ISSN 2964-0490

Design and Development of a Mobile Plastic Paving Block Unit for the Revitalization of the Parking Area at the Faculty of Engineering, Universitas Graha Nusantara Padangsidimpuan

Ahmad Rafii
Civil Engineering Study Program, Faculty of Engineering, Universitas Graha Nusantara, Padangsidimpuan, Indonesia
Email: rafiia336@gmail.com

Pavement damage and standing water in the parking area of the Faculty of Engineering, Universitas Graha Nusantara (UGN) Padangsidimpuan indicate that sustainable infrastructure principles have not yet been optimally applied in the revitalization of campus facilities, while the national plastic-waste recycling rate remains low. This study aims to analyze the existing condition of the pavement, examine the potential of plastic waste as an environmentally friendly paving-block material, and design a mobile plastic paving-block unit that is technically feasible for revitalizing the parking area. The study employs an engineering-based research approach at Technology Readiness Level (TRL) 3, drawing on field observation, compressive-strength and water-absorption testing of four polypropylene (PP) plastic-waste mix compositions, and functional testing of the mobile-unit prototype across five production batches. The results show that the existing pavement damage ratio reaches 34.0% of the total parking area, dominated by standing water and alligator cracking. The PP:sand 60:40 composition yields a compressive strength of 15.6 MPa and a water absorption of 2.1%, satisfying SNI 03-0691-1996 Grade C for pedestrian walkways and two-wheeled-vehicle parking, but not yet meeting Grade B for four-wheeled-vehicle parking. The mobile unit achieved an average production efficiency of 87.2%, rising from 76% in the first batch to 92% in the fifth. This study contributes an integration of plastic-waste-based material innovation with a mobile, field-deployable production system, distinct from conventional approaches that remain static and laboratory-oriented, and provides a foundation for advancing to the next technology readiness stage.

Keywords: Plastic paving block, plastic waste, mobile production unit, parking area revitalization, sustainable infrastructure

Corresponding Author:
Ahmad Rafii
Graha Nusantara University
Padangsidimpuan
rafiia336@gmail.com

1. Introduction

Global plastic production has exceeded 400 million tonnes per year, while the global recycling rate remains below 10%, so that most plastic waste ends up in landfills or pollutes terrestrial and marine environments [1]. Without improvements in waste-management systems, the amount of plastic waste entering aquatic ecosystems is projected to keep rising over the coming decade, since current mitigation efforts have not kept pace with the growth of global plastic production [2][3]. This situation places plastic-waste management among the most pressing environmental issues, one that calls for applied technological innovation rather than consumption-restriction policy alone.

The urgency of this problem is equally evident at the institutional level. The construction sector has substantial capacity to absorb large volumes of plastic waste through non-structural building-material innovations such as paving blocks, which have been shown capable of utilizing various types of plastic waste as a partial or complete substitute for natural aggregate [4]. Numerous studies report that plastic-based paving blocks offer the advantages of relatively light density and low water absorption compared

ISSN 2964-0490

with conventional concrete paving blocks, making them a promising material solution that simultaneously addresses environmental concerns and lightweight-infrastructure needs [5].

The scope of this study is centered on the revitalization of the parking area at the Faculty of Engineering, Universitas Graha Nusantara (UGN) Padangsidimpuan, which currently suffers from pavement damage and standing water that compromise the comfort and safety of the academic community. The study focuses on three aspects: the technical condition of the existing pavement, the mechanical feasibility of plastic-waste-based paving block as an alternative material, and the operational feasibility of a mobile production system that can be deployed directly at the revitalization site—so that the scope of the research does not stop at material characterization in the laboratory, as has commonly been the case in prior studies [6][7].

Based on the foregoing, this study aims to: (1) analyze the existing condition of the parking area at the Faculty of Engineering, UGN Padangsidimpuan, in terms of pavement performance and infrastructure sustainability; (2) examine the potential of plastic waste as an environmentally friendly paving-block material through technical characterization testing; and (3) design and develop a mobile plastic paving-block unit that is technically feasible and applicable as a solution for campus infrastructure revitalization, as a proof of concept at Technology Readiness Level (TRL) 3.

