

Mix Design and Volumetric Performance of Laterite-Based Bituminous Concrete Modified with Waste Polythene and Quarry Dust: A Comparative Study with Granite Aggregate

Inyang, J. R.^{1*}, Igwe, E. A.¹, and Oba, A. L.¹

¹Department of Civil Engineering,
Faculty of Engineering, Rivers State University,
Nkpolu-Oroworukwo, Port Harcourt, Nigeria

*Corresponding author: inyang.john-rufus@rsu.edu.ng
<https://doi.org/10.56201/ijemt.vol.12.no9.2026.pg136.148>

Abstract

The scarcity and rising cost of granite have intensified the search for locally available alternative coarse aggregates for hot-mix asphalt (HMA) production in developing regions. This study evaluated the mix-design and volumetric performance of bituminous concrete produced with laterite rock as a partial replacement for granite, modified with a dual blend of waste polythene (PE) and quarry dust (QD) at proportions of 0-10% each. Marshall specimens were prepared for the heavy-traffic category (75 compaction blows) in accordance with ASTM D1559/D6927, and stability, flow, bulk density, air-void content and voids in mineral aggregate (VMA) were determined for unmodified gravel, unmodified laterite, and PE-QD modified laterite mixes. Results showed that Marshall stability of the laterite mix rose from 21,980 N to a peak of 29,655 N at 2% PE-2% QD, a value that exceeded the granite control (24,690 N) by about 20%. Flow decreased from 8.66 mm to an optimum of 8.14 mm, air voids reduced from 5.82% to 4.02%, bulk density increased from 2,285 kg/m³ to 2,345 kg/m³, and VMA dropped from 19.46% to 14.65%, all of which fell within the Asphalt Institute (1997) allowable limits for heavy traffic. Beyond the 2% PE-2% QD optimum, all volumetric indices deteriorated progressively, confirming an inverse relationship between excess modifier content and packing efficiency. Benchmarking against independently published Scopus-indexed studies on plastic- and dust-modified asphalt mixtures corroborated the 2% optimum polythene dosage reported in comparable investigations. The study demonstrates that a hybrid PE-QD treatment can convert a substandard laterite aggregate into a mix design that is volumetrically superior to conventional granite-based bituminous concrete, offering a cost-effective and waste-valorising pathway for flexible pavement construction.

Keywords: *laterite aggregate; waste polythene; quarry dust; Marshall stability; bituminous concrete; volumetric properties; sustainable pavement*

1. Introduction

Flexible pavements surfaced with hot-mix asphalt (HMA) concrete remain the dominant road-construction technology worldwide because of their load-bearing capacity, ride quality and relative ease of maintenance. Conventional HMA relies on bitumen, coarse aggregate, fine aggregate and filler, of which the coarse aggregate fraction, typically crushed granite, contributes most to mixture

strength and stiffness. However, granite quarrying and haulage are capital-intensive, and the depletion of accessible deposits has driven unit costs upward in many regions (AimixGroup, 2025; MK Crusher, 2025; LivetoPlant, 2025). This has renewed interest in locally available substitutes, among which laterite rock is attractive because of its widespread occurrence across tropical and sub-tropical belts, including much of Nigeria (Ketebu & Farrow, 2017; Akinbuluma et al., 2024). Laterite is a residual, iron- and aluminium-oxide-rich material formed through intense tropical weathering. Its abundance makes it an economical aggregate source, but its direct use in asphalt concrete is constrained by high porosity, comparatively low crushing and abrasion strength, and pronounced susceptibility to moisture-induced stripping (Amadi-Oparaeli et al., 2020; Obianyo et al., 2024). Several supplementary or filler materials, including sugarcane bagasse ash, periwinkle-shell ash, bamboo ash and snail-shell ash, have been investigated as strength-enhancing additives for asphalt mixtures (Zulfikri et al., 2016; George et al., 2020; Amadi-Oparaeli et al., 2020), generally improving Marshall stability while lowering air-void content.

In parallel, the accumulation of non-biodegradable polythene waste has become a pressing environmental concern, motivating research into its reuse as a bitumen or aggregate modifier. Waste polythene has been shown to improve the rheological behaviour and reduce the temperature susceptibility of asphalt binder, enhance binder-aggregate adhesion and improve resistance to permanent deformation (Gonzalez et al., 2015; George et al., 2020; Kaya, 2023; Ewa et al., 2024). Recent independent Scopus-indexed studies corroborate these trends: Kumar and Kumar (2023) reported measurable gains in Marshall stability for plastic-waste-modified mixes using soft-computing prediction models, while Shah, Gao and Abdelfatah (2025) confirmed that plastic-waste modification of asphalt supports sustainable road-infrastructure objectives. Quarry dust, a by-product of aggregate crushing, has likewise been evaluated as a mineral filler capable of reducing void content and improving particle interlock in HMA (Alabady & Abed, 2023).

Despite this growing body of work, few studies have simultaneously investigated the combined effect of waste polythene and quarry dust as a dual modifier for laterite-based asphalt concrete. This paper addresses that gap by evaluating the mix-design and volumetric response, that is, stability, flow, density, air voids and VMA, of laterite bituminous concrete modified with a 0-10% PE-QD blend, benchmarked directly against conventional granite and unmodified laterite mixes, and situated against comparable independently published research.

