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Improvement of Marshall Properties of the Asphalt Concrete Mixtures Using the Polyethylene as Additive

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Abstract

In order to increase the durability of highway pavement specific requirements are needed to control the quality of pavement materials. Therefore, the aim of this study is to make and test laboratory specimens in order to characterize asphalt-polymer and aggregate mixtures by using results from conventional test procedures. The research work covers six percentages of polymer content those are (2%, 4%, 6%, 8%, 10%, and 12%) percent by weight of asphalt content. The polymer modified mixes were designed in accordance with Marshall method and the engineering properties of these mixes were determined. The engineering properties of the control and polymer modified mixes (stability, flow, bulk density, percent of voids in total mix, and percent of voids filled with asphalt) were evaluated by conventional test (Marshall test).The test results show that the engineering properties of polymer modified mixes meet the requirements of the S.O.R.B. specification for the asphalt mix used in the construction of surface course. The Marshall stability for modified mixes is higher than of control mixes.

الخلاصة

من اجل زيادة ديمومة الطرق المبلطة ظهرت الحاجة إلى توفر متطلبات خاصة، في هذا البحث تم دراسة تأثير إضافة بولي اثلين كبوليمر باستخدام ست نسب من البوليمر(٢%، ٤%، ٦%، ٨%، ١٠%, ١٢%) من وزن الإسفلت.هيئت خلطات محسنة طبقا لطريقة مارشال وحددت الخصائص الهندسية لهذه الخلطات، إضافة إلى ذلك قمنابدراسة أداء الخلطات المحسنة.كذلك .هيئت خلطات مرجعية غير محسنة لأجل المقارنة.و قد تم تقيم الخصائص الهندسية للخلطات المرجعية والمحسنة والتي تتضمن (ثبات مارشال والكثافة ونسبة الفجوات في الخلطة ونسبة الفجوات المملوءة بالإسفلت. أظهرت النتائج التجريبية إن الخصائص الهندسية للخلطات المحسنة تحقق الخصائص المطلوبة من قبل المؤسسة العامة للطرق والجسور للخلطات الإسفلتية المستخدمة في إنشاء الطبقة السطحية وتحقق زيادة كبيرة في ثبات مارشال.

Introduction

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. In Iraq, the major road deterioration occurs due to extraordinarily high temperatures and excessive lack of solar isolation during summer. [1]

Asphalt- polymer as defined is the combination of hot asphalt cement and polymer. Polymer is added to asphalt binder as the percent of the weight of the binder asphalt and polymer are blended and are added to the hot aggregate as asphalt - polymer binder.

The objective of the present study is to evaluate the performance of

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asphaltic concrete mixes using the Asphalt- polymer blend as a binder.

Background

Asphalt is a widely used material of construction. It is known to blend asphalts with polymeric materials so as to improve certain properties of the modified asphalt. The use of polymer modifiers increases the cost of the final composition, so a cost-benefit analysis is required before commercial use becomes a reality. For example, block styrene-butadiene elastomer (also known as "block SB rubber" and "block SBS rubber") is used to modify paving asphalts which are used in road construction. The so-modified paving asphalts typically exhibit excellent physical properties. However, the cost of the block styrene-butadiene elastomer has restricted its use in paving applications. Thus, it is apparent that a need exists for a ***polymer modified asphalt*** that is conveniently prepared from a comparatively inexpensive polymer. [2]

Asphalt/O-modified polyethylene preparing by asphalt blend with polyethylene which has been modified by shearing action in the presence of an O-containing gas (such as oxygen or ozone)Asphalt/O-modified polyethylene compositions that are characterized by having both of increased viscosity at high temperatures (which is desirable, as increased viscosity has been associated with a decrease in the so-called "rutting" phenomenon which occurs in asphalt roads that are subjected to heavy traffic loads at high temperatures) and improved flexibility at low temperatures (which is also desirable, as improved flexibility has been associated with a decreased in the tendency of asphalt to crack when subjected to loads at low temperatures). A paving mix prepared using the asphalt blend has an improved Marshall Test Value (ASTM DI559), indicating that the paving mix should have a reduced tendency to become rutted under the load of traffic. [3]

Goodrich, et al**.** [4] relates to the reaction of asphalt and polymers to produce an improved polymer-linked-asphalt product. The improved polymer-linked-asphalt product is particularly useful in road paving and roofing applications.

