DOI: 10.2478/rjti-2024-0016
ROMANIAN JOURNAL
OF TRANSPORT INFRASTRUCTURE

PERFORMANCE EVALUATION OF ASPHALT CONCRETE WEARING CONTAINING PLASTIC BAGS USING THE DRY METHOD UNDER VARIOUS THERMAL CYCLES

Youssra Bousmaha, FIMAS Laboratory, University of Tahri Mohammed, Bechar B.P 417, Bechar, 08000 Algeria
M'hammed Merbouh, FIMAS Laboratory, University of Tahri Mohammed, Bechar B.P 417, Bechar, 08000 Algeria
Suhana Koting, Center for Transportation Research, Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
Ali Mohammed Babalghaith, Interdisciplinary Research Center for Construction and Building Materials, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Abstract

Premature technical issues in roads and highways worldwide often stem from inadequate asphalt concrete composition or intense traffic loads under varying climatic conditions. This study evaluated the performance of both original and low-density polyethylene (LDPE)-modified asphalt concrete under various thermal cycling conditions. Three thermal cycling ranges [-20°C to +20°C, +20°C to +40°C, and +40°C to +60°C] were applied to assess the mixtures' mechanical performance. The LDPE modification involved replacing 5% of the bitumen weight with dry plastic bags. Performance was assessed using Marshall stability, dynamic creep, wheel tracking, and resilient modulus tests. Results indicated that LDPE modification significantly improved Marshall stability, reduced permanent deformation, and increased the stiffness modulus of the asphalt concrete. Notably, freezing-thawing cycles [-20°C to +20°C] caused more damage to the asphalt concrete compared to heating-cooling cycles. Moreover, the LDPE-modified mixture demonstrated enhanced performance across all thermal cycling ranges, suggesting its potential to improve road durability under diverse climatic conditions.

Keywords: Thermal cycles, asphalt concrete, LDPE, stiffness modulus, permanent deformation, rutting

1. INTRODUCTION

At the start of the 21st century, many countries began exploring new road construction technologies that incorporated additives and recycled materials into pavement formulations. The focus was on utilizing solid, liquid and even Nano particles wastes like plastics, polymers, steel, glass, oils, reclaimed asphalt, palm materials, and demolition debris [1][2][3][4][5][6]. This allowed enhancing road performance under diverse climatic conditions and high traffic intensities. Proper waste plastic management also minimizes environmental pollution impacts while promoting sustainable construction practices that conserve natural resources through increased valorization rates.

Polymers are viable modifier materials for asphalt mixtures, though using raw polymers is costlier than recycled plastic waste. Globally, 381 million tonnes of plastic waste are produced annually [7], with most plastic bags going unrecycled and posing significant environmental and public health concerns. Numerous studies have highlighted the benefits of using plastic bags as bitumen additives due to their availability and remarkable improvements observed in pavement behavior, high-temperature asphalt performance, and reduced temperature susceptibility. Their primary findings of studies evaluating the fatigue and rutting performance of asphalt mixtures incorporating Low-Density Polyethylene (LDPE). Rutting resistance was assessed using the Wheel Tracking Test in eight studies, the Dynamic Creep Test in five studies, and the Hamburg Wheel Tracking Test in two studies. The majority of these tests demonstrated positive effects of LDPE addition[8][9][10][11][12][13], while only two tests showed negative outcomes. Notably, one of the negative results was observed in the Dynamic Creep Test. Interestingly, contradictory results were found by Almeida et al. and Fonseca et al. when using identical conditions - 6% LDPE flakes by weight of bitumen (0.3% of mixture weight) added via the dry method[8] . In contrast, Radeef et al. reported positive outcomes when incorporating 5-10 mm LDPE particles at 1% of aggregate weight (0.95% of mixture weight) using the same dry method [9]. Regarding fatigue performance, four studies employed the Four Point Bending Test, with three indicating decreased fatigue resistance and one showing improved performance, particularly when considering ageing effects. These varied results highlight the complexity of LDPE modification in asphalt mixtures and the need for further research to optimize its use.

Otherwise ambient temperatures significantly influence asphalt's mechanical response due to its viscoelastic properties. At high temperatures, the binder's viscosity decreases, rendering it softer and more susceptible to external loads. Consequently, asphalt mixtures can easily undergo permanent deformation, a major contributor to rutting in wheel paths. To distribute traffic loads evenly and prevent water ingress into underlying unbound layers, an asphalt concrete wearing course is necessary to cover and protect the pavement base [14]. However, bituminous surface layers are prone to various distresses like permanent deformation (rutting) and fatigue cracking, exacerbated by increasing traffic volumes and heavy vehicles [15].

Dynamic creep, wheel tracking, and indirect tensile tests have been developed to investigate permanent deformation or rutting, a predominant issue in regions with high pavement service temperatures and heavy traffic. Permanent deformation can incur substantial maintenance costs and pose safety risks due to water accumulation in ruts, potentially causing accidents.

In densely populated areas with cities, industries, agriculture, and trade activities, heavy traffic can induce severe rutting within the first two service years. Conversely, regions with sparse populations and long distances between cities experience lower traffic volumes. Nevertheless, these pavements face thermal cycling phenomena [heating/cooling] and [freezing/thawing] daily and seasonally, leading to thermal fatigue cracking that progressively propagates from the top down through the pavement layers. Furthermore, day-night temperature fluctuations, especially in winter, render pavements vulnerable to freeze-thaw cycles that can accelerate degradation due to bitumen's organic structure and sensitivity to climatic impacts [16].

Objective

The primary goal of this study is to utilize plastic bags as a dry addition (in shredded pieces of 1 to 3 mm²) and assess their effect on the mechanical properties of asphalt concrete wearing before and after various thermal cycles.

2. MATERIALS, METHODS AND EXPERIMENTS

2.1. Materials

2.1.1. The binder

A base asphalt binder sample with 80/100 penetration grade was obtained from the Highway Laboratory at the University of Malaya for characterization and testing. The key properties of the base binder are summarized in Table 1.

Table1. Properties of the base binder.

Properties	Values
Penetration	87
Softening	46°C
Viscosity	312 cps
Specific	1.02
G*/ sin δ at	1.576 kPa

2.1.2. The aggregates

The aggregates used in this present study were collected from Kajang Rock Sdn. Bhd Malaysia crusher. Their properties are collected in table 2.

Table 2. Properties of the aggregates.

