Hindawi
Advances in Civil Engineering
Volume 2019, Article ID 6969826, 6 pages
https://doi.org/10.1155/2019/6969826

Research Article

Effects of Recycled Polyethylene Terephthalate (PET) on Stiffness of Hot Asphalt Mixtures

D. Movilla-Quesada, A. C. Raposeiras, and J. Olavarría

Institute of Civil Engineering, Universidad Austral de Chile, P.O. Box 567, Valdivia, Chile

Correspondence should be addressed to D. Movilla-Quesada; diana.movilla@uach.cl

Received 29 September 2018; Revised 10 January 2019; Accepted 22 January 2019; Published 20 February 2019

Academic Editor: Giulio Dondi

Copyright © 2019 D. Movilla-Quesada et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In recent years, Chile's vehicle fleet has undergone great changes, with 25% growth in motor vehicles. This increase is directly related to improvements in the performance of flexible pavements, which make infrastructure less susceptible to permanent deformations and/or cracking at high and low temperatures, respectively. In 2016, the Ministry of the Environment passed the Law on Recycling and Accountability to promote the search for innovative ideas and materials in different sectors. This research focused on the experimental study of the mechanical behaviour of a mixture of hot asphalt, incorporating thick particles of polyethylene terephthalate (PET) from bottle recycling, using the Marshall stability and flow test and the resilience module (rigidity) test at 5°C and 22°C. Based on previous research, significant PET fibre sizes were used, increasing the optimum amount of polyethylene terephthalate from 6% to 14% in the mixture. The results show that incorporating this polymeric additive provides greater stability, in addition to an increase in resistance to permanent deformations and fatigue, compared to a "traditional" mixture.

1. Introduction

Durability is a crucial factor when designing a road, as it is necessary to ensure that the layers of pavement maintain desired properties [1]. Durability is based above all on the annual increase in volume and traffic loads. It is important to note that flexible pavement is less susceptible to permanent deformations at high temperatures and cracking at low temperatures. Flexible pavement can be created by modifying asphalt binder, which can be done during the fabrication process by considering the origins and processing of petroleum. Unfortunately, both methods are difficult [2]. A third option focuses on modifying the asphalt binder using additives in the mixture to significantly improve the performance of the pavement. Recycled plastic can be used to increase the durability of the pavement [3, 4].

Plastics are used in almost every productive segment of the economy, and their use tends to increase with development, thus generating an increase in plastic waste. A typical example is PET bottles, which possess a short useful lifetime and become waste soon after use [5]. The high temperature of the fusion of PET hinders mixing with asphalt binder, making its incorporation impractical [5]. However, different studies have promoted its use through another method. Once reaching the temperature of glass transition (70°C), it gradually obtains crystalline properties, contributing to the stiffness of the asphalt mixture [6–8]. Thus, researchers have incorporated PET as an additive by reducing its size into small particles with a nominal maximum of less than 2.36 mm [9, 10].

The objective of this research was to determine the effect of incorporating thick PET particles in hot asphalt mixtures without generating a negative impact on mechanical resistance. This involved the Marshall stability and flow test and the resilient modulus test at two temperatures, with mixtures of different percentages of PET. Finally, the results were compared.

2. Materials and Methods

2.1. Aggregates and Asphalt Binder. A granulometric band corresponding to a semidense IV-A-12 was used for the dosage, as specified in the Road Guide of Chile [11]. The aggregates used were limestone; Figure 1 shows their gradation curves.

The traditional asphalt binder CA-24 is used in warm areas; Table 1 shows its characteristics.

2.2. PET Additives. Polyethylene terephthalate (PET) is the most commonly used thermoplastic polyester. It is a transparent polymer with high mechanical properties and excellent dimensional stability under varying loads that is used in magnetic tape, garments, and drink containers.

In this investigation, plastic from PET bottles was used as an additive in the asphalt mixture. The bottles were cut to small flakes and then reduced to their final size by shredding in a shredder, as shown in Figure 2.

With the aim of simplifying the reutilization process of PET, the plastic particles were not separated by size. Table 2 shows the characterization of the particles. There is a significant size difference between these particles and those used in past investigations. Fine particles were used in the past, with the greatest nominal maximum being 2.36 mm [12]; this investigation involved plastic of greater size, with fewer than 5% passing through a no. °4 sieve with openings of 2.36 mm and more than 70% sized between 5 and 10 mm.

