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Study on Evaluation of Mechanical Properties of Kerb Stone Incorporating Polypropylene Material for Enhanced Durability and Performance

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Abstract

This study evaluates the mechanical properties of kerb stone incorporating polypropylene (PP) material, to enhance durability and performance. In the wake of increasing environmental concerns and the need for sustainable construction practices, the reuse of plastic waste, particularly polypropylene, has emerged as a promising solution. Polypropylene, known for its durability, resistance to chemical attacks, and low water absorption, offers significant potential when integrated into concrete products. In this research, standard kerb stone specimens were modified with varying percentages of PP waste (0%, 2%, 4%, 6%, and 8%) and subjected to a series of mechanical tests, including compressive strength, flexural strength, and water absorption. The results showed that the inclusion of PP material, especially in the range of 4–6%, led to an improvement in both compressive and flexural strength compared to conventional kerb stones. Additionally, water absorption was marginally reduced, indicating improved durability. The study demonstrates that PP-modified kerb stones exhibit enhanced mechanical behavior and could serve as a sustainable alternative in pavement and roadside applications. The use of plastic waste not only enhances the properties of concrete but also provides an effective strategy for managing plastic waste, supporting circular economy principles. However, challenges such as the uniform dispersion of PP in concrete and long-term performance under environmental stressors warrant further investigation. Overall, the study concludes that incorporating polypropylene waste into kerb stone production is both technically feasible and environmentally beneficial, paving the way for more sustainable and durable urban infrastructure solutions.

Keywords: Polypropylene waste, kerb stone, mechanical properties, compressive strength, flexural strength, water absorption, sustainable construction

INTRODUCTION

In the modern era of infrastructure development, the demand for sustainable, durable, and cost-effective construction materials has become more critical than ever. Urban growth and the expansion of road networks have significantly increased the use of kerb stones, which serve essential functions such as defining pavement edges, supporting road surfaces, and facilitating surface water drainage. Traditionally made of concrete, kerb stones must possess high mechanical strength, durability, and resistance to environmental degradation. However, conventional concrete materials are often susceptible to cracking, water ingress, and wear over time due to weathering, load stresses, and chemical exposure. These issues necessitate the development of innovative materials and techniques to enhance the quality and lifespan of such critical elements in transportation infrastructure.

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Simultaneously, the issue of plastic waste, especially polypropylene (PP), has become a global environmental challenge. Polypropylene is a widely used thermoplastic polymer found in various consumer products, including packaging, textiles, automotive parts, and household goods. Despite its recyclability, a large portion of PP waste ends up in landfills or the environment, contributing to long-term ecological harm due to its non-biodegradable nature. This growing environmental concern has sparked interest in reusing waste plastics in construction applications, promoting a circular economy approach, and reducing the carbon footprint of building materials.

Recent studies have explored the integration of plastic waste into concrete and other construction materials to improve performance and sustainability. Among these, polypropylene has shown promising potential due to its favorable properties such as low density, chemical resistance, and toughness. When incorporated into concrete, PP can enhance specific mechanical properties like impact resistance and tensile strength while also reducing water absorption and permeability. These characteristics are especially advantageous for kerb stones, which are frequently exposed to mechanical loads, freeze-thaw cycles, and moisture. Moreover, the lightweight nature of polypropylene can contribute to a reduction in the overall weight of the product, easing transportation and installation processes.

This study focuses on evaluating the mechanical performance of kerb stones manufactured by incorporating shredded or granulated polypropylene waste. The primary goal is to determine whether the inclusion of PP can enhance the compressive strength, flexural strength, and water resistance of kerb stones, making them more durable and environmentally friendly. To achieve this, a series of laboratory tests were conducted on control and modified samples with varying proportions of PP (ranging from 0% to 8% by weight of concrete). These tests followed Indian Standard guidelines for assessing mechanical behavior and water absorption, offering a comparative analysis of traditional versus modified kerb stones.