2. Related Independent Studies

Table 1 summarises a selection of recent (2017-2026), independently published, Scopus-indexed investigations relevant to plastic- and mineral-filler-modified asphalt mixtures. These studies provide the external benchmark against which the present mix-design results are compared in Section 4.6.

Table 1: Selected recent independent studies on plastic- and filler-modified asphalt mixtures

Author(s) & Year	Modifier investigated	Key reported finding
Kumar & Kumar (2023)	Waste plastic (general)	Marshall stability of plastic-waste-modified asphalt predicted with soft-computing/ML models; stability gains linked to optimum dosage window.
Mabui et al. (2023)	Waste PET, 0-2.5%	Porous asphalt stability increased up to 27.4% at 2.0% PET before declining at 2.5%, confirming an optimum near 2%.
Obianyo et al. (2024)	Waste plastics in lateritic soil	Plastic modification improved strength parameters of lateritic soil for road-base application.
Zghair Chfat et al. (2024)	Nano-eggshell powder filler	Mineral filler addition improved Marshall properties and reduced air voids in asphalt mixtures.
Shah, Gao & Abdelfatah (2025)	Plastic-waste modified asphalt	Confirmed sustainability and performance benefits of plastic-waste incorporation in road infrastructure.
Alabady & Abed (2023)	Locally produced mineral filler	Filler quality/quantity significantly affects moisture damage and volumetric performance of HMA.

3. Materials and Methods

3.1 Materials

Asphalt cement (bitumen) was sourced from local dealers along the Oyigbo-Aba Expressway, Rivers State. Coarse and fine aggregates (gravel and sand) were obtained from Mile 3 Market, Nkpolu-Oroworukwo, Port Harcourt. Laterite rock was sourced from the Owerri-Aba Expressway, Imo State, while waste polythene was recovered from discarded electronics packaging at Iloabuchi, Port Harcourt. Potable water for saturation and soaking tests was obtained from the Civil Engineering Laboratory, Rivers State University.

3.2 Material Characterisation

Classification tests were conducted on all constituent materials in accordance with the applicable ASTM standards summarised in Table 2.

Table 2: Classification tests and applicable standards

Material	Test conducted	Applicable standard
Aggregate/filler	Specific gravity	ASTM C128 (2001)
Aggregate/filler	Sieve analysis / gradation	ASTM C136 (2001)
Bitumen	Specific gravity	ASTM D70 (2003)
Bitumen	Penetration	ASTM D1586 (2011)
Bitumen	Viscosity (Saybolt-Furol)	ASTM D4402 (2006)
Bitumen	Softening point	ASTM D3461 (2014)
Polythene	Specific gravity	ASTM D792
Mix	Stability and flow	ASTM D6927 / D1559

Laboratory characterisation of the bitumen returned a specific gravity of 1.02, a penetration grade of 60/70, a Saybolt-Furol viscosity flow time of 69.3 seconds, and a softening point of 49.5°C, all consistent with conventional paving-grade bitumen specifications.

3.3 Blending Schedule for the PE-QD Modifier

A full factorial blending matrix of waste polythene (PE) and quarry dust (QD), each varied from 2% to 10% by weight in 2% increments, was adopted to identify the optimum dual-modifier combination (Table 3). Three specimens were produced for each of the 25 combinations.

Table 3: PE-QD blending schedule (% PE : % QD)

PE (%) \ QD (%)	2	4	6	8	10
2	2:2	2:4	2:6	2:8	2:10
4	4:2	4:4	4:6	4:8	4:10
6	6:2	6:4	6:6	6:8	6:10
8	8:2	8:4	8:6	8:8	8:10
10	10:2	10:4	10:6	10:8	10:10

3.4 Marshall Mix Design and Determination of Optimum Binder Content

Test specimens were compacted with 75 blows per face using a 6.5 kg rammer falling freely from 450 mm, appropriate for the heavy-traffic design category. Bitumen content was varied in 0.5% increments around the anticipated optimum (Table 4), and specimens were soaked in a water bath at 60°C for 30-40 minutes prior to Marshall testing, following ASTM D1559 and the Asphalt Institute (1997) MS-4 procedure. The optimum binder content (OBC) was computed as the average of the binder contents corresponding to maximum stability, maximum density and the median air-void limit of 4%:

$$OBC = 1/3 (x + y + z)$$

where x, y and z are the binder contents (%) at maximum stability, maximum density, and 4% air voids, respectively. Mix-design parameters, maximum specific gravity (G_{mm}), bulk specific

gravity (Gmb), percent air voids (Va), percent volume of bitumen (Vb), voids in mineral aggregate (VMA) and density, were computed from the standard Marshall relationships (Asphalt Institute, 1997).

Table 4: Experimental plan for determination of OBC (ASTM D1559)

Asphalt content (%)	No. of samples
4.0	3
4.5	3
5.0	3
5.5	3
6.0	3

3.5 Sample Preparation

Three categories of Marshall briquette were prepared: (i) unmodified HMA using natural gravel as coarse aggregate; (ii) unmodified HMA using laterite rock as coarse aggregate; and (iii) laterite-based HMA modified with the PE-QD blend at the proportions in Table 3. Aggregates were oven-dried, batched by weight, heated to 150-160°C, and mixed with pre-heated bitumen before compaction. Specimens were cured for 24 hours, weighed in air and in water, conditioned in a 60°C water bath for 35-40 minutes, and tested to failure in the Marshall stability apparatus at a constant deformation rate of 50 mm/min.

