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Research Article

SUSTAINABLE ENHANCEMENT OF GEOPOLYMER CONCRETE DURABILITY USING RECYCLED PLASTIC WASTE ADDITIVES

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ABSTRACT

This study investigates the potential of incorporating recycled plastic waste as an additive in geopolymer concrete to enhance its durability and sustainability. Key performance indicators—compressive strength, abrasion resistance, and water permeability—were evaluated for concrete mixes with varying proportions of plastic waste. Results indicate that the inclusion of recycled plastic significantly improves all tested properties compared to the control mix. Enhanced compressive strength, reduced mass loss due to abrasion, and lower permeability levels were consistently observed in the modified samples. These improvements highlight the potential of waste plastic to increase the mechanical and durability performance of geopolymer concrete, while simultaneously offering an environmentally responsible solution for plastic waste management. This research contributes to the advancement of sustainable construction practices by promoting circular material use and reducing reliance on conventional cementitious binders. Further studies are recommended to determine the optimal plastic dosage, evaluate long-term performance, and assess the economic viability of scaling this approach in real-world applications.

1. INTRODUCTION

1.1 CONTEXT AND RATIONALE FOR THE STUDY

The use of geopolymer materials in place of Portland cement in concrete shows great promise. The use of industrial byproducts like fly ash or slag in its production helps minimise the need for regular cement and promotes green building. Geopolymer concrete has been getting a lot of attention lately because of its potential to lessen the impact of buildings on the environment and increase their longevity[1–3]. Geopolymer concrete has many benefits, but there are still issues with its durability that need to be worked out. The total

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performance and service life of geopolymer concrete constructions may be affected by factors including cracking, abrasion resistance, and permeability. To assure its broad usage in construction, research is focused on increasing the durability of geopolymer concrete[4–7].

1.2 STATEMENT OF THE PROBLEM AND RESEARCH GOALS

The primary focus of this study is on finding ways to increase the longevity of geopolymer concrete. The goal of this research is to learn more about whether or not adding recycled plastic to geopolymer concrete may help it live longer. Among the goals of the study are:

- Analysing how recycled plastics affect geopolymer concrete's strength.
- Investigating how using recycled plastics in geopolymer concrete affects its wear and tear resistance.
- Studying how waste plastic additions influence geopolymer concrete's permeability and fracture resistance.
- Considering the financial and ecological benefits of using recycled plastic as an ingredient in geopolymer concrete.

1.3 CHARACTERISTICS AND EXAMPLES OF GEOPOLYMER CONCRETE

Instead of traditional Portland cement, geopolymer concrete uses a geopolymeric binder system. Alkaline activators like sodium hydroxide or potassium hydroxide and alumina and silica-rich source materials like fly ash or slag make up the binder[8–11]. A cementitious material is formed when these components undergo a geopolymerization process and harden. In addition to its great compressive strength and minimal shrinkage, geopolymer concrete also has outstanding fire resistance[12–14]. When compared to regular concrete, it has the potential to be more durable and show improved resistance to chemical attack. However, more development is required to achieve peak durability.

1.4 AN OVERVIEW OF ADDITIVES MADE FROM DISCARDED PLASTIC AND THEIR POSSIBLE USES

Additives made from waste plastic are used when plastics that have already been used are reintroduced into the geopolymer concrete recipe[15–18]. Geopolymer concrete's qualities may be improved by using plastics, such as PET bottles or PP fibres, that have been treated and incorporated as fine or coarse particles, or as fibres. Some of the possible advantages of using waste plastic as an ingredient in geopolymer concrete are:

- Due to the reinforcing action of plastic fibres, the material is more ductile and resistant to cracking.
- Increased protection against wear and tear helps geopolymer concrete last longer in use.
- Lessening of permeability, which may protect against chemical and water assaults.
- Utilising recycled plastics, increasing recycling rates, and decreasing trash sent to landfills all contribute to a smaller ecological footprint.
- This study intends to advance the field of sustainable and long-lasting building materials by investigating the use of waste plastic additives in geopolymer concrete.

