Use of Pyrolisis Polyethylene Terephthalate (PET) as Asphalt Modifier in Asphalt Concrete Mix

Dhirar Taha Mohammed, Zaid Hazim Hussein

***Abstract*- This research investigates the ability of improving the performance of asphalt mixtures using PET obtained from plastic waste in Mosul landfills. Five different percentages of PET by weight of asphalt binder were added using wet process. Marshall test, moisture susceptibility and durability test known as Cantabro Loss were conducted on unmodified and modified asphalt mixtures. The experimental results showed that the optimum polymer content of PET was 4%. The addition of this percentage of polymer caused an increase of the Marshall stability by 36.09 % for PET modified mixtures, while the flow values reduced slightly. Also the addition of this percentage of polymer led to an improvement in the durability and resistance of asphalt mixture to moisture damage.**

***Index Terms* – Asphalt, Durability, Modified asphalt, Moisture susceptibility, PET.**

I. Introduction

The term "polymer" refers to very large molecules made by chemically react many small molecules (monomers) to produce long chains. Polymeric materials are basically composed of two thermal groups: thermoplastics and thermosets [**1**]. These macromolecules can be in the form of plastomers or elastomers. For improved performance, asphalt binders may modify by using different types of polymers [**2**]. Plastomers increase the viscosity and stiffness of the asphalt by forming rigid network structure resisting deformation, while elastomers improve the elastic behavior of the asphalt since elastomers resist permanent deformation under tensile forces and recover their original shape after loading [**2**],[**3**]. Two of the common methods that are usually employed to add the polymer to the asphalt mixture are the wet and dry processes. In the first method, the wet process, the polymer is mixed with the asphalt binder prior to adding the asphalt binder to the aggregates. While in the dry process, the polymer is blended with the aggregate before adding the binder to the mixture [**4**]. In this case, using waste materials as additives would be a better solution in order to avoid the additional cost by using additives in asphalt mixture [**5**].

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In literature, Prasad, Mahendra and Kumar, 2013**[6]** studied the possibility of using Polyethylene Terephthalate (PET) as polymer additives in bituminous mix. The binders were prepared by mixing the asphalt with PET in (2, 4, 6, 8 and 10) % by the weight of asphalt at temperature of (200-220) ºC and concluded that PET-modified asphalt provide better stability compared to conventional binders, the 8% PET content was sufficient to increase the stability of the bituminous mixes.

Nassar, Kabel and Ibrahim, 2012 **[7]** evaluated the effect of waste PS on performance of asphalt binder, they used (2, 3, 4 and 6) % of polystyrene using a high shear mixer at 180 ºC and applied Marshall Test on asphalt concrete mixture. Analysis showed that, the best results were recorded for polymer modified asphalt (PMAs) containing (5% WPS) and all modified binders gave higher stability values, increase in air voids and slightly decrease in flow.

This study tries to use pyrolisis Polyethylene Terephthalate bottle (which is one of the plastic materials that is widely spread in the world) as modifier asphalt paving to achieve the following aims to:

1- Study the effect of adding different percentages of pyrolisis PET on the properties of asphalt mix comparing it with conventional mix properties.
2- Improve the durability of asphalt paving mixture to resist the conditions of the changing temperature.
3- Reduce life costs of pavements
4- Reduce the environmental pollution resulted from random discarded polymers which are hardly disintegration by bacteriological creatures.

II. Selection of Materials

A. Asphalt Binder

(40-50) penetration-grade asphalt cement was used in this study; it was supplied from Baiji refinery (220 Km north of Baghdad the capital). The table (I) displays the physicochemical properties of the asphalt [**8**]-[**14**]

Table (I) Physical and Chemical Properties of Asphalt Cement

Property	ASTM Standard	Test Result	SCRB Specification
Penetration	D-5	47	40-50
SP. Gr.	D-70	1.042	----------
Softening Point	D-36	54	----------
Ductility	D-113	147	>100
Loss on heat	D-1754	0.28	----------
Solubility in trichloroethylene	D-2042	99.7	>99

B. Aggregates

Al-Khazer aggregate was used in this research and it was crushed in a specialized factory to make it according to SCBR specifications**,** the properties of aggregates are determined according to ASTM D-127 and ASTM D-131 respectively [**15],[16**]. Table (II) shows the aggregate sieve analysis according to SCRB [**17**]. Table (III) displays the results of the physical properties of coarse and fine aggregates.

