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Utilization of Waste Plastic Water Bottle as a Modifier For Asphalt mixture Properties

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Abstract:

Utilization of waste material in asphalt pavement would be beneficial in order to find an alternative solution to increase service life of asphalt pavement and reduce environmental pollution as well. One of these waste materials is plastic water Bottles(Polyethylene Terephthalate) (PET) which are being produced in large amount. In this research Polyethylene Terephthalate (PET) was used to investigate the possibility of using waste plastic bottles made of Polyethylene Terephthalate (PET) was used as polymer additives in Bituminous Mixture to overcome the pavement problems . Added five different proportions of (PET) in (2%, 4%, 6%, 8% and 10%) by weight of optimum bitumen to prepare the specimens . The tests include the determination of bulk density, stability and flow. Marshall Mix design requires the determination of the percentages of air voids and air voids of mineral aggregate. The results indicated the optimum modifier content was found to be (8 %) for Waste plastic water Bottles(PET) modified asphalt mixture . It is found to give the maximum stability, VFA ,stiffness and minimum flow, Air Voids (AV), compared to the non-modified mixtures and gave better resistance against permanent deformations and better engineering properties .

Key Word: modified bitumen, Asphalt mixture, Polyethylene Terephthalate, Waste plastic.

استفادة من مخلفات قناني المياه البلاستيكية كمحسن لخصائص خلطة الإسفلت

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الملخص

أن استخدام مواد النفايات في تبليط الأسفلت يكون مفيدا من أجل إيجاد حل بديل لزيادة خدمة الحياة في تبليط الأسفلت والحد من التلوث البيئي كذلك. واحدة من هذه النفايات هي قناني المياه البلاستيكية (البولي ايثيلين ثيريفثاليت) التي يتم إنتاجها في كمية كبيرة ، في هذا العمل الحالي البولي ايثيلين تيريفثاليت تستخدم للتحقيق في إمكانية استخدام قناني النفايات البلاستيكية (البولي ايثيلين تيريفثاليت) كبوليمر مضاف في خليط القار للتغلب على مشاكل التبليط،اضافة خمس نسب مختلفة من قناني المياه البلاستيكيه (2 ٪، 4 ٪، 6 ٪ ، 8 ٪ ، 10 ٪)من وزن البيتيومين الأمثل لتحضير العينات. وتشمل الاختبارات تحديد الكثافة الظاهرية والاستقرار و التدفق. تصميم خلطة مارشال يتطلب تحديد النسب المئوية لفراغات الهواء و فراغات الهواء الركام المعدني والفراغات المليئة بالاسفلت ، أشارت النتائج الى محتوى التحسين الأمثل لتكون عند نسبة (8 ٪) للنفايات زجاجات المياه البلاستيكية المحسن لخليط الأسفلت ، حيث وجد بانها تعطي أقصى قدر من الاستقرار ،والصلابة ، و فراغات مليئة بالأسفلت ، والحد الأدنى من تدفق الهواء، وفراغات الهواء ، مقارنة بالخلائط غير المحسنة وأعطى المقاومة الافضل ضد التشوهات الدائمة وخواص هندسية افضل.

1- Introduction:

The asphaltic paving mixture is normally subjected to various detrimental types of distresses during its service life. These distresses are caused by load (heavy traffic), poor binders (asphalts) properties, weathering (temperature ,humidity, rain..) and bad mix designs. Some of these serious distresses include rutting (permanent deformation), shoving, stripping, and fatigue cracking which finally may lead to completed failure of pavement at the same time. Such distresses will reduce the performance of asphalt pavements under the effect of heavy traffic loading, high temperatures and water damages, specific requirement are needed to control the quality of highway pavement materials in order to increase its durability[1] .

The most important property of the bitumen mixture in the wearing course design is its ability to resist shoving and rutting under traffic. Therefore, stability should be high enough to handle traffic adequately, but not higher than the traffic conditions required. The lack of stability in an asphalt mixture causes unraveling and flow of the road surface. Flow is the ability of an

HMA(Hot Mixture Asphalt) pavement to adjust to gradual settlements and movements in the subgrade without cracking[2,3].

There are different ways to improve asphalt mixture properties:

- First is constructing road pavement with higher thickness.
- Second is using different types of additives as modifier (e.g. different types of fibers and polymers) in asphalt mixture constructing high-thickness pavement will cause considerably higher construction cost. Thus, using additives might be a better solution to overcome the pavement deterioration problem[4].It has possible to improve the performance of bituminous mixes of the surfacing course of road pavements, with the help of various types of additives to bitumen such as polymers, rubber latex, crumb rubber - treated with some chemicals, etc. Some limited studies have been reported on the use of recycled plastic, Plastic is a non-biodegradable material and researchers are found that the material can remain on earth for 4500 years without degradation, one of the plastic uses is the plastic water bottles, which is Mainly plastic bottle is mostly made by Polyethylene Terephthalate (PET), in the manufacture of polymer-modified asphalt .Recycled Polyethylene Terephthalate (PET) may be useful in asphalt (bituminous) pavements, resulting in reduced pavement deformation and increases the resistance of the material to temperature changes has been reported in these modified mixes as compared to the conventional mixes[5].