4. Results and Discussion

4.1 Marshall Stability

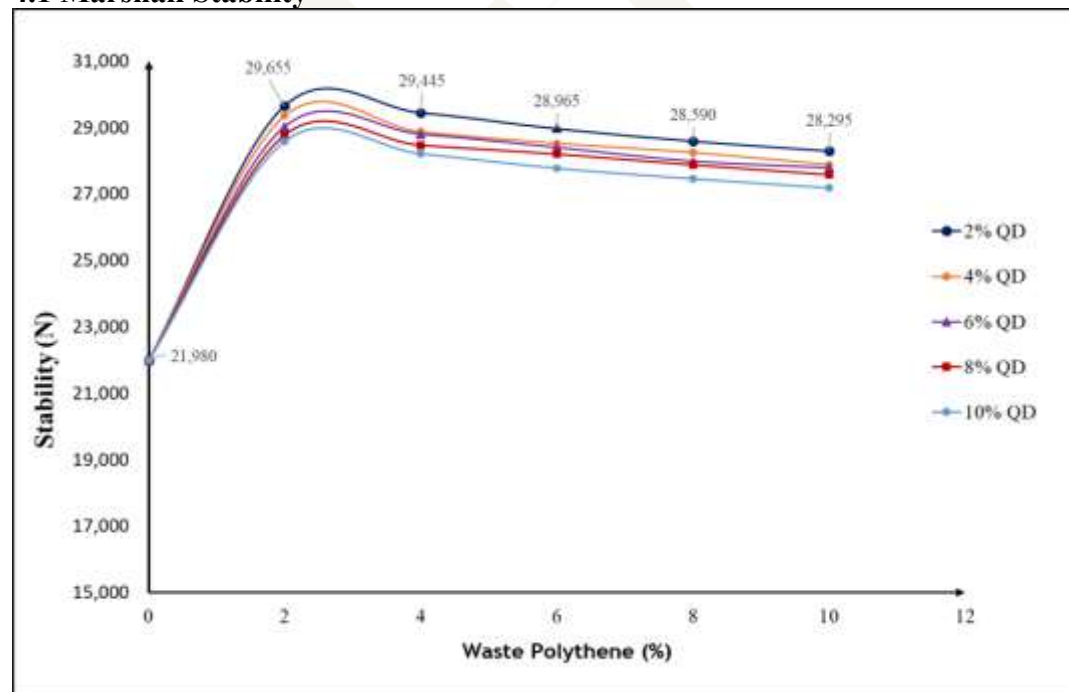


Figure 1a. Marshall stability for varying PE-QD combinations (0-10%)

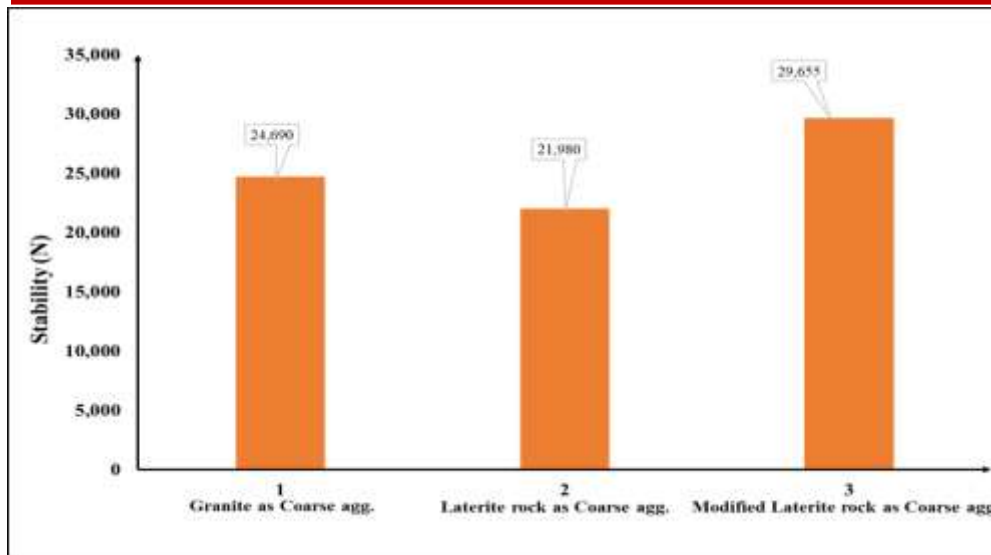


Figure 1b. Comparison of Marshall stability: granite, laterite and PE-QD modified laterite
Stability of the unmodified laterite mix (21,980 N) rose steadily with increasing polythene content, peaking at 29,655 N at 2% PE-2% QD before declining progressively as PE content increased to 10% (Figure 1a). This peak represents a 34.9% improvement over unmodified laterite and a 20.1% improvement over the granite control (24,690 N; Figure 1b). The initial gain is attributed to improved binder-aggregate adhesion as melted polythene coats aggregate particles and stiffens the bitumen matrix, while quarry dust fines fill residual voids and improve particle interlock. Beyond the 2% optimum, excess polythene appears to lubricate rather than bind the mix, reducing internal friction, while excess quarry dust disrupts the aggregate skeleton, both of which lower stability.