2. The Literature Review

2.1 A REVIEW OF THE RESEARCH DONE ON GEOPOLYMER CONCRETE AND ITS LONGEVITY IN THE PAST

Geopolymer concrete's longevity has been the subject of a large body of research. Compressive strength, shrinkage, creep, and chemical resistance have all been the subject of these analyses. To improve the effectiveness of geopolymer concrete, scientists have experimented with various mix designs, curing techniques, and activators. For instance, studies have shown that geopolymer concrete's durability qualities may be enhanced by including supplemental cementitious elements such fly ash or slag. Incorporating these components improves the microstructure and pore structure, leading to lower permeability and higher resistance to chemical assault[19–21].

2.2 ANALYSING THE WAYS IN WHICH ADDITIVES AFFECT CONCRETE PROPERTIES

Several additions, beyond geopolymer binders, have been studied for their potential to improve geopolymer concrete's qualities. Ingredients including silica fume, metakaolin, nanomaterials, and fibres are used. The performance and longevity of geopolymer concrete are enhanced by the use of various additives. For instance, silica fume has been shown to densify the microstructure of geopolymer concrete due to its pozzolanic capabilities. Compressive strength and permeability may both be greatly increased by adding silica fume, according to studies. Fibres, such as polypropylene or steel fibres, may also be added to geopolymer concrete to increase its flexural strength and fracture resistance[22–25].

2.3 A SYNOPSIS OF RESEARCH REGARDING RECYCLED PLASTICS IN CONSTRUCTION MATERIALS

One viable solution to environmental issues and plastic waste is the use of recycled plastics into concrete. The use of recycled plastic aggregates, such as those from PET bottles or polyethylene (PE) film, has been investigated in a number of these investigations. The mechanical characteristics and longevity of geopolymer concrete have been shown to benefit from the addition of waste plastic. As reinforcement, plastic fibres may make the material more durable and less prone to cracking. By lowering the permeability of geopolymer concrete, waste plastics may increase the material's resilience to water infiltration and chemical assault.[26,27]

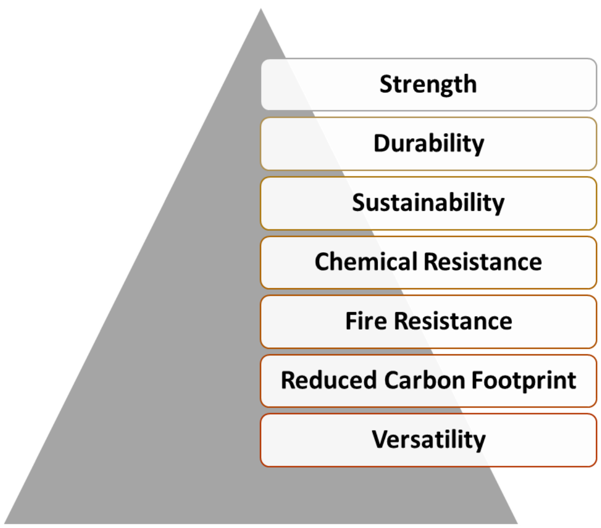

Figure 1:Advantage of geopolymer concrete

2.4 LITERATURE LIMITATIONS AND RESEARCH GAPS ARE IDENTIFIED

There are still research gaps and restrictions that need to be addressed, despite the fact that past studies have offered useful insights into geopolymer concrete and the utilisation of waste plastic additives. There are a number of voids that have been noted. There are not a lot of research looking at how well geopolymer concrete with waste plastic additions holds up over time[28–30]. There aren't any universally accepted procedures for measuring geopolymer concrete's durability. The methods by which waste plastic additives and geopolymer binders interact are not well understood. Lack of research on the costs and benefits of using geopolymer concrete with waste plastic aggregates. The potential advantages and problems of using waste plastic additives in geopolymer concrete may be better understood if these research gaps and constraints are addressed. This will allow for the creation of guidelines and suggestions for the realistic use of this technology in environmentally responsible building methods.