2-Background:

The performance of the road pavement is determined by the properties of the bitumen, as bitumen is the continuous phase and the only deformable component [6]. Bitumen is also a viscoelastic material with suitable mechanical and rheological properties for waterproofing and protective coverings for roofs and roads, because of its good adhesion properties to aggregates [7, 8].

Polymer modified binders improved adhesion and cohesion properties, rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility. These improvements have led polymer modified binders to be substituted for asphalt in many paving and maintenance applications. In many cases, they are selected to reduce life cycle costs [6, 9].

Polymer modification of asphalt binders have become increasingly standardized in designing optimally performing pavements[10]. The uses of virgin polymers in bitumen to improve the properties of bitumen, has been performed for many years. In spite of that, recently there is interest in the replace of commercial virgin material by recycled polymers[7].

In view of plastic materials versatility, relatively low cost and their small duration of life the consumption of plastic materials has been growing steadily, although the disposal of waste plastics constitutes a severe environmental problem, due mainly to their chemical inertness[11]. The Feature of polymer/ waste plastic modified mixes is **:**

• Stiffen binders and mix at high temperatures to minimize rutting.

• Minimizing non-load associated thermal cracking.

• Improve fatigue resistance, where higher strains are imposed on bituminous mixes.

• Improve aggregate-bitumen bond and reduce stripping.

• Improve bituminous pavement durability.

• Reduce cost of maintenance.

• Clean environment.

Some aromatic polyesters are biodegradable but Polyethylene Terephthalate (PET) waste is not biodegradable, and PET become very popular during the last decade because it is known as safe, durable and good material for packaging thus, it will create environmental hazards if disposed in landfills. Therefore, the only way of addressing the problem of disposal of post-industrial and postconsumer PET waste is through recycling[12]. Methods for recycling waste polymer have been developed and new recycling approaches are being investigated[13,6].Recycling waste polymer in road construction as a bitumen modifier is a new method.

3-Objective of this study:

The principle objectives of this research were to:

• Study the effect of adding polyethylene Terephthalate on the properties of hot mix asphalt and compared to conventional mixes.

4- Materials and methods

4-1 Bituminous material:

The asphalt used in this research is petroleum asphalt brought from Al-Daurah refinery. The laboratory tests performed to evaluate the bitumen properties were: Specific Gravity, Ductility, Penetration, and Softening point. The properties of asphalt binder which are presented in **Table (1)** and the results were within the values of Iraqi specification for Roads and Bridges (2003) of surface course.

Table (1) Properties of Asphalt Binder of Al-Daurah refinery*.

Test	ASTM	Test results	Specification	
			Min	Max
Penetration (0.1 mm)	ASTM D5	44.56	40	50
Ring and ball softening point (°C)	ASTM D36	50.5	50	60
Ductility (cm)	ASTM D113	+100	100	
Specific gravity	ASTM D70	1.013	1.01	1.06
Flash point (°C)	ASTM D 92	309	250	

*These tests had been done in asphalt technology laboratory of Al-Mustansiriyah University – College of Engineering.

4-2 Aggregate:

Aggregates are the second principal material in asphalt mixture. The coarse and fine aggregates were used from Al-Nibaee quarryat the northern of Baghdad, the physical properties of al-Nibaee aggregate listed in **table (2**) had been done in cooperation with national center for construction and laboratories.

Table (2) Physical Properties of Al-Nibaee Aggregates.

Property	ASTM	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	ASTM C127 and C128	2.618	2.63
Apparent Specific Gravity	ASTM C127 and C128	2.693	2.6802
Percent Water Absorption	ASTM C127 and C128	0.486	0.61
Percent Wear (Los-Angeles Abrasion)	ASTM C131	27.1	…….

4-3 Filler:

The mineral filler used is Portland cement to supplement the fine materials size in hot mix asphalt (HMA) mixture design. **Table (3)** shows the physical properties of filler.

Table (3): Physical Properties of Filler (Cement).

Property	Results
Specific Gravity	**3.12**
%Passing sieve No.200 ASTM C117	**96**

4-4 Additives: (Waste Plastic Water Bottle (Polyethylene terephthalate) (PET)):

Polyethylene terephthalate (PET) is linear, aromatic polyester that has an aliphatic-aromatic polymer composition and thermoplastic, shows a rather hydrophobic nature due to its rigid structure, PET has the wide range of mechanical properties, relative high melting point and glass transition temperature, insensitivity to common solvents and moisture, chemical inertness. PET Characterizes tough, shatter resistant, gas permeation resistant. PET Can be recycled so that the PET can be used over and over again and has the number "1" as its recycling symbol. Figure **(1)** shows Chemical structure of polyethylene terephthalate and **Figure (2)** shows PET recycling symbol[14].

