

Performance Evaluation of Bituminous Concrete Incorporating Recycled Waste Plastic as a Partial Bitumen Modifier

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Abstract— The rapid growth of plastic consumption and the associated challenges of plastic waste management have emerged as critical environmental concerns worldwide. Simultaneously, the demand for durable, cost-effective, and sustainable road infrastructure continues to increase due to escalating traffic volumes and climatic stresses. In this context, the present study investigates the feasibility and performance of waste plastic–modified bituminous mixes as a sustainable alternative for road construction, with particular emphasis on rheological behavior and long-term durability characteristics. Waste plastic materials are incorporated as partial modifiers of conventional bitumen using controlled blending techniques to enhance binder performance while diverting plastic waste from landfills.

The rheological properties of the modified binders are evaluated through comprehensive laboratory testing, including viscosity, temperature susceptibility, and resistance to permanent deformation. These parameters are analyzed to understand the influence of waste plastic content on binder stiffness, elasticity, and workability across a range of service temperatures. Furthermore, durability performance is assessed through aging resistance, moisture damage susceptibility, and fatigue behavior of the modified bituminous mixes. Comparative analysis with conventional mixes highlights the improvements achieved in terms of rutting resistance, reduced thermal cracking potential, and enhanced service life.

The findings demonstrate that waste plastic modification significantly improves the rheological stability and durability of bituminous mixes without compromising constructability. The study concludes that waste plastic–modified bituminous mixes offer a technically viable and environmentally responsible solution for sustainable road construction, contributing to resource conservation, reduced environmental pollution, and improved pavement performance. This research provides valuable insights for policymakers, pavement engineers, and researchers seeking to integrate circular economy principles into transportation infrastructure development.

Keywords:

Sustainable road construction; Waste plastic utilization; Bituminous mix modification; Rheological properties; Pavement durability; Environmental sustainability; Circular economy.

1. INTRODUCTION

The rapid expansion of transportation infrastructure has become a cornerstone of socio-economic development across both developed and developing nations. Flexible pavements, predominantly constructed using bituminous mixes, account for a major share of global road networks due to their adaptability, ease of construction, and cost effectiveness. However, the long-term performance of conventional bituminous pavements is increasingly challenged by heavy axle loads, traffic congestion, extreme climatic variations, and premature material aging. These factors often lead to pavement distresses such as rutting, fatigue cracking, moisture damage, and thermal cracking, thereby increasing maintenance costs and reducing service life [1].

At the same time, the exponential growth in plastic consumption has created a parallel environmental crisis. Plastic waste, owing to its non-biodegradable nature and improper disposal practices, poses severe threats to ecosystems, public health, and urban sustainability. Conventional waste management strategies such as landfilling and incineration are associated with land scarcity, groundwater contamination, and greenhouse gas emissions [2]. Consequently, there is a pressing need to explore innovative, large-scale applications for plastic waste that align with sustainability goals and circular economy principles. Road construction has emerged as a promising sector for such valorization due to its high material consumption and long service periods [3].

The incorporation of waste plastic into bituminous binders and mixes has gained increasing attention as a sustainable pavement modification technique. Waste plastic, when used as a bitumen modifier, has been reported to enhance binder stiffness, reduce temperature susceptibility, and improve resistance to permanent deformation [4]. Depending on processing methods, plastics such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) can be introduced into bituminous systems through dry or wet processes, each influencing the interaction mechanisms between plastic polymers and bitumen constituents [5]. These interactions play a critical role in determining the rheological behavior and performance characteristics of the modified binder.

Rheological properties of bituminous binders are fundamental indicators of pavement performance, as they govern the

material response under varying stress, temperature, and loading conditions. Parameters such as viscosity, complex modulus, phase angle, and elastic recovery provide insights into the resistance of binders against rutting at high temperatures and cracking at low temperatures [6]. Waste plastic modification has been shown to alter the viscoelastic balance of bitumen, promoting improved elasticity and reduced flow behavior under sustained loads [7]. However, excessive plastic content or inadequate dispersion may result in phase separation, workability issues, and construction challenges, necessitating systematic rheological evaluation.

