ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INVESTIGATION THE EFFECTS OF ADDING WASTE PLASTIC ON ASPHALT MIXES PERFORMANCE

Ahmad M. Abu Abdo
Department of Civil and Infrastructure Engineering, American University of Ras Al Khaimah, Ras Al Khaimah, United Arab Emirates
E-Mail: ahmed.abuabdo@aurak.ac.ae

ABSTRACT

Recently, calls for greener and more sustainable construction projects have gained momentum and are spreading worldwide. With the increase of the amount of wastes worldwide, many attempts are made to incorporate these waste materials into construction projects, especially flexible pavements. Thus, this study was initiated to investigate the effects of adding plastic waste particles to hot mix asphalt (HMA) when it comes to performance. Two different Superpave mixes with 0%, 0.2%, 0.5%, and 1% plastic waste of aggregates weight were investigated. 3D Move Analysis software was utilized to determine rutting depths and top down and bottom up cracking in a typical asphalt concrete layer with the different plastic waste contents at various temperatures. Results showed that adding 0.2% plastic waste to HMA would enhance the performance of these mixes. Also, mixes with 0% (control) and 0.5% plastic waste performed similarly. However, when adding 1% plastic waste, mixes performed poorly. Based in these results, utilizing 0.5% plastic waste by weight of aggregates in HMA would make flexible pavement design eco-friendlier and more sustainable, since a big amount of plastic waste could be incorporated without effecting the performance of hot mix asphalt.

Keywords: flexible pavement, asphalt mixes, plastic waste, rutting, top down cracking, bottom up cracking, mechanistic method.

INTRODUCTION

Eco-friendly and Sustainable projects have become the main target and concern of any agency. With the depletion of natural resources and the increase of solid wastes worldwide, different industries are looking at alternative materials (i.e., recycled materials) to be utilized in construction projects [1]. Recently, asphalt pavement materials costs increased tremendously, which paved the way to find alternative cheap materials. In addition, more concerns are directed to reserving natural resources and reducing environmental impacts, thus more attention is focused on the use of recycled materials in the pavement industry [2]. In addition, it can be argued that carbon footprint on road construction could be reduced by using recycled materials and the use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefits [3,4].

Disposal of plastic waste has become a major concern worldwide due to the considerable increase in volume and growth [1], since it is not a biodegradable material and considered a major environmental pollutant [5]. Therefore, it would be beneficial if plastic waste could be reused in pavement construction. Recent studies were conducted to evaluate utilization of plastic waste in asphalt mixes and its effects on the performance on flexible pavements [6-9]. Results of these studies showed asphalt mixes containing plastic waste exhibited improvement in engineering properties (i.e., Marshall stability, resistant to water, and resistant to crack propagation).

Several studies investigated using plastic waste as an asphalt binder modifier to enhance its performance. Hinislioglua and Agar [10] evaluated the use of plastic waste as an asphalt binder modifier with 4, 6 and 8% by weight of optimum binder content. Lab test results showed that mixes with 4% plastic waste yielded the highest Marshall stability and the smallest flow, and mix was also highly resistant to permanent deformation (rutting). Al-Humeidawi [11] evaluated the use of plastic waste to enhance the engineering properties of asphalt mixes. Results showed that Plastic Waste Modified Bitumen (WPMB) mix yielded higher Marshall Stability, higher retained stability, and higher indirect tensile strength than a conventional mix with an increase of 10% in Marshall Stability, 7% in Marshall retained stability and 9% in indirect tensile strength. Attaelmanan *et al*. [12] studied the viability of modifying asphalt binder by adding different ratios of plastic waste. Results illustrated that the penetration values and the temperature susceptibility decreased and the softening point increased with the increase of plastic waste content. In addition, modified asphalt mixes performed better than conventional mixes when it came to stability, tensile strength ratios (TSRs), and resilient modulus values at high temperatures with smaller strain values. Modarres and Hamedi [4] investigated the effects of adding plastic to asphalt mixes by adding plastic by 2-10% of asphalt binder weight directly as the method of dry process. They conducted resilient modulus and fatigue tests on these mixes and found that stiffness of asphalt mixes increased when adding lower amount of plastic and fatigue resistance improved for these mixes.