Table (II) Gradation of aggregate

Sieve size (In)	(mm)	% (passing)	Research Job mix
1	25.0	100	100
¾	19.0	90-100	95
½	12.5	76-90	83
3/8	9.5	56-80	68
No. 4	4.75	35-65	50
No.8	2.36	23-49	36
No.50	300 μm	5-19	12
No.200	75 μm	3-9	6

Table (III) Main properties of aggregate

Property	ASTM Designation No.	Coarse aggregate	Fine aggregate	ASTM limits
L.A. abrasion	C-131	20.6	--------	40 max.
Bulk Sp. gr.	C-127	2.638	2.575	-------

C. Filler

Calcium carbonate (CaCO3) was used as a mineral filler with calculated specific gravity of (2.711) and it was taken from the asphalt plant. Table (IV) shows the sieve analysis of the filler used in mixes according to SCRB [**17**].

Table (IV) Sieve analysis of filler

Sieve size (In)	Sieve size (mm)	Percentage Passing by Weight (%)	SCRB Specification
(No. 30)	0.600	100	100
(No. 50)	0.300	100	100
No.200	0.075	72	70-100

D. Polyethylene Terephthalate (PET)

It is a thermoplastic polymer resin of the polyester family. It is a linear and aromatic [**18**]. The source of PET was water bottles taken from waste solid materials pits. Fig. (1) shows the chemical structure of PET.

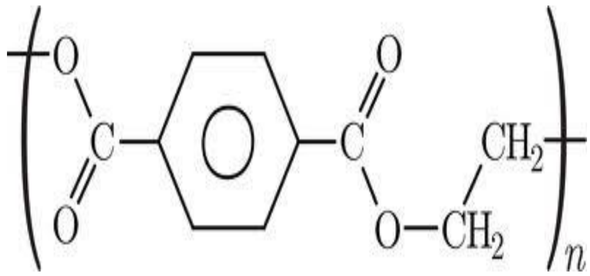

Fig. (1): chemical structure of PET[**18**]

III. MARSHALL MIX DESIGN

The ideal amount of asphalt was set According to ASTM D- 1559, by preparing the Marshall specimens in various amounts of asphalt (4.0 ,4.5 ,5.0 ,5.5 ,6.0) %.Optimum asphalt contents were determined according to the maximum stability, maximum density and 4% air voids according to Asphalt Institute specification. Table (V) shows the results of Marshall mix design for the control mix. The 4.866 % asphalt was finally selected as optimum percentage. The following steps were performed for the formulation of compacted specimens [**19**]:

1. The modified asphalt was heated to 160 °C in an electrically controlled oven.
2. The mixture of aggregate and filler was heated to 165±5 °C in an electrically controlled oven.
3. The combination of aggregate, filler and modified binder was mixed mechanically at a temperature of 165±5 °C for 1.5 min.
4. The specimens then were compacted at 145 °C using electrical Marshall Apparatus.

Table (V) Marshall results of conventional mixture

Asphalt content	Stability KN	Flow mm	Unit weight Kg/m^3	Air voids %	V.M.A %	V.F.A %
4.0	10.847	2.44	2.365	6.310	13.144	51.99
4.5	12.125	2.58	2.381	4.320	12.97	66.62
5.0	12.625	2.99	2.389	3.380	13.18	73.596
5.5	12.006	3.78	2.378	2.93	14.03	79.06
6.0	11.458	4.3	2.360	2.80	15.133	81.497
SCRB	Min. 7	2-4	-----	2-6	Min. 13	60-80

IV. PREPARING THE PYROLISIS PET

At first (PET) was subjected to thermal degradation (pyrolisis) process, mentioned by Mohammed D. T. and Hussein Z. H. [**20**], after grinding to powder (passing sieve No. 200) by means of mechanical grinding, then the asphalt was mixed with different percentage of (PET) (1,2,3,4& 5) %wt by weight of asphalt at temperature (155±5) °C for about (40-50) minutes at speed (2000 rpm) using electrical mixer.

V.LABORATORY TESTING

A series of tests were carried out on PET/asphalt mixtures for different percentages of PET as an additive. The following tests were used

A. Marshall test

The effect of adding polymers using wet process on the Marshall properties has been determined according to ASTM D1559 [**21**] in terms of stability, flow and Marshall Quotient (MQ).

