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The Effect of Polyethylene Terephthalate (PET) on the Marshall Properties of Reclaimed Asphalt

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ABSTRACT : *This study evaluated the effect of polyethylene terephthalate (PET) on the Marshall properties of reclaimed asphalt with a view to evaluating its suitability as an additive in reclaimed asphalt. The reclaimed asphalt used for this study was obtained from an identified reclaimed asphalt stockpile along Ife-Sekona Road, Osun State, Nigeria and was reduced to manageable sizes to ensure ease of handling. The PET was sourced from dump sites within Obafemi Awolowo University, Ile-Ife. It was sorted, cleaned, and shredded by mechanical means into pieces ranging from 0.6 – 2.36mm at a recycling factory in Ido Osun, Osogbo. The PET was introduced into reclaimed asphalt at an increasing rate of 0.5%,1.0%, 1.5% and 2.0% of the sample. The samples were subjected to Marshall stability test. The stability, flow, specific gravity, voids filled with bitumen (VFB), air voids (VA) and voids in the mineral aggregate (VMA) were determined. The results of Marshall stability, flow, bulk density, air voids (VA), voids filled in bitumen (VFB), and voids in mineral aggregate (VMA) of the reclaimed asphalt sample at 0% PET were 17.8kN, 3.6mm, 2.57gm/cm^3, 3.74%, 5.04%, 25.80%, respectively, while the values at 1.0% PET content were 20.2kN, 3.8%, 2.5gm/cm^3, 3.1%, 5.15% and 39.80% respectively. The result showed that the Marshall properties of the reclaimed asphalt were improved by PET and yielded an optimum PET content of 1.0 %.*

KEYWORDS: *Polyethylene Terephthalate (PET), Reclaimed Asphalt, Marshall Stability, Air Voids, Voids in Mineral Aggregate*

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I. INTRODUCTION

Flexible pavement remains the widely used type of road pavement in most countries- particularly it is the preferred choice for many developing countries because it is cheaper to construct and maintain than the rigid pavement. It however has a disadvantage of deteriorating faster than the rigid pavement due to excessive vehicular load, unfavorable environmental conditions and the use of poor-quality materials for the pavement (Ezeagu and Ezema, 2022; Usanga et al., 2023). Consequently, a large volume of reclaimed asphalt is generated from the process of road rehabilitation and repair. The safe disposal of this waste becomes a challenge thus creating problems in the environment (Siddiqua et al., 2022; Liu et al., 2023).

The large volume of reclaimed asphalt being disposed raises public health and environmental concern, for which the government and regulatory agencies around the world are responding with suitable environmental and sustainable regulations (Rout et al., 2023). Reclaimed asphalt contains valuable material due to its asphalt binder and aggregates being reusable even after the pavement structure has reached the end of its lifespan (Mujtaba et al., 2022). As more roads undergo maintenance or rehabilitation, large amounts of reclaimed asphalt continue to accumulate. Its prolonged storage takes up a large portion of land area which could be used for other value adding activities, adds to environmental burden and increases the costs of disposal and storage (Magar et al., 2022).

Reclaimed asphalt refers to the processed material obtained from the removal or milling of existing asphalt pavements during maintenance, rehabilitation, or reconstruction works (Roberts et al., 2018). It consists primarily of high-quality mineral aggregates coated with aged bituminous binder that has undergone oxidation and hardening over time (Adeleke et al., 2021). The source of reclaimed asphalt is typically road resurfacing, pavement rehabilitation, and full-depth reclamation projects where existing asphalt layers are milled and processed for reuse (Mogawer et al., 2019).

The reliance on virgin aggregates persists, contributing to environmental degradation and higher infrastructure expenditure (Oguara & Ezenwa, 2022). Establishing a national policy framework for reclaimed asphalt documentation, quality control, and recycling standards is therefore critical to advancing Nigeria's commitment to sustainable infrastructure development and circular economy objectives. This absence of structured data hampers evidence-based decision-making, particularly in the planning and implementation of sustainable pavement management systems. Without accurate records, government agencies and contractors are unable to quantify potential savings in cost, energy, and emissions that could be achieved through systematic reclaimed asphalt reuse (Ogunrinde et al., 2020; Adeleke et al., 2021). In Nigeria, official statistics show that the quantity of reclaimed asphalt generated and recycled annually remains undocumented (Ogunrinde et al., 2020).

