

Experimental Study on Compressive Strength and Water Absorption of Paving Blocks Incorporating Polypropylene Plastic Waste

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Abstract

Plastic waste, particularly polypropylene (PP), poses a serious environmental challenge due to its resistance to natural degradation and long persistence in landfills. This study investigates the feasibility of utilizing polypropylene plastic waste as a partial or full substitute for conventional binder materials in paving block production. Experimental paving blocks measuring 200 × 100 × 60 mm were manufactured using five mix proportions of polypropylene plastic waste and sand: 100% PP, 90% PP:10% sand, 80% PP:20% sand, 70% PP:30% sand, and 60% PP:40% sand. Compressive strength tests were conducted at curing ages of 7 and 28 days, while water absorption tests were performed at 7 days. The results indicate that the compressive strength of paving blocks decreased with increasing polypropylene content, with the lowest strength observed in the 100% PP mixture (5.5 MPa at 7 days and 4.0 MPa at 28 days). The highest compressive strength was obtained from the 60% PP:40% sand mixture, reaching 9.6 MPa at 7 days. Water absorption values ranged from 1.39% to 2.36%, reflecting the hydrophobic nature of polypropylene. However, none of the tested mixtures fully satisfied the requirements of SNI 03-0691 (1996). These findings suggest that polypropylene plastic waste has potential for non-structural paving applications, particularly pedestrian pathways, while also contributing to plastic waste reduction.

Keywords: Paving block; Polypropylene plastic waste; Compressive strength; Water absorption

1. Introduction

Plastic materials are extensively used in modern society because of their durability, lightweight nature, and low production cost[1–3]. However, these same advantages have led to a significant environmental burden, as plastic waste is highly resistant to natural degradation and can persist in landfills for decades. In developing countries, including Indonesia, the rapid growth of plastic consumption driven by population increase and changes in lifestyle has intensified challenges related to waste management and environmental pollution. The construction sector has increasingly been explored as a potential absorber of plastic waste through material recycling-based innovations. One promising application is the utilization of plastic waste in paving block production. Paving blocks are widely used for pedestrian pathways and open spaces due to their ease of installation. Their modular nature makes them suitable for experimental material development and sustainability-oriented construction practices. Polypropylene (PP) is one of the most commonly used plastic types in household and industrial products[4–6].

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PP is characterized by high chemical resistance, low water absorption, and good thermal stability. These properties suggest that polypropylene plastic waste may be suitable for incorporation into paving blocks, particularly for non-structural applications[5,6]. However, non-cementitious nature of polypropylene may also negatively affect bonding mechanisms and mechanical performance[7,8]. Despite growing interest in plastic-based paving materials, existing studies have primarily focused on other plastic types such as high-density polyethylene (HDPE) and low-density polyethylene (LDPE), with limited experimental evidence specifically addressing polypropylene plastic waste without the use of cement as a binder[9–11]. Furthermore, many studies report mechanical performance at early curing ages without sufficient evaluation of strength development and degradation over time. The accumulation of polypropylene plastic waste presents a serious environmental challenge, while the construction industry continues to rely heavily on natural resources for paving block production. There is a need for alternative paving materials that can reduce plastic waste while maintaining acceptable mechanical and durability performance. However, the feasibility of using polypropylene plastic waste as a primary material in paving blocks, particularly in terms of compressive strength and water absorption characteristics, remains insufficiently understood.

Although the use of plastic waste in paving block production has been widely explored, existing studies remain limited in several important aspects. Most previous research has concentrated on polyethylene-based plastics, such as HDPE and LDPE, while experimental investigations focusing specifically on polypropylene plastic waste are still scarce. In addition, many studies emphasize early-age mechanical performance without adequately examining changes in compressive strength at later curing stages, particularly in mixtures that do not rely on cementitious binding mechanisms. Furthermore, systematic evaluation of water absorption behavior in polypropylene-based paving blocks, especially in relation to national quality standards, has not been sufficiently addressed. These limitations indicate a lack of comprehensive understanding regarding the mechanical reliability and practical applicability of polypropylene plastic waste as a paving block material. In response to these gaps, this study aims to experimentally investigate the feasibility of utilizing polypropylene plastic waste in paving block production. Specifically, the objectives are to evaluate the compressive strength of paving blocks produced with varying proportions of polypropylene plastic waste and sand at curing ages of 7 and 28 days, to determine their water absorption characteristics, and to assess their compliance with the requirements of SNI 03-0691 (1996). Through these objectives, the study seeks to identify mixture proportions that are suitable for pedestrian and other non-structural paving applications.