Beyond rheological enhancement, durability performance remains a critical criterion for the large-scale adoption of waste plastic-modified bituminous mixes. Pavement durability is influenced by aging resistance, moisture susceptibility, fatigue life, and thermal stability. Oxidative aging of bitumen over time leads to increased stiffness and brittleness, accelerating crack initiation and propagation [8]. Several studies have indicated that polymeric waste plastics can retard aging processes by forming protective networks within the binder matrix, thereby improving long-term performance [9]. Similarly, improved adhesion between binder and aggregates due to plastic modification has been associated with enhanced resistance to moisture-induced damage [10].

Despite the growing body of research on plastic-modified bitumen, significant variability exists in reported outcomes due to differences in plastic type, dosage, processing techniques, and testing methodologies. Moreover, many studies focus primarily on mechanical strength parameters, with limited emphasis on comprehensive rheological characterization and durability assessment under realistic service conditions. This highlights the need for an integrated evaluation framework that correlates rheological behavior with durability performance to establish optimal modification strategies [11].

In this context, the present study aims to provide a detailed rheological and durability-oriented investigation of waste plastic-modified bituminous mixes for sustainable road construction. By systematically analyzing the influence of waste plastic incorporation on binder rheology and mix durability, the research seeks to bridge existing knowledge gaps and offer practical insights for pavement engineers and policymakers. The outcomes of this work contribute toward environmentally responsible infrastructure development by transforming plastic waste into a value-added construction material while enhancing pavement longevity and performance [12].

2. Objectives

The bituminous mix design focuses to estimate the proportions of bitumen, filler material, fine aggregates, coarse aggregates & polythene to produce a mix which should have workability in the appropriate range so that there is no segregation under load. Enough strength to survive heavy wheel loads & tyre pressures.

- Sufficient durability
- Must be economical

3. Waste plastic is a concern

Plastics are durable & non biodegradable cannot be decomposed the chemical bonds make plastic very durable & resistant to normal natural processes of degradation. Since 1950s, around 1 billion tons of plastic have been discarded, and that they may persist for hundreds or even bunch of years. The plastic gets mixed with water, does not disintegrate, and takes the form of small pellets which causes the death of fishes and many other aquatic animals life as well as waster ecosystem. Today the availability of the plastic wastes is in huge amount, as the plastic materials have become the part of our daily life. Either they get mixed with the Municipal Solid Waste or thrown over a land area. If they are not recycled, their present disposal may be by land filling or it may be by incineration process. Both the processes have significant impacts on the environment. If they are incinerated, they polluted the air with very unwanted gases such as carbondioxide, nitrogendioxide etc, and if they are dumped into some place, they cause soil & water pollution. Under these circumstances, an alternate use for these plastic wastes is required.

4. RELATED WORK

4.1 Evolution of mix design concepts

- During 1900's, this technique, of using bitumen in pavements, was firstly used on rural roads in order to stop rapid removal of the fine particles such as dust, from Water Bound Macadam, which was caused because of fast growth of automobiles [Roberts et al. 2002]. At initial stages, heavy oils were used as dust palliative. An eye estimation process which is called pat test, was used to estimate the required quantities of the heavy oil, in the mix.
- The 1st formal technique of mix design was Hubbard field method, which was actually developed on sand-bitumen mixture. Mixtures with larger sized aggregates particles could not be handled during this technique. This was one limitation of this procedure.
- Francis Hveem, 1942; who was a project engineer of California, Department of Highways engineering, has developed the Hveem stabilometer in 1927. He did not have any previous experience on judgement that, the required mix from its colour, hence he decided to measure various mixture parameters to find the optimum quantity of bitumen [Vallegra and Lovering 1985]. He had applied the surface area calculation concept, (which was already in use, at that time for the cement concrete mix design), to estimate the quantity of bitumen actually required.
- Bruce Marshall developed the Marshall testing machine just before the World War
- It was adopted in the US Army Corpes of Engineers in 1930's and subsequently modified in 1940's and 50's.

4.2 Polymer modification

- Bahia and Anderson, 1984; studied about the visco-elastic nature of binders and found that, the complex modulus & phase angles of the binders, need to be

measured, at temperatures and loading rates with which different resemble climatic and loading conditions as well as past conditions.

