



(RESEARCH ARTICLE)



Mechanical performance and stiffness characteristics of plantain leaf ash and quarry dust modified asphalt concrete towards a sustainable pavement construction

Weje, Chioma and Oba Achemie L *

Department of Civil Engineering, Faculty of Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt.

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Abstract

The increasing demand for sustainable construction materials has driven the exploration of agricultural and industrial wastes as alternative fillers in asphalt concrete. This study investigates the effect of Plantain Leaf Ash (PLA), an agricultural waste, and Quarry Dust (QD), an industrial by-product, as composite fillers on the mechanical properties of asphalt concrete. The research aimed to determine the optimal blend that balances sustainability with structural performance. Initially, the physical properties of the base materials—including the specific gravity of aggregates, the grading of the bitumen (60/70 penetration grade), and the particle size distribution of the aggregates were characterized. The control aggregate (gravel) was found to be gap-graded, deficient in intermediate particles. Asphalt concrete specimens were prepared with varying proportions of PLA (0%, 2%, 4%, 6%, 8%, and 10% by weight of filler) and QD (0%, 2%, 4%, 6%, 8%, and 10%) in a full factorial design. The specimens were evaluated for Marshall Stability, Tensile Strength (TS), and Young's Modulus (Stiffness). The results revealed a clear trade-off: increasing PLA content consistently degraded mechanical performance due to its low specific gravity (1.80) and organic nature, while increasing QD content (Specific Gravity 2.62) proportionally enhanced all properties. The highest absolute performance was recorded for the control mix with 10% QD (Stability 42.2 kN; TS 4.16 N/mm²; Modulus: 1.487 N/mm²). However, a significant interaction was identified at moderate replacement levels. The combination of 4% PLA with 10% QD yielded superior mechanical properties (Stability 39.0 kN; TS: 3.85 N/mm²; Modulus: 1.284 N/mm²) compared to the baseline mix containing no fillers (Stability 35.6 kN; TS: 3.51 N/mm²; Modulus: 1.066 N/mm²). This represents improvements of 9.6%, 9.7%, and 20.5% in stability, tensile strength, and stiffness, respectively. In conclusion, up to 4% of conventional mineral filler can be replaced with Plantain Leaf Ash without compromising, and indeed enhancing, pavement performance, provided it is combined with an optimal dose of Quarry Dust (10%). This approach offers a viable pathway for the use of agricultural waste in pavement construction, contributing to sustainability while improving the structural integrity of asphalt concrete.

Keywords: Plantain Leaf Ash; Quarry Dust; Asphalt Concrete; Marshall Stability; Tensile Strength; Young's Modulus; Pavement

1. Introduction

As the demand for sustainable construction materials grows, researchers have increasingly focused on the use of waste materials to enhance the properties of traditional construction materials like asphalt concrete. The integration of alternative fillers, particularly industrial by-products and natural materials, has been the subject of various studies aimed at improving both strength and durability while reducing environmental impact.

Recent literature highlights the potential of using agricultural waste as a partial replacement for conventional fillers. Plantain leaf ash (PLA), a by-product of plantain processing, has garnered attention for its pozzolanic properties, which can improve the mechanical performance of asphalt concrete. [1] investigated the impact of plantain ash on the soil

* Corresponding author: Oba Achemie L

geotechnical properties, and reported that the ash initiated more than 100% increment in the soil CBR. CBR is one of the parameters used to assess soil samples load-bearing capacity and strength characteristics. Also studies indicate that incorporating PLA can enhance the compressive strength, tensile strength, and overall durability of asphalt mixtures. However, the optimal percentage of PLA for maximizing these properties remains inadequately addressed, representing a research gap.

