environmental Imperative in Construction

The building and construction industry is a significant contributor *to* the consumption of resources and emissions of greenhouse gases on a global scale. It is responsible for roughly 38 percent of the total CO_2 emissions that are related to energy worldwide [1]. Particularly energy-intensive and a large contributor to the industry's overall carbon footprint is the manufacturing of cement, which serves as the principal binder in concrete for construction purposes. In addition, the mining and processing of raw materials for construction, such as aggregates and sand, deplete natural resources and disturb ecosystems. This is a problem because materials are used in construction.

In order to address these environmental issues, the construction industry has been aggressively researching new methods. The utilisation of waste materials as alternative resources in the manufacturing of concrete is one strategy that fall under this category. Repurposing waste streams allows the industry to not only lessen its dependency on virgin raw materials but also redirect garbage away from landfills and incineration, so contributing to the development of an economy that is more circular and has a greater capacity for sustainability.

1.1.2 Glass Fiber Waste: A Burgeoning Problem

There are several different industries that make extensive use of glass fibre as a reinforcement material. Some of these industries include building, renewable energy, and transportation. The growing demand for items

that are reinforced with glass fibre has resulted in a corresponding increase in the generation of waste glass fibre, which presents considerable issues in terms of disposal.
Incineration releases hazardous air pollutants and greenhouse gases, while landfilling adds to the depletion of important land resources. Both of these processes are harmful to the environment. Furthermore, the fact that waste glass fibre is not biodegradable makes it a chronic environmental concern with regard to the environment.