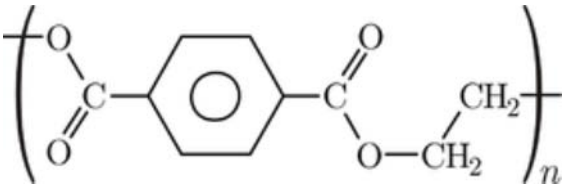

Figure (1) Chemical structure of polyethylene terephthalate.

Figure (2) PET recycling symbol.

plastic bottle is mostly made by Polyethylene Terephthalate (PET), and PET become very popular during the last decade because it is known as safe, durable and good material for packaging properties is shown in **table(4).**

Table (4): Properties of waste PET[15]

Properties	Results
Density	1370 kg/m^3
melting point	260°C

5-Sample preparation:

Suitably designed bituminous mix will withstand heavy traffic loads under adverse climatic conditions and also fulfill the requirement of structural and pavement surface characteristics. The objective of the design of bituminous mix is to determine an economical blend through several trial mixes. The average values of three samples for the unit weight, Marshall Stability and flow properties for each binder content were determined. The measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D1559) [ASTM, 2003]. This method includes preparation of cylindrical specimen which is 4 inch (101.6mm) in diameter and 2.5inch (63.5mm) in height.

The optimum bituminous content was (5%). 15 samples of asphalt concrete mixtures were prepared at this binder content for type of additive (Waste plastic bottles Polyethylene Terephthalate (PET)) to test the effect of adding this additive to the mixture. The samples were prepared by adding five different proportions, (2, 4, 6, 8 and 10%) as additive of optimum asphalt content. Three samples were tested for each proportion for determining the unit weight, stability and flow. The Marshal Mold, spatula, and compaction hummer are heated on a hot plate to a temperature between (120-150 °C).

The procedure of adding the additive is completed by put the bitumen into the oven and heated until it became liquid , the waste plastic bottles(PET) were cut into a small size by using shredding machine r , then they were added to the bitumen and they were leaved in the oven for (45) minutes at (150) °C and° heating 1140gm of aggregates and filler of each specimen until it reaches a (160-170 °C)and mixed together then the asphalt mixture is placed in the preheated mold and it is then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior.

Place two filter papers on the bottom of the mold in preparation for placing the asphalt mix in the assembled mold. Apply 75 blows with the compaction hammer. Then apply the same number of compaction blows to the face of the reversed specimen. When compaction is completed, the sample should be cooled in the mold in air until Sufficient cohesion has developed to result in the proper cylindrical shape, then the specimen should be extruded using a hydraulic jacking device to provide a constant pressure.

6- Results and discussion:

A comparison between asphalt mixture performance due to type of the additive is presented below. The comparison also includes the conventional asphalt mixture (No additive), which acts as the control group, table(5) shows the results of Marshall tests of Waste Plastic Water Bottle (PET) modify asphalt mixture and these results of Marshall tests had been done in asphalt technology laboratory of Al-Mustansiriyah University – College of Engineering.

Table (5) Marshall Results of Waste Plastic Water Bottle (PET) modify asphalt mixture (as average of three Marshall Specimens).

Marshall Properties	Polyethylene terephthalate (PET) Content %					
	0	2	4	6	8	10
Stability (KN)	10.318	11.855	12.821	14.050	14.489	12.2941
Flow (mm)	3.8	3.6	3.30	2.90	2.7	3.02
Bulk Density (gm/cm^3)	2.355	2.366	2.369	2.37	2.371	2.375
V.T.M%	4.4	4.10	3.91	3.70	3.52	3.10
V.M.A%	16.9	16.515	16.409	16.38	16.349	15.23
V.F.A%	73.964	75.174	76.232	77.411	78.591	79.645
Marshall Stiffness	2.715	3.293	3.885	4.844	5.366	4.0708

6-1 Bulk density- additive content relationships:

The bulk density of Waste plastic bottle modified asphalt mixture is higher than the conventional asphalt mixture value (2.355 g/cm3). Generally the bulk density increases as the Waste Plastic Bottle content increases. The maximum bulk density is (2.375 g/cm3) at waste plastic bottle content (10%). This increase of bulk density can be explained to be as a result of the high density added of plastic bottle material. **Figure (1)** shows the curve relationship of Asphalt Mixture Bulk density – Additive Content (Modifier).The results are according to Iraqi specification for Roads and Bridges 2003 of surface course [the specification values of bulk density extend from (2.1 to 2.45 gm/cm^3)].