Plastic serves as a key resource in today's global economy. According to Smith & Vignieri, (2021), it is projected that the manufacturing of plastic will rise to approximately 12 billion tons by 2050. PET is among the most frequently used plastics globally. PET is used in food packaging as well as for packaging cosmetics and cleaning products (Tsakona et al., 2021). In most of the developing countries, plastic waste management is a big challenge due to inadequate policy, system or infrastructure for collecting, reusing or recycling plastic waste. It is important for nations to develop plans for plastic waste management in order to address the environmental, economic, and political challenges (Kehinde et al., 2020).

The main constituents of reclaimed asphalt are the mineral aggregates comprising coarse and fine fractions and the residual bituminous binder that originally served as the adhesive matrix in the hot mix asphalt. The aged binder in reclaimed asphalt often exhibits increased viscosity, stiffness, and brittleness due to prolonged exposure to traffic loading and environmental conditions such as heat, oxygen, and ultraviolet radiation (Roberts et al., 2018; Zhang et al., 2020). However, these changes can be partially reversed or improved through blending with virgin binder or rejuvenating agents during recycling (Adeleke et al., 2021).

Polymers as additives have gained significant attention in road construction. PET as a type of polymer is widely used in hot-mixed asphalt mixtures – it forms a thin layer around aggregates in asphalt mixtures, this layer strengthens the adhesion between aggregates and improves surface texture, thereby establishing PET as an ideal option because of its superior mechanical properties (Movilla-Quesada, 2019). Reclaimed asphalt possesses several engineering properties that make it suitable for reuse in new pavement construction. The aggregates in reclaimed asphalt offers comparable physical and engineering quality as fresh aggregates. Reclaimed asphalt also has good gradation characteristics, and residual binder content that can contribute to cost and energy savings (Mogawer et al., 2019; Oguara & Ezenwa, 2022). Moreover, introducing reclaimed asphalt into new asphalt mixtures can reduce the burden on natural resources (aggregates and bitumen) exploitation, minimize landfill disposal, and lower greenhouse gas emissions, thereby promoting sustainable pavement management (Ogunrinde et al., 2020; Zhang et al., 2020).

This paper therefore evaluated the effects of polyethylene terephthalate (PET) on the Marshall properties of reclaimed asphalt with a view to investigating its potential as an additive in reclaimed asphalt.

II. METHODOLOGY

2.1 Materials

The primary materials used for this study were polyethylene terephthalate (PET) and reclaimed asphalt. The reclaimed asphalt samples were collected from a dump site located along the Ife to Osogbo road; near Sekona town in Osun State, Nigeria. Waste PET bottles were collected from various dumpsters and waste receptacles within the Obafemi Awolowo University, Ile-Ife campus. Plate 1 shows the sample of the reclaimed asphalt and the shredded polyethylene terephthalate are shown in Plate 2.

Plate 1: Reclaimed Asphalt

Plate 2: Shredded Polyethylene Terephthalate

2.2 Methods

Preparation of Specimens**:** The reclaimed asphalt materials were initially pulverized manually using a hammer to obtain smaller, manageable particles suitable for blending. This preparation ensured ease of handling and improved uniformity during sample preparation. The collected PET bottles were sorted to remove impurities such as caps and labels, followed by thorough washing to eliminate contaminants. The cleaned PET bottles were then mechanically shredded into small flakes of sizes ranging between 0.6 mm and 2.36 mm in size at a recycling facility located in Ido Osun, Osogbo, Osun State. The dry mixing method was used to blend PET with reclaimed asphalt, in a way that the shredded PET was added directly to reclaimed asphalt heated to a temperature of 160^oC without prior melting or dissolution. This method has been widely adopted for incorporating waste polymers into asphalt mixtures due to its simplicity and efficiency (Haider et al., 2020).