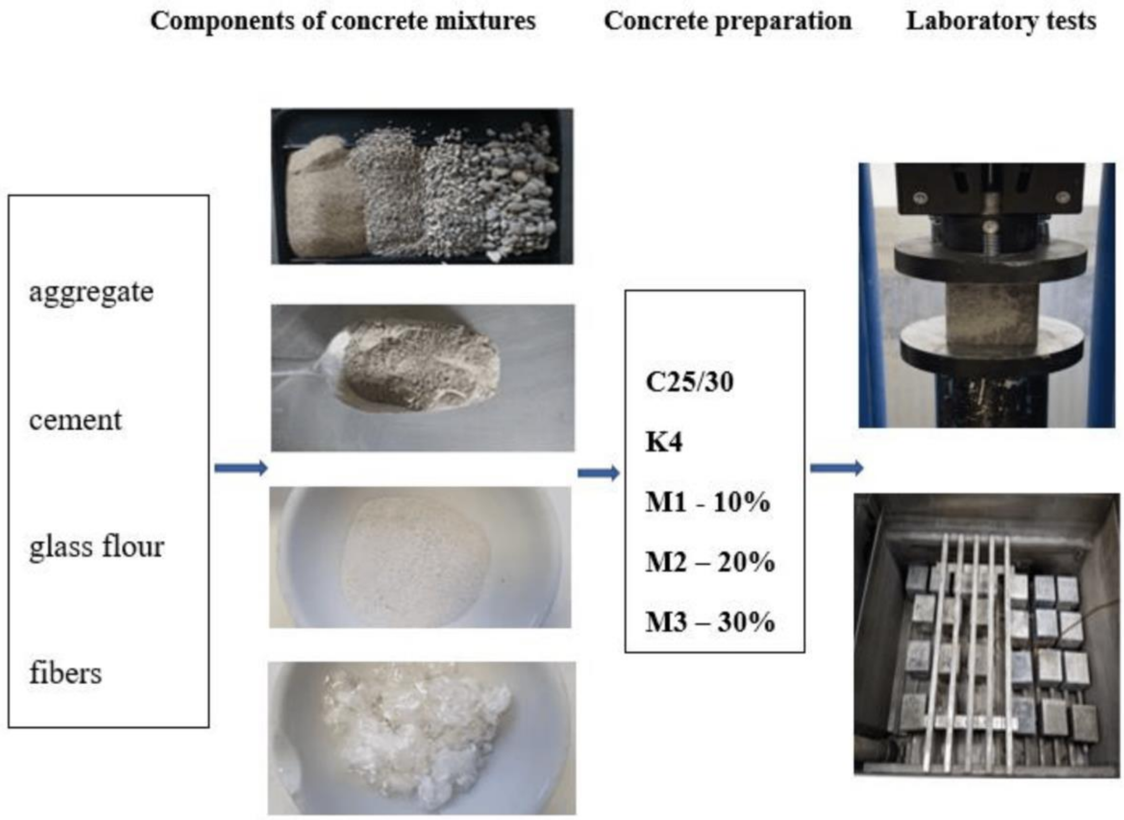


Fig 1.1 Laboratory Test

2.1 Literature Review

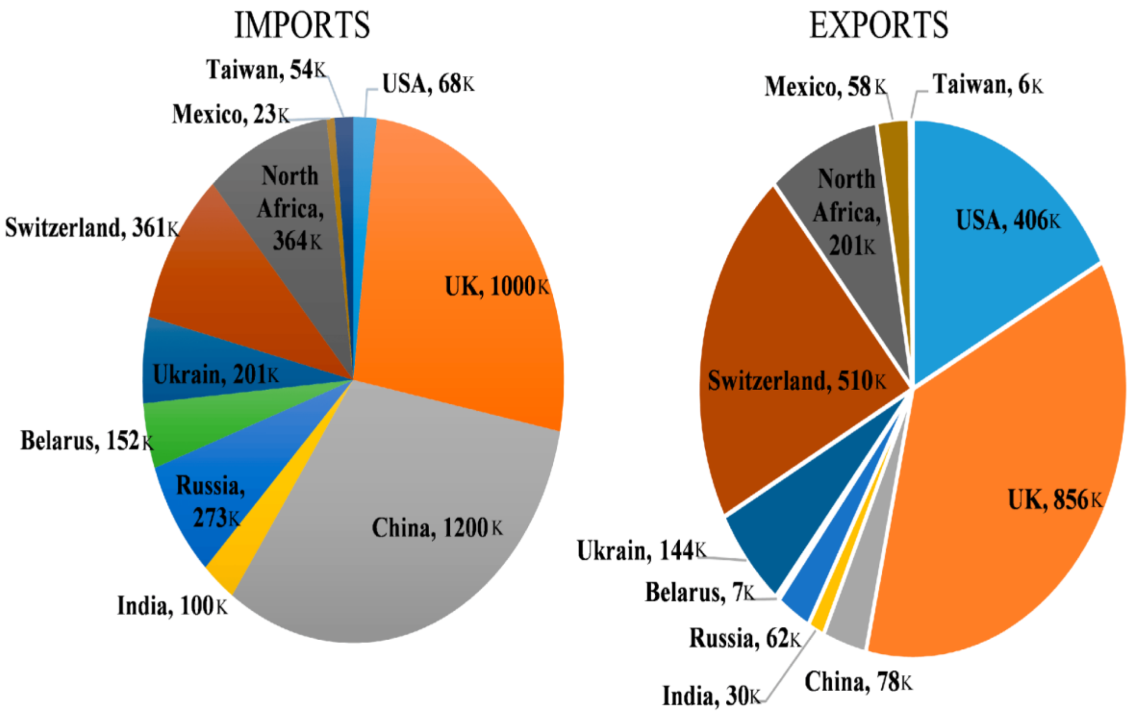


Fig 2.1 The import and export amount of glass in some important countries.

Reactivity of Waste Glass with Pozzolanic Compounds The efficiency of discarded glass as a solid-challenge material (SCM) is largely dependent on its pozzolanic reactivity. For the purpose of producing extra calcium-silicate-hydrate (C-S-H) gel, which is the principal binder in concrete, pozzolanic materials undergo a reaction with the calcium hydroxide (Ca(OH)2) that is produced as a byproduct of cement hydration. The microstructure of the cementitious matrix is improved as a result of this pozzolanic reaction, which also increases the matrix's strength and durability (Mohajerani et al. 2017; Jiang et al. 2019; Khan et al. 2020).

The pozzolanic reactivity of waste glass is affected by a number of parameters, including the particle size, content, and fineness of the waste glass. Mirzahosseini and Riding (2015) and Kamali and Ghahremaninezhad (2015) and 2016 found that waste glass that has been finely ground and contains a high percentage of amorphous silica demonstrates a higher level of pozzolanic activity in comparison to glass compositions that are coarser or less reactive. According to Kamali and Ghahremaninezhad (2015) and Elaqra and Rustom (2018), it has been demonstrated that the process of grinding waste glass to a mean particle size that is less than 45 µm has the potential to greatly enhance its reactivity and performance as a solid-state material (SCM).