The term "polymer-linked-asphalt" refers to a polymer and asphalt composition in which the polymer is substantially covalently-bound to asphalt by one or more covalent bonds. The product of polymer-linked-asphalt of the present invention provides a number of important performance characteristics, including: improved resistance to permanent deformation (rutting), improved resistance to flexural fatigue, improved resistance to low temperature thermally-induced cracking, and improved resistance to moisture damage (stripping). Oxidized asphalt contains neutralized mixtures of oxidized asphalt and an acid functionalized polymer.

Oxidized asphalt compositions relates to asphaltic compositions having viscoelastic properties that are suitable for use as binders in dense graded and open graded hot mix asphalt pavement. The compositions comprise blends of asphalt or bitumen and synthetic polymers which are storage stable between the time of preparation and the time of use in hot mix pavement.[5]

Materials

The materials used in current study are aggregate, asphalt, cement, Portland cement as filler. These are currently used in roads paving in Iraq. Also, Poly Maleic Anhydrite grafted Polyethylene (MAH-g-PE) is used as a polymer.

Aggregate

The aggregate used in this study is crushed aggregate. The aggregate is divided into coarse aggregate ranges (25.4mm) to (4.75mm) while fine aggregate ranges between (4.75mm) sieve (0.075mm) (No.200) according to S.O.R.B specification [6],[7]. The physical properties of aggregate are presented in Table (1). The gradation of the aggregate is presented in Table(2) which represents limits of grading requirements according to S.O.R.B. specification for asphalt mixes used in the construction coarse surface.

Mineral filler

Portland cement was used in this study as filler. The physical properties of the Portland cement used are shown in Table (3).

Asphalt cement

The asphalt cement used in this study was of grade (40-50) Penetration brought from Al-Basrah refinery. The physical properties and the tests of the asphalt cement are listed in Table (4).

Maleic Anhydrite grafted Polyethylene (MAH-g-PE)

MAH-g-PE has good mechanical properties so it can be added to other material such as Soil, Clay, Cement, Sand and Asphalt in order to improve mechanical properties of the matter. Also, it can be used as binder matter for Concrete, and Asphalt paving, as well as can be used as adhesive matter for coating pipes [8].

MAH-g-PE is prepared by adding maleic anhydrite to molten polyethylene in the presence of organic peroxide as catalyst at 140 ^{O}C. Flow chart (1) shows the following reactions. Six percentages were used in preparing modified mixes (2%, 4%, 6%, 8%, 10%, and 12%).

Preparation of mixes

The weight of polymer can be determined by multiplying its percent by required weight of asphalt cement. There are six percentages of polymers used in preparing modified mixes. The asphalt cement with known weight was heated in an oven until reached temperature of 150^{o}C, then adding the desired weight of polymer (as quickly as possible approximately 10 sec). They were mixed thoroughly keeping the temperature constant at150^{o}C .The modified asphalt was weighted to the desired amount and then added to the heated aggregates and filler in the mixing bowl .All components were mixed thoroughly until all aggregates and filler particles were completely coated with asphalt. The mixing temperature was maintained within required limits (145-155)^{o}C. The asphalt mixture was placed in the preheated mold and it was then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior. Then 75 blows on the top and bottom of the specimen were applied with a compaction hammer of 4.35Kg sliding weight, and a free fall in 457,2mm.

The specimen in mold was left to cool at room temperature for 24 hours and then it was removed from mold .Three Marshall specimens were prepared at each asphalt content.15 specimens were prepared for each control and modified mixes.

Determining Marshall Properties

Marshall Specimens prepared with various Asphalt cement content were tested to determine Marshall Properties. The procedure used for determining these properties are as follows:

Determination of the Bulk Density

The bulk density is determined in accordance with method described by ASTM D2726 [9] the weight of the specimen is measured in air and then in water at 25°C and then in condition of saturated surface dry condition. The bulk density (g/cm^3) is the calculated as follows: Gmb=

$$\frac{W_A}{W_{SSD} - W_W} \quad \ldots\ldots\ldots 1$$

where:

Gmb = Bulk density of the compacted specimen.