- Shukla and Jain (1984) described that the effect of wax in bitumen can be decreased by adding EVA (Ethyl Vinyl Acetate), aromatic resin and SBS in the waxy bitumen. The addition of 4% EVA or 6% SBS or 8% resin in waxy bitumen effectively degraded the Susceptibility to high temperatures, bleeding at high temperature and brittleness at low temperature of the mixes.
- The findings of the studies conducted by the Shell Research and Technology Centre in Amsterdam indicated that the rutting rate is enormously reduced by the result of SBS modification of the binder. Button and Little (1998) on the basis of stress controlled fatigue testing at 20 and 0°C, reported that SBS polymer exhibited superior fatigue properties as compared to straight AC-5 bitumen.
- Shuler et al. (1987) found that the tensile strength of SBS modified binder rised considerably as compared to unmodified asphalt mix at -21, 25^{and} 41⁰C.
- Collins et al. (1991) and Baker (1998) reported that SBS modified asphalt mixes have longer lives than unmodified asphalt mixes. The addition of SBS polymer to unmodified bitumen also increases its resistance to low temperature cracking.
- Denning and Carswell (1981) according that asphalt concrete using polyethylene modified binders were more resistant to permanent deformation at elevated temperature.
- Palit et al. (2002) found improvement in stripping characteristics of the crumb rubber modified mix as compared to unmodified asphalt mix.
- Sibal et al. (2000) evaluated flexural fatigue lifetime of asphalt concrete modified by 3% crumb rubber as a part of aggregates.
- Goodrich (1998) according that fatigue life and creep properties of the polymer modified mixes increased considerably as compared to unmodified asphalt mixes.
- The Indian Roads Congress Specifications Special Publication: fifty three (2002) indicate that the period of next renewal may be extended by 50% in case of surfacing with modified bitumen as comparing with unmodified bitumen.

4.3 Recent applications

- A 25 km plastic changed bituminous concrete road was set in Bangalore. This plastic road showed superior smoothness, uniform behaviour and fewer rutting as compared to a plastics-free road which was laid at same time, which began developing terrible “crocodile cracks” very soon after. The process has also been approved, in 2003 by the CRRI (Central Road Research Institute Delhi).
- Justo et al (2002), at the Centre for Transportation Engineering, at Bangalore University used processed

plastic luggage bags as associate additive in asphalt concrete mixes. The properties of this modified bitumen were compared to that of ordinary bitumen. It was noted that penetration and ductility values, of modified bitumen was decreasing with the rise in proportion of the plastic additive, up to 12 % by weight.

- Mohammad T. Awwad et al (2007), polyethylene as synthetic resin collectively variety of polymers employed to research the potential prospects to boost asphalt mixture properties. The objectives also include determining the best type of polyethylene to be used and its proportion. Two types of polyethylene were added to coat the aggregate
- High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). The results indicated that grinded HDPE polyethylene modifier provides better engineering properties. The recommended proportion of the modifier is 12% by the weight of bitumen content. It is found to extend the stability and soundness, reduce the density and slightly increase the air voids and the voids of mineral aggregate.
- Shankar et al (2009), crumb rubber modified bitumen (CRMB 55) was blended at specified temperatures. Marshall’s mix design was applied by ever changing the modified bitumen content at constant optimum rubber content and subsequently tests have been performed to determine the different mix design characteristics and for conventional bitumen (60/70) additionally. This has resulted in much improved characteristics when compared with straight run bitumen and that too at reduced optimum modified binder content (5.67%).

5. Basic materials

5.1 Aggregate

Aggregate constitutes the granular part in bituminous concrete mixtures which contributes up to 90-95 % of the mixture weight and contributes to most of the load bearing & strength characteristics of the mixture. Hence, standard of the quality and physical properties of the aggregates should be controlled to ensure a good pavement. The properties that aggregates should have to be utilized in pavement are shown below-

- Aggregates should have minimal plasticity for better output. The presence of clay fines in bituminous combines can result in problems like swelling and adhesion of bitumen to the rock which may cause stripping problems. Clay lumps and friable particles should be limited to utmost 1%.
- Durability or resistance to weathering should be measured by sulphate soundness testing.
- The ratio of dust to asphalt cement, by mass should be a maximum of 1.2 & a minimum of 0.6. It is suggested for better result AASHTO T-209 to be used for determinant the maximum specific gravity of bituminous concrete mixes.