2.3. Hot Asphalt Mixtures. The optimal binder percentage for the reference mix was 5.3%. This percentage was obtained from previous investigations using aggregates of the same origin, granule, and asphalt binder [13]. To understand the effects of PET particle incorporation in a reference mix, it is important to maintain the same content of the binder in the modified mixtures. The optimal content of the binder for these asphalt mixtures should be very similar to the reference mix [3]. Therefore, the same asphalt binder content was used for every combination. This content corresponded to the optimal asphalt binder percentage previously mentioned.

There are two alternatives for incorporating PET particles into the mix: the wet method and the dry method. In the former process, the additives are mixed with the asphalt binder before being added to the mix, and then, both are united with the aggregates later. In the latter process, the additive is combined with the aggregates before adding the asphalt binder. Due to the high temperature of the fusion of PET (250°C) in comparison with the fabrication temperature of the Marshall samples (150–170°C), it was not possible to mix additives and asphalt binder using the wet process and obtain a homogeneous mix; the dry method was used instead.

In the dry method, PET particles were incorporated in 5 different quantities: 3.5, 5.8, 8.2, 10.5, and 12.8 g, corresponding to 6, 10, 14, 18, and 22% content of binder, respectively.

2.4. Testing. Two tests were performed: the *Marshall stability and flow test* and the *resilient modulus test*. The Marshall stability and flow test was performed in accordance with the AASHTO T 245 [14], using a Marshall press with the velocity of deformation at 50 mm/min. The samples were submerged in a water bath at 60°C for 40 minutes and then were superficially dried before the test.

Calculating the air void percentage involved the PET particles' presence in proportion to the weight of the mineral aggregate, as well as its density at room temperature, which

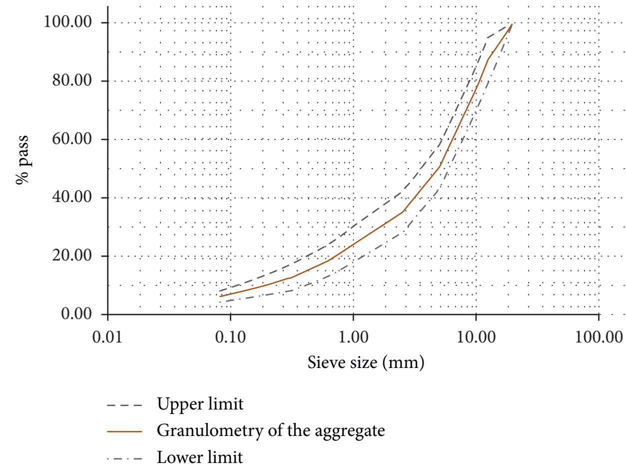

Figure 1: Gradation curves (IV-A-12).

Table 1: Specifications of the asphalt binder CA-24.

Properties	Standard	Value
Penetration at 25°C, 100 g, 5 s, 1/10 mm	MC 8.302.3	54.00
Softening point (°C)	MC 8.302.16	50.00
Absolute viscosity at 60°C (Poise)	MC 8.302.15	2950.00
Kinematic viscosity at 135°C (cP)	MC 8.302.13	513.00
Ignition point (°C)	MC 8.302.9	+232.00
Ductility at 25°C, 5 cm/min (cm)	MC 8.302.8	+150.00
Strain test (% Xilol)	MC 8.302.7	−30.00
Solubility in trichloroethylene (%)	MC 8.302.11	+99.00
Penetration index (IP)	MC 8.302.18	−1.00

Figure 2: PET particles used on asphalt mixtures.

Table 2: PET particles according to ASTM sieves.