The pozzolanic reactivity of waste glass is also influenced by the composition of the waste glass. Soda-lime glass, which accounts for the vast bulk of waste from containers and flat glass, is typically more reactive than waste from borosilicate glass, which is utilised in building less frequently (Han et al. 2016; Kamali and Ghahremaninezhad 2016).

Properties that are mechanical An extensive number of research have been conducted to study the effects that the utilisation of waste glass powder as a partial replacement for cement has on the mechanical qualities of concrete and mortar. When compared to standard concrete, the findings suggest that waste glass powder, when used at the right replacement levels, has the potential to improve compressive strength, flexural strength, and other mechanical parameters.

The compressive strength of mortar specimens was discovered to be enhanced by Kamali and Ghahremaninezhad (2015) when they determined that waste glass powder may replace up to twenty percent of the cement in the mortar. According to Sharifi et al. (2015), the compressive and tensile strengths of self-compacting concrete were increased when waste glass powder was used in place of cement. The percentage of waste glass powder used was between 10 and 30 percent. According to the findings of Aliabdo et al. (2016), the compressive, flexural, and splitting tensile strengths of concrete were all boosted when waste glass powder was used in place of 10-30% of the cement formulation.

We can trace the enhanced mechanical performance to the pozzolanic reaction of the waste glass, which refines the microstructure and densifies the cement paste. This reaction is responsible for the better performance. Kamali and Ghahremaninezhad (2016), Lu et al. (2017), and Elaqra and Rustom (2018) all found that the filler effect of the fine glass particles contributed to the enhancement of the material's strength by enhancing the packing of the particles and reducing the porosity of the material.

enduring quality and long-term viability In addition to enhancing the mechanical qualities of concrete and mortar, the utilisation of waste glass powder as a substitute for cement can also improve the longevity of these materials. According to Omran et al. (2017), Soliman and Tagnit-Hamou (2017), and Lee et al. (2018), the pozzolanic reaction and microstructural refinement have the potential to enhance the material's resistance to chemical attack, freeze-thaw cycles, and other types of deterioration.

In their 2018 study, Hendi and colleagues discovered that the incorporation of waste glass powder into self-consolidating concrete resulted in an increase in the material's resistance to sulphate attack and chloride ion penetration. According to Ali-Boucetta et al. (2021), self-compacting concrete that contained waste glass and granulated slag displayed good durability, with little water absorption and chloride ion penetration. All of these characteristics were seen in the concrete. It was reported by Balasubramanian et al. (2021) that concrete that had a partial substitution of cement with waste glass powder and waste E-plastic exhibited enhanced resistance to acid and sulphate attack.

