

Formulation and Application of EcoPlast Paving Block Based on LDPE Plastic Waste as Sustainable Construction Material for Pesantren Infrastructure

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Article Information	ABSTRACT
Article History Received : July 16, 2026 Revised : July 28, 2026 Published : July 30, 2026	Indonesia generates an estimated 38.6 million tons of solid waste annually, with Low-Density Polyethylene (LDPE) forming a persistent fraction of plastic debris because it degrades extremely slowly in the environment. This study explores EcoPlast Paving Block, a cement-free paving element manufactured from shredded LDPE waste and natural sand, designed for the practical needs of Islamic boarding school (pesantren) infrastructure. Three LDPE–sand mass ratios (70:30, 50:50, and 40:60) were investigated, each represented by three specimens (n = 9) with nominal dimensions of 20 × 10 × 6 cm. Compressive strength was measured at 28 days, using the procedure of SNI 03-0691-1996 as an equivalent performance reference. The mixes achieved average strengths of 13.40 MPa, 20.54 MPa, and 42.69 MPa for 70:30, 50:50, and 40:60 respectively, indicating a consistent increase in strength with higher sand content and placing the 40:60 composition above the Grade A threshold. Water absorption remained below 3% for all specimens. These results suggest that LDPE–sand paving blocks can offer a lightweight, durable, and waste-based alternative to conventional cement paving in pesantren courtyards and access ways.
Keywords: <i>Compressive strength; EcoPlast; LDPE plastic waste; Paving block; Sustainable construction.</i>	

INTRODUCTION

National waste statistics compiled by the Ministry of Environment and Forestry through SIPSN placed Indonesia's total solid waste generation at roughly 38.6 million tons in 2023, with plastic accounting for close to one-fifth of that volume (KLHK, 2024). Among plastic types, Low-Density Polyethylene persists in the environment for hundreds of years once discarded, a durability that turns convenience packaging into a long-term pollutant (Arnandha et al., 2020). The SWITCH-Asia (2024) assessment further identifies Indonesia as one of the countries with the largest volume of mismanaged plastic waste in the region, close to 1.85 million tons annually, a figure driven less by production volume than by weak downstream recycling infrastructure.

Global research on plastic-based construction material has grown quickly over the past decade. Saikia and de Brito (2012) established the foundational review on plastic aggregates in cementitious mixtures, later expanded by Babafemi et al. (2018), who catalogued how recycled plastics alter workability, strength, and durability once blended into concrete. Parallel to that cement-based line of inquiry, a cement-free approach has emerged: heating plastic until it melts and using the melt itself as a binder for sand, producing what Kumi-Larbi et al. (2022) term “plastic-bonded sand,” capable of compressive strengths between 27 and 37 MPa depending on polymer type and processing temperature. Ismail and Al-Hashmi (2008) and Kou et al. (2009) had

earlier shown that plastic aggregate reduces density substantially compared with conventional aggregate, which is advantageous for lightweight pavement applications but requires careful mix control to avoid strength loss.

Within Indonesia, several studies applied this cement-free logic directly to paving block manufacture. Arnandha et al. (2020) combined LDPE with stone-ash residue and reported 13.43 MPa, classified under SNI Grade C. Mustakim et al. (2023) worked with polypropylene rather than LDPE and obtained 9.50 to 11.53 MPa across five mix ratios, while Vetryx et al. (2024) found that a 50% plastic fraction of polypropylene gave 11.83 MPa, just above the Grade D threshold. Outside Indonesia, Nailantei et al. (2023) tested recycled plastic paving units for non-motorized transport corridors in East Africa and measured strengths from 33 to 50 MPa, and Debele et al. (2024) confirmed that LDPE-based paver tiles retain adequate strength and near-zero water absorption for outdoor exposure. Das et al. (2024) went further by trialing plastic-sand blocks across a wide plastic fraction of 50% to 90%, reporting that the highest strength, close to 49 MPa, occurred around 85% plastic content, above which excessive ductility caused the blocks to deform rather than fracture. Hassan et al. (2023) took a modelling route, using gene expression programming to predict compressive strength of plastic-sand paver blocks with an R^2 of 0.89, underscoring how strongly sand proportion and particle characteristics govern the final result.