This research contributes to the field of sustainable construction materials by providing experimental evidence on the mechanical and physical performance of paving blocks manufactured using polypropylene plastic waste without cement. The study offers insight into strength development and degradation behavior over time, highlighting the limitations and potential of polypropylene-based paving blocks for practical use. In addition, the findings support environmentally friendly construction practices by demonstrating an alternative pathway for polypropylene plastic waste reutilization, while also supplying reference data that may inform future research.

2. Material and Methods

2.1. Materials

The primary materials used in this study consisted of polypropylene (PP) plastic waste and natural fine aggregate (sand). The polypropylene plastic waste was sourced from discarded household plastic products, such as packaging containers and consumer goods, which are commonly available in municipal solid waste streams. Prior to use, the collected PP waste underwent a systematic preparation process, including manual sorting to remove impurities, thorough washing to eliminate dirt and organic contaminants, and drying at ambient conditions. The cleaned plastic waste was then mechanically processed into smaller particles to achieve a size suitable for homogeneous mixing with the fine aggregate. The natural fine aggregate used in this study was river sand, selected due to its widespread application in paving block production. The sand was sieved and characterized to ensure compliance with the relevant Indonesian standards (SNI) for grading, cleanliness, and particle size distribution required for paving block manufacture. An example of the polypropylene plastic waste utilized in this study is presented in Figure 1.



Figure 1. Polypropylene (PP) Plastic

Waste

2.2. Mix Proportions and Specimen Preparation

Five mixture variations were prepared based on the proportion of polypropylene plastic waste to sand: 100% PP, 90% PP:10% sand, 80% PP:20% sand, 70% PP:30% sand, and 60% PP:40% sand. Paving block specimens were molded into rectangular blocks with dimensions of $200 \times 100 \times 60$ mm. The molding process involved heating the polypropylene plastic to achieve adequate bonding before mixing with sand and compacting into molds. The setting time observed during specimen preparation was approximately 30 seconds.

2.3. Testing Methods

Compressive strength tests were conducted using a compression testing machine in accordance with SNI 03-1974-1990. Tests were performed at curing ages of 7 and 28 days, with five specimens tested for each mixture variation to obtain average values. Water absorption tests were carried out at 7 days by immersing specimens in water for 24 hours, following the procedures outlined in SNI 03-0691 (1996).

3. Results and Discussion

3.1. Properties of Fine Aggregate

Sieve analysis of the fine aggregate resulted in a fineness modulus of 2.57, indicating medium sand classification. The saturated surface dry (SSD) moisture content was measured at 3.44%, meeting the requirements for paving block production. Mud content tests yielded values below 5%, confirming the suitability of the sand for construction applications. The average specific gravity of the sand was 1.255, which falls within the acceptable range specified by SNI 03-2471-1991. Figure 2 describes the fine aggregate analysis results.

