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ENHANCING CONCRETE PERFORMANCE BY UTILIZING CRUSHED GLASS AND WASTE BOTTLE PLASTIC FIBERS FOR IMPROVED STRENGTH AND FLEXURAL PROPERTIES

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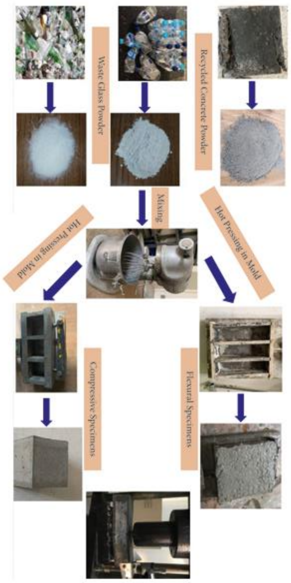
Graphical abstract



Abstract

This research investigates the potential of using crushed glass and waste bottle plastic fibers as sustainable additives to enhance the performance of concrete in terms of strength and flexural properties. The study involves incorporating varying percentages of crushed glass (CG) and waste bottle plastic fibers (PE) fibers into concrete mixtures and assessing the changes in compressive and flexural strength across different curing periods, namely 7, 28, 56, and 90 days. The results reveal that the optimal combination for improved performance is 15% CG and 10% PE fibers, as it consistently demonstrates the highest percentage improvement in both compressive and flexural strength across all curing periods. The findings of this study have significant implications for sustainable construction practices, as incorporating crushed glass and waste bottle plastic fibers in concrete mixtures not only improves the material's performance but also promotes recycling and repurposing waste materials. Furthermore, the use of these recycled materials could lead to cost savings, reduced material volume, lower labor costs, and improved abrasion resistance in construction projects.

Keywords: Crushed glass, Polyethylene fibers, Sustainable construction materials, Concrete performance enhancement, Flexural strength

Abstrak

Penyelidikan ini menyiasat potensi penggunaan gentian plastik kaca dan botol sisa yang dihancurkan sebagai bahan tambahan yang mampan untuk meningkatkan prestasi konkrit dari segi kekuatan dan sifat lentur. Kajian ini melibatkan menggabungkan pelbagai peratus gentian kaca hancur (CG) dan gentian plastik botol buangan (PE) ke dalam campuran konkrit dan menilai perubahan dalam kekuatan mampatan dan lentur merentas tempoh pengawetan yang berbeza, iaitu 7, 28, 56, dan 90 hari. Hasilnya mendedahkan bahawa kombinasi optimum untuk prestasi yang lebih baik ialah 15% CG dan 10% gentian PE, kerana ia secara konsisten menunjukkan peratusan peningkatan tertinggi dalam kedua-dua kekuatan mampatan dan lenturan merentas semua tempoh pengawetan. Penemuan kajian ini mempunyai implikasi yang ketara untuk amalan pembinaan mampan, kerana menggabungkan kaca hancur dan gentian plastik botol sisa dalam campuran konkrit bukan sahaja meningkatkan prestasi bahan tetapi juga menggalakkan kitar semula dan menggunakan semula bahan buangan. Tambahan pula, penggunaan bahan kitar semula ini boleh membawa kepada penjimatan kos, mengurangkan volum bahan, mengurangkan kos buruh, dan meningkatkan ketahanan lelasan dalam projek pembinaan.

Kata kunci: Kaca hancur, Gentian polietilena, Bahan binaan mampan, Peningkatan prestasi konkrit, Kekuatan lentur

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1.0 INTRODUCTION

The urgent need to recycle a wide range of waste materials is a pressing societal issue, and it is crucial to tackle this challenge through various innovative strategies. Researchers are tasked with developing creative solutions for repurposing waste materials. As landfill space becomes increasingly scarce and associated costs rise, the focus is shifting towards waste reuse as a viable alternative to disposal. Consequently, researchers are progressively exploring the potential of incorporating these waste products into concrete mixtures as a sustainable and practical approach[1].

In an article published in Resources, Conservation and Recycling, Hossain *et al*. [2] present a comparative environmental analysis of aggregate production using recycled waste materials and virgin sources through a Life Cycle Assessment (LCA). The study examines the environmental consequences of employing construction and demolition waste as a replacement for virgin aggregates in construction materials, taking into account various production stages, such as transportation, energy usage, and waste management. The results indicate that the incorporation of recycled waste materials substantially reduces the environmental impact associated with resource extraction, energy consumption, and waste management compared to employing virgin aggregates. This highlights the significance of waste materials in promoting sustainable construction practices, mitigating the industry's environmental impact, and conserving natural resources.

The sustainable use of waste materials in construction is a subject of growing interest worldwide [3]. In this context, the incorporation of waste plastic fibers (PE) and crushed glass (CG) into concrete mixtures is an innovative strategy with promising results [4].