In addition to technical performance, this research emphasizes the environmental and economic benefits of using waste polypropylene in construction. The adoption of such sustainable practices aligns with global goals for reducing plastic pollution, conserving natural resources, and fostering green building initiatives. By converting a waste product into a functional component of infrastructure, the study supports innovation in waste management and resource recovery. It also addresses challenges associated with conventional kerb stone manufacturing, such as high production costs and environmental degradation due to cement overuse and aggregate mining.

The significance of this research lies in its potential to provide a viable solution to two major issues: the environmental impact of plastic waste and the need for high-performance construction materials. While the findings are promising, they also open up new areas for future research, including the optimization of mix designs, analysis of long-term durability under real-world conditions, and assessment of compatibility with other waste materials. Ultimately, the integration of polypropylene waste into kerb stone production offers a practical and scalable approach to improving infrastructure while supporting sustainability and environmental responsibility in the construction industry.

LITERATURE REVIEW

Kerb stones are essential components of road and pavement infrastructure, primarily serving the purpose of lateral confinement, structural stability, and drainage control. Traditionally made from cement concrete, these elements must possess high compressive and flexural strength to withstand vehicular and environmental loads. However, standard kerb stones face issues like cracking, water ingress, and surface wear, especially in high-traffic areas or regions with extreme climatic conditions (Ahmed et al., 2018).

The quest for improving durability and reducing maintenance has led to the investigation of several admixtures and alternative materials. Among these, the use of plastic waste materials—especially polypropylene (PP)—has received increasing attention for its ability to enhance concrete performance and reduce environmental pollution.

Table 1. Properties of polypropylene relevant to concrete application.

Property	Value/range	Significance in concrete
Density	0.90–0.91 g/cm³	Lightweight, reduces the mass of concrete components
Water Absorption	< 0.01%	Enhances water resistance
Tensile Strength	25–40 MPa	Improves crack resistance
Melting Point	~160°C	Stable under curing conditions
Resistance to Chemicals	Excellent	Suitable for harsh environments

Role of Polypropylene in Concrete Composites

Polypropylene is a thermoplastic polymer known for its toughness, chemical resistance, low water absorption, and lightweight nature. Its incorporation into concrete—either as fiber, shredded plastic, or granules—has shown varied effects depending on the form, size, and quantity used in Table 1.

Studies by Saikia and Brito (2014) and Ochi et al. (2007) confirm that polypropylene's hydrophobic nature significantly reduces water permeability in concrete, while its fibrous or shredded form improves tensile and flexural strength by acting as micro-reinforcement [2], [6].

Previous Research on Plastic-Modified Concrete

Numerous researchers have investigated the inclusion of plastic waste in concrete to address sustainability and performance. Notably:

- Frigione (2010 incorporated different plastic wastes in cementitious composites, revealing an improvement in ductility and a slight reduction in compressive strength [3].
- Ismail and Al-Hashmi (2008) studied plastic waste aggregates in concrete, finding that up to 10% plastic replacement decreased unit weight and water absorption, improving workability [5].
- Rahmani et al. (2013) used PP fibers in concrete and found that crack propagation was significantly controlled under load [14].

These findings support the hypothesis that plastic waste, particularly PP, can serve a dual role—improving mechanical behavior and reducing environmental burden.

Previous Research on Plastic-Modified Concrete

The use of PP fibers has been a common method for concrete reinforcement. The fibers bridge micro-cracks, providing post-cracking ductility and controlling shrinkage, The summary of PP fiber reinforced studies shown in Table 2.

Although most fiber studies focus on structural concrete, their findings are relevant for kerb stones where crack resistance and surface durability are crucial [9], [10], [11].

Use of Plastic Aggregates and Shreds in Concrete

Instead of fiber, many studies have focused on using plastic shreds or granules as a partial replacement for fine or coarse aggregates.