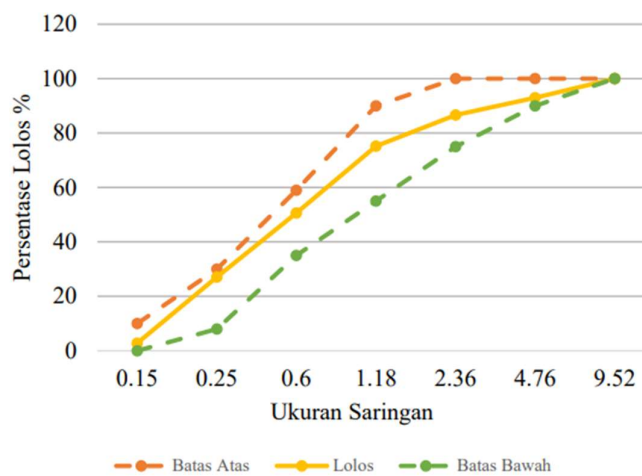


Figure 2. Fine aggregate

chart

analysis test

3.2. Compressive Strength of Paving Blocks

The compressive strength results showed a decreasing trend with increasing polypropylene content. At 7 days, the lowest average compressive strength was observed in the 100% PP mixture (5.5 MPa), while the highest value was recorded for the 60% PP:40% sand mixture (9.6 MPa). At 28 days, all mixtures experienced a reduction in compressive strength, which can be attributed to the absence of cementitious hydration mechanisms in polypropylene-based mixtures. Similar trends have been reported in previous studies involving plastic-based paving blocks. Based on SNI 03-0691 (1996), only the 70% PP:30% sand and 60% PP:40% sand mixtures can be classified as quality grade D, suitable for pedestrian use. Figure 3 illustrates the compressive strength development of paving blocks at curing ages of 7 days and 28 days with varying proportions of PP (natural sand) and PS. Overall, the results indicate that both curing age and PS substitution level significantly influence compressive strength. The mixture containing 100% PP exhibits the lowest compressive strength, reaching 5.6 MPa at 7 days and slightly decreasing to 5.2 MPa at 28 days, suggesting limited strength development without PS substitution. As the PS content increases from 10% to 30%, a gradual improvement in compressive strength is observed. At the 70% PP : 30% PS mixture, the compressive strength increases to 9.3 MPa at 7 days and 8.7 MPa at 28 days.

The optimum performance among the substituted mixtures is achieved at 60% PP : 40% PS, where compressive strength reaches 10.3 MPa at 7 days and significantly increases to 15.1 MPa at 28 days. This improvement indicates that a higher PS content enhances particle packing, interfacial bonding, and microstructural densification during curing. For

comparison, the conventional paving block (0% substitution) demonstrates the highest compressive strength, attaining 18.5 MPa at 28 days, serving as the benchmark performance. Nevertheless, the results suggest that PS substitution up to 40% provides a promising alternative material for paving block production, particularly for non-structural applications, while supporting material efficiency and sustainability objectives.

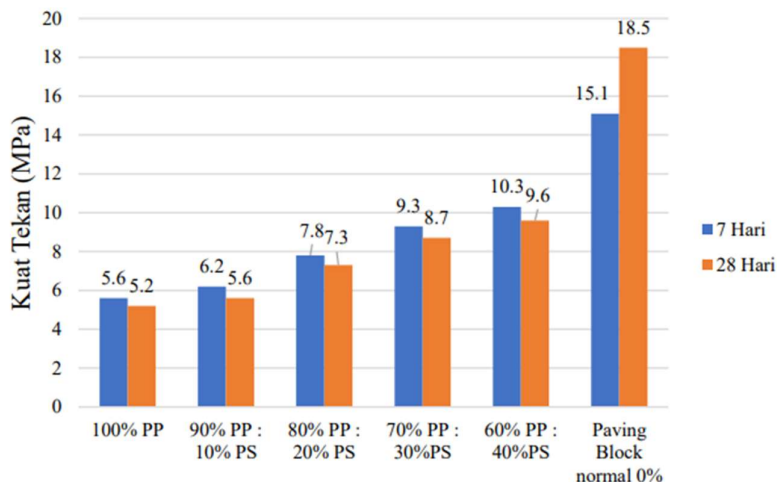


Figure 3.

Final Compressive Strength Graph

Paving Block

3.3. Water Absorption Characteristics

Water absorption values ranged from 1.39% to 2.36% across all mixtures, as described in Table 1. The lowest absorption was observed in the 60% PP:40% sand mixture, while the highest occurred in the 80% PP:20% sand mixture. The generally low absorption values are associated with the hydrophobic nature of polypropylene, which limits water penetration. Despite favorable absorption characteristics, the results did not fully meet the standard requirements, indicating that further optimization of mix proportions is necessary.