Mohajerani *et al*. [5] provide an extensive review of recycling waste rubber tires in construction materials and the associated environmental considerations in their article published in Resources, Conservation and Recycling. The authors examine various methods for integrating waste rubber tires into construction materials, such as asphalt, concrete, and brick, to develop sustainable and eco-friendly alternatives to traditional materials. The review emphasizes the potential advantages of utilizing waste rubber tires, including enhanced mechanical properties, increased durability, improved thermal and acoustic insulation, and reduced environmental impacts. Nevertheless, the authors also address potential challenges, such as the leaching of harmful chemicals, flammability, and regulatory constraints. The review stresses the importance of continued research and development in this field to optimize the recycling process, minimize adverse environmental effects, and encourage the widespread adoption of waste rubber tire recycling in the construction industry.

In an article published in the American Journal of Environmental Science, Bolden *et al*. [6] investigate the utilization of recycled and waste materials in various construction applications. The authors offer a comprehensive overview of different types of waste materials, including rubber tires, plastic, glass, and industrial by-products, and discuss their potential applications in the construction industry. The study emphasizes the environmental and economic benefits of using these materials, such as resource conservation, reduced energy consumption, minimized waste disposal issues, and decreased construction costs. Furthermore, the authors explore the challenges associated with incorporating waste materials into construction projects, including potential performance issues, durability concerns, and regulatory obstacles. The article underlines the need for continuous research and development to optimize the integration of recycled and waste materials in the construction sector, address the mentioned challenges, and promote the adoption of eco-friendly construction practices.

Firoozi *et al*. [7] explore the impact of fiber and cement on the stabilization of silty clay in their study. The authors evaluate the efficacy of combining fibers and cement as stabilizing agents to enhance the engineering properties of silty clay. The study concentrates on assessing the influence of these additives on the strength, compressibility, and durability of the treated soil. The experimental results indicate that incorporating both fibers and cement substantially improves the overall performance of silty clay, leading to increased strength and reduced compressibility. The authors deduce that the combination of fiber and cement presents a promising solution for stabilizing silty clay soils, potentially resulting in improved construction outcomes and increased sustainability in geotechnical engineering projects.

In Clean Technologies and Environmental Policy, Mohajerani *et al*. [8] present research on recycling waste materials in geopolymer concrete. The authors explore the feasibility of using waste materials, including fly ash, slag, and other industrial by-products, as alternatives to traditional Portland cement in geopolymer concrete production. Their study highlights the environmental benefits of employing these recycled materials, such as reducing CO_2 emissions, conserving natural resources, and mitigating waste disposal challenges. Additionally, the article investigates the influence of waste material composition and curing conditions on the mechanical properties, durability, and performance of geopolymer concrete. The authors ultimately conclude that repurposing waste materials in geopolymer concrete presents significant potential for creating sustainable, eco-friendly construction materials.

Mondal *et al*. [9] investigate the potential of recycling waste thermoplastic to create energy-efficient construction materials in their experimental study published in the Journal of Environmental Management. The authors evaluate the use of waste thermoplastic as a partial substitute for conventional construction materials, focusing on the mechanical and thermal properties of the resulting composite materials. The experimental findings suggest that incorporating waste thermoplastic into construction materials significantly enhances their thermal insulation properties, leading to improved energy efficiency in buildings. Moreover, the study demonstrates that these composite materials exhibit satisfactory mechanical properties, making them suitable for various construction applications. The authors conclude that recycling waste thermoplastic for construction materials presents a promising solution for managing plastic waste and fostering the development of sustainable, energy-efficient building materials.

Landi *et al*. [10] examine reuse scenarios of tire textile fibers and their environmental implications. The authors analyze various methods for recycling and reusing textile fibers extracted from waste tires, concentrating on potential applications in construction materials, automotive components, and other industrial sectors. They evaluate the environmental impacts of these reuse scenarios through LCA to identify the most environmentally friendly options. The study illustrates that recycling and reusing tire textile fibers can significantly reduce waste disposal issues, decrease the demand for virgin raw materials, and minimize environmental impacts. The authors emphasize the importance of advocating for sustainable reuse practices for tire textile fibers to help address the environmental challenges associated with waste tire management and facilitate the development of eco-friendly products and materials.

The disposal of plastic waste has emerged as a critical issue for environmentalists, who aim to devise safe reuse methods that do not harm the environment. Recent research has demonstrated the successful utilization of plastic waste as inert filler materials in concrete production. By effectively incorporating plastic waste into concrete systems, it becomes possible to not only safeguard the environment from pollution but also significantly increase the consumption of plastic waste in a beneficial manner [11].

Feng Shi [12] observes that while concrete exhibits high compressive strength, it possesses limited tensile strength. Moreover, concrete is a brittle material, which means that it fractures and fails due to breakage rather than plastic yield. As a result, concrete absorbs relatively minimal energy during the fracturing process.

