Research Article

Using of Plastic Wastes as Additives in Bituminous Mixes

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DOI: 10.14416/j.asep.2020.11.003
Received: 15 July 2020; Revised: 8 August 2020; Accepted: 21 September 2020; Published online: 5 November 2020

Abstract

Plastic wastes are everywhere in today's lifestyle and are growing rapidly specially in a developing country like Egypt. As these are non-biodegradable, there is a main issue facing the community concerning the handling of this plastic rubbish. On the other hand, different forms of increased distresses in flexible pavements such as cracking and rutting as well as moisture damage ratio should be faced and reduced by modifying the performance of hot asphalt mixtures. The reclaimed plastics that originally made of polymers have been used as an anti-stripping modifier to reduce the appearance of distresses in asphalt pavement surface and increase the resistance against moisture damage. In this research, the recycled plastic wastes have been used according to dry mixing process using contents (0.0, 2.0, 3.0, 4.0 and 5%) from the total weight of hot asphalt mixture. The optimal bitumen content has been derived for each polymer content by using Marshall procedure. The performance of modified bitumen mixtures have been recognized using Marshall quotient (as indicator of the stiffness), static indirect tensile strength and tensile strength ratio (as indicator of moisture damage resistance), dynamic modulus value (as indicator of stiffness of the asphalt mixture when tested in a compressive and repeated load test under different temperatures) and flow number (as indicator of permanent axial deformation resistance). The results obtained that the addendum of plastic rubbish to HMA improves its characteristics such as stability, strength, resistance to moisture damage and permanent deformation. The addition ratio of 3% polymer provides better pavement performance. Moreover, it has an economic importance where it reduces the exhaustion of natural asphalt in paving works by about 14.5%.

Keywords: Plastic Wastes, Additives, Bituminous Mixes, Dynamic Modulus, Flow Number

1 Introduction

Nowadays, the steady increment in high traffic intensity and the significant variation in daily and seasonal temperature in Egypt put us in a situation to think about some alternative ways to improve the pavement characteristics and quality by applying some necessary modifications that shall satisfy strength aspects [1]. Flexible pavements, if designed and executed properly, provide quite satisfactorily performance under various situations while traffic increases daily. Considering that, laboratory tests have been done to use additives and modifiers in asphalt mixtures. From these investigated modifiers, using polymers in bituminous mixtures has developed the performance of bituminous mixes significantly [2], [3].

Highway organizations have known the advantages of utilizing modifiers in asphalt in rasing life of service

Please cite this article as: A. E. A. El-Maaty, I. R. I. Sourour, and W. A. E. S. Bekheet, "Using of plastic wastes as additives in bituminous mixes," *Applied Science and Engineering Progress*, vol. 14, no. 1, pp. 131–141, Jan.–Mar. 2021, doi: 10.14416/j.asep.2020.11.003.

with reduction in amount and intensity of pavement deteriorations. Rutting resistance is considered as one of the essential benefits of using these modified asphalts. Moreover, cracking resistance and durability are subaltern advantages. Many modifiers in asphalt binder help in resisting pavement stripping (moisture damage) effectively. Some highway organizations illustrate that the pavement life can be increased by about 4–6 years if constructed utilizing a modification process for asphalt [4], [5].

Garbage is rich of plastic materials; these materials are basically based on polymers. The availability of plastic rubbish is enormous and constantly increasing in our daily life. Plastic wastes are considered durable and non-biodegradable materials. The improper disposal of plastic by may emit toxic chemicals causing environment pollution. Also, incineration or landfilling may not be the optimum solution to get rid of these materials. Thus, using of these plastic mixed polymers in construction is always welcomed [6], [7].

According to some studies in the recent period, the world plastic production is almost reached 350 million tons in 2017. In comparison with 2016 the production increased from 335 to 350 million tons with approximate growth factor equals 4.4%. Plastic wastes are considered as a main source for pollution [8]. At 2018, China takes the highest portion (28%) of mismanaged plastic rubbish of the universal total, followed by Indonesia (10%), Philippines and Vietnam (6%), Thailand (3.2 %), Egypt (3%), Nigeria (2.7%) and South Africa (2%) [9].

The chemical compositions of the most plastics wastes are consisting of polypropylene (PP), low density polyethylene (LDPE) and high-density polyethylene (HDPE). These three types form the majority of the total composition. There are other plastic types such as polyethylene terephthalate (PETE), Polyvinyl Chloride (PVC) and Polystyrene (PS). There are some types of plastics are difficult to be recycled such as polycarbonate (PC), polylactic acid or polylactide (PLA), acrylonitrile butadiene styrene (ABS), polyamide (PA) [10].

