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Evaluation of Modified Asphalt Binders Incorporating Recycled Plastic Waste for Enhanced Pavement Performance

Chy Teng[1*], Kuchvichea Kan[1], Phanny Yos [2]

[1] *Faculty of Civil Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia*

[2] *Research and Innovation Centre, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia*

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Abstract: *The increasing accumulation of plastic waste poses a significant environmental challenge, with millions of tons being discarded annually. At the same time, conventional asphalt binders used in road construction often exhibit inadequate performance under high temperatures, leading to rutting and deformation. To address both concerns, this study explores the potential of incorporating recycled plastic waste into asphalt binders as a sustainable solution for improving pavement durability. The objective of this research is to evaluate the mechanical properties, thermal stability, and overall performance of modified asphalt binders incorporated with recycled plastic waste. This study focuses on modifying asphalt binders using only two materials: 60/70 penetration-grade bitumen and recycled plastic bottle caps composed primarily of HDPE.The methodology involves laboratory experiments where asphalt binders are modified with different percentages of plastic waste (0%, 1%, 3%, 5%, 7% and 9%) and subjected to standard performance tests, including penetration, softening point, and ductility tests based on ASTM standards. The results indicate that increasing plastic content enhances the binder's resistance to deformation, increases softening point temperatures, and reduces penetration values, signifying improved binder hardness and durability. However, a higher plastic percentage reduces ductility, necessitating optimization for practical applications.This study demonstrates that incorporating recycled plastic waste into asphalt binders can enhance binder performance while mitigating plastic pollution. The findings suggest that plastic-modified asphalt is a viable alternative for sustainable road construction, with economic and environmental benefits. Further research is recommended to evaluate the full mechanical performance of HDPE-modified asphalt mixtures particularly through Marshall stability testing as well as to assess their long-term field performance and environmental impacts.*

Keywords: Recycled Plastic Waste; Asphalt Binder Modification; Pavement Performance; Sustainable Road Construction; Plastic Pollution Reduction.

1. INTRODUCTION

The global surge in plastic waste has become a major environmental concern due to its synthetic and non-biodegradable nature, which leads to long-term pollution of land and marine ecosystems [1]. With over 430 million metric tons of plastic produced annually, much of which ends up in landfills or oceans, innovative reuse strategies are urgently needed [2].

[*] Corresponding author: TENG Chy
E-mail: chy_teng@gsc.itc.edu.kh

One such approach is incorporating recycled plastic waste into asphalt binders for road construction, which can improve mechanical and thermal performance while contributing to sustainability [3]. In Cambodia, particularly Phnom Penh, plastic waste management faces significant challenges due to urbanization, population growth, and limited infrastructure. The city generates around 10,000 tons of plastic waste annually, much of which is not properly segregated or recycled, leading to increased environmental stress [4]. Past reports, such as Stemming the Tide [5], originally emphasized the contribution of Asian rivers like the Mekong to ocean plastic pollution. However, this report was later retracted by Ocean Conservancy for inaccuracies and bias.

Although many studies have explored the use of recycled plastic in asphalt mixtures, most focus on general performance enhancements or compare different types of polymers without considering regional material conditions or binder-specific effects. In Cambodia, waste plastic remains a growing environmental issue, while bitumen performance under tropical conditions is a critical concern for road durability. However, limited research has been conducted on the effects of locally sourced recycled HDPE specifically from bottle caps on the performance of 60/70-grade bitumen using the wet process. Furthermore, previous study[6], highlighted that recycled HDPE, due to its thermoplastic nature and relatively low melting point, is one of the most suitable materials for road-grade asphalt modification. They observed that HDPE can significantly increase binder stiffness and softening point while reducing penetration values, which supports the current study's findings. However It does not define an optimal dosage range based on standardized performance thresholds.

2. METHODOLOGY

This study focuses on the wet process for modifying asphalt binders with recycled plastic waste, specifically targeting the reuse of plastic bottle caps as a sustainable additive. In this method, shredded plastic is blended directly into hot 60/70 penetration-grade bitumen at elevated temperatures (typically between 160 °C and 170 °C) to form a plastic-modified binder. The plastic is incorporated at varying dosages 1%, 3%, 5%, 7% and 9% by weight of the binder to evaluate the influence of plastic content on the binder's physical and mechanical properties.