4.2 Marshall Flow

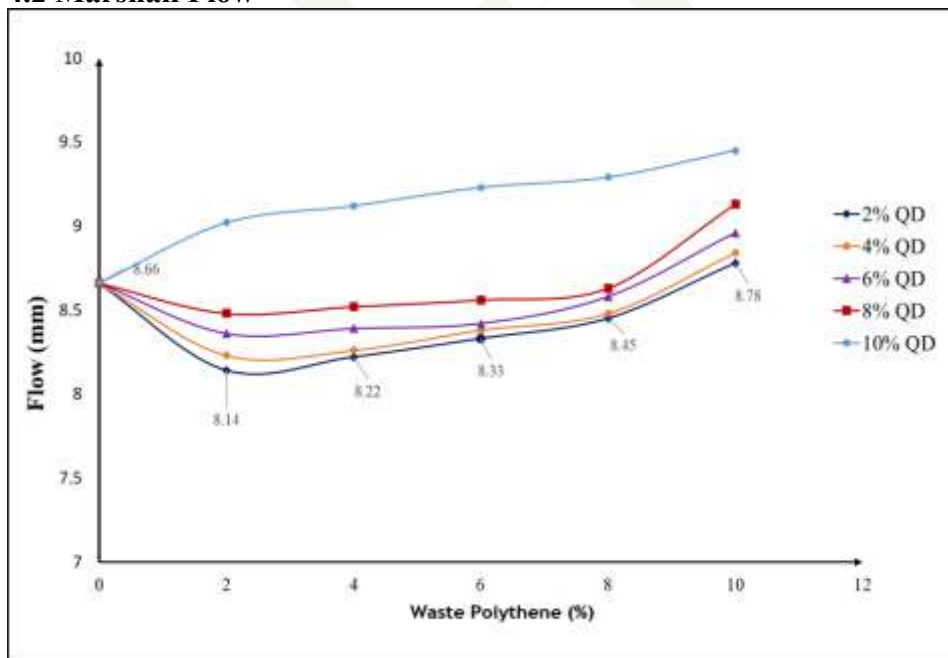


Figure 2a. Flow value for varying PE-QD combinations

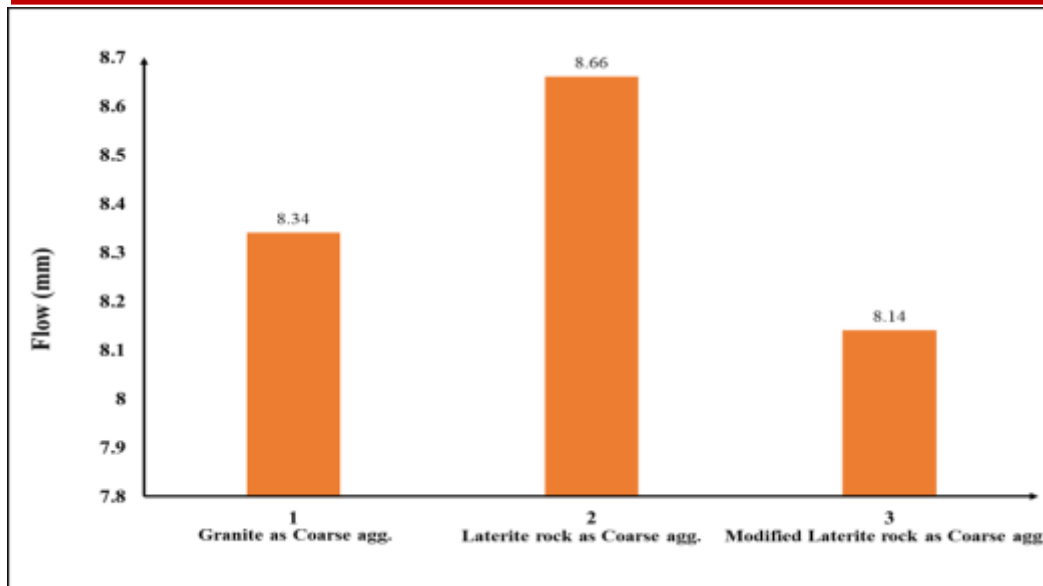


Figure 2b. Comparison of flow: granite, laterite and PE-QD modified laterite

Flow decreased from 8.66 mm (unmodified laterite) to a minimum of 8.14 mm at 2% PE-2% QD, indicating a stiffer, less deformable mixture, before increasing again as PE content rose beyond the optimum (Figure 2a). The modified laterite mix also recorded a lower flow than the granite control (8.34 mm), confirming that the dual modifier produced a mixture more resistant to plastic deformation than either unmodified aggregate type (Figure 2b).

