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Evaluation of Quarry Dust–Plantain Leaf Ash Filler on Marshall Properties of Asphalt Concrete

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***Abstract*—** *Mineral fillers play a critical role in controlling the mechanical and volumetric behaviour of asphalt concrete. This study evaluates the combined use of quarry dust (QD) and plantain leaf ash (PLA) as filler in asphalt concrete, with the aim of promoting the valorisation of industrial and agricultural waste in pavement construction. A 60/70 penetration-grade bitumen was used, and the Marshall method was adopted to determine the optimum binder content (OBC), which was found to be 5.4%. At the OBC, QD and PLA were varied independently from 0% to 10% at 2% intervals, producing a 6 × 6 experimental matrix. Briquette samples were compacted with 75 blows on each face and tested for Marshall stability, flow, density, air voids, and voids in mineral aggregate (VMA). The results show that stability increased consistently with QD content, reaching 42.2 kN at 10% QD and 0% PLA, compared with 35.6 kN for the control mix, an increase of 18.5%. When PLA replaced QD, stability decreased systematically; the 10% PLA–0% QD mix recorded 25.8 kN. Flow increased with PLA content, from 2.15 mm at 10% QD–0% PLA to 3.55 mm at 0% QD–10% PLA, indicating reduced stiffness. Density increased with QD and decreased with PLA, while air voids and VMA increased with PLA and decreased with QD. The study concludes that QD should remain the dominant filler component, with PLA limited to about 0%–4% for balanced strength and volumetric performance. The 10% QD–0% to 2% PLA combination is recommended as the most promising sustainable mix. The findings provide useful data for tropical pavement construction where QD and PLA are locally available.*

***Keywords*—** *Asphalt concrete; Quarry dust; Plantain leaf ash; Marshall Stability; Sustainable pavement; Filler replacement*.

I. Introduction

Asphalt concrete is one of the most widely used materials in flexible pavement construction because of its satisfactory load-distribution ability, riding quality, and maintainability. Its performance depends not only on aggregate gradation and bitumen grade but also on the type and proportion of mineral filler. Although filler usually constitutes a small fraction of the total mixture mass, it strongly influences the stiffness, bonding, durability, and volumetric properties of the asphalt mastic and the resulting mixture [1]. Conventional fillers include limestone dust, hydrated lime, cement, and quarry dust (QD). However, the production of cement and lime is energy-intensive and associated with substantial carbon dioxide emissions. In addition, the accumulation of quarry fines and agricultural residues creates environmental management challenges in many developing countries [2], [3].

In recent years, researchers have explored biomass ashes as partial or full replacements for conventional fillers in asphalt mixtures. Rice husk ash, sugarcane bagasse ash, palm shell ash, peanut husk ash, bamboo leaf ash, cassava peel ash, and cow bone ash have been investigated with varying degrees of success [4]–[7]. These studies generally indicate that biomass ashes can improve stiffness, stability, and moisture resistance when used at optimum contents, but excessive replacement may increase air voids, reduce density, and impair durability. The performance of biomass ash depends on its specific gravity, particle shape, surface chemistry, unburned carbon content, and interaction with bitumen [6], [8].

Quarry dust is a by-product of aggregate crushing and is widely available in Nigeria and other parts of sub-Saharan Africa. It has been used as a filler in hot-mix asphalt because its fine, angular particles improve interlocking and stiffen the bitumen film [2], [9]. Plantain leaf ash (PLA), on the other hand, is an agricultural waste obtained from the combustion of plantain leaves. It is rich in silica and alumina and has been studied mainly in soil stabilisation and concrete [3]. Its use in asphalt concrete is still limited, and its combined effect with QD has not been adequately documented. This gap is important because QD and PLA have very different specific gravities—2.62 and 1.80, respectively—which means that equal mass replacement does not correspond to equal volume replacement. This volumetric mismatch can significantly affect Marshall stability, flow, density, air voids, and VMA [10].

The present study was therefore designed to evaluate the Marshall properties of QD–PLA modified asphalt concrete using locally sourced materials from Rivers State, Nigeria. The specific objectives were to: (i) characterise the constituent materials, (ii) determine the OBC using the Marshall method, (iii) prepare hybrid mixes in which QD and PLA were varied from 0% to 10%, and (iv) assess stability, flow, density, air voids, and VMA as functions of filler composition. The novelty of the work lies in the systematic comparison of QD and PLA as competing fillers in the same mixture design, with particular attention to the volumetric effects of their different specific gravities. The outcome is expected to support the sustainable use of local waste materials in pavement construction, especially in tropical regions where plantain leaves are abundant and quarry fines are readily available [4], [11].