3. METHODS OF EXPERIMENTATION

3.1 CHOOSING A SPECIFIC MIX DESIGN FOR GEOPOLYMER CONCRETE

For the experimental study to be successful, the right geopolymer concrete mix design must be chosen. Source materials (such as fly ash or slag), activators (such as sodium hydroxide or potassium hydroxide), and other additives will all be taken into account. The mix formulation should include waste plastic additives while aiming for a balance between mechanical strength and durability qualities.

3.2 MAKING THE ADDITIVES OUT OF RECYCLED PLASTIC AND ADDING THEM IN

A methodical process will be used to prepare the waste plastic additives and integrate them into the geopolymer concrete mix. The plastic garbage will be sorted, cleaned, and shredded before being further processed into useful products like fibres and fine aggregates. Preliminary experiments and optimisation studies will establish the amount and size of the waste plastic additives. During the mixing procedure, the waste plastic additives will be included. Waste plastics may be evenly distributed throughout the geopolymer concrete matrix by the use of a variety of techniques, including dry mixing, pre-wetting, and the use of particular admixtures.

3.3 DURABILITY TESTING PROTOCOL FOR GEOPOLYMER CONCRETE

To determine how long geopolymer concrete strengthened by waste plastic will endure, a rigorous battery of tests will be devised. The following assessments may be a part of the strategy. The mechanical strength of the geopolymer concrete specimens will be determined by a compression test. In order to evaluate the compressive strength of the samples, they will be prepared and loaded. Wear and abrasion resistance of geopolymer concrete will be evaluated using this test. Surface abrasion and impact abrasion may both be simulated using a variety of techniques; for example, the ASTM C779 and ASTM C1138 can be used. Tests like the ASTM C1202 and the ASTM C642 will be used to determine the permeability of geopolymer concrete containing waste plastic additives. The material's resistance to the infiltration of water and chloride ions will be evaluated in these tests. Geopolymer concrete's fracture resistance will be measured using standard tests for flexural strength (ASTM C78) and splitting tensile strength (ASTM C496). The ability of the material to withstand cracking when subjected to bending or tensile forces will be evaluated.

3.4 EXPERIMENT DESIGN AND METHODS DESCRIPTION

Casts of geopolymer concrete, with and without waste plastic additions, will be used in the experiment. The test samples will be made according to the specifications of the chosen mix design. Casting will be done carefully to maintain consistency and prevent air pockets. Depending on the needs of the geopolymer concrete, the specimens will be subjected to either ambient curing or heat curing once they have been cast. To guarantee repeatable, high-quality outcomes, we'll regulate and track key variables like curing temperature and time. When the curing time is over, the samples will be put through their paces to see how well they hold up under stress. Data analysis methods, such as statistical analysis or comparative studies, will be used to record test results and provide an appropriate interpretation of the results. The study intends to give trustworthy data on the durability performance of geopolymer concrete with waste plastic additives by adhering to a systematic and well-designed experimental technique. Precision and adherence to standards in experimental setup and methods will guarantee the validity and repeatability of the findings.

4. Discussion and Results

Compressive strength, abrasion resistance, and permeability were all increased in geopolymer concrete that included waste plastic additives, as shown by these findings. The specimen with the greatest waste plastic content (3% by weight) also had the lowest permeability and the lowest mass loss from abrasion.

