

Experimental investigation of waste LDPE and quarry dust as a cement replacement for paving blocks

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Research Article

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Abstract

Plastic waste presents a persistent environmental management challenge, while the manufacture of cement-based paving products requires substantial material resources. Here, waste low-density polyethylene (LDPE) was investigated as a complete replacement for cement in paving blocks, with quarry dust used as the mineral component. Concrete paving blocks produced at a 1:2:4 cement:fine aggregate:quarry dust ratio served as the control. LDPE and quarry dust were combined at 50:50, 60:40 and 80:20 by mass. Specimens were evaluated for splitting tensile strength at 7, 14, 21 and 28 days, water absorption after 72 h immersion, and thermal resistance. At 28 days, the 60:40 LDPE:quarry dust mixture achieved the highest splitting tensile strength among the plastic mixes (3.3 N/mm²), compared with 3.5 N/mm² for the control. Water absorption was substantially lower for all plastic mixes than for the control, decreasing from 9.43% for the control to 2.08%, 1.46% and 1.37% for the 50:50, 60:40 and 80:20 mixtures, respectively. The observed deterioration temperatures were 180, 140 and 110°C for the 50:50, 60:40 and 80:20 mixtures. The results indicate potential for the recycled material in low-load and moisture-exposed applications, while its lower tensile performance and thermal limitations should be considered in service selection.

1 Introduction

Plastic waste is a persistent environmental problem because many commonly used plastics remain in the environment for long periods and can accumulate in landfills, waterways and aquatic environments [1–4]. At the same time, conventional paving products depend on cement and mineral aggregates, creating opportunities for the incorporation of recycled materials into construction products. Previous studies have examined waste plastics as modifiers or constituents in construction materials and have reported potential benefits including reduced water absorption, material savings and improved resource recovery [5–9].

Low-density polyethylene (LDPE) is a thermoplastic polymer with useful processing characteristics and resistance to chemical attack. Its use in composite materials depends on the interaction between the polymer matrix and the mineral component, including filler content and interfacial bonding [10, 11]. Waste plastic has also been investigated in pavement and paver applications, including as a modifier and as a replacement material [12–15]. Quarry dust can provide a fine mineral component in composite paving products and may contribute to mechanical performance [16].

Despite these developments, the suitability of a plastic–quarry dust paving block depends on a balance between mechanical performance, water resistance and thermal behaviour. The present study therefore evaluates paving blocks produced by completely replacing cement with LDPE in combination with quarry dust at three mass ratios. The study compares their splitting tensile strength and water absorption with a conventional concrete control and evaluates their thermal resistance.

2 Materials and methods

2.1 Materials

Ordinary Portland cement supplied by Ghana Cement (Ghacem), reported as complying with GS 914:2007 Class 42.5R, was used for the control mixture. River sand obtained from Bogoso was air-dried and passed through a 4.75 mm sieve. Quarry dust with a maximum reported size of 10 mm was obtained from Atlantic Concrete Product Limited and dried and sieved before use. Potable water supplied by Ghana Water Company Limited was used. Waste LDPE was collected within Takoradi township, cleaned, dried and manually shredded into smaller flakes.

2.2 Mix design and specimen preparation

The control mixture used a 1:2:4 ratio by mass for cement:fine aggregate:quarry dust. Concrete paving blocks measuring 200 × 100 × 80 mm were cast as the control. For the recycled plastic specimens, cement was completely replaced and LDPE was combined with quarry dust at 50:50, 60:40 and 80:20 by mass. The mix quantities reported in the original experimental programme are summarized in Table 1.

Table 1
Mix proportions used for the paving-block specimens

Mixture	LDPE:QD	Cement (g)	Fine aggregate (g)	Quarry dust (g)	Water (g)	LDPE (g)
Control	0	2950	5450	11505	1475	—
LDPE:QD 50:50	50:50	—	—	1697	—	1697
LDPE:QD 60:40	60:40	—	—	1867	—	1527
LDPE:QD 80:20	80:20	—	—	2206	—	1188

For the control, cement and sand were weighed and dry-mixed before quarry dust and water were incorporated. Fresh concrete was subjected to a slump test in accordance with BS EN 12350-2:2009. Moulds measuring 200 × 100 × 80 mm were cleaned and oiled before casting. Control specimens were demoulded and cured, while the plastic–quarry dust mixtures were prepared by heating the shredded LDPE and incorporating the weighed quarry dust before moulding.