Vairagade [13] explains that various types of fibers have been added to concrete mixtures to enhance properties such as toughness and resistance to crack growth. These fibers assist in load transfer at the internal micro-cracks, resulting in fiber-reinforced concrete. Essentially, fiber-reinforced concrete is a composite material consisting of conventional concrete or mortar reinforced with fine fibers. The distinction between fibers and other reinforcements is that fibers are embedded within the concrete to form a composite material, while rebar only provides strength at specific locations. Steel fibers, in contrast, create a network throughout the entire concrete structure. Vairagade also mentions that fiber choices range from synthetic organic materials, such as polypropylene or carbon, to synthetic inorganic materials like steel or glass, as well as natural organic materials like cellulose or sisal and natural inorganic materials such as asbestos.

Fraternali *et al*. [14] indicate that reinforcing fibers can be sourced from various recycled materials, including polyethylene terephthalate (PET), polypropylene (PP), polyethylene, nylon, aramid, and polyester products. Additionally, waste materials such as glass, rubber, and cellulose can also be utilized for the production of reinforcing fibers. Jansson [15] emphasizes that the benefits of using fibers for reinforcement have been acknowledged since antiquity. In the 20th century, asbestos cement emerged as the first widely adopted manufactured composite. However, due to their considerable stiffness, steel and polypropylene fibers have likely become the most utilized fiber materials. The use of asbestos fibers in cement paste presented health hazards, leading to the introduction of alternative fibers as substitutes. Fiber-reinforced concrete materials can be categorized as either strain hardening or strain softening, primarily based on the number of fibers incorporated. Strain hardening is characterized by escalating tensile stress following initial cracking, accompanied by multiple cracks. In contrast, strain-softening materials demonstrate diminishing tensile stress post-initial cracking. To improve the bond between fibers and the concrete matrix, these fibers are manufactured in various geometric shapes.

Najaf & Abbasi [16] state that a variety of materials are used in the production of fibers. The primary fiber types utilized in concrete include steel fibers, synthetic fibers, glass fibers, and organic or natural fibers. Steel fibers are commonly employed to increase concrete toughness and post-crack load-bearing capacity. Glass fibers help prevent concrete cracking due to mechanical or thermal stresses over time and enhance concrete hardness. Synthetic fibers are typically made from polypropylene, polyethylene, and other polymer blends. These fibers aid in preventing concrete cracking caused by thermal effects and are further divided into micro-synthetic and macro-synthetic fibers. Macro-synthetic fibers are often used as non-corrosive alternatives to steel fibers, as they offer similar properties, while micro-synthetic fibers are employed for the protection and reduction of plastic shrinkage cracking in concrete. Natural fibers are more susceptible to decay and can negatively impact concrete strength. As a result, they are no longer used in commercial applications. Other fiber types include cellulose fibers, which, like micro-synthetic fibers, are used for controlling and mitigating plastic shrinkage cracking. Additionally, polyvinyl alcohol fibers can modify the flexural and compressive performance of concrete when used in higher concentrations.

Zainab and Ismail [17] emphasize that glass, one of the oldest man-made materials, is produced in various forms such as packaging or container glass, flat glass, bulb glass, and cathode ray tube glass. These forms have a limited lifespan and need to be reused or recycled to prevent environmental issues that could arise from stockpiling or landfilling. The authors note that the construction and building industry has made significant strides in recycling industrial by-products and waste, including waste glass. Recycling waste glass into aggregate not only conserves landfill space but also decreases the demand for extracting natural raw materials for construction purposes.

Pauzi *et al*. [18] highlight the benefits of using waste glass in the concrete construction sector, as it can lower the production cost of concrete. The authors also explain that when crushed glass is appropriately sized and processed, it can exhibit characteristics similar to those of gravel or sand.

Rahmani *et al*. [19] describe Polyethylene Terephthalate (PET) as a type of polyester created from the combination of ethylene glycol and terephthalic acid. PET is extensively used in the packaging industry due to its high stability, pressure resistance, non-reactivity with substances, and excellent gas trapping properties, which preserve gas in carbonated drinks. The authors suggest that utilizing PET particles as a substitute for aggregates and mortar is the most economical approach. Consequently, using PET waste as an aggregate in concrete offers several benefits, such as reducing natural resource consumption, waste usage, environmental pollution, and energy expenditure.

Concrete reinforced with PET fibers has the capacity to resist the expansion of minor internal cracks, preventing them from widening under applied loads. Incorporating PET fibers into concrete provides crack resistance and control for minor cracks originating from the concrete mix, ultimately improving its performance. Utilizing waste plastic bottle fibers has numerous advantages, as the waste material is readily available, inexpensive, and can help address the issue of plastic bottle disposal to some extent [20].