In addition to PLA, quarry dust (QD) has also been explored as a filler material in asphalt concrete. It was initially considered as waste, QD is now utilized in road construction as filler in the bituminous concrete blend and as a surface finishing material, reducing waste and environmental impact while enhancing pavement durability and performance significantly [2]. The properties of QD, such as its high strength, angularity, and gradation, can improve the stability and workability of asphalt mixes. Previous research suggests that QD can effectively replace traditional fillers, but its combination with PLA has not been thoroughly investigated. This dual approach of using both PLA and QD in asphalt concrete offers an innovative avenue for improving environmental sustainability while enhancing material performance.

Despite the encouraging findings regarding each material separately, there is limited research on the combined effects of using plantain leaf ash and quarry dust as filler materials in asphalt concrete. The existing studies often lack comprehensive evaluations of their combine effects on strength and durability. Therefore, this research aims to bridge the gap by examining how varying proportions of PLA and QD can influence the mechanical properties of asphalt concrete, providing valuable insights into sustainable construction practices.

This study will contribute to the existing body of knowledge by exploring the optimal compositions of PLA and QD that yield the best performance in asphalt concrete applications. By addressing this gap, we hope to pave the way for the adoption of more sustainable materials in road construction, ultimately leading to improved environmental benefits and resource efficiency in the construction industry.

2. Materials and Methods

2.1. Materials

The bitumen used in this study was obtained from Reynold Construction Company (RCC) Asphalt plant in Rivers State, Nigeria. The coarse (gravel) and fine (sand) aggregates were obtained from the dealers at Mile III building materials market in Port Harcourt, Rivers State. The Quarry dust used was gotten from a chipping dump at Eleme Junction in Port Harcourt. While Plantain leaves were gotten from various plantain plantation farms scattered all over Rivers State, Nigeria. The plantain leaves were dried and burnt to ashes and the ashes sieved using 200 microns sieve which was then used in the investigation.

2.2. Methods

2.2.1. Classification and Characterization of Materials

Sieve analysis provides the particle size distribution, it is required in classifying the aggregates and also used in the blending of aggregates. Sieve analysis was carried out on the coarse and fine aggregates in accordance with [3] see Table 1 for the sieve analysis result of the aggregates. The specific gravity test was conducted in line with [4] for gravel, sand, bitumen and plantain leaf ash (PLA). Table 2 shows the specific gravity of materials used. The penetration test involve the depth in tenth of mm of a bitumen sample at 25°C temperature with a standard needle under a load of 100g for 5 seconds. The test procedure was in accordance with [5]. The viscosity test involved the measurement of time it will take fluid (bitumen) flowing through an orifice at a given temperature to fill a 50ml receiver. The Standard tar viscometer was used as specified by [6]. The softening point of the specimen was measured using the ring and ball softening point test as specified by [7].The result of physical property tests of bitumen used is shown in Table 3.

2.3. Blending of Aggregates/ Mix Proportions

For specification and classification requirements of aggregate gradation to be met, the particle size distribution of each aggregate was obtained and recorded. The Excel Solver method of aggregate combination was adopted to get the blending proportion for the aggregates. The specification limits are provided in accordance with [3].Table 4 gives the particle size distribution of the gravel and sand with their mix proportion to meet the specification used.

2.4. Sample Preparations

The method used in preparing the test specimen was in accordance with [8]. The total weight of one specimen is 1200g. The sample was prepared by heating the aggregates and bitumen before mixing them. The specimen was compacted by subjecting it to 75 blows on both top and bottom (corresponding to heavy volume traffic category on wearing course) by a hammer 6.5 kg rammer in weight, dropped from a height of 450 mm manually. The specimen was extruded from the mould and allowed to cool overnight before testing. The testing method used involved the application of load to the specimen in compression, to failure in the Marshall Stability testing machine. The Marshall Stability test was carried out on varying amount of bitumen (between 4 – 6%) and optimum asphalt cement was obtained which was then used in the specimen preparation

Similar procedure was carried out, for the preparation of modified asphalt concrete mixes with varying percent (2%, 4%, 6%, 8% and 10%) quarry dust and plantain leave ash (PLA) blend content at optimum binder content (O.B.C) in accordance to the matrix combination shown in Table 1. Tensile Strength of the specimen were then determined and the results shown in Table 6

