# Effect of Density of the Polyethylene Polymer on the Asphalt Mixtures

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## Abstract :

In Iraq, for few recent years , the increasing number of vehicles and trucks with their heavy traffic loading and with the effects of other exterior factors such air temperatures effects and moisture , accumulation of these factors on the roads surfaces with an insufficient maintenance have caused distresses or deteriorations on pavement . Polymer-modified asphalt mixtures have been used for many years to reduce the amount and severity of distress and extend the service life of hot mix asphalt (HMA) pavements. The polymers have acceptable effects on asphalt mixes in low and high temperature due to increasing the resistance to fatigue cracking , rutting (permanent deformation) and thermal cracking .

The major objective of this research is to evaluate the effect of the density of polyethylene (PE) polymer, that one of physical properties of this locally polymer on the properties of the Hot Mix Asphalt (HMA). One asphalt cement grade (40-50) from Al-Daurah refinery, two different types of locally available polymers (Low-Density Polyethylene LDPE and High-Density Polyethylene HDPE) have been used with three percentages for each type. These percent's are (2, 5 and 7)% by weight of asphalt cement. HDPE mixing at 180 C º and LDPE at 175 C º for 90 minutes by wet process with asphalt binder. The properties of asphalt mixtures that investigated in the experimental test are Marshall volumetric properties (Marshall stability , Marshall flow) and rutting depth at (40 Cº & 50 Cº) by wheel track test to evaluate (the permanent deformations). It can be concluded that the density of PE have significant effect on the asphalt mixtures at the optimum percent of PE (2%) , where the increasing density increasing in Marshall Stability about (above 100%) and reducing in rutting depth about (67%) , after compared with control mixtures .The increasing percent of HDPE & LDPE causing reducing in the asphalt mixture properties . And concluded that HDPE modified mixtures provide better resistance against permanent deformations , because of their higher stability and stiffness, relatively lower flow. Therefore the using of HDPE to modified asphalt mixtures give better properties to asphalt mixtures from modified mixtures by LDPE .

The effect of temperatures on the rutting depth and on the number of wheel loading passes is clearly apparent . The samples failed at 50 Cº testing temperature faster that at 40 Cº testing temperature in which the wheel passes are decreasing to half also the rutting depth is increasing by (100%) .

**Key Words**: Asphalt, pavement, polymer, aggregate ,polyethylene , polymer density, performance , hot mix asphalt , temperatures ,permanent deformation , stability .

## الخلاصة:

في العراق ، للسنوات القليلة السابقة ، تزايد عدد المركبات والشاحنات وحمولتها المرورية العالية وبتأثير العوامل الخارجية الأخرى مثل درجات حرارة الجو وتأثير الرطوبة ، تراكم هذه العوامل على اسطح الطرق مع الصيانة الغير كافية تسببت في حصول تشوهات وعيوب في طبقات التبليط . وقد استعملت الخلطات الاسفلتية المعدلة بالبوليمر لعديد من السنوات لتقليل كمية وشدة العيب او التشوه ولتمديد العمر الخدمي لطبقات التبليط بالخرسانة الاسفلتية الحارة .(HMA) حيث ان البوليمرات يكون لها آثار مقبولة على خلطات الأسفلت في درجة الحرارة المنخفضة والعالية ، من خلال زيادة المقاومة لتشقق الكلل , التخدد (التشوهات الدائمة (والتشقق الحراري .