Property	Test method	Value (%)	Requirement
Los Angeles abrasion	ASTM: C131-14	19.8	<30%
Flakiness index	BS 182: Part 3	7.3	<20%
Elongation index	BS 182: Part 3	13.4	<20%
Impact value	BS 182: Part 3	10.3	<15%

An Asphaltic Concrete Wearing 14 "ACW14" is needed to cover the underlying unbound layers from the water filtration. The gradation of ACW14 was according to the Malaysian Public Works-Road Department (Jabatan Kerja Raya-JKR) [17], as shown in Fig. 1.

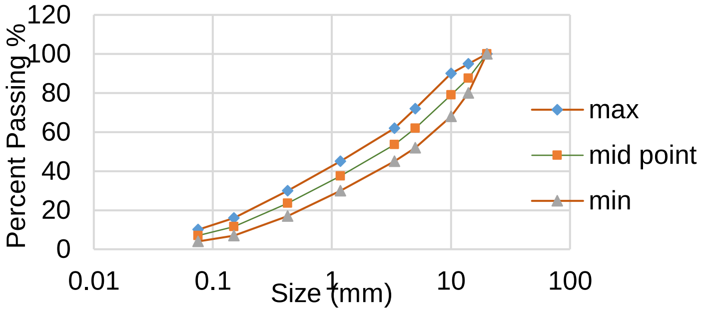

Figure 1. ACW14 aggregate gradation.

2.1.3. The plastic waste

The plastic waste utilized in this study consisted of blue plastic bags commonly used in retail stores. These bags are made from low-density polyethylene (LDPE) with a general chemical structure of (C2H4) n and a melting temperature range of 120°C to 130°C. The density of LDPE typically varies between 0.910 and 0.927 g/cm^3. To facilitate incorporation into the hot asphalt mixture, the plastic bags were shredded into small pieces ranging from 1 to 3 mm^2 in size, as illustrated in Figure 2.

Figure 2. Shredded plastic bag waste

2.2. Methods

2.2.1. Preparation of samples

The Marshall test samples were prepared in five groups with an average aggregate weight of 1123g and asphalt contents ranging from 4.5% to 6.5% by weight of the mixture. The aggregates were heated for two hours at 180°C, while the asphalt was heated separately for one hour at 150°C. The heated materials were then mixed, and the samples were molded and compacted using a Marshall hammer with 50 blows applied to each side at a temperature of 140°C [17].

Two processes exist for modifying asphalt concrete: wet and dry. This study adopted the dry process as a suitable modification method due to its relative ease and cost-effectiveness compared to the wet method, although specific equipment is required for blending the asphalt and polymer [18]. Four additional sample groups were molded with varying percentages of waste plastic (0%, 3%, 5%, and 7%) by weight of the optimum asphalt content determined from the Marshall test.

For the indirect tensile test, both unmodified and LDPE-modified samples were prepared using a Marshall hammer with 50 blows on the top and bottom surfaces, yielding specimens with a diameter of 101.6 mm and a depth of 65 ± 1 mm. A similar compaction process was used for the dynamic creep test samples, which were subsequently cut to a final thickness of 50 mm with smooth surfaces using a cutting machine. Prior to testing, the sample surfaces were coated with a thin grease layer protected by aluminum foil, and graphite powder was applied to minimize friction with the loading plate and facilitate uniform uniaxial stress distribution.

Unmodified and LDPE-modified slabs for wheel tracking tests were molded in a 40 x 30 cm plate. They were compacted using a steel roller with 39 passes in a dynamic compactor, following the recommended cycle from the

Instruction Manual Dyna-Comp (Table 3). The steel roller was raised 5 cm to achieve the desired slab thickness. The slabs were then cut into two 20 x 30 x 5 cm sections for placement in the wheel tracking test machine.

Table 3. recommended compaction cycles

Step	Force (KN)	Passes
1	2	4
2	3	4
3	7	4
4	11	4
5	15	4
6	19	5
7	23	7
8	28	7

2.2.2. Thermal cycles

To simulate the varying daily temperature conditions experienced in different climatic regions during winter and summer, original and LDPE-modified asphalt concrete (ACW14) specimens were subjected to thermal cycling. Three temperature ranges were selected, as illustrated in Figure 3:
a) [40/60]°C heating/cooling cycle, representing the day/night temperature fluctuations in hot regions. b) [20/40]°C heating/cooling cycle, representing the day/night temperature variations in warm regions. c) [-20/20]°C freezing/thawing cycle, representing the day/night temperature extremes in cold regions.
An oven was utilized to achieve the 40°C and 60°C temperatures, while an air conditioner maintained the 20°C climate, and a freezer provided the -20°C temperature. The samples underwent these laboratory thermal cycles for a duration of 45 days to model the conditions experienced during half a season (summer or winter).

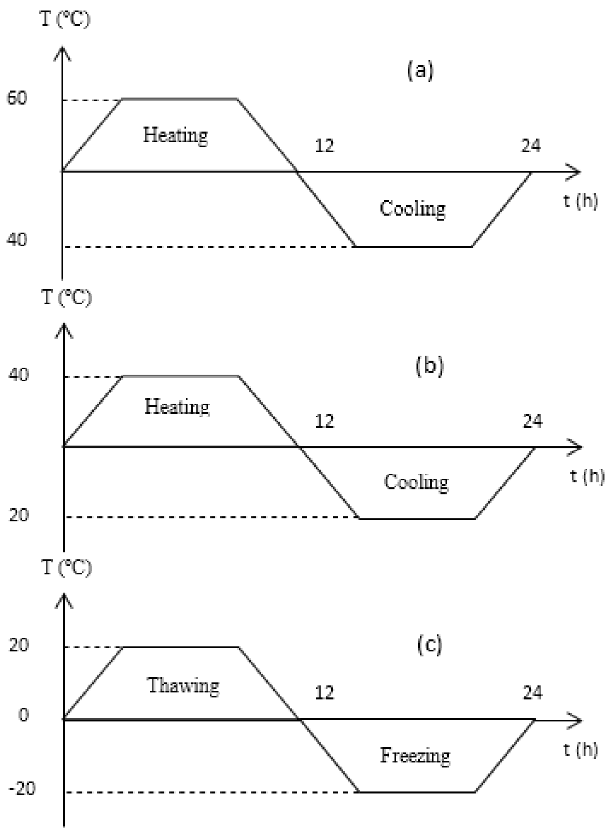

Figure 3. One thermal cycle, (a) heating-cooling" hot", (b) heating–cooling" warm", (c)freezing-thawing

2.3. Experiments

2.3.1. Marshall test

The Marshall mix design method is the most common approach used to determine the optimum binder content and the appropriate percentage of waste plastic that provides adequate Marshall stability, flow, and mixture density.