II. Materials and Methods

2.1 Materials

The materials used in this study were obtained from local dealers in Mile 3 market and within Rivers State, Nigeria. They included asphalt cement (bitumen) as the binding material, gravel as coarse aggregate, sand as fine aggregate, quarry dust as mineral filler, and plantain leaf ash as an agricultural waste

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filler. The bitumen was a 60/70 penetration-grade asphalt cement. The gravel and sand were washed and air-dried before use. The QD was collected from a local quarry and sieved through a 0.075 mm sieve. The PLA was prepared by collecting dry plantain leaves, burning them in an open-air controlled process, and sieving the resulting ash through a 0.075 mm sieve. The ash was stored in airtight containers before mixing.

The physical properties of the bitumen are presented in Table 2. The specific gravity was 1.01, penetration was 63.3 (0.1 mm), viscosity at 100 s was 65, and softening point was 51.1 °C. These values indicate that the bitumen is suitable for hot-mix asphalt in a tropical climate. The specific gravities of the aggregates and fillers are shown in Table 1. Gravel had a specific gravity of 2.60, sand 2.78, QD 2.62, and PLA 1.80. The low specific gravity of PLA is consistent with its porous, organic-derived ash structure and is a key factor in the interpretation of the volumetric results, [12].

TABLE 1. Specific Gravity of Materials

Material	Specific Gravity
Gravels (Coarse aggregate)	2.60
Sand (fine aggregate)	2.78
Quarry Dust (filler)	2.62
Plantain Leaf Ash (PLA)	1.80

TABLE 2. Physical Properties of Bitumen

Physical properties	Value
Specific Gravity	1.01
Penetration	63.3
Viscosity 100 (sec)	65
Softening Point (°C)	51.1

2.2 Aggregate Gradation

The coarse and fine aggregates were blended at 60% gravel and 40% sand by mass. The combined gradation was checked against the specification limits for asphalt concrete wearing courses. The results are shown in Table 3. The blend satisfied the specified limits at all sieve sizes. The gravel fraction was coarse and had a gap in the intermediate sizes, but the sand fraction compensated for this gap and produced a continuous combined curve. The filler fraction passing the 0.075 mm sieve was 0.4%, which is within the specified range.

TABLE 3. Combination of Aggregates

Sieve Size (mm)	Specification limit	% Passing Aggregate A (Gravel)	% Passing Aggregate B (Sand)	The Blend A=.60% B = 40%
19	100 - 100	100	100	100.0
12.5	86 - 100	95.7	100	97.4
9.5	70 - 90	62.5	100	77.5
6.3	45 - 70	15	100	49.0
4.75	40 - 60	1.5	99	40.5
2.36	30 - 52	0.5	95.8	38.6
1.18	22 - 40	0.5	88.1	35.5
0.6	16 - 30	0.5	77.5	31.3
0.3	9 - 19	0.5	25.4	10.5
0.15	3 - 7	0.5	3.4	1.7
0.075	0 - 0	0.5	0.3	0.4

2.3 Marshall Mix Design

The Marshall method was used to determine the OBC. Trial mixes were prepared at different bitumen contents, and the combined results of stability, flow, density, and air voids were analysed. The OBC was fixed at 5.4%. This value was used for all subsequent unmodified and modified mixes. The Marshall mix design procedure followed ASTM D6927 and related standards [21]–[21]. The choice of 75 blows per face was consistent with heavy-traffic pavement requirements and was maintained for all briquettes to ensure comparability.

2.4 Preparation of QD–PLA Modified Mixes

At the OBC of 5.4%, QD and PLA were varied independently from 0% to 10% at 2% intervals. This produced 36 filler combinations. In each combination, the total filler content was held at the sum of QD and PLA, and PLA replaced QD on an equal-mass basis. The mixes were prepared by first heating the aggregates to 160–170 °C and the bitumen to 150–160 °C. The filler was added and mixed until a uniform coating was obtained. The loose mix was then compacted in standard Marshall moulds with 75 blows on each side. After compaction, the specimens were allowed to cool, extracted, and tested.