2. Literature Review and Problem Statement

The mechanical characterization of plastic-waste-based paving block and concrete has been extensively studied over the past decade. Al-Hadithi, Hilal, and Taha [6] reported that adding plastic waste to self-compacting concrete tends to reduce compressive strength while improving casting characteristics, while Siddique, Khatib, and Kaur [8] and Ismail and Al-Hashmi [9] consistently showed that substituting natural aggregate with plastic reduces both weight and water absorption, albeit accompanied by a compressive-strength reduction proportional to the plastic fraction used. Askar and Dawood [10], [11] further noted that the size and shape of plastic particles influence stress distribution within the composite matrix, indicating that the variability of results across studies is largely attributable to differences in the type and geometry of the plastic waste used rather than the substitution ratio alone.

At the systematic-review level, Zulkernain et al. [12] synthesized more than 160 studies on the use of plastic as aggregate in concrete, mortar, paving block, and brick, concluding that plastic-based materials generally still satisfy construction standards despite reductions in mechanical properties and durability at high substitution rates. Similar conclusions were drawn by Babafemi et al. [13] and Gu and Ozbakkaloglu [13] [14]who emphasized that the most realistic application for plastic-based concrete or paving block is as a non-structural element subject to light-to-moderate loading, rather than as a primary structural element. Almohana et al. [15][16] reinforced this argument from a sustainability perspective, showing that the environmental benefits of plastic substitution in concrete must be balanced against an optimal mix composition to keep mechanical performance adequate for the intended application.

Problem Statement: although the scientific evidence for the technical feasibility of plastic-based paving-block material is fairly consistent [6], [17], all of these studies were conducted at laboratory scale using static, centralized production systems a limitation also found in studies on the utilization of non-plastic waste for construction materials [8]. No model has yet integrated the utilization of plastic waste with a portable production system that can be operated directly at an infrastructure-revitalization site, particularly for a specific context such as an educational institution's parking area that requires small-to-medium-scale production flexibility. Based on this gap, the research problems addressed are: (1) what is the existing condition of the parking area at the Faculty of Engineering, UGN Padangsidimpuan, in terms of pavement performance and infrastructure sustainability; (2) what is the potential for utilizing plastic waste as an environmentally friendly paving-block raw material for parking-area revitalization; and (3) how can a mobile plastic paving-block unit be designed and developed that is technically feasible and applicable to support that revitalization.

3. Method

This study employs an engineering-based research method oriented toward developing an appropriate-technology prototype as a proof of concept at Technology Readiness Level (TRL). This method was chosen because it is effective for producing applicable solutions through the integration of material innovation and a production system that is tested directly under real-world conditions, in contrast to purely experimental approaches that stop at laboratory material characterization as in most prior studies [6]. The research design is iterative, comprising five stages: needs analysis, technical design, initial prototype fabrication, production and initial testing, and deployability evaluation, as illustrated in Figure 1.

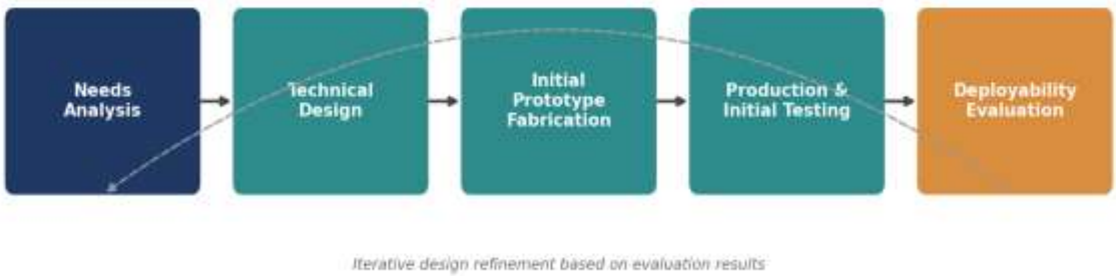

Figure 1. Iterative Research Design Flow

The object of the study is the parking area of the Faculty of Engineering, UGN Padangsidimpuan, with a measured total area of 850 m². The design materials comprise sorted polypropylene (PP) plastic waste as the primary non-structural paving-block material, mechanical components and the mobile-unit frame, a heating and mixing system, and paving-block molds of the standard 20 cm × 10 cm × 6 cm size. The material test samples consisted of four mix-composition variants of PP plastic waste and sand (100:0, 80:20, 70:30, and 60:40 by weight fraction), each with three specimens (n = 3 per composition, 12 specimens in total), together with one control group of conventional K-175-grade concrete paving block for comparison. Functional testing of the mobile unit was conducted across five consecutive production batches to observe the stabilization pattern of operational performance over time.