2.3.2. The dynamic creep test

The dynamic creep test, developed by Monismith et al. (1975) [19], is one of the best methods for investigating the resistance of asphalt mixtures to permanent deformation. This test provides creep curves that illustrate permanent deformation versus loading cycles.

The Universal Testing Machine (UTM) is the standard device for evaluating permanent deformation. The creep test was repeated for each range of thermal cycling to minimize variability among replicates of one sample type. As recommended by EN 12697-25 (2005) [20], the samples were subjected to constant uniaxial cyclic compression using UTM-5P from IPC, and a Linear

Variable Displacement Transducer (LVDT) was used to measure vertical deformation. The UTM machine is equipped with servo-pneumatic software that allows researchers to select all parameters (load, stress, frequency, etc.) and an environmental chamber to control the testing temperature.

This study conducted the dynamic creep test for both modified and original samples following the Australian Standard (AS 2891.12.1) [21]. The samples were conditioned at 40°C in the environmental chamber for three hours to ensure they reached the test temperature and to simulate a hot weather.

2.3.3. The resilient modulus test

The resilient modulus test, also known as the indirect tensile test, is a non-destructive test and the primary method for investigating the stiffness modulus of asphalt mixtures. The samples were left in the climatic chamber of the Universal Materials Testing Apparatus (UMATTA) machine at 25°C for 2 hours. The stiffness modulus was calculated according to ASTM D4123 using the following equation:

$$RM = \frac{P(\upsilon+0.25)}{H\times T} \qquad (1)$$

Where:
RM: the resilient modulus (MPa)
P: the peak load (N)
υ: the Poisson's ratio
T: the average thickness (mm)
H: the total recoverable deformation on the horizontal axis (mm)

Each sample underwent extensive testing, with the vertical dimension plan of the cylindrical sample being modified for each test. Finally, the results of the three duplicate samples were averaged and recorded.

2.3.4. The wheel tracking test

The wheel tracking test is one of the most popular tests for simulating rutting performance. The test is conducted at 60°C to model a heavily stressed site where the maximum rut rate is 5 mm/hr and the maximum rut depth is 7 mm, following BS 598-110 [22]. Slabs with dimensions of 20x30 cm and 5 cm thickness were placed in the wheel tracking test machine under a steel wheel with a 20 cm diameter and 5 cm width, applying a load of 520 N and shifting on the center of the slab's top surface in a constant trajectory at 21 cycles per minute for 45 minutes or until the maximum rut depth reached 15 mm. The rut depth was recorded for each slab every 105 cycles (5 minutes).

The mean values of the triplicate samples were calculated and recorded as the final results for all tests in this study.

3. RESULTS AND DISCUSSION

3.1. Marshall test

3.1.1. Determination of Optimum binder content

The values of the mix's properties (table 4) are determined for each mix with different bitumen content (4,5; 5; 5,5; 6; 6,5), and the following graphical plots are prepared as Fig.4 shows.

The graphical plots were plotted as follows:

Binder content versus percentage of void in the total mix (air void).

Binder content versus unit weight or bulk specific gravity.

Binder content versus Marshall flow.

Binder content versus percentage of voids in compacted mineral aggregates (VMA).

Binder content versus corrected Marshall stability.

Binder content versus Percent Voids Filled with a binder (VFB).

Table4. Values of the mixes properties.

Binder content (%)	**Bulk density (g/ml)**	**VMA (%)**	**Air voids (%)**	**Stability (KN)**	**Flow (mm)**	**VFB (%)**
4,5	2,2905	16,35	6,24	12,99	2,57	61,86
5,0	2,3011	16,40	5,12	16,68	2,57	68,79
5,5	2,3269	15,91	3,36	16,41	3,04	78,99
6,0	2,3273	16,34	2,65	14,44	2,94	83,79
6,5	2,3326	16,60	1,73	12,25	3,57	89,64