Table 1 Blending Schedule for Quarry Dust (QD) and Plantain leave Ash (PLA)

PLA (%)	Quarry Dust (QD) %				
	Blend A	Blend B	Blend C	Blend D	Blend E
	2	4	6	8	10
0	0 : 0	0 : 0	0 : 0	0 : 0	0 : 0
2	2 : 2	4 : 2	6 : 2	8 : 2	10 : 2
4	2 : 4	4 : 4	6 : 4	8 : 4	10 : 4
6	2 : 6	4 : 6	6 : 6	8 : 6	10 : 6
8	2 : 8	4 : 8	6 : 8	8 : 8	10 : 8
10	2 : 10	4 : 10	6 : 10	8 : 10	10 : 10

2.5. Determination of Tensile Strength of Asphalt Concrete Mixes

Tensile strength obtained from indirect tensile testing was used to characterize the stiffness of asphalt concrete mixtures and it is indicative of the strength of the asphalt concrete against fatigue, cracking and rutting. It is actually the strength of the material in tension. The indirect tensile strength of the asphalt concrete samples was determined using equation 1.

$$\sigma_t = \frac{2P}{\pi dt} \quad \dots\dots\dots 1$$

Where;

σ_t = Tensile strength (MPa)

P = failure load during indirect tensile test (N)

d = diameter of asphalt concrete sample at failure (mm)

t = thickness of asphalt concrete sample (mm)

3. Results and discussion

3.1. Preliminary Tests

The result of laboratory tests to determine the gradation of gravel, sand and combined aggregate; specific gravity of gravel, sand and plantain leave ash (PLA) used are presented in Table 2 and 3 respectively. While Table 4 contains the physical properties of the Bitumen.

The mix proportion of 60% of gravel and 40% of sand meet the specification requirement for particle size distribution see Table 2

Gravel Sand, Gravel and Quarry Dust) with high specific gravities (2.60–2.78) are suitable for conventional asphalt concrete, and PLA (Biomass material) with a low specific gravity (1.80), can be potentially used as a lightweight filler or pozzolanic material, see Table 3.

The results in Table 4 indicate a standard 60/70 penetration grade bitumen. It possesses a balanced set of properties: it is hard enough to resist deformation (Penetration), has a good temperature susceptibility (Softening Point), and is workable (Viscosity). This specific combination makes it suitable for paving applications in regions with average temperature variations.

Table 2 Combination of Aggregates

Sieve (mm)	Size	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

Table 3 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 4 Physical Properties of Bitumen

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

3.2. Marshall Stability of QD-PLA Modified Asphalt Concrete

The optimum binder content (OBC) from investigation is 5.4%. The OBC was then used to prepare OD-PLA modified asphalt concrete at varying percentage.

Table 5 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

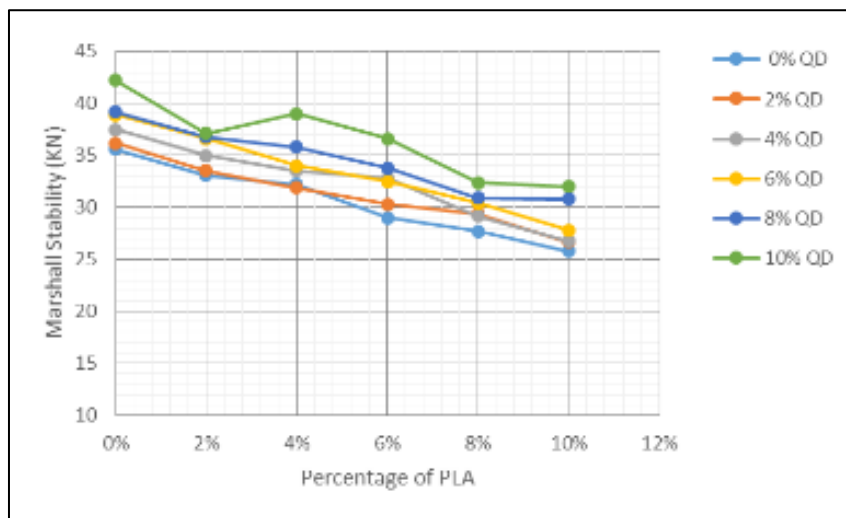


Figure 1 Graph of Marshall Stability against Percentage of PLA

There is a consistent and sharp decline in stability as the PLA content increases from 0% to 10%.