Preparation of Samples for Marshall Stability Test: The samples were prepared as per ASTM D6927-15. The reclaimed asphalt sample was thoroughly mixed to ensure uniformity and a total weight of 1200 g was subjected to heating in an oven at 160°C for two hours to achieve the mixing and compaction temperature. The heated reclaimed asphalt sample was poured into a cylindrical mold and 75 blows were applied on each side of the samples to replicate the vehicular load from heavy traffic. After compaction, the samples were allowed to cool at ambient temperature for 24 hours to achieve adequate stability. The samples were immersed in a water bath with a controlled temperature of 60^oC for 30 minutes. Each sample was consequently loaded in the Marshall testing machine at a constant rate of 50.8 mm/min, until failure occurred. The maximum load needed to break the specimen, along with the diametrical deformation, were recorded as the Marshall stability and flow values. To assess the effect of PET on reclaimed asphalt, shredded PET was incorporated at 0.5, 1.0, 1.5, and 2.0 % by weight of reclaimed asphalt using the dry process, three specimens were prepared for each PET percentage to ensure consistency of results. The Marshall stability test was conducted in accordance with standard procedures to evaluate the mechanical and volumetric properties of the modified mixtures. The parameters determined from the test included Marshall Stability, flow value, bulk density, air voids (VA), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). These properties were used to assess the influence of PET modification on the performance characteristics of the reclaimed asphalt. Plate 3 and 4 show the Marshall stability tester and compacted reclaimed asphalt specimens with varying percentage of PET.

Plate 3: Marshall Stability Tester

Plate 4: Compacted Reclaimed Asphalt Specimens with Varying Percentage of PET

III. RESULTS AND DISCUSSION

3.1 Marshall Stability

Fig. 1 illustrates the variation in the Marshall stability of reclaimed asphalt samples with different PET contents. The stability increased progressively with PET addition up to 1.0%, beyond which it declined. The observed improvement in stability up to the optimum PET content can be attributed to the stiffening effect of PET, which enhances the interlocking between aggregates and improves the overall load-bearing capacity of the mixture (Movilla-Quesada, 2019). However, at PET contents above 1.0%, the stability decreased, likely due to the excessive presence of PET disrupting the cohesive bonding between the asphalt binder and aggregates. This phenomenon impedes compaction and weakens the internal structure of the mixture (Hayat et al., 2020). The trend suggests that incorporating PET up to 1.0% optimizes mixture stiffness and stability, beyond which the mix becomes brittle and less compactable.

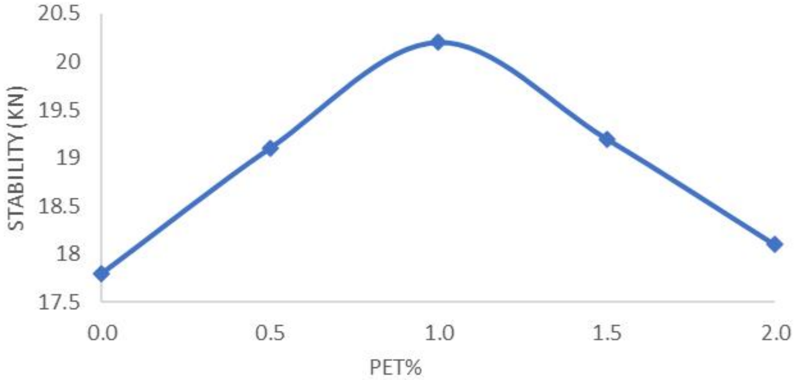

Fig. 1: Marshall stability against PET %

3.2 Flow

Fig. 2 presents the relationship between the flow values of reclaimed asphalt samples and PET content. The results show a gradual increase in flow with higher PET additions. This increase indicates that the modified mixtures exhibited greater plasticity and deformation under applied loads. This trend is consistent with findings reported by Kalantar et al. (2012) and Baghaee et al. (2013), who observed that Marshall flow values increased as PET content in asphalt mixtures increased. The rise in flow can be attributed to PET's lubricating effect within the mixture, which reduces internal friction and increases the material's tendency to deform (Baghaee et al., 2013).