Other studies evaluated the use of plastic waste as a partial replacement of aggregates. Mustafa *et al.* [13] used waste rubber and plastic to replace aggregates sizes of 4.75mm, 0.85mm, and 0.075mm aggregates sizes with a 5%, 10%, and 20% of the total aggregates weight in the mix to improve the Marshall Stability and moisture susceptibility of asphalt mixes. Hassani *et al.* [14] used plastic waste in asphalt concrete mixes as aggregates replacement of 3mm and concluded that the optimum value of plastic waste was 6.6% of total volume. Rajasekaran *et al.* [15] argued that any source of plastic wastes could be incorporated in the production of asphalt mixes. They stated that plastic waste would not produce

ARPN Journal of Engineering and Applied Sciences

any toxic gases during heating; it had a tendency to form a film covering aggregates if sprayed over the hot aggregate at 160˚C. Furthermore, they concluded that Plastics Coated Aggregates (PCA) was a better raw material for the construction of flexible pavement. Their results showed that mixes with PCA had higher Marshall Stability and 100% increase in load bearing capacity of flexible pavements. Shiva Prasad *et al*. [16] investigated the addition of shredded plastic waste bottles to asphalt mixes by evaluating various mix properties; Marshall Stability, flow, bulk density, air voids, and voids filled with binder. They concluded that adding 8% plastic waste to coat aggregates led to the highest Marshall stability. Moghaddam *et al*. [17] evaluated the effects of adding crushed plastic bottles on flexible pavements. Results showed that Marshall Stability and flow values and fatigue resistance of tested mixes increased with the increase of waste crushed plastic bottle content. However, adding higher amounts of plastic resulted in lower specific gravity and mix stiffness. Angelone *et al.* [1] investigated the influence of adding plastic waste in a dry process on asphalt mixes. Tests included Marshall Stability, Marshall Quotient, indirect tensile strength, fracture energy, resilient modulus, permanent deformation and creep compliance. They argued that the addition of recycled plastics would improve the physical and mechanical characteristics of asphalt mixes. Thus, making it a sustainable solution and a viable alternative that contributes to the reduction of plastic wastes as well as the protection of the environment.

Objectives

The main objective of his study was to analytically evaluate the performance of hot asphalt mix with added plastic waste using mechanistic approach by:

- Investigating the effects of adding plastic waste bottle particles to hot mix asphalt mix on the performance of flexible pavement, and
- Determine the optimum percent of plastic waste bottle particles to be added to the hot asphalt mix without undermining the performance of flexible pavements.

Experimental program

Materials

Two Superpave mixes were used in the analysis; two different aggregate structures (Figure 1); Mix 1 and Mix 2. Details of these mixes are shown in Table 1. PET bottles were shredded and grinned and added during mixing. Three different percentages of plastic waste particles were investigated: 0.2%, 0.5%, and 1% by weight of aggregate particles. In addition, a control mix with 0% plastic waste particles was prepared to compare results. Initially, it was planned to evaluate a mix with 5% plastic waste particles, as well. However, it was dropped from the study due to problems with mixing and compacting such mix.

Table-1. Properties of hot asphalt mixes.

Mix ID	Mix 1	Mix 2
Binder Grade	PG 70-28	PG 64-34
Maximum Mix Specific Gravity, G_{mm}	2.449	2.393
Binder Content	4.9%	4.35%
Binder Specific Gravity, G_b	1.021	1.024
Aggregate Effective Specific Gravity, G_{se}	2.639	2.568

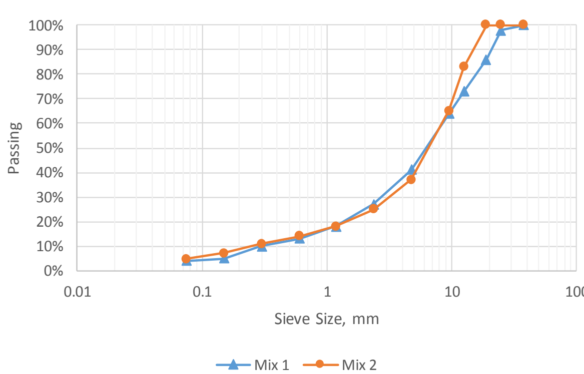


Figure-1. Aggregates gradations for Mix 1 and Mix 2.

Lab Tests

Dynamic Modulus (|E*|) Test

Dynamic Modulus (|E*|) test (AASHTO TP 62-03 [18]) was conducted to determine stiffness of mixes at different temperatures and frequencies; 4.4, 21.1, 37.8 and 54.4 °C and loading frequencies of 0.1, 1, 5, and 10 Hz at each temperature. Samples were compacted to achieve 175mm high and a total 9% air voids specimens via Superpave Gyratory Compactor. Then cored and sawed to obtain samples with 100mm diameter, 150mm high and 7% air voids.

Binder Dynamic Shear Modulus (|G*|) Test

Dynamic Shear Rheometer Test (AASHTO T315-06 [19]) was conducted to determine the Binder

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Dynamic Shear Modulus (|G*|) for both mixes (PG 70-28 and PG 64-34). Tested binders were aged using Rolling Thin Film Oven (RTFO) to simulate the mix aging during mixing and compaction. Tests were conducted under a constant stress of 5000 Pa at temperatures of 21.1 °C.

METHODOLOGY

3D Move Analysis software [20] was utilized in this analysis. The software was developed by the Asphalt Research Consortium and is available at http://www.arc.unr.edu/Index.html. A continuum-based finite-layer method is utilized by the software. Thus, the software can apply different moving traffic load, traffic velocity, axle configurations, and tire contact area to a pavement structure with different material properties. In addition, 3D Move Analysis Software allows inputting the frequency sweep test data (|E*| and |G*| test data) of asphalt mixes in the analysis. It can take into account the viscoelastic materials properties in the analysis. Thus, making it ideal to model asphalt concrete (AC) layer's reactions to traffic loads and its response as a function of vehicle velocity [20, 21]. Furthermore, 3D Move Analysis utilized stresses and strains due to loading to predict rutting depths and top down and bottom up cracks due to loading based on NCHRP 1-37A models. Earlier studies [21-26] demonstrated that 3D Move Analysis software could capture asphalt mixes performance.

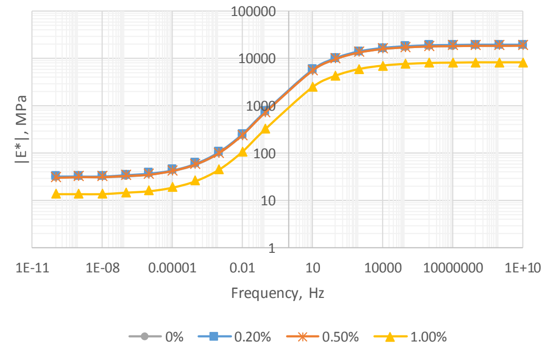
A typical 3-layer flexible pavement structure was used in the analysis, consisting of 15cm AC layer, 30cm untreated base, and subgrade. The design load was a standard dual axle load with 3 million repetitions during the design period of 20 years. Analysis was conducted by changing the AC layer materials properties based on the percentage of plastic. To capture the effects of plastic on flexible pavement performance, simulations were conducted at different temperatures: 4.4, 21.1, and 37.8 °C. Analysis temperatures were chosen to match |E*| test temperatures, however, at 54.4 °C simulations did not converge and no solution was obtained.

RESULTS AND ANALYSIS

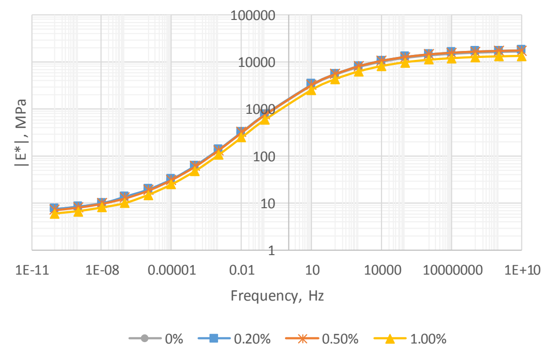
Upon running 3D Move Analysis for the two asphalt mixes with different percentages of plastic, rutting depth and top down and bottom up cracking were determined for each mix. In the following subsections, the effects adding different percentages of plastic to asphalt mixes are discussed.

Dynamic Modulus (|E*|)

As illustrated in Figure-2, Master curves for the evaluated mixes were constructed by 3D Move Analysis software. It is clearly shown that the Master curves for mixes with 0.2% and 0.5% plastic waste were similar to control mixes' Master curves, whereas the Master curves for mixes with 1.0% plastic waste were shifted downward. Thus, adding higher percentages of plastic (i.e., 1.0%) to asphalt mixes decreased the stiffness, which would have a huge effect on the performance of these mixes.



a) Mix 1

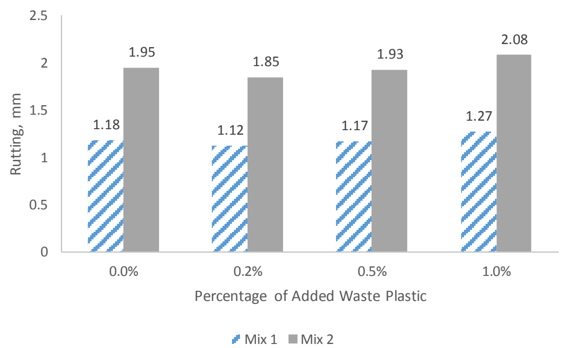


b) Mix 2

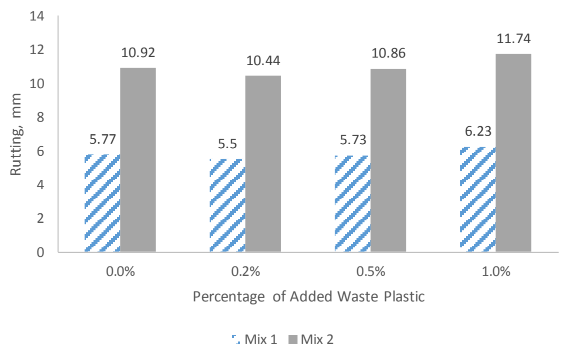
Figure-2. Master curves for asphalt mixes.

Rutting of asphalt concrete layer

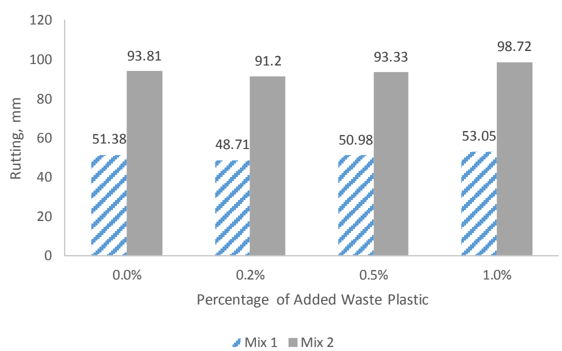
Rutting depths of asphalt concrete layer were determined for Mix 1 and Mix 2 with different percentages of plastic at the three temperatures; 4.4, 21.1, and 37.8 ºC. Results showed that mixes with 0.2% plastic waste exhibited the least rutting, while mixes with 0.5% plastic waste performed similarly to the control mixes. However, mixes with 1% plastic waste performed poorly with the highest rutting values for Mix 1 and Mix 2, as shown in Figure-3. Furthermore, results showed a huge jump in rutting values (around 10 times) between when 21.1 and 37.8 ºC temperatures were used in the analysis for both mixes. Finally, it is clearly shown that Mix 1 would perform better than Mix 2 in rutting, which was expected, since it had bigger aggregates structure and higher PG grade (PG 70-28).



a) at 4.4 ºC



b) at 21.1 ºC



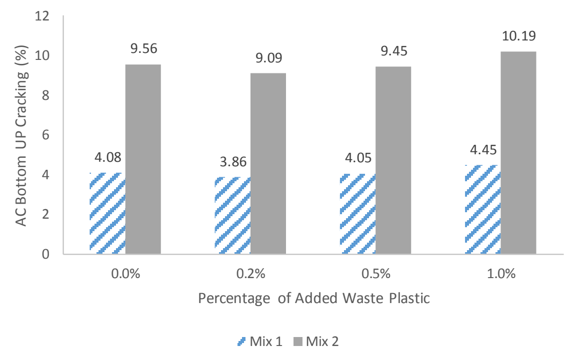
c) at 37.8 ºC

Figure-3. Rutting results of evaluated asphalt mixes at different temperatures.

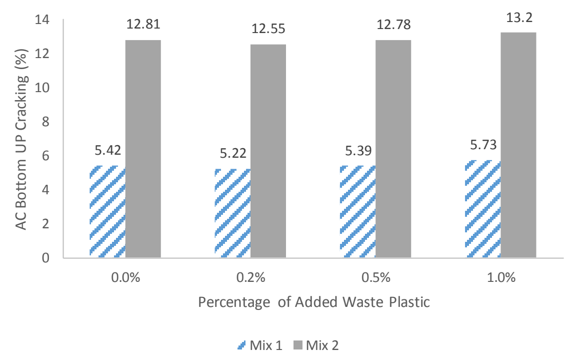
Cracking of asphalt concrete layer

Bottom up and Top down cracks in asphalt concrete layer were determined, as shown in Figure 4 and 5. Results for Bottom-up and Top-down cracking followed the same trend, at which mixes with 0.2% plastic waste had the best performance at different temperatures except for Mix 1 at 21.1 and 37.8 ºC (Figure 5-b and 5-c), at which analysis showed that an HMA with 0.2% plastic waste yielded the highest Top-down cracking. Furthermore, Bottom-up and Top-down cracking results of the control mixes and mixes with 0.5% plastic waste was almost the same. Similar to rutting, mixes with 1.0% plastic waste exhibited the highest values of Bottom-up and Top-down cracking.

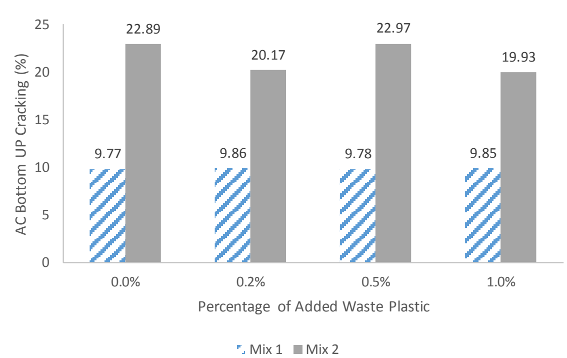
Overall results of the analysis showed that mixes could be ranked based on the performance and predicted distresses in the following order; mixes with 0.2% plastic waste in first place, then Mixes with 0.5% and 0%, finally Mixes with 1%. Thus, making 0.2% plastic waste the optimum plastic content. Since it increased the resistance of HMA to pavement distresses. However, if 0.5% is used the performance of these mixes is similar to the control (0%), which means using more plastic waste and less aggregates, making the design eco-friendlier with without undermining the performance of these mixes.



a) at 4.4 ºC



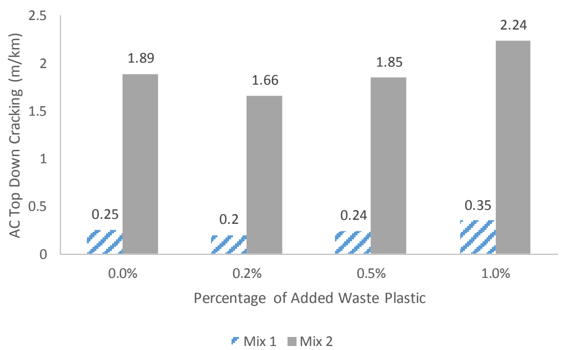
b) at 21.1 ºC



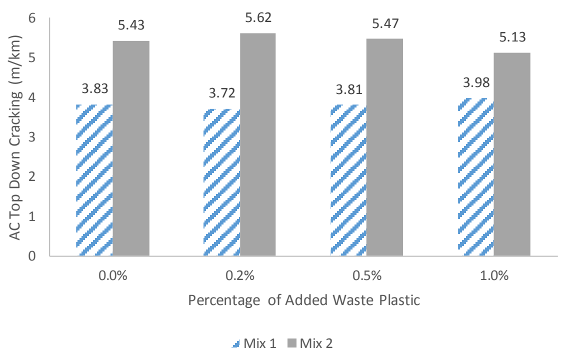
c) at 37.8 ºC

Figure-4. Bottom-up cracking results of evaluated asphalt mixes at different temperatures.

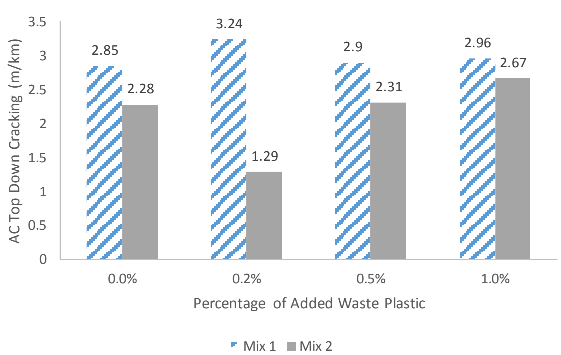
ARPN Journal of Engineering and Applied Sciences



a) at 4.4 ºC



b) at 21.1 ºC



c) at 37.8 ºC

Figure-5. Top-up cracking results of evaluated asphalt mixes at different temperatures.

CONCLUSIONS

Based on the results presented, the following observations are made:

a) Adding plastic waste to hot mix asphalt in low percentages increased their stiffness measured by the Dynamic Elastic Modulus |E*| Test. Master curves developed from the test data showed that asphalt mixes with 0.2% and 0.5% plastic waste were similar to control mixes' Master curves. However, Master curves for mixes with 1.0% plastic waste were shifted downward (lower stiffness).

b) Asphalt mixes with 0.2% plastic waste had the best performance when it came to rutting depths, top-down cracking, and bottom-up cracking for Mix 1 and Mix 2 at different temperatures.

c) Results showed that mixes with 0.5% plastic waste exhibited almost the same rutting depths, top-down cracking, and bottom-up cracking as the control mixes at different temperatures.

d) Asphalt mixes with 1% plastic waste performed poorly with the highest rutting depths, top-down cracking, and bottom-up cracking rutting values for Mix 1 and Mix 2.

e) With different plastic waste content, Mix 1 would perform better than Mix 2 with regard to all distresses at different temperatures due the bigger aggregates structure and higher upper binder grade.

In conclusion, using 0.2% plastic waste of aggregates weight in hot mix asphalt would enhance the performance of asphalt pavements. However, adding 0.5% plastic waste would assist in reducing the amount of plastic waste without hindering the performance of asphalt pavements. Thus, achieving an eco-friendly and sustainable flexible pavement designs.

ACKNOWLEDGEMENT

The author would like to extend his gratitude to School of Graduate Studies and Research at the American University of Ras Al Khaimah, UAE for the provided support (Seed Grant Project ENGR/001/17).

REFERENCES

[1] Angelone S, Cauhape Casaux M and Martinez FO. 2016. Green Pavements: Reuse of Plastic Waste in Asphalt Mixtures. Materials and Structures. 49(5): 1655-1665.

[2] Abu Abdo AM. 2016. Utilizing Reclaimed Asphalt Pavement (RAP) Materials in New Pavements - A Review. International Journal of Thermal & Environmental Engineering. 12(1): 61-66.

[3] Molenaar A. 2012. Durability, A Prerequisite for Sustainable Pavements, 5th Eurasphalt & Eurobitume Congress, Istanbul, Turkey.

[4] Modarres A and Hamedi H. 2014. Effect of Plastic Waste Bottles on the Stiffness and Fatigue Properties of Modified Asphalt Mixes. Materials and Design. 61: 8-15.

[5] Siddiqui MN. 2009. Conversion of Hazardous Plastic Wastes into Useful Chemical Products. Journal of Hazardous Materials. 167(1-3): 728-735.

[6] Chavan MAJ. 2013. Use of Plastic Waste in Flexible Pavements. International Journal of Application or Innovation in Engineering and Management. 2(4): 540-552.

[7] Gawande A, Zamare G, Renge VC, Tayde S and Bharsakale G. 2012. An Overview on Plastic Waste Utilization in Asphalting of Roads. Journal of Engineering Research and Studies. 3(2): 1-5.

[8] Sangita GR and Verinder K. 2011. A Novel Approach to Improve Road Quality by Utilizing Plastic Waste in Road Construction. Journal of Environmental Research and Development. 5(4): 1036-1042.

[9] Swami V and Jirge A. 2012. Use of Plastic waste in Construction of Bituminous Road. International Journal of Engineering Science and Technology. 4(5): 2351-2355.

[10] Hinislioglua S and Agar E. 2014. Use of Waste High Density Polyethylene as Bitumen Modifier in Asphalt Concrete Mix. Materials Letter. 58:267-271.

[11] Al-Humeidawi BH. 2014. Utilization of Plastic waste and Recycle Concrete Aggregate in Production of Hot Mix Asphalt, Al-Qadisiya Journal for Engineering Sciences. 7(4): 322-330.

[12] Attaelmanan M, Feng CP and Al-Haididy AI. 2011. Laboratory Evaluation of HMA with High Density Polyethylene as a Modifier. Construction and Building Materials. 25(5): 2764-2770.

[13] Mustafa T, Ahmed T and Altan C. 2003. The Use of Waste Materials in Asphalt Mixtures. Journal of Waste Management and Research. 21(2): 83-92.

[14] Hassani A, Ganjidoust H, and Amir AM. 2007. Use of Plastic Waste (Poly-ethylene terephthalate) in Asphalt Concrete mix as Aggregate Replacement. Journal Waste Management and Research. 23(4): 322-327.

[15] Rajasekaran S, Vasudevan R and Paulraj S. 2013. Reuse of Plastic Wastes Coated Aggregates-Bitumen Mix Composite for Road Application - Green Method. American Journal of Engineering Research (AJER). 2(11): 01-13.

[16] Prasad KS, Manjunath KR, and Prasad KVR. 2012. Study on Marshall Stability Properties of BC Mix Used in Road Construction by Adding Plastic Waste Bottles. IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE). 2(2): 12-23.

[17] Moghaddam TB, Karim MR and Soltani M. 2013. Utilization of Plastic Waste Bottles in Asphalt Mixtures. Journal of Engineering Science and Technology. 8(3): 264-271.

[18] AASHTO. 2004. Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures. American Association of State Highway and Transportation Officials, AASHTO TP 62-03.

[19] AASHTO. 2006. Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR). American Association of State Highway and Transportation Officials. AASHTO T315-06.

[20] ARC. 2013. Report J: Pavement Response Model to Dynamic Loads 3D Move. Quarterly Technical Progress Report. Asphalt Research Consortium, USA.

[21] Abu Abdo A and Jung SJ. 2016. Effects of Asphalt Mix Design Properties on Pavement Performance: A Mechanistic Approach. Advances in Civil Engineering. Article No. 9354058: 1-8.

[22] Souliman MI and Eifert A. 2016. Mechanistic and Economical Characteristics of Asphalt Rubber Mixtures, Advances in Civil Engineering. Article No. 8647801: 1-6.

[23] Priest AL, Timm DH and Barrett W. E. 2005. Mechanistic Comparison of Wide-Base Single Vs. Standard Dual Tire Configurations. NCAT Report 05-03, NCAT, Albama, USA.

[24] Siddharthan RV, Yao J, and Sebaaly PE. 1998. Pavement Strain from Moving Dynamic 3-D Load Distribution. Journal of Transportation Engineering, ASCE. 124(6): 557-566.

[25] Siddharthan RV, Krishnamenon N, and Sebaaly PE. 2000. Pavement Response Evaluation using Finite-Layer Approach. Transportation Research Record. 1709: 43-49.

[26] Siddharthan RV, Krishnamenon N, El-Mously M, and Sebaaly PE. 2002. Investigation of Tire Contact Stress Distributions on Pavement Response. Journal of Transportation Engineering, ASCE. 128(2): 136-144.