2.3 Aggregate characterization

A silt-content test was conducted on the fine aggregate using a 1000 mL measuring cylinder and salt solution. The reported silt content was 5.0%, which was considered to meet the 6% requirement referenced in the original study [17]. Particle-size distribution was determined using sieves of 4.75, 2.00, 1.18, 0.60, 0.425, 0.300 and 0.150 mm. The reported fineness modulus was 3.15, and the coefficients of uniformity and curvature were 3.0 and 1.09, respectively.

2.4 Testing procedures

Splitting tensile strength was determined in accordance with BS EN 12390-6:2009. Specimens were tested at 7, 14, 21 and 28 days. Water absorption was measured after 72 h of immersion by comparing the dry and wet specimen masses. Thermal resistance was evaluated by placing air-dried specimens in an oven for up to 2 h and recording the temperature at which visible deterioration occurred. The original study identified the procedures with BS EN 12390-6:2009, BS EN 1881-5:1970 and IS 3809:1979, respectively.

3 Results and discussion

3.1 Splitting tensile strength

Splitting tensile strength increased with curing age for all mixtures. The control reached 3.5 N/mm² at 28 days, while the 50:50, 60:40 and 80:20 LDPE:quarry dust mixtures reached 3.1, 3.3 and 2.9 N/mm², respectively. The 60:40 mixture therefore produced the highest tensile strength among the recycled-plastic specimens and was closest to the control at 28 days. The original study reported the corresponding increases from 7 to 28 days as 21.21% for the 60:40 mixture and 17.24% for the 80:20 mixture.

Table 2
Splitting tensile strength of paving-block specimens at different curing ages (N/mm²)

Mixture	7 days	14 days	21 days	28 days
Control	2.6	3.1	3.4	3.5
50:50 LDPE:QD	2.5	2.8	2.9	3.1
60:40 LDPE:QD	2.6	3.0	3.1	3.3
80:20 LDPE:QD	2.4	2.5	2.7	2.9

The 28-day splitting tensile strength of the 60:40 mixture was approximately 94% of the control value (3.3 versus 3.5 N/mm²), whereas the 50:50 and 80:20 mixtures reached approximately 89% and 83% of the control, respectively. These results show that the intermediate LDPE:quarry dust ratio provided the best tensile performance among the investigated plastic mixtures. The original thesis also compared the results with a C25 designation; however, because the reported test was splitting tensile strength rather than compressive strength, direct equivalence to a C25 compressive-strength requirement should be interpreted cautiously.

3.2 Water absorption

Water absorption was substantially lower in the plastic–quarry dust specimens than in the control. The control absorbed 9.43% water after 72 h, compared with 2.08% for 50:50, 1.46% for 60:40 and 1.37% for 80:20. Thus, all three recycled-plastic mixtures showed markedly reduced water uptake. The original

study attributed this behaviour to the low water affinity of the plastic and interfacial bonding between LDPE and quarry dust.

Table 3
Water absorption of paving-block specimens after 72 h immersion

Mixture	Dry mass (g)	Wet mass (g)	Water absorption (%)
Control	3437	3795.0	9.43
50:50 LDPE:QD	3392.5	3464.5	2.08
60:40 LDPE:QD	3312.0	3361.1	1.46
80:20 LDPE:QD	2965.5	3006.7	1.37

3.3 Thermal resistance

The reported temperatures associated with visible deterioration were 180°C for the 50:50 mixture, 140°C for the 60:40 mixture and 110°C for the 80:20 mixture. The results indicate that increasing the quarry-dust fraction was associated with higher observed thermal resistance within the tested mixtures. The original study noted that the plastic component is susceptible to heat and that the mineral fraction may contribute to thermal resistance.

Table 4
Thermal resistance of plastic–quarry dust paving blocks

LDPE:QD ratio	Temperature at visible deterioration (°C)
50:50 LDPE:QD	180
60:40 LDPE:QD	140
80:20 LDPE:QD	110

3.4 Practical implications

The combined results identify a trade-off among mechanical and thermal properties. The 60:40 mixture gave the highest splitting tensile strength among the plastic mixtures, whereas the 80:20 mixture gave the lowest water absorption but also the lowest tensile strength and lowest deterioration temperature. Based on the experimental results reported in the thesis, the plastic paving blocks are better considered for low-load applications such as walkways, footpaths and building premises rather than heavy-traffic applications. Their low water absorption also suggests potential in moisture-exposed settings, subject to further durability and service-temperature testing.