ان الهدف الرئيسي من هذا البحث هو تقييم تأثير الكثافة لبوليمر البولي ايثلين (PE)، والتي هي احد الخصائص الفيزيائية لهذا البوليمر المحلي على خصائص خلطات الخرسانة الاسفلتية الحارة (HMA) . تم استخدام نوع واحد من الإسفلت ذو اختراق (٤٠– ٥٠) من مصفى الدورة ، استخدام نوعين مختلفين من البوليمرات المتوفرة محليا" وهي (البولي إيثلين واطئ الكثافة LDPE والبولي إيثلين عالي الكثافة HDPE) حيث تم استخدام ثلاث نسب لكل بوليمر وهذه النسب هي (٢ ، ٥ ، ٧) % كنسب وزنية من وزن الاسفلت .البولي ايثلين عالي الكثافة HDPE يخلط عند درجة حرارة ١٨٠ درجة سيليزية والبولي إيثلين المنخفض الكثافة LDPE عند ١٧٥ درجة سيليزية وبزمن خلط ٩٠ دقيقة مع الإسفلت الرابط وباستخدام الطريقة الرطبة. ان خصائص الخلطات الإسفلتية التي تقييم من خلال الفحص المختبري هي خصائص فحص مارشال (ثباتيه مارشال ، وتدفق مارشال) وعمق التخدد عند درجة حرارة الاختبار (٤٠ & ٥٠) درجة سيليزية من فحص عجلة المسار لتقييم (المقاومة للتشوهات الدائمة). ويمكن الاستنتاج ان كثافة بوليمر البولي اثلين (PE) يكون لها تأثير

ملحوظ وكبير على خصائص الخلطات الإسفلتية وعند نسبة خلط مثلى تبلغ (٢%)، حيث ان زيادة الكثافة تسبب زيادة في قوة ثباتيه مارشال بنسبة (تفوق ١٠٠%) وتخفض في عمق التخدد بنسبة حوالي (٦٧%) ، مقارنة بالخلطات الاسفلتية الاعتيادية الغير المطورة بالبوليمرات . إن زيادة نسبة تركيز بوليمر ( LDPE &HDPE) تسبب تقليل في خصائص الخلطات الاسفلتية. ونستنتج بانه الخلطات الاسفلتية المعدلة باستخدام بولي ايثلين عالي الكثافة HDPE توفر افضل مقاومة ضد التشوهات الدائمة ، بسبب امتلاكها ثباتيه عالية وصلابة ، وقيمة اقل في تدفق مارشال. وبالتالي فإن استخدام HDPE في تعديل الخلطات الإسفلتية تعطي خصائص أفضل من الخلطات الاسفلتية المعدلة باستخدام LDPE .

ان تأثير درجات الحرارة على عمق التخدد في الطبقات الاسفلتية وعلى عدد دورات مرور عجلة التحميل يظهر بوضوح، حيث ان النماذج الاسفلتية تفشل عند درجة حرار اختبار ٥٠ درجة سيليزية اسرع منها عند درجة حرار اختبار ٤٠ درجة سيليزية والتي عندها تقل عدد دورات عجلة التحميل للنصف وكذلك يزداد التشوه الدائم (عمق التخدد) بمقدار(١٠٠%) .

**الكلمات المفتاحية** :اسفلت، تبليط، بوليمر، ركام، بولي إيثلين، كثافة البوليمر، الأداء، الخلطة الاسفلتية الحارة، درجات الحرارة، تشوه دائم، ثباتية.

## • Introduction:

In Iraq , for few recent years , the increasing number of vehicles and trucks with their heavy traffic loading and with the effects of other exterior factors such air temperatures effects and moisture , accumulation of these factors on the road surfaces with an insufficient maintenance have caused distresses or deteriorations on pavement . Decreases of pavement distresses or improving the performance of flexible pavement must take many improvements on pavement surfaces such improve design, structure of paving and performance of mix by controlling with properties that effected on it . In order to improve HMA performance, the practice of modifying the asphalt binder became common and polymers in particular have received widespread attention as the performance improvers of the asphalt binder**, (Lenoble and Nahas, 1994)** .

The use of polymer-modified asphalt (PMA) to achieve better asphalt pavement performance has been observed for a long time . The improved functional properties include permanent deformation , fatigue, low temperature cracking , stripping , and aging, **(Raad *et al.*1996; Lu and Isacsson 1997b)** .

In this research the surface (wearing) coarse is selected because this layer is always in direct contact with traffic loadings and variations in environmental conditions therefore this layer must be improved by polymers to withstand these conditions and to obtain better modification asphalt pavement with a high performance life.