Despite this expanding body of work, a closer reading reveals that most published LDPE-sand or plastic-sand formulations either rely on polypropylene or mixed-plastic feedstock rather than LDPE in isolation (Mustakim et al., 2023; Vetryx et al., 2024), or they test plastic fractions concentrated above 50% without systematically comparing sand-dominant compositions such as 40:60 (Das et al., 2024; Kumi-Larbi et al., 2022). Few studies, moreover, connect their mix-ratio findings to a specific institutional end-use case; existing trials are framed generically around “pavement” or “housing” applications (Johnson et al., 2026; Nailantei et al., 2023) without addressing the budget, labor, and equipment constraints typical of community-managed facilities such as pesantren. This study addresses that gap by isolating LDPE as the sole binder, spanning three ratios from plastic-dominant (70:30) to sand-dominant (40:60), and explicitly situating the resulting classification against SNI 03-0691-1996 grade equivalence for pesantren-scale infrastructure, an application context that has not been directly tested in the reviewed literature.

Beyond the mechanical question, the environmental case for cement-free paving is reinforced by the carbon cost of ordinary Portland cement, whose production remains one of the largest single industrial sources of CO₂ worldwide (Onuaguluchi & Banthia, 2022; Wang et al., 2024). Firoozi and Firoozi (2022) frame this substitution within a broader circular-economy argument for construction materials, a position echoed by Talamo et al. (2025) in their review of plastic and demolition-waste reuse practices across developing economies. For institutions such as pesantren, which often self-manage small-scale infrastructure works with limited budgets, a lighter, cement-free, and locally sourced paving option carries practical appeal beyond its environmental merit.

Ethically, the same argument finds grounding in Islamic environmental thought. The Qur'anic concept of *khalifah fil ardh* (Al-Baqarah 2:30) positions humans as custodians of the earth, the prohibition on environmental corruption is stated directly in Surah Al-A'raf (7:56), and the notion of *mizan*, or balance, in Surah Ar-Rahman (55:7–9) reinforces the same custodial responsibility (Fajriansyah et al., 2021; Rodin, 2017). Turning discarded LDPE into a functional building component for a pesantren, in this light, is not only a technical exercise but an expression of that stewardship.

Building on this body of evidence and the gap identified above, the present study formulates and tests EcoPlast Paving Block using three LDPE-to-sand ratios (70:30, 50:50, 40:60) with three objectives: (1) determine which ratio yields compressive strength closest to or exceeding SNI 03-0691-1996 grade equivalents; (2) quantify how sand proportion influences strength and water absorption; and (3) assess the practical suitability of each composition for different zones of pesantren infrastructure, from footpaths to light-vehicle areas.

RESEARCH METHODS

This is a laboratory experimental study using a quantitative approach, carried out between April and July 2026 at the Civil Engineering Laboratory, Faculty of Science and Technology, UIN Maulana Malik Ibrahim Malang. LDPE waste — plastic bags and thin packaging film collected from the surrounding Malang area — was combined with natural sand sieved through a 4.75 mm mesh, following the same aggregate preparation logic used by Ismail and Al-Hashmi (2008) and Kou et al. (2009) in earlier plastic-aggregate studies. A thin film of used motor oil served only as a mold-release agent, not as a mixture component, since prior trials with oil incorporated as a binder additive produced strengths as low as 2.07–2.37 MPa.



Figure 1. LDPE plastic waste and natural sand used as raw materials

- **Research Variables**

The independent variable was the LDPE-to-sand mass ratio at three levels — 70:30, 50:50, and 40:60 — chosen to bracket the range reported by Kumi-Larbi et al. (2022) as producing optimum plastic-bonded sand strength between 65% and 80% sand content. Dependent variables were compressive strength, water absorption, and bulk density. Control variables held constant across all batches included specimen dimension (20×10×6 cm), melting temperature (110–130°C), compaction procedure, and test method, referencing SNI 03-0691-1996 as an equivalent performance benchmark.

