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Durability and Aging Characteristics of Sustainable Paving Mixture

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ABSTRACT

With the industrial revolution, many inventions have been introduced with many solid waste materials in return. This study investigates the potential recycling of waste plastic sheets, made from low-density polyethylene, as asphalt modifier in the paving mixture. The shredded plastic sheet was used in the asphalt mixture via the wet process. The dosage rate was set up to 9 % by weight of asphalt binder (0,3,6, and 9)%. The experimental program was designed to assess the mechanical properties (Marshall stability and flow, and volumetric properties), durability, and short-term aging of asphalt mixtures, in addition to economical assessment. The test results revealed the applicability of using this solid waste material in paving construction as a surface layer, since its usage enhances the pavement performance by increasing stability, index of retained strength, and volumetric characteristics before and after aging as well as saving in cost. The best enhancement can be achieved with 6% of recycled low-density polyethylene.

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1. INTRODUCTION

Works on the polymer-modified asphalt mixture have been increased in recent years [1-6]. Researchers recommended using polymers to enhance pavement performance to accommodate local traffic and weather conditions and avoid the common types of distresses. With the industrial revolution and the advance of material science, more materials and polymers have been introduced and used in every detail of life. Some of these materials are non-biodegradable like plastics. In other words, it would be stuck in dump places for hundreds of years and cause real risks to the environment as land and marine pollution. The presence of microplastic in the seawater threatens the aquatic organisms, thereby disrupting the bio-system [7]. Moreover, soil contamination with microplastics may damage the health of the flora-fauna ecosystem. And these plastic particles would intake by the human body through food chains [8]. To alleviate these concerns, these materials are recycled by crushing and using again as secondary paving materials. Apart from virgin polymers, incorporating waste polymers has also been revealed to improve the asphalt pavement properties to a level similar to that observed with virgin polymers besides its potential sustainable practice [9]. Researchers in the field of pavement engineering used recycled expanded polystyrene as Al-Haydari and Masued [10]. They noticed a reduction in Marshall properties and increasing moisture resistance with the inclusion of this recycled polymer. Whereas, Ramadan et al. [11] enhanced binder performance in terms of rutting resistance to achieve mixtures that can sustain up to 64°C temperatures with styrofoam incorporation. Additionally, Al-Haydari and Al-Haidari [12] and Naghawi et al. [13] utilized recycled polyethylene terephthalate to enhance the mechanical properties, tensile strength, and moisture damage resistance of the hot mix asphalt. Mosa et al. [14] also used this type of additive to modify the warm mix asphalt performance in terms of rutting resistance in addition to other mechanical properties.

Plastic bags, characterized as low-density polyethylene (LDPE), are widespread plastic polymers that can be shredded to 5 mm× 5mm particles or smaller

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and used in paving layers. It can be used in form of pellets or flakes. However, Angelone et al. [15] recommended using LDPE as flakes in the paving mixture. Singh et al. [16] stated that the inclusion of shredder polyethylene to the asphalt mixture enhances the volumetric properties, Marshall stability, and flow for the mixture. Also, it improves the recovered asphalt binder in terms of complex modulus and phase angle. Similarly, El-saikly [17] recommended using waste plastic bags as a modifier for pavement mixture as well as a sustainable practice. To sum up, Wu and Montalvo [9] summarized most of the studies conducted on the utilization of recycled LDPE on asphalt mixture. They stated that there is a common consensus among researchers that recycled LDPE can enhance the mixture resistance to rutting, fatigue, and moisture susceptibility. However, resistance against thermal cracking is still problematic. To solve this problem, using waste oil as facilitator can possibly improve the aging resistance and reduce thermal cracks, as well as enable the engineers to use an extra amount of the recycled LDPE, as stated by Nouali et al. [18], even with reclaimed asphalt pavement [19].

In Iraq, it is estimated that the population provides 31000 tons of solid waste daily with the capacity to dispose of 4000 tons per day only [20]. Most of the trash is waste plastics. This discrepancy in solid waste production and disposing necessitates the local government to find a suitable management system to overcome these challenging environmental tasks. Moreover, most of the LDPE-modified pavement mixtures studies did not take into consideration the change in mixture properties during the mixing and construction process. The plastic is affected by temperature change during mixing and compacting for the surface paving layer. This change in behavior would affect the pavement mixture performance. Thereby this research aims to investigate the short-term aging to simulate the mixture behavior when mixed, placed, and compacted in the field. In addition, the effect of weather through moisture susceptibility on this layer (durability) of hot mix asphalt containing recycled plastic sheets, made from LDPE, besides its cost-effectiveness are the main focus of this study.

2. MATERIALS

2. 1. Conventional Paving Mixture

The materials used for asphalt concrete pavement are natural quartz aggregate with a maximum nominal aggregate size of 12.5mm, limestone dust with a 2.78 specific gravity of mineral filler, and (40-50) penetration grade of asphalt binder. All these materials were individually tested following ASTM C127 and C128 procedures for coarse and fine aggregate respectively, to ensure that it complies with Iraqi`s specifications for roads and bridges [21]. Test results are reported in Table 1. Besides, aggregate gradation is presented in Figure 1.

2. 2. Recycled LDPE Polymers

The used modifier is the shredded plastic bags, made from low-density polyethylene, which is globally available and non-biodegradable material. Thermoplastic monomer ethylene, recycled low-density polyethylene LDPE polymers, have been used in this study from shredded plastic sheets, in a wet process as partial replacement of asphalt binder. The dosage rates, used in this investigation, are 0, 3, 6, and 9% of asphalt weight. Material descriptions are presented in Table 2.

3. EXPERIMENTAL PROGRAM

The initial stage of the experimental program is to find the optimum asphalt content that satisfies most of the

TABLE 1. Physical properties of aggregate

Property	Coarse Aggregate	Fine Aggregate
Apparent specific gravity	2.69	2.68
Bulk specific gravity	2.62	2.63
water absorption, %	0.49	0.61
Los-Angeles abrasion, %	27.1	---

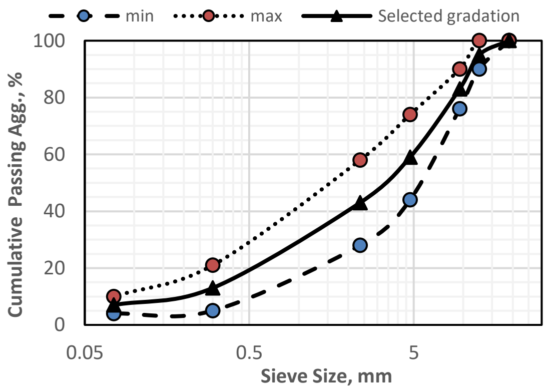


Figure 1. Gradation of aggregate in wearing layer III

TABLE 2. Properties of the LDPE waste material

Property	Measure
Chemical formation	(-CH2-CH2-)n
Tensile strength (N/mm^2)	0.2 – 0.4
Density (gm/cm^3)	0.91 - 0.94
Thermal expansion coefficient	100 – 220 × 10^{-6}
Softening point (°c)	100-120 °c
Melting point (°C)	110

desirable characteristics of the asphalt concrete mixture. Triplicate samples were prepared in accordance with ASTMD 6926 [22] at varying asphalt content (4-6) % of mixture weight with 0.5% interval, and tested in accordance with ASTMD 6927 [23]. From test results, 5% is found the optimum binder content the revealed higher stability and bulk density, lower flow, with accepted range of voids ratio.

To study the effect of the recycled LDPE on durability and aging of HMA, three sets were prepared as illustrated in Figure 2. The HMA samples were prepared by heating aggregate and asphalt binder at (160, and150) °C, respectively. Then, it was mixed together for approximately two minutes to ensure wetting and covering of all aggregate particles. The first two sets were compacted by Marshall hammer for 75 blows for each side. While the third set was placed in the oven before the compaction stage to prepare the mixture for short-term aging.

The work plan for this research is presented in Figure 2.

3. 1. Durability in bituminous mixes can be assessed through water sensitivity. Index of retained strength (IRS), the loss of pavement serviceability due to the presence of moisture is usually used for durability estimation. IRS is the stability ratio of water-conditioned samples to the unconditioned ones. [24]

$$IRS=\frac{S_2}{S_1}\times \mathbf{100}\% \quad (1)$$

where, IRS: Index of Retained Strength, %, S_1: Marshall stability of the standard specimens, (S wet, 60°C, and 30 min.) KN, and S_2: Marshall stability of the wet specimens, (S wet, 60°C, and 24 hrs.) KN.

The higher IRS value is the more resistance to water damage mixture.

A total of 8 sets of Marshall specimens of Hot Mix Asphalt stabilized with recycled LDPE additives (0, 3, 6, and 9) % by weight of asphalt, were prepared and divided into two groups (4 specimens each). The first group was immersed in a water bath at 60°C, for 24 hours (conditioned sample). The samples were then removed from the water bath to be tested for Marshall Stability at 60°C. Another set of samples (unconditioned sample) are immersed in a water bath at 60°C for a half-hour, then tested at 60°C.

3. 2. Aging The short-term aging of the asphaltic paving mixture is used to simulate the effect of plant mixing and construction on the mechanical properties of the asphalt mixture. This test was conducted under AASHTO R30 [25] designation.

The same procedure that has been adopted to prepare the control mixture was used except the oven- condition stage. The loose mixtures were spread in a pan to an even thickness of 20-50mm. The pans containing the loose mixtures were conditioned in the oven at 135℃ temperature for 4 hours. During the condition period, the loose mixtures were stirred every 60 minutes to ensure uniform conditioning. After the conditioning periods, the mixtures were removed from the oven and compacted by a Marshall hammer in the same procedure that has been adopted for the control mixture.

4. RESULTS AND DISCUSSION

4. 1. Analysis of Modified Bitumen The properties of the standard and LDPE-modified asphalt binder were investigated through the traditional tests for the asphalt, like penetration [26], ductility [27], and softening point [28] tests. The blending dosage rate was limited to 9% as a partial replacement by the weight of the asphalt. Through visual observation, an extra amount requires more heating and energy during blending, which is not a cost-effective solution. Thereby, the mixes were prepared

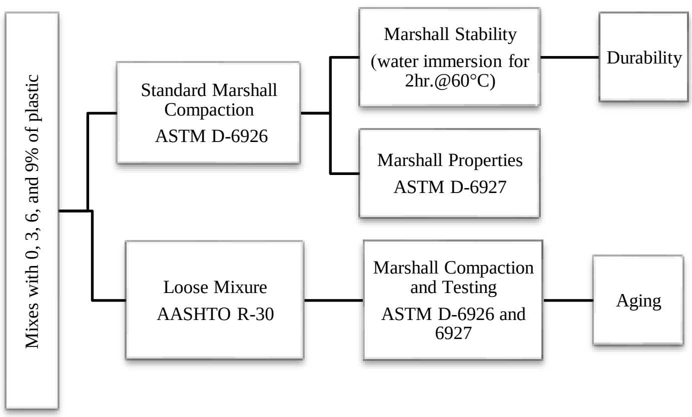


Figure 2. Flow-chart for the experimental program

and tested with a concentration of (0, 3, 6, and 9) % by weight of asphalt. The test results are summarized in Table 3.

The chemical function of asphalt is similar to plastic which is a hydrocarbon. When the plastic polymers are induced to asphalt, it works as modifiers. This modifier does not chemically react with base asphalt, but it is dispersed and absorbed by the asphalt component. So, compatibility is the main requirement to ensure homogeneity in the asphalt medium without stratification or cohesion, or separation from each other [9].

Table 3 summarized the penetration and ductility of modified binders substantially decrease with an increase of blending dosage rate. This resulted in losing workability, thus required more heating to reach the required viscosity that can cover all aggregate particles. This behavior is also noted by Nouali et al. [18]. However, adding plastic to the asphalt binder increase the plasticity and toughness of the mixture. It is also noticed an increase in penetrability index which indicates that the mixture would have higher temperature stability [29]. That means less affected by temperature variations.

4. 2. Analysis of the Modified Mixture All the essential tests were performed according to ASTM D6927 [23], ASTM D 2726 [30], and ASTM D [31] to highlight the physio-mechanical behavior of the LDPE-modified mixture. The test results are illustrated in Figure 3. Obviously, addition of recycled LDPE enhance the mixture properties by increasing stability and bulk density and reducing the flow value besides keeping other volumetric properties with the prescribed limits recommended by Iraqi`s specifications for roads and bridges [21].

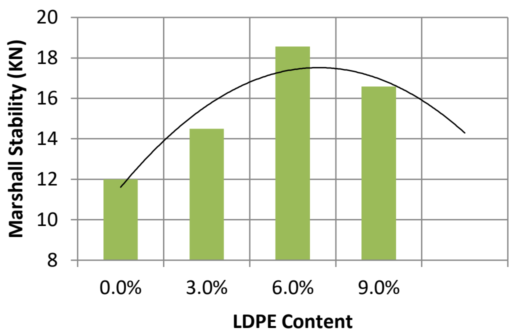
This enhancement may be attributed to the bonding ability of the recycled plastic polymer. Since recycled polyethylene works as a "*glue*" [16] to bond aggregate particles and strengthens the aggregate-binder matrix.

TABLE 3. Physical properties of the standard and modified asphalt binders

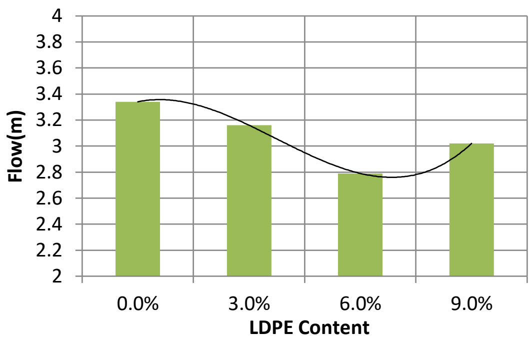
LDPE-dosage	Penetration	Ductility	Softening point	Penetration Index
Test methods [units]	25°C, 100g, 5 s [0.1mm]	25°C [0.1 cm]	°C [1°C]	
0%	43	125	56	-0.16
3%	39	101	60	0.43
6%	31	87	69	1.52
9%	26	63	73	1.76
Iraqi`s specification*	**40-50**	**>100**	**50-60**	----

* Iraqi specification of roads and bridges SCRB [21]

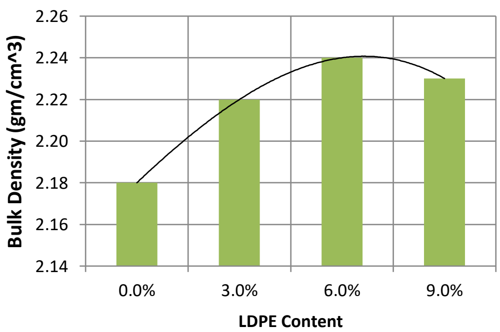
Although, there is a reduction in pavement performance with a 9% of LDPE rate as compared to the previous rate. However, the laboratory test results are still within the required limit of the Iraqis specifications [21] and better when compared with the reference mixture. This reduction in performance of the 9% mixture could be attributed to the reduction in LDPE-modified asphalt characteristics as penetration and ductility values. This means that the binder is stiffer and having higher viscosity that could not cover all aggregate particles. These deficiencies in the aggregate covering cause improper compaction that can be inferred from other volumetric characteristics as lower density, and higher air voids.



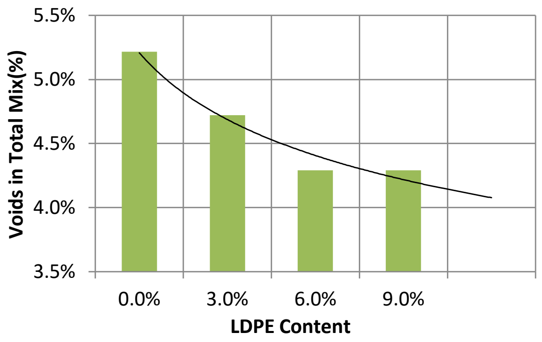
A: Marshall Stability



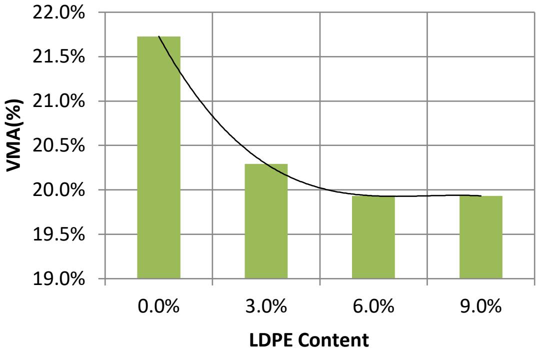
B: Marshall Flow



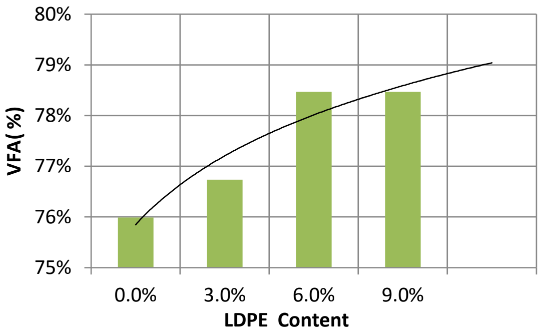
C: Bulk density



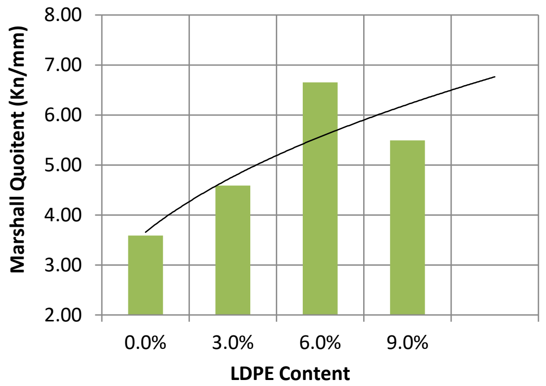
D: Air voids



E: Voids in mineral aggregate



F: Voids filled with asphalt



G: Marshall Quotient

Figure 3. Effect of LDPE on Phsiomechanical properties of Asphalt Mixtures

4. 3. Durability is the ability of a material to sustain weather conditions [32]. For pavements, moisture is a fundamental parameter that causes pavement deterioration in a form of moisture damage (stripping) distress [33]. The moisture sensitivity of the control and the recycled LDPE-modified mixtures was evaluated following ASTM D 6927 [23] specification. This test assesses the loss in cohesion resulted from water ingression through the mixture. The Marshall stability of the conditioned and unconditioned samples with the selected LDPE dosage rates with the corresponding Index of retained strength IRS are presented in Figure 4. The test results indicates that the IRS increase with increasing LDPE ratio, and the rate of increase in the index of retained strength is improving significantly with 9% of recycled LDPE material. This behavior is also remarked by other researchers [16]. They attributed this behavior to the bonding ability of the polyethylene polymer with aggregates particles, acting as glue to bind the aggregate particles together and reduce waste ingress. Since the moisture damage depends not only on the aggregate mineralogy but also on asphalt-aggregate interaction as well as other volumetric properties and the layer film thickness [12]. Enhancing these characteristics would result in improving the moisture resistance of the paving mixture. Noticeably, the addition of any type of recycled plastic polymer enhances the pavement properties against moisture damage [12, 34], especially when using the wet method of mixing.

4. 4. Short-term Aging Volumetric properties of the mixture are essential in predicting the performance of the pavement service life since they affect durability. After the aging process, the asphalt binder loses the volatile materials through oxidation and volatilization, thereby reducing its volume, and increase its viscosity [35]. Subsequently, decreasing the mixture weight, and density. This behavior is clearly noticed in Figure 5.

Figure 6 shows the effect of short-term aging on Marshall stability, flow, and quotient which is the ratio

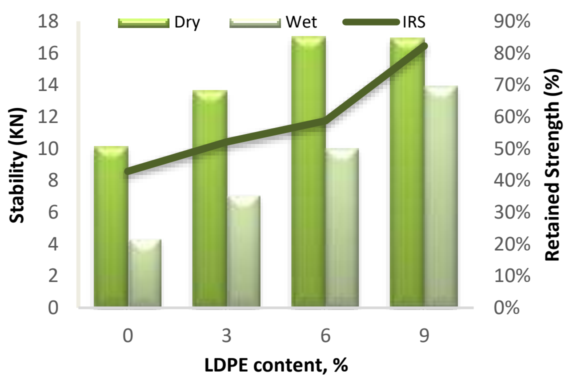
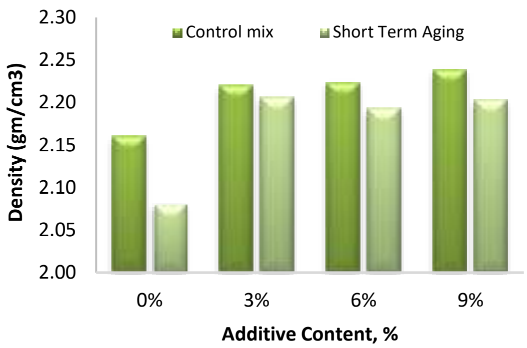
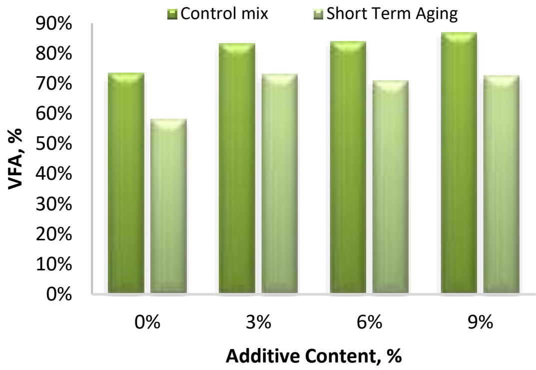


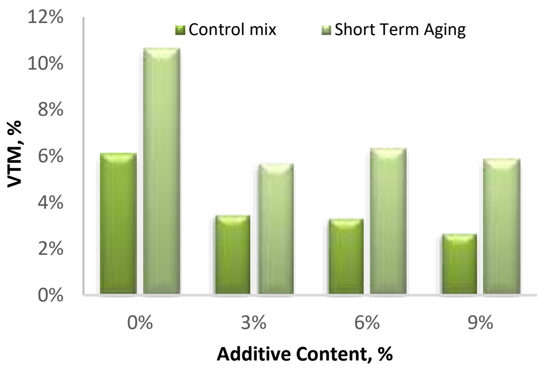
Figure 4. Marshall stability, and retained stability for control and conditioned samples



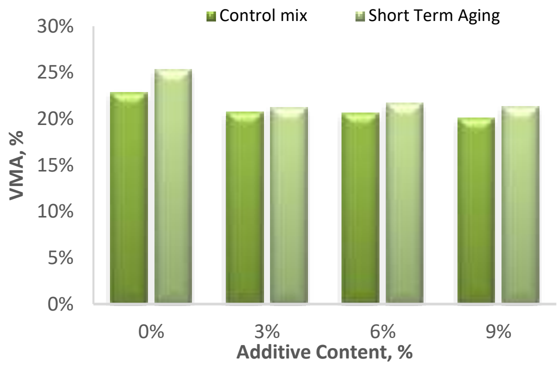
A: Density



B: Voids filled with asphalt

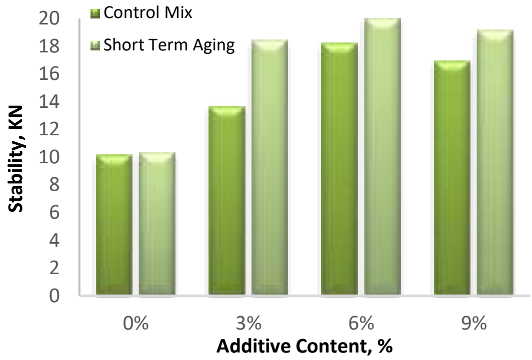


C: voids in the total mixture

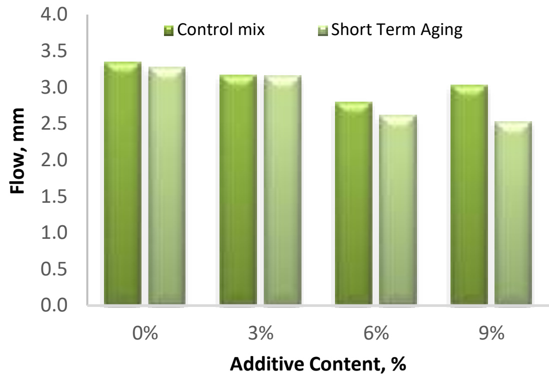


D: voids in mineral aggregate

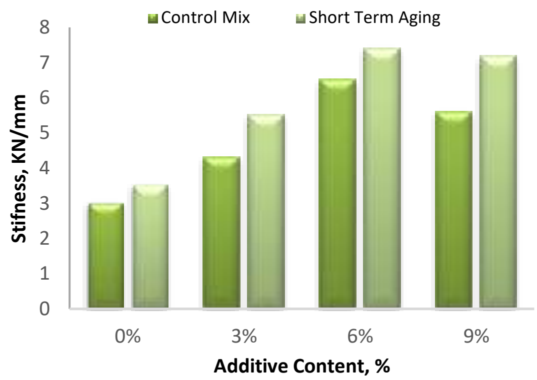
Figure 5. Effect of recycled LDPE and short-term aging on volumetric properties of asphalt mixture



A: Stability



B: Flow



C: Quotient

Figure 6. Effect of recycled LDPE and short-term aging on Marshall stability and flow of asphalt mixture

of Marshall stability to flow [15]. The aging process causes loss of volatiles that makes the asphalt binder and mixture stiffer and can resist deformation. This behavior is inferred from increasing Marshall stability, and quotient values, and decreasing flow values. Moreover, the percent change in the modified mixture is less than that observed in the control mix. The LDPE, when mixed with asphalt binder, disperses and absorbed by its components [9] making the maltene phase stiffer and less susceptible to aging. This behavior has been also inferred from the penetrability index, presented in Table 3, which shows an increase in this value with increasing dosage rate of LDPE. So, it can be concluded that the LDPE-modified paving mixture is less susceptible to temperature. Especially, at high temperature that causes rutting, which is the common type of distress in Iraq [36].

4. 5. Economic Analysis The important aspect of sustainable production is the economic assessment to show the cost-effectiveness of a specific intervention. Therefore, a quantity calculation and cost analysis were implemented and explained in Table 5. The assumptions were set as 1 km of a four-lane highway, with a surface thickness of 50 mm. The savings are presented in Table 6 in terms of the quantity of materials per m^3 of the mixture with their corresponding cost.

A cheaper and eco-friendlier material could be achieved by incorporating recycled LDPE in the paving mixture as a surface layer.

TABLE 5. Design parameters for the assumed road section

Design Parameters	Values
Length of pavement section	1 km
Number of lanes	4
Width of lane	3.6 m
Thickness of surface layer	5 cm
Volume of pavement mixture	length × width × thickness = 720 m^3
Approximate density of surface layer	2400 kg/m^3
Percentage of asphalt binder	5%
Quantity of asphalt binder	volume × mix density × binder percentage = 86400 kg = 86.4 ton
Quantity of asphalt binder for 1m^3	86400 kg/720 m^3 = 120 kg
Bitumen cost	0.5$/kg

TABLE 7. Description of saving in binder volume and cost

LDPE rate	The required quantity of bitumen (kg/ m^3)	Quantity of bitumen saving (kg/ m^3)	Saving cost ($/$m^3$)
0 %	120	0	0
3 %	116.4	3.6	1.8
6 %	112.8	7.2	3.6
9 %	109.2	10.8	5.4

5. CONCLUSION

The hot mix asphalt with different percentages of recycled low-density polyethylene had been prepared and tested for Marshall stability and flow and other volumetric properties. Another set was immersed in water to measure its durability, whereas the other set was conditioned in the oven before compaction to test the short-term aging. Based on test results, the main conclusions can be highlighted as:

- The partial replacement of asphalt binder by recycled LDPE enhances Marshall properties and maintains other volumetric properties to the specified limits. Additionally, the resistance to moisture damage increases.
- The addition of LDPE to asphalt mixture via the wet process improves the aging characteristics of the short-term aged mixture.

To sum up, utilization of waste materials as plastic bags or sheets, made from low-density polyethylene, extends pavement service life by enhancing pavement properties in terms of mechanical, and physical properties, durability, aging, and provides an economical and eco-friendly paving material and maintain a sustainable environment.

5. ACKNOWLEDGMENT

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6. REFERENCES

1. A. I. Al-Hadidy, “Engineering behavior of aged polypropylene-modified asphalt pavements,” ***Construction and Building Materials***, Vol. 191, (2018), 187-192, https://doi.org/10.1016/j.conbuildmat.2018.10.007.
2. A. H. Abed and H. U. Bahia, “Enhancement of permanent deformation resistance of modified asphalt concrete mixtures with nano-high density polyethylene,” ***Construction and Building Materials***, Vol. 236, (2020), 117604, https://doi.org/10.1016/j.conbuildmat.2019.117604.
3. A. H. Abed, Z. I. Qasim, H. Al-mosawe, H. H. Norri, and F. G. Pratico, “The effect of hybrid anti-stripping agent with polymer on the moisture resistance of hot-mix asphalt mixtures,” ***Cogent Engineering***, Vol. 6, (2019), 1-15, doi: 10.1080/23311916.2019.1659125.
4. E. N. Ezzat and A. H. Abed, “The influence of using hybrid polymers , aggregate gradation and fillers on moisture sensitivity of asphaltic mixtures,” ***Materials Today: Proceedings***, Vol. 20, (2020), 493-498, doi: 10.1016/j.matpr.2019.09.176.
5. M. A. Al-Jumaili and H. A. Al-Jameel, “Reducing Rutting in Flexible Pavement Using Specified Polymers with HMA,” ***IOP Conference Series: Material Science Engineering***, Vol. 978, No. 1, (2020), 012006, doi: 10.1088/1757-899X/978/1/012006.
6. A. A. Abdulmawjoud and L. S. Thanoon, “Evaluation of SBR and PS-Modified Asphalt Binders and HMA Mixtures Containing Such Binders,” ***Applied Research Journal***, Vol. 1, No. 9, (2015).
7. M. N. Issac and B. Kandasubramanian, “Effect of microplastics in water and aquatic systems,” ***Environmental Science and Pollution Research***, Vol. 28, No. 16, (2021), 19544-19562, doi: 10.1007/s11356-021-13184-2.

8. Y. Zhou, J. Wang, M. Zou, Z. Jia, S. Zhou, and Y. Li, "Microplastics in soils: A review of methods, occurrence, fate, transport, ecological and environmental risks," *Science Total **Environment***, Vol. 748, (2020), 141368, doi: 10.1016/j.scitotenv.2020.141368.

9. S. Wu and L. Montalvo, "Repurposing Waste Plastics into Cleaner Asphalt Pavement Materials: A Critical Literature Review," ***Journal of Clean. Production,*** (2020), 124355, doi: 10.1016/j.jclepro.2020.124355.

10. I. S. Al-Haydari and G. G. Masued, "Benefit of Using Expanded Polystyrene Packaging Material to Improve Pavement Mixture Properties," ***Applied Research Journal***, Vol. 11, (2017).

11. K. Z. Ramadan, G. G. Al-khateeb, and M. M. Taamneh, "Mechanical properties of styrofoam-modified asphalt binders," ***Int. J. Pavement Res. Technol.***, (2019), https://doi.org/10.1007/s42947-019- 0102-4.

12. [12] I. S. Al-Haydari and H. S. Al-Haidari, "Mechanical Properties of Polyethylene Terephthalate-Modified Pavement Mixture," *IOP **Conference Series Material Science Engineering***, Vol. 870, (2020), 012073, doi: 10.1088/1757-899X/870/1/012073.

13. H. Naghawi, R. Allouzi, A. Alklub, and K. Masarwah, "Plastic Waste Utilization as Asphalt Binder Modifier in Asphalt Concrete Pavement," ***World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering***., Vol. 12, No. 5, (2018), 566-571,.

14. A. M. Mosa, I. T. Jawad, and L. A. Salem, "Modification of the Properties of Warm Mix Asphalt Using Recycled Plastic Bottles," ***International Journal of Engineering, Transactions C: Aspects***., Vol. 31, No. 9, (2018), 1514-1520, doi: 10.5829/ije.2018.31.09c.06.

15. S. Angelone, M. C. Casaux, M. Borghi, and F. O. Martinez, "Green pavements: reuse of plastic waste in asphalt mixtures," ***Materials and Structures***,Vol. 49, No. 5, (2015), 1655-1665. doi: 10.1617/s11527-015-0602-x.

16. P. Singh, A. Tophel, and A. K. Swamy, "Properties of asphalt binder and asphalt concrete containing waste polyethylene," ***Petroleum Science and Technology***, Vol. 35, No. 5, (2017), 495-500, doi: 10.1080/10916466.2016.1265559.

17. M. A. El-saikaly, "Study of the Possibility to Reuse Waste Plastic Bags as a Modifier for Asphalt Mixtures Properties (Binder Course Layer)," The Islamic University of Gaza, (2013).

18. M. Nouali, Z. Derriche, and E. Ghorbel, "Effect of Used Engine Oil Addition on the Rheological Properties of a Plastic Bag Waste - Modified 40/50 Grade Bitumen," ***Journal of Materials in Civil Engineering,*** Vol. 33, No. 3, (2021), 1-10, doi: 10.1061/(ASCE)MT.1943-5533.0003533.