2.5 Testing Procedures

The Marshall stability and flow tests were carried out in accordance with ASTM D6927 [19]. The specimens were conditioned in a water bath at 60 °C for 30 min and then loaded at a constant rate of 50.8 mm/min until failure. Stability was recorded as the peak load in kN, and flow was recorded as the deformation at peak load in mm. Bulk density was determined according to ASTM D2726 [20]. Theoretical maximum density was determined according to ASTM D2041 [21]. Air voids and VMA were calculated from the bulk and theoretical maximum densities. Material characterisation tests on aggregates, bitumen, QD, and PLA were carried out in line with appropriate British Standard, ASTM, and AASHTO procedures [19]–[21]. All tests were replicated three times, and the average values are reported.

III. Results and Discussion

3.1 Marshall Stability

The Marshall stability results are presented in Table 4. Stability increased with QD content at every PLA level. For the unmodified PLA series (PLA = 0%), stability increased from 35.6 kN at 0% QD to 42.2 kN at 10% QD. This represents an 18.5% improvement over the control. The increase is attributed to the stiffening effect of QD on the asphalt mastic. QD particles are angular and fine, and they provide a large surface area for bitumen adsorption. This increases the effective viscosity of the mastic and improves load transfer between aggregates [3]. Similar observations have been reported for quarry fines and limestone dust in hot-mix asphalt [9], [10].

When PLA replaced QD, stability decreased. At 10% QD, stability dropped from 42.2 kN at 0% PLA to 37.1 kN at 2% PLA, 39.0 kN at 4% PLA, 36.6 kN at 6% PLA, 32.4 kN at 8% PLA, and 32.0 kN at 10% PLA. The small rebound at 4% PLA may be due to a temporary improvement in filler packing, but the overall trend is clearly downward. At 0% QD, stability decreased from 35.6 kN at 0% PLA to 25.8 kN at 10% PLA. This shows that PLA alone is not an effective stiffening filler. The low specific gravity of PLA means that, for the same mass, it occupies about 1.46 times the volume of QD. This dilutes the

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effective concentration of the stronger QD filler and increases the volume of the filler phase. In addition, the organic origin of PLA may reduce its affinity for bitumen compared with mineral fillers [3], [6].

TABLE 4. Marshall Stability Result of QD –PLA Modified Asphalt Concrete

% of PLA	Stability (KN)					
	% of QD					
	0	2	4	6	8	10
0	35.6	36.2	37.5	38.9	39.2	42.2
2	33.1	33.5	35.0	36.6	36.8	37.1
4	32.2	31.9	33.5	34.0	35.8	39.0
6	29.0	30.3	32.8	32.5	33.8	36.6
8	27.7	29.4	29.2	30.4	30.9	32.4
10	25.8	26.7	26.8	27.8	30.8	32.0

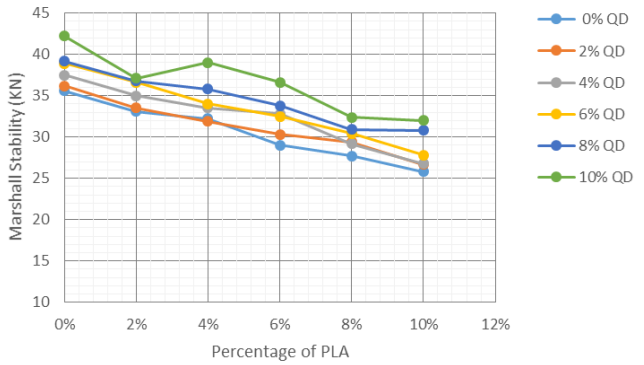


Figure 1: Graph of Marshall Stability against Percentage of PLA

From a practical standpoint, most mixes containing at least 6% QD maintained stability above 30 kN, even at 10% PLA. The 10% QD–0% to 2% PLA mixes gave the highest stability and are therefore the most promising for heavy-duty pavements. The results agree with the general finding that biomass ashes should be used at moderate replacement levels and preferably in combination with a stronger mineral filler [6], [7].