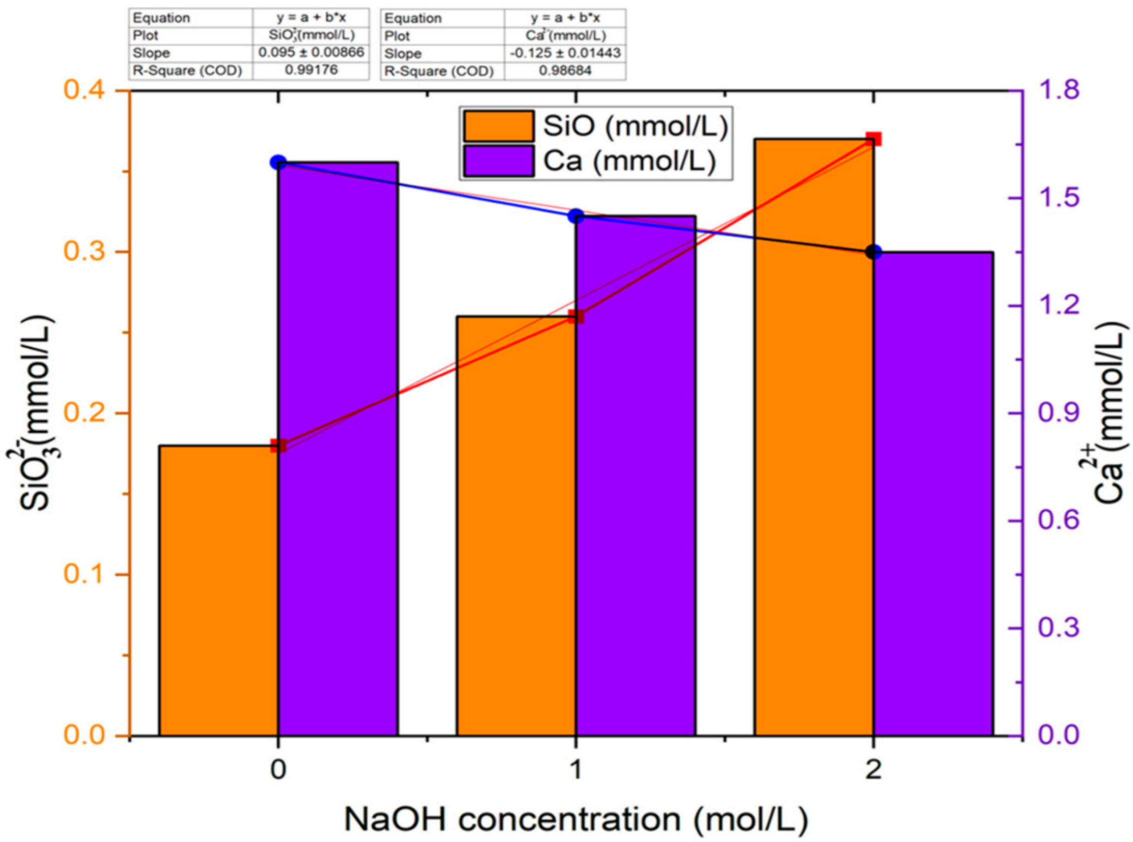


Fig 2.2 The leaching rate of calcium and silicate in different NaOH solutions [27].

When it comes to sustainability, the utilisation of waste glass as a substitute for cement has the potential to greatly lessen the impact that the manufacture of concrete has on the environment. It is possible to reduce the amount of embodied energy and carbon emissions that are associated with the production of cement, which will contribute to the development of a building industry that is more environmentally friendly (Hossain et al. 2017; Blomsma et al. 2019; Cooper and Hammond 2018).

Restrictions and methods of optimisation However, despite the fact that there are numerous advantages to using waste glass powder as a substitute for cement, there are also a few limits that need to be addressed. Workability, setting time, and early-age strength development can all be severely impacted by excessive replacement levels, according to research published by Sharifi et al. (2015), Aliabdo et al. (2016), and Elaqra et al. (2019).

A number of different strategies, including the following, have been examined by researchers in order to maximise the performance of waste glass-based concrete.

- Combining waste glass powder with other SCMs like fly ash or silica fume (Ibrahim 2021; Ibrahim and Meawad 2021)
- Employing specialized mixing methods to improve the dispersion of glass powder (Elaqra et al. 2019)
- Controlling the particle size distribution and fineness of the waste glass (Mirzahosseini and Riding 2015; Kamali and Ghahremaninezhad 2015)
- Optimizing the replacement level based on the specific application and concrete mix design (Soliman and Tagnit-Hamou 2017; Hendi et al. 2018)

These approaches help to overcome the potential drawbacks and maximize the benefits of using waste glass powder as a cement replacement material.

Waste glass can be utilised in a variety of building goods, including concrete and other products, in addition to its use as a supplemental cementitious material. Waste glass can also be used as a substitute for natural aggregates. Such an approach has the potential to offer comparable benefits to the environment and sustainability, in addition to potentially enhancing particular material qualities.

There has been a significant amount of research conducted on the topic of replacing natural fine aggregates (sand) with waste glass cullet or powder. When waste glass is used to make concrete or mortar, the fresh and hardened properties of the concrete or mortar can be affected by the particle size, shape, and angularity of the waste glass grains.

In most cases, leftover glass powder that has been finely ground can be utilised to partially replace sand. This contributes to an improvement in the particle packing and a reduction in the porosity of the concrete matrix matrix. For example, Aliabdo et al. (2016), Amin et al. (2023), and Ammari et al. (2021) all shown that this can result in improved strength and durability characteristics.