Egypt produces annually about 80 million tons of waste as reported in March 2018 [11]. El-Refaie Kenawy [12] mentioned in his report that, Egypt produces annually about 16.2 millions tons of plastic Wastes. About 65% of theses plastic Wastes are not collected, and burned in ways that could be done incorrect which causes pollution to the surrounding environment. Thus, the environment in Egypt and similar developing countries face a real problem.

To use wastes of plastic in bituminous pavement, two main methods are used, wet method and dry method. Wet method, concerns with applying modification on the pure bitumen by melting the plastic wastes and mixing them with asphalt, the mix shall be utilized in producing the hot asphalt mixtures. In other words, the dealing with plastic wastes according to wet process is exactly like bitumen. The researches about the wet process display an increase in softening point, Marshall stability and anti-stripping properties, while they show a decrease in penetration and ductility values. Wet process has disadvantages such as needing a high power stirrer with thermostatic facilities to maintain the temperature between 160–1800°C, and needing to be stored in a freezer. Another strategy has been achieved for utilizing higher content of plastic junk in the asphalt pavement called dry process. In this method, the plastic wastes are melted and mixed with the aggregate as a percentage of the total mix weight exactly like bitumen or filler, the aggregate covered with plastic is used as the virgin material to produce hot asphalt mixtures [13], [14]. The dry method has been used in the current research due to some limitations of wet method in producing or storing polymer modified mix.

Silva *et al*. [15] studied the effect of combining polyethylene from silo bags in dry mix method to asphalt mixtures. It was illustrated that the mixtures of 2% SBF (silo bag flakiness) and SBP (silo bag pellets) had better performance than the control mixtures. Dalen *et al*. [16] recommended to replace up to 30% of bitumen content by LDPE (low density polyethylene) and PET (polyethylene terephthalate) plastic wastes, LDPE and PET incorporation of 15% by weight of binder content gave better result than that of the 30% by weight LDPE and PET wastes incorporation in terms of the Marshall stability, flow, and voids. The results indicated that, the cost of road construction reduced by about 15% of bitumen cost.

Bindu *et al*. [17] concluded that the using 10% plastic wastes by bitumen weight provided better performance of HMA. With 10% plastic content, stability was increased by about 64%, tensile as well as compressive strengths were increased by about 18 and 75% respectively compared to the control mix.

Mohamed *et al*. [18] concluded that the values of ductility and penetration for mixtures modified with low density polyethylene (LDPE) decreased with increasing content of polymer additive up to 12% by weight. Moreover, the modified asphalt softening point increased with the addition of plastic additive up to 8%. Using of 8% polymers content regards as the optimum percent of polymer that gave maximum stability.

In asphalt pavement building, bitumen makes the aggregate hold together by covering its surface and helps the pavement strength to get better. However, its resistance to water is not good. Anti-stripping agents are being utilized. A popular way to improve the goodness of bitumen is by adjusting the rheological characteristics of bitumen by mixing with synthetic polymers like rubber and plastics. Researches on this issue are going on both at local and global level [13], [19].

The main objectives of this research are evaluating the effect of waste plastic addition using dry process on the performance of hot asphalt mixtures, determining the optimal asphalt ratio with respect to different plastic waste content to estimate the savings in raw bitumen consumption as a result of adding plastic waste, estimating the effect of plastic wastes adding as an anti-stripping agent on moisture damage resisting of asphalt mixtures and moreover highlighting a friendly-environment way to get rid of the daily large amount of plastic wastes generated in Egypt.

2 Experimental Work

2.1 *Materials*

2.1.1 Aggregates

Gradation of aggregates according to the Egyptian code for urban and rural highway works [20] is as illustrated in Table 1. Table 2 shows the aggregates properties.

2.1.2 Bitumen

The Suez bitumen 60–70, one of conventional commonly bitumen in Egypt, was used to prepare the samples. Conventional tests were performed to determine the properties of this type. Table 3 illustrates the natural properties of bitumen used in this study. The limit standards are shown according to Egyptian the code for urban and rural highway works [20].