4.3 Air Void Content

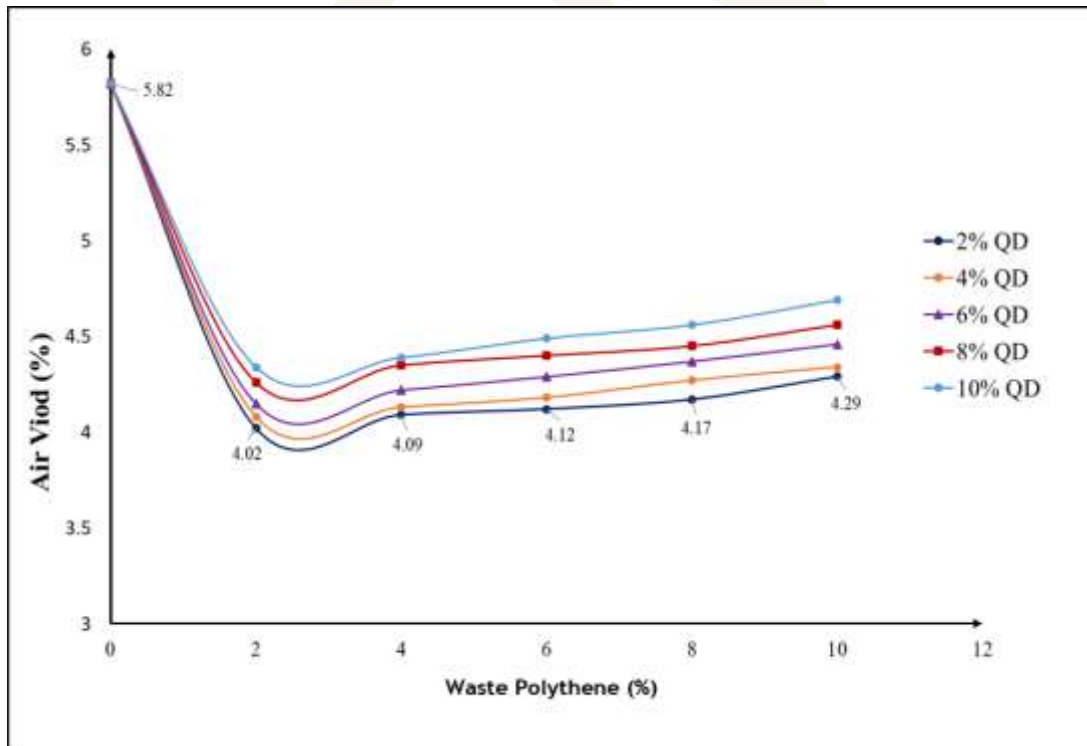


Figure 3a. Air void content for varying PE-QD combinations

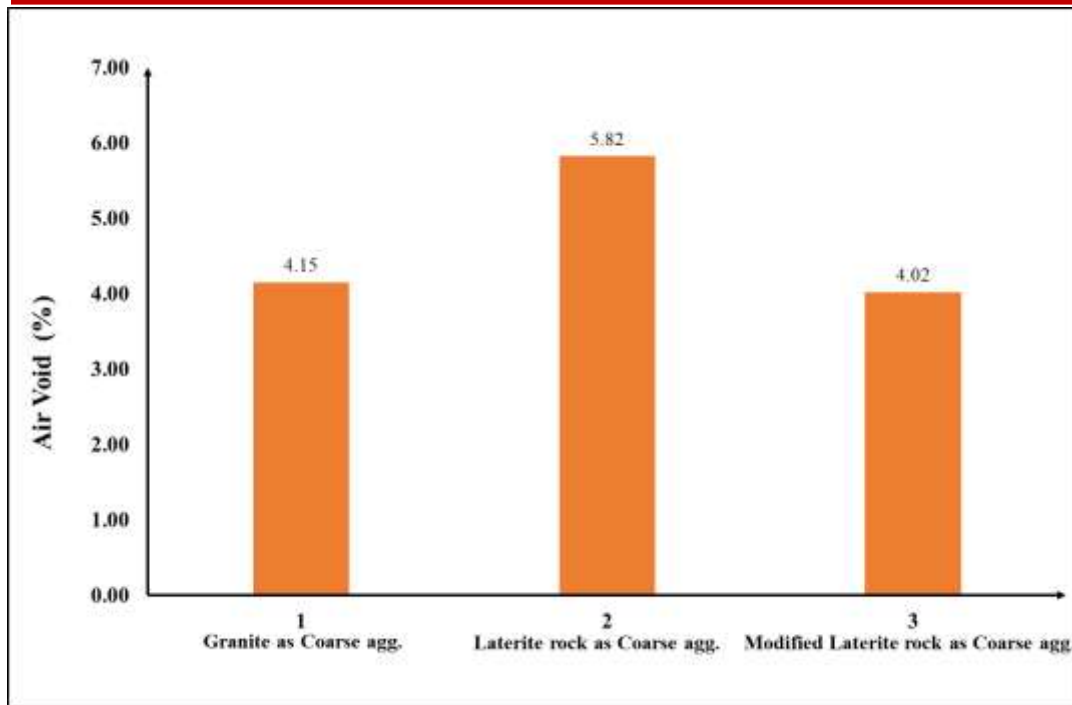


Figure 3b. Comparison of air voids: granite, laterite and PE-QD modified laterite

Air voids reduced from 5.82% in the unmodified laterite mix to a minimum of 4.02% at 2% PE-2% QD (Figure 3a), reflecting improved compaction as polythene enhances binder cohesion and quarry dust fills inter-particle void spaces. The modified laterite mix achieved a lower air-void content than the granite mix (4.15%), suggesting the PE-QD treatment yields a denser, less permeable microstructure than either baseline mix (Figure 3b), with favourable implications for reduced moisture ingress.