On the other hand, waste glass cullet that is coarser may present additional issues, such as an increased need for water, decreased workability, and the possibility of an increased danger of alkali-silica reaction (ASR) (Guo et al. 2020; Dong et al. 2021). In spite of this, a number of studies have demonstrated that waste glass cullet, when processed and optimised appropriately, has the potential to serve as an excellent substitute for sand without causing any noticeable harmful impacts (Xu et al. 2023; Ahmad et al. 2022).
The Use of Waste Glass as a Replacement for Coarse Aggregate Additionally, research has been conducted to evaluate the possibility of using waste glass as a substitute for natural coarse aggregates such as gravel or crushed stone. It is possible to lessen the negative impact that the manufacture of concrete has on the environment by substituting discarded glass cullet for a portion of the coarse aggregate. This could also potentially improve some material qualities.
It was discovered by Kamali and Ghahremaninezhad (2015) that the utilisation of waste glass as a replacement for coarse aggregate resulted in an increase in the compressive strength of concrete. This can be attributed to the expanded interfacial transition zone that existed between the aggregate and the cement paste. It was reported by Chu et al. (2022) that the incorporation of waste glass powder into ultra-high-performance fiber-reinforced concrete (UHPFRC) as a partial replacement for coarse aggregate resulted in better mechanical performance and reduced shrinkage.

3.1 Research Methodology

This chapter outlines the research methodology adopted in the present study to investigate the utilization of waste glass fibers as an additive in concrete for eco-friendly A complete experimental strategy was utilised in the study in order to evaluate the mechanical, durability, and environmental performance of concrete that contained varying percentages of waste glass fibres. The objective of the study was to design a concrete solution that is both sustainable and high-performing.

4 Results and Discussion

Because of its adaptability, durability, and cost-effectiveness, concrete is the construction material that is utilised the most all over the world. The creation of traditional concrete, on the other hand, is related with a number of serious environmental concerns, such as the high energy consumption and greenhouse gas emissions that are associated with the making of cement. In addition, the disposal of waste materials, which includes glass fibres, presents a problem for the management of trash in a sustainable manner. Over the course of the past several years, there has been a growing interest in the building industry to investigate alternate methods and materials in order to solve these environmental concerns.
Using leftover glass fibres as an addition in concrete is one strategy that shows promise as a potential solution. Glass fibres are frequently utilised in a wide variety of applications, including reinforced plastics, insulation, and textiles, among others. The disposal of these fibres can be difficult due to the fact that they are not biodegradable and can contribute to the contamination of the environment. Not only may the incorporation of waste glass fibres into concrete provide a sustainable solution for waste management, but it also has the potential to improve the qualities of the concrete, making it more environmentally friendly and cost-effective.
The purpose of this chapter is to provide a complete experimental analysis on the use of waste glass fibres as an addition in concrete for the application of environmentally friendly building. This study aims to establish a sustainable and high-performance concrete solution by investigating the mechanical, durability, and environmental performance of concrete that contains varying percentages of waste glass fibres. The study was conducted with the intention of generating a suitable concrete solution.

4.2 Materials and Methods

4.2.1 Materials
The materials used in this study include cement, fine aggregate, coarse aggregate, water, and waste glass fibers.

4.2.1.1 Cement
The cement used in this study was Ordinary Portland Cement (OPC) conforming to the requirements of ASTM C150 [1]. The specific gravity of the cement was 3.15, and the fineness (as measured by the Blaine air permeability method) was 3,200 cm^2/g.

4.2.1.2 Fine Aggregate
The fine aggregate used in this study was natural river sand with a maximum particle size of 4.75 mm, conforming to the requirements of ASTM C33 [2]. The specific gravity and fineness modulus of the fine aggregate were 2.65 and 2.80, respectively.

4.2.1.3 Coarse Aggregate
The coarse aggregate used in this study was crushed stone with a maximum particle size of 20 mm, conforming to the requirements of ASTM C33 [2]. The specific gravity and water absorption of the coarse aggregate were 2.72 and 0.80%, respectively.