B. Moisture Susceptibility test

The moisture susceptibility of bituminous mixtures is defined as the vulnerability of the asphalt mixture to be damaged by water. When moisture collects within the bituminous mixture, it can cause a loss of adhesion between the asphalt binder and the aggregate surface, and accelerates the development of other distresses such as a pothole, cracking and raveling [**22],[23**]. The moisture susceptibility test was carried out in accordance with AASHTO T-283 and ASTM D-4867 [**24**]. Specimens were sorted into two groups such that each group has approximately the same specific gravity. The first group was unconditioned, where the specimens were immersed in water for 2 h at 25 °C. The second group was conditioned, where the specimens were immersing in water for 24 h at 60 °C, they were immersed again in water for 2 h at 25 °C. Indirect tensile strength (ITS) in Kpa was determined from the equation (1) given below

$$ITS = \frac{2000\,P}{\pi\,DT} \quad (1)$$

Where

P= peak value of the applied vertical load (kN);

T = the mean thickness of the test specimen (mm); and finally

D = the diameter of the specimen (mm).

The tensile strength ratio (TSR) was determined by the average indirect tensile strength (ITS) of a conditioned specimens divided by the average ITS of unconditioned specimen; TSR value can be calculated by equation (2)

$$TSR = \frac{ITS\ con}{ITS\ uncon} * 100 \quad (2)$$

Where

TSR= tensile strength ratio (%);

ITS con = the indirect tensile strength of the conditioned specimens (Kpa)

ITS uncon = the indirect tensile strength of the unconditioned specimens. (Kpa). Tensile stiffness modulus of the mixtures was obtained as a relationship between applied stress and specimen's deformation. TSM value can be calculated by equation (3):

$$TSM = \frac{Pmax\,(v + 0.2734)}{L.H} \quad (3)$$

Where

TSM = tensile stiffness modulus

P = max. Load;

***v* =** Poisson's ratio (0.35 at 25°C);

0.2734= dimensionless strain integration;

L = thickness of specimen and

H = average horizontal deformation

A. Cantabro Loss

The Cantabro test was used to evaluate the resistance of specimen to particle loss. This test can be made by rotating the Los Angeles machine at a speed of 30 to 33 revolutions per minute for 300 revolutions without balls. The specimen is weighed before and after the test, and the percentage loss by weight of the original specimens is calculated as the Cantabro abrasion. Cantabro loss was determined from the equation (4) given below [**25**].

$$CL = \frac{A-B}{A} * 100 \quad (4)$$

Where:

CL = Cantabro Loss, %

A = Initial weight of test specimen (gm) and

B = Final weight of test specimen (gm).

VI. DISCUSSION OF RESULTS

A. Marshall Properties Results

The mechanical properties of the HMA containing polymer modified asphalt and base asphalt such as stability; flow and MQ, are presented in Fig. (2,3 and 4). The addition of PET has given more stability to the asphalt mixture. The increase was 36.09% at 4% PET as compared to the control mix. Moreover, the flow was decreased to 16.61% at 4%. Afterward, this value starts to increase due to the lack of homogeneity of the material within the asphalt, while the value of flow remained within the SCRB. Improved stability would positively influence the fatigue and rutting resistance of the modified asphalt mix leading to more durable asphalt pavement. Marshall Quotient (MQ) can be calculated as the ratio of stability (KN) to flow (mm), which increases to 60.06% with addition of 4% PET. By this way, a higher value of MQ indicates a stiffer mixture and hence, indicates that the mixture is likely more resistant to permanent deformation, shear stress and rutting in the road service [**26],[27**].