4 Conclusions

Waste LDPE can be incorporated with quarry dust to produce cement-free paving-block specimens with measurable splitting tensile strength and substantially lower water absorption than the conventional control investigated. The 60:40 LDPE:quarry dust mixture provided the highest 28-day splitting tensile strength among the plastic mixtures at 3.3 N/mm², compared with 3.5 N/mm² for the control. Water absorption decreased from 9.43% for the control to 2.08%, 1.46% and 1.37% for the 50:50, 60:40 and 80:20 mixtures, respectively. The observed deterioration temperatures were 180, 140 and 110°C for the 50:50, 60:40 and 80:20 mixtures. The material therefore shows potential for selected low-load applications, but further testing is required before broader structural or heavy-traffic use.

Declarations

5.1 Funding

No funding was received for this work.

5.2 Ethics approval and consent to participate

Not applicable.

5.3 Consent for publication

Not applicable.

5.4 Competing interests

The author declares no competing financial or non-financial interests related to this work.

5.5 Author contributions

Richard Cudjoe: conceptualization, methodology, investigation, data collection, analysis, visualization and writing of the manuscript.

5.6 Trial Registration

Not applicable. This study was not a clinical trial and did not involve human participants or clinical interventions.

5.7 Data availability

The data supporting the findings reported in this study are contained within the manuscript and its tables. Additional underlying laboratory records may be obtained from the corresponding author on reasonable request.