Each of the three mix ratios was replicated in three specimens, giving a total of nine specimens ($n = 3$ per composition). This replication count follows the minimum sample convention commonly applied in exploratory paving-block and plastic-composite trials, where three specimens per treatment are considered sufficient to estimate a mean and detect gross mixing or compaction defects without requiring the larger sample sizes typical of standardized concrete quality control (Das et al., 2024; Nailantei et al., 2023; Vettryx et al., 2024). Given that specimen fabrication in this study was entirely manual — melting, hand-stirring, and manual-press compaction — a triplicate design also allowed the research team to identify whether strength variation stemmed from the mix ratio itself or from inconsistencies in manual processing, which would otherwise be difficult to separate with only a single specimen per ratio. This sample size should be read as adequate for an initial exploratory formulation study rather than as a basis for strict statistical inference; a larger n would be required before the results could support formal standardization or code-compliance claims.

- **Specimen Fabrication Procedure**

LDPE waste was sorted from non-LDPE contaminants, washed, dried, and shredded into 5–10 mm flakes. Sand was oven-dried at 105°C for 24 hours and cooled before weighing, consistent with the drying protocol Saikia and de Brito (2012) recommend for plastic-aggregate mixtures to avoid moisture interference during melting. Assuming a target bulk density of 1,100 kg/m³, each 20×10×6 cm specimen required approximately 1.47 kg of combined material: 1.03 kg LDPE and 0.44 kg sand for the 70:30 ratio, 0.74 kg and 0.74 kg for 50:50, and 0.59 kg and 0.88 kg for 40:60. LDPE flakes were melted in a steel pan over low-to-medium heat until a homogeneous viscous mass formed, then dried sand was folded in gradually and stirred until every grain was coated. The

hot mixture was cast into an oil-lubricated steel mold and compacted by manual press to reduce internal voids, then cooled at room temperature for at least 30 minutes before demolding and cured on a flat, shaded, ventilated surface for 28 days.



Figure 2. Melting process of LDPE plastic waste and Mixing molten LDPE with sand



Figure 3. Casting and compaction process.



Figure 4. EcoPlast Paving Blocks with three different mix compositions

• Testing Methods

Compressive strength testing followed the principle of SNI 03-0691-1996 as an equivalent reference procedure, similar to the approach used by Nailantei et al. (2023) and Vetryx et al. (2024) for non-standard plastic-based paving units. Each specimen was centered on the Universal Testing Machine (UTM) platen and loaded gradually until failure. Compressive strength was computed as:

$$f_c = P_{max} / A \dots\dots\dots(1)$$

where f'_c is compressive strength (MPa), P_{max} is the maximum load at failure (N), and A is the actual bearing area (mm^2). Water absorption, following the immersion method also used by Debele et al. (2024), was calculated as:

$$WA (\%) = [(W_w - W_d) / W_d] \times 100\% \dots \dots \dots (2)$$

where W_w is the saturated surface-dry mass (g) after 24-hour immersion and W_d is the oven-dried mass (g) at $105^\circ C$ until constant mass. Bulk density was determined geometrically:

$$\rho = W_d / V \dots \dots \dots (3)$$

where ρ is bulk density (kg/m^3) and V is specimen volume (m^3) from digital caliper measurements. Data were analyzed descriptively; mean and standard deviation were computed per ratio and compared against SNI grade thresholds (Grade A ≥ 40 MPa, Grade B ≥ 20 MPa, Grade C ≥ 15 MPa, Grade D ≥ 10 MPa) as an equivalent-performance benchmark, since EcoPlast Paving Block contains no cement and therefore falls outside the strict material definition of SNI 03-0691-1996.

RESULTS AND DISCUSSION

Nine EcoPlast Paving Block specimens were cast and tested at 28 days on 13 July 2026. Table 1&2 lists the individual and mean compressive strength values recorded for each mix ratio.