Sieve size (mm)	Pass (%)
10	100
5	22
2.36	4
0.63	0

was 1.38 g/cm^3. Because of this, the relative expression in the calculation of the maximum density of the mixtures was adjusted for different amounts of asphalt, as shown in the Chilean Roads Guide [15]. In the new expression, the PET percentage and its density were incorporated as a third component in the mix:

$$D'_{\mathrm{mm}} = \frac{100 + P_{\mathrm{b}} + P_{\mathrm{p}}}{(100/D_{\mathrm{a}}) + (P_{\mathrm{b}}/\rho_{\mathrm{b}}) + (P_{\mathrm{p}}/\rho_{\mathrm{t}})}, \quad (1)$$

where D'_{mm} is the maximum density of the mix (kg/m^3), D_{a} is the effective density of the aggregate (kg/m^3), P_{b}: is the percentage of asphalt about the aggregate (%), ρ_{b} is the density of the asphalt (kg/m^3), P_{p} is the percentage of PET in the aggregate (%), and ρ_{t} is the density of PET (kg/m^3).

The resilient modulus test was performed in accordance with UNE-EN-12697-26 (2006) at temperatures of 22°C and 10°C during indirect tensile strength. The samples were conditioned for 4 hours before performing the test, and the previously mentioned temperatures were held by the conditioner chamber [16]. This test was performed in the universal test machine UTM-30, where horizontal deformations were measured using two LDVTs installed along the diameter of the sample, as shown in Figure 3.

The resilient modulus was calculated through the following equation:

$$M_{\mathrm{r}} = \frac{P(\nu + 0.27)}{h * w}, \quad (2)$$

where P is the maximum dynamic load (N), ν is the Poisson modulus, h is the height of the sample (mm), and w is the horizontal deformation.

The Poisson moduli for the testing temperatures of 22°C and 10°C were equal to 0.24 and 0.31, respectively. These are used in equation (3), developed by Witczak et al. [17]:

$$\nu = 0.15 + \frac{0.35}{1 + e^{3.1849 - 0.04233 * t}}, \quad (3)$$

where t is the temperature (°F).

3. Results and Discussion

The Marshall stability and flow test involved the optimal percentage of the asphalt binder for the granulometric band IV-A-12 obtained in previous investigations [13], which was 5.3% per weight of the aggregate. Twenty-four Marshall samples were fabricated with a diameter of 101.6 mm and a height of 63 mm, with percentages of PET additive 0%, 6%, 10%, 14%, 18%, and 22% per weight of the binder. These samples were compacted by 75 surface blows to simulate the conditions of heavy traffic.

Figure 4 shows the results for Marshall stability for the different percentages of PET addition. There is a greater dispersion of stability values concerning the reference sample, with an initial loss of stability in samples with low PET content, reaching a maximum around 14% addition, with a subsequent failure.

Figure 5 shows the flow values. Marshall flow, the parameter associated with the deformation the sample receives when reaching the maximum load before the lapse, gives a reference of the vertical distortion of the sample when reaching its lapsing state. The results show that the flow increases along with the samples' PET content, even when all samples contained the same percentage of the asphalt

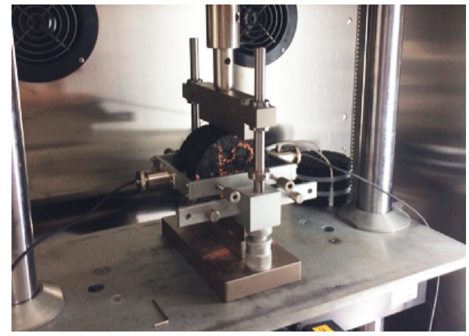

Figure 3: Resilient modulus test of indirect tensile strength.

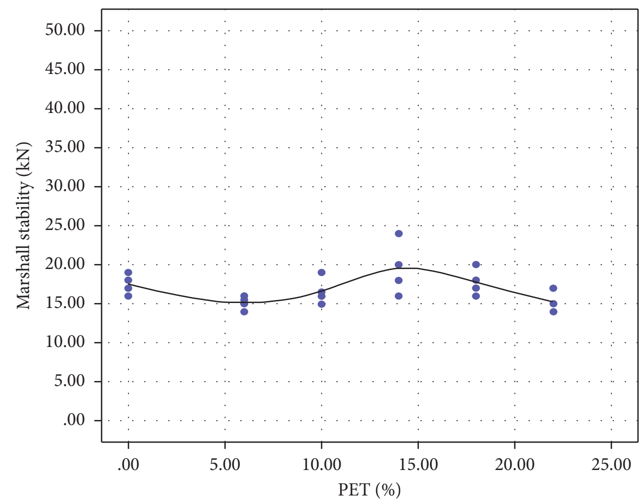

Figure 4: Marshall stability for different percentages of PET additions.