Table 1: Coarse and fine aggregate gradation based on Egyptian standards

Aggregate	Sieve No.	Min Passing (%) [20]	Max Passing (%) [20]	Proposal Gradation (%)
Coarse Aggregates	1"	100	100	100
	3/4"	75	100	95
	3/8"	45	70	67
	No. 4	30	50	42
Fine Aggregates	No. 8	30	35	33
	No. 30	5	20	19
	No. 50	3	12	10
	No. 100	2	8	5
	No. 200	0	4	0

Table 2: Aggregates physical properties based on Egyptian standards

Test	Results	Limits [20]
Los Angeles (%)	21.8	< 40
Water absorption (%)	0.98	< 5
Swelling (%)	0	< 3
Coarse aggregates specific gravity	2.64	---
Fine aggregates specific gravity	2.57	---
Elongation (%)	0.68	< 10
CBR (%)	100 +	> 80

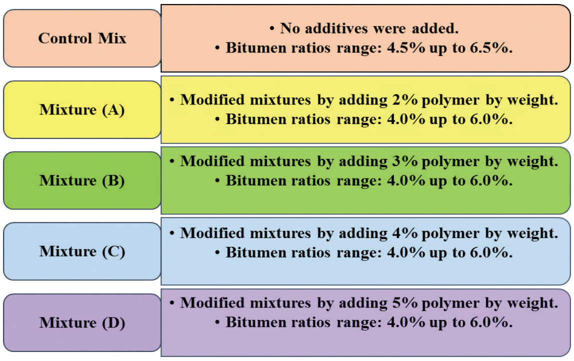
Table 3: Natural properties of bitumen based on Egyptian standards

Test	Results	Limits [20]
Penetration at 25°C (mm)	63.7	60–70
Softening Point (°C)	51.0	49–56
Specific Gravity	1.03	1.01–1.06

2.1.3 Plastic wastes (polymers)

Plastic wastes were collected from the common daily used items. Wastes were washed and cleaned by hot pressured water for 3–5 min to remove any dust attached to the surface, it was then dried. The dried plastic wastes were shredded, heated at 220°C to achieve a liquid consistency to be mixed with other ingredients. Figure 1 shows a sample of these plastic wastes during preparation, shredding and heating. The plastic waste specific gravity was calculated from three samples where obtained as 0.919.

Figure 1: A sample of plastic wastes after collecting and shredding (right picture) and during heating and mixing (lift picture).



Control Mix	**• No additives were added. • Bitumen ratios range: 4.5% up to 6.5%.**
Mixture (A)	**• Modified mixtures by adding 2% polymer by weight. • Bitumen ratios range: 4.0% up to 6.0%.**
Mixture (B)	**• Modified mixtures by adding 3% polymer by weight. • Bitumen ratios range: 4.0% up to 6.0%.**
Mixture (C)	**• Modified mixtures by adding 4% polymer by weight. • Bitumen ratios range: 4.0% up to 6.0%.**
Mixture (D)	**• Modified mixtures by adding 5% polymer by weight. • Bitumen ratios range: 4.0% up to 6.0%.**

Figure 2: Different mixtures contents in this study.

2.2 *Bitumen mixtures design*

Marshall test was executed according to ASTM D6926 [21]. Polymer modified mixtures as well as control sample were prepared and tested. Polymer modified mixes were prepared with contents starting from 2% up to 5%. Figure 2 shows the different mixtures contents in this study.

2.3 *Experimental tests*

Otherwise Marshall test, experimental parameters were obtained as indicators of HMA performance such as indirect tensile strength (ITS), tensile strength ratio (TSR), dynamic modulus and flow number. Three samples were producted and tested for each mix design for the following tests.

2.3.1 Indirect tensile strength test

The mixtures for indirect tensile strength (ITS) test were performed based on ASTM D 6931 [22], the ITS value (KPa) was calculated as follows:

$$ITS = \frac{2000 \times P}{\pi \times T \times D}$$

Where P is maximum load, (N), T is sample height (mm) and D is sample diameter (mm).

2.3.2 Moisture damage test

Moisture damage test may be utilized to expect the stripping sensibility of the asphalt mixture. This test measures the change of tensile strength due to the effects of water conditioning. The moisture damage test was executed according to AASHTO T283 [23]. The tensile strength ratio (TSR) was calculated as (ITS_2/ITS_1), where ITS_1 is average tensile strength of the unconditioned mixtures, and ITS_2 is average tensile strength of the saturated mixtures.

2.3.3 Dynamic modulus test

Dynamic modulus test usedtypically measures the behavior of the asphaltic pavement under loads at a range of controlled temperatures. In this test, a specimen at a specific temperature was subjected to a controlled compressive stress of various frequencies. The applied stresses and resulting axial strains were measured as a function of the time and utilized to estimate the dynamic modulus (E*) and phase angle. The dynamic modulus (the modulus of a visco-elastic material) is a performance-related property that can be used for characterizing the stiffness of asphalt mixtures for mechanistic-empirical pavement design. Samples for this test were prepared according to AASHTO TP-62 [24] using the universal testing machine (UTM).