- ***Research Objective :*** The research has two main objectives:

1. To evaluate the effects of density of polyethylene polymer on the properties of asphalt concrete mixtures (stability and strength to permanent deformation (rutting depth)) .
2. To evaluate the effect of temperature on the rutting depth for the asphalt concrete mixtures modified by polyethylene (PE) with different densities .

## • Materials and Methods :

### 3-1 Asphalt Cement :

One type of asphalt cement is used with (40-50) penetration grade brought from AL- Daurah refinery . The physical properties and tests of the asphalt cement used are shown in Table (1) .

### 3-2 Aggregate Properties :

The coarse aggregate used in this study is crushed aggregate from Al- Najaf quarry. This aggregate is widely used in the middle and south areas of Iraq for asphalt pavement . The particles tend to off white in color with angular surfaces . The fine aggregate obtained from Karbala quarry. The coarse and fine aggregates used in this work are sieved and recombined in the proper proportions to meet the wearing coarse gradation as required by SCRB specification **(SCRB, R/9. 2004)** . Routine tests are performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the ***SCRB*** are summarized in Table (2) . The selected gradation with specification limits are presented in Table (3).

**3-3 Filler :-**

In this study , one type of mineral fillers is used ; ordinary Portland cement Tasluja .(The physical properties of filler are presented in Table) (4) .

**4-3: Polymer:**

In order to evaluate the effect of polyethylene density on the performance of asphalt mixtures . Two types of polyethylene grades were used in this research , Low-Density Polyethylene (**LDPE**) and High-Density Polyethylene (**HDPE**) are shown in Plate (1) below , (2%, 5% and 7%) by weight of asphalt cement . the mechanical and physical properties are shown in Tables (5 & 6) .

***LDPE*** is brought from tires factory in AL-Najaf governorate , which is a white granules and used to produce plastic belts in the tires factory and another private factories in Iraq . it offers good corrosion resistance and low moisture permeability. It can be used in applications where corrosion resistance is important, but stiffness, high temperatures and structural strength are not .

***HDPE*** is brought from locally market in Iraq and provided from State Company for Petrochemical Industry (SCPI) in Basrah City, Iraq, which is a white granules and used to produce plastic belts in the tires factory and another private factories in Iraq . High-Density Polyethylene (HDPE) (0.941 < density < 0.965) is a plastomers thermoplastic polymer material composed of carbon and hydrogen atoms joined together forming high molecular weight products. It offers excellent impact resistance, light weight, low moisture absorption and high tensile strength .

Plate (1) : Photo of LDPE & HDPE

- **Test Methods and Sample preparation :**

**4-1 Marshall Test :-**

**1- Marshall Mix Design for Optimum Asphalt Content -:**

In order to complete the requirements of the experiment design work , specimens are tested by Marshall apparatus test . Four different percentages of asphalt contents (4.2 , 4.8 , 5.4 and 6) % are used . Figure (1) shows Marshall mix design curves for optimum asphalt content and it is found ( 4.8 %) . The mixtures properties at optimum asphalt contents must be compared with Table (٧) that meet the Iraqi specification requirements) **SCRB, R/9 2004** (for surface (wearing) layer of pavement .

## 2- Marshall Test for Specimens -:

Standard method of Marshall as in***) ASTM D-1559 ،(***specifications is used to find Marshall properties (volumetric properties) for compacted asphalt concrete specimens. The specimens with 10 cm diameter are tested by Marshall apparatus to determine the mixtures properties(Stability, flow, bulk density and air voids) for control mixtures and evaluate the effect of density of PE polymers on these mixtures properties .