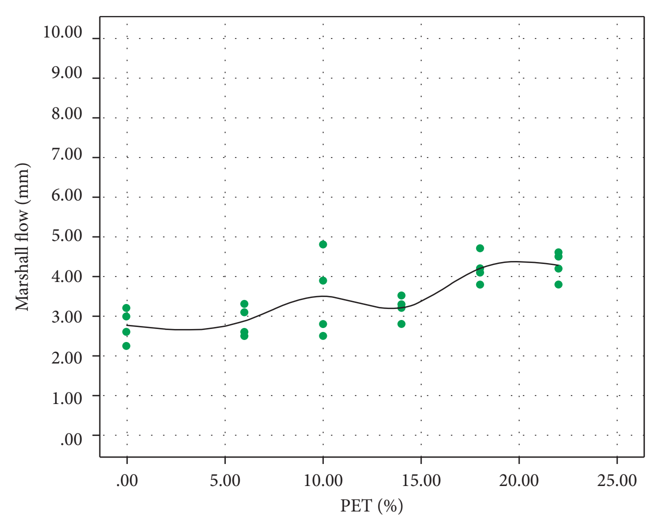

Figure 5: Marshall flow for different percentages of PET additions.

binder. The increase in flow, associated with the presence of PET particles, creates a more flexible mix. Additions between 6% and 14% still gave flow values that are within the Chilean norm, which demands a maximum flow of 4 mm for Marshall samples. Percentages of 18% and 22% exceed the limit, reaching flow values close to 5 mm for some samples, which would not be acceptable for an asphalt mix used as a bearing layer.

Beyond Marshall stability and flow, Marshall stiffness, the quotient of the said variables, can provide more information. Greater Marshall stiffness is evidence of better performance, with elevated values for stability and smaller values of flow. In our investigation, we reached a maximum of Marshall stiffness with the addition of 14% plastic particles, which is like the reference sample, as shown in Figure 6. Adding higher percentages of PET, such as 18% and 22%, reduced Marshall stiffness, which is associated with less stability and greater flow values.

The percentage of voids in the mineral aggregate (VAM) shows the volume of voids between aggregate particles in the compacted mix, as seen in Figure 7. The acceptable value for asphalt mixtures, recommended by the Institute of Asphalt, is a minimum of 14% for a mineral aggregate with a maximum size nominal of 19 mm [18]. This is the case for the gradation curve IV-A-12, which is satisfactory both for the reference mix and for mixtures with different additions of PET. The values range between 16% and 19% voids in the aggregate. The presence of plastic additives generates greater voids in the aggregate, as it is not capable of homogeneously uniting with the asphalt binder or with the aggregate. This creates spaces in the mixture and lessens density.

For a bearing layer, it is suggested to maintain a percentage of air voids between 4% and 6%, a range that satisfactorily complies with the reference mix and its optimal asphalt binder content. In conventional asphalt mixtures, an increase in the asphalt binder content diminishes air voids, as the binder fills those spaces. However, PET particles cannot reach the necessary fusion temperature, so they are not capable of mixing homogeneously with the binder or the aggregate. Because of this, spaces are created in the mix, as shown in Figure 8. When adding plastic particles in the mix, with the same percentage of the asphalt binder, the air voids grow, maintaining themselves within a range of 4% to 6% for mixtures with an addition of 6% to 18% PET. A 22% addition of PET exceeds the recommended value for air voids.

For the resilient modulus test, 24 Marshall samples were fabricated and compacted with 50 surface blows. In our investigation, the increase of stiffness within asphalt mixtures at low temperatures was shown through the resilient modulus test. The tests revealed an increase of 2 to 3 times to stiffness when lowering the temperature from 22°C to 10°C, as seen in Figure 9.

The stiffness modulus was considerably reduced when the test temperature was increased from 10°C to 22°C, which caused the appearance of plastic deformations. The addition of PET generated an increase in the initial rigidity of the mixture, associated with the crystalline properties of the plastic added to the mixture through the dry process, maintaining its natural state of semi-crystallinity [11].