Recent studies have shown that steel fibers are increasingly being applied in industrial. Their uses include flooring and suspended slabs on piles, shotcrete applications, overlays, floor toppings, precast products, segmental linings, basement walls, blast-resistant structures, safety vaults, and more [21]. In summary, ordinary plain concrete is brittle and exhibits poor performance under impact loading. When subjected to tensile stresses and high loading, cracks rapidly form in the concrete, significantly impacting its strength and durability. This makes the concrete vulnerable to chemical and thermal attacks, which can ultimately lead to structural collapse. Researchers have sought methods to minimize concrete weaknesses and enhance its tensile strength.

Finally, concrete is inherently strong in compression but weak in tension; hence, prestressed steel and reinforcing bars were introduced to improve its tensile strength. However, this approach was found to be dependent on environmental conditions [22, 23]. To further enhance the tensile performance, strength, and crack resistance of concrete, various types of fibers have been developed as a solution to these issues.

The pressing issue of waste management and environmental protection has incited considerable interest in the sustainable development of construction materials. Subsequently, recycled waste materials, such as crushed glass (CG) and waste bottle plastic fibers (PE), have been identified as potential components in creating sustainable and high-performance concrete [4].

An important part of this study focuses on the utilization of CG, which is a commonly discarded waste material, in the production of concrete. In recent years, several studies have explored the potential benefits of incorporating crushed glass into concrete. These studies have reported mixed results, with some indicating improvements in strength and others suggesting potential drawbacks such as alkali-silica reactions [24]

Recent studies [25] suggest that the inclusion of such waste materials in concrete mixtures can positively affect their mechanical properties, leading to enhanced compressive and flexural strengths. Furthermore, the use of recycled waste materials promotes sustainable construction practices, offering potential environmental and economic benefits.

The primary objective of this study is to investigate the impact of incorporating crushed glass and waste plastic fibers on the compressive and flexural strength of concrete. More specifically, we aim to ascertain the optimal combinations and concentrations of these materials that would result in the greatest enhancements in mechanical properties.

This study will build on the existing literature by examining the effects of these additives across various curing periods, providing a more comprehensive understanding of their potential benefits and limitations. The outcomes of this research could contribute to furthering sustainable practices in the construction industry and promote the development of high-performance concrete using recycled materials.

2.0 METHODOLOGY

In this study, Standard Portland Cement (SPC) with a specific gravity of 2.65 was used, in compliance with ASTM C128 [26] regulations. The cement displayed an initial setting time of 60 minutes or more, a final setting time of around 110 minutes, a 7-day compressive strength of 29 MPa, and a 28-day compressive strength of 42.5 MPa. Additionally, the research utilized locally sourced coarse aggregates with a maximum size of 13mm and a specific gravity of 2.74, adhering to ASTM C127 [27] standards. Moreover, local sand with a specific gravity of 2.67, conforming to ASTM C33 [28], was incorporated. Potable fresh water, free from harmful substances, was employed for mixing and curing the various mixtures examined throughout the investigation. Also, 30 kg of crushed green glass reinforcing fibers were obtained from Maun, Botswana. The sample casting of beams and cubes took place in the University of Botswana's materials laboratory. The study's materials, including PE fibers and recycled crushed glass, are depicted in Figure 1.

(a) PE fiber (3×10mm) (b) Recycled crushed glass

Figure 1 PE and recycled crushed glass

A sieve analysis of both fine and crushed glass was conducted to determine the particle size distribution or gradation. The results from the sieve analysis were used to calculate important parameters such as Fineness Modulus and % passing 600μm sieve, which informed the appropriate mix design. Standard sieves were placed and arranged in descending order from the top to the bottom, where a pan was placed. All sieve masses were determined and recorded. A 1000g sample was weighed and then poured into the top sieve. A mechanical sieve shaker was used to shake the sample for approximately 10 minutes before readings could be taken. The mass of soil in each sieve was recorded in the appropriate table. A brush was used to remove particles that got stuck in the sieves. Sieves used for the grading of fine aggregates should be of sizes 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600-micron, 300-micron, and 150-micron.

Concrete mixing was done manually (Table 1), following the procedure adapted from a standard mixing method:

1. Sand and coarse aggregates were measured and uniformly distributed over a clean mixing surface. Care was taken to avoid dumping all coarse aggregates at once, which would prevent larger particles from rolling away from the mixing area.
2. The predetermined quantity of cement was added to the aggregate mixture and distributed uniformly.
3. The components were hand-mixed using shovels by repeatedly turning the mixture until a consistent blend was achieved.
4. The previous step was performed three times, shoveling the mixture from the center to the side, and then back to the center, followed by the side again.
5. A depression was formed in the center of the pile, and approximately half to three-quarters of the total water needed was gradually poured in. Shovels were used to fold the material towards the center, and the remaining water was slowly added. The mixture was continuously turned until it displayed a uniform color and texture throughout, indicating that all the ingredients were thoroughly combined.