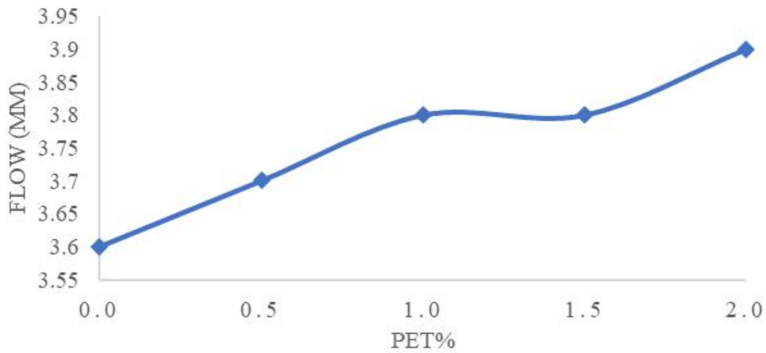

Fig. 2: Flow against PET %

3.3 Bulk Density

Fig. 3 depicts the variation in bulk density with PET content. A steady decrease in bulk density was observed with increasing PET addition. This reduction is primarily due to the lower specific gravity of PET compared to mineral aggregates, resulting in lighter mixtures (Ahmadinia et al., 2011). Furthermore, previous studies have shown that the dry process produces a lower bulk density than the modified dry process due to less effective aggregate coating and compaction (Movilla-Quesada et al., 2023). Reduced bulk density is generally undesirable as it may indicate insufficient aggregate packing, but it also reflects the potential of PET to produce lighter, more sustainable asphalt mixtures.

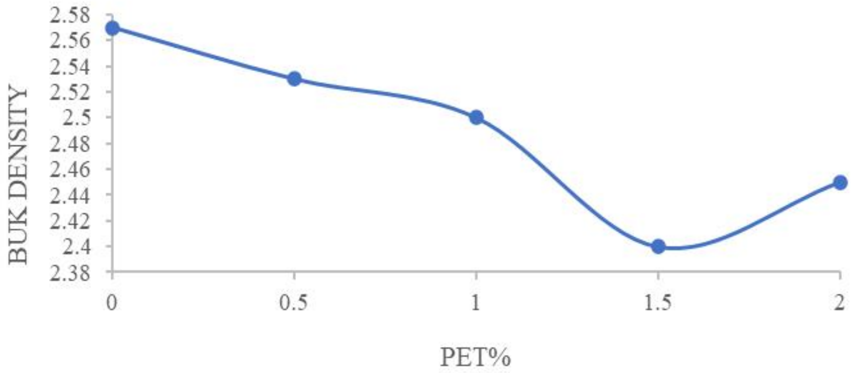

Fig. 3: Bulk Density against PET %

3.4 Air Voids (VA)

As shown in Fig. 4, the air voids in the reclaimed asphalt mixtures exhibited a non-linear trend with increasing PET content. A slight increase in air voids was observed from 0% to 0.5%, followed by a reduction up to 1.0%, and then another increase at 2.0%. The reduction in voids may be due to PET particles partially filling void spaces within the mixture, thereby improving compaction (Shah et al., 2024). However, at higher PET contents, incomplete coating of aggregates by the asphalt binder leads to poor adhesion, increasing the presence of unfilled voids (Bilema et al., 2024). This suggests that the effectiveness of PET in modifying air voids depends on achieving proper dispersion and binder interaction.