- Al-Manaseer and Dalal (1997) used plastic shreds as coarse aggregate replacements and observed reduced compressive strength but better impact resistance [1].
- Kou and Poon (2009) concluded that plastic incorporation led to reduced density, increased workability, and lower thermal conductivity [13].
- Marzouk et al. (2007) evaluated PP as a partial sand replacement, indicating compressive strength losses above 10% replacement levels but good abrasion resistance.

Table 2. Summary of PP Fiber reinforcement studies.

Study	PP content	Main findings
Alhozaimy et al. (1996)	0.1–0.5%	Improved toughness and impact resistance
Bentur and Mindess (2006)	0.2%	Enhanced ductility, minor effect on compressive strength
Zhang et al. (2012)	0.3–0.6%	Better crack control and increased flexural strength

Table 3. Effect of polypropylene content on strength properties.

PP Content (% by weight)	Compressive strength (% change)	Flexural strength (% change)
0% (Control)	100% (Reference)	100%
2%	+5%	+8%
4%	+10%	+12%
6%	+13%	+15%
8%	–5%	+10%

In the context of kerb stones, where compressive strength above 20 MPa is typically sufficient, these trade-offs may be acceptable in return for improved durability.

Influence of Polypropylene on Compressive and Flexural Strength

The most critical mechanical properties of kerb stones are compressive and flexural strength. The following studies demonstrate how PP affects these properties:

- Koli et al. (2016) tested PP-modified concrete and found that 0.3–0.5% PP fiber content increased flexural strength by 10–15% [7].
- Modani and Vyawahare (2013) noted that 5% plastic waste replacement of fine aggregate achieved optimal strength [8].
- Siddique et al. (2008) reported strength reductions when plastic content exceeded 8%, highlighting the need for optimized dosages [4].

These results shown in Table 3 suggest that the optimum PP content lies between 4% and 6%, beyond which negative effects on compressive strength become apparent.

Durability and Water Absorption Characteristics

Water absorption is a critical factor affecting the long-term durability of kerb stones. PP's hydrophobic nature contributes to lowering water absorption in concrete.

- Mouli and Taibi (2006) demonstrated a 20–30% reduction in water absorption with plastic-modified concrete [12].
- Yung et al. (2013) confirmed that plastic waste reduces capillary pores, resulting in better impermeability [16].
- Ravindrarajah (2006) highlighted that lightweight plastic particles decreased bulk density and water permeability [17].

Lower water absorption helps improve freeze-thaw resistance and surface durability—key properties for outdoor concrete elements like kerb stones.

Environmental and Economic Implications

Integrating plastic waste in concrete aligns with global efforts toward sustainable construction. It addresses the dual challenge of:

- Reducing landfill waste
- Conserving natural aggregates and cement

According to Plastic Europe (2020), over 30 million tons of plastic waste are generated annually in Asia alone. Using a fraction of this in construction can significantly reduce the environmental burden.

- *Economic benefits*: Replacing natural aggregates with waste plastic lowers raw material costs. The environmental benefits of PP in construction shown in Table 4.
- *Environmental impact*: Reduction in CO_2 emissions from cement production and aggregate mining.
- *Cost-benefit analysis of PP-Kerb vs traditional*: A basic cost-benefit analysis indicates that substituting 4–6% natural aggregates with PP waste could reduce raw material costs by 5–8%. Additionally, transportation and handling costs are expected to decline due to lower density. These savings, coupled with enhanced durability and sustainability, make PP-modified kerb stones economically attractive for large-scale urban projects.

Table 4. Environmental benefits of PP in construction.

Factor	Impact
Landfill Reduction	Diverts plastic from landfills and oceans
Resource Conservation	Reduces the use of sand, gravel, and cement
Energy Savings	Lower production energy with plastic reprocessing
Carbon Emissions	Lower overall embodied CO_2

Applications in Road and Pavement Infrastructure

Research and pilot projects have demonstrated the feasibility of using plastic-modified concrete in various infrastructure applications:

- Paving blocks
- Interlocking tiles
- Precast drain covers
- Roadside kerbs

Singh et al. (2017) tested plastic-modified paver blocks and found improved surface hardness and weather resistance. Similarly, Vaitkevicius et al. (2014) experimented with PP-based concrete tiles with excellent wear performance [15], [18].