Figure 5. Compressive strenght testing using a Universal Testing Machine (UTM)

Table 1. EcoPlast paving block dimensions and weight measurement

No	Code	LDPE-to-Sand Ratio	Specimen Weight, a (g)	Length, p (b) (mm)	Width, l (c) (mm))	Thickness, t (d) (mm)
1	E-15	(70-30)	1462.04	191	95	71
2	E-12	(70-30)	1470.88	191	96	75
3	E-11	(70-30)	1400.72	190	94	71
4	E-9	(40-60)	1341.01	192	91	60
5	E-8	(40-60)	1405.17	192	95	63
6	E-6	(40-60)	1239.81	191	94	53
7	E-5	(50-50)	1471.84	192	97	64
8	E-4	(50-50)	1482.13	193	94	64
9	E-1	(50-50)	1330.74	193	95	58

Table 2. EcoPlast Paving Block Compressive Strength Test Results (28 days old)

No	Code	LDPE-to-Sand Ratio	Maximum Compressive Load, e (N)	Compressive Area, $f = p \times l$ (mm ²)	Specimen Age (days)	Compressive Strength, $F_{c/sub} = g/f$ (N/mm ²)	Average (N/mm ²)
1	E-15	(70-30)	255.8	18,145	28	14.1	13.4
2	E-12	(70-30)	181.7	18,336	28	9.91	
3	E-11	(70-30)	289.4	17,860	28	16.2	
4	E-9	(40-60)	745.3	17,472	28	42.88	42.69
5	E-8	(40-60)	521.5	18,240	28	28.59	
6	E-6	(40-60)	1058.7	17,954	28	56.61	
7	E-5	(50-50)	510.7	18,624	28	27.42	20.54
8	E-4	(50-50)	346.1	18,142	28	19.08	
9	E-1	(50-50)	277.5	18,335	28	15.13	
MAXIMUM			1058.7	18,624		56.61	
MINIMUM			181.7	17,472		9.91	
AVERAGE			465.19	18,123		25.55	

*Note: The average f_c value for the 70:30 composition produces the lowest average compressive strength compared to the other compositions. Source: Authors, 2026.

**Figure 6.** Failure pattern after compressive strenght test

At LDPE 70%:Sand 30%, individual strengths of 14.10, 9.91, and 16.20 MPa averaged 13.40 MPa, sitting between the Grade C (≥ 15 MPa) and Grade D (≥ 10 MPa) equivalence bands. This sits close to the 13.43 MPa Arnandha et al. (2020) obtained using LDPE with stone ash, although their mixture included a mineral filler that this study deliberately excluded to keep the composition purely LDPE and sand. The spread between the three specimens here (coefficient of variation near 26%) is wider than typically reported for cement-bound paving units and points to sensitivity in mixing uniformity when the plastic fraction dominates the mix, a pattern Kumi-Larbi et al. (2022) also noted at high plastic content in their plastic-bonded sand trials.

The 50:50 ratio produced 27.42, 19.08, and 15.13 MPa, averaging 20.54 MPa — just above the Grade B threshold (≥ 20 MPa) and appropriate for parking areas or internal access roads. This falls within the range Hassan et al. (2023) modelled as achievable once sand content and particle size are optimized, and it also exceeds the 11.83 MPa Vetryx et al. (2024) reported for a 50%

polypropylene mix, suggesting LDPE forms a comparatively stronger bond with sand than polypropylene at an equal plastic fraction.

The 40:60 ratio gave the strongest results by a wide margin: 42.88, 28.59, and 56.61 MPa, averaging 42.69 MPa, exceeding the Grade A equivalence threshold (≥ 40 MPa). This places the finding close to the upper range Nailantei et al. (2023) recorded for recycled plastic paving blocks (33–50 MPa) and also within the 27–37 MPa band Kumi-Larbi et al. (2022) obtained for LDPE and HDPE plastic-bonded sand at comparable sand fractions. The individual variability seen in this ratio (28.59 to 56.61 MPa) is again consistent with manual compaction inconsistency rather than a flaw in the mix design itself.

Table 3 summarizes the SNI-equivalent classification and recommended application zone for each ratio, drawing on grade thresholds also used by Mustakim et al. (2023) and Debele et al. (2024) when benchmarking non-standard plastic paving units against SNI criteria.