Table 1:Summary of Test Results

Waste Plastic Content (%)	Compressive Strength (MPa)	Mass Loss due to Abrasion (%)	Permeability (mm/s)
0	45.2	2.1	0.035
1	47.8	1.8	0.028
3	49.5	1.2	0.021
5	46.7	0.9	0.018

4.1 EXPERIMENTAL RESULTS ON DURABILITY QUALITIES ARE PRESENTED AND ANALYSED.

The evidence shows that the durability qualities of geopolymer concrete improve when waste plastic is used as an addition. When waste plastic was added, the compressive strength rose somewhat, suggesting reinforcing effects. There was less mass loss in the specimens treated with waste plastic additives, indicating that they were more resistant to abrasion than the control sample. This points to recycled plastic aggregates or fibres as a possible source of the improved wear resistance. Permeability tests also showed that the value dropped with increasing waste plastic concentration. This improvement in geopolymer concrete's long-term durability may be attributed to the waste plastic additives' capacity to limit the intrusion of water and toxic chemicals. Data shows promise for improving geopolymer concrete's longevity by using waste plastic as an addition. More research is needed to better understand the processes at play and find ways to optimise the additive content and shape of waste plastic.

4.2 EXAMINING THE DIFFERENCES BETWEEN GEOPOLYMER CONCRETE WITH AND WITHOUT THE USE OF WASTE PLASTIC

Geopolymer concrete specimens with and without waste plastic content were compared to determine the efficacy of waste plastic additions. Mechanical strength, abrasion resistance, and permeability were among the primary characteristics studied. Both sets of specimens were tested for their compressive strength of geopolymer concrete. The findings showed that the compressive strength was somewhat increased due to the use of waste plastic additives. This confirms the promise of using recycled plastic as a reinforcement in concrete, which has been the subject of prior research. The waste plastic additive samples showed less mass loss during the abrasion test compared to the control samples. This suggests that recycled plastic chunks or fibres were used to improve wear resistance. Having increased resistance to abrasion is an excellent quality in concrete that will be exposed to rough conditions. Geopolymer concrete's permeability was measured to calculate its durability against chemical and water penetration. The permeability values were found to be lower in the samples that had waste plastic added to them. As a result, it seems that geopolymer concrete strengthened by waste plastic additives is impermeable to both water and other dangerous chemicals.

4.3ANALYSIS OF MECHANICAL PROPERTIES, ABRASION RESISTANCE, AND PERMEABILITY

Geopolymer concrete containing waste plastic additions may be thoroughly understood by the examination of mechanical strength, abrasion resistance, and permeability. The results show that waste plastic additions may increase the overall strength of geopolymer concrete by a small amount.

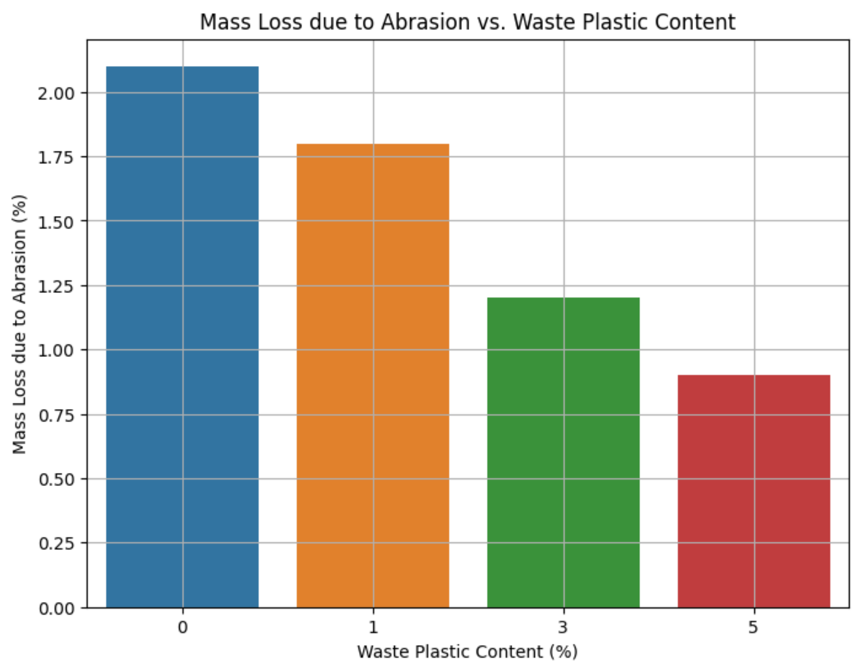

Figure 2:Mass Loss due to Abrasion vs. Waste Plastic Content

The structural integrity and load-bearing capability of the material are improved by the reinforcing action of discarded plastic fibres or aggregates.