2.3.4 Flow number test

The flow number is a property related to the resistance of asphalt mixtures to permanent deformation. It may be utilized to evaluate and design asphalt mixtures with specific resistance to permanent deformation. Flow number is the number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated-load test using the universal testing machine (UTM). The flow number is known as the number of load cycles corresponding to the minimum rate of change of permanent axial strain. The samples tested for flow number were the same

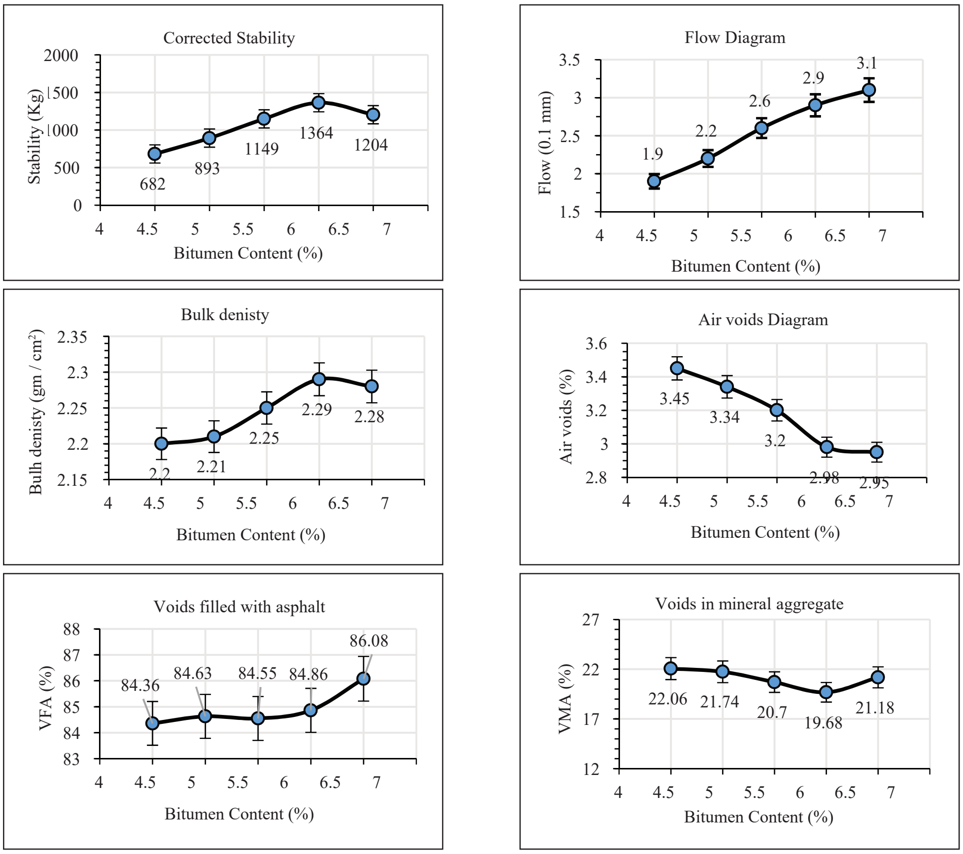


Figure 3: Marshall test results for control mixture based on replicating three times for each bitumen content.

tested for dynamic modulus test, as dynamic modulus test in non-destructive test. The parameters of this test are shown in Table 4.

Table 4: Flow number test parameters applied to asphalt mixtures

Test	Value
Test temperature	54.4°C
Repeated axial stress	600 kPa
Contact stress	30 kPa
Confining stress	0 kPa (unconfined)
Termination condition	20000 cycle or 100000 micro strain

3 Results and Discussion

3.1 *Marshall test results*

The optimal content of bitumen (OBC) was determined according to Marshall test for control mix as well as polymer modified mixes (A, B, C and D). Figure 3 shows the Marshall test results for control mixture after replicating three times for each bitumen content. Table 5 provides the optimal asphalt ratio where it decrease by about (9.5, 14.5, 14.5 and 23%) with increasing polymer ratios to 2, 3, 4 and 5% respectively compared with control mix. Thus, it can be said that the recycling of plastic rubbish in asphalt mixtures has an economic importance where it reduces the consumption of raw asphalt in paving works by about 9.5 and 14.5% at adding plastic wastes of 2 and 3% respectively. Moreover, Table 5 illustrates the stability, flow, density, air voids at OBC for each mixture. The Marshall Quotient (MQ) is an indicator of the stiffness of HMA. It is well- known that the MQ is used to estimate the resistance of HMA to the shear stresses, permanent deformation, and rutting subsequently.