The results obtained in the tests carried out at different temperatures show that the presence of PET increases the rigidity of the mixture to a certain extent. Due to its elastic response, the presence of these additives reduces the stress induced on the material under any load. This coincides with the results obtained in prior investigations, where the use of cellulose or polyester fibres reduced the rigidity of the asphalt mixture by making it more flexible, reaching values below 5000 MPa [18–20].

4. Conclusions

PET particles were added into an asphalt mixture with the gradation curve IV-A-12, corresponding to a semidense band used in wearing layers. Plastic originating from plastic bottles was shredded to sizes between 0.63 mm and 10 mm and then was added through the dry process to the mix in percentages between 6% and 22% per weight of a binder, at increments of 4% between samples. The first percentage of 6% plastic particles was chosen because it was the optimal percentage in previous investigations, even though the plastic in these investigations was smaller. Variations in plastic additions were made so that the incorporation would be comparable to the content of the binder used. The asphalt binder percentage used in all mixes remained constant, corresponding to the optimal amount of the binder used in the reference mix (containing 0% PET). Twenty-four samples were fabricated for the Marshall stability and flow test. All samples were compacted with 75 surface blows. This caused an initial loss of stability; however, the mixtures with PET additive exceeded the stability of the reference sample. When increasing the amount of incorporated PET particles, the particles become dominant and interrupted the correct function of the mix. An optimal additive content should be found to improve the mechanical properties of the mix.

The flow increases with the addition of polymers, generating greater deformability when reaching stability failure. One should be cautious, as excessive flow is harmful for the correct performance of pavement, which is why PET additions should be controlled to reach normative values.

The analysis of air voids in the mineral aggregates and the percentage of voids show that adding PET creates spaces in the mixtures, which could have caused the significant deformability that the tested samples presented. Along with flow, the number of voids in a mix increased with the addition of PET. The resilient modulus test was carried out for two temperatures, 5°C and 22°C, to analyse the behaviour of the mix both at operating temperatures and at low temperatures. The incorporation of plastic additives produced a mix that was more flexible even at low temperatures. This is an improvement to traditional asphalt mixtures that, in low temperatures, considerably increase in stiffness, which makes them susceptible to cracking. The mixture samples containing 22% PET reached a 30% loss of stiffness (in comparison with reference mixture) when tested at 10°C.

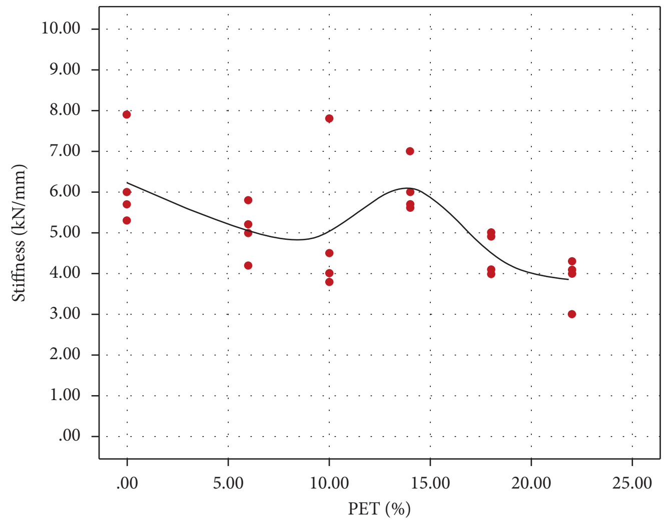

Figure 6: Marshall stiffness modulus for different percentages of PET at 60°.

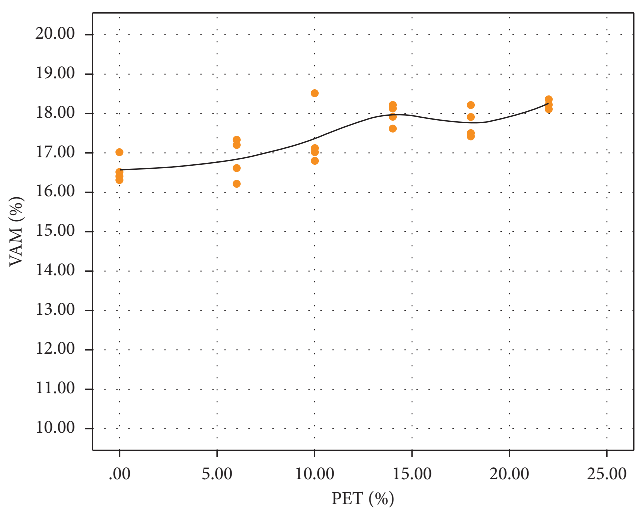

Figure 7: Percentage of air voids in the mineral aggregate.