For instance, at 0% QD, stability drops from 35.6 kN (0% PLA) to 25.8 kN (10% PLA). This indicates that PLA, due to its lower specific gravity (1.80), and potentially porous structure, weakens the mixture's internal structure and load-bearing capacity when used in high proportions [9]. It likely forms a weaker mastic with the bitumen compared to mineral fillers.

Stability generally increases as the QD content rises from 0% to 10%. At a high 8% PLA, stability improves from 27.7 kN (0% QD) to 32.4 kN (10% QD). At 10% PLA, it rises from 25.8 kN (0% QD) to 32.0 kN (10% QD). QD, being a dense, mineral-based material (Specific Gravity 2.62), acts as a stiffener. It fills voids and provides a rigid skeleton that helps to offset the weakening effect of the PLA [10]. The single highest stability value in the entire matrix is 42.2 kN, achieved at the control point of 0% PLA and 10% QD. This confirms that conventional mineral filler (QD) provides excellent stability on its own [11]. At 4% PLA, increasing QD to 10% boosts stability to 39.0 kN, which is higher than the control mix with 0% of both materials (35.6 kN). This suggests that up to 4% PLA can be tolerated, and its negative effect can be completely compensated for by a high QD content, potentially leading to a more sustainable mix without a loss in strength.

A study by [10] found that BLA (another agricultural ash) could improve Marshall Stability, but only when used at a very low optimal content of **1.44%**. Exceeding this limit led to a decline in performance, similar to the trend seen with PLA in your data. In their study, the industrial waste (steel slag) was more effective at enhancing stability. [12] confirmed that fillers like Rice Husk Ash (RHA) and Bagasse Ash (BA) can significantly improve stability and stiffness, with optimal performance typically at **4-8%** content. This aligns with the finding that the highest stability with PLA (4%) occurs when combined with the maximum QD (10%)

In conclusion, the results demonstrate that while PLA alone is detrimental to Marshall Stability at high doses, it can be used as a partial filler replacement (up to **4%**) if combined with an optimal amount of Quarry Dust (**10%**). This combination successfully mitigates the strength loss, pointing towards a viable, sustainable mix design.

3.3. Tensile Strength of QD-PLA Modified Asphalt Concrete

Table 6 Tensile Strength Result of QD –PLA Modified Asphalt Concrete

% of PLA	Tensile Strength (N/mm ²)					
	% of QD					
	0	2	4	6	8	10
0	3.51	3.57	3.70	3.83	3.86	4.16
2	3.27	3.31	3.45	3.61	3.63	3.66
4	3.17	3.15	3.31	3.36	3.53	3.85
6	2.86	2.99	3.24	3.20	3.33	3.61
8	2.73	2.90	2.88	3.00	3.05	3.20
10	2.54	2.64	2.65	2.74	3.04	3.16