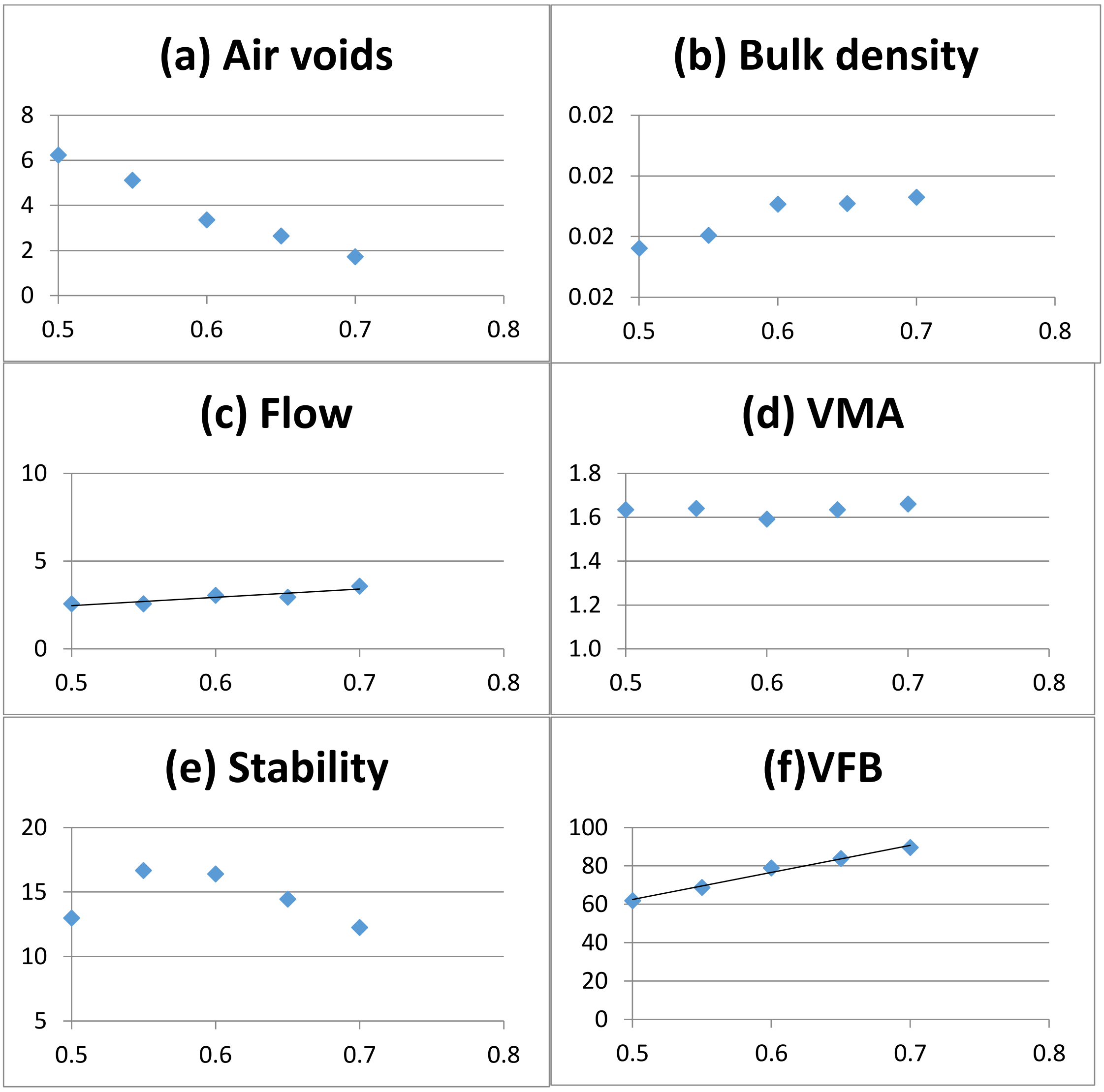

Figure 4 a.b.c.d.e.f. Marshall test, Typical plots.

The following equation calculated the optimum binder B_0:

$$B_0 = \frac{B_1 + B_2 + B_3}{3} \qquad (1)$$

Where B_1 = % asphalt content at maximum unit weight, B_2 = % asphalt content at maximum stability and B_3 = % asphalt content at 4% of air voids in the total mix.

According to the Marshall plots,

$$B_0 = \frac{6.5 + 5 + 5.3}{3} = 5.6\%$$

3.1.2 Determination of suitable LDPE percentage

The Marshall properties of the different LDPE percentages are collected in table 5 and illustrated in fig. 5,6,7,8 and 9.

Table 5. The Marshall properties of the different LDPE percentages.

LDPE %	Bulk density	VMA	Air voids	stability	Flow	VFB
0	2,31	16,6	3,91	17,62	3,07	76,44
3	2,3242	15,71	3,93	18,87	2,87	75,01
5	2,3286	15,30	4,14	19,77	2,88	72,95
7	2,3020	16,03	5,62	21,06	3,23	64,92

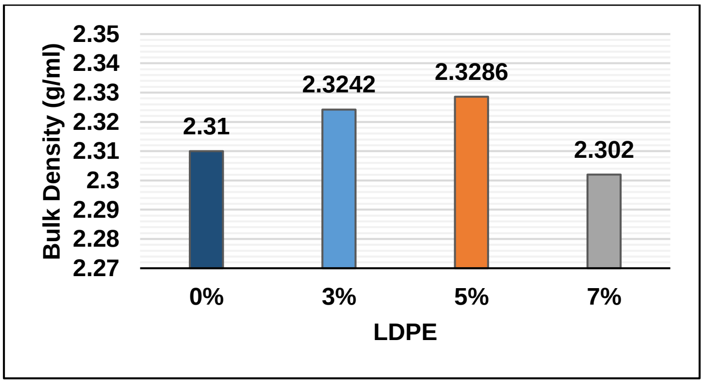

Figure 5. Bulk Density for different percentages of LDPE

Figure 5 demonstrates the impact of waste plastic on bulk density. The densities of the 3% and 5% modified samples are higher than that of the original sample because the waste plastic pieces were well melted with the 80/100 binder. However, the density of the 7% samples is lower, which can be attributed to the large quantity of waste plastic causing the hot mix to become visually heterogeneous. Additionally, since waste plastic has a lower density than ACW14, the overall density decreased.

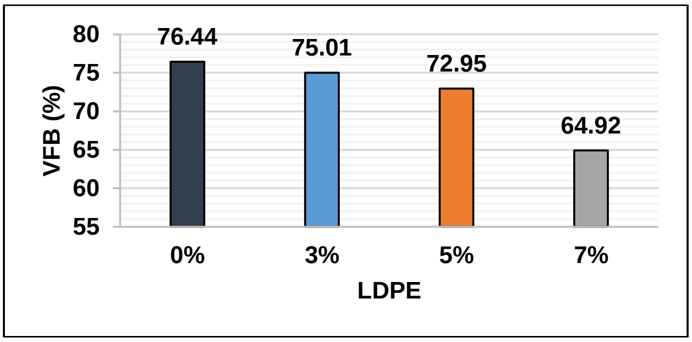

Figure 6. VFB for different percentages of LDPE

It is evident from Figure 6 that the percentage of voids filled with binder (VFB) decreased as the LDPE percentage increased, leading to a decrease in the binder percentage. According to the Marshall Mix Design Criteria, the VFB values of 0%, 3%, and 5% samples are acceptable, but the VFB value of 7% samples falls outside the criteria [23].

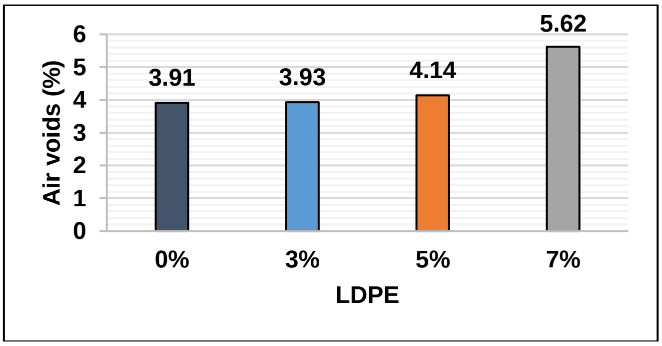

Figure 7. Air voids for different percentages of LDPE

The air voids increased with the increase in LDPE percentage, as shown in Figure 7, and this increase in LDPE also led to a decrease in binder percentage. Numerous studies have highlighted that as the binder percentage decreases, the air voids increase [24][25][26][27][28][29] because the quantity of binder used in the mix is distributed into the air voids. This study found that the 0%, 3%, and 5% samples had acceptable values [17]. However, the 7% sample had a higher air voids percentage than the desired value, leading to cracking in the hot mix [2].