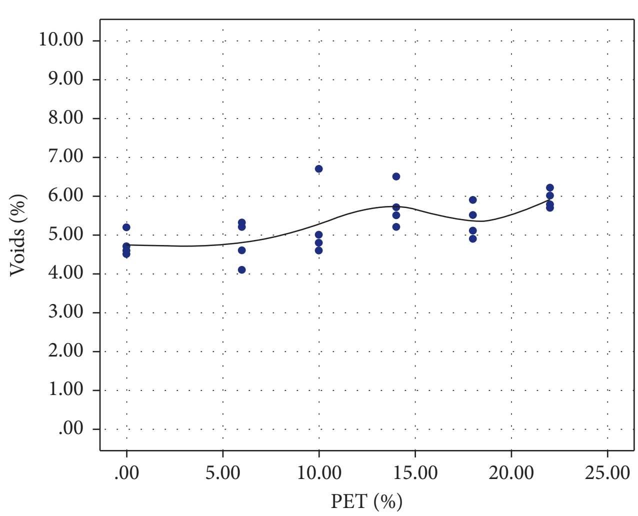

Figure 8: Air voids percentage obtained in the asphalt mixtures.

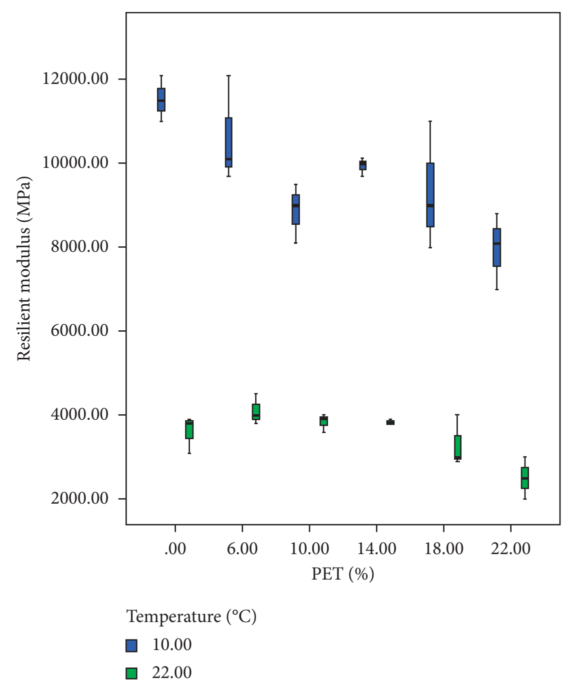

Figure 9: Resilient modulus adjusted for different percentages of PET at 10 and 22°C.

The optimal percentage of PET additions in this investigation was 14% PET particles per weight of a binder when added through the dry process. This created a mixture with greater stability, flow within the normative limits and less stiffness, thereby promoting reduced behaviour in low temperatures. This opens the door to future investigations that can evaluate fatigue and the rutting behaviour of pavement, with the ultimate goal of discovering a favourable asphalt mixture to be used in roads.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by Transportation Engineering Research Group (Gi^2V) and *Bitumixture S.A.* and *Química Latinoamericana* by material donation. Also, the authors gratefully acknowledge the institutional support provided by the Department of Research and Development of the University Austral of Chile (DID UACh), which made it possible to carry out this research.

References

[1] Y. R. R. Saragi, P. Lumbangaol, R. A. Sidabutar, and B. S. Siahaan, "Marshall characteristics in asphalt concrete—wearing corse (AC-WC) in various length and temperature submersion," *Procedia Engineering*, vol. 171, pp. 1421–1428, 2017.