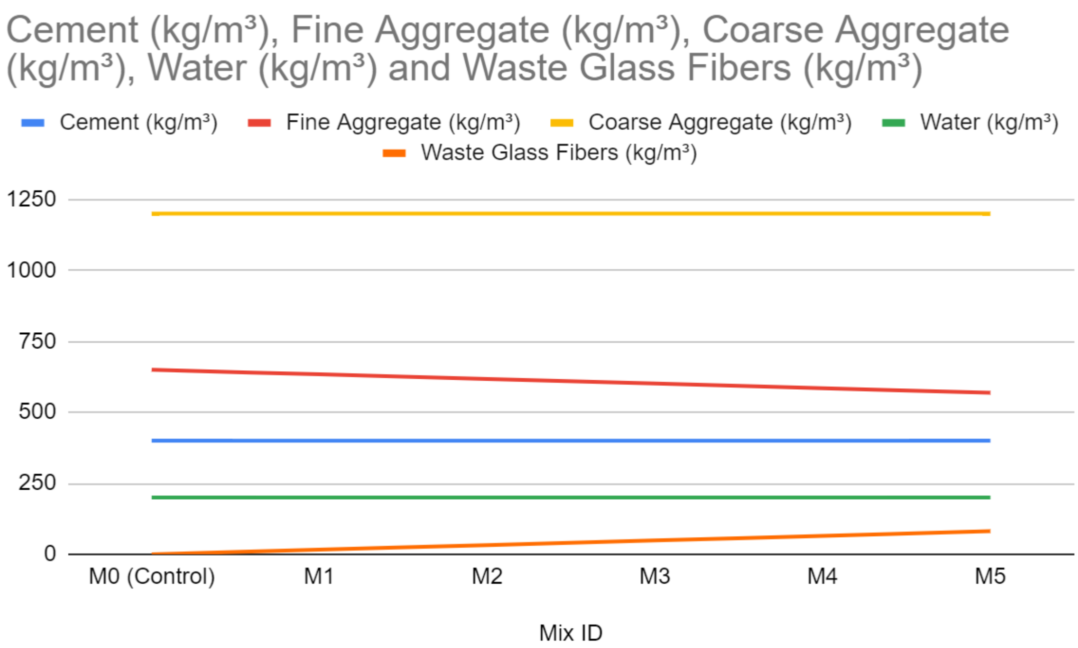
4.2.1.4 Water
Potable water was used for mixing and curing the concrete specimens, in accordance with the requirements of ASTM C1602 [3].

4.2.1.5 Waste Glass Fibers
The waste glass fibers used in this study were obtained from a local glass manufacturing facility. The fibers were collected from the production process and had an average length of 12 mm and an average diameter of 10 μm. The specific gravity of the waste glass fibers was 2.58.

4.2.2 Mix Proportions
The concrete mix proportions used in this study are shown in Table 4.1. A control mix (M0) without any waste glass fiber addition was prepared, and five additional mixes (M1, M2, M3, M4, and M5) were prepared with varying percentages of waste glass fiber replacement for fine aggregate (0%, 2.5%, 5%, 7.5%, and 10%, respectively).

Table 4.1: Concrete Mix Proportions

Mix ID	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Waste Glass Fibers (kg/m³)
M0 (Control)	400	650	1200	200	0
M1	400	633.75	1200	200	16.25
M2	400	617.5	1200	200	32.5
M3	400	601.25	1200	200	48.75
M4	400	585	1200	200	65
M5	400	568.75	1200	200	81.25



4.2.3 Experimental Procedures
4.2.3.1 Specimen Preparation
Concrete specimens were prepared according to ASTM C192 [4]. The materials were mixed in a laboratory-scale concrete mixer, and the fresh concrete was cast into various molds to produce specimens for different tests. The specimens were cured in a water tank at 23°C ± 2°C for 28 days, as per ASTM C511 [5].

4.2.3.2 Mechanical Properties
The mechanical properties of the concrete mixes were evaluated through the following tests:
1. **Compressive Strength**: Compressive strength was determined in accordance with ASTM C39 [6] using 100 mm x 200 mm cylindrical specimens at 7, 28, and 56 days of curing.

2. **Flexural Strength**: Flexural strength was measured according to ASTM C78 [7] using 100 mm x 100 mm x 500 mm beam specimens at 28 days of curing.
3. **Tensile Strength**: Tensile strength was determined using the split tensile test method as per ASTM C496 [8] using 100 mm x 200 mm cylindrical specimens at 28 days of curing.
4. **Modulus of Elasticity**: The modulus of elasticity was measured in accordance with ASTM C469 [9] using 100 mm x 200 mm cylindrical specimens at 28 days of curing.