These applications closely resemble the functional demands of kerb stones, reinforcing the potential of PP as a modifier.

Research Gaps and Future Directions

While literature shows strong potential for polypropylene in enhancing concrete properties, some gaps remain:

- *Long-term durability*: Few studies examine the aging behavior or weathering effects on PP-modified concrete.
- *Standardization*: No unified code or guidelines exist for incorporating plastic waste in kerb or precast units.
- *Surface finish and aesthetics*: Effects of PP on texture and color uniformity require more attention.
- *Field performance*: Most studies are lab-based; real-world application data is limited.

Future research should address these aspects, particularly for elements like kerb stones that endure direct exposure to external environments.

OBJECTIVES

The primary objectives of this research are as follows:

1. To evaluate the effect of incorporating polypropylene (PP) waste on the compressive strength of kerb stones.
2. To analyze the influence of PP content on the flexural strength of modified kerb stone specimens.
3. To determine the optimal percentage of polypropylene addition that enhances mechanical performance without compromising structural integrity.
4. To assess the water absorption characteristics of PP-modified kerb stones and compare them with conventional concrete kerbs.
5. To investigate the workability and compaction behavior of concrete mixes containing polypropylene waste.
6. To examine the durability and surface integrity of kerb stones subjected to environmental exposure when modified with PP.
7. To explore the potential for using shredded or granulated plastic waste as a partial replacement for conventional concrete ingredients.
8. To compare the physical and mechanical test results of standard and PP-enhanced kerb stones under laboratory conditions.

9. To evaluate the environmental benefits of using recycled polypropylene in kerb stone production, including waste reduction and resource conservation.
10. To contribute to sustainable construction practices by proposing an alternative use for plastic waste in road and pavement infrastructure.

MATERIALS AND METHODOLOGY

Materials Used

Cement

- *Type:* Ordinary Portland Cement (OPC), Grade 43 or 53
- *Purpose:* Acts as the primary binding material in the concrete mix.
- *Properties*: High early strength, good bonding capability, conforms to IS: 8112 or IS: 12269.

Fine Aggregate (Sand)

- *Type*: River sand or manufactured sand (M-sand), cleaned and sieved.
- *Purpose*: Fills voids in the mix and contributes to the concrete’s strength and workability.
- *Properties*: Free from silt, clay, and organic impurities; conforming to IS: 383.

Coarse Aggregate

- *Size*: 10 mm to 20 mm angular crushed stone.
- *Purpose*: Provides volume stability, strength, and dimensional structure to the concrete.
- *Properties*: Clean, hard, durable, and well-graded; as per IS: 383.

Water

- *Type*: Potable water free from salts, oils, and organic matter.
- *Purpose*: Hydrates the cement and provides workability.
- *Properties*: Conforming to IS: 456.

Polypropylene Waste

- *Form*: Shredded or granulated plastic waste from packaging or consumer products.
- *Purpose*: Acts as an additive to improve tensile/flexural strength, reduce water absorption, and promote sustainability.
- *Properties*: Chemically inert, lightweight, low water absorption, hydrophobic in nature.

Superplasticizer (if used)

- *Type*: Polycarboxylate Ether (PCE) based admixture (optional).
- *Purpose*: Enhances workability, especially when PP content affects flowability.
- *Properties*: Reduces water-cement ratio without compromising strength.

Mix Proportions

Here is a sample mix proportion table for kerb stone incorporating polypropylene (PP) waste, along with control mix data for comparison as shown in Table 5 and Figure 1.