## 4-2 Wheel Track Apparatus(WTA)Test -:

For the wheel track apparatus (WTA) test , the cylindrical specimens have 150 mm in diameter and 60 mm in height with 4% air void contents are prepared using the compaction apparatus in the laboratory to evaluate the number of blows with 4% air voids for wearing asphalt layer . The load will be applied on the specimen with load (705 ± 5) N (158 Ib ± 1.0 Ib) with dimensions 320 mm (12.60 inch) long and 260 mm (10.24 inch) wide , using steel mold with two holders have 151mm (6 inch) diameter and 6cm (2.36 inch) thick to put cylindrical specimens with diameter 150 mm (5.91 inch), ***(Lab Procedure-LLP-AC1, 2011)***. The WTA test is conducted dry to 6000 passes (3000 cycles) at 40˚C and 50˚C in which the rut depths are measured continuously. WTA test is conducted on two cylindrical samples at one time and compacted with standard Marshall compacter. In case that WTA is a completion of the 6000 passes at 40˚C and 50˚C , the testing was manually stopped and rut depth is recorded , ***(AASHTO T324, 2004)***.

- **Test Results and Discussions :-**

## 5-1 Result of Marshall Test :-

The properties of asphalt concrete mixtures that evaluated from Marshall test , such as (stability , stiffness , flow, bulk density, and air void) has been investigated to evaluate the effect of PE density on these properties and compared with properties of control asphalt mixtures . The results of this test are shown in Table (8) for control mixtures and modified mixtures with HDPE & LDPE . Three samples are used to obtain the average value. Density of polyethylene polymer is one of the physical properties of polymers , and the comparison between various densities of polyethylene(PE) with different percentages of concentration at fixed suitable predicted time of blending, to evaluate the effect of this physical property (density) of PE on the performance properties of Marshall test for modified asphalt concrete mixtures as following .

**Bulk Density :**

The bulk density of the normal asphaltic mixtures (control) is higher than the modified asphalt concrete mixtures , regardless of the modifier type, physical property and its concentration .Asphalt concrete mixtures modified with HDPE have highest bulk density than those modified with LDPE , because when the density of polyethylene increases, the bulk density of mixtures is increasing too .

**Stability :**

Two different densities of PE are selected to show the effects on stability . The asphalt concrete mixtures modified by HDPE have stability(27.20KN) at (2% HDPE) , it is higher than mixtures modified by (2% LDPE, 14.76KN) . The stability is increasing with decreasing the polymer percent , where the optimum percent of concentration is 2% for two polyethylene types as shown in Figure(2). The density of polyethylene has significant effect on stability. The stability is increased by increasing the density of polymers , because the plastomers polymers product mixtures with higher stability and stiffness that dependent on the molecular weight of polymers , it is related to increasing of density.

**Marshall Stiffness:**

Marshall stiffness represents the ratio of stability to flow . The obtained results from this test for modified mixtures with polyethylene meet the SCRB specifications (flow= (2 (٤ - mm) exhibited a higher Marshall stiffness or resistance to shear stresses , permanent deformation and hence rutting from control mixtures. The increasing of PE density causing increasing in mixtures stiffness .

**Air Void-:**

The air void content of the modified mixture dose not differ much from that of the non-modified mixture, although the air void of modified mixtures is increased with increasing polymer content, but the proportion remains within limits (3-5) % to meet the SCRB specifications . the AV proportion of the modified asphalt concrete mixtures and regardless of the modified type or state is higher than the conventional asphalt concrete mixture - no modifier (4.1%) .

## 5-2 Result of WTA Rut Test :-

**Effect of Polyethylene Density on the Rutting Depth : -**

The permanent deformations (rutting) resistant of flexible pavement for surface layer are evaluated using wheel track test. The results of this test for asphalt control mixtures and asphalt mixtures modified by polymers are shown in Table (9) . The obtained results represented the average values of the maximum rutting depth for two samples that occur at number of cycles (passes) of loading to samples failure , (6000cycle (12000passes)) at 40 C$^o$ case and (3000cycle(6000passes)) at 50 C$^o$ .

Asphalt mixtures modified by (2%HDPE) have rutting depth (2.05mm & 2.08mm) at (40 C$^o$ & 50 C$^o$ ) , respectively , lower than modified mixtures by (2% LDPE , 2.45mm at 40 C$^o$ & 50 C$^o$).These modified mixtures have rutting depth lower than modified mixtures by(5% & 7% (HDPE &LDPE)) as shown in Figures (3) & (4). The density of polyethylene (PE) has impact on the rutting , in which the rutting depth decreasing by increasing in density at the optimum percent of PE polymer (2%) . Increases of percent of concentration of HDPE & LDPE corresponded increasing on the rutting depth , so the HDPE is better than LDPE because it has high molecule weight(high density) that gives a high stiffness then better resistance of permanent deformation , ***(Crossley, 1998)***.