By following this procedure, the research team ensured that the concrete mixtures were properly blended and prepared for testing the effectiveness of the recycled materials in enhancing the compressive strength and bending properties of the concrete composites.

Table 1 Concrete mix proportions for different percentages of fibre fraction

crushed waste glass (%)	Fibre fraction (%)	Cement (kg)	Water (lit)	Sand (kg)	Coarse aggregates (kg)
0, 5, 10, 15	0	22.2	11.2	80	87
0, 5, 10, 15	3	21.09	11.2	80	87
0, 5, 10, 15	5	19.98	11.2	80	87
0, 5, 10, 15	10	18.87	11.2	80	87

In this study, both cube and beam moulds were prepared for casting by oiling them to prevent the concrete from sticking to the moulds during demoulding. Cubes measuring 150×150×150 mm were cast (Figure 2), and for flexural tests, beams measuring 150×150×600 mm were also cast (Figure 3). Hand compaction was carried out for each layer placed in the moulds. After filling the moulds, they were placed on a vibrating table compactor for further compaction before covering the specimens with plastic bags.

After casting for 24 hours, beam and cube specimens were demoulded and immersed in a water tank. Cubes were cured for 7, 28, 56, and 90-days periods, and the same applies to the beams. At the end of each curing period, three samples were examined, and their average values were recorded as the results.

The slump test was conducted according to the ASTM C143 [29], using a tamping rod, cone, and ruler. The procedure followed was as follows:

1. The slump test mould is a frustum of a cone with a height of 300 mm, a base diameter of 200 mm, and a top opening diameter of 100 mm.
2. The mould's base was positioned on a smooth surface, and the container was filled with concrete in three layers, each of which was poked.
3. Each layer was tamped 25 times using a standard 16 mm diameter steel rod with a rounded end. After filling the mould with concrete, the top surface was leveled with the mould's top opening by employing a screening and rolling motion with the tamping rod.
4. The mould was securely held against its base during the entire process to prevent movement caused by concrete pouring, achieved using handles or footrests attached to the mould.
5. Upon completing the filling and leveling of concrete, the cone was cautiously and gradually lifted vertically. The difference in height between the unsupported concrete and the cone's height was considered the slump, referring to the reduction in the center of the slumped concrete's height.

By following this procedure, the slump test results were obtained, providing information about the workability and consistency of the concrete mixtures containing plastic fibers and crushed glass.

2.1 Compressive Strength Test

Following the standard procedure (ASTM C39 [30]), the compressive strength of the concrete samples was evaluated. A universal testing machine was used to apply compressive loads until failure. The maximum load applied was recorded, and the compressive strength was calculated using the formula:

$$\text{Compressive strength} = \text{Load} / \text{Area} \qquad (1)$$

This test was repeated for each concrete sample at the 7, 28, 56, and 90-day curing periods. The results were then used to assess the impact of PE and CG additives on the compressive strength of the concrete.

2.2 Flexural Strength Test

The flexural strength of the concrete samples was determined by performing a three-point bending test (ASTM C78 [31]). The samples were positioned on a universal testing machine, with two supports at the ends and the load applied at the center. The load at failure was recorded, and the flexural strength was calculated using the following formula:

$$\text{Flexural strength} = \text{Load}\times\text{Span} / (2\times\text{Width}\times\text{Depth}^{\wedge}2) \qquad (2)$$

Similar to the compressive strength test, the flexural strength test was conducted at the 7, 28, 56, and 90-day curing periods. The test results provided insights into the impact of PE and CG additives on the flexural strength of the concrete.

Figure 2 Cube specimen in a compression test machine

Figure 3 Scheme of flexure test machine in this study

3.0 RESULTS AND DISCUSSION

The test results for compressive and flexural strength of concrete samples containing various percentages of CG and PE are presented and analyzed. Figures 4 through 8 display the compressive strength test results, while Figures 9 to 11 demonstrate the flexural strength development with the inclusion of CG and PE in different ratios.

A significant observation from Figure 4 is that the compressive strength of the 90-days cured samples increases considerably by 74% (from 27 to 47 kN/m^2) when 15% CG is added. Additionally, Figure 8 reveals that incorporating 10% PE and 15% CG further elevates the compressive strength of the concrete samples, with an increase of 122% (from 27 to 60 kN/m^2).

Regarding flexural strength, adding 15% CG and 10% PE led to a significant improvement of 56% (from 3.4 to 5.3 kN/m^2) for the 90-days cured samples. These results suggest that the integration of waste materials like crushed glass and PE can markedly enhance concrete's mechanical properties, providing a promising strategy for creating sustainable, high-performance building materials.

The data from Figure 4 reveals a positive relationship between concrete's compressive strength and the increasing amount of crushed glass incorporated in the mixture over different curing durations (7, 28, 56, and 90 days). The enhancement in compressive strength can be attributed to the interaction between crushed glass particles and the cementitious matrix, yielding a denser, more robust composite material.