Table 1. Water absorption result

Variation mix	Average water absorption value (%)
100% PP	1,45
90% PS, 10% PP	1,64
80% PS, 20% PP	2,36
70% PS, 30% PP	1,66
60% PS, 40% PP	1,39

3.4. Discussion

The experimental results indicate that the mechanical and physical performance of paving blocks is strongly influenced by the proportion of polypropylene plastic waste used in the mixture. The decrease in compressive strength with increasing polypropylene content reflects the fundamental difference between thermoplastic-based and cement-based binding mechanisms. Polypropylene does not undergo hydration or chemical hardening; therefore, load transfer within the paving block matrix relies primarily on physical adhesion and mechanical interlocking between the molten plastic and sand particles. When the polypropylene content is excessive, the reduction in granular skeleton and internal friction leads to lower load-bearing capacity. The reduction in compressive strength observed at 28 days further confirms the absence of time-dependent strength development in polypropylene-based paving blocks and may be associated with interfacial stress relaxation or microstructural weakening over time. This behavior is consistent with previous studies on HDPE- and LDPE-based paving blocks, which also reported strength degradation at later curing ages. In contrast, water absorption values remained relatively low for all mixtures due to the hydrophobic nature of polypropylene, indicating good resistance to moisture ingress. However, low water absorption alone does not compensate for insufficient mechanical strength, as structural performance remains the primary criterion for paving block applications. Consequently, paving blocks incorporating moderate proportions of polypropylene plastic waste may be suitable for

non-structural and low-load applications such as pedestrian pathways and landscape pavements, while further material optimization is required to achieve compliance with national standards.

4. Conclusions

This study investigated the feasibility of utilizing polypropylene plastic waste as a primary material in paving block production by evaluating its compressive strength and water absorption characteristics. Based on the experimental results, it can be concluded that the proportion of polypropylene plastic waste plays a critical role in determining the mechanical performance of paving blocks. Increasing polypropylene content generally led to a reduction in compressive strength, reflecting the non-cementitious and thermoplastic nature of the material, which relies on physical adhesion rather than chemical bonding mechanisms.

The highest compressive strength was achieved by paving blocks containing 60% polypropylene plastic waste and 40% sand, which reached an average strength of 9.6 MPa at 7 days and met the requirements for quality grade D paving blocks intended for pedestrian use. In contrast, mixtures with higher polypropylene content exhibited insufficient strength and experienced a noticeable decrease in compressive strength at 28 days, indicating the absence of time-dependent strength development typically observed in cement-based materials. This strength reduction highlights an inherent limitation of polypropylene-based paving blocks when used without supplementary binders.

Water absorption test results demonstrated relatively low absorption values for all mixture variations, ranging from 1.39% to 2.36%, which can be attributed to the hydrophobic properties of polypropylene. Although low water absorption is beneficial for durability, it does not directly translate into improved structural performance. Consequently, the overall applicability of polypropylene-based paving blocks remains constrained by mechanical strength rather than moisture resistance.

In summary, polypropylene plastic waste shows potential for reuse in non-structural paving applications, particularly in pedestrian pathways, parks, and landscape pavements, while simultaneously contributing to plastic waste reduction and sustainable construction practices. However, to achieve broader applicability and full compliance with national standards, further research is recommended to optimize mixture compositions, enhance interfacial bonding, or incorporate hybrid cementitious or geopolymer binders.

5. Declarations

5.1. Author Contributions

Conceptualization, S.A.A.K.J.A.A.K.M., Y.A.S.; and N.H., methodology, Y.A.S.; software, N.H.; validation, S.A.A.K.J.A.A.K.M., and A.F.K.K.; formal analysis, Y.A.S.; investigation, A.; resources, Y.A.S.; data curation, N.H.; writing—original draft preparation, S.A.A.K.J.A.A.K.M.; writing—review and editing, A.F.K.K.; visualization, A.F.K.K.; supervision, Y.A.S.; project administration, N.H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

Funding information is not available.

5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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