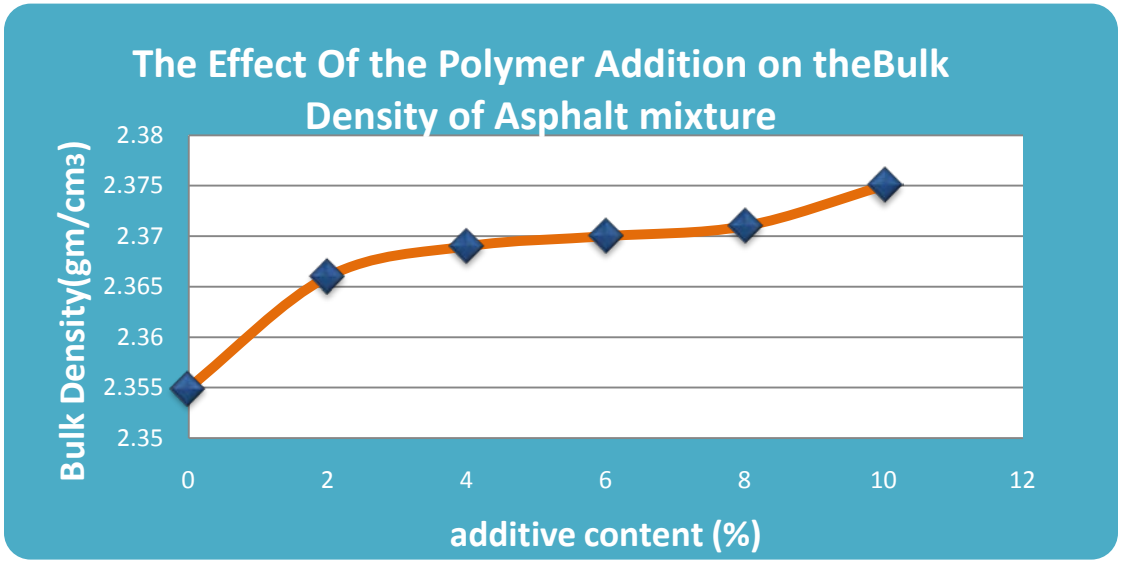

Figure (1) the effect of the PET addition in the asphalt mixture on the bulk density.

6-2 Mixture Stability- Additive Content Relationships:

Stability is the maximum load required to produce failure of the specimen when load is applied at constant rate**.** Generally, all the values of stability for different modified asphalt percentages are higher than stability of conventional mixture value(10.318 KN), while the maximum stability value is found nearly (14.489 kg) at Waste plastic water bottle content around(8%). **Figure (2)** shows that the stability of modified asphalt mixture increases as the WPB content increases till it reaches the peak at (8 %) waste plastic bottle content then it started to decline at higher waste plastic water bottle content. The improvement of stability in WPB modified asphalt mixture can be explained as a result of the better adhesion development between asphalt binder and aggregate particles by adding waste plastic bottle, This leads to enhanced strength of asphalt mixture, which in turn help to enhance stability of the asphalt mixture. The results are according to Iraqi specification for Roads and Bridges 2003 [the specification determined the minimum value of stability test (8 KN)].

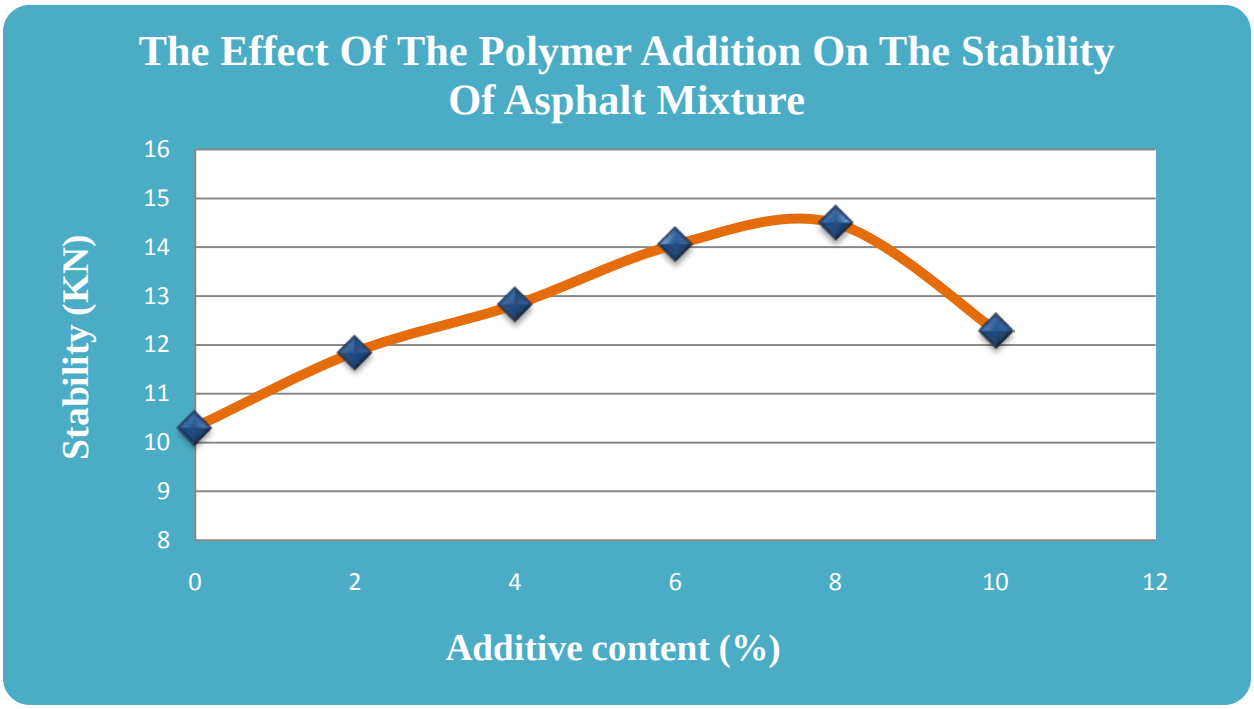

Figure (2) the effect of the PET addition in the asphalt mixture on the stability.