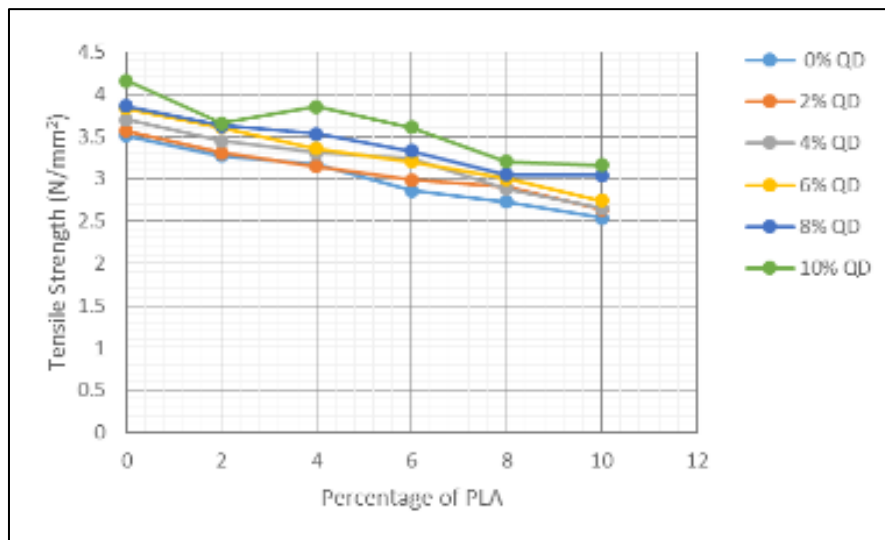


Figure 2 Graph of Tensile Strength against Percentage of PLA

There is a consistent and sharp decline in tensile strength (TS) as the PLA content increases from 0% to 10%. For instance in Table 6, at 0% QD, TS drops from 3.51 N/mm² (0% PLA) to 2.54 N/mm² (10% PLA). This indicates that PLA, due to its organic nature and lower specific gravity, weakens the mixture's internal structure and its ability to resist tensile stresses when used in high proportions. It likely forms a weaker mastic with the bitumen compared to mineral fillers.

Tensile strength generally increases as the QD content rises from 0% to 10%. At a high 8% PLA, TS improves from 2.73 N/mm² (0% QD) to 3.20 N/mm² (10% QD). At 10% PLA, it rises from 2.54 N/mm² (0% QD) to 3.16 N/mm² (10% QD).

QD, being a dense, mineral-based material (Specific Gravity 2.62), acts as a stiffener. It fills voids and provides a rigid skeleton that helps to offset the weakening effect of the PLA. The single highest TS value in the entire matrix is 4.16 N/mm², achieved at the control point of 0% PLA and 10% QD. This confirms that conventional mineral filler (QD) provides excellent tensile strength on its own, which is consistent with findings that quarry dust contributes to a dense and stiff mix [13]. The potential for interaction at moderate PLA levels when combined with high QD. At 4% PLA, increasing QD to 10% boosts TS to 3.85 N/mm², which is higher than the control mix with 0% of both materials (3.51 N/mm²). This suggests that up to 4% PLA can be tolerated, and its negative effect can be completely compensated for by a high QD content, potentially leading to a more sustainable mix without a loss in tensile strength.

A study by [11] found that Coffee Husk Ash (CHA) as a filler exhibited better performance than basaltic stone dust, showing a 35.80% increase in indirect tensile strength. While your study shows PLA generally decreases TS, the positive interaction with QD at moderate PLA levels (4%) mirrors the potential for agricultural ashes to contribute positively when properly optimized. An investigation by [12] confirmed that agricultural waste fillers like Rice Husk Ash (RHA) and Bagasse Ash (BA) can significantly improve stability and stiffness, with optimal performance typically at 4-8% content 7. This aligns with the finding that the highest tensile strength with PLA (4%) occurs when combined with the maximum QD (10%). [13] characterized quarry dusts and found that mixing quarry dusts with other materials can be beneficial for rendering hydrophilic dusts more hydrophobic 8 . This supports the observed synergy between QD and PLA in your study, where QD likely improves the moisture resistance and overall performance of mixes containing PLA [13].

The results demonstrate that while PLA alone is detrimental to Indirect Tensile Strength at high doses (beyond 4%), it can be used as a partial filler replacement (up to 4%) if combined with an optimal amount of Quarry Dust (10%). This combination successfully mitigates the strength loss and even produces TS values exceeding the control mix, pointing towards a viable, sustainable mix design that incorporates agricultural waste without compromising tensile performance.