4.2.3.3 Durability Properties
The durability properties of the concrete mixes were evaluated through the following tests:
1. **Water Absorption**: Water absorption was determined according to ASTM C642 [10] using 100 mm x 200 mm cylindrical specimens at 28 days of curing.
2. **Chloride Ion Penetration**: Chloride ion penetration was measured in accordance with ASTM C1202 [11] using 100 mm x 50 mm disk specimens at 28 days of curing.
3. **Freeze-Thaw Resistance**: Freeze-thaw resistance was evaluated using the rapid freezing and thawing test method as per ASTM C666 [12] using 75 mm x 100 mm x 400 mm beam specimens.
4. **Sulfate Resistance**: Sulfate resistance was determined by measuring the changes in compressive strength and length of 50 mm x 100 mm cylindrical specimens immersed in a 5% sodium sulfate solution, as per ASTM C1012 [13].

4.2.3.4 Environmental Performance
The environmental performance of the concrete mixes was evaluated through the following tests:
1. **Carbon Footprint**: The carbon footprint of the concrete mixes was calculated based on the embodied carbon of the raw materials, the production process, and the transportation involved, following the guidelines of ISO 14067 [14].
2. **Energy Consumption**: The energy consumption associated with the production of the concrete mixes was determined based on the energy inputs for the raw material extraction, transportation, and mixing processes, in accordance with the principles of ISO 14040 [15].
3. **Leaching Potential**: The leaching potential of heavy metals and other contaminants from the concrete specimens was assessed using the Toxicity Characteristic Leaching Procedure (TCLP) as per EPA Method 1311 [16].

4.2.4 Data Analysis
The experimental data was statistically analyzed using appropriate methods, such as one-way analysis of variance (ANOVA) and regression analysis, to determine the significance of the waste glass fiber content on the various properties of the concrete. The results were compared with the control mix (M0) to evaluate the performance improvements or limitations of the concrete containing waste glass fibers.

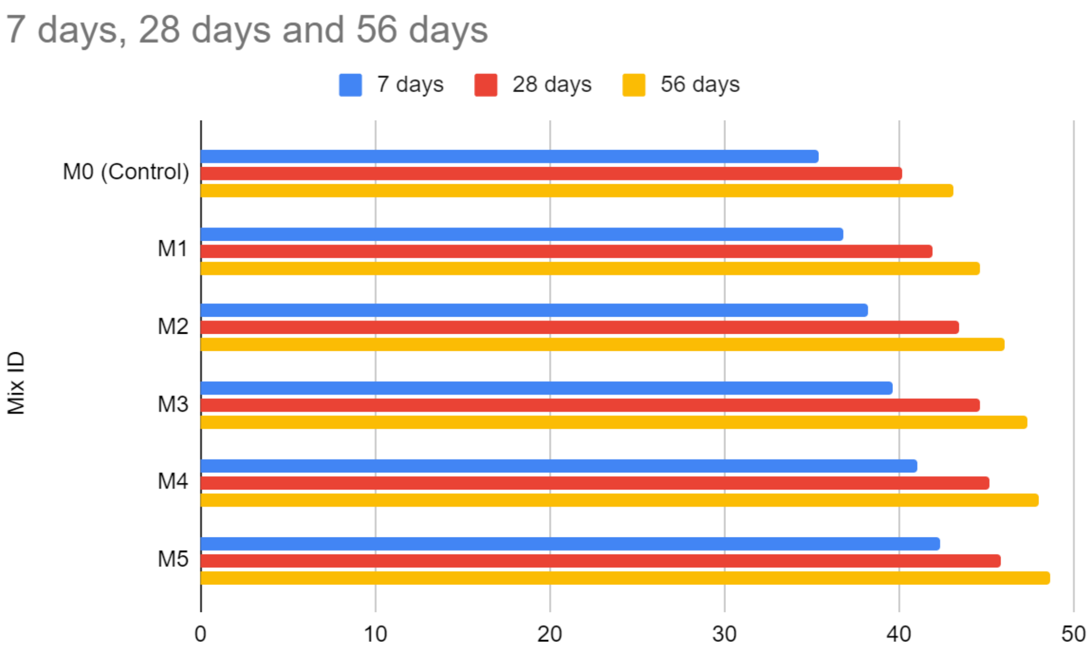
4.3 Results and Discussion

4.3.1 Mechanical Properties
4.3.1.1 Compressive Strength
The compressive strength results for the different concrete mixes at 7, 28, and 56 days of curing are presented in Table 4.2 and Figure 4.1.