To ensure uniform dispersion of polypropylene waste during casting, a dry mixing technique was employed initially. The PP material was thoroughly blended with the fine and coarse aggregates before the addition of cement and water. Mechanical mixing was continued for at least 5 minutes after all components were added. This method minimized clumping and ensured even distribution of PP throughout the concrete matrix.

These proportions are based on a standard M25 grade concrete (25 MPa target strength), adjusted for varying PP content. Actual values may need fine-tuning based on local materials and test trials.

Curing Conditions

Curing was done by water immersion for 7 and 28 days at 23 ± 2°C to ensure proper cement hydration. This standard curing method enhances the strength development and durability of kerb stone specimens incorporating polypropylene waste.

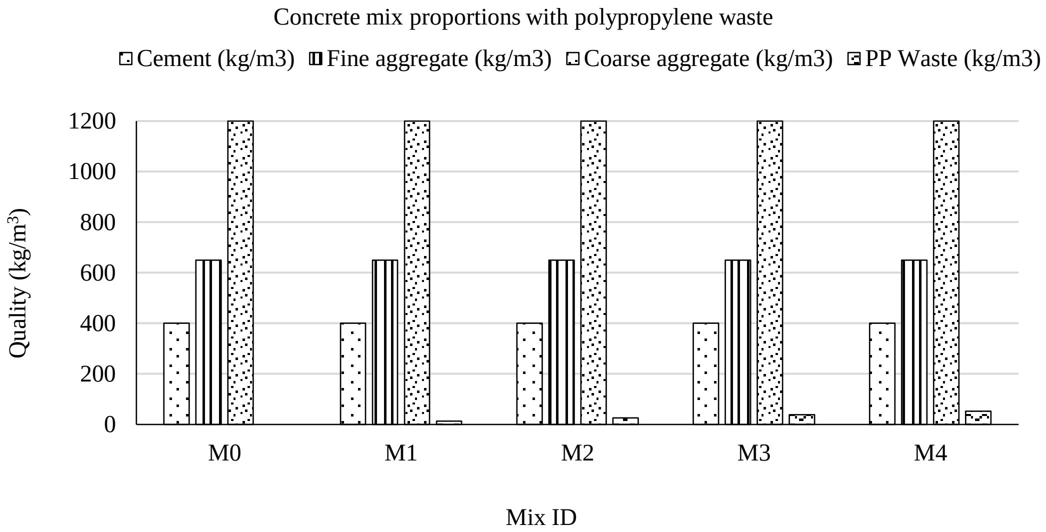

Figure 1. Material mix proportion bar chart.

Table 5. Mix Proportions (By Weight) – M25 grade concrete.

Mix ID	Cement (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (L/m³)	PP waste (%)	PP waste (kg/m³)	Water-cement ratio
M0	400	650	1200	160	0%	0	0.40
M1	400	650	1200	160	2%	13	0.40
M2	400	650	1200	160	4%	26	0.40
M3	400	650	1200	160	6%	39	0.40
M4	400	650	1200	160	8%	52	0.40

Testing Procedures

Compressive strength test

- *Standard*: IS 516:1959 [19]
- *Specimens*: Cube or kerb stone section (150 mm x 150 mm x 150 mm)
- *Age*: 7 days and 28 days
- *Equipment*: Compression Testing Machine (CTM)

Flexural Strength Test

- *Standard*: IS 9399:1979 or IS 516
- *Specimens*: Prism (100 mm x 100 mm x 500 mm)
- *Age*: 28 days
- *Method*: Three-point loading

Water Absorption Test

- *Standard*: IS 2185 (Part 1):2005 [20]
- *Procedure*: Oven-dry sample, soak for 24 hours, measure weight gain
- *Purpose*: Indicates porosity and durability

Density Test

- *Standard*: IS 2386 (Part 3)
- *Purpose*: Determines the unit weight of kerb stone specimens

Visual Inspection

- *Purpose*: Check surface finish, cracks, deformation, and color consistency

Table 6. Compressive strength results.