Data collection was carried out through three channels tailored to each research problem: field observation and technical documentation for the existing pavement condition; material collection and technical testing (compressive strength and water absorption) for the characteristics of the plastic paving block, referring to SNI 03-0691-1996; and technical documentation and functional testing for the operational performance of the mobile unit.

Data were analyzed using a descriptive-technical approach. The existing pavement condition was analyzed through the pavement damage ratio (Pk):

$$Pk = \frac{Ak}{At} x\, 100\% \quad (1)$$

where Ak is the area of damaged pavement (m²) and At is the total parking area (m²). The compressive strength (fc) of the paving block was calculated as:

$$fc = \frac{F}{A} \quad (2)$$

where F is the maximum load applied during testing (N) and A is the compressed cross-sectional area of the specimen (mm²), wh ile water absorption (W) was calculated as:

ISSN 2964-0490

$$W = \frac{(W_b - W_k)}{W_k} \, x \, 100\% \quad (3)$$

where Wb is the wet specimen weight (grams) and Wk is the dry specimen weight (grams). The operational performance of the mobile unit was analyzed through production efficiency (Ep):

$$E_p = \frac{Q_a}{Q_r} \, x \, 100\% \quad (4)$$

where Q^a is the number of paving blocks actually produced and Qr is the number of paving blocks corresponding to the planned or designed capacity.

4. Results and Discussion

Field observation of the 850 m² parking area at the Faculty of Engineering, UGN Padangsidimpuan identified 289 m² of damaged pavement, yielding a pavement damage ratio (Pk) of 34.0%. This figure indicates that more than a third of the parking-area surface is in a suboptimal condition, directly affecting user comfort and safety, particularly during the rainy season.

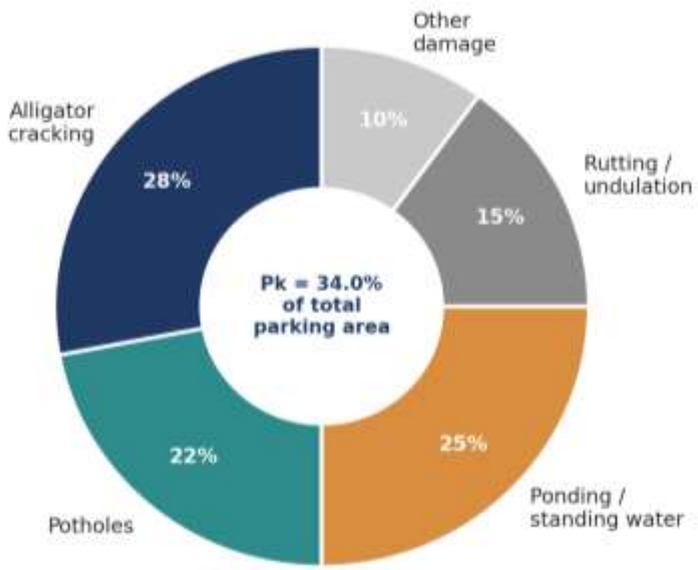

Figure 2. Proportion of Pavement Damage Types at the Parking Area, Faculty of Engineering, UGN Padangsidimpuan

Figure 2 shows that standing water (25%) and alligator cracking (28%) are the two dominant damage types, followed by potholes (22%), rutting/undulation (15%), and other damage (10%). This pattern is consistent with the characteristics of conventional pavement, whose drainage performance deteriorates over time as recurring standing water accelerates the softening of the sub-base layer and triggers further cracking. The 34.0% damage ratio serves as a quantitative baseline that reinforces the urgency of revitalization using an alternative material more resistant to standing water.

Technical testing of the four PP-plastic-and-sand mix compositions revealed a pattern consistent with the literature: increasing the sand proportion raises compressive strength while also increasing water absorption, although both remain far more favorable than those of conventional concrete paving block.