4.4 Bulk Density

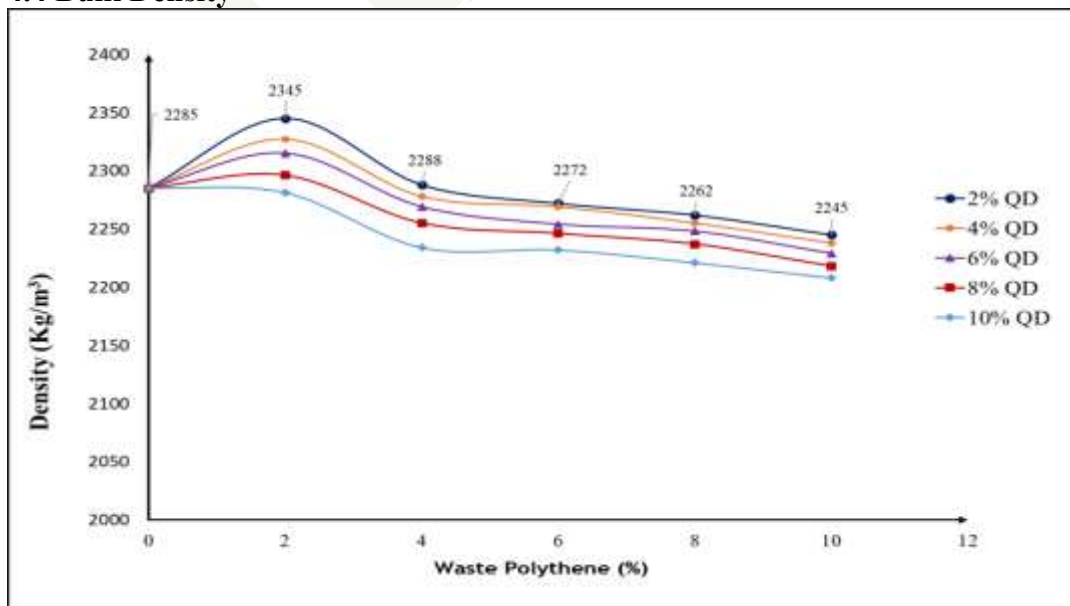


Figure 4a. Bulk density for varying PE-QD combinations

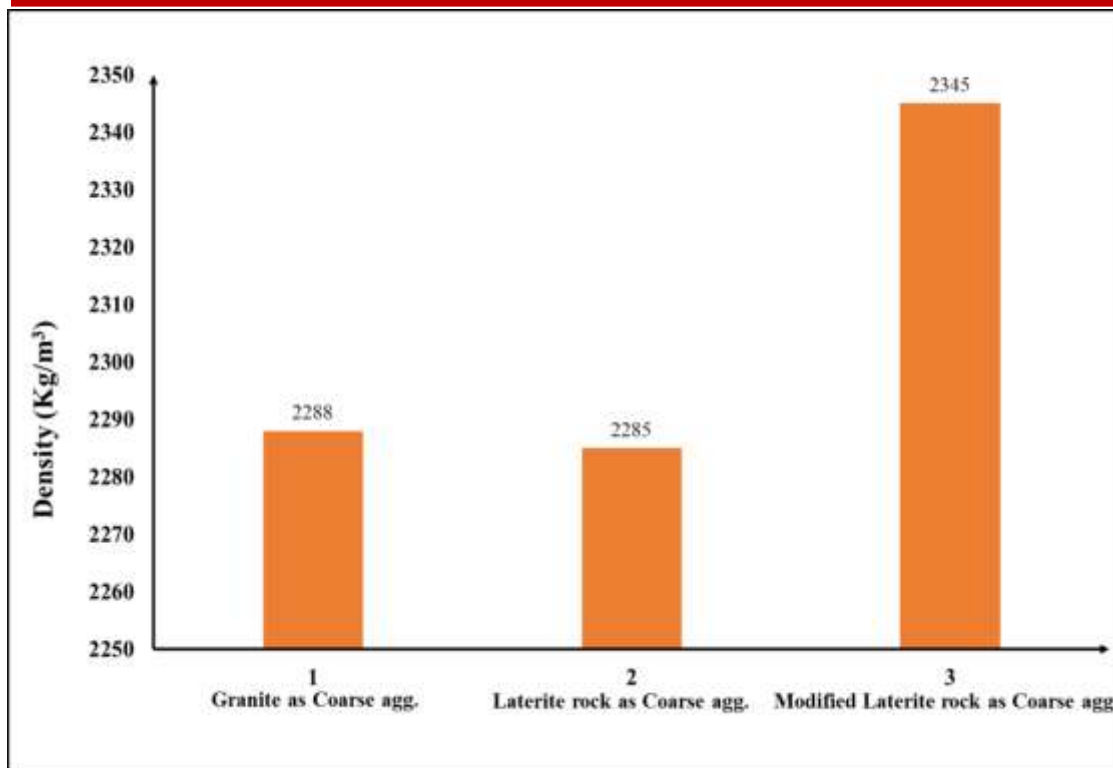


Figure 4b. Comparison of density: granite, laterite and PE-QD modified laterite

Bulk density increased from about 2,285 kg/m³ at 0% PE to a peak of 2,345 kg/m³ at 2% PE-2% QD (Figure 4a), before decreasing progressively at higher modifier contents. Granite and unmodified laterite mixes produced comparable densities (2,288 and 2,285 kg/m³, respectively), whereas the modified laterite mix was markedly denser (Figure 4b), consistent with the reduced air-void trend and indicative of improved particle packing.