19. C. Rodrigues, S. Capitão, L. Picado-Santos, and A. Almeida, "Full recycling of asphalt concrete with waste cooking oil as rejuvenator and LDPE from urban waste as binder modifier," ***Sustainability***., Vol. 12, No. 19, (2020), 8222, doi: 10.3390/su12198222.

20. H. Caliendo, "City in Iraq Opens its First Recycling, Production Plant," ***Recycled Materials***, (2016). https://www.ptonline.com/blog/post/city-in-iraq-opens-its-first-recycling-production-plant- (accessed Dec. 25, 2020).

21. SCRB, "Materials Specification and Construction Works." State Corporation of Roads and Bridges, Ministry of Housing and Construction, Iraq, (2009).

22. ASTM D6926, "Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus," *ASTM International, West Conshohocken, PA*, (2020).

23. ASTM D6927, "Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures." ASTM International, West Conshohocken, PA, (2015).

24. Laboratory Testing Manual, "Method of Test for Resistance to Stripping of Asphalt Cement in Bituminous Mixture by Marshall Immersion," No. 17. Ministry of Transportation, Ontario, (1998).

25. AASHTO R 30-02, "Standard Practice for Mixture Conditioning of Hot Mix Asphalt," *American Association State Highway Transportation Office*, (2019).

26. ASTM D5 / D5M, "Standard Test Method for Penetration of Bituminous Materials," *ASTM International West Conshohocken*, (2020).

27. ASTM D113, "Standard Test Method for Ductility of Asphalt Materials," *ASTM International West Conshohocken, PA*, (2017).

28. ASTM D36 / D36M - 14, "Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)," *ASTM International West Conshohocken, PA*, (2020).

29. M. Ghasemi and S. M. Marandi, "Laboratory studies of the effect of recycled glass powder additive on the properties of polymer modified asphalt binders," ***International Journal of Engineering, Transactions A: Basics***, Vol. 26, No. 10, (2013), 1183-1190, doi: 10.5829/idosi.ije.2013.26.10a.08.

30. ASTM D 2726, "Standard Test Method for Bulk Specific Gravity and Density of Non- Absorptive Compacted Bituminous Mixtures." ASTM International, (2014).

31. ASTM D2041, "Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixture." ASTM International, (2011).

32. N. G. Ahmed, Y. M. Al-Badran, and D. M. Azeez, "Laboratory Evaluation of Moisture Damage and Durability of Hot Mix Asphalt (HMA)," ***Journal of Engineering and Sustainable Development***, Vol. 21, No. 2, (2017), 149-162.

33. G. L. S. Babu, P. S. Kandhal, N. M. Kottayi, R. B. Mallick, and A. Veeraragavan, *Pavement Drainage: Theory and Practice*. Taylor & Francis Group, (2020).

34. S. Haider, I. Hafeez, Jamal, and R. Ullah, "Sustainable use of waste plastic modifiers to strengthen the adhesion properties of asphalt mixtures," ***Construction and Building Materials***, Vol. 235, (2020), 117496, doi: 10.1016/j.conbuildmat.2019.117496.

35. S. I. Sarsam and S. M. Adbulmajeed, "Influence of Aging Time on Asphalt Pavement Performance," ***Jounal of Engineering,*** Vol. 20, No. 12, (2014), 1-12.

36. A. H. A. Al-Haddad and I. S. J. Al-Haydari, "Modeling of flexible pavement serviceability based on the fuzzy logic theory," ***Journal of Transportation Engineering, Part B: Pavements***, Vol. 144, No. 2, (2018), doi: 10.1061/JPEODX.0000026.

Persian Abstract

چکیده

با انقلاب صنعتی ، بسیاری از اختراعات با بسیاری از مواد زائد جامد در ازای آن ارائه شده است. این مطالعه بازیافت بالقوه ورق های پلاستیکی زباله ، ساخته شده از پلی اتیلن با چگالی کم ، به عنوان اصلاح کننده آسفالت را در مخلوط روسازی بررسی می کند. ورق پلاستیکی خرد شده از طریق فرآیند مرطوب در مخلوط آسفالت استفاده شد. میزان دوز تا ۹ از وزن چسب آسفالت تنظیم شد. این برنامه آزمایشی علاوه بر ارزیابی اقتصادی ، برای ارزیابی خصوصیات مکانیکی ، دوام و پیری کوتاه مدت مخلوط های آسفالت نیز طراحی شده است. نتایج آزمون کاربرد استفاده از این مواد زائد جامد در ساخت روسازی را نشان داد زیرا استفاده از آن با افزایش پایداری ، شاخص مقاومت حفظ شده و خصوصیات حجمی قبل و بعد از پیری و همچنین صرفه جویی در هزینه ، عملکرد روسازی را افزایش می دهد. با ۶٪ پلی اتیلن با چگالی کم بازیافت شده ، بهترین پیشرفت را می توان بدست آورد.