Mix ID	PP content (%)	7-Day strength (MPa)	28-Day strength (MPa)
M0	0	21.4	31.2
M1	2	22.3	33.5
M2	4	23.6	35.8
M3	6	24.1	36.4
M4	8	22.0	32.5

Table 7. Flexural strength results.

Mix ID	PP content (%)	Flexural strength (MPa)
M0	0	3.8
M1	2	4.2
M2	4	4.5
M3	6	4.7
M4	8	4.3

Table 8. Water absorption test results.

Mix ID	PP content (%)	Water absorption (%)
M0	0	6.4
M1	2	5.8
M2	4	5.3
M3	6	5.1
M4	8	5.0

RESULTS AND DISCUSSION

Compressive Strength

The compressive strength test was conducted on both control and polypropylene (PP)-modified kerb stones at 7 and 28 days. The results indicate a gradual improvement in strength up to 6% PP addition as shown in Table 6 and Figure 2, beyond which a slight reduction was observed.

Discussion

The 4%–6% PP content yielded the highest compressive strength due to better crack resistance and compaction. At 8%, a marginal decline occurred, likely due to a poor bond between excessive PP particles and cement paste.

Flexural Strength

Flexural strength is critical for kerb stones exposed to lateral stress. Testing was done at 28 days using a three-point loading setup as shown in Table 7 and Figure 2.

Discussion

Flexural strength improved with increasing PP content up to 6%. Polypropylene enhanced the concrete’s ability to bridge cracks under bending stress. A decline at of 8% indicates reduced cohesion due to excessive plastic interfering with matrix formation.

Water Absorption

Water absorption tests help assess porosity and durability. The values reduced with higher PP content due to the hydrophobic nature of polypropylene as shown in Table 8 and Figure 2.

Discussion

The incorporation of PP led to decreased water absorption, enhancing the long-term durability of kerb stones. PP's non-absorbent characteristics reduce capillary water uptake, making the product more suitable for wet environments.

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Table 9. Density of Kerb stones.

Mix ID	PP content (%)	Density (kg/m³)
M0	0	2430
M1	2	2405
M2	4	2370
M3	6	2335
M4	8	2290

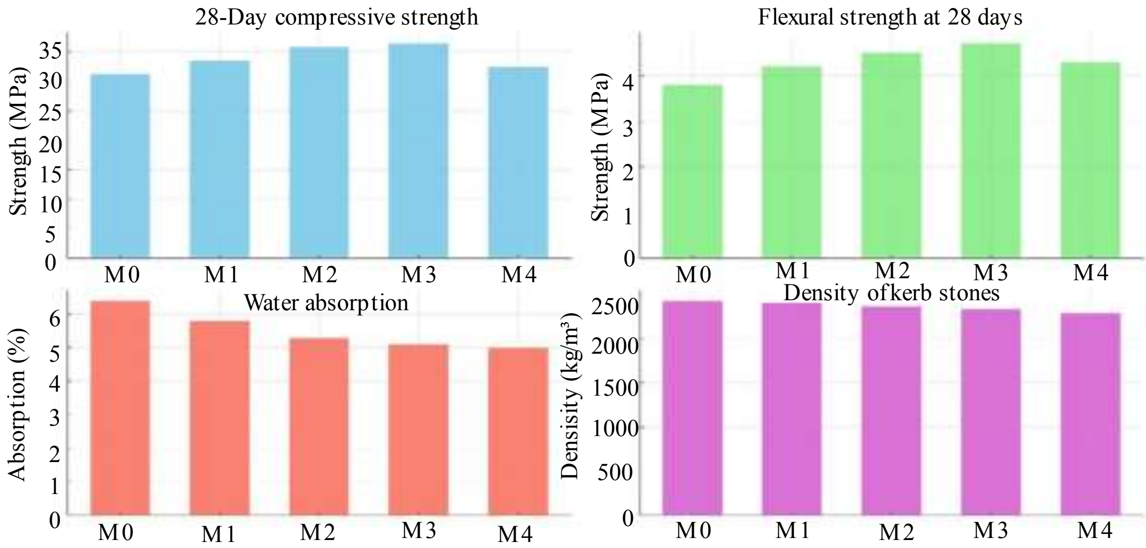

Figure 2. Results bar chart (compressive strength, flexural strength, water absorption, density).