 ISSN 2964-0490

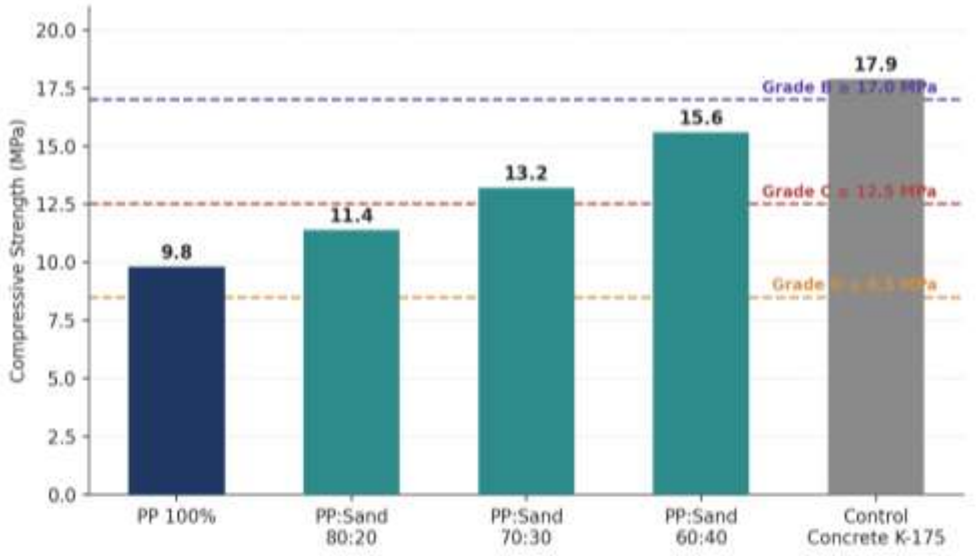

Figure 3. Compressive Strength of Plastic Paving Block at Various Compositions Compared to SNI 03-0691-1996 Quality Thresholds

Figure 3 shows that the pure-PP (100%) composition yielded a compressive strength of only 9.8 MPa, marginally above the SNI 03-0691-1996 Grade D threshold (≥8.5 MPa). Progressively adding sand increased the compressive strength to 11.4 MPa (80:20), 13.2 MPa (70:30), and 15.6 MPa (60:40). The 70:30 and 60:40 compositions satisfied the Grade C threshold (≥12.5 MPa) for pedestrian walkways and two-wheeled-vehicle parking, but none of the plastic-based compositions reached the Grade B threshold (≥17.0 MPa) required for four-wheeled-vehicle parking, as demonstrated by the K-175 concrete control, which reached 17.9 MPa. This decreasing trend in compressive strength with increasing plastic fraction is consistent with the findings of Al-Hadithi et al. [6] and Siddique et al. [17], who attribute it to the generally weaker bond between plastic particles and the binder matrix compared with conventional mineral aggregate.