3.4. Young Modulus of QD-PLA Modified Asphalt Concrete

Table 7 Young Modulus Result of QD -PLA Modified Asphalt Concrete

% of PLA	Young Modulus (N/mm ²)					
	% of QD					
	0	2	4	6	8	10
0	1.066	1.121	1.218	1.305	1.327	1.487
2	0.965	1.002	1.099	1.185	1.202	1.262
4	0.906	0.922	1.016	1.066	1.130	1.284
6	0.822	0.888	1.009	1.031	1.081	1.219
8	0.755	0.821	0.861	0.905	0.936	1.044
10	0.676	0.716	0.763	0.786	0.889	1.006

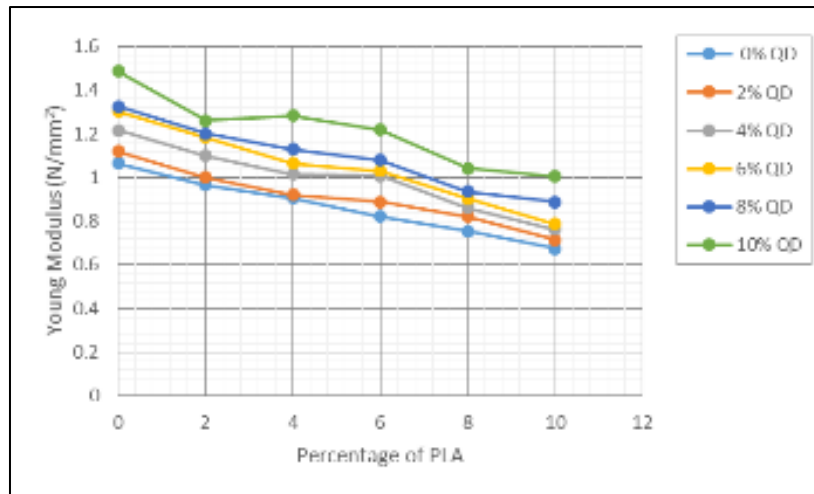


Figure 3 Graph of Young Modulus against Percentage of PLA

There is a consistent decline in Young's Modulus as the PLA content increases from 0% to 10%. From Table 7, at 0% QD, the modulus drops from 1.066 N/mm² (0% PLA) to 0.676 N/mm² (10% PLA)—a reduction of approximately 36.6%. This indicates that PLA, due to its organic nature and lower specific gravity (1.80), weakens the mixture's load-bearing capacity and its ability to resist deformation under stress when used in high proportions. The PLA likely forms a softer, less rigid mastic with the bitumen compared to mineral fillers, resulting in a lower stiffness modulus [14]. Young's Modulus consistently increases as the QD content rises from 0% to 10%. At a high 8% PLA, the modulus improves from 0.755 N/mm² (0% QD) to 1.044 N/mm² (10% QD)—an increase of 38.3%. At 10% PLA, it rises from 0.676 N/mm² (0% QD) to 1.006 N/mm² (10% QD). QD, being a dense, mineral-based material (Specific Gravity 2.62), acts as a stiffening agent. It fills voids, provides a rigid skeletal structure, and increases the stiffness of the asphalt mastic, which helps to offset the softening effect of the PLA [14]. The Optimal Combination for Peak Performance: The single highest Young's Modulus value in the entire matrix is 1.487 N/mm², achieved at the control point of 0% PLA and 10% QD. This confirms that conventional mineral filler (quarry dust) provides excellent stiffness on its own, which is consistent with findings that mineral fillers significantly enhance the stiffness modulus of asphalt mixtures [15; 16]. At 4% PLA, increasing QD to 10% boosts the modulus to 1.284 N/mm², which is 20.5% higher than the control mix with 0% of both materials (1.066 N/mm²). This suggests that up to 4% PLA can be tolerated, and its negative effect can be not only compensated for but actually reversed by a high QD content, producing a stiffer mix than the baseline while incorporating sustainable materials.