Mixture of higher MQ means that it has higher stiffness and higher resistance to creep deformation.

Table 5: Summary of Marshall test results (stability, flow, density, air voids and Marshall quotient MQ)

Marshall Parameters Results	Different Bitumen Mixtures Investigated in This Research				
	Control Mix 0.0% Polymer	Mixture (A) 2% Polymer	Mixture (B) 3% Polymer	Mixture (C) 4% Polymer	Mixture (D) 5% Polymer
Optimum Bitumen Content OBC (%)	5.84	5.3	5.0	5.0	4.5
Stability @ OBC (kg)	1310	1344	2392	1953	1272
Flow @ OBC (mm)	2.8	3.82	4.23	4.53	5.37
Density @ OBC (km/cm^3)	2.27	2.25	2.23	2.22	2.13
Air Voids @ OBC (%)	3.05	2.23	2.49	2.35	2.31
MQ @ OBC (Kg/mm)	467	476	565	431	236

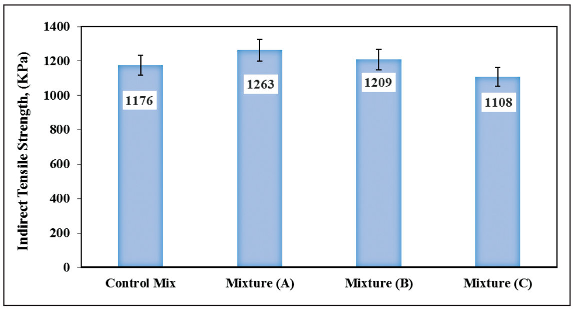


Figure 4: Indirect tensile strength results.

MQ value can be calculated as (Marshall stability/ Marshall flow). As shown in Table 5, the maximum MQ value achieves at 3% polymer additive (mixture B). With increasing polymer contents at mixtures (C) that contains 4% plastic wastes, the Marshall quotient decreases compared with control mix by about 7.7%. For mixture (D) that contains 5% plastic wastes, Marshall quotient suddenly and dramatically decreases by about 50% compared with control mix, thus it may be eliminated in the next tests because it doesn't provide any improvements in HMA stiffness.

3.2 *Indirect tensile strength test results*

Figure 4 shows the indirect tensile strength (ITS) values where the polymer-modified mixtures (A and B) of 2 and 3% plastic wastes respectively provide an improvement in ITS reached to 7.5 and 2.8% respectively compared with the control mix. Using 4% plastic wastes (mixture C) results in a quite loss in tensile strength reached to 5.8% compared with the control mix.

3.3 *Moisture damage results*

After conditioning for control mixture as well as polymer modified mixture, the ITS test was performed again and the tensile strength ratio (TSR) was calculated. As shown in Table 6 that illustrates the TSR values, the polymer modified mixtures for all studied ratios provide higher TSR compared with control mix. This clarifies the important impact of plastic waters addition as anti- stripping agent on moisture damage resistance of hot asphalt mixtures. The maximum TSR is obtained at mixture (A) of 2% polymer additive.

Table 6: Tensile strength ratio (TSR) for control and polymer modified asphalt mixtures

Mixture	Control Mix	Mixture (A)	Mixture (B)	Mixture (C)
TSR	0.209	0.360	0.247	0.238

3.4 *Dynamic modulus test results*

The dynamic modulus E* is the main input material property of asphalt mixtures for modern mechanistic empirical flexible pavements design methods. It determines the distribution of stress and strains in the pavement structure. Moreover, it can be correlated with the fatigue and rutting cracking behaviour of the bituminous layers [25]. Table 7 lists the dynamic modulus values at frequencies of 0.1, 0.5, 1.0, 10 and 25. Hz passing over four temperatures (4.4, 21.1, 37.8 and 54.4°C). As shown in Table 7, at low temperature (4.4°C), the dynamic modulus almost the same in the four mixtures, this may be due to almost zero viscous effect at low temperatures. While at high temperature (54.4°C), the modified mixtures obtain better performance compared with the control mix especially at using 4% plastic waste (mixture C). At moderate temperatures (21.1 and 37.8°C), it can be noticed that, the mixture containing 3% plastic waste (mixture B) achieves higher dynamic modulus values compared with control mixture at all frequencies.