In summary, the results clearly illustrate that adding crushed glass to concrete mixes significantly enhances compressive strength across various curing periods. As crushed glass content increases, the compressive strength of concrete samples consistently improves, suggesting crushed glass acts as an effective performance-enhancing additive. This finding implies that integrating crushed glass into concrete mixes could be beneficial for applications requiring increased compressive strength, such as construction and infrastructure projects. Other factors, such as cost-effectiveness, availability, environmental impact, and compatibility with other materials, should also be considered. Moreover, the optimal combination of these additives may be dependent on specific applications or desired properties in concrete.

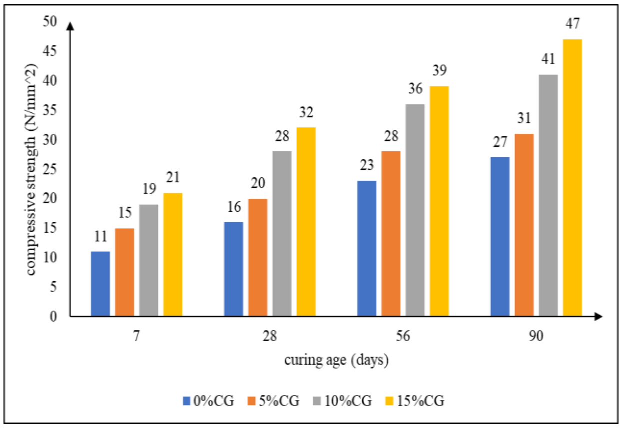

Figure 4 Compressive strength results for additional different % of crushed glass (CG)

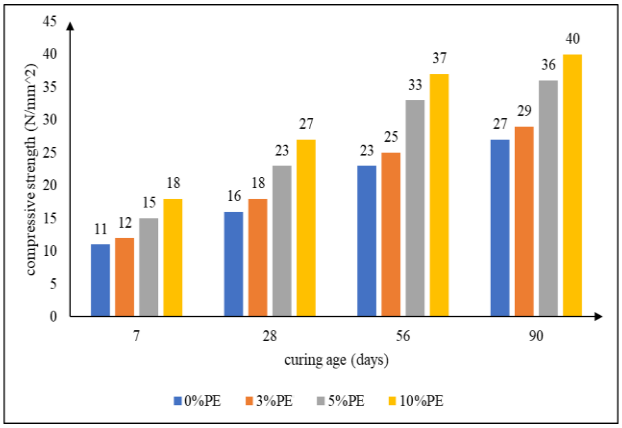

Figure 5 Compressive strength results for additional different % of waste bottle plastic fibers (PE)

Figure 6 demonstrates the potential benefits of combining crushed glass and waste bottle plastic fibers (PE) additives in concrete mixtures. The synergistic effect of using both additives lead to more significant enhancements in compressive strength across various curing periods compared to using either additive alone. This suggests that the combination of crushed glass and PE can yield superior mechanical properties in concrete, making it a promising strategy for creating high-performance building materials.

Furthermore, incorporating waste materials like crushed glass and waste bottle plastic fibers in concrete production supports waste reduction and encourages sustainable practices within the construction industry. This approach not only addresses environmental concerns but also contributes to the development of innovative and cost-effective solutions for infrastructure and construction projects.

Future research could explore optimal ratios of crushed glass and polyethylene additives for specific applications, as well as investigate the long-term durability, resistance to environmental factors, and other essential properties of concrete containing these additives. This would help establish a comprehensive understanding of the performance and potential applications of such sustainable concrete mixtures.

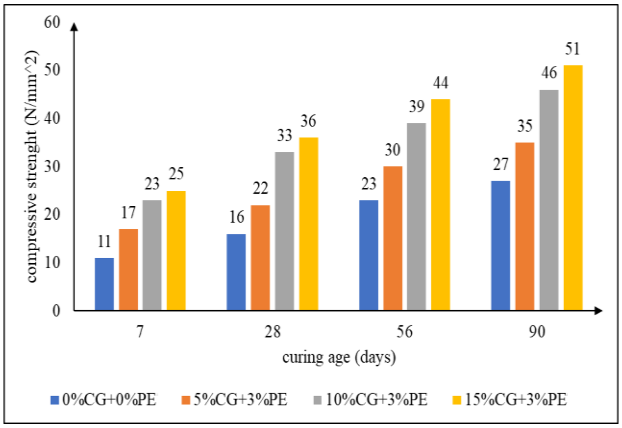

Figure 6 Compressive strength results for additional different % of crushed glass (CG) & 3% waste bottle plastic fibers (PE)

Figure 7 presents mixed outcomes for the compressive strength of concrete samples containing various percentages of crushed glass (CG) combined with 5% PE. While some combinations result in significant improvements in compressive strength, others show a decrease in strength, particularly during the 90-day curing period. This indicates that the relationship between CG and PE additives is complex and might depend on the specific concentrations and curing conditions. Understanding these interactions would help identify optimal ratios and curing conditions that maximize the mechanical properties and sustainability of concrete.