The objective is to assess how the direct incorporation of recycled plastic into the binder affects critical characteristics such as penetration, softening point, and ductility. This method promotes uniform dispersion of plastic within the asphalt matrix and is considered effective for enhancing binder stiffness, high-temperature performance, and overall durability. The findings aim to support the development of environmentally responsible pavement materials while addressing the issue of plastic waste through practical reuse strategies.

2.1. Materials

2.1.1. Bitumen

Table 1: Physical Property of Bitumen 60/70

Test Item	*Test method*	*Spec.*	*Result*	*Unit*
Ductility	ASTM D113	>1000	1500	mm
Softening point	ASTM D36	45-55	45.5	ºC
Penetration	ASTM D5	60-70	66.87	0.1mm
Density	ASTM D70	-	1.032	g/cm^3

Bitumen 60/70 was selected as the bituminous material in this research. The test performance of the laboratory to evaluate the properties were ductility, softening and penetration, and density. Table 1 indicates the properties of the bitumen 60/70.

2.1.2. Recycle plastic

The recycled plastic utilized in this study was collected from post-consumer plastic bottle caps, which primarily consist high-density polyethylene (HDPE). Prior to use, a heating test at 180 °C for 90 minutes was performed to assess the thermal behavior of the materials. This test confirmed that plastics with melting points below 200 °C, particularly PP with a melting point of approximately 160 °C, were suitable for asphalt binder modification without undergoing degradation. Recycled HDPE plastics could be incorporated into asphalt through the wet method due to their relatively low melting temperature (~135°C) [6].

2.1.3. Testing Method

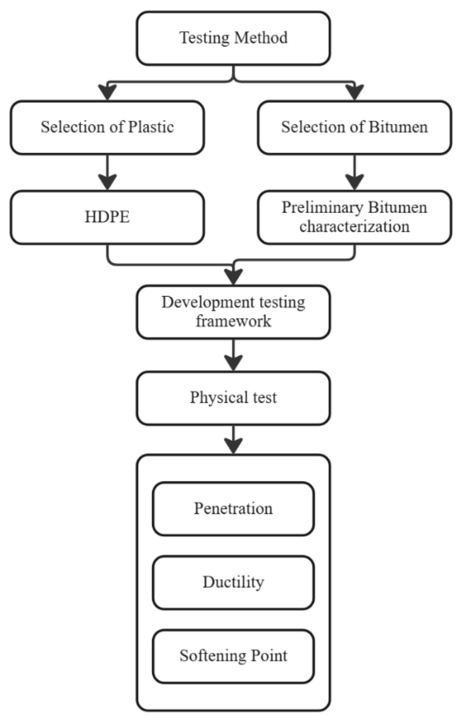

Fig. 1: Testing Procedure for the research

The performance of the modified asphalt binders was evaluated through standard laboratory tests in accordance with ASTM specifications. Penetration (ASTM D5), softening point (ASTM D36), and ductility (ASTM D113) tests were conducted to assess the consistency, thermal resistance, and flexibility of the binders, respectively (See Fig. 1)

2.1.4. Sample preparation

The total binder mass was fixed at 1 kg for each sample. The asphalt weight was reduced according to the plastic dosage (1–9 %) to maintain a constant total mass. This ensures proportional substitution of bitumen by recycled HDPE and allows consistent comparison between samples. (see Table 2).

The mixing process was carried out manually by hand since a mechanical mixer was not available in the laboratory. The 60/70 penetration-grade bitumen was heated to 160–170 °C, and the shredded HDPE was added gradually while continuously stirring for approximately 5–6 hours. The extended manual mixing period was necessary to ensure that the HDPE was fully melted and uniformly blended throughout the binder, resulting in a homogeneous plastic-modified asphalt binder.

Table 2: Plastic content for each sample preparation

Plastic content (%)	*Plastic weight (g)*	*Asphalt weight (g)*
0	0	1000
1	10	990
3	30	970
5	50	950
7	70	930
9	90	910

2.1.5. Laboratory test

Recycled (HDPE) sourced from plastic bottle caps was cleaned, shredded into 2–5 mm particles, and added to 60/70 penetration-grade bitumen in varying proportions (0%, 3%, 5%, 7%, and 9% by binder weight). The bitumen was heated to 170 °C–180 °C, and the HDPE was gradually introduced using manual stirring to ensure uniform dispersion. Each batch was mixed for 5–6 hours, then poured into standardized molds for penetration, softening point, and ductility tests. The prepared samples were cooled at room temperature and stored in sealed containers for subsequent testing.

3. RESULTS AND DISCUSSION

This section discusses the effects of recycled high-Density Polyethylene (HDPE) on the physical properties of asphalt binders, focusing on penetration, softening point, and ductility. The results for each plastic content level (0% to 9%) are compared against the Japan Road Association (JRA) standards to evaluate performance suitability. Key trends and trade-offs between stiffness and flexibility are highlighted to determine the optimal modification range.

3.1. Penetration (ASTM D5)

Table 3 presents the penetration test results of asphalt binders modified with varying percentages of recycled High-Density Polyethylene (HDPE). Each mixture was tested in triplicate to ensure accuracy, and the corresponding average and standard deviation (SD) values are reported.

Table 3: Penetration test reuslt

HDPE Content (%)	Penetration (0.1mm)			
	Test 1	Test 2	Test 3	Average
0	66.2	67.13	67.3	66.9± 0.61
1	52.9	53.10	52	52.7± 0.59
3	45.9	45.14	46.04	45.7± 0.48
5	40.2	39.33	39.7	39.7± 0.44
7	22.75	23.1	21.5	22.5± 0.84
9	17.27	17.60	17.6	17.5± 0.19

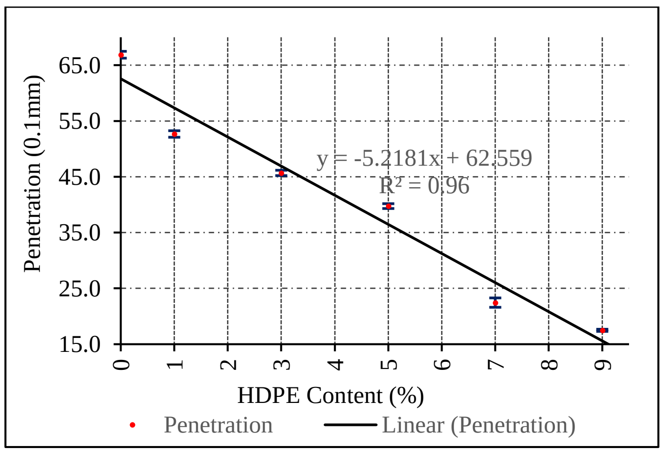

Fig. 2: Penetration affected by plastic percentage

According to *Fig. 2* the penetration values of the asphalt binder decreased consistently with the increasing proportion of recycled HDPE, confirming a significant stiffening effect. The unmodified binder exhibited a penetration value of approximately 66–67 1/10mm, characteristic of 60/70-grade bitumen. Upon adding 3% HDPE, the value dropped to approximately 45 1/10mm. Further increases in plastic content to 5%, 7%, and 9% resulted in penetration values of 39 1/10mm, 22 1/10mm, and 15 1/10mm, respectively. These results demonstrate that the addition of HDPE reduces binder penetration, enhancing its stiffness and resistance to deformation under high temperatures. However, excessive stiffness may lead to increased brittleness, which must be addressed in practical applications.

These findings are consistent with previous studies that report a significant reduction in penetration as plastic content increases[7], [8], [9]. The behaviour observed in this experiment confirms that recycled HDPE acts as a plastomeric modifier that reinforces the binder structure, making it suitable for pavements exposed to high temperatures and heavy loads.

The reduction in penetration occurs because HDPE increases the stiffness of the asphalt binder. When HDPE is heated and blended with bitumen, it partially melts and disperses within the binder matrix, forming a dense three-dimensional polymer network. This network restricts the mobility of bitumen molecules and reduces the ability of the binder to deform under load. As a result, the binder becomes harder and more resistant to penetration.

3.2. Softening Point (ASTM D36)

Table 4 presents the softening point results of asphalt binders modified with varying contents of recycled High-Density Polyethylene (HDPE). Each sample was tested three times, and the mean and standard deviation (SD) values are reported to indicate the consistency of the results.

Table 4: Softening testing result

HDPE Content (%)	softening Point(°C)			
	Test 1	Test 2	Test 3	Average
0	45.6	45.40	47.1	46.0± 0.929
1	48.7	49.80	50.1	49.5± 0.737
3	55.1	55.70	55.2	55.3± 0.321
5	59.5	58.85	58.4	58.9± 0.527
7	71.3	72.9	73.4	72.5± 1.097
9	94.4	94.40	95.7	94.8± 0.751

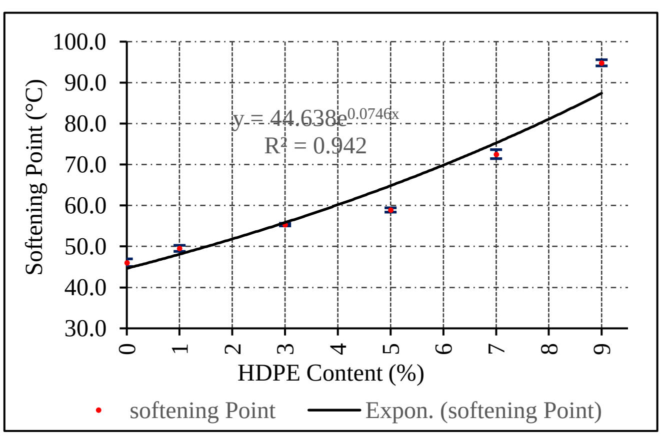

Fig. 3 Softening Point affected by plastic percentage

According to *Fig. 3,* tthe softening point of the bitumen increased with higher percentages of HDPE, indicating improved resistance to thermal deformation. The control sample (0% HDPE) had a softening point of approximately 45.5 °C. With 3% HDPE, the value rose to about 50 °C, while 5% and 7% contents led to softening points of 55 °C and 61 °C, respectively. At the highest modification level (9% HDPE), the softening point exceeded 70 °C. This trend demonstrates that plastic-modified binders can endure higher temperatures without losing structural integrity, which is beneficial for hot-climate applications.

With the addition of recycled plastics, the plastic-modified binder becomes less sensitive to temperature. The reduction of thermal susceptibility is consistent with the polymer modification of a neat bitumen.[10].

These results are supported by literature where similar increases in softening points have been reported with the addition of polyolefin plastics like HDPE [11]. The higher thermal stability observed in this study indicates better rutting resistance, a critical performance metric for asphalt binders used in high-traffic roads.

3.3. Ductility (ASTM D103)

Table 5: Ductility testing reulst

HDPE Content (%)	Ductility (mm)			
	Test 1	Test 2	Test 3	Average
0	1500	1500	1500	1500± 0.00
1	829.8	798.48	734.09	787.5± 48.79
3	307.9	249.13	262.86	273.3± 30.74
5	150.8	160.81	153.48	155.0± 5.20
7	134.86	111.75	120.33	122.3± 11.68
9	79.29	84.29	82.08	81.9± 2.51

Table 5 summarizes the ductility test results for asphalt binders modified with different percentages of recycled High-Density Polyethylene (HDPE). Each value represents the average of three replicate tests, with standard deviations (SD) provided to reflect the variability of the measurements.

While stiffness and thermal stability improved, ductility decreased sharply with increasing HDPE content. The control binder had a ductility value exceeding 1500 mm, but this dropped to 700 mm at 3% HDPE and 500 mm at 5%. At 7% and 9% HDPE, ductility values were recorded at 123 mm and 82 mm, respectively. This decline highlights a key trade-off: as the binder becomes more resistant to deformation, it simultaneously loses flexibility, making it more prone to cracking under tensile stresses or low temperatures. (see Fig. 4). This reduction in ductility is consistent with previous research, which notes that thermoplastic additives like HDPE tend to embrittle the binder at high concentrations [8], [12].

Therefore, while high-temperature performance is enhanced, care must be taken to balance stiffness with sufficient flexibility to prevent cracking.

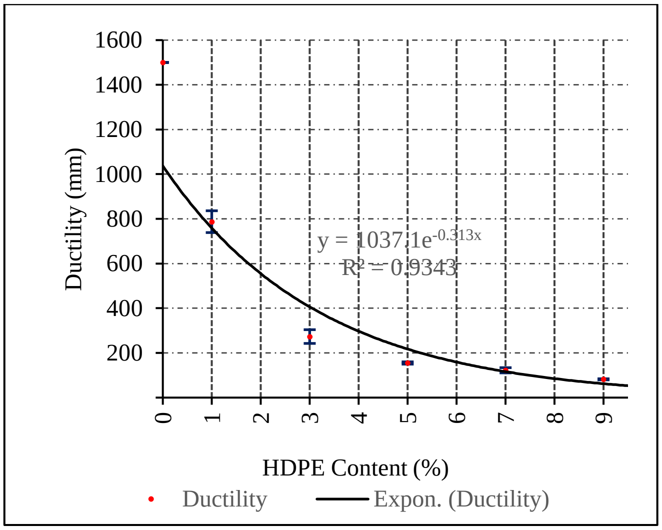

Fig. 4: Ductility affected by plastic percentage

3.4. Overall Performance Implication

To evaluate the suitability of the recycled plastic-modified asphalt binder, the experimental results for penetration, softening point, and ductility were compared against the standard requirements for polymer-modified asphalt established by the Japan Road Association as shown in Table 6. These standards provide benchmark values that ensure the modified binder possesses sufficient stiffness, high-temperature stability, and flexibility needed for durable pavement performance.

Table 6: Standard Property of Polymer Modified asphalt (According to Japan Road Association)[13]

Test item	*Value*
Softening Point ºC	min.56
Ductility (15ºC) , mm	min 300
Penetration (25ºC), 1/10mm	min 40

Softening point of modified asphalt binders compared to JRA standard as shown in Fig. 5**.** The graph illustrates that the softening point rises with increasing plastic content. The binders with 3% to 9% PP and higher surpass the JRA minimum softening point standard (≥56°C), indicating improved resistance to thermal deformation.

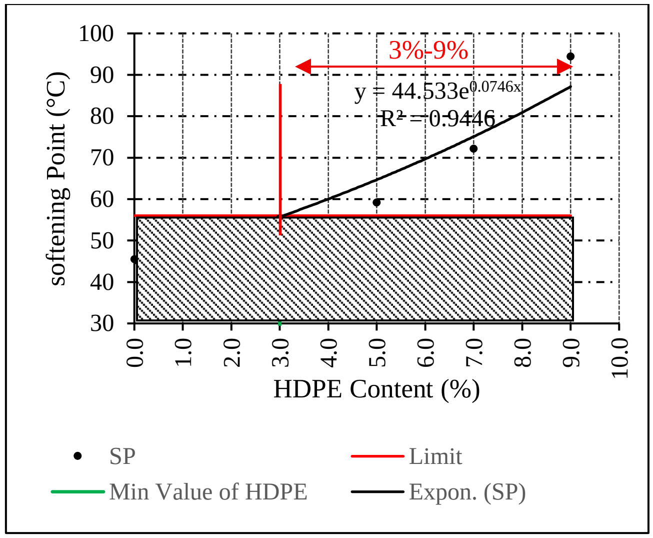

Fig. 5: Softening Point Results Compared to JRA Standards

Penetration values of modified asphalt binders compared to Japan Road Association (JRA) standard as shown in Fig. 6. This figure shows how penetration decreases with increasing recycled HDPE content. Binders with 0% to 4.3% HDPE meet the JRA minimum penetration requirement (≥40 1/10 mm), while higher percentages result in excessively stiff binders.

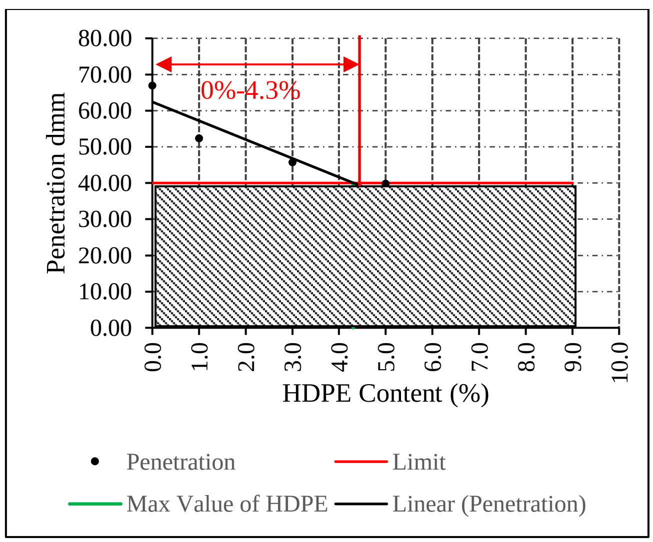

Fig. 6: Penetration Results Compared to JRA Standards

Ductility of modified asphalt binders compared to JRA standard as shown in Fig. 7 This figure depicts the decrease in ductility as HDPE content increases. Only binders with up to 4% HDPE maintain ductility above the JRA minimum standard (≥300 mm at 15°C).

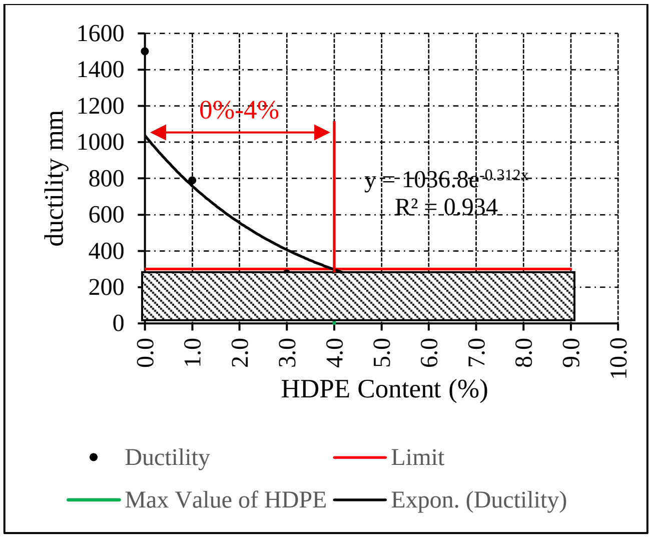

Fig. 7: Ductility Results Compared to JRA Standards

Overall, performance evaluation of modified asphalt binders relative to JRA standards as shown in Fig. 8.

The figure summarizes how penetration, softening point, and ductility of the plastic-modified binders align with JRA benchmarks, indicating that 3-4% PP provides the optimal balance between mechanical performance and flexibility.

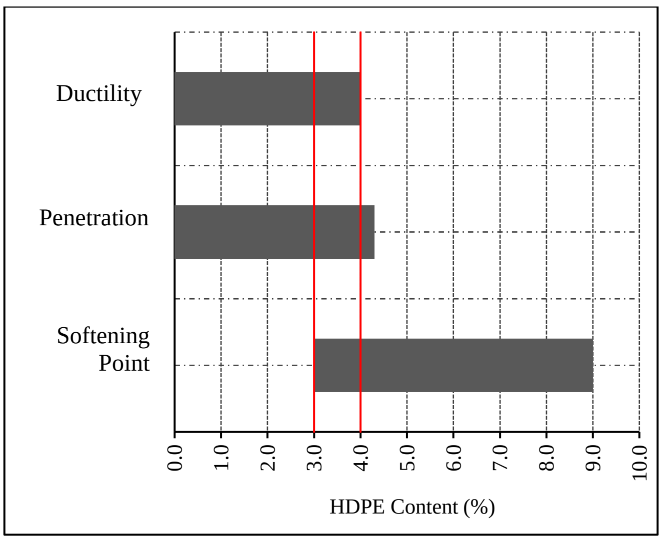

Fig. 8: Overall Performance Assessment Relative to JRA Standards

The results clearly show that HDPE modification improves binder stiffness and thermal resistance, both of which contribute to enhanced rutting performance. However, the trade-off in flexibility indicates that a moderate HDPE content around 3–4% by weight of binder is likely to offer the most balanced performance. Excessive HDPE dosage, while improving softening point and penetration resistance, significantly reduces ductility, potentially compromising long-term durability due to increased cracking risk.

4. CONCLUSIONS

This study demonstrates that modifying asphalt binder with recycled High-density polyethylene (HDPE) significantly enhances high-temperature performance by increasing hardness and softening point while reducing penetration. However, higher HDPE content also leads to a notable decrease in ductility, indicating reduced flexibility. The optimal binder performance was observed at 3%-4% HDPE, which offers a balanced improvement in thermal resistance without severely compromising elasticity. These findings support the use of recycled HDPE as a sustainable asphalt modifier, particularly for hot climates like Cambodia, and contribute to the circular economy by repurposing plastic waste into durable infrastructure materials. Further research, including Marshall stability testing, is recommended to evaluate the full mechanical performance of HDPE-modified asphalt mixtures.

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REFERENCES

[1] A. L. Andrady and M. A. Neal, “Applications and societal benefits of plastics,” *Phil. Trans. R. Soc. B*, vol. 364, no. 1526, pp. 1977–1984, Jul. 2009, doi: 10.1098/rstb.2008.0304.

[2] UNDP, “Advancing circularity in Cambodia: Focus on plastic pollution | UNDP Climate Promise.” Accessed: Apr. 19, 2025. [Online]. Available: https://climatepromise.undp.org/news-and-stories/advancing-circularity-cambodia-focus-plastic-pollution

[3] T. Baghaee Moghaddam, M. R. Karim, and T. Syammaun, “Dynamic properties of stone mastic asphalt mixtures containing waste plastic bottles,” *Construction and Building Materials*, vol. 34, pp. 236–242, Sep. 2012, doi: 10.1016/j.conbuildmat.2012.02.054.

[4] World Bank, *Urban Development In Phnom Penh*. 2017.

[5] Q. Megan, “Ocean Conservancy rescinds 2015 ocean plastics report | Waste Dive.” Accessed: Apr. 19, 2025. [Online]. Available:

https://www.wastedive.com/news/ocean-conservancy-rescinds-ocean-plastic-report-asia/627368/

[6] A. P. F. Giustozzi and Y. J. Boom, "Use of Road-grade Recycled Plastics for Sustainable Asphalt Pavements: Overview of the Recycled Plastic Industry and Recycled Plastic Types".

[7] S. Fernandes, L. Costa, H. Silva, and J. Oliveira, "Effect of incorporating different waste materials in bitumen," *Ciência & Tecnologia dos Materiais*, vol. 29, no. 1, pp. e204–e209, Jan. 2017, doi: 10.1016/j.ctmat.2016.07.003.

[8] Y. Yildirim, "Polymer modified asphalt binders," *Construction and Building Materials*, vol. 21, no. 1, pp. 66–72, Jan. 2007, doi: 10.1016/j.conbuildmat.2005.07.007.

[9] M. L. Pallavi, S. Dey, and G. T. N. Veerendra, "Applications of plastic waste materials in bituminous mixes pavement for increasing the strengthen of pavement materials," Sep. 12, 2022, *In Review*. doi: 10.21203/rs.3.rs-2043629/v1.

[10] A. P. F. Giustozzi, "Use of Road-grade Recycled Plastics for Sustainable Asphalt Pavements: Final Performance and Environmental Assessment Part A".

[11] L. Jenny Liu, W. Yizhuang David Wang, and Z. Anyou Zhu, *Feasibility Study of Incorporation of Recycled High-Density Polyethylene in Asphalt*. 2022.

[12] A. Oyelere and S. Wu, "State of the art review on the principles of compatibility and chemical compatibilizers for recycled plastic-modified asphalt binders," *Journal of Cleaner Production*, vol. 492, p. 144895, 2025, doi: https://doi.org/10.1016/j.jclepro.2025.144895.

[13] K. KUBO *et al.*, *Asphalt hand book*, First edition. Japan: Japan Road Association, 2019. [Online]. Available: https://www.maruzen-publishing.co.jp/book/b10120514.html