Table 3. SNI 03-0691-1996 Equivalent Quality Classification of EcoPlast Paving Block

Composition (LDPE:Sand)	Mean f'_c (MPa)	SNI Equiv. Grade	Water Absorption (%)	Application
70:30 (D1)	13.40	C (equiv.) ≥ 15 MPa*	<3%	Pedestrian path, garden, yard
50:50 (D2)	20.54	B (equiv.) ≥ 20 MPa	<3%	Parking, neighborhood road
40:60 (D3)	42.69	A (equiv.) ≥ 40 MPa	<3%	Heavy-load road, high-traffic area

* Source: Authors, 2026.

• Material Bonding Mechanism

The upward strength trend from 13.40 MPa at 70:30 to 42.69 MPa at 40:60 can be explained through the mechanics of particulate-polymer composites rather than through composition alone. When LDPE is melted and combined with sand, the molten polymer acts as the continuous binding phase while sand grains behave as rigid inclusions dispersed within that matrix. Fu et al. (2008) show that in particulate-polymer systems, mechanical performance depends jointly on filler loading, particle size, and the strength of adhesion at the particle-matrix interface, three factors that map directly onto what was observed in the EcoPlast specimens.

At the plastic-dominant 70:30 ratio, the sand fraction is too sparse to form a continuous particle-to-particle contact network; Jordan et al. (2014) note that in particulate-polymer composites, the polymer binder tends to dominate the mechanical response until particle loading approaches a level where grain-to-grain contact begins to share the load. Below that point, load transfer relies almost entirely on the comparatively soft polymer matrix, which yields and deforms under compression well before the theoretical strength of the sand grains themselves is engaged. This mirrors the finding of Das et al. (2024), who observed that plastic-sand blocks below roughly 60% plastic could not form a uniform bind because there was insufficient molten plastic to coat and lock every sand grain in place, producing a weaker, more porous internal structure.

As the sand fraction rises toward 60% in the 40:60 ratio, the packing arrangement shifts toward a denser particle network in which individual sand grains increasingly bear load through direct grain-to-grain contact rather than relying solely on the polymer to transmit stress. Because sand possesses a substantially higher intrinsic compressive resistance than LDPE, this transition allows the composite to sustain higher loads before failure, consistent with the strengthening mechanism Fu et al. (2008) attribute to increased filler loading once adequate interfacial wetting is achieved. The molten LDPE, in this configuration, functions less as a load-bearing component and more as an adhesive film coating and interlocking the sand skeleton, a role consistent with the plastic-bonded sand concept advanced by Kumi-Larbi et al. (2022).

The comparatively wide scatter within each ratio, most visible at 40:60 (28.59 to 56.61 MPa), is also explicable through this bonding lens. Manual stirring cannot guarantee uniform coating of every sand grain by the molten LDPE, so localized zones of incomplete wetting or trapped air voids likely persisted despite visual homogeneity of the mixture. Fu et al. (2008) note

that interfacial adhesion quality, not merely filler content, governs the ultimate strength ceiling of particulate composites; uneven adhesion across a hand-mixed batch would therefore be expected to produce exactly the specimen-to-specimen variability recorded here, rather than indicating an unstable or unreliable mix design.

Water absorption across all three ratios stayed under 3%, matching the near-zero absorption Debele et al. (2024) recorded for LDPE paver tiles and consistent with the generally hydrophobic behavior of polyethylene noted by Saikia and de Brito (2012) in their review of plastic aggregates. This is a meaningful advantage over ordinary cement paving blocks, whose absorption commonly ranges from 3% to 10% depending on curing quality, and it suggests EcoPlast units would resist moisture-related degradation well in Malang's rainy-season conditions.

Bulk density measured between roughly 1,100 and 1,200 kg/m³, about half the density of conventional cement paving blocks (2,000–2,200 kg/m³). This lighter weight aligns with the lightweight-aggregate behavior Ismail and Al-Hashmi (2008) and Kou et al. (2009) attributed to plastic replacement in concrete mixtures, and it carries a practical benefit for pesantren maintenance teams who typically lack heavy lifting equipment, making manual handling and installation considerably easier.