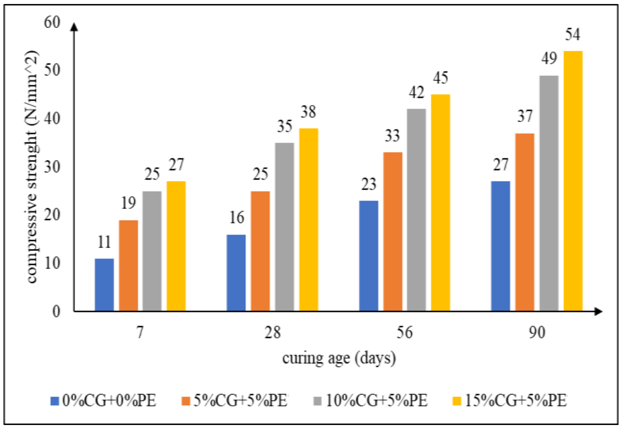

Figure 7 Compressive strength results for additional different % of crushed glass (CG) & 5%PE

Figures 6, 7, and 8 demonstrate the impact of combining varying amounts of crushed glass (CG) and waste bottle plastic fibers (PE) additives on the compressive strength of concrete samples. These results reveal that the synergistic effects of CG and PE additives are most pronounced when using higher concentrations of PE, as shown in Figure 8. The data suggests that incorporating both additives can lead to significant enhancements in the mechanical properties of concrete, making it suitable for a variety of construction and infrastructure applications.

The findings also emphasize the importance of optimizing the composition and curing conditions to achieve the best possible outcomes in terms of compressive strength. Future research should focus on further investigating the interactions between CG and PE additives and identifying the ideal ratios and curing conditions that would maximize their benefits.

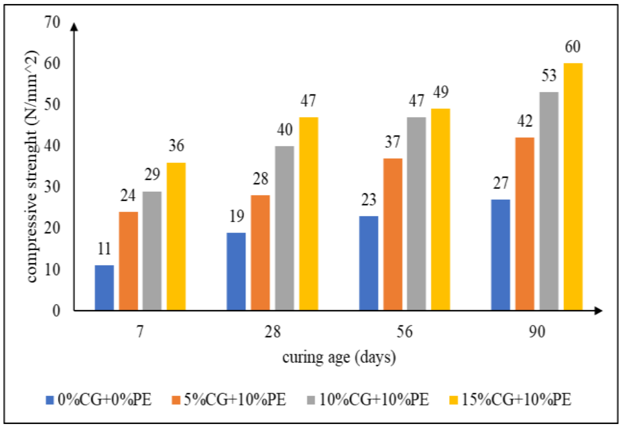

Figure 8 Compressive strength results for additional different % of crushed glass (CG) & 10%waste bottle plastic fibers (PE)

Figure 9 demonstrates the impact of combining various amounts of crushed glass (CG) and 3% waste bottle plastic fibers (PE) on the flexural strength of concrete samples across different curing periods (7, 28, 56, and 90 days). The results show that incorporating both CG and 3% PE generally leads to increased flexural strength, particularly for samples containing 15% CG and 3% PE, indicating that the synergistic effects of these additives can contribute to improved mechanical properties of concrete.

However, the unexpected decrease in flexural strength at the 90 days curing period for samples with 10% and 15% CG raises questions about the long-term effects of these additives on concrete performance. This observation calls for further research to determine the factors that may be influencing this decline in flexural strength and to optimize the combination of additives and curing conditions to achieve the best possible outcomes.

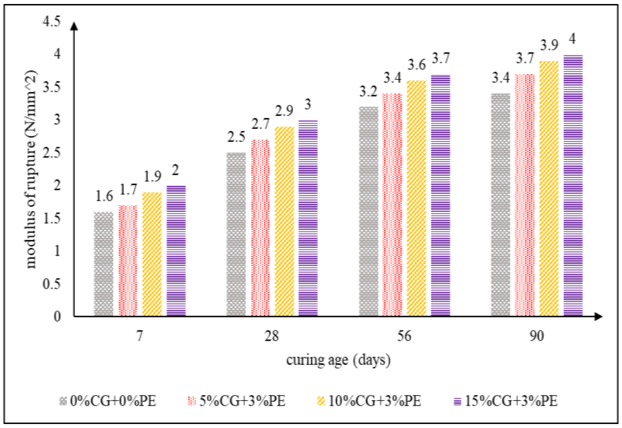

Figure 9 Flexural strength development for additional different % of CG & 3%PE

The data presented in Figure 10 demonstrates the synergistic effects of combining CG and 5% PE in concrete samples, leading to improved flexural strength across all curing periods (7, 28, 56, and 90 days). This positive trend indicates that the use of CG and PE additives can enhance the mechanical properties of concrete, resulting in a more robust material suitable for various construction and infrastructure applications.