6-3 Flow- Additive Content Relationships:

Generally, the flow of modified asphalt mixture is lower than the conventional asphalt mixture value(3.8mm). **Figure (3)** shows that the flow decreases continuously as the Waste plastic bottle modifier content increases. The flow values extend from (3.8mm) till it reach (2.12mm) at Waste plastic bottle content of (8%), then increase at Waste plastic bottle content of (10%).The results are according to Iraqi specification for Roads and Bridges 2003 of surface course [the specification values extend from (2 to 4 mm)].

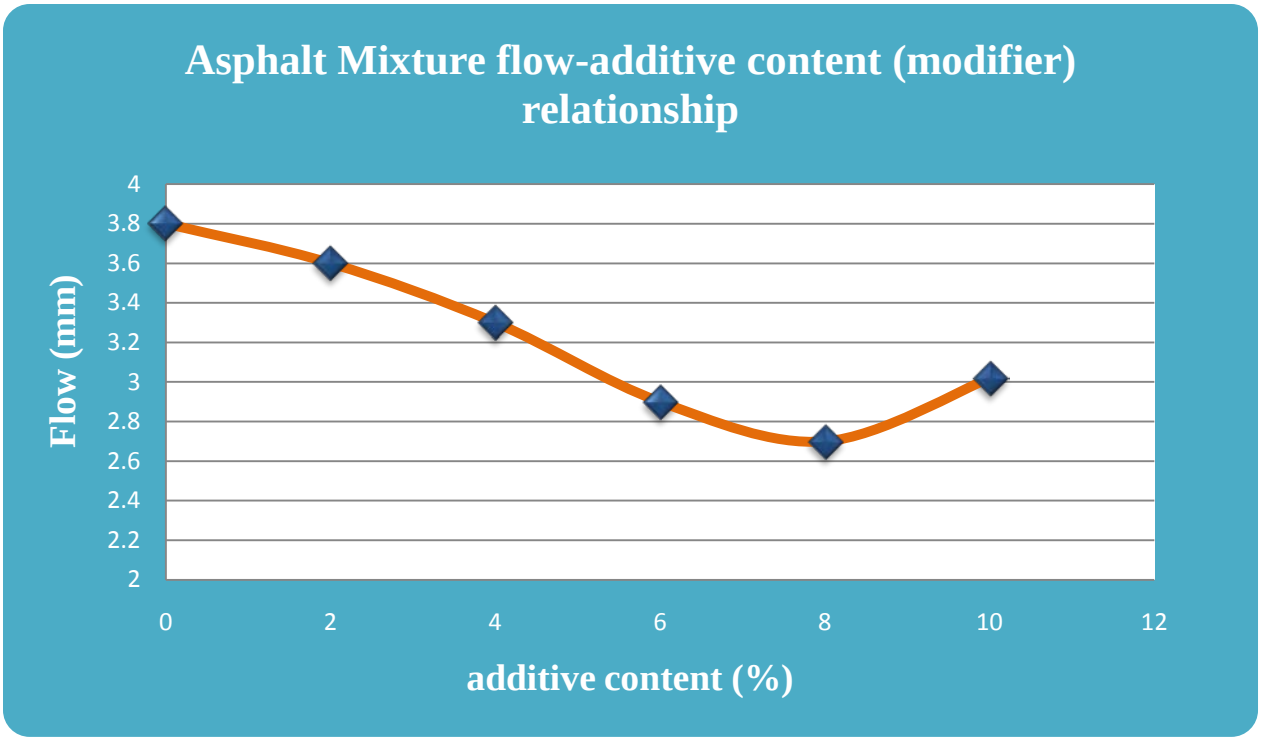

Figure (3) the effect of the PET addition in the asphalt mixture on the flow.

6-4 Air Voids (AV) percentage- Additive content relationships:

The AV proportion of the modified asphalt mixture is lower than the conventional asphalt mixture - no modifier of (4.4%)**.**AV % of modified asphalt mixture decrease gradually as the Waste plastic bottle content increase till it reaches the lowest AV% value at 10% waste plastic bottle. because the modifier fills the voids in asphalt mixture. As shown in **Figure (4)** the curve Relationship of Asphalt Mixture Air Voids (AV) percentage – Additive Content (Modifier). The results are according to Iraqi specification for Roads and Bridges 2003 of surface course [the specification values of Air Voids in Marshall specimen extend from (3 to 5%)].