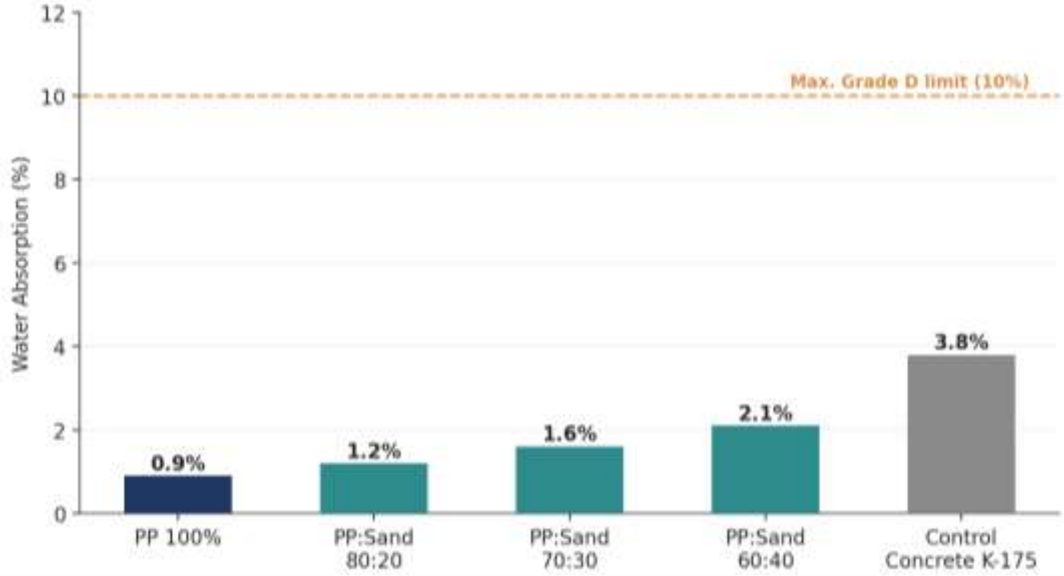

Figure 4. Water Absorption of Plastic Paving Block at Various Mix Compositions

In terms of water absorption, Figure 4 shows that all plastic-based compositions (0.9%–2.1%) fall well below the maximum limits of both Grade D (10%) and Grade C (8%), and are markedly lower than the conventional concrete control (3.8%). This finding confirms the comparative advantage of plastic paving block reported by Ismail and Al-Hashmi [18] and Gu and Ozbakkaloglu [14] namely, the non-porous nature of plastic that inhibits water penetration into the material. Given that standing water dominates the existing damage pattern (Figure 2), this low water-absorption characteristic represents a strategic advantage for the revitalization of the Faculty of Engineering parking area. Table 1 summarizes the technical test results together with the corresponding SNI quality grades and application recommendations.

Table 1. Summary of Technical Test Results for Plastic Paving Block (Referring to SNI 03-0691-1996)

Composition (PP:Sand)	Compressive Strength (MPa)	SNI Grade (Strength)	Water Absorption (%)	SNI Grade (Absorption)	Recommendation
PP 100%	9,8	D	0,9	D/C/B	Garden/park
80 : 20	11,4	D	1,2	D/C/B	Garden/park
70 : 30	13,2	C	1,6	D/C/B	Pedestrian, 2-wheel
60 : 40	15,6	C	2,1	D/C/B	Pedestrian, 2-wheel
Control K-175	17,9	B	3,8	D/C/B	4-wheel parking

The mobile plastic paving-block unit prototype was designed as a wheeled frame integrating three main subsystems: a heating system to melt the sorted plastic waste, a mixing system to homogenize the plastic-and-sand blend, and a modular molding unit. This configuration allows the unit to be operated directly at the revitalization site without requiring raw materials to be transported to a centralized production facility, addressing the static-production-system limitation identified in prior studies [16].

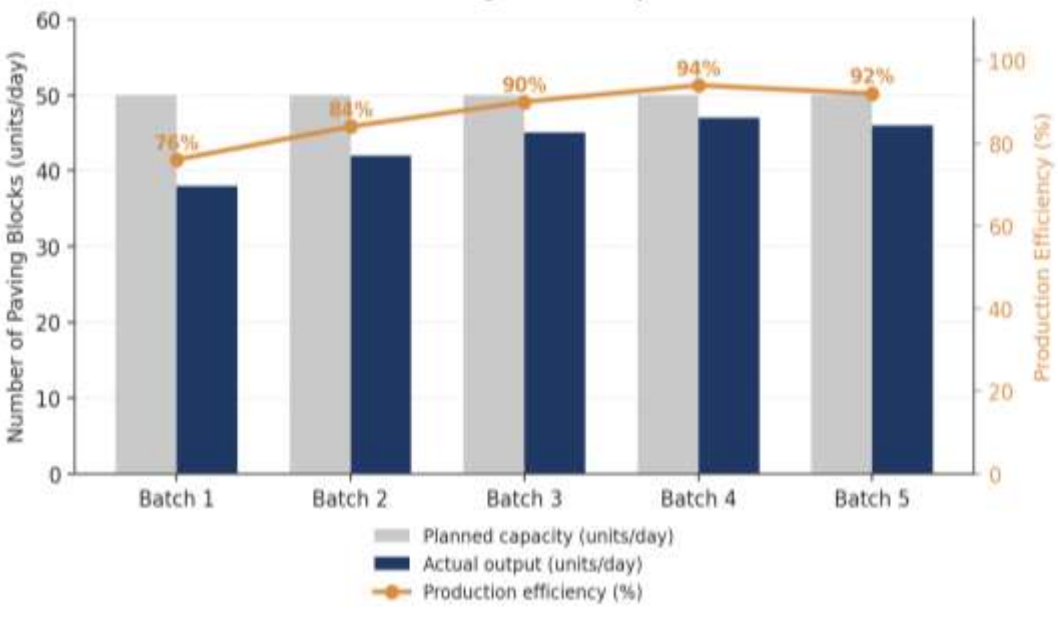

Figure 5. Planned Capacity vs. Actual Output and Efficiency of the Mobile Unit per Test Batch