W_A = Weight of specimen in air (gm).

W_{SSD} = Weight of saturated surface dry specimen (gm).

W_W = Weight of specimen in water (gm).

Determination of the Marshall Stability and Flow

Marshall stability and flow test is performed on each specimen in accordance with procedure described by ASTMD 1559[9]. Resistance to the plastic flow of bituminous mixture using Marshall apparatus with Electronic recording system. The specimen is placed in water bath at 60 °C for (30-40) min. The Marshall stability is the maximum load in (KN), while the Marshall flow is the total movement or strain occurring in the specimen between no load and maximum load during the stability test.

Determination of Percentage of Air Voids and Maximum Specific Gravity

This test was performed in accordance with standard test method of ASTM D204[9]. The maximum specific gravity and air voids can be calculated as follows:

Max. Sp. Gr. (SG) at 25°C =

$$\frac{W_D}{W_D - W_W} \quad \ldots\ldots\ldots\ldots 2$$

$$\text{VTM}(\%) = \frac{SG - Gmb}{SG} * 100 \quad \ldots\ldots.3$$

where:

W_D = Weight of dry sample in air (gm).

W_W = Weight of sample in water at 25°C.

SG = Maximum specific gravity.

VTM= Voids in total mix

Gmb = Bulk density of the compacted specimen (gm / cm^3)

Determination of Percentage of Voids Filled with Asphalt in Each Specimen VFA (%)

The percentage of VFA (%) represents the effective asphalt in compacted specimens as percent of the voids in mineral aggregate (%VMA). It is calculated as follows:

$$\text{VFA}(\%) = \frac{VMA(\%) - VTM(\%)}{VMA(\%)} * 100 \quad \ldots\ldots 5$$

where:

VTM = Voids in Total Mix or air void.

VMA = Voids in Mineral Aggregate.

Calculation of Optimum Asphalt Content For Control and Modified Mixes

The optimum asphalt content of the various mixes is determined from Marshall property curves (stability, bulk density, and air voids in total mix) .It is numerical average of the percentages of the asphalt content determined corresponding to maximum Marshall stability, maximum bulk density, and medium range of voids in total mix. It is determined according to the method described by the Asphalt Institute [10]

Results and Discussion

Marshall Stability

Figure (1) shows the Marshall stability values for control and different modified mixes against asphalt content. It indicates that stability values for various mixes are following the typical trend in their relation with asphalt content .These values increase with increasing percent of asphalt content until a maximum value is reached after which stability tends to decrease.

Also Figure (1) shows that for the same asphalt content, Marshall stability for different modified mixes is higher as compared with control mixes .It indicates that Marshall stability of modified mixes increases as the percentage of polymer content increases until polymer content reaches 10% after which stability tends to decrease.

The largest value of stability that occured at polymer content equal to 10% is 13.5 KN while the maximum stability that occured at control mixes is 8.4 KN. The stability of a mixture depends on internal friction and cohesion. Internal friction among the aggregate particles (inter particle friction) is related to aggregate characteristics such as shape and surface texture. Cohesion results from the bending ability of asphalt [11]. High stability values of the modified mixes are caused by the high workability of the mixture with polymer particles. Kam [3] determined. the Marshall stability of the comparative paving mix compositions had a maximum value of 10,004 when 6.0 weight % asphalt was used in the mix. The Marshall stability of paving mixing compositions prepared using 5.5 or 6.0% weight % of modified asphalt (Asphalt/ O-modified polyethylene) was greater than 11,000. This result indicates that the Marshall stability will increase 1KN when the Asphalt modified polyethylene is added.

In this paper the Marshall stability will increase 5.1 KN when Maleic Anhydrite grafted Polyethylene is added. This result clearly indicates that the modified asphalt should provide paving compositions having a reduced tendency to become "rutted".