4.5 Voids in Mineral Aggregate (VMA)

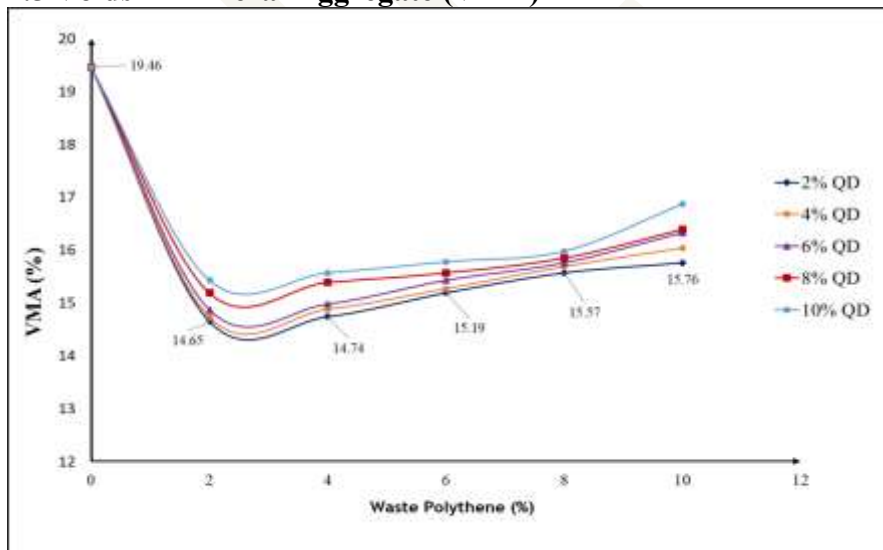


Figure 5a. VMA for varying PE-QD combinations

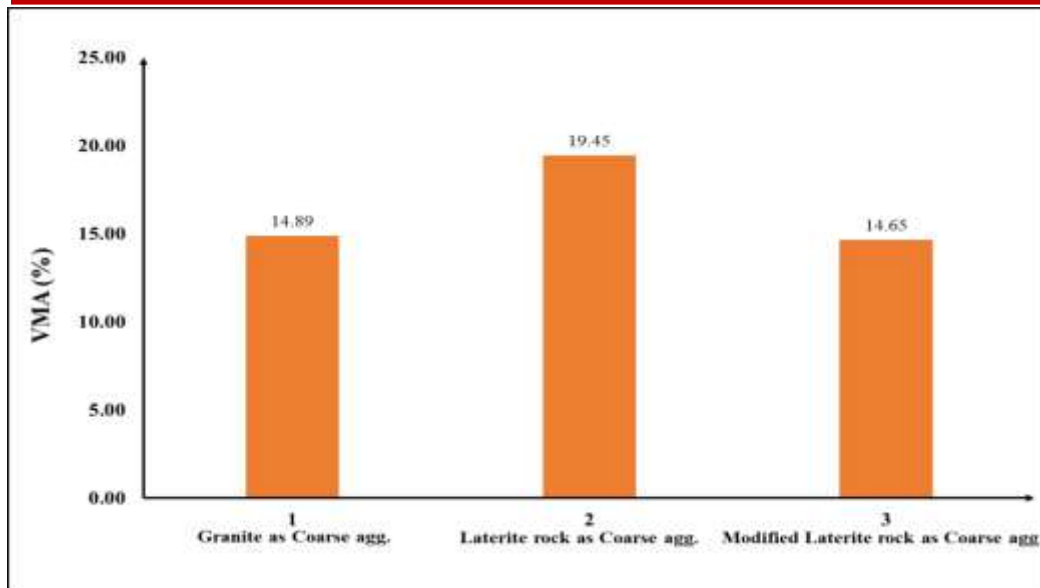


Figure 5b. Comparison of VMA: granite, laterite and PE-QD modified laterite

VMA decreased from 19.46% at 0% PE to a minimum near 14.65% at 2% PE-2% QD (Figure 5a), then increased again at higher polythene and quarry-dust contents. Unmodified laterite exhibited the highest VMA of all mixes (19.45%), while granite (14.89%) and PE-QD modified laterite (14.65%) produced closely comparable, and substantially lower, values (Figure 5b), confirming improved aggregate interlock in the modified mix.

4.6 Compliance with Design Criteria and Benchmarking Against Independent Studies

Table 5 compares the PE-QD modified mix-design properties against the Asphalt Institute (1997) allowable limits for the heavy-traffic category. All parameters for the 2% PE-2% QD mix satisfy the specified minimum and maximum bounds.

Table 5: Mix-design properties versus Asphalt Institute (1997) allowable limits

Property	Minimum allowable	Maximum allowable	2% PE-2% QD result	Remark
Stability (N)	8,000	-	29,655	Satisfactory
Flow (mm)	8	16	8.14	Satisfactory
Air voids (%)	3	5	4.02	Satisfactory
Density (kg/m ³)	2,200	2,700	2,345	Satisfactory
VMA (%)	13.01	-	14.65	Satisfactory

Benchmarking the present findings against the independent studies summarised in Table 1 shows good qualitative agreement. Mabui et al. (2023) reported an optimum plastic-waste dosage of 2% for porous asphalt stability, matching the 2% PE optimum identified in the present dual-blend mix. Kumar and Kumar (2023) similarly identified a non-monotonic stability-dosage relationship for plastic-modified asphalt, consistent with the stability rise-then-decline pattern observed here beyond 2% PE. Zghair Chfat et al. (2024) reported mineral-filler-driven reductions in air-void

content of a similar order to the 1.8 percentage-point reduction recorded in this study with quarry-dust incorporation. These convergences across independently conducted, differently sourced studies strengthen confidence that a 2% polythene, low-quarry-dust dosage represents a genuine, transferable optimum rather than a laterite- or site-specific artefact, while also indicating that the dual PE-QD blend used here achieves at least comparable, and in several respects superior, volumetric performance to single-modifier systems reported in the wider literature.