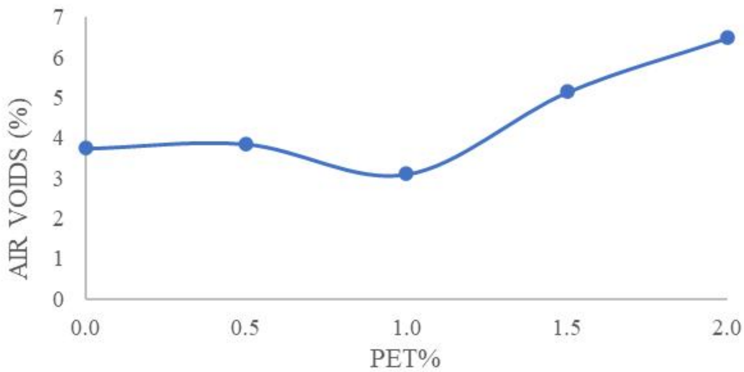

Fig. 4: Air voids against PET %

3.5 Voids in Mineral Aggregate (VMA)

The variation of voids in mineral aggregate (VMA) with PET content is also shown in Fig. 5. The VMA initially increased slightly up to 0.5% PET, decreased at 1.0%, and rose again at higher PET content. The initial variation may be attributed to the influence of PET particles on the compaction process and binder coating characteristics (Modarres & Hamedi, 2014). At elevated PET levels, the formation of a thick polymer layer around aggregates prevented dense packing, resulting in increased VMA values (Fadhil, 2017). High VMA values indicate greater space available for binder and air voids, which may enhance durability if adequately filled but may also reduce mixture stability if excessive.

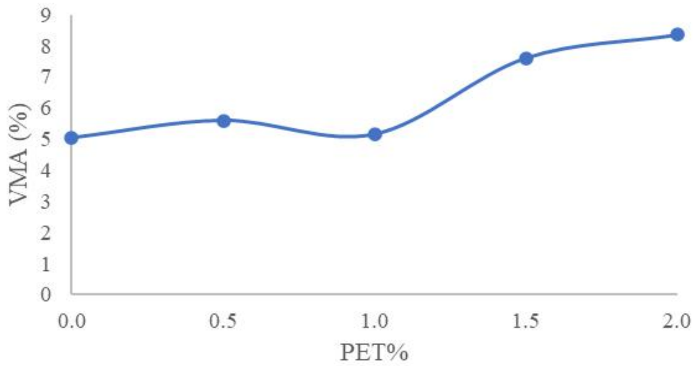

Fig. 5: VMA against PET %

3.6 Voids Filled with Bitumen (VFB)

Fig. 6 illustrates the trend of voids filled with bitumen (VFB) across different PET contents. The VFB increased up to the optimum PET level and declined thereafter. The initial increase can be attributed to PET improving the binder's ability to fill aggregate voids through better coating and interfacial bonding (Awaeed et al., 2015). At higher PET levels, excess polymer interfered with the adhesion between binder and aggregates, reducing the effective binder coating and consequently decreasing the VFB values (Choudhary et al., 2018). A similar trend was observed by Hafidz et al. (2025), where VFB peaked at an intermediate content. This pattern reinforces the existence of an optimum PET content at which binder utilization and aggregate coating are maximized.

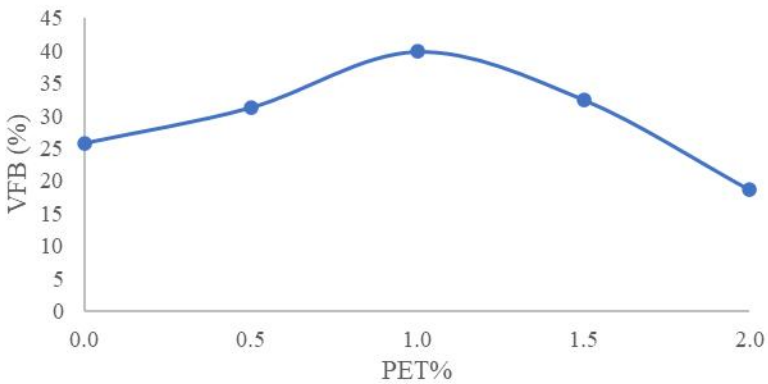

Fig. 6: VFB against PET %

IV. CONCLUSION

Overall, the results demonstrate that PET modification significantly influences the mechanical and volumetric properties of reclaimed asphalt mixtures. The optimum PET content was found to be 1.0%, beyond which the mixture exhibited a decline in stability and density but increased flow and void characteristics. These outcomes indicate that the addition of PET can enhance mixture stiffness and stability to a limit of 1.0%, beyond which bonding and compaction efficiency of the reclaimed asphalt are compromised.

It is therefore recommended that further tests such as indirect tensile strength (ITS), dynamic creep, four-point bending test, moisture susceptibility and repeated load axial tests could be done to fully evaluate the effect of polyethylene terephthalate on reclaimed asphalt. Also, rejuvenators could be used to restore the hardened and stiff binder within the reclaimed asphalt.