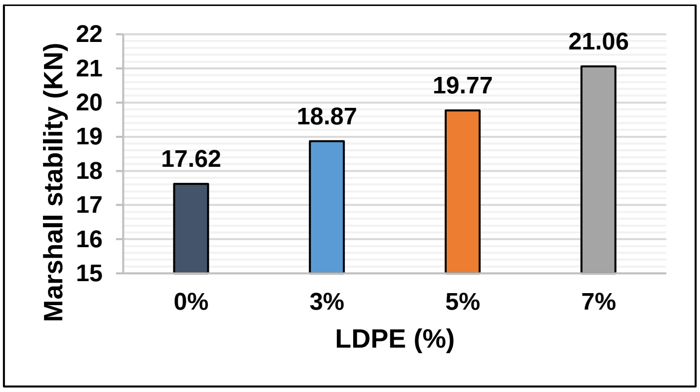

Figure 8. Marshall Stability for different percentages of LDPE

The stabilities of all percentages were higher than the minimum stability required, Figure 8 demonstrates a clear trend of increasing stability as the percentage of waste plastic increases. This suggests that the waste plastic is effectively reinforcing the asphalt concrete mixture, likely by improving the binder's cohesive properties and there is a notable enhancement in the mixture's ability to resist deformation under load. Furthermore, the waste plastic made the ACW14 more rigid. This increased rigidity could contribute to better resistance against rutting and permanent deformation.

The plastic bags are not just acting as a filler, but is chemically interacting with the bitumen. This could be creating a more complex, stable binder matrix.

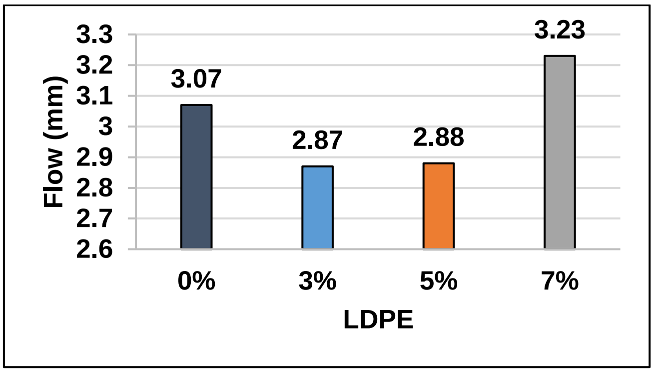

Figure 9. Flow for different percentages of LDPE

The flows of all samples with different LDPE percentages are within permissible values[17] . Figure 9 illustrates that samples with 3% and 5% LDPE had lower flows, indicating good homogeneity between the binder and waste plastic.

After discussing the results from the Marshall test, it is evident that a 5% LDPE modification was highly suitable. It provided adequate density, flow, VFB, stability, and air voids, enhancing the quality of ACW14 as observed in previous research studies [30].

3.2. Dynamic creep test

Figure 10 depicts the dynamic creep curves of different samples of original ACW14 influenced by thermal cycling. The samples subjected to heating-cooling cycles [20/40] and [40/60] °C exhibit remarkable resistance to permanent deformation by reducing permanent strain compared to the original sample after 1100 load cycles. Under repetitive heating-cooling cycles at temperatures of 40 and 60°C, the binder in ACW14 underwent oxidation, a damage process occurring at high temperatures that can lead to aging, where the binder loses some chemical substances due to evaporation and volatilization [31]. This phenomenon causes the binder to become stiffer and harder with rising temperatures [16], explaining the lower resistance to permanent deformation between samples in the 20-40 °C range compared to those in the 40-60°C range.

During the freezing stage at -20°C, a thin layer of ice covered the samples, causing the binder to contract due to its organic structure, allowing the ice to enter the air voids of the asphalt concrete. In the thawing stage at +20°C, the ice turned into water in the air voids, creating tension on the binder. With repeated freezing-thawing cycles, more tension was applied inside the sample, leading to weak cohesion and adhesion between the binder and aggregate, explaining the higher permanent strain observed in Figure 10. The samples became more deformable after the freezing-thawing cycles.

Table 06. Comparison between permanent deformation of an original and modified LDPE samples under different thermal cycles

	Maximum permanent deformation under: (mm)			
	No cycles	[20/40] °C cycles	[40/60] °C cycles	[-22/20] °C cycles
Original	2.173	1.478	1.629	2.771
Modified	1.617	1.088	1.039	2.299

Figure 10.11 and Table 06 demonstrate the effectiveness of using plastic bags as a modifier. The thermal cycles affected both the modified and original samples similarly; however, the use of plastic bags reduced permanent deformation (Table 07). The inclusion of LDPE helps the binder lose less weight at high temperatures, resulting in reduced evaporation and increased heat stability

[32]. The solid form of the plastic bags also enhances the samples' resistance to freezing.

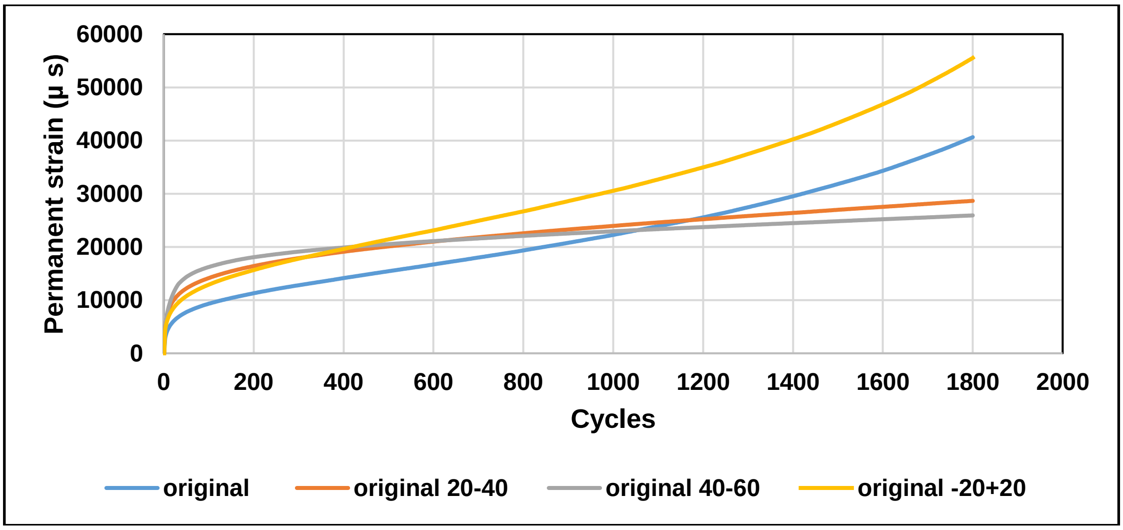

Figure 10. Permanent strain versus cycles for original ACW14 under different thermal cycles.