Marshall flow

Figure (2) presents Marshall flow values with respect to asphalt content percent. It is clear that flow values of control and different modified mixtures increase as the asphalt content increases, this is common in the asphalt concrete mixture when they are prepared with various percentages of asphalt content. Also, it shows the modified mixes giver higher values of Marshall flow than those given by control mixes and for these modified mixes, Marshall flow increases with increasing polymer percent.

Bulk density

Figure (3) shows the bulk density values for various mixes as a function of asphalt content .In this figure bulk density curves of both control and modified mixes show the same trend that is expected from hot mixes prepared with various asphalt contents where the bulk density increases with increasing asphalt content until a maximum value is reached after which the bulk density tends to decrease. Also, Figure (3) shows that for the same asphalt content, the bulk density for control mixes is higher than that of various modified mixes. This reduction in values of bulk density for modified mixes results from the low specific gravity of the polymer content.

Voids in total mix (VTM) percent

Figure (4) shows the relationship between the percent of voids in total mix and asphalt content for control and different modified mixes. It can be noticed that percent of VTM decreases with increasing of asphalt content (it is common in the asphalt mixture).Also, it can be noticed that percent of VTM for modified mixes is lower than that of control mixes for various asphalt content. The polymer content leads to increase mixture workability and efficiency of compaction for modified mixes and hence increases percent of VTM.

Voids filled with asphalt (VFA) percent

Figure (5) shows voids filled with asphalt (VFA) percent against asphalt content for various mixes. It indicates that percent of VFA curves exhibits the same trend that is expected for any asphalt mixture where (%VFA) increases with the increase of asphalt content.

Figure (5) indicates that for the same asphalt content, (%VFA) for modified mixes is higher than that of the control mixes. The high (%VFA) can be explained as the modified mixes have low (%VTM) in comparison with control mixes .As for the same asphalt content the decreasing (%VTM) increases (%VFA).

Optimum asphalt content for control and different modified mixes

The optimum asphalt content for control mixes is 5.5 while for the modified mixes is 5.45, 5.43, 5.4, 5.38, 5.35,and 5.3 for (2%, 4%, 6%, 8%, 10%, and 12%)respectively. There is a small difference in the optimum asphalt content between control mixes and modified mixes. This difference is within S.O.R.B tolerance ($\pm 0.3\%$).Therefore, it can be considered the optimum asphalt content for modified mixes is (5. 5).

Marshall stability at O.A.C

The effect of polymer content percent on Marshall stability at optimum asphalt content (O.A.C) for control and different modified mixes is depicted in Figure (6) .This figure shows that for modified mixes, Marshall stability increases with an increasing polymer content until 10 percent reached after that Marshall stability decreases. From Figure (6), it is noticed those values of Marshall stability for various mixes above the minimum (8 KN) required by S.O.R.B specification for asphalt concrete mixes are used in the surface course.

Marshall Flow at O.A.C

Figure (7) shows the effect of Polymer content percent on Marshall flow at optimum Asphalt content (O.A.C). Marshall flow values for various mixes are within the range of (2-4) mm specified by S.O.R.B. specification for the Asphalt mix used in surface course. All modified mixes exhibit high value of flow in comparison with those obtained from control mix.

Voids in Total Mix (VTM) Percent at O.A.C

Figure (8) shows the effect of Polymer content percent on VTM at optimum asphalt content (O.A.C). VTM values for various mixes are within the range of (3-5) % specified by S.O.R.B. specification for the asphalt mix used in the construction of surface course. Voids in total mix (VTM) percent decrease with increasing Polymer content. The decrease in VTM is usually in order because the Polymer fills the void in the mixture.

Voids Filled with Asphalt (VFA) Percent at O.A.C

Figure (9) shows the effect of Polymer content percent on voids filled with asphalt at optimum asphalt content (O.A.C). This figure shows that for modified mixes, the V.F.A increases with increasing polymer content. And values of VFA for various mixes are within the range of (70-85) % specified by S.O.R.B. specification for the asphalt mix used in surface course.

Conclusions

The following conclusions can be drawn from the finding of the present paper:

1-Adding Maleic Anhydrite grafted Polyethylene leads to increase mixture workability and efficiency of compaction for modified mixes.

2- Marshall properties for polymer modified mixes show the same trend that is expected from any asphalt concrete hot mixes.