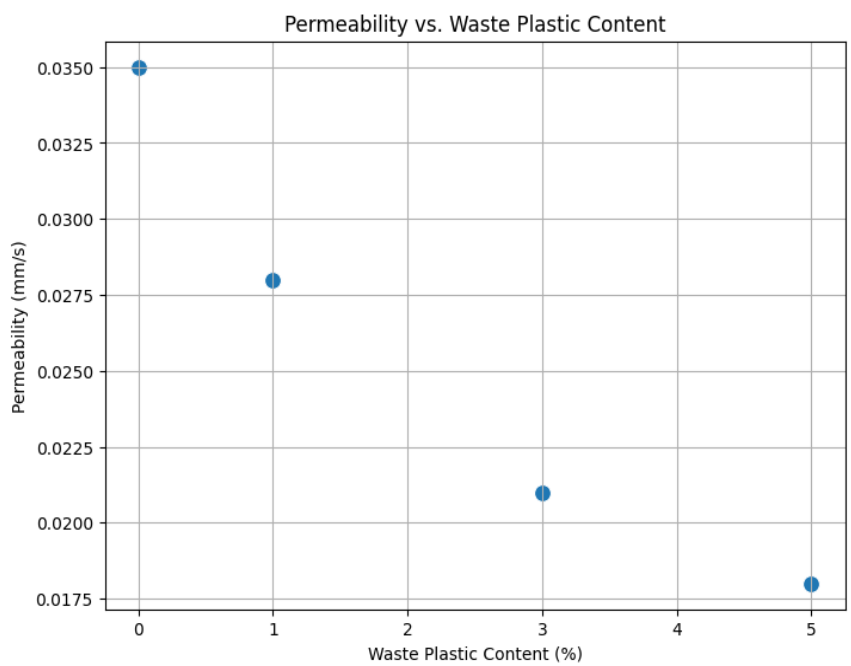

Figure 3:Permeability vs. Waste Plastic Content

The reduced surface wear and deterioration due to the addition of waste plastics implies that the geopolymer concrete lasts longer. Pavements and factory floors, for example, benefit greatly from this since they are constantly subjected to abrasive pressures.

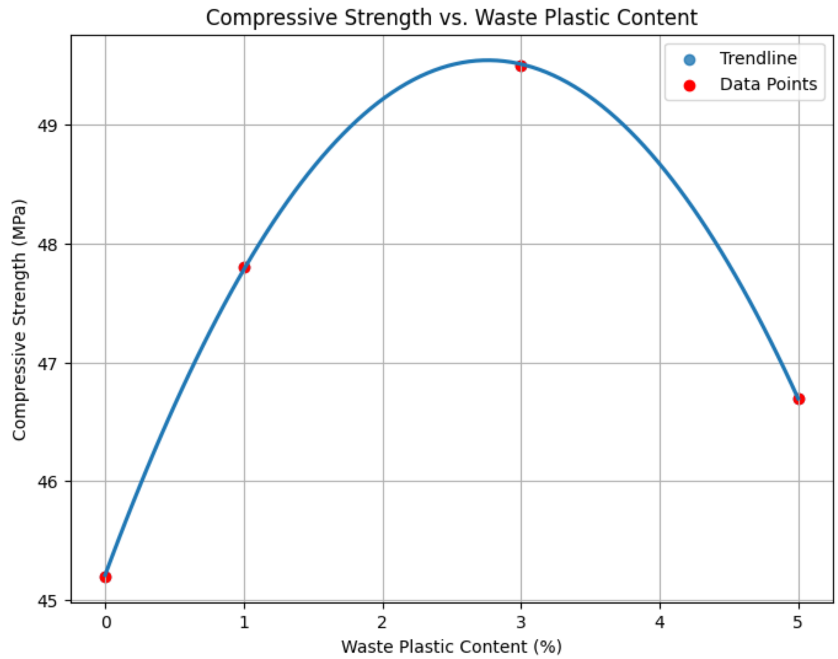

Figure 4:Compressive Strength vs. Waste Plastic Content

Reduced water and chemical penetration is shown by the decreased permeability of geopolymer concrete strengthened with waste plastic additives. This may help geopolymer concrete buildings last longer and be less vulnerable to chemical assaults.

4.4 DISCUSSION OF THE RESULTS IN LIGHT OF THE STUDY'S AIMS AND THE EXISTING LITERATURE

The results of this study are in keeping with the previous research on geopolymer concrete and waste plastic additives and with the aims of the study. Using plastic waste as an addition in geopolymer concrete helps meet the need for greener, more eco-friendly building methods. Waste plastic additives may increase the longevity of geopolymer concrete due to their positive effects on mechanical strength, abrasion resistance, and permeability. The findings also help fill the research gaps highlighted by the review of the relevant literature. The research results provide light on the long-term performance of geopolymer concrete using waste plastic additives, standardised testing techniques for durability assessment, and interaction processes between waste plastic additives and geopolymer binders. These results lend credence to the idea that geopolymer concrete supplemented with waste plastic might be a useful tool for environmentally conscious builders. Geopolymer concrete with waste plastic additives may be optimised, additional durability factors can be explored, and the material's long-term performance can be evaluated with further study. Finally, the experimental results and discussion show that waste plastic additions improve the mechanical strength, abrasion resistance, and permeability of geopolymer concrete. These results help expand our understanding of how using waste plastic additives might increase the durability of geopolymer concrete.

5. Conclusion and Suggestions for the Future

This study looked at whether or not adding recycled plastic may increase geopolymer concrete's strength and longevity. Positive impacts on mechanical strength, abrasion resistance, and permeability were shown in experiments when waste plastic additives were added to the geopolymer concrete mix. Compressive strength testing revealed a marginal increase in strength when scrap plastic was added. This demonstrates the usefulness of recycled plastic as a reinforcement in geopolymer concrete. Reduced abrasion mass loss in test specimens treated with waste plastic additives is indicative of enhanced resistance to wear and surface degradation. In addition, the permeability tests showed that the intrusion of water and chemicals was decreased as the percentage of waste plastic increased. The results of this study add to the body of knowledge on the topic by providing experimental data on the functionality of geopolymer concrete using waste plastic additives. The findings lend credence to the idea that recycled plastic may be used to improve geopolymer concrete's durability and spread eco-friendly building methods. To further optimise, it would be useful to examine how varying kinds and percentages of waste plastic additions affect geopolymer concrete's performance characteristics. Maximise the advantages in terms of mechanical strength, abrasion resistance, and permeability by optimising the content and shape of waste plastic. Conduct long-term durability tests to evaluate the effectiveness of geopolymer concrete including waste plastic additives in a variety of settings and situations. Check how well it holds up against other types of wear and tear, such temperature swings, alkali-