REFERENCES

[1] Adeleke, T. J., Aderinlewo, O. R., & Afolabi, J. O. (2021). Assessment of reclaimed asphalt pavement usage in highway construction in Nigeria. *Nigerian Journal of Technology, 40*(2), 215–222. https://doi.org/10.4314/njt.v40i2.6

[2] Ahmadinia, E., Zargar, M., Karim, M. R., Abdelaziz, M. & Shafigh, P. (2011). Using Waste Plastic Bottles as Additive for Stone Mastic Asphalt. *Materials and Design* 32: 4844–4849.

[3] ASTM International. (2015). ASTM D6927-15: Standard test method for Marshall stability and flow of asphalt mixtures. West Conshohocken, PA: ASTM International.

[4] Awaeed, K.M., Fahad. B.M., & Rasool, D.A. (2015). Utilization of waste bottles as a modifier for asphalt mixture properties. *Journal of Engineering and Development*, 20 (2) 1-4.

[5] Baghaee, T. M., Karim, M. & Mehrtash, S. (2013). Utilization of waste plastic bottles in asphalt mixture. *Journal of Engineering Science and Technology*., 8, 264–271.

[6] Bilema, M., Mohamed, A., Atiq, I., Maftah, S. & Alsaiti, A. M. (2024). Incorporating waste plastic bottles as an additive in asphalt mixtures through a dry method. *Slovak Journal of Civil Engineering, 32*(4), 42–49. https://doi.org/10.2478/sjce-2024-0024

[7] Choudhary, R., Kumar, A. & Murkute, K. (2018). Properties of Waste Polyethylene Terephthalate (PET) Modified Asphalt Mixes: Dependence on PET Size, PET Content, and Mixing Process. *Periodica Polytechnica Civil Engineering*.

[8] Ezeagu, C. A. & Ezema, N. (2022). Deterioration and failure rates of maintained roads in Nigeria. *Saudi Journal of Civil Engineering*, 6(4), 64–71.

[9] Fadhil, A. (2017). *Performance Analysis of AC-WC Asphalt Mixture with the Addition of Plastic Bottle Waste (PET) Under Various Soaking Durations. ETD Unsyiah*, 1(1), Article.

[10] Hafidz, M., Mayuni, S. & Azwansyah, H. (2025). Utilization of Polyethylene Terephthalate (PET) Plastic Waste as Material in AC-WC Mixture. *Jurnal Teknik Sipil (JTS*), 25(3), p.2237-2249. https://doi.org/10.26418/jts.v25i3.90392

[11] Haider, S., Hafeez, I., Jamal. & Ullah, R. (2020**).** Sustainable Use of Waste Plastic Modifiers to Strengthen the Adhesion Properties of Asphalt Mixtures. *Construction Building and Materials*., 235, 117496

[12] Hayat, U., Rahim, A., Khan, A. H. & Rehman, Z. U. (2020). Use of plastic wastes and reclaimed asphalt for sustainable development. *The Baltic Journal of Road and Bridge Engineering*, 15(2), 182–196.

[13] Kalantar, Z. N., Karim, M. R. & Mahrez, A. (2012). A review of using waste and virgin polymer in pavement. *Construction and Building Materials*, 33, 55–62.

[14] Kehinde, O., Ramonu, O. J., Babaremu, K. O. & Justin, L. D. (2020). Plastic wastes: Environmental hazard and instrument for wealth creation in Nigeria. *Heliyon, 6*(10) e05131.

[15] Liu, C., Zhao, B., Xue, Y., He, Y., Ding, S., Wen, Y. & Lv, S. (2023). Synchronous Method and Mechanism of Asphalt-Aggregate Separation and Regeneration of Reclaimed Asphalt Pavement. *Construction and Buildings Materials*., 378, 131127.

[16] Magar, S., Xiao, F., Singh, D. & Showkat, B. (2022). Applications of reclaimed asphalt pavement in India - A review. *Journal of Cleaner Production*, *335*, 130221.