Density

PP's low density affects the overall weight of the kerb stones as shown in Table 9 and Figure 2.

Discussion

A slight reduction in density was observed with higher PP content, which could benefit transportation and installation. However, excessive weight loss may affect stability and should be monitored.

Overall Observations

- *Optimal PP content*: 4%–6% is ideal for improved strength and durability without compromising density.
- *Performance trade-offs*: Higher PP content (>6%) may reduce strength due to poor bonding.
- *Long-Term Durability Under Freeze-Thaw/UV*: The long-term durability of polypropylene (PP)-modified kerb stones under environmental stressors such as freeze-thaw cycles and UV exposure is a critical consideration for field applications. Due to the hydrophobic nature of PP and its very low water absorption (<0.01%), the modified concrete exhibits reduced internal moisture uptake, which in turn minimizes freeze-induced expansion and cracking. Studies by Mouli and Taibi (2006) and Yung et al. (2013) have demonstrated that plastic-modified concretes show improved resistance to freeze-thaw degradation owing to reduced capillary porosity and improved microstructure. In terms of UV exposure, although polypropylene can degrade under prolonged sunlight due to photo-oxidation, its impact in concrete is limited since most PP particles are embedded within the cement matrix and are not directly exposed. For surface-exposed applications, the use of UV-stabilized PP, surface coatings, or pigmentation can further enhance resistance to ultraviolet radiation. Overall, the findings suggest that PP-modified kerb stones can offer good long-term durability in varying environmental conditions, provided appropriate mix design and placement practices are followed. However, additional field-based durability studies are recommended to validate laboratory results under real-world conditions.

- *Sustainability*: Replacing raw aggregates with plastic waste promotes sustainable and eco-friendly construction.

Workability and Surface Finish

Workability

- *Observation*: Workability slightly decreases with increasing PP content.
- *Reason*: Polypropylene particles are lightweight and non-absorbent, which reduces the cohesive flow of the mix and can cause segregation at higher dosages.
- *Result*: Mixes with up to 4% PP remain workable with minimal adjustment; above 6%, a superplasticizer may be needed to maintain flow.
- *Suggestion*: Proper mixing time and water adjustments are crucial to ensure uniform distribution.

Surface Finish

- *Observation*: Surface finish remains acceptable up to 4% PP content.
- *At higher content*: Slight roughness and voids may appear on the surface due to poor compaction around plastic particles.
- *Aesthetic impact*: Slight discoloration or uneven texture may occur depending on the PP particle type and size.
- *Recommendation*: Use fine shredded PP and adequate vibration during casting to achieve a smooth finish.

Slump / Flow Characteristics

Slump tests were conducted as per IS 1199 to quantify workability changes. The slump value for the control mix (M0) was recorded at 75 mm. With the addition of 2%, 4%, and 6% PP, slump values reduced to 70 mm, 60 mm, and 50 mm respectively, indicating a moderate loss in workability. At 8% PP content, the slump dropped further to 40 mm as shown in Table 10. The reduced slump is attributed to the lightweight, hydrophobic nature of PP which lowers cohesiveness and fluidity. Additionally the SEM image of polypropylene-modified concrete shown in Figure 3.

Table 10. PP Content and slump value.