A study by [17] found that asphaltic concrete containing 2% to 4% BRHA showed excellent performance in terms of resilient modulus (stiffness) properties. However, exceeding this optimal range led to diminished returns, mirroring the trend in your data where PLA beyond 4% causes progressive stiffness reduction unless compensated by high QD content. [12] confirmed that RHA and BA significantly improve stability and stiffness, with optimal performance typically at 4-8% filler content. This aligns with the finding that the highest Young's Modulus with PLA (4%) occurs when combined with maximum QD (10%). Another study by the same research group demonstrated that BA achieved the highest stability and Marshall Quotient at 4% filler, while RHA performed well at lower levels [12]. [16] in their comprehensive review of waste materials as alternative fillers, emphasized that the influence of fillers on asphalt mix properties is linked to their physical and chemical characteristics. They noted that suitable wastes added at optimum concentration could produce superior asphalt mixes. This strengthens the principle—the combination of PLA and QD at specific ratios (4% PLA with 10% QD) produces superior stiffness compared to conventional filler alone.

The results demonstrate that while PLA alone is detrimental to Young's Modulus at high doses (beyond 4%), it can be used as a partial filler replacement (up to 4%) if combined with an optimal amount of Quarry Dust (10%). This combination successfully mitigates the stiffness loss and even produces modulus values exceeding the control mix (1.284 N/mm² vs. 1.066 N/mm²), pointing towards a viable, sustainable mix design that incorporates agricultural waste without compromising the structural stiffness of the pavement. The stiffening effect of QD compensates for the softening effect of PLA, demonstrating the importance of filler optimization in asphalt concrete design.

4. Conclusion

This study investigated the effect of Plantain Leaf Ash (PLA), an agricultural waste material, and Quarry Dust (QD), a mineral filler mixture, on the Marshall stability, Tensile strength, and Young's modulus of asphaltic concrete, the following conclusions are established:

The inclusion of Quarry Dust significantly enhanced the stability of the mix, achieving a peak value of 42.2 kN at 10% QD and 0% PLA. Conversely, increasing PLA content consistently reduced stability. At 4% PLA combined with 10% QD, the stability (39.0 kN) exceeded the control mix (0% PLA, 0% QD) at 35.6 kN, demonstrating that the negative impact of low-level PLA can be fully compensated by QD.

The tensile strength followed a similar trend to stability. The maximum TS of 4.16 N/mm² was achieved with 10% QD. PLA content above 4% weakened the mix's resistance to tensile stresses. The optimal sustainable combination was identified at 4% PLA and 10% QD, yielding an TS of 3.85 N/mm², which was superior to the baseline mix (3.51 N/mm²).

The stiffness modulus results confirmed that QD acts as a rigidifying agent, while PLA softens the mastic. The highest stiffness (1.487 N/mm²) was recorded for the 10% QD mix. The blend of 4% PLA and 10% QD produced a stiffness of 1.284 N/mm², representing a 20.5% increase over the control mix. This indicates that the combined fillers can produce a mix that is not only stronger but also more resistant to permanent deformation than the conventional mixture.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