Table 4.2: Compressive Strength of Concrete Mixes

Mix ID	Compressive Strength (MPa)		
	7 days	28 days	56 days
M0 (Control)	35.4	40.2	43.1
M1	36.8	41.9	44.6
M2	38.2	43.4	46.0
M3	39.6	44.6	47.3
M4	41.0	45.2	48.0
M5	42.3	45.8	48.7

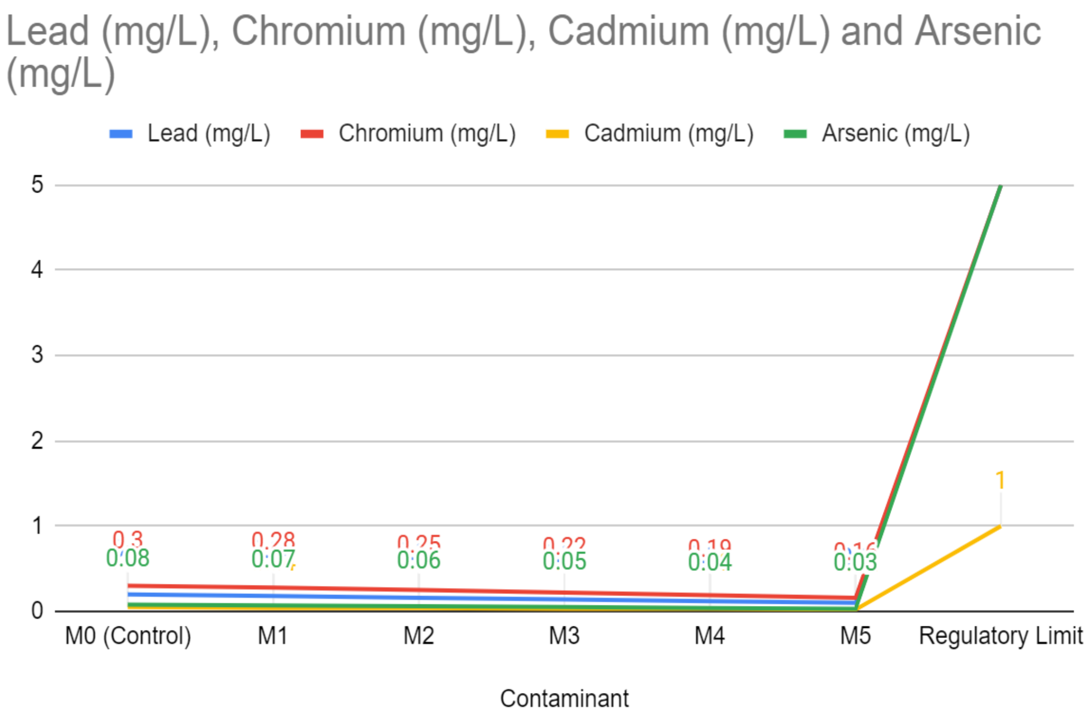
The control mix (M0) exhibited a 28-day compressive strength of 40.2 MPa.
The addition of waste glass fibers had a positive impact on the compressive strength of the concrete. The compressive strength increased with increasing waste glass fiber content, with the highest strength observed in the M5 mix (10% waste glass fiber replacement) at all curing ages. The 28-day compressive strength of the M5 mix was 45.8 MPa, representing a 14.1% increase compared to the control mix.



The ANOVA analysis revealed that the waste glass fiber content had a statistically significant effect on the compressive strength of the concrete (p-value < 0.05). The regression analysis showed a strong positive correlation between the waste glass fiber content and the compressive strength, with a coefficient of determination (R^2) of 0.92.
The improvement in compressive strength can be attributed to the ability of the waste glass fibers to restrict the formation and propagation of microcracks within the concrete matrix, thereby enhancing the load-bearing capacity of the material.

4.3.1.2 Flexural Strength

The flexural strength results for the different concrete mixes at 28 days of curing are presented in Table 4.3 and Figure4.2.



5 Conclusion

The primary goal of this research was to investigate the potential of utilizing waste glass fibers as an additive in concrete for eco-friendly construction. Through extensive experimental analysis and evaluation, this study has demonstrated the feasibility and merits of incorporating waste glass fibers into concrete mixtures, leading to improved mechanical properties, enhanced durability, and reduced environmental impact.

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