3.2 Flow

The flow results are shown in Table 5. Flow decreased with increasing QD and increased with increasing PLA. At 0% PLA, flow decreased from 2.92 mm at 0% QD to 2.15 mm at 10% QD. At 10% PLA, flow increased from 2.92 mm at 0% PLA–0% QD to 3.55 mm at 10% PLA–0% QD. Even at 10% QD, the 10% PLA mix recorded 2.61 mm, which is higher than the 2.15 mm recorded for the 0% PLA–10% QD mix.

TABLE 5. Flow Result of QD –PLA Modified Asphalt Concrete

% of PLA	Flow (mm)					
	% of QD					
	0	2	4	6	8	10
0	2.92	2.88	2.70	2.48	2.21	2.15
2	3.07	2.99	2.70	2.78	2.57	2.52
4	3.41	3.37	3.20	3.04	2.87	2.67
6	3.49	3.23	3.15	2.88	2.81	2.47
8	3.52	3.30	3.22	2.96	2.84	2.57
10	3.55	3.44	3.01	2.96	2.73	2.61

The increase in flow with PLA indicates a softer mixture. This is consistent with the lower stiffness observed in the stability results. The higher flow may be beneficial for fatigue resistance, but excessive flow can lead to permanent deformation under traffic. In this study, all flow values remained within the commonly accepted range of about 2–4 mm, suggesting that the mixes are still workable and not excessively plastic. The 10% QD mixes, in particular, maintained flow values below 3.0 mm even at 6%–10% PLA, indicating that QD helps to control the softening effect of PLA [8], [10].

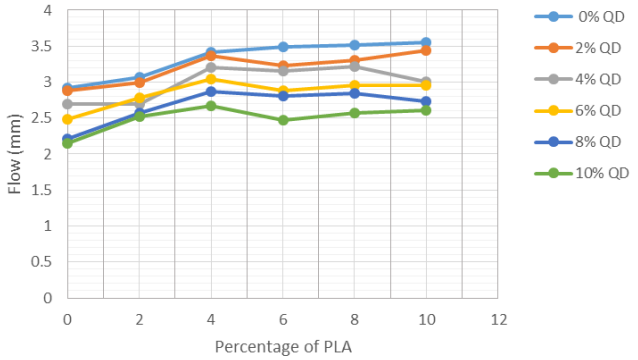


Figure 2: Graph of Flow against Percentage of PLA

3.3 Density

Table 6 presents the density results. Density increased with QD content and decreased with PLA content. At 0% PLA, density increased from 2320 kg/m³ at 0% QD to 2356 kg/m³ at 10% QD. At 10% PLA, density decreased to 2296 kg/m³ at 0% QD and 2322 kg/m³ at 10% QD. The trend is directly related to the specific gravities of the two fillers. QD has a specific gravity of 2.62, while PLA has a specific gravity of 1.80. When PLA replaces QD on an equal-mass basis, the volume of the filler increases, and the overall mass per unit volume decreases [12].

TABLE 6. Density Result of QD –PLA Modified Asphalt Concrete

% of PLA	Density (Kgm³)					
	% of QD					
	0	2	4	6	8	10
0	2320	2328	2335	2343	2349	2356
2	2318	2325	2332	2338	2344	2350
4	2313	2318	2326	2331	2337	2345
6	2307	2315	2320	2326	2330	2337
8	2302	2308	2314	2320	2324	2330
10	2296	2299	2307	2310	2318	2322

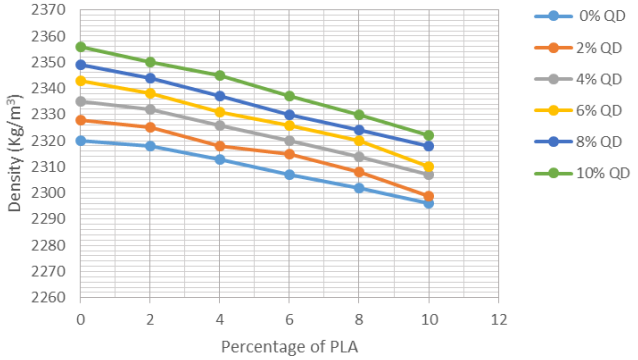


Figure 3: Graph of Density against Percentage of PLA

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The density reduction caused by PLA is modest. Even at 10% PLA and 0% QD, the density is only about 1% lower than the control. This suggests that PLA can be used without causing a severe loss of compacted density, provided that the mix is properly designed. However, the lower density also means that a higher volume of filler is required to achieve the same mass, which can affect the optimum binder content and the volumetric balance of the mix [6], [13].

3.4 Air Voids

Air voids results are shown in Table 7. Air voids decreased with increasing QD and increased with increasing PLA. At 0% PLA, air voids decreased from 5.380% at 0% QD to 3.759% at 10% QD. At 10% PLA, air voids decreased from 2.427% at 0% QD to 1.165% at 10% QD. The lowest air voids were obtained at high QD and high PLA contents, but this may not be desirable because excessively low air voids can lead to bleeding and rutting. The control mix had 5.380% air voids, which is slightly above the typical target range of 3%–5% for wearing courses. The addition of QD reduced air voids into the desirable range [9], [10].

TABLE 7. Air voids Result of QD –PLA Modified Asphalt Concrete

% of PLA	Air Voids (%)					
	% of QD					
	0	2	4	6	8	10
0	5.380	4.994	4.699	4.323	4.059	3.759
2	4.648	4.356	4.019	3.749	3.482	3.202
4	4.055	3.829	3.458	3.212	2.969	2.567
6	3.544	3.166	2.923	2.648	2.442	2.126
8	2.947	2.656	2.373	2.081	1.906	1.595
10	2.427	2.271	1.877	1.737	1.343	1.165

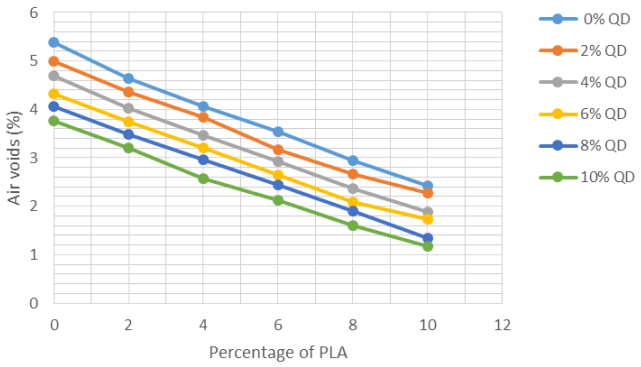


Figure 4: Graph of Air voids against Percentage of PLA

The increase in air voids with PLA is consistent with the lower density and higher VMA. PLA particles are lighter and may not pack as efficiently as QD particles. In addition, the organic nature of PLA may reduce adhesion between the filler and bitumen, creating more voids at the interface [6], [14]. Mixes with high PLA and low QD should therefore be avoided if durability is a primary concern. The 10% QD–0% to 2% PLA mixes gave air voids of 3.759% to 3.202%, which is within the desirable range. The 10% QD–10% PLA mix gave 1.165% air voids, which is too low for practical use.

TABLE 8. Voids in Mineral Aggregate (VMA) Result of QD –PLA Modified Asphalt Concrete

% of PLA	Voids in Mineral Aggregate (%)					
	% of QD					
	0	2	4	6	8	10
0	13.09	12.76	12.52	12.20	11.99	11.74
2	13.15	12.91	12.63	12.41	12.20	11.97
4	13.33	13.15	12.85	12.65	12.46	12.13
6	13.58	13.27	13.08	12.86	12.71	12.45
8	13.75	13.52	13.30	13.07	12.94	12.70
10	13.99	13.88	13.56	13.47	13.15	13.02

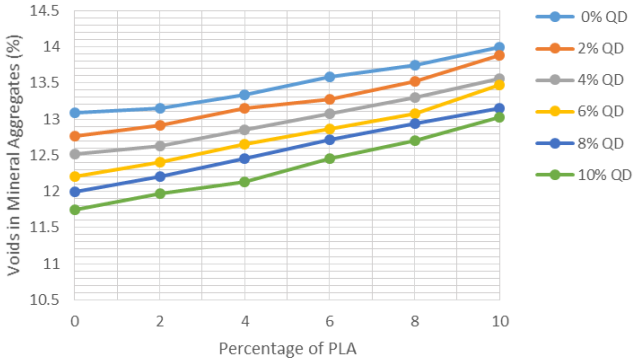


Figure 5: Graph of Voids in Mineral Aggregates against Percentage of PLA

VMA is an important parameter because it indicates the available space for bitumen. If VMA is too low, the mix may be too stiff and prone to cracking. If VMA is too high, the mix may require more bitumen and may be less durable. In this study, the VMA values ranged from 11.74% to 13.99%. The control mix had 13.09%, which is within the typical range. The 10% QD mixes had lower VMA, indicating a denser aggregate skeleton. The PLA-rich mixes had higher VMA, indicating a looser structure. For balanced performance, a VMA of about 12%–13% is desirable. The 10% QD–0% to 4% PLA mixes fall in this range [16], [17].

3.6 Interaction between QD and PLA

The results show a clear interaction between QD and PLA. QD improves stability, density, and stiffness while reducing flow, air voids, and VMA. PLA has the opposite effect. The two fillers therefore play complementary but opposing roles. QD acts as a reinforcing filler, while PLA acts as a bulking filler. The volumetric effect of PLA is particularly important because its low specific gravity means that equal-mass replacement produces a much larger volume of filler. This explains why even small PLA contents cause measurable changes in flow, air voids, and VMA [19].

From a sustainability perspective, PLA has the advantage of being a renewable agricultural waste. Its use can reduce the demand for quarry dust and lower the environmental burden of waste disposal. However, the results suggest that PLA should not be used as the sole filler. Instead, it should be blended with QD, which provides the necessary strength and volumetric stability. The optimum range appears to be 10% QD with 0%–4% PLA. This combination gives stability above 35 kN, flow below 3.0 mm, density above 2330 kg/m³, air voids between 2.5% and 3.8%, and VMA between 12.1% and 12.6%. These

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values are comparable to or better than those of the control mix [4], [7].

3.7 Practical Implications

The findings have practical implications for pavement construction in Nigeria and similar tropical countries. QD is widely available at quarry sites and is often considered a waste material. PLA is generated in large quantities from plantain cultivation and processing. Using both materials in asphalt concrete can reduce the cost of filler, lower the environmental impact of waste disposal, and improve some engineering properties. However, quality control is essential. The PLA must be well burned and sieved to remove unburned carbon and coarse particles. The moisture content of the ash should be controlled because PLA is hygroscopic. The mixing temperature should be maintained within the standard range to ensure proper coating [5], [11].

The results also suggest that the Marshall method can be used effectively to optimise QD–PLA filler blends. The stability–flow–density–air void–VMA framework provides a comprehensive picture of mix performance. For design purposes, a minimum stability of 30 kN and a flow range of 2–4 mm can be used as preliminary acceptance criteria. The optimum filler blend can then be selected based on the desired balance between strength, durability, and sustainability [19]–[22].

IV. Conclusions

This study evaluated the Marshall properties of asphalt concrete modified with quarry dust and plantain leaf ash. Based on the experimental results, the following conclusions are drawn:

1. Quarry dust significantly improved the Marshall stability of asphalt concrete. At 0% PLA, stability increased from 35.6 kN at 0% QD to 42.2 kN at 10% QD, an increase of 18.5%. QD also reduced flow, air voids, and VMA while increasing density.
2. Plantain leaf ash reduced stability and density and increased flow, air voids, and VMA. The 10% PLA–0% QD mix recorded the lowest stability of 25.8 kN and the highest flow of 3.55 mm. These effects are attributed to the low specific gravity of PLA and its weaker filler–bitumen interaction.
3. The interaction between QD and PLA is dominated by the volumetric difference between the two fillers. Equal-mass replacement of QD by PLA increases the filler volume by about 46%, which explains the observed increases in flow, air voids, and VMA.
4. The optimum filler composition for balanced performance is 10% QD with 0%–4% PLA. This range provides stability above 35 kN, flow below 3.0 mm, density above 2330 kg/m³, air voids between 2.5% and 3.8%, and VMA between 12.1% and 12.6%.
5. PLA can be used as a partial replacement for QD in asphalt concrete, but its content should be limited. A replacement level of 0%–4% is recommended for wearing courses. Higher PLA contents may be acceptable in lower-traffic applications where stiffness is less critical.
6. The use of QD and PLA in asphalt concrete supports sustainable pavement construction by valorising industrial and agricultural waste. However, further research is needed on durability, field performance, and life-cycle benefits.

Statements on compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest, financial or otherwise, associated with this research

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