5.2 Bitumen

- Asphalt binder 60/70 and 80/100 are used in this research. The bitumen used should have the following required properties.
- Grade of bitumen used in the pavements should be selected on the basis of climatic conditions and their performance in recent days.
- It is usually recommended that the bitumen should be accepted on certification by the supplier (along with the testing results) and also the State project, verification samples. The procedures for acceptance should provide information, on the physical properties of the bitumen in timely manner.
- The physical properties of bitumen used which are very important for pavements are shown below. Every State should obtain this information (by central laboratory or supplier tests) and should have specification necessities for each property except specific gravity of bitumin.

5.3 Mineral Filler

Mineral filler consists of, very fine, inert mineral matter that is added to the hot mix asphalt, to increase the density and enhance strength of the mixture. These fillers should pass through 75µm(micron) IS Sieve.

The fillers may be cement or fly ash.

6 EXPERIMENTAL WORK

6.1 General

It involves mainly 2 processes. i.e.

- Preparation of samples
- Void analysis
- Testing

Prior to these experiments, the specific gravity of polythene used was calculated as per the guidelines provided in ASTM D792-08.

Determination of specific gravity of polythene

The procedure adopted is given below

- The weight of the polythene in air was measured by a balance. Let it be denoted by “a”.
- An immersion vessel full of water was kept below the balance.
- A piece of iron wire was attached to the balance such that it is suspended about 25 mm above the vessel support.
- The polythene was then tied with a sink by the iron wire and allowed to submerge in the vessel and the weight was measured. Let it be denoted as “b”.
- Then polythene was removed and the weight of the wire and the sink was measured by submerging them inside water. Let it be denoted as “w”.

The specific gravity is given by

$$s = a / (a + w - b)$$

6.2 Mixing Procedure

The mixing of ingredients was done as per the following procedure (STP 204-8).

- Required quantities of coarse aggregate, fine aggregate & mineral fillers were taken in an iron pan.
- This was kept in an oven at temperature 160°C for 2 hours. This is because the aggregate and bitumen are to be mixed in heated state so preheating is required.
- The bitumen was also heated up to its melting point prior to the mixing.
- The required amount of shredded polythene was weighed and kept in a separate container.
- The aggregates in the pan were heated on a controlled gas stove for a few minutes maintaining the above temperature.
- The polythene was added to the aggregate and was mixed for 2 minutes.
- Now bitumen (60 gm), i.e. 5% was added to this mix and the whole mix was stirred uniformly and homogenously. This was continued for 15-20 minutes till they were properly mixed which was evident from the uniform colour throughout the mix.
- Then the mix was transferred to a casting mould.
- This mix was then compacted by the Marshall Hammer. The specification of this hammer, the height of release etc.
- 75 no. Of blows were given per each side of the sample so subtotal of 150 no. of blows was given per sample.
- Then these samples with moulds were kept separately and marked



Figure – 1: MARSHALL SAMPLES



Figure 2: CLOSER VIEW OF A MARSHALL SAMPLE

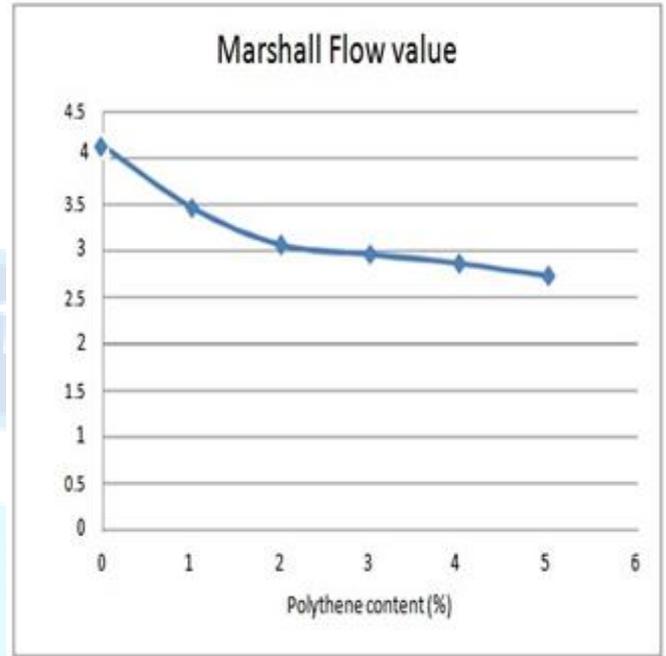


Figure 4: Marshall Flow Value

7 RESULTS

7.1 Plotting Curves

Five curves were plotted. i.e.