References

- [1] Alshawmar, E., (2024). Utilization of Nano Silica and Plantain Leaf Ash for Improving Strength Properties of Expansive Soil. *Sustainability* 2024, 16, 2157. Retrieved from <https://doi.org/10.3390/su16052157>
- [2] Oba, K. M. and Tigbara, E. L., (2021). Characterisation of Saw Dust Ash – Quarry Dust Bituminous Concrete. *International Journal of Engineering and Management Research* e-ISSN: 2250-0758 | p-ISSN: 2394-6962 Volume-11, Issue-1 (February 2021) www.ijemr.net <https://doi.org/10.31033/ijemr.11.1.17> 123
- [3] American Society for Testing and Materials. (2001). ASTM C136: Standard test method for gradation of aggregates. ASTM International, USA
- [4] American Society for Testing and Materials. (2001). ASTM C128: Standard test method for specific gravity and absorption of fine aggregate. ASTM International, USA
- [5] American Society for Testing and Materials. (2011) ASTM D1586: Standard test method for penetration of bituminous material. ASTM International, USA
- [6] American Society for Testing and Materials. (2006) ASTM D4402: Standard test method for viscosity of bituminous material. ASTM International, USA
- [7] American Society for Testing and Materials. (2014) ASTM D3461: Standard test method for softening point of bituminous material. ASTM International, USA
- [8] American Association of State Highway and Transportation Officials (2017). AASHTO T245: Procedure for hot mix asphalt using Bruce Marshall Mix Design. Washington DC
- [9] Adanikin, A., Oyedepo, O. J., Ajayi, J. A., & Agbetanmije, K. (2019). Laboratory Study of the Use of Alternative Materials as Fillers in Asphaltic Concretes. *International Journal of Scientific Research Engineering & Technology (IJSRET)*, 8(6), 325-332.
- [10] Singh, N. P., Mishra, J. K., Olawuyi, O. A., Arinkoola, A. O., Osuolale, O. M., Adebajo, A. U., & Dixit, S. (2024). Optimization, Modelling and Evaluation of Marshall Stability of Asphaltic Concrete with Agricultural and Industrial Wastes Through Response Surface Method. *Advanced Computing and Intelligent Technologies: Proceedings of ICACIT 2023*. Pp. 151–164.

- [11] Tessema, A. T., Alene, G. A., & Wolelaw, N. M. (2022). The Influence of Coffee Husk Ash as a Filler on the Performance of Bituminous Concrete Mix. *Advances in Materials Science and Engineering*, 2022(1), 2888098. <https://doi.org/10.1155/2022/2888098>
- [12] Pratiwi, L., Putri, E. E., Adji, B. M., & Andriani, A. (2025). Sustainable Asphalt Mixtures Using Agricultural Waste Fillers: A Systematic Review of Rice Husk Ash, Bagasse Ash and Palm Shell Ash. *Civil and Environmental Engineering*, 21(2). <https://doi.org/10.2478/cee-2026-0014>
- [13] Valentin, J., Trejbal, J., Nežerka, V., Valentová, T., & Faltus, M. (2021). Characterization of quarry dusts and industrial by-products as potential substitutes for traditional fillers and their impact on water susceptibility of asphalt concrete. *Construction and Building Materials*, 301, 124294. <https://doi.org/10.1016/j.conbuildmat.2021.124294>
- [14] Zulkati, A. (2013). Composite effects of filler on properties of asphalt concrete mixture and its bonding characteristics with asphalt [Doctoral thesis, Nanyang Technological University]. DR-NTU. <https://hdl.handle.net/10356/52722>
- [15] Kareem, A. I., Khaled, T. T., Aljubory, A., Al-Hamd, R. K. S., & Isaac, D. (2024). Investigating the influence of mineral fillers at Australian asphalt mixtures. *Civil and Environmental Engineering*, 20(1), 109–123. <https://doi.org/10.2478/cee-2024-0010>
- [16] Choudhary, J., Kumar, B., & Gupta, A. (2020). Utilization of solid waste materials as alternative fillers in asphalt mixes: A review. *Construction and Building Materials*, 234, 117271. <https://doi.org/10.1016/j.conbuildmat.2019.117271>
- [17] Ramadhansyah, P. J., Haryati, Y., Norhidayah, A. H., Mohd Rosli, H., Muhammad Naquiuddin, M. W., Azman, M., Abdul Rahim, A. H., & Ekarizan, S. (2019). Creep and resilient modulus properties of asphaltic concrete containing black rice husk ash (BRHA). *IOP Conference Series: Earth and Environmental Science*, 220(1), 012005. <https://doi.org/10.1088/1755-1315/220/1/012005>