Table 7: Dynamic modulus results at different temperatures and frequencies

Dynamic Modulus E* at (4.4)°C, MPa						
Plastic Waste Content	**Frequency, Hz**					
	25	**10**	**5**	**1**	**0.5**	**0.1**
Control Mix	11358	10246	9381	7394	6552	4743
Mixture (A)	10952	9943	9187	7243	6492	4801
Mixture (B)	11267	10049	9343	7773	7098	5587
Mixture (C)	10730	9837	9043	7257	6516	4859
Dynamic Modulus E* at (21.1)°C, MPa						
Plastic Waste Content	**Frequency, Hz**					
	25	**10**	**5**	**1**	**0.5**	**0.1**
Control Mix	5415	4383	3658	2246	1784	978.3
Mixture (A)	4925	4116	3574	2153	1706	952
Mixture (B)	5959	5086	4402	2994	2488	1533
Mixture (C)	4752	3959	3329	2046	1645	901.1
Dynamic Modulus E* at (37.8)°C, MPa						
Plastic Waste Content	**Frequency, Hz**					
	25	**10**	**5**	**1**	**0.5**	**0.1**
Control Mix	1577	1124	839.8	412.8	309.6	161.8
Mixture (A)	1507	1196	877	419	316	169
Mixture (B)	2306	1781	1436	866.3	715.5	469.3
Mixture (C)	1386	1042	787.6	399.6	307.5	171.6
Dynamic Modulus E* at (54.4)°C, MPa						
Plastic Waste Content	**Frequency, Hz**					
	25	**10**	**5**	**1**	**0.5**	**0.1**
Control Mix	354.1	260.2	194.1	120.3	107.2	82.4
Mixture (A)	539	448	392	252	204	179
Mixture (B)	797.6	616.4	502.9	334.5	295.8	346.4
Mixture (C)	1753	1448	1124	634.9	563.9	408.4

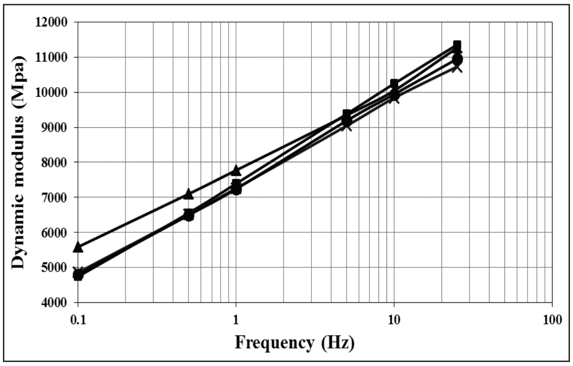


Figure 5: Dynamic modulus test results at (4.4)°C.

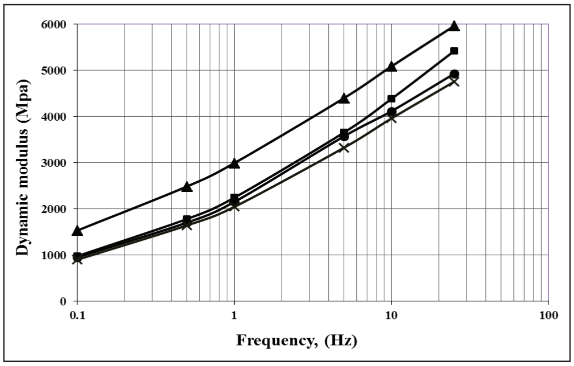


Figure 6: Dynamic modulus test results at (21.1)°C.

Figures 5–8 show the dynamic modulus values at different frequencies under four temperatures (4.4, 21.1, 37.8 and 54.4°C) respectively. It can be illustrated that with increasing frequencies, the dynamic modulus (E*) values increase for all mixtures with different rates where the dynamic modulus increasing rate is reducing with increasing temperature. The dynamic modulus values of HMA decrease with higher temperature where the higher (E*) is achieved at 4.4°C while the lower value is obtained at 54.4°C. The effect of plastic wastes addition is obviously obtained at hotter temperature (54.4°C), where with increasing the

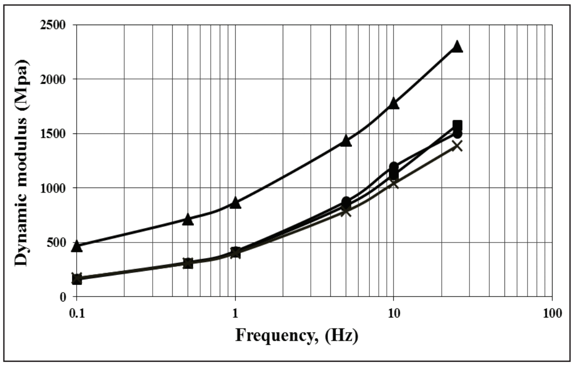


Figure 7: Dynamic modulus test results at (37.8)°C.