- i. Marshall Stability Value vs. Polythene Content
- ii. Marshall Flow Value vs. Polythene Content
- iii. VMA vs. Polythene Content
- iv. VA vs. Polythene Content
- v. VFB vs. Polythene Content
- vi. Bulk unit weight vs. Polythene Content

For each % of polythene, 3 samples have been tested. So the average value of the 3 was taken.

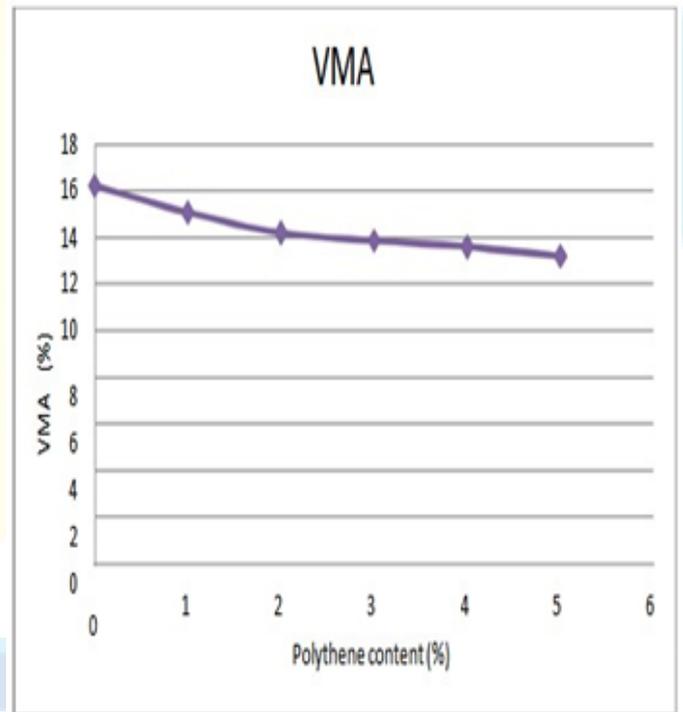


Figure 5 VMA vs Polythene

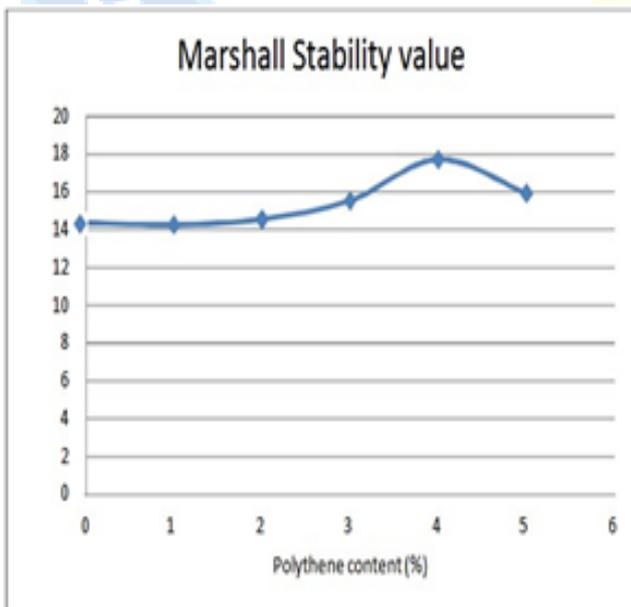


Figure 3 Marshall Stability

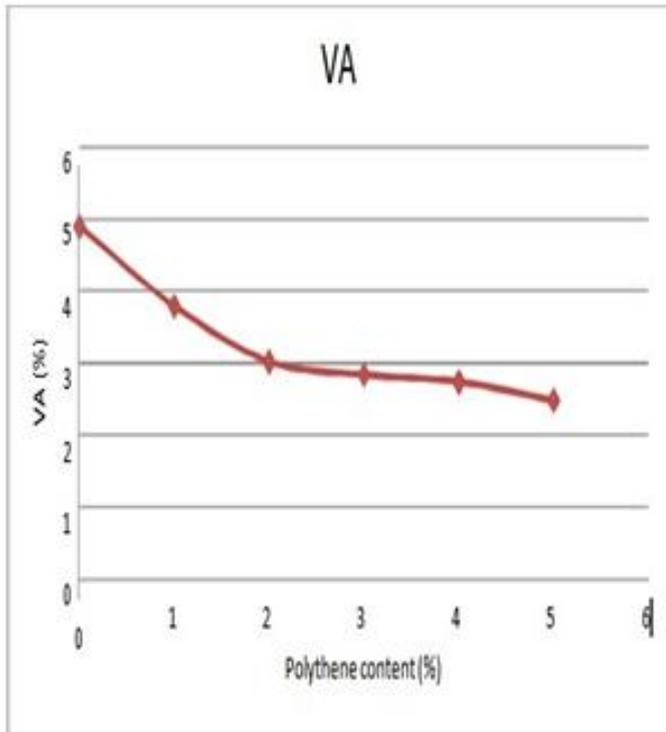


Figure 6: VA vs Polythene

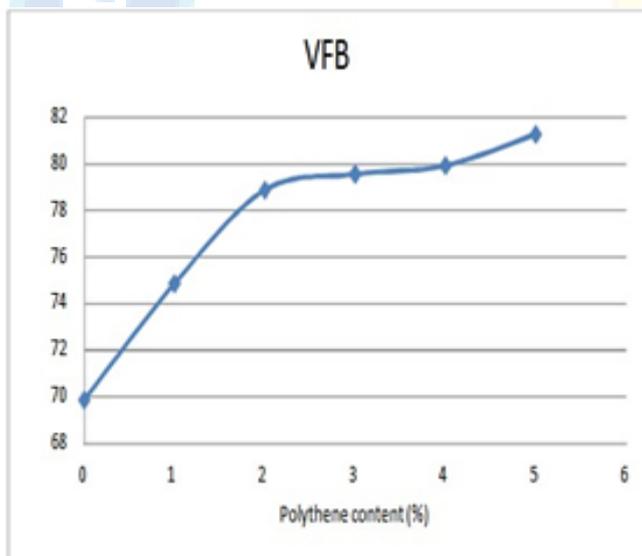


Figure 7: VFB vs Polythene

8 CONCLUSION

This study has comprehensively examined the potential of waste plastic-modified bituminous mixes as a sustainable and high-performance alternative for conventional flexible pavement construction, with particular emphasis on rheological behavior and durability characteristics. The findings clearly demonstrate that the strategic incorporation of waste plastic into bituminous binders leads to notable improvements in viscoelastic performance, temperature stability, and resistance to permanent deformation. Enhanced rheological properties, such as increased stiffness at high service temperatures and improved elastic response, contribute

directly to superior rutting resistance while maintaining adequate workability during mixing and compaction.

From a durability perspective, waste plastic modification has shown a positive influence on aging resistance, moisture damage tolerance, and fatigue performance of bituminous mixes. The presence of plastic polymers within the binder matrix effectively mitigates oxidative hardening and reduces susceptibility to environmental degradation, thereby extending the functional service life of pavements. Improved binder-aggregate adhesion further minimizes moisture-induced stripping, which is a critical factor affecting long-term pavement integrity in regions subjected to heavy rainfall and fluctuating climatic conditions.

The study also highlights the importance of optimizing plastic type, dosage, and blending methodology to achieve balanced performance. While moderate plastic content enhances rheological stability and durability, excessive incorporation may adversely affect homogeneity and constructability. This underscores the necessity of a scientifically guided mix design approach supported by advanced rheological testing and durability evaluation rather than reliance on empirical strength parameters alone.

Overall, waste plastic-modified bituminous mixes represent a technically viable and environmentally responsible solution for sustainable road construction. By transforming non-biodegradable plastic waste into a value-added pavement material, this approach contributes to effective waste management, conservation of natural resources, and reduction of lifecycle maintenance costs. The insights derived from this research provide a strong foundation for the development of performance-based specifications and policy frameworks that encourage the adoption of circular economy principles in transportation infrastructure. Future research should focus on long-term field performance monitoring, recyclability of plastic-modified pavements, and life cycle assessment to further validate and enhance the sustainability credentials of this innovative pavement technology.

REFERENCE

- [1] Y. H. Huang, *Pavement Analysis and Design*, 2nd ed. Upper Saddle River, NJ, USA: Pearson Prentice Hall, 2004.
- [2] R. Geyer, J. R. Jambeck, and K. L. Law, "Production, use, and fate of all plastics ever made," *Sci. Adv.*, vol. 3, no. 7, pp. 1–5, 2017.
- [3] A. Vasudevan, R. Ramalinga Chandra Sekar, and R. Sundarakannan, "Utilization of waste plastics for flexible pavement," *Indian Highways*, vol. 40, no. 4, pp. 49–57, 2012.
- [4] S. K. Khanna and C. E. G. Justo, *Highway Engineering*, 10th ed. New Delhi, India: Nem Chand & Bros., 2019.
- [5] M. A. Arabani, H. Mirabdolazimi, and M. Sasani, "The effect of waste plastic bottles on the stiffness and fatigue properties of hot mix asphalt," *Constr. Build. Mater.*, vol. 72, pp. 367–376, 2014.
- [6] R. S. McGennis, R. M. Anderson, T. W. Kennedy, and M. Solaimanian, *Background of Superpave Asphalt Binder Test Methods*. Washington, DC, USA: Transportation Research Board, 1994.



[7] A. Modarres and H. Hamed, "Effect of waste plastic bottles on the stiffness and moisture damage of asphalt mixtures," *J. Mater. Civ. Eng.*, vol. 26, no. 4, pp. 1–8, 2014.

[8] J. Read and D. Whiteoak, *The Shell Bitumen Handbook*, 5th ed. London, U.K.: Thomas Telford, 2003.

[9] S. Kalantar, A. Karim, and M. Mahrez, "A review of using waste plastic in asphalt mixture," *Constr. Build. Mater.*, vol. 33, pp. 448–456, 2012.

[10] B. Singh and S. Kumar, "Performance evaluation of waste plastic modified bituminous concrete mixes," *Road Mater. Pavement Des.*, vol. 20, no. 4, pp. 1–15, 2019.

[11] M. A. Hassan, N. Mashaan, and A. Karim, "Rheological properties of polyethylene-modified asphalt binders," *J. Eng. Sci. Technol.*, vol. 11, no. 3, pp. 380–391, 2016.

[12] P. T. Ravindra and R. N. Nagabhushana, "Sustainable road construction using plastic waste," *Int. J. Pavement Eng.*, vol. 22, no. 9, pp. 1121–1133, 2021.

[13] A. Punith and A. Veeraragavan, "Behavior of asphalt mixtures with reclaimed polyethylene as additive," *J. Mater. Civ. Eng.*, vol. 23, no. 2, pp. 163–172, 2011.

[14] N. Mashaan, A. Karim, M. Abdelaziz, M. R. Mansour, and M. R. Ibrahim, "Rheological properties and aging resistance of polymer modified asphalt binder," *Constr. Build. Mater.*, vol. 72, pp. 175–184, 2014.

[15] S. Tapkın, "The effect of polypropylene fibers on asphalt performance," *Build. Environ.*, vol. 43, no. 6, pp. 1065–1071, 2008.

[16] Z. You, J. Mills-Beale, J. M. Foley, S. Roy, G. M. Odegard, Q. Dai, and S. W. Goh, "Nanoclay-modified asphalt materials: Preparation and characterization," *Constr. Build. Mater.*, vol. 25, no. 2, pp. 1072–1078, 2011.

[17] M. R. Hainin, H. Yaacob, and A. Jamaluddin, "Rheological properties of asphalt binders modified with polyethylene waste," *J. Appl. Sci.*, vol. 12, no. 6, pp. 561–567, 2012.

[18] J. Shen, S. Amirhanian, and J. Xiao, "Influence of crumb rubber concentration on the performance of rubberized asphalt," *Road Mater. Pavement Des.*, vol. 10, no. 4, pp. 881–899, 2009.

[19] A. Rahman and A. Wahab, "Use of plastic waste in bituminous pavement construction: An environmental approach," *Int. J. Environ. Sci. Dev.*, vol. 4, no. 4, pp. 419–423, 2013.

[20] P. R. Kandhal and R. B. Mallick, *Pavement Engineering: Principles and Practice*. Boca Raton, FL, USA: CRC Press, 2018.

[21] S. B. Mishra and M. B. Gupta, "Performance evaluation of waste plastic modified asphalt mixtures under aging conditions," *Int. J. Pavement Res. Technol.*, vol. 12, no. 3, pp. 234–242, 2019.

[22] S. K. S. Hossain, M. Z. Hossain, and M. A. Islam, "Durability and moisture damage resistance of plastic waste modified bituminous mixes," *Constr. Build. Mater.*, vol. 248, pp. 118–129, 2020.