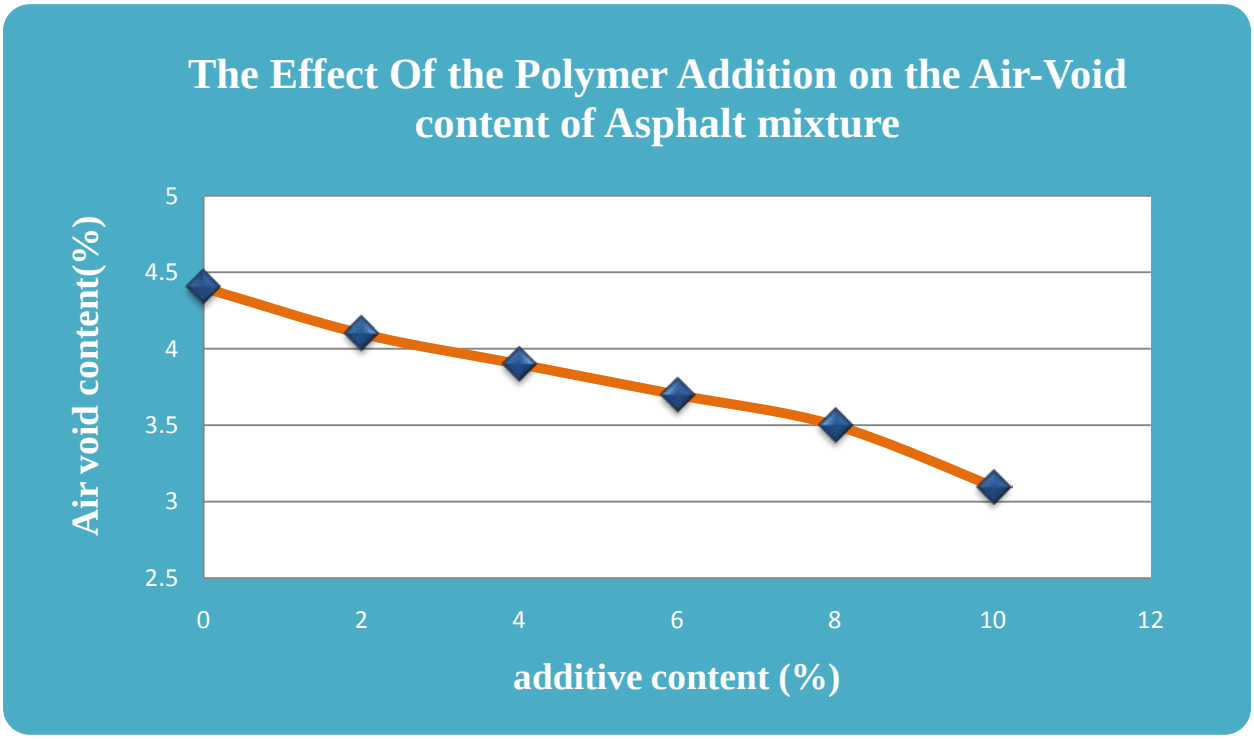

Figure (4) the effect of the PET addition in the asphalt mixture on the Air void percentage.

6-5 Voids in Mineral Aggregate (VMA) Percentage- Additive Content Relationships:

In general, as shown in **Figure (5**), the VMA percentage of the modified asphalt concrete mixtures is lower than the conventional asphalt concrete mixture value of (16.9), the (VMA) decreases continuously as the Waste plastic bottle modifier content increases. The(VMA) values extend from (16.9%) till it reach (16.21%) at Waste plastic bottle content of (10%).the results are according to Iraqi specification for Roads and Bridges 2003 of surface course [the specification determines the minimum value of(VMA) of 14%].