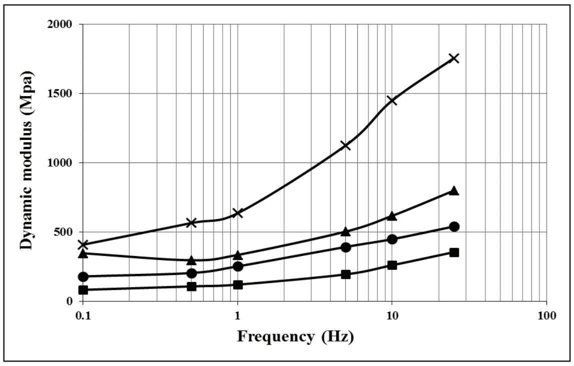


Figure 8: Dynamic modulus test results at (54.4)°C.

polymer contents, the dynamic modulus significantly increases. At colder temperature (4.4°C), there isn't obvious effect for polymer addition on (E*) values especially at higher load frequencies. For moderate temperatures (21.1°C) and (37.8°C), mixture (B) that containing 3% plastic waste achieves a significant higher dynamic modulus compared with other mixtures. There is no an obvious difference between the dynamic modulus values for the other mixtures. Thus it can be said that the adding of 3% polymer (plastic waste) provides a significant improvement in asphalt dynamic modulus at moderate temperatures 37.8 and 21.1°C. Figure 9 shows the dynamic modulus sample during the test.

3.5 *Flow number test results*

The flow number test is used to measure the rutting occurs in asphaltic mixtures by recording the cumulative strain after each cycle of the applied load. As shown in Table 8 and Figure 10, the polymer modified mixtures provide higher rutting resistance compared with the control mix by about 32, 392 and 60% for 2, 3 and 4% plastic waste content, respectively. The control mixture reaches a permanent deformation equals 100,000 μ strain after only 29 cycles to achieve a flow number equal to (25). Mixture (A) achieves a flow number equal to (33) while mixture (B) provides a flow number of (123). Finally, mixture (C) reaches a permanent deformation equals 100,000 μ strains after 81 cycles to achieve a flow number equal to (40).

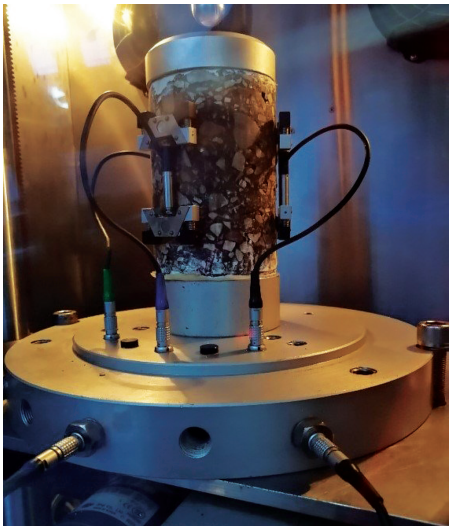
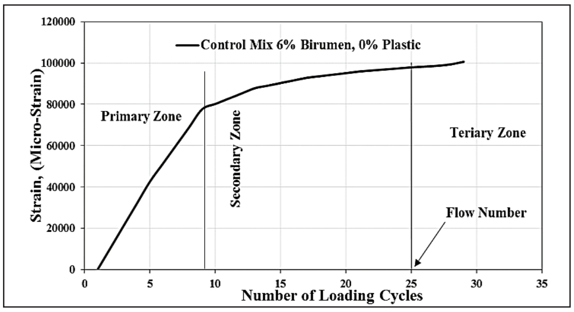


Figure 9: Dynamic modulus sample during test in the universal testing machine (UTM).

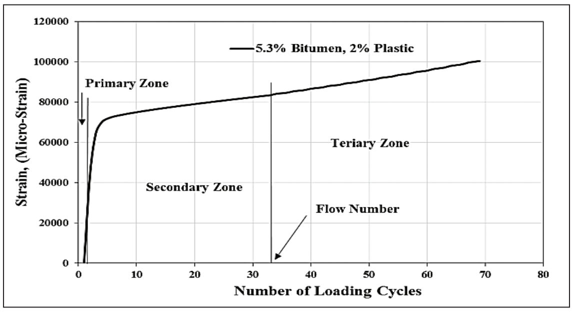
It can be illustrated that the addition of 3% plastic wastes (mixture B) provides an obvious effect in decreasing the permanent deformation or rutting where it provides an improvements in flow number as indicator of rutting resistance reaches to 392, 272 and 207% compared with control mixture, mixture (A) and mixture (C) respectively.