Figure 5 shows an increasing trend in actual output, from 38 units in the first batch to 46 units in the fifth, with production efficiency rising from 76% to 92% and an overall average efficiency of 87.2%. This pattern indicates an operational learning curve, in which technical adjustments to heating temperature, mixing duration, and mold-release time contributed to progressive performance improvements from batch to batch. The gap between planned capacity and actual output in the early batches was mainly caused by mold cooling time, which acted as the limiting factor for production rate—a finding consistent with the

ISSN 2964-0490

mixture-homogeneity challenges and their effect on the fresh and hardened properties of plastic-waste-based materials reported in previous self-compacting-concrete studies [19].

Taken together, the integration of findings on the existing condition, material characteristics, and mobile-unit performance yields three key insights. First, the low water-absorption characteristic of plastic paving block directly addresses the dominant problem in the existing parking area—standing water—making this material choice contextually responsive to the site-specific problem rather than merely a generic waste-management solution. Second, the compressive-strength ceiling that falls short of Grade B for four-wheeled-vehicle parking indicates that the plastic paving block developed in this study is best positioned as a phased zoning solution—applied to pedestrian walkways and two-wheeled-vehicle parking, while high-load zones continue to use conventional pavement—rather than as a full substitute, as often implicitly assumed in laboratory feasibility studies [6][17][12][14]. Third, the operational learning curve observed in the mobile unit demonstrates that deployability is as important as the mechanical feasibility of the material itself, and that both should be evaluated simultaneously from the proof-of-concept stage onward to accelerate progression toward a higher technology readiness level.

5. Conclusion

This study draws three main conclusions that address its objectives. First, the existing condition of the parking area at the Faculty of Engineering, UGN Padangsidimpuan, shows a pavement damage ratio of 34.0% of the total 850 m² area, dominated by standing water and alligator cracking, indicating that sustainable infrastructure principles have not yet been optimally applied at this campus facility. Second, polypropylene plastic waste is shown to have potential as an environmentally friendly paving-block material: the PP:sand 60:40 composition achieved a compressive strength of 15.6 MPa and a water absorption of 2.1%, satisfying SNI 03-0691-1996 Grade C for pedestrian walkways and two-wheeled-vehicle parking, although it does not yet meet Grade B for four-wheeled-vehicle parking. Third, the design and development of the mobile plastic paving-block unit proved technically and functionally feasible, achieving an average production efficiency of 87.2% with a consistent upward trend from 76% to 92% across five test batches, thereby demonstrating proof of concept (TRL 3) for integrating plastic-waste material with a portable production system.

The contribution of this study lies in a campus-infrastructure revitalization model that integrates plastic-waste utilization with a field-deployable mobile production system, distinct from conventional approaches that remain static and laboratory-oriented [6], [17]. The recommended revitalization strategy is a phased zoning approach: plastic paving block for pedestrian walkways and two-wheeled-vehicle parking, while four-wheeled-vehicle parking zones continue to rely on conventional pavement until a mix composition with higher compressive strength is successfully developed. Future research should focus on optimizing the mix composition to achieve Grade B, refining the mold-cooling system, and conducting long-term durability testing under cyclic loading and weather exposure, as part of advancing the Technology Readiness Level toward full-scale implementation.

6. Referensi

[1] R. Geyer, J. R. Jambeck, and K. L. Law, "Production , use , and fate of all plastics ever made," *Sci. Adv.*, vol. 7, no. July, pp. 25–29, 2017, doi: https://www.science.org/doi/10.1126/sciadv.1700782.

[2] J. R. Jambeck *et al.*, "Supplementary Materials for Plastic waste inputs from land into the ocean," *Sci. AAAS*, vol. 347, no. 768, p. 15, 2015, doi: 10.1126/science.1260352.

[3] S. B. Borrelle *et al.*, "Supplementary Materials for Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution Stephanie," *Sci. AAAS*, vol. 369, no. 1515, p. 24, 2020, doi:

ISSN 2964-0490

10.1126/science.aba3656.