**Effect of Temperature on the Rutting Depth for the Asphalt Mixtures Modified by Polyethylene(PE) with Different Densities :-**

The temperatures have significant effect on the rutting depth and on the number of wheel loading passes . The samples failed under wheel loading passes 12000 passes(6000cycles) at temperature 40 C$^o$ test , and 6000 passes(3000 cycles) at temperature 50 C$^o$, according to (***AASHTO ,T324-04*** ) for typical curve of Hamburg wheel track test results . So the wheel loading passes are reduced to half due to increase of temperature from 40 C$^o$ to 50 C$^o$.

The effect of temperature is illustrated in Table ، (١٠) for rutting depth after 6000 passes at 40˚C and 50˚C, in which the results are presented in Figure .(٥) It is clear that when the temperature increases to 50˚C rutting depth increased. However, at higher test temperatures, mixes with polymer modified binder are performed relatively better than mixes with an unmodified binder.

**Conclusions:-**

within the limitation of this research , the following results are concluded :-

1. Polyethylene modified mixtures have a significant higher performance properties (stability , stiffness , fatigue resistance and permanent deformation resistance) among the other used polymers in which the increasing of the density for polyethylene (HDPE polymer) causing increasing in the stability (above 100%) , and decreasing in the rutting depth by (67%) times than control asphalt mixes.
2. The results from wheel track test show that the rutting depth for the modified specimens are lower than control mixtures , therefore the resistance to permanent deformation for modified mixtures is higher than control mixtures under the two different test temperatures (40 C$^o$ and 50 C$^o$) . The modified mixtures with HDPE have rutting depth values are lower than about (65%) at 40 C$^o$ and about(67%) at 50 C$^o$ temperature test , but LDPE gives rutting depth values are lower than about(56%) at 40 C$^o$ and about(61%) at 50 C$^o$ temperature test, after compared with control

mixtures .Therefore the HDPE is better than LDPE to modified mixtures that causing from increasing in polymer's density (molecular weight) .

3. Test temperature plays an important role in permanent deformation, when increasing test temperature from (40 to 50)°C permanent deformation (rutting depth) increased by (100%). The effect of temperatures are clearly shown, where the control and modified specimens need half cycles of wheel passes to failure under the same loading if the temperatures increasing from 40 C° to 50 C° , and the rutting depth become have a higher values .

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Table (1): Physical properties and tests of asphalt cement * .

| *Property* | *ASTM Designation* | *Test Result* | *SCRB Specification* |
|---|---|---|---|
| Penetration (25 $^0$C,100 gm,5 sec) (mm٠,١)، | D-5 | ٤٦ | (٥٠-٤٠) |
| (cst)Kinematic viscosity at 135 C$^0$, | D-2170 | ٣٨٥ | ------ |
| (cm)Ductility (25 C$^0$, 5 cm/min). | D-113 | ١٠٩ | ١٠٠< |
| (C$^0$) ،Flash point(Cleveland open cup) | D-92 | ٣٣٩ | Min.232 |
| (C$^0$)Softening Point. | D-36 | ٥٤ | ------ |
| C$^0$ ٢٥Specific gravity at | D-70 | ١,٠٤ | (١,٠٥-١,٠١) |

- ***These tests were accomplished in the transportation laboratory of civil department engineering in the Babylon University and the laboratory of AL -Daurah refinery ، south-west of Baghdad.***

Table (2): Physical properties of aggregate.*

| *Property* | *ASTM Designation* | *Coarse aggregate* | *Fine aggregate* | *SCRB specification* |
|---|---|---|---|---|
| Bulk specific gravity | C-127 C-128 | ٢,٥٤ | ٢,٦٦ | ----- |
| Apparent specific gravity | C-127 C-128 | ٢,٦٧ | ٢,٦٨ | ----- |
| % water absorption | C-127 C-128 | ٠,٨٦ | ٠,٦٣ | ----- |
| (Los Angeles)Abrasion | C-131 | % ٢٥ | ------ | % ٣٠Max |
| % ,Fractured pieces | D-5821 | % ٩٦ | ------ | % ٩٥Min |