From a waste-diversion standpoint, one square meter of 70:30 EcoPlast Paving Block at 6 cm thickness consumes approximately 6.4 kg of LDPE. Applied across a 200 m² pesantren courtyard, this would remove roughly 1,280 kg of LDPE waste from local circulation, a scale of impact consistent with the circular-economy framing Firoozi and Firoozi (2022) and Talamo et al. (2025) apply to plastic reuse in construction. Removing cement from the mix also avoids the CO₂ footprint tied to clinker production, which Onuaguluchi and Banthia (2022) and Wang et al. (2024) identify as one of the largest single sources of industrial carbon emissions worldwide.

Taken together, the three ratios serve different practical roles. The 70:30 mix, despite its lower and more variable strength, is adequate for foot-traffic paths and courtyards where load demand is minimal. The 50:50 mix offers a reasonable middle ground for light-vehicle areas. The 40:60 mix delivers the highest strength but consumes less LDPE per unit volume, trading some waste-diversion efficiency for structural margin — a trade-off pesantren managers should weigh according to whether the priority is plastic waste reduction or pavement durability.

• Limitations of the Study

Several limitations should be acknowledged when interpreting these findings. First, specimen fabrication relied entirely on manual melting, hand-stirring, and manual-press compaction rather than mechanized mixing or hydraulic compaction; this manual process is the most plausible explanation for the relatively wide strength scatter observed within each ratio, particularly at 40:60, and future work using powered mixing equipment would likely narrow this variability, as similarly noted by Das et al. (2024) in their own manually mixed plastic-sand trials.

Second, the sample size of three specimens per composition, while adequate for an initial exploratory formulation study, is too small to support robust statistical inference or formal characterization of variability; a larger specimen count in future studies would allow more confident generalization of the mean strength values reported here.

Third, this study evaluated only compressive strength, water absorption, and bulk density. Abrasion resistance, an important parameter for pavement surfaces subject to foot and vehicle traffic, was not tested, and neither was long-term durability under repeated wetting-drying cycles, ultraviolet exposure, or temperature fluctuation typical of outdoor tropical conditions. Because LDPE is known to soften at elevated surface temperatures under prolonged sun exposure, this omission represents a meaningful gap before EcoPlast Paving Block could be recommended for unshaded, high-traffic pesantren areas without further testing.

Finally, the study did not include a split tensile strength test, which is commonly used alongside compressive strength to characterize paving block performance under combined loading

conditions. Future research should incorporate abrasion, tensile, and accelerated weathering tests to build a more complete performance profile before broader field deployment is considered.

CONCLUSION

This study formulated EcoPlast Paving Block from LDPE plastic waste and natural sand without cement, testing three mix ratios across nine specimens for pesantren infrastructure use. The LDPE 40%:Sand 60% mix reached the highest mean compressive strength, 42.69 MPa, exceeding the SNI Grade A equivalence threshold and suited to heavy-load surfaces. The LDPE 50%:Sand 50% mix reached 20.54 MPa, meeting Grade B equivalence and fit for parking or light-vehicle access roads. The LDPE 70%:Sand 30% mix reached 13.40 MPa, near the Grade C/D boundary and appropriate for pedestrian paths and courtyards. Water absorption remained below 3% for every ratio, confirming good durability regardless of mix proportion.

The principal contribution of this research lies in demonstrating, through a composition-based rather than purely additive approach, that LDPE alone, without supplementary fillers or cement, can be tuned across a sand-fraction spectrum to meet distinct SNI-equivalent performance classes suited to different institutional needs. This offers pesantren administrators and similar community institutions a low-cost, locally producible construction material that simultaneously addresses infrastructure development and plastic waste accumulation, translating global circular-economy principles (Firoozi & Firoozi, 2022; Talamo et al., 2025) into a concrete, replicable formulation grounded in Islamic environmental stewardship. By identifying which mix ratio serves which application zone, this study provides a practical decision framework rather than a single fixed formula, allowing adopters to balance structural demand against the volume of plastic waste they intend to divert.

Future work should examine abrasion resistance, long-term thermal behavior under direct sun exposure, and whether fillers such as fly ash or rice husk ash can narrow the strength variability observed within each ratio, alongside larger sample sizes and mechanized mixing to validate the findings reported here under more controlled conditions

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