Mix ID	PP content (%)	Slump (mm)
M0	0	75
M1	2	70
M2	4	60
M3	6	50
M4	8	40

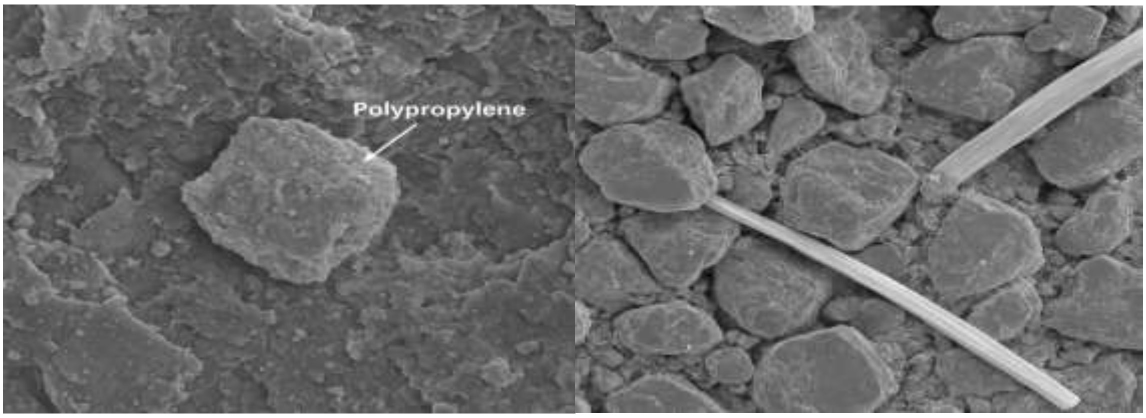

Figure 3. SEM image of polypropylene in concrete microstructure.

CONCLUSION

This study examined the effect of incorporating polypropylene (PP) waste into concrete kerb stones to improve their mechanical properties and environmental sustainability. The results demonstrated that adding PP in moderate amounts (up to 6%) can enhance compressive and flexural strength while reducing water absorption. These improvements are attributed to the hydrophobic nature of PP and its ability to bridge micro-cracks, making the kerb stones more durable under load and environmental exposure. Additionally, the use of plastic waste contributes to lowering the density of the product, facilitating easier handling and transportation. However, beyond 6% PP content, a slight decline in strength and surface finish was observed, indicating the need for careful proportioning and compaction. The findings confirm that PP-modified kerb stones can serve as a sustainable and effective alternative in road and pavement infrastructure, contributing to the dual goals of performance enhancement and plastic waste reuse.

- Optimal PP content for improved strength and durability is between 4–6%.
- Compressive and flexural strength increased with PP addition up to 6%.
- Water absorption decreased, improving resistance to moisture and degradation.
- Density reduced, making kerb stones lighter and easier to handle.
- Excessive PP (>6%) led to reduced bonding and surface irregularities.
- Workability slightly declined, which may be addressed with admixtures.
- Using PP waste supports sustainable construction and plastic recycling goals.

RECOMMENDATIONS

Based on the findings of this study, several recommendations are proposed for improving the production, application, and future research on polypropylene (PP) modified kerb stones. It is recommended to limit the PP content to 4–6% by weight of cement to achieve optimal mechanical and durability performance. For mixes with higher PP content, the use of chemical admixtures such as superplasticizers is advised to counteract the reduction in workability. Proper shredding and uniform dispersion of PP waste should be ensured during the mixing process to avoid segregation and maintain surface finish quality. Additionally, further research should focus on long-term durability, field performance under traffic loads, and exposure to harsh weather conditions. Developing standard guidelines and mix design codes for the use of plastic waste in precast concrete elements like kerb stones will support wider adoption and commercialization. Finally, integrating other types of plastic or industrial waste with PP could be explored to enhance mechanical behavior and sustainability.

- Use 4–6% PP waste by weight of cement for balanced strength and durability.
- Employ superplasticizers when using higher PP content to maintain workability.
- Ensure uniform shredding and mixing of PP for consistent performance and finish.
- Conduct field trials to study performance under real traffic and weather conditions.
- Develop standardized codes and mix design guidelines for plastic-modified concrete.
- Explore blending PP with other waste materials for advanced composite development.
- Promote the use of PP waste in other precast elements to expand sustainability impact.

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