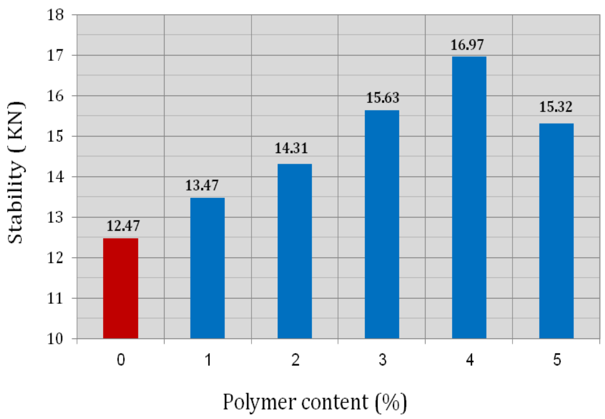

Fig. (2): Relationship between polymer content and stability

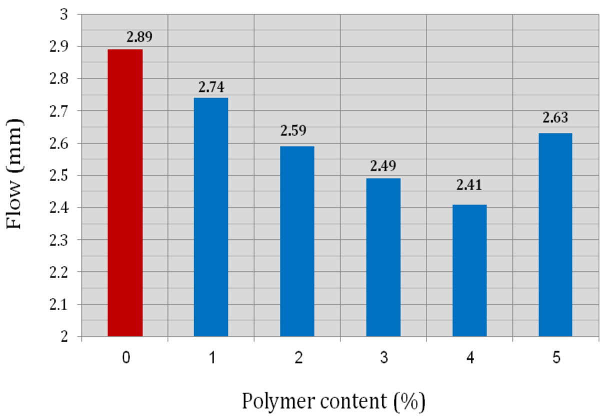

Fig. (3): Relationship between polymer content and flow

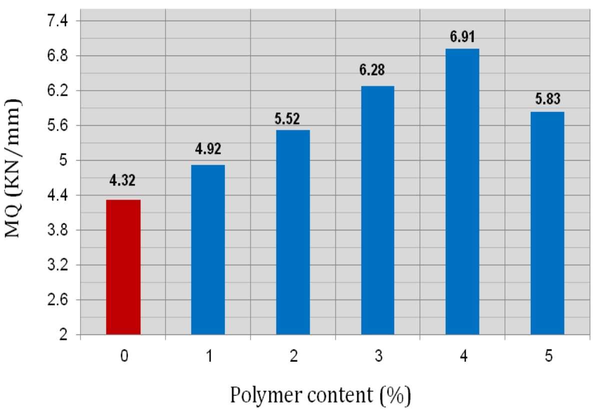

Fig. (4): Relationship between polymer content and MQ

B. *Moisture Susceptibility Test Results*

There are two mechanisms on road deterioration induced by moisture: loss of cohesive strength and the failure of adhesive bond between the aggregate and asphalt. Failure of the adhesive bond leads to a serious reduction in the durability of the mix and possibility of premature failure [**28**]. The study showed that adding polymer led to minimize that problems as well as an increment in ITS value to 43.28% at 4%PET for the dry samples and 69.58% at 4%PET and for wet samples as shown in Fig. (5 and 6). Additionally, the tensile strength for the wet samples dipped in water for 24 hours at 60°C increases while adding polymer, but it was less than the tensile strength for the dry samples for the same percentage. Also the results have revealed that the tensile strength ratio (TSR) value increases always with addition of polymer up to 93.61% at 5%PET. The higher tensile strength ratio means more resistance to humidity. Therefore, and based on the results mixture with the polymer is less affected by humidity than the original mixture. Fig. (7) shows the relationship between polymer content and TSR.