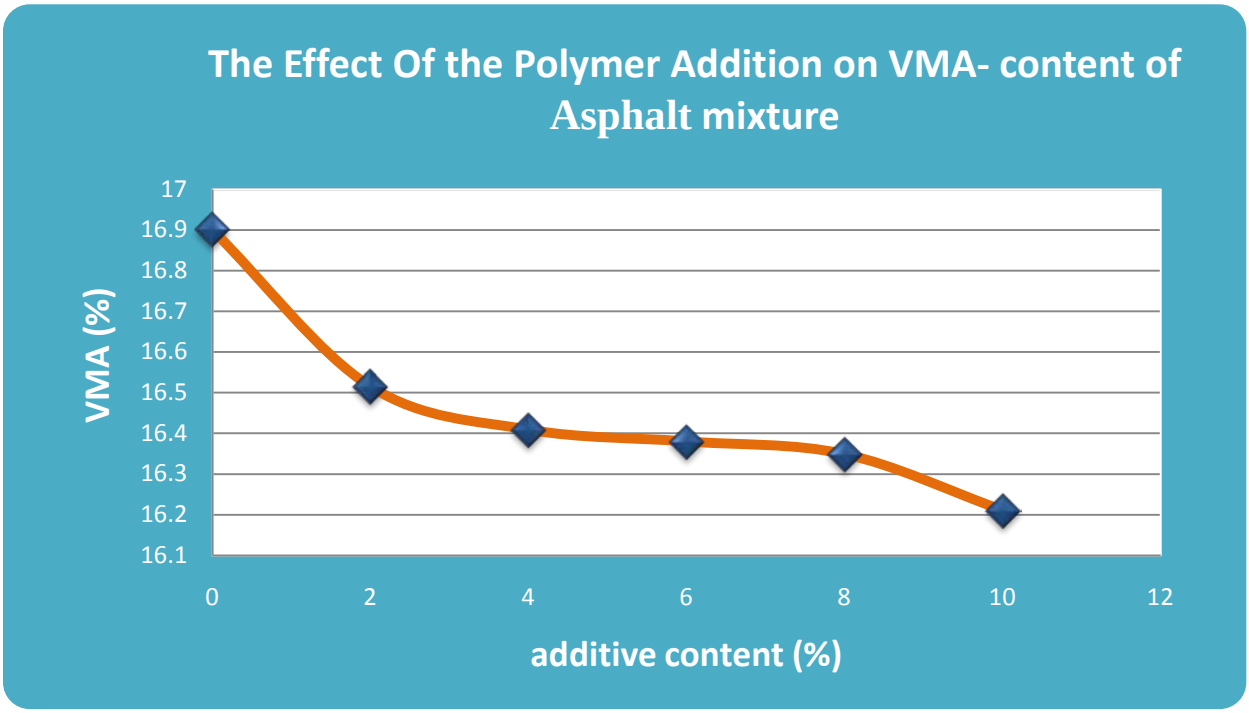

Figure (5) the effect of the PET addition in the asphalt mixture on the Voids in Mineral Aggregate (VMA) Percentage.

6-6 Voids Filled with Asphalt (VFA) Percentage- Additive Content Relationships:

In general, as shown in **Figure (6),**the VFA percentage of the modified asphalt concrete mixtures is higher than the conventional asphalt concrete mixture value of (73.96%), the (VFA) increases continuously as the Waste plastic bottle modifier content increases. The(VFA) values extend from (73.96%) till it reach (80.87%) at Waste plastic bottle content of (10%).the results are according to Iraqi specification for Roads and Bridges 2003 of surface course [the specification values of (VFA) in Marshall specimen extend from (70-85)%].

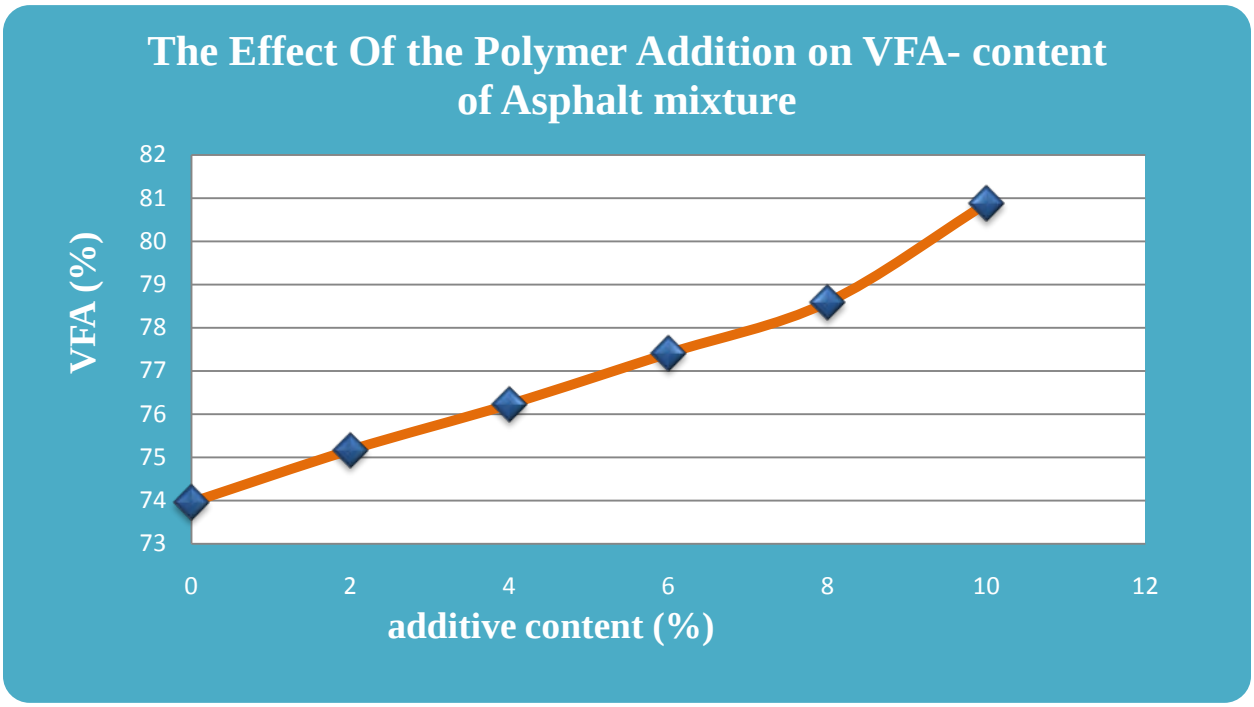

Figure (6) the effect of the PET addition in the asphalt mixture on the Voids Filled with Asphalt (VFA) Percentage.