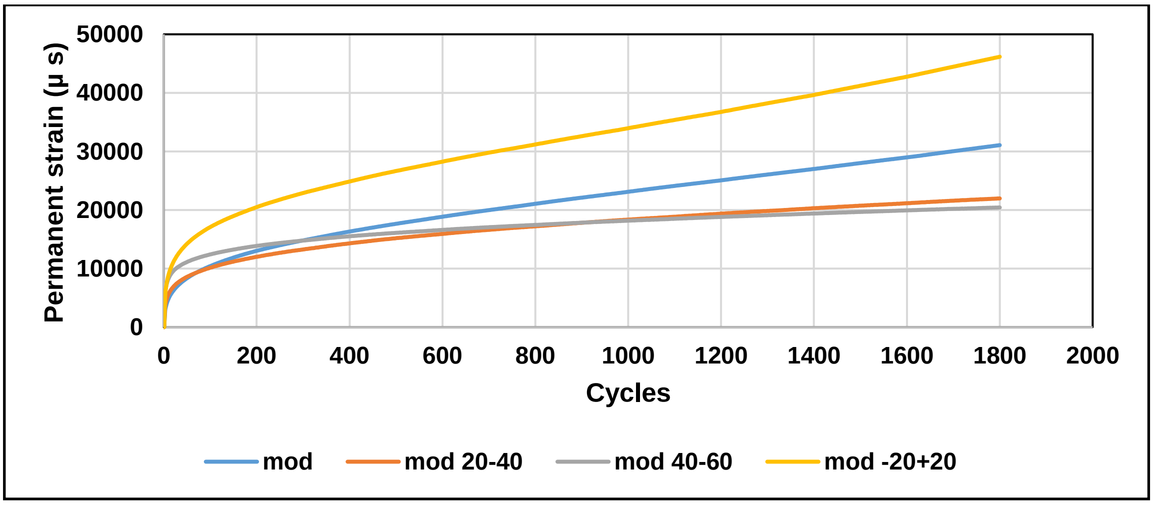

Figure 11. Permanent strain versus cycles for modified ACW14 under different thermal cycles.

3.3. The resilient modulus test

The mean values of the triplicate samples were calculated and recorded as the final results

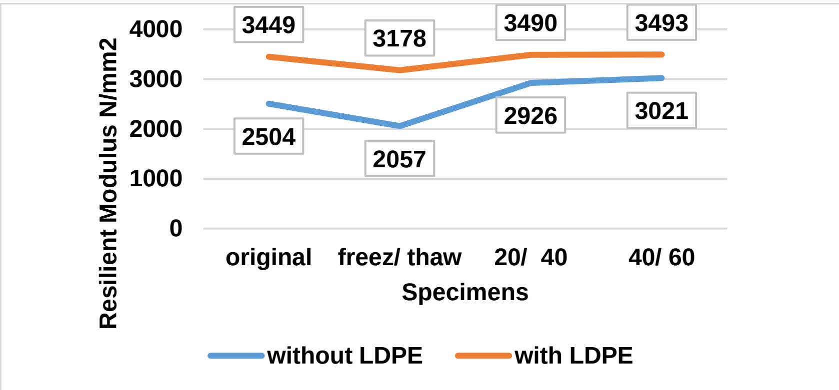

Figure 12. Resilient modulus for original and modified ACW14 under thermal cycles at 25°C

Figure 12 depicts the resilient modulus for all samples with and without LDPE modification under various thermal cycles. It's evident that using plastic bags as a modifier increased the resilient modulus values. The asphalt concrete became harder as the weight of the binder reduced and was replaced by the solid addition of plastic bags. During the mixing phase of the modified asphalt concrete, the shredded pieces of plastic bags were affected by the mixing temperature (140°C), transforming into thin fibers that promote good cohesion between aggregate and binder, resulting in a stiffer asphalt concrete.

The thermal cycles have a similar effect on the samples as discussed in the dynamic creep section.

3.4. Wheel trucking test

The mean values of the triplicate samples were calculated and recorded as the final results

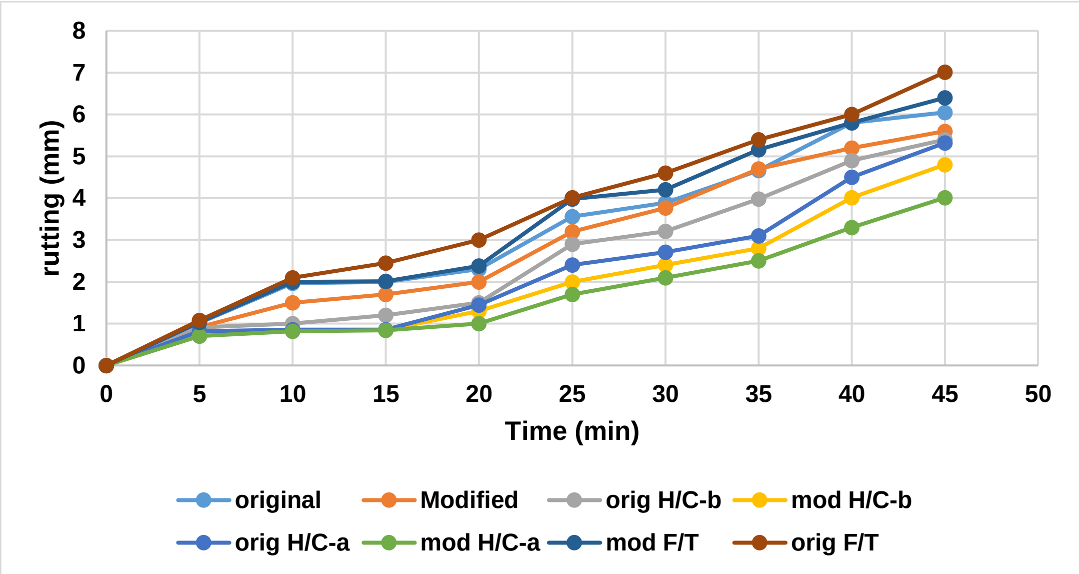

Figure 13. Rut depth versus time for original and modified ACW14 under thermal cycles at 60°C

Figure 13 summarizes the results of rut depth versus time for all slabs, both modified and original, under different thermal cycles at 60°C. The rut depth outcomes for all samples met the standard requirements [26]for a heavily stressed site. Slabs subjected to cooling-heating cycles exhibited great resistance to rutting compared to the original slab. However, freezing-thawing cycles made the slabs fragile, making them more susceptible to deformation during the test. The use of plastic bags reduced the rut depth values of both modified and unmodified samples, with and without thermal cycling [33].