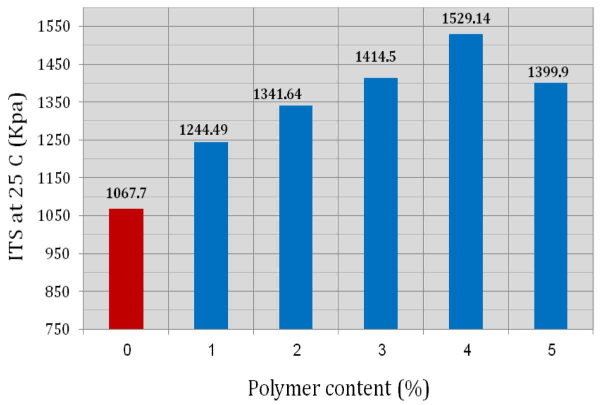

Fig. (5): Relationship between polymer content and ITS at 25C

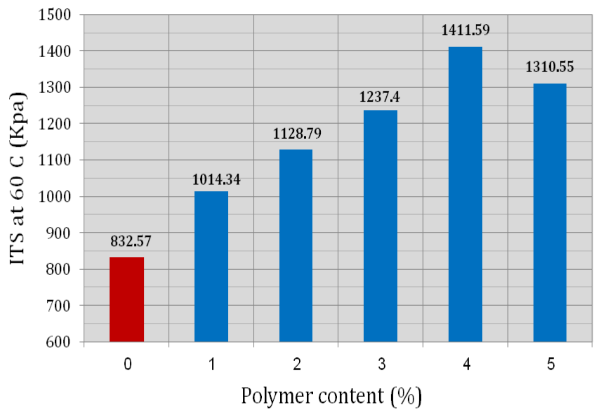

Fig. (6): Relationship between polymer content and ITS at 60C

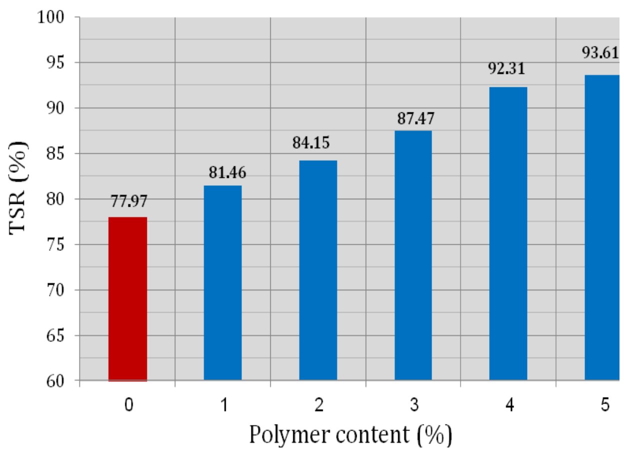

Fig. (7): Relationship between polymer content and TSR

By observing Fig. (8), the tensile stiffness modulus (TSM) value increases and reaches its maximum level at 4% of PET and then drops afterwards. The addition of polymer led to a rise in the modulus of rigidity and enhanced the adhesion between the aggregates and the asphalt which cause reducing in stripping incidents as well as side deformation.

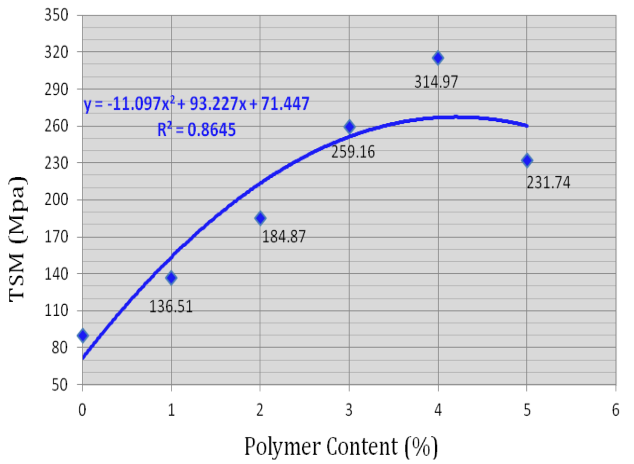

Fig. (8): Relationship between polymer content and TSM

C. Cantabro Loss Results

The Cantabro test was used to assess the durability of asphaltic mixes in terms of resistance to disintegration between aggregate and bitumen under the effect of traffic [**28**]. Fig. (9) shows that adding polymers led to a reduction of the Cantabro loss at (25°C) compared to conventional mixture. The percent of weight loss “Cantabro loss” is an indication of durability of mixture and is related to the quantity and quality of the asphalt binder. The decrease in loss was 45.23% with addition of 4% PET.

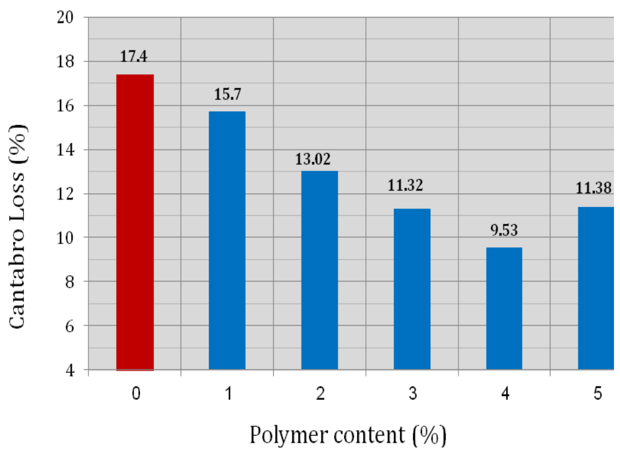

Fig. (9): Relationship between polymer content and Cantabro loss

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