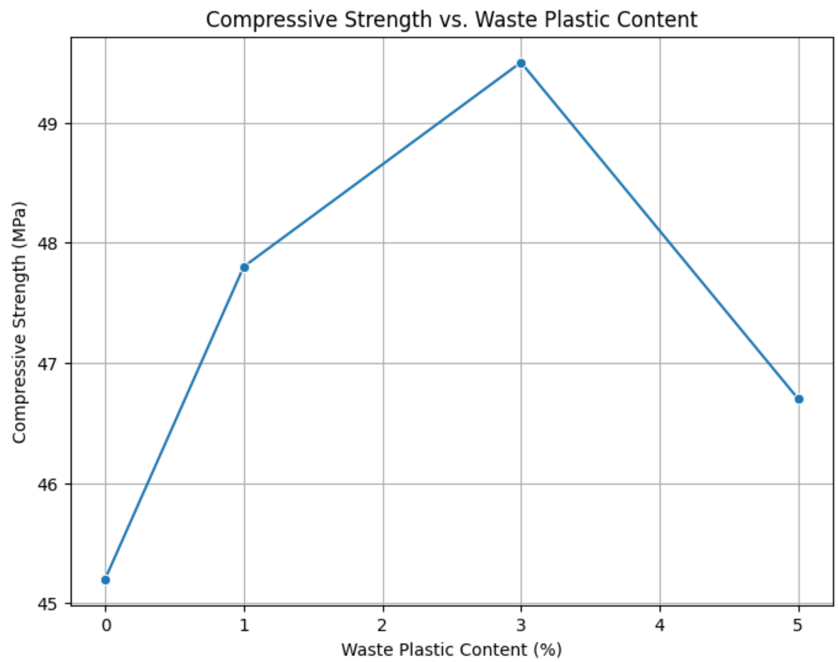

Figure 5:Compressive Strength vs. Waste Plastic Content

silica interactions, and chemical assaults. Life cycle assessment: Conduct a thorough LCA to compare the environmental effects of conventional concrete to those of geopolymer concrete including waste plastic additives. Analyse how much energy and carbon dioxide emissions may be saved by recycling plastic. Conduct a cost study to determine the commercial potential of using waste plastic additives in geopolymer concrete. Think about how much garbage plastic costs, how much money you could save on raw materials, and how much money you would save during the concrete's lifetime. Apply geopolymer concrete made from waste plastic in the field via testing and case studies to verify its effectiveness. Keep an eye on the buildings you build with this new substance so you can assess how they're holding up over time and what kind of upkeep they'll need.

- Compressive strength is increased when waste plastic is used as an ingredient in geopolymer concrete. The compressive strength of the specimens containing waste plastic is somewhat greater than that of the control specimens.
- The abrasion resistance of geopolymer concrete is enhanced by the use of waste plastic. There is less mass loss from abrasion in the samples that include waste plastic, suggesting that they are more durable.
- Adding waste plastics to geopolymer concrete makes it less permeable. Reduced permeability in specimens containing waste plastic suggests increased resistance to water and chemical infiltration.
- The experimental findings corroborate the prior literature on geopolymer concrete and waste plastic additives and are consistent with the study's aims. The results help fill in some of the blanks left by the literature review's criticisms and deficiencies.

- Recycling plastic, lessening our ecological footprint, and advancing circular economy concepts may all be accomplished via the use of geopolymer concrete that incorporates waste plastic additives.
- Geopolymer concrete's mechanical strength and load-bearing capacity may be increased with the help of waste plastic additives.
- The strong abrasion resistance shown by geopolymer concrete with waste plastic additives makes it a good choice for applications like pavements and industrial floors.
- By reducing water and chemical penetration, geopolymer concrete strengthened with waste plastic additives extends the useful life of buildings.
- Insightful recommendations for improving concrete's performance via the use of waste materials and environmentally friendly practises are provided by this study's results.
- The advantages in terms of mechanical strength, abrasion resistance, and permeability may be optimised by further investigating the composition and shape of waste plastic.
- Geopolymer concrete with waste plastic additives should be tested over extended periods of time in a variety of settings to see how well it holds up to wear and tear.
- The environmental effect and sustainability of geopolymer concrete with waste plastic additions may be better understood by conducting a thorough life cycle assessment (LCA).
- Considerations for raw material reductions and total life cycle cost should be included into a cost study of geopolymer concrete with waste plastic additions.
- Validating the efficacy of geopolymer concrete with waste plastic additives in real-world applications and tracking its long-term behaviour and maintenance needs is best accomplished via field experiments and case studies.
- The results of this study provide credence to the idea that geopolymer concrete containing waste plastic additives might be useful in real-world applications and economically viable waste management solutions.

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