Figure 14 illustrates the comparison between normalized deformations of dynamic creep and wheel tracking tests. These tests demonstrate a consistent rate of deformation, indicating that thermal cycles affect the samples and binder behavior in a similar manner.

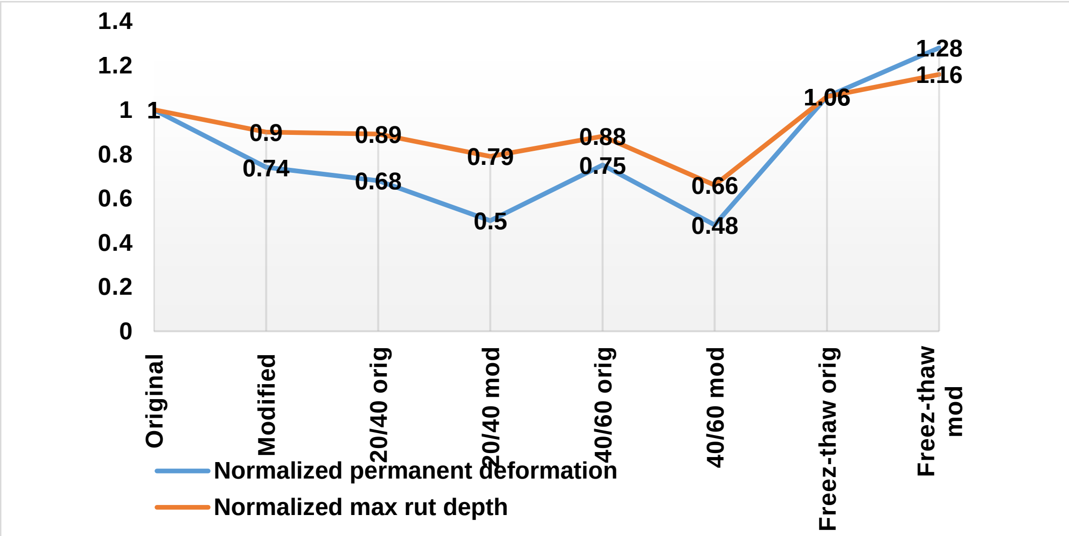

Figure 14. The rate of deformations due to dynamic creep and wheel trucking tests

4. CONCLUSION

The investigation into the utilization of waste plastic bags as a modifier for asphalt concrete reveals significant insights into pavement performance under diverse thermal conditions. The research demonstrates that strategic incorporation of plastic bags, specifically replacing 5% of the binder weight, yields substantial improvements in the mechanical characteristics of asphalt mixtures. Marshall stability tests confirm enhanced structural integrity, while flow measurements indicate optimal performance characteristics. The study's critical findings highlight the material's remarkable adaptability across different thermal cycles: under heating-cooling scenarios, the plastic bag-modified binder exhibits exceptional resistance to permanent deformation and rutting, suggesting increased durability and longevity of road surfaces. Conversely, while freezing-thawing cycles tend to render traditional asphalt concrete more fragile and susceptible to deformation, the innovative plastic bag modification consistently demonstrates its ability to mitigate structural vulnerabilities. These findings not only underscore the potential of recycling waste plastic bags into road construction materials but also present a promising avenue for sustainable infrastructure development, addressing both environmental waste management and pavement engineering challenges. The research provides compelling evidence that strategic material modification can significantly enhance the resilience and performance of asphalt concrete under challenging thermal stress conditions.

REFERENCES

[1] A. A. Yousefi, H. F. Haghshenas, B. Shane, J. Harvey, and P. Blankenship, "Performance of warm asphalt mixtures containing reclaimed asphalt pavement , an anti-stripping agent , and recycling agents : A study using a balanced mix design approach," *Constr. Build. Mater.*, vol. 363, no. October 2022, p. 129633, 2023, doi: 10.1016/j.conbuildmat.2022.129633.

[2] A. Mohammed Babalghaith, S. Koting, N. H. Ramli Sulong, M. R. Karim, and B. Mohammed AlMashjary, "Performance evaluation of stone mastic asphalt (SMA) mixtures with palm oil clinker (POC) as fine aggregate replacement," *Constr. Build. Mater.*, vol. 262, p. 120546, 2020, doi: 10.1016/j.conbuildmat.2020.120546.

[3] M. Nouali, Z. Derriche, E. Ghorbel, and L. Chuanqiang, "Plastic bag waste modified bitumen a possible solution to the Algerian road pavements," *Road Mater. Pavement Des.*, vol. 21, no. 6, pp. 1713–1725, 2020, doi: 10.1080/14680629.2018.1560355.

[4] G. Shafabakhsh, O. J. Ani, and S. M. Mirabdolazimi, "Rehabilitation of Asphalt Pavement to Improvement the Mechanical and Environmental Properties of Asphalt Concrete by Using of Nano Particles," vol. 2, pp. 1–20, 2021, doi: 10.22075/JRCE.2019.17407.1326.

[5] J. Adaluz, E. Victoria, H. Alexander, F. A. Reyes-lizcano, and J. Gabriel, "Mechanical Behavior of Low-Density Polyethylene Waste Modified Hot Mix Asphalt," 2022.

[6] R. Journal and O. F. T. Infrastructure, "CONSIDERATIONS ON THE BENEFITS OF USING imposed by traditional rehabilitation methods . The European Asphalt Pavement Association (EAPA) provides world- wide statistical data on how recycled asphalt is used :," vol. 6, no. 4, pp. 43–53, 2017, doi: 10.1515/rjti-2017-0053.

[7] "100+ Plastic in the Ocean Statistics & Facts (2020-2021)." https://www.condorferries.co.uk/plastic-in-the-ocean-statistics (accessed Jul. 27, 2022).

[8] A. Almeida, S. Capitão, C. Estanqueiro, and L. Picado-santosc, "Possibility of incorporating waste plastic film flakes into warm-mix asphalt as a bitumen extender," *Constr. Build. Mater.*, vol. 291, p. 123384, 2021, doi: 10.1016/j.conbuildmat.2021.123384.

[9] H. R. Radeef, N. A. Hassan, A. Razin, and Z. Abidin, "Enhanced Dry Process Method for Modi fi ed Asphalt Containing Plastic Waste," vol. 8, no. July, pp. 1–14, 2021, doi: 10.3389/fmats.2021.700231.