3-No significant difference was found of optimum asphalt content between control and modified mixes.

4-Marshall properties (stability, flow, bulk density, percent of voids in total mix, and percent of voids filled with asphalt) for control and modified mixes at O.A.C achieve the engineering properties required by S.O.R.B. specification for the asphalt mix used in the construction of surface course.

5- The largest value of Marshall stability occurs at polymer content equal to 10%.

6- Adding Maleic Anhydrite grafted Polyethylene leads to increase flow value .

7- Adding Maleic Anhydrite grafted Polyethylene leads to decrease the air voids in total mix.

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Table (1) Physical properties of aggregate

Property	Coarse aggregate	Fine aggregate
Bulk specific gravity (ASTM C127&C128)	2.646	2.63
Apparent specific gravity(ASTM C127&C128)	2.656	2.667
Percent water absorption (ASTM C127&C128)	0.14	0.523

Table (2) Aggregate gradation for surface layer according to S.O.R.B [7]

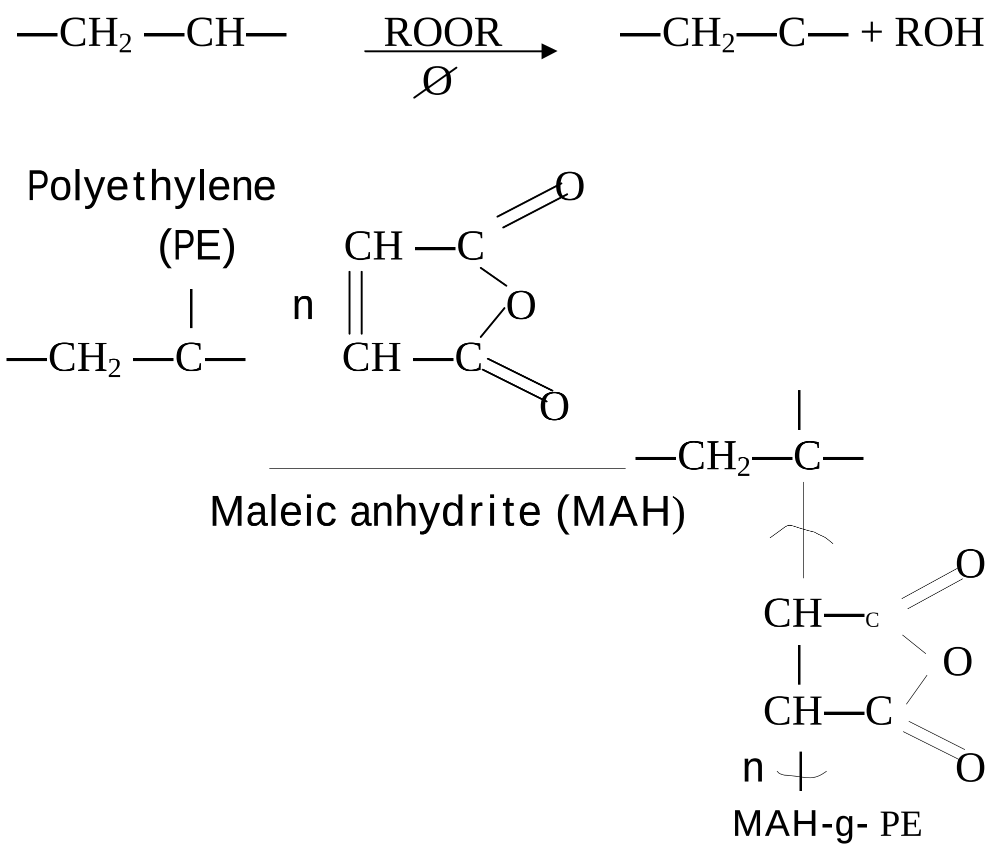
Sieve size(mm)	Passing%
12.5	100
9.5	80-100
4.75	46-76
2.36	28-58
0.3	8-24
0.075	4-12