[4] P. O. Awoyera and A. Adesina, "Case Studies in Construction Materials Plastic wastes to construction products : Status , limitations and future perspective," *Case Stud. Constr. Mater.*, vol. 12, pp. 1–11, 2020, doi: 10.1016/j.cscm.2020.e00330.

[5] N. Saikia and J. De Brito, "Waste Polyethylene Terephthalate as an Aggregate in Concrete," *Mater. Res.*, vol. 16, no. 2, pp. 341–350, 2017, doi: 10.1590/S1516-14392013005000017.

[6] A. I. Al-hadithi and N. N. Hilal, "The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fi bers," *J. Build. Eng.*, vol. 8, pp. 20–28, 2016, doi: 10.1016/j.jobe.2016.06.011.

[7] Medrilzam *et al.*, *Ekonomi Sirkular Indonesia 2025 – 2045*. Jakarta: Bappenas, 2025.

[8] O. M. Okeyinka, D. A. Oloke, and J. M. Khatib, "A Review on Recycled Use of Solid Wastes in Building Materials," *Int. J. Civ. Environ. Eng.*, vol. 9, no. 12, pp. 1570–1579, 2015.

[9] M. D. Basuki, Burhanuddin, "Pemanfaatan Limbah Plastik Bekas Untuk Bahan Utama Pembuatan Paving Block," *J. Rekayasa Lingkung.*, vol. 18, no. 1, pp. 1–7, 2018.

[10] M. K. Askar, Y. S. S. Al-Kamaki, and A. Hassan, "Utilizing Polyethylene Terephthalate PET in Concrete: A Review," *Polymers (Basel).*, vol. 15, pp. 1–38, 2023, doi: https://doi.org/10.3390/ polym15153320 Academic.

[11] A. O. Dawood, Al-khazraji, Hayder, Falih, and R. S, "Physical and mechanical properties of concrete containing PET wastes as a partial replacement for fine aggregates," *Case Stud. Constr. Mater.*, vol. 14, p. e00482, 2021, doi: 10.1016/j.cscm.2020.e00482.

[12] N. Hanis, P. Gani, N. Chuck, and T. Uvarajan, "Utilisation of plastic waste as aggregate in construction materials : A review," *Constr. Build. Mater.*, vol. 296, p. 123669, 2021, doi: 10.1016/j.conbuildmat.2021.123669.

[13] A. J. Babafemi, B. Šavija, S. C. Paul, and V. Anggraini, "Engineering Properties of Concrete with Waste Recycled Plastic : A Review," *Sustainability*, vol. 10, pp. 1–26, 2018, doi: 10.3390/su10113875.

[14] T. O. Lei Gu, "Use of recycled plastics in concrete: A critical review," *Waste Manag.*, vol. 51, pp. 19–42, 2016, doi: 10.1016/j.wasman.2016.03.005.

[15] A. M. R. Azizah, Anisah, Indra Ariani, Kayla Fatima, Fathia Syafira, "BETON RAMAH LINGKUNGAN : SOLUSI HIJAU Untuk Konstruksi Masa Depan," *J. Teknol. Sipil*, vol. 8, no. 2, pp. 35–40, 2024.

[16] A. I. Almohana, M. Y. Abdulwahid, I. Galobardes, J. Mushtaq, and S. F. Almojil, "Producing Sustainable Concrete with Plastic Waste : a review," *Environ. Challenges*, vol. 9, p. 100626, 2022, doi: 10.1016/j.envc.2022.100626.

[17] R. Siddique, J. M. Khatib, and I. Kaur, "Use of recycled plastic in concrete : A review," *Manag. Waste*, vol. 28, no. December, pp. 1835–1852, 2007, doi: 10.1016/j.wasman.2007.09.011.

[18] M. Najmi, F. Firdaus, A. Pujiati, and S. Fitriana, "Implementasi Strategi Penanggulangan Sampah Plastik di Universitas Negeri Semarang : Menuju Green Campus," *J. Ilmu Lingkung.*, vol. 23, no. 3, pp. 751–766, 2025, doi: 10.14710/jil.23.3.751-766.

[19] B. S. and R. C. Youcef Ghernouti, Bahia Rabehi, "USE OF RECYCLED PLASTIC BAG WASTE IN THE CONCRETE," *J. Int. Sci. Publ. Mater. Methods Technol.*, vol. 8, pp. 480–487, 2019.