6-7 Marshall Stiffness - Additive Content Relationships:

The results of division of the stability to the flow (stiffness=stability/flow) KN/mm is shown in **Figure (7).**The stiffness of Waste plastic bottle modified asphalt mixture is higher than the conventional asphalt mixture value of (2.715). Generally the Stiffness increases as the Waste Plastic Bottle content increases till it reach the value (6.834) at Waste plastic bottle content of (8%), then decrease at Waste plastic bottle content of (10%).

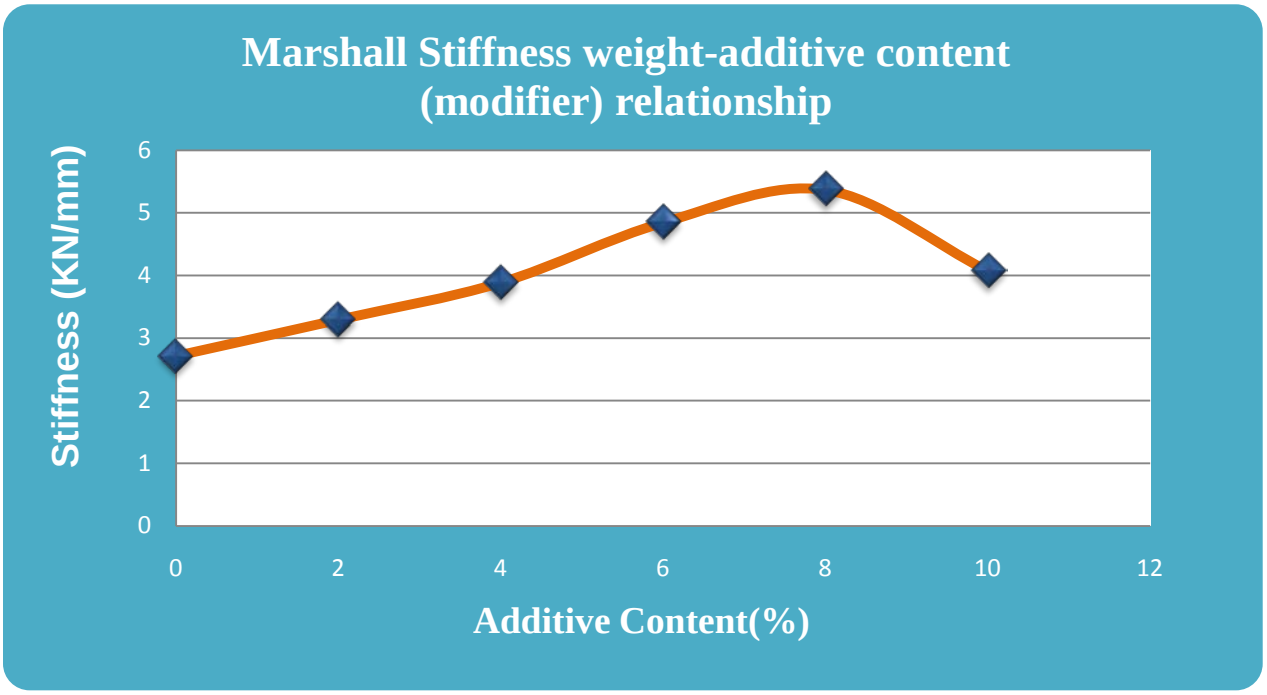

Figure (7) the effect of the PET addition in the asphalt mixture on the Marshall stiffness.

6-8 Optimum modifier content:

The optimum modifier content is selected as the specimen satisfies the following Characteristic:

* Maximum Bulk Density

* Maximum Marshall Stability
* Minimum Flow
* Maximum stiffness

7-conclusion:

The use of innovative technology not only strengthened the road construction but also increased the road life as well as will help to improve the environment and also creating a source of income. Plastic roads would be a boon for Iraqi's hot climate in summer, where temperatures frequently cross 50°C. It is hoped that in near future we will have strong, durable and eco-friendly roads which will relieve the earth from all types of plastic-waste.

By experimentation, the appropriate amount of the additives was determined to be (2-10%) by weight of the optimum asphalt percent (5.0%), however, the optimum modifier content was found to be 8 % of Waste plastic water Bottles (PET) modified asphalt mixture. The results of the study indicated that the modified mixtures) which indicates that the values of the bulk density, stability ,stiffness and VFA increase and the values of flow, VTM, VMA decrease these results indicate that the modifier (PET) improves the properties of asphalt and asphalt mixture. These results are within specification Iraqi roads and bridges(2003), compared to the non-modified mixtures reduce Permanent Deformation and fatigue life of asphalt mixture with plastic bottles was longer in comparison with the mixture without plastic . It also contributes to recirculation of plastic wastes as well as to the protection of the environment.

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