5. Conclusion

This study demonstrates that laterite rock, despite its inherently poor performance as a coarse aggregate in bituminous concrete (21,980 N stability, 5.82% air voids, 19.46% VMA when unmodified), can be transformed into a mix-design-compliant, and indeed superior, alternative to conventional granite when modified with an optimum dual blend of 2% waste polythene and 2% quarry dust by weight. At this optimum, Marshall stability increased by approximately 35% relative to unmodified laterite and 20% relative to granite, while flow, air voids, density and VMA all satisfied Asphalt Institute (1997) design criteria for heavy-traffic pavements. Beyond the 2% PE-2% QD optimum, progressive deterioration in all volumetric indices was observed, underscoring the importance of dosage control. The convergence of these findings with independently published, Scopus-indexed studies on plastic- and filler-modified asphalt reinforces the reliability of the 2% optimum dosage and supports the wider adoption of waste-polythene-quarry-dust modification as a sustainable, cost-effective strategy for valorising marginal aggregates such as laterite in flexible-pavement construction.

References

- AimixGroup. (2025). Granite crushing from an economic perspective: Cost, benefit, and market demand analysis.
- Akinbuluma, A. T., Isa, M. H., & Ogundare, D. A. (2024). African lateritic soils and pavement failure: A review.
- Alabady, H. F. A., & Abed, A. H. (2023). Effect of quality and quantity of locally produced filler on moisture damage hot asphaltic mixtures. *E3S Web of Conferences*, 427, 03039. <https://doi.org/10.1051/e3sconf/202342703039>
- Amadi-Oparaeli, K., Oju, M., & Igwe, E. A. (2020). Contribution of periwinkle shell ash on the stability and elastic properties of modified asphalt concrete for a high-traffic road. *International Journal of Constructive Research in Civil Engineering*, 6(2).
- American Society for Testing and Materials. (2001). ASTM C128-01: Standard test method for relative density (specific gravity) and absorption of fine aggregate.
- American Society for Testing and Materials. (1989). ASTM D1559-89: Standard test method for resistance to plastic flow of bituminous mixtures using Marshall apparatus.
- Asphalt Institute. (1997). MS-4: The asphalt handbook (7th ed.).
- Asphalt Institute. (2016). MS-2: Asphalt mix design methods (7th ed.).
- Ewa, D. E., Ukpata, J. O., Etika, A. A., Egbe, E. A., & Iduku, A. O. (2024). Mechanical properties of polythene modified asphalt. *Journal of Sustainable Construction Materials*, 9(1), 84-92.
- George, F. A., Ayobami, A. B., Abayomi, E. M., & Adeyemi, O. A. (2020). Engineering properties of paving stones made with bamboo ash as partial replacement for cement. *IOP Conference Series: Materials Science and Engineering*, 1107.
- Gonzalez, L. A., Pech-Canul, M. I., Bahrami, A., & Soltani, N. (2015). Review on physiochemical treatments of rice husk for production of advanced materials. *Chemical Engineering Journal*, 264, 899-935.
- Kaya, O. (2023). Experimental investigation of modified asphalt binder with waste expanded polythene. *Journal of Innovative Transportation Research*.
- Ketebu, O., & Farrow, T. S. (2017). Comparative study on cementitious content of ground mollusca and clam shell and their mixture as an alternative to cement.
- Kumar, B., & Kumar, N. (2023). Assessment of Marshall stability of asphalt concrete with plastic waste using soft computing techniques. *Multiscale and Multidisciplinary Modeling, Experiments and Design*, 6(4), 733-745. <https://doi.org/10.1007/s41939-023-00180-x>
- LivetoPlant. (2025). The environmental impact of quarrying granite for landscaping.
- Mabui, D. S., Tumpu, M., Tjaronge, M. W., Irianto, Gusty, S., & Mansyur. (2023). Stability Marshall of porous asphalt mixed with waste polyethylene terephthalate (PET) and modified asbuton. *International Journal of Engineering Trends and Technology*, 71(7), 216-222. <https://doi.org/10.14445/22315381/IJETT-V71I7P221>
- MK Crusher. (2025). Production cost of granite crushed stone.
- Obianyo, I. I., Taiwo, I. A., Dayyabu, A., et al. (2024). Modification of lateritic soil using waste plastics for sustainable road construction. *Polymers*, 16(19), 2689.
- Shah, S. K., Gao, Y., & Abdelfatah, A. (2025). Plastic-waste-modified asphalt for sustainable road infrastructure. *Sustainability*, 17(21), 9832.
- West, T., Jenbarimiema, J., & Azerube, D. (2020). Laterite rock modified asphalt concrete mix design properties. *International Journal of Constructive Research in Civil Engineering*, 6(2), 11-25.

Zghair Chfat, A. H., Yaacob, H., Mohd Kamaruddin, N. H., Al-Saffar, Z. H., & Jaya, R. P. (2024). Performance of asphalt mixtures modified with nano-eggshell powder. *Civil Engineering Journal*, 10(11), 3699-3720. <https://doi.org/10.28991/CEJ-2024-010-11-016>

Zulfikri, M. Z., Faridah, H. K., Chong, P. N., & Siti, K. C. E. A. (2016). Effect of sugarcane bagasse ash as filler in hot mix asphalt. *Materials Science Forum*, 846, 683-689.