[2] M. Sulyman, J. Haponiuk, and K. Formela, "Utilization of recycled polyethylene terephthalate (PET) in engineering materials: a review," *International Journal of Environmental Science and Development*, vol. 7, no. 2, pp. 100–108, 2016.

[3] Z. Z. Ismail and E. A. AL-Hashmi, "Use of waste plastic in concrete mixture as aggregate replacement," *Waste Management*, vol. 28, no. 11, pp. 2041–2047, 2008.

[4] D. Casey, C. McNally, A. Gibney, and M. D. Gilchrist, "Development of a recycled polymer modified binder for use in stone mastic asphalt," *Resources, Conservation and Recycling*, vol. 52, no. 10, pp. 1167–1174, 2008.

[5] M. Gürü, M. K. Çubuk, D. Arslan, S. A. Farzanian, and İ. Bilici, "An approach to the usage of polyethylene terephthalate (PET) waste as roadway pavement material," *Journal of Hazardous Materials*, vol. 279, pp. 302–310, 2014.

[6] Z. Dehghan and A. Modarres, "Evaluating the fatigue properties of hot mix asphalt reinforced by recycled PET fibers using 4-point bending test," *Construction and Building Materials*, vol. 139, pp. 384–393, 2017.

[7] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and E. Ahmadinia, "Performance evaluation of utilization of waste polyethylene terephthalate (PET) in stone mastic asphalt," *Construction and Building Materials*, vol. 36, pp. 984–989, 2012.

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

[9] 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," *Procedia Engineering*, vol. 53, pp. 124–128, 2013.

[10] T. B. Moghaddam, M. Soltani, M. R. Karim, and H. Baaj, "Optimization of asphalt and modifier contents for polyethylene terephthalate modified asphalt mixtures using response surface methodology," *Measurement*, vol. 74, pp. 159–169, 2015.

[11] M. D. O. PÚBLICAS, "Manual de carreteras," *Especificaciones Técnicas Generales de Construcción*, vol. 5, 2016.

[12] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and P. Shafigh, "Using waste plastic bottles as additive for stone mastic asphalt," *Materials & Design*, vol. 32, no. 10, pp. 4844–4849, 2011.

[13] C. M. Santibáñez, A. C. Raposeiras, and D. Movilla Quesada, *Evaluación de la Influencia de la Escoria de Cobre en Mezclas Asfálticas Altos Contenidos de RAP Frente al Ensayo de Sensibilidad al Agua*, Universidad Austral de Chile, Valdivia, Chile, 2016.

[14] American Association of State Highway and Transportation Officials, *Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus*, American Association of State Highway and Transportation Officials, Washington, DC, USA, 2014.

[15] M. D. O. PÚBLICAS, "Manual de carreteras," *Especificaciones y Métodos de Muestreo, Ensaye y Control*, vol. 8, 2016.

[16] UNE EN 12697, "Bituminous Mixtures-Test Methods for Hot Mix Asphalt-Part 26: Stiffness," AENOR, Madrid, Spain, 2012.

[17] M. W. Witczak, K. Kaloush, T. Pellinen, M. El-Basyouny, and H. Von Quintus, *Simple Performance Test for Superpave Mix Design*, Transportation Research Board, Washington, DC, USA, 2002.

[18] S. Oda, J. L. Fernandes, and J. S. Ildefonso, "Analysis of use of natural fibers and asphalt rubber binder in discontinuous asphalt mixtures," *Construction and Building Materials*, vol. 26, no. 1, pp. 13–20, 2012.

[19] F. Moreno-Navarro, M. Sol-Sánchez, M. C. Rubio-Gámez, and M. Segarra-Martínez, "The use of additives for the improvement of the mechanical behavior of high modulus asphalt mixes," *Construction and Building Materials*, vol. 70, pp. 65–70, 2014.

[20] M. Karami, H. Nikraz, S. Sebayang, and L. Irianti, "Laboratory experiment on resilient modulus of BRA modified asphalt mixtures," *International Journal of Pavement Research and Technology*, vol. 11, no. 1, pp. 38–46, 2018.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
Advances in Multimedia
Advances in Civil Engineering
Journal of Control Science and Engineering
Hindawi
Submit your manuscripts at
www.hindawi.com
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration