

Physical Properties of Asphalt Binder Modified Using Plastic Waste

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Abstract

The issue of managing plastic waste has become a serious global concern, driving researchers to explore practical and sustainable recycling alternatives. One promising approach is incorporating plastic waste into asphalt binders for road construction. This study aims to evaluate the physical characteristics of asphalt binders modified with plastic waste polymers, specifically Low-Density Polyethylene (LDPE) and Polystyrene (PS), to enhance pavement performance while supporting environmental sustainability. In this research, different proportions of plastic waste (2%, 6%, and 10%) were blended with conventional 60/70 penetration grade bitumen using the wet mixing method. The modified binders were then tested for penetration and softening point according to Malaysian Standard (MS 124). The results showed that plastic modification reduced penetration values and increased softening points, indicating higher stiffness and improved resistance to high temperatures. Among the modifiers, LDPE exhibited the most significant improvement, while the PS+LDPE blend provided a balanced performance between flexibility and strength. These findings align with previous studies which reported that polymer-modified bitumen improves thermal stability and rutting resistance. Overall, the study demonstrates that the use of plastic waste as a bitumen modifier enhances the performance of asphalt binder and contributes to more sustainable road pavement development.

Keywords: Low-Density Polyethylene, Polystyrene, Plastic Waste, Rheological Properties, Sustainability

1. Introduction

The developing accumulation of plastic waste, particularly in the form of Low-Density Polyethylene (LDPE) and Polystyrene (PS), has become a pressing environmental issue due to their non-biodegradable nature and extensive use in consumer packaging (Aldaihan et al., 2021). These plastics are disposed of in large quantities, ending up in landfills or polluting ecosystems, which adds significantly to long-term waste management challenges (Nizami et al., 2021). In response, the civil engineering sector has begun exploring recycling methods that transform plastic waste into value-added construction materials, particularly in asphalt pavement technology (Yaseen et al., 2022).

Flexible pavement construction relies heavily on the performance of bitumen as a binder, which is often vulnerable to rutting, thermal cracking, and moisture susceptibility under heavy traffic and adverse weather conditions (Jassim et al., 2020). Studies have shown that modifying bitumen with LDPE and PS can enhance thermal stability, hardness, and resistance to deformation, thereby extending pavement durability (Aldaihan et al., 2021). When properly processed and blended with hot bitumen, LDPE and PS improve viscosity, elasticity, and temperature susceptibility, resulting in better resistance to both high-temperature rutting and low-temperature cracking (Nizami et al., 2021). Beyond technical advantages, this approach also offers an environmentally friendly solution by reducing plastic waste through recycling into high-demand infrastructure applications. However, limited research has examined the combined effects of LDPE and PS in binder modification, particularly with respect to optimal mixing levels, processing temperatures, and long-term pavement performance under field conditions (Yaseen et al., 2022).

Maintaining road infrastructure also presents a financial burden, as premature pavement failures require costly repairs and resurfacing. Conventional asphalt mixtures often struggle to withstand extreme weather and traffic conditions, leading to rutting, cracking, and pothole formation. At the same time, inefficient plastic disposal methods continue to exacerbate environmental pollution and public health risks (Nizami et al., 2021). Although plastic-modified asphalt has shown promise, issues of compatibility, phase separation, and brittleness at low temperatures remain concerns, highlighting the need for further investigation (Yaseen et al., 2022).

Therefore, this study aims to evaluate the feasibility of utilizing Low-Density Polyethylene (LDPE) and Polystyrene (PS) as modifiers to enhance the performance of bitumen used in flexible pavements.

2. Research Method

2.1 Research Design

This study employed a quantitative experimental research design to evaluate the physical measurement of changes in binder characteristics when blended with Low-Density Polyethylene (LDPE) and Polystyrene (PS) at varying proportions. Laboratory experiments were conducted under controlled conditions to ensure accuracy and reproducibility of results.

The experimental design involved preparing asphalt binder samples with different percentages of plastic waste (2%, 6%, and 10%) using the wet mixing method at specified temperatures. The prepared samples were subjected to standardized physical tests, including penetration (MS 124), softening point (MS 124) , in accordance with Malaysia Standards.

By adopting this experimental research design, the study facilitated the collection of quantifiable data on binder performance, enabling the identification of trends and patterns related to the influence of LDPE and PS on bitumen modification. This approach ensured that the findings could be objectively analyzed, compared, and validated to achieve the study's objectives of enhancing pavement performance and promoting sustainable road construction.

2.2 Materials/Measures

The samples in this study consisted of asphalt binder and plastic waste materials prepared for laboratory testing. The base binder used was a penetration grade 60/70 bitumen obtained from the Highway Laboratory at Universiti Teknologi MARA Shah Alam, which is commonly employed in road construction due to its balance of hardness and flexibility. The plastic waste included post-consumer Low-Density Polyethylene (LDPE) and Polystyrene (PS), which were collected from packaging and household containers. Prior to testing, the plastic waste was cleaned, dried, and shredded into small particles to ensure uniform dispersion during mixing.

In total, 9 modified binder samples were prepared by blending bitumen with LDPE and PS at varying percentages (2%, 6%, and 10%) using the wet mixing method. These samples, along with the unmodified binder, were subjected to standard physical tests (penetration, softening point). The preparation and testing followed the relevant Malaysia Standards to maintain accuracy and reliability of results.

Table 1. Sample content

No.	Sample	Content
1	A	Polystyrene (PS)
2	B	Low Density Polyethylene (LDPE)
3	C	Low-Density Polyethylene (LDPE) + Polystyrene (PS)
4	D	Original bitumen 60/70

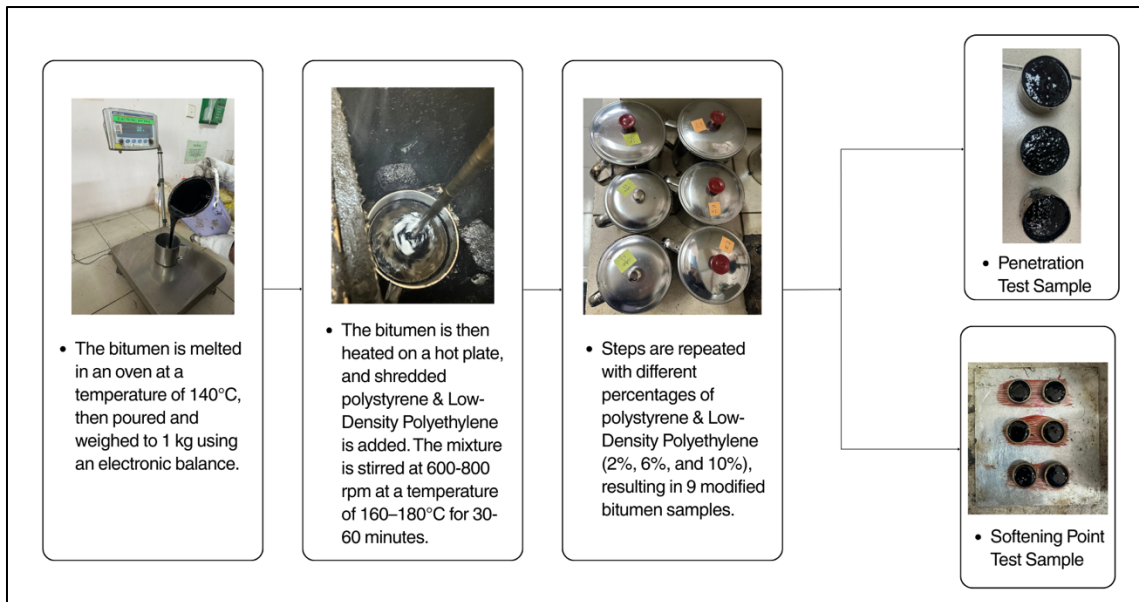


Figure 1. Preparation of Polystyrene and Low-density Polyethylene sample (2%,6%,10%)

2.3 Procedure

The research procedure involved collecting 60/70 penetration grade bitumen from the Highway Laboratory, UiTM Shah Alam, and preparing post-consumer LDPE and PS wastes through cleaning, drying, and shredding into uniform particles. The plastic waste was incorporated into the bitumen using the wet mixing method, with the binder heated to 160°C–180°C, a temperature range widely reported as suitable for reducing bitumen viscosity while avoiding thermal degradation of thermoplastic polymers (Airey, 2003; Polacco et al., 2006). LDPE and PS were added at 2%, 6%, and 10% by weight of bitumen, and the mixture was blended using a high-shear mixer at 600–800 rpm for 30–60 minutes, in accordance with previous studies demonstrating that these conditions promote effective polymer dispersion and limit phase separation (Lu and Isacsson, 2000; Yao et al., 2014). Preliminary trial mixes confirmed that the selected mixing parameters produced a homogeneous binder without visible segregation, after which the modified binders were evaluated using the Penetration and Softening Point tests following MS 124 standards.

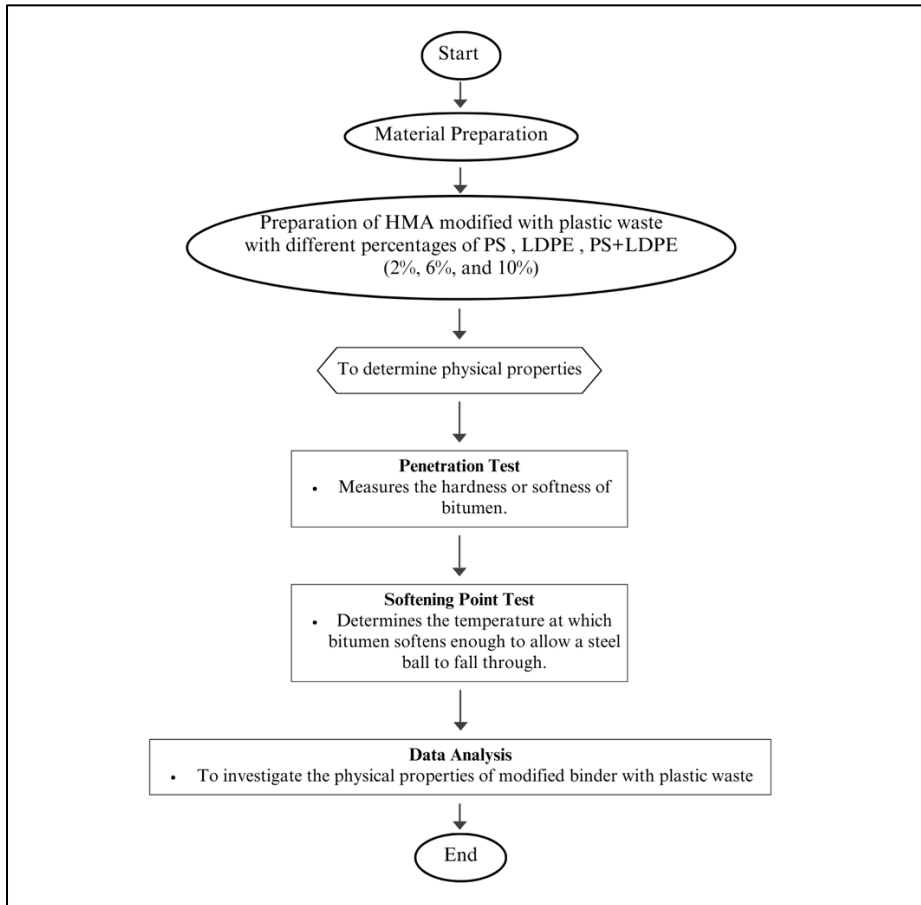


Figure 2. Flowchart of the study

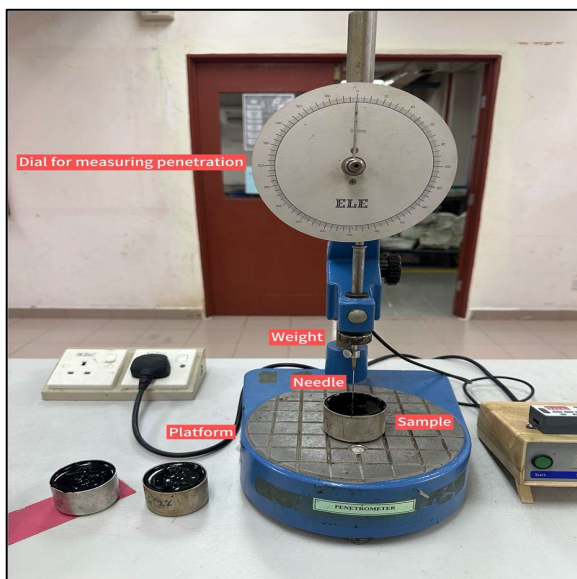


Figure 3. Penetration test apparatus

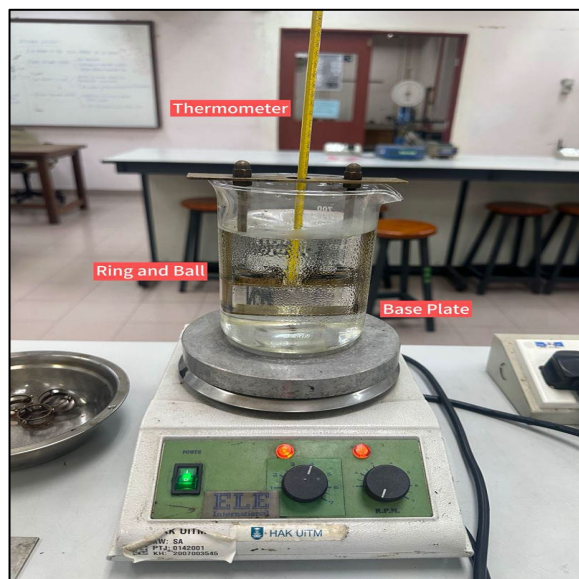


Figure 4. Softening point test apparatus

2.4 Data Analysis

The results from the laboratory tests were organized into tables and graphs to observe trends and variations in the penetration and softening point values of asphalt binders modified with LDPE and PS. Descriptive statistics such as averages and ranges were applied to summarize the data, providing a clear basis for interpreting the findings.

3. Results and Discussion

3.1 Penetration Test

The penetration test was conducted to measure the hardness of the asphalt binder by recording how far a standard needle penetrates the sample under a fixed load, time, and temperature. In this study, the test was applied to both unmodified 60/70 penetration grade bitumen and binders modified with different percentages (2%, 6%, and 10%) of Polystyrene (PS), Low-Density Polyethylene (LDPE), and a PS+LDPE blend.

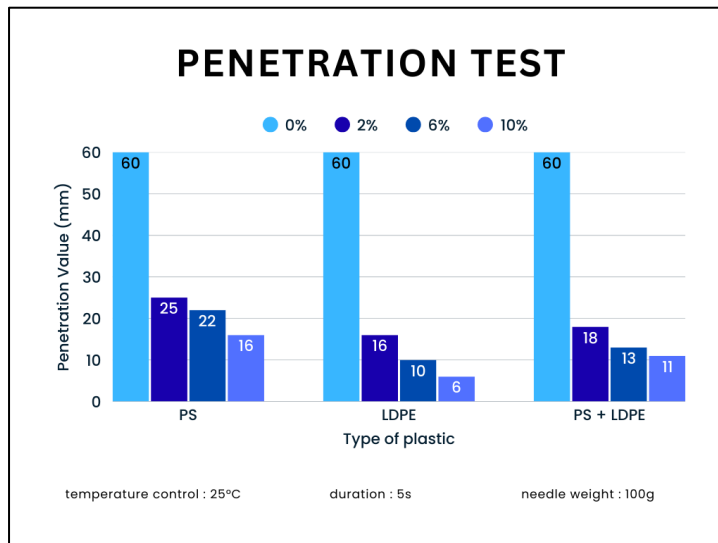


Figure 5. Result of penetration test asphalt binder modified with plastic waste

The results of the penetration test for bitumen modified with different types of plastic waste—polystyrene (PS), low-density polyethylene (LDPE), and a combination of both—are shown in Figure 5. These results are compared with the standard range set by MS 124 for 60/70-grade bitumen, which is 6.0 to 7.0 mm (or $60-70 \times 0.1$ mm). In all cases, adding plastic waste led to a noticeable decrease in penetration values, indicating that the modified bitumen became stiffer as more plastic was added. However, it should be noted that all modified binders remained well outside the MS 124 penetration range, indicating non-compliance with the standard

For the polystyrene (PS)-modified binder, the penetration values started high at around 24.5 mm for 2% PS and dropped to about 16 mm at 10%. This shows that even a small number of PS makes the bitumen significantly harder. Despite this increase in stiffness, the values are far above the allowable MS 124 range, confirming that PS-modified binders do not meet the standard for 60/70-grade bitumen. While this extra hardness might improve resistance to deformation under heavy loads, it could also make the binder more brittle, especially in colder temperatures. So, while PS helps increase stiffness, too much of it could negatively affect the flexibility and durability of the pavement.

In the case of LDPE-modified binders, the penetration values were lower than those of PS at the same concentrations, starting at around 16 mm (2%) and going down to 5.5 mm (10%). Interestingly, the sample with 10% LDPE was the only one that came close to meeting the MS 124 standard. This suggests that LDPE has a more balanced effect on the bitumen. Nevertheless, most LDPE-modified samples still fall outside the MS 124 range, indicating that they are not fully compliant with the standard. Because LDPE is more ductile, it may offer better flexibility, making it a more suitable modifier, especially when the goal is to stay within standard penetration limits.

For the combination of PS and LDPE, the penetration values fell somewhere between the individual results of the two plastics, about 17.5 mm at 2%, decreasing to 11.5 mm at 10%. This blend appears to strike a middle ground, softening the stiffness of PS with the flexibility of LDPE. Even so, the penetration values remain above the MS 124 standard, so these binders also do not meet the specified requirements. While the change is more gradual, suggesting better control over the binder's consistency, using a mix of plastics might offer a practical approach to balancing strength and flexibility for further development.

3.2 Softening point test

The softening point test was carried out to determine the temperature at which the asphalt binder softens, indicating its ability to resist high-temperature deformation. In this study, the test was performed on unmodified 60/70 penetration grade bitumen and binders modified with 2%, 6%, and 10% Polystyrene (PS), Low-Density Polyethylene (LDPE), and a PS+LDPE blend.

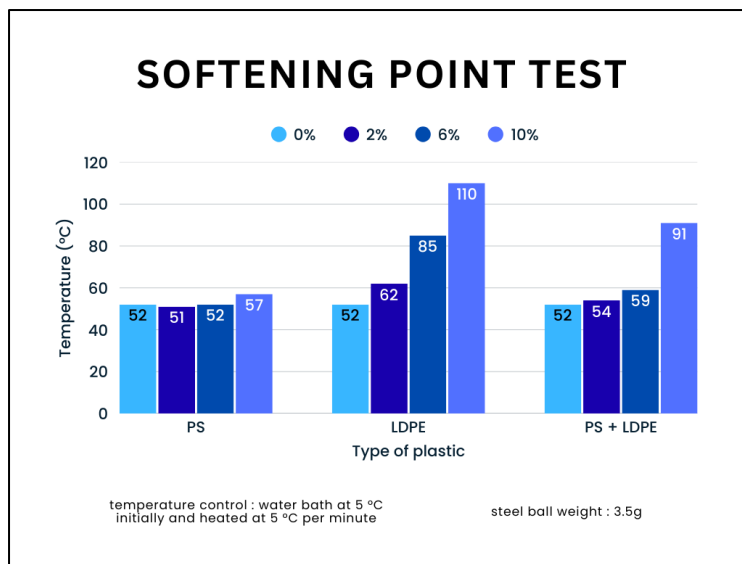


Figure 6. Result of softening point test asphalt binder modified with plastic waste

The results of the softening point test for bitumen modified with polystyrene (PS), low-density polyethylene (LDPE), and a blend of both plastics are presented in Figure 6. These results were compared with the Malaysian Standard (MS 124), which specifies a softening point range of 48–56 °C for 60/70-grade bitumen. In all cases, the addition of plastic waste increased the softening point of the binder. This rise indicates that as plastic content increased, the binder became stiffer and more resistant to heat, which directly improves rutting resistance under high-temperature conditions.

For the PS-modified binder, the softening point showed a gradual increase with increasing plastic content, rising from approximately 52 °C at 2% PS to about 57 °C at 10% PS. These values fall within or slightly above the MS 124 specification range, indicating that PS provides a modest improvement in thermal stability. The binder

became slightly harder and more resistant to heat while still maintaining a degree of flexibility, making PS a mild yet effective modifier.

In contrast, the LDPE-modified binder demonstrated a much more pronounced increase in softening point, increasing from around 62 °C at 2% LDPE to nearly 110 °C at 10% LDPE. This extreme hardening significantly exceeds the MS 124 standard limit of 48–56 °C, indicating non-compliance. Such a high softening point may lead to excessive brittleness, reduced flexibility, and practical difficulties during mixing and compaction in road construction, despite the excellent rutting resistance at high temperatures.

The behaviour of the PS+LDPE blend can be justified by considering the thermal and mechanical characteristics of the two plastics. Polystyrene (PS) is relatively stiff and has a higher softening temperature, while low-density polyethylene (LDPE) is more flexible with a lower softening point. When combined, the blend produces intermediate properties, which explains why the softening point values fall between those of the individual plastics and increase gradually from about 54 °C at 2% to nearly 90 °C at 10%. This controlled increase indicates that the blend enhances high-temperature resistance without causing an abrupt rise in stiffness, unlike LDPE alone. Although the softening point at higher concentrations exceeds the MS 124 limit, the gradual trend suggests that an optimum dosage can still meet specification requirements while improving binder performance. The combined effect of PS and LDPE provides a better balance between stiffness and flexibility, which is essential for resisting deformation at high temperatures while maintaining adequate workability during mixing, compaction, and construction processes.

4. Conclusion

This study evaluated the effects of incorporating polystyrene (PS), low-density polyethylene (LDPE), and their combined blend into 60/70 penetration grade asphalt binder by examining changes in penetration and softening point properties in accordance with MS 124. The findings demonstrate that the addition of plastic waste consistently reduced penetration values and increased softening points, indicating enhanced binder stiffness and improved resistance to high-temperature deformation.

Among the modifiers investigated, PS produced only modest improvements, while LDPE resulted in substantial increases in stiffness, particularly at higher dosages, leading to softening point values well beyond standard limits. In contrast, the PS+LDPE blend exhibited a more balanced performance, achieving improved thermal stability while moderating excessive hardening compared to LDPE alone. These results suggest that blending different plastic waste types may offer a viable approach to optimizing binder performance.

It is important to note that this investigation was limited to laboratory-scale physical testing and did not assess long-term aging, field performance, or durability under traffic and environmental loading. Therefore, while the results indicate promising potential for plastic-modified binders, further studies incorporating rheological characterization, aging simulations, and field validation are required before large-scale implementation in road construction can be recommended.

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Author Contribution

Conceptualisation, Rosmawati Mamat; Methodology, Rosmawati Mamat, Nurul Najihah Mad Rosni; Validation, Rosmawati Mamat; Analysis, Faradillah Ahmad, Rosmawati Mamat, Ekarizan Shaffie; Noor Azreena Kamaluddin; Investigation, Faradillah Ahmad; Resources, Rosmawati Mamat; Data Curation,

Faradillah Ahmad; Writing – Draft Preparation, Faradillah Ahmad; Writing – Review & Editing, Rosmawati Mamat, Nurul Najihah Mad Rosni, Wardati Hashim; Visualisation, Faradillah Ahmad, Ekarizan Shaffie; Supervision, Rosmawati Mamat Project Administration, Rosmawati Mamat.

All authors have reviewed and approved the final version of the manuscript for publication.

Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

Declaration of Generative Ai in The Writing Process

During the preparation of this work, the author(s) used CHATGPT in order to improve the readability of the sentence. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Data Availability/Supplementary Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Statement

The authors declare that this research did not involve human or animal subjects. All experimental procedures were performed following the institutional Safety, Health, and Environmental (HSE) protocols of Universiti Teknologi MARA.

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