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Figures

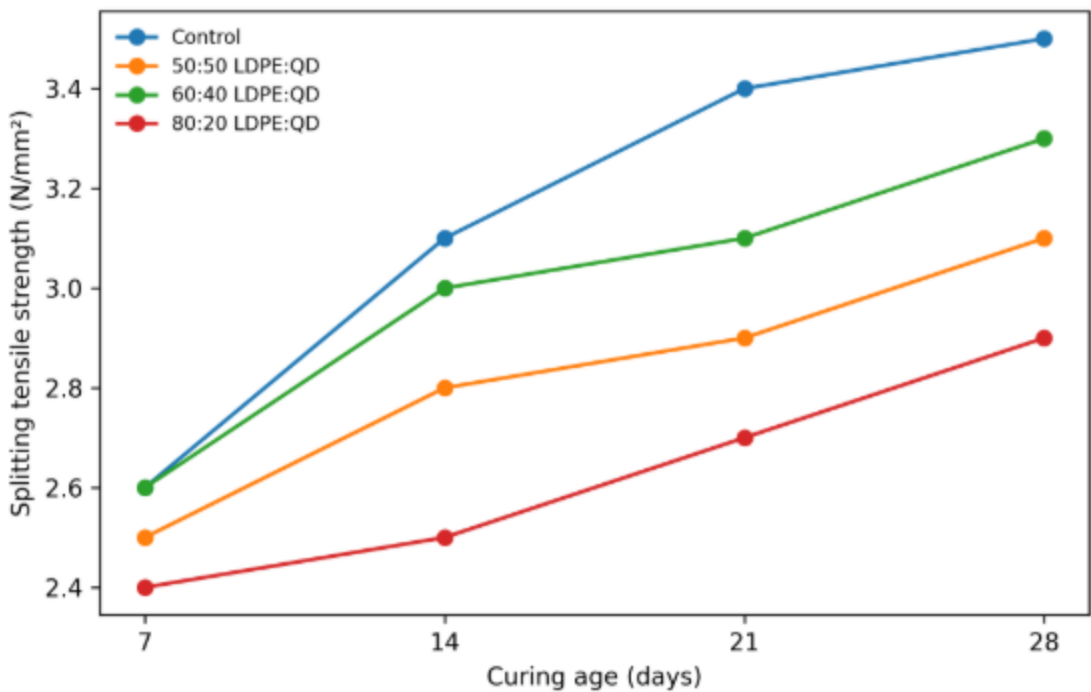


Figure 1

Variation of splitting tensile strength with curing age

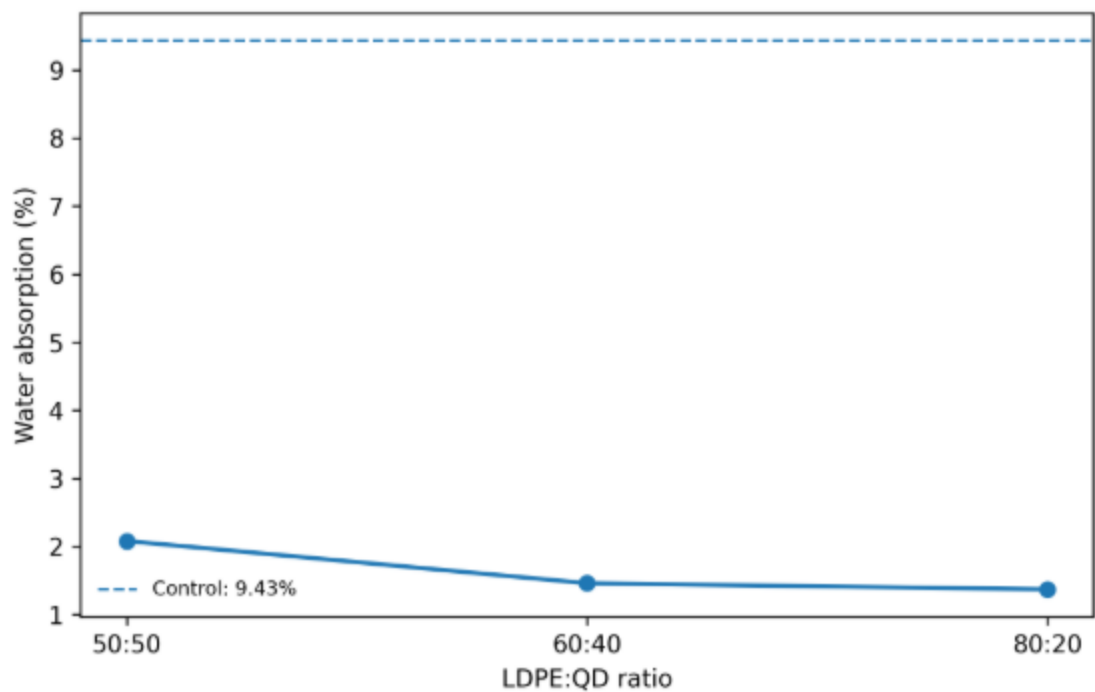


Figure 2

Water absorption of the plastic–quarry dust mixtures compared with the control

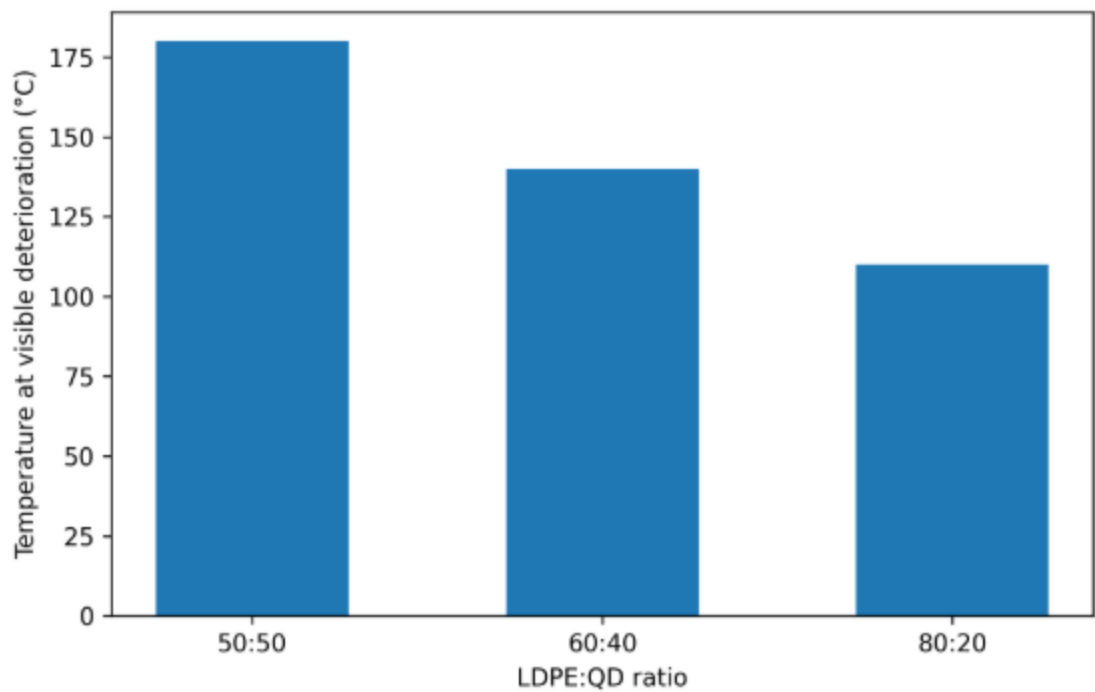


Figure 3

Temperature at visible deterioration of plastic–quarry dust paving blocks