Table (3) Physical properties of fillers

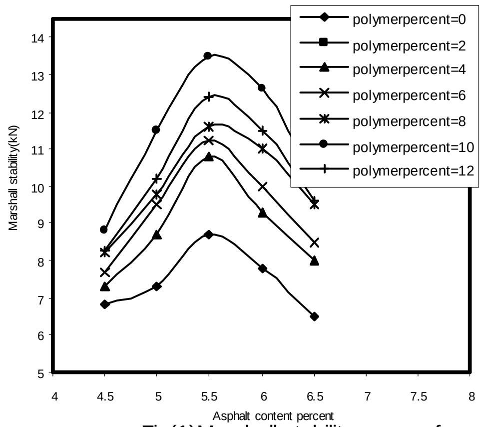
Property	Portland Cement
Passing sieve No. 200, (%)	95.25
Specific gravity (ASTMC188)	3.04

Table (4) Physical properties of the selected Asphalt cement

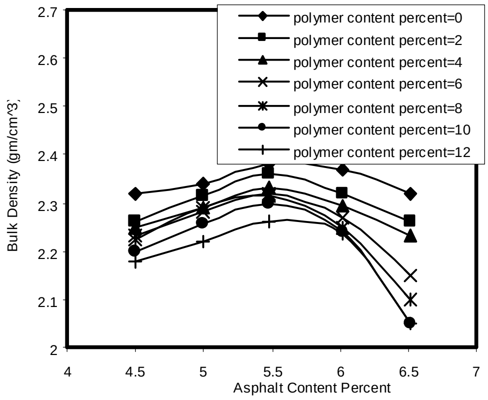
Property	Test	Units	value	S.O.R.B Specification
Penetration(25°C 100 gm, 5 Sec)	**ASTM D5**	**1/10 mm**	**40**	**40-50**
Softening point (R+B)	ASTM D36[30]	°C	59	50-60
Ductility (25°C, 5cm/min)	ASTM D113	Cm	>100	>100
Flash Point (cleven and open cup)	ASTM D92	°C	323	>240
Specific gravity at 25°C.	ASTM D70		1.04	1.03-1.06



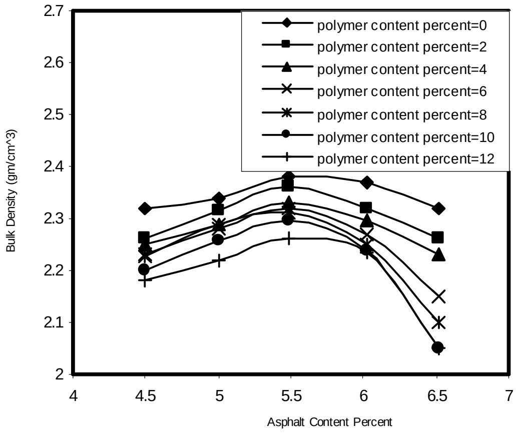
Flowchart (1) Polymer preparation



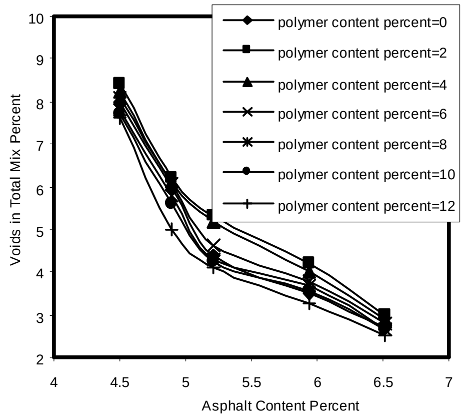
Fig(1)Marshall stability curves for control and modified mixes



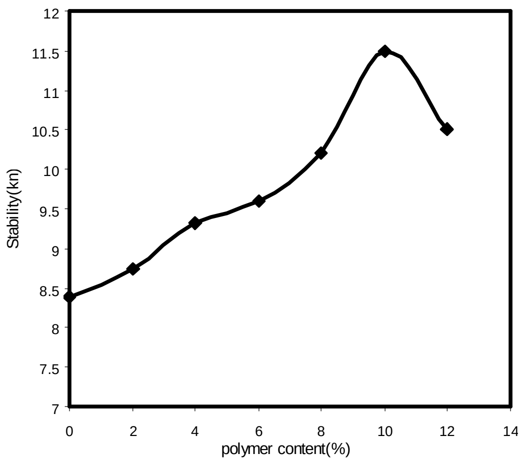
Figure(3)Bulk Density Curves for Control and Modified Mixes