Table 8: Flow number test results for control and polymer modified asphalt mixtures

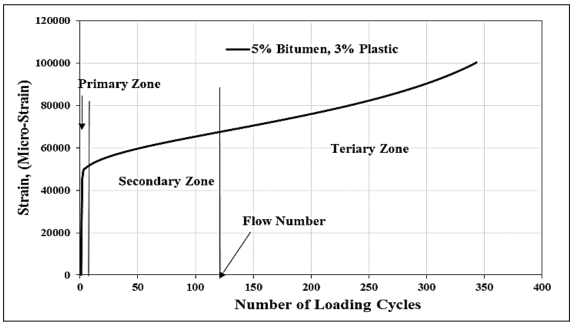
Plastic Waste Content	Terminal Condition (Micro Strain)	Total Cycles	Flow Number
Control Mix	100000	29	25
Mixture (A) 2% polymer	100000	68	33
Mixture (B) 3% polymer	100000	343	123
Mixture (C) 4% polymer	100000	81	40



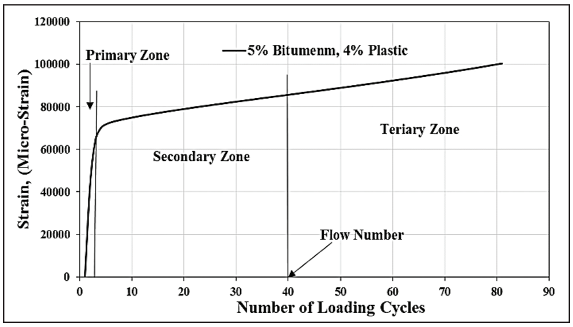
Control mixture containing 0.0% polymer



Mixture (A) containing 2.0% polymer



Mixture (B) containing 3.0% polymer



Mixture (C) containing 4.0% polymer

Figure 10: Flow number test results for control and polymer modified asphalt mixtures.

From the experimental tests results that conducted in this research, generally, it can be illustrated that, the addition of 3% polymer (mixture B) improves the strength characteristics of bituminous mix thus the mixtures contained 3% polymer provides the highest Marshall quotient, the highest dynamic modulus at medium temperature and the highest flow number that measure the resistance of asphalt mixtures to permanent deformation. For polymer addition of 2% (mixture A), it improves the tensile characteristics in bituminous mixtures modified with waste plastics. Asphalt mixture B that modified with 3% polymer can be recommended to be used according to these results.

4 Conclusions

Based on the extensive laboratory evaluation of different mixtures containing plastic wastes, it is concluded that the using of plastic wastes (polymers) mixed to asphalt mixtures is a successful step for a clean environment with better pavement performance against rutting, cracking and stripping (moisture damage).

The optimal bitumen ratio was decreased by about 9.5% when plastic waste content increased from 0% to 2% in HMA and by about 14.5% when plastic waste content increased from 0% to 3% or 4%. Thus, the recycling of plastic rubbish in bitumen mixtures obtained an economic importance where it reduced the consumption of natural asphalt. There was a significant improvement in the characteristics of polymer modified asphalt mixtures using plastic wastes. The highest stiffness and the maximum impedance to persistent deformation using Marshall quotient indicator was achieved by adding 3% plastic wastes.

The adding of plastic wastes had a great influence on improving the indirect tensile strength of the HMA where the highest value was achieved at using 2% plastic waste. Moreover, for long-term stripping susceptibility, the asphalt mixtures of 2% followed by 3% plastic waste provided the highest moisture damage resistance by achieving the highest tensile strength ratio. The attitude of the bituminous mixtures under loads at a range of controlled temperature was investigated using the dynamic modulus value. At colder temperature (4.4°C), there wasn't any obvious effect for polymer addition on the dynamic modulus values especially at higher load frequencies. While at hotter temperature (54.4°C), the dynamic modulus significantly increased with increasing the polymer contents. At moderate temperatures (21.1 and 37.8°C) the mixture containing 3% plastic waste achieved the highest dynamic modulus values at all frequencies.

The flow number was calculated using the universal testing machine (UTM) as a measure of the rutting occurs in asphaltic mixtures. The polymer modified mixtures obtained higher rutting resistance compared with the control mix by about 32, 392 and 60% for 2, 3 and 4% plastic waste content, respectively.

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