[10] M. Fonseca, S. Capit, and A. Almeida, "applied sciences Influence of Plastic Waste on the Workability and Mechanical Behaviour of Asphalt Concrete," 2022.

[11] H. Radhi *et al.*, "Case Studies in Construction Materials The mechanical response of dry-process polymer wastes modified asphalt under ageing and moisture damage," *Case Stud. Constr. Mater.*, vol. 16, no. January, p. e00913, 2022, doi: 10.1016/j.cscm.2022.e00913.

[12] S. Ullah, M. Raheel, R. Khan, and M. Tariq, "Characterization of physical & mechanical properties of asphalt concrete containing low- & high-density polyethylene waste as aggregates," *Constr. Build. Mater.*, vol. 301, no. May, p. 124127, 2021, doi: 10.1016/j.conbuildmat.2021.124127.

[13] S. Haider, I. Hafeez, and R. Ullah, "Sustainable use of waste plastic modifiers to strengthen the adhesion properties of asphalt mixtures," *Constr. Build. Mater.*, vol. 235, p. 117496, 2020, doi: 10.1016/j.conbuildmat.2019.117496.

[14] A. Epps, J. T. Harvey, Y. R. Kim, and R. Roque, "Structural requirements of bituminous paving mixtures," *Transp. New Millenn.*, pp. 2–3, 2000.

[15] S. Mirzapour Mounes, M. R. Karim, A. Khodaii, and M. H. Almasi, "Evaluation of permanent deformation of geogrid reinforced asphalt concrete using dynamic creep test," *Geotext. Geomembranes*, vol. 44, no. 1, pp. 109–116, 2016, doi: 10.1016/j.geotexmem.2015.06.003.

[16] M. Merbouh, "Effect of thermal cycling on the creep-recovery behaviour of road bitumen," *Energy Procedia*, vol. 18, no. December 2012, pp. 1106–1114, 2012, doi: 10.1016/j.egypro.2012.05.125.

[17] J. R. M. (JKR), *Standard Specification for RoadWork. In Section 4: Flexible Pavement;Malaysian Public Works Department: Kuala Lumpur*, vol. 7, no. 1. 2008, pp. 37–72. [Online]. Available: https://www.researchgate.net/publication/269107473_What_is_governance/link/548173090cf22525dcb61443/download%0Ahttp://www.econ.upf.edu/~reynal/Civil wars_12December2010.pdf%0Ahttps://think-asia.org/handle/11540/8282%0Ahttps://www.jstor.org/stable/41857625

[18] M. Ranieri, L. Costa, J. R. M. Oliveira, H. M. R. D. Silva, and C. Celauro, "Asphalt Surface Mixtures with Improved Performance Using Waste Polymers via Dry and Wet Processes," *J. Mater. Civ. Eng.*, vol. 29, no. 10, 2017, doi: 10.1061/(asce)mt.1943-5533.0002022.

[19] C. R. Monismith, C. L., Ogawa, N., & Freeme, "Permanent deformation characterization

of subgrade soils due to repeated loading," *Transp. Res. Rec.*, 1975.

[20] EN 12697-25, *Bituminous mixtures Test methods for hot mix asphalt Part 25: Cyclic compression test*. 2005.

[21] "Australian Standard, Method 12.1: Determination of the permanent compressive strain characteristics of asphalt-dynamic creep test., AS 2891.12. 1: Methods of sampling and testing asphalt Standards Australia, Australia, Sydney, 1995".

[22] "British Standards Institute, Sampling and examination of bituminous mixtures for roads and other paved areas- Part 110: Methods of test for the determination of wheel-tracking rate and depth, BS 598-110, British Standards Institute, 1998".

[23] "Mix Design Methods For Asphalt Concrete And Other Hot Mix Types, The Asphalt Institute, MS-2, Sixth Edition, 1993".

[24] W. M. N. W. A. Rahman and A. F. A. Wahab, "Green pavement using recycled Polyethylene Terephthalate (PET) as partial fine aggregate replacement in modified asphalt," in *Procedia Engineering*, 2013, vol. 53. doi: 10.1016/j.proeng.2013.02.018.

[25] D. A. Álvarez, A. A. Aenlle, A. J. Tenza-Abril, and S. Ivorra, "Influence of partial coarse fraction substitution of natural aggregate by recycled concrete aggregate in hot asphalt mixtures," *Sustain.*, vol. 12, no. 1, 2020, doi: 10.3390/SU12010250.

[26] H. Akbulut and C. Gürer, "Use of aggregates produced from marble quarry waste in asphalt pavements," *Build. Environ.*, vol. 42, no. 5, 2007, doi: 10.1016/j.buildenv.2006.03.012.

[27] I. M. Asi, "Laboratory comparison study for the use of stone matrix asphalt in hot weather climates," *Constr. Build. Mater.*, vol. 20, no. 10, 2006, doi: 10.1016/j.conbuildmat.2005.06.011.

[28] M. Panda, A. Suchismita, and J. Giri, "Utilization of Ripe Coconut Fiber in Stone Matrix Asphalt Mixes," *Int. J. Transp. Sci. Technol.*, vol. 2, no. 4, 2013, doi: 10.1260/2046-0430.2.4.289.

[29] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and P. Shafigh, "Using waste plastic bottles as additive for stone mastic asphalt," *Mater. Des.*, vol. 32, no. 10, 2011, doi: 10.1016/j.matdes.2011.06.016.

[30] Y. Menaria and R. Sankhla, "Use of Waste Plastic in Flexible Pavements-Green Roads," *Open J. Civ. Eng.*, vol. 05, no. 03, 2015, doi: 10.4236/ojce.2015.53030.

[31] J. M. Krishnan and K. R. Rajagopal, "On the mechanical behavior of asphalt," *Mech. Mater.*, vol. 37, no. 11, pp. 1085–1100, 2005, doi: 10.1016/j.mechmat.2004.09.005.

[32] H. Z. Farahani, M. Palassi, and S. Sadeghpour Galooyak, "Thermal analysis of bitumen modified with LDPE and CR," *Pet. Sci. Technol.*, vol. 35, no. 15, 2017, doi: 10.1080/10916466.2017.1319385.

[33] C. Fang *et al.*, "Pavement properties of asphalt modified with packaging-waste polyethylene," *J. Vinyl Addit. Technol.*, vol. 20, no. 1, pp. 31–35, 2014, doi: 10.1002/vnl.21328.