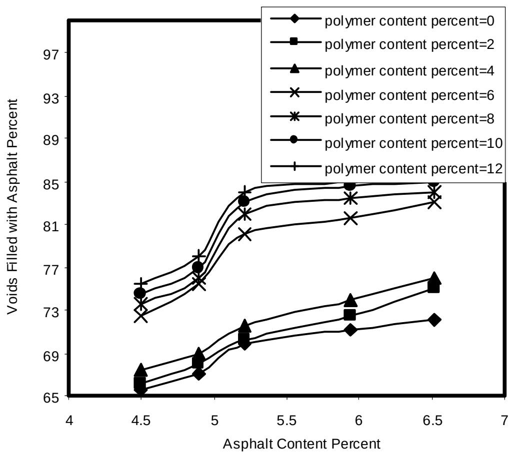
Figure(3)Bulk Density Curves for Control and Modified Mixes



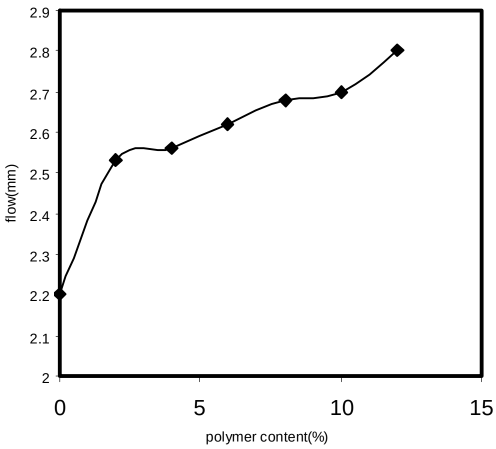
Figure(4)Voids in Total Mix Percent Curves for Control and Modified Mixes



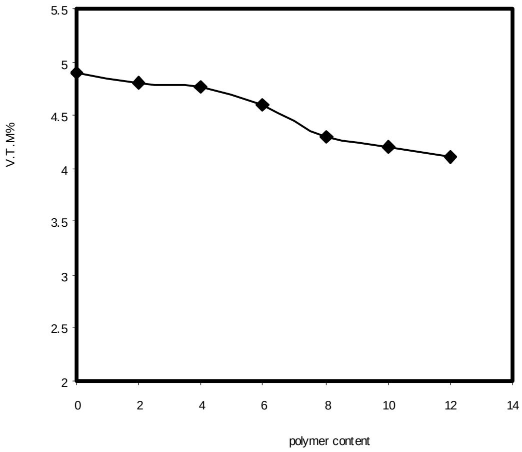
Fig(6)The relationship betw een Stability and polymer



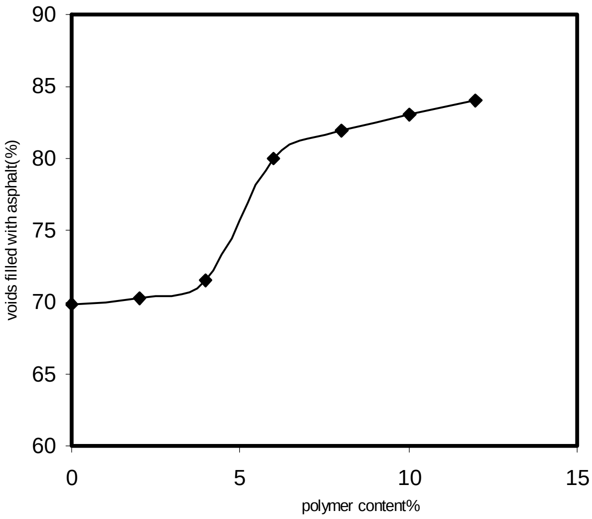
Figure(5)Voids Filled w ith Asphalt Percent Curves for Control and Modified



Fig(7)The relationship between flow and polymer content



Fig(8)The relationship between V.T.M and polymer



Fig(9)The relationship between voids filled with asphalt and polymer content