[17] Modarres, A. & Hamedi, H. (2014). Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes. *Materials and Design.*, *61*, 8–15

[18] Mogawer, W. S., Austerman, A. J., & Daniel, J. S. (2019). Performance characteristics of hot mix asphalt containing different fractions and sources of reclaimed asphalt pavement. *Construction and Building Materials*, 209, 629–638. https://doi.org/10.1016/j.conbuildmat.2019.03.142

[19] Movilla-Quesada, D., Raposeiras, A. C. & Olavarría. J. (2019). Effects of recycled polyethylene terephthalate (PET) on stiffness of hot asphalt mixtures. *Advances in Civil Engineering*, vol. 2019, p. 6969826.

[20] Movilla-Quesada, D., Raposeiras, A. C., Guíñez, E., & Frechilla-Alonso, A. (2023). A Comparative Study of the Effect of Moisture Susceptibility on Polyethylene Terephthalate–Modified Asphalt Mixes under Different Regulatory Procedures. *Sustainability*, *15*(19), 14519. https://doi.org/10.3390/su151914519.

[21] Mujtaba, H., Khalid, U., Rehman, Z.U. & Farooq, K. (2022). Recycling of reclaimed subbase materials in flexible pavement design. *Road Materials and Pavement Design*, 23, 2713–2732.

[22] Oguara, T. M., & Ezenwa, I. A. (2022). Sustainable approaches to asphalt recycling and reuse in Nigeria's road sector. *Journal of Construction Materials and Sustainability*, 3(1), 45–53

[23] Ogunrinde, E. O., Adejumo, T. E. & Amadi, A. A. (2020). Development of an empirical model for A-6 soil stabilized with reclaimed asphalt pavement. *Proceedings of 2nd International Civil*

Engineering Conference. Minna: Federal University of Technology, Minna, Nigeria.

[24] Ogunrinde, O. K., Adeyemi, O. A., & Ajayi, O. O. (2020). Recycling of asphalt pavements: A review of challenges and prospects in Nigeria. *International Journal of Pavement Engineering and Construction Technology*, **7**(3), 89–98.

[25] Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. Y., & Kennedy, T. W. (2018). *Hot mix asphalt materials, mixture design and construction* (3rd ed.). National Asphalt Pavement Association Research and Education Foundation

[26] Rout, M. D., Biswas, S., Shubham, K. & Sinha, A. K. (2023). A Systematic Review on Performance of Reclaimed Asphalt Pavement (RAP) as Sustainable Material in Rigid Pavement Construction: Current Status to Future Perspective. *Journal of Building Engineering*, 76, 107253.

[27] Shah, M. M., Yousaf, J., Khalid, U., Li, H., Yee, J.-J., & Naqvi, S. A. Z. (2024). Plastic roads: Asphalt mix design and performance. *Discover Applied Sciences, 6*(195). https://doi.org/10.1007/s42452-024-05772-x

[28] Siddiqua, A., Hahladakis, J. & Al-Attiya, W. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research*, 29(43), 58514–58536. https://doi.org/10.1007/s11356-022-21578-z

[29] Smith, J. & Vignieri, S. (2021). A devil's bargain. Science 373, 34–35.

[30] Tsakona, M., Baker, E., Rucevska, I., Maes, T., Rosendahl Appelquist, L., Macmillan-Lawler, M., Harris, P., Raubenheimer, K., Langeard, R. & Savelli-Soderberg, H. (2021). *Drowning in Plastics: Marine Litter and Plastic Waste*. Vital Graphics; United Nations Environment Programme (UNEP): Nairobi, Kenya. ISBN 978-92-807-3888-9.

[31] Usanga, I., Okafor, F. & Ikeagwuani, C. (2023). Impact of rest time on creep recovery of asphalt mixtures modified with calcined marl filler. *Journal of Infrastructure Preservation and Resilience*, 4(25), 1–15. https://doi.org/10.1186/s43065-023 00087-4

[32] Zhang, J., Zhang, Y., & Yang, J. (2020). Influence of aged asphalt binder properties on the performance of recycled asphalt mixtures. *Materials*, 13(5), 1148. https://doi.org/10.3390/ma13051148