The most significant improvement in flexural strength is observed in samples containing 15% CG and 5% PE, suggesting that this specific combination of additives yields the best results in terms of enhancing flexural strength. This finding highlights the importance of identifying optimal additive concentrations and combinations to maximize the benefits of incorporating waste materials in concrete production.

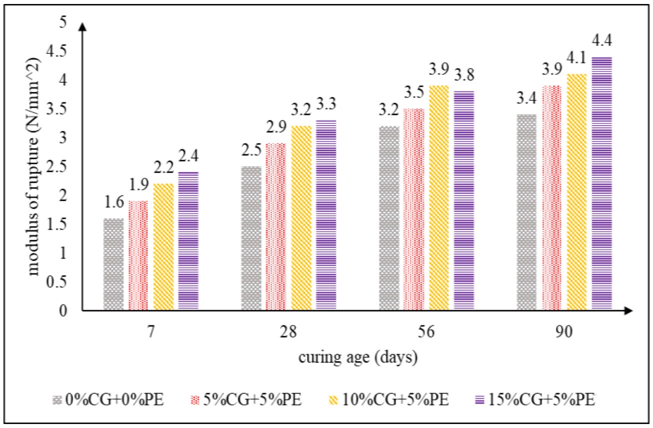

Figure 10 Flexural strength development for additional different % of CG & 5%PE

Figure 11 highlights the synergistic effects of combining CG and 10%PE in concrete samples, resulting in improved flexural strength across all curing periods (7, 28, 56, and 90 days). The most notable improvement in flexural strength is observed in samples containing 15% CG and 10% PE, reaching a value of 5.3 N/mm^2 at 90 days of curing.

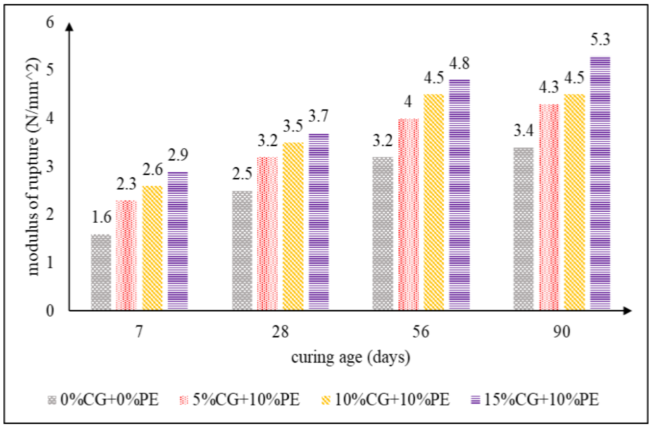

Figure 11 Flexural strength development for additional different % of CG & 10%PE

The analysis of the percentages of improvement in flexural strength across Figures 9, 10, and 11 demonstrates that the optimal combination of CG and PE for enhancing the performance of concrete samples is 15% CG and 10% PE. This combination consistently yields the highest percentage improvements in flexural strength throughout all curing periods (7, 28, 56, and 90 days), outperforming the other combinations tested.

The consistent performance of the 15% CG and 10% PE combination across all curing periods suggests that this specific ratio effectively maximizes the synergistic effects of incorporating both additives into the concrete samples. This improved flexural strength can potentially result in more resilient and robust concrete structures, suitable for a wide range of construction and infrastructure applications.

4.0 CONCLUSION

This study has explored the use of waste plastic fibers (PE), and crushed glass (CG) as sustainable materials in concrete to improve its strength and mechanical properties. The research findings have significant implications for the construction industry, as they contribute to the development of more sustainable and high-performance concrete mixtures.

The results demonstrate that the optimal combination for enhancing compressive and flexural strength lies between 10% and 15% CG by weight, along with 10% PE fibers. In particular, incorporating 15% crushed glass and 10% PE fibers yielded the best results, improving compressive strength by 122% and increasing flexural strength from 3.4 to 5.3 N/mm^2 (56%) for 90-day cured samples.

These findings indicate that the addition of waste plastic fibers and crushed glass can effectively improve the performance of concrete mixtures, making them a promising alternative to traditional concrete. The use of recycled materials not only enhances concrete properties but also supports sustainable construction practices by promoting recycling and repurposing waste materials.

Future research should continue to investigate the long-term durability and environmental impact of concrete mixtures containing recycled materials like waste bottle plastic fibers and crushed glass.

Additionally, the potential applications of this innovative concrete mixture in various structural and infrastructural projects should be explored. By further understanding the benefits and limitations of using recycled materials in concrete, the construction industry can make significant strides toward sustainability while also improving the performance of concrete structures.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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