- ***These tests were accomplished in the transportation and material laboratories of civil engineering in the Babylon University***

Table (3): Asphalt mixture grading for surface (wearing) course , Type A.

| *Specification limits for SCRB),Type )wearing coarse IIIA* | *(% passing by weight +of total aggregate (filler* | *Sieve size* | |
|---|---|---|---|
| | | *English sieves ((in* | *Standard sieves ((mm* |
| ١٠٠ | ١٠٠ | "٤/٣ | ١٩ |
| ١٠٠-٩٠ | ٩٥ | "٢/١ | ١٢,٥ |
| ٩٠-٧٦ | ٨٣ | "٨/٣ | ٩,٥ |
| ٧٤-٤٤ | ٥٩ | No.4 | ٤,٧٥ |
| ٥٨-٢٨ | ٤٣ | No.8 | ٢,٣٦ |
| ٢١-٥ | ١٣ | No.50 | ٠,٣ |
| ١٠-٤ | ٧ | No.200 | ٠,٠٧٥ |
| ٦-4 | ٤,٨ | Asphalt cement (by weight of total mix %) | |

Table (4): Physical properties of the used filler.*

| *Property* | *Cement filler* |
|---|---|
| Specific gravity | ٣,١٣ |
| Passing sieve No.200 (mm0.075) | 96 |

- ***These tests were accomplished in the transportation and material laboratories of civil engineering in the . Babylon University***

Table (5) : Physical properties of LDPE .
. ( *State Company for Petrochemical Industry , SCPI ,2008 )*

| *Value* | *Unit* | *ASTM-Standard* | *property* |
|---|---|---|---|
| ٠,٩٢٢ | gm/cm$^3$ | ١٥٠٥–D | Density |
| ٠,٣٣ | g/10 min | ١٢٣٨–D | Melt index |
| ٢١ | MPa | MD ،D – 882 | Tensile strength at break |
| 19 | | TD ،D – 882 | |
| ٩ | MPa | MD ،D – 882 | Tensile strength at yield |
| | | TD ،D – 882 | |
| ١٧٥ | MPa | MD ،D – 882 | ( (1% Secant Modulus |
| 210 | | TD ،D – 882 | |
| ٣١٠ | % | MD ،D – 882 | Elongation at break |
| 550 | | TD ،D – 882 | |
| ٠,٦ | ---- | ١٨٩٤–D | Kinetic coefficient |
| ١٧٠ | C$^o$ | ---- | Melting point |

. Table (6): Physical properties of HDPE
. ( *State Company for Petrochemical Industry , SCPI , 2008 )*

| *Value* | *Unit* | *ASTM-Standard* | *property* |
|---|---|---|---|
| ٠,٩٤٩ | cm$^3$ /gm | ١٥٠٥-D | Density |
| ٠,٣٣ -0. 15<br>٣٢ -18 | g/10 min<br>MPa | ١٢٣٨-D<br>٨٨٢ -D | Melt index<br>Tensile yield strength |
| ٦٠ -10 | MPa | ٨٨٢ -D | Tensile strength at break |
| ٧٠ -45 | Shore D | ------ | Hardness |
| ١١٠٣–758 | MPa | ٧٩٠ -D | ( Ef)Flexural modulus |
| ١٨٠ | C$^o$ | ------ | Melting point |

Table (7) : Mix Properties at Optimum Asphalt Content and Specification Requirements.

| *(Specification requirements (SCRB* | *Mixture properties* | *Marshall property* |
|---|---|---|
| .min ٨ | ١٠,٦٠ | ***KN ،Stability*** |
| ٤ -2 | ٣,٠٠ | ***mm ،Flow*** |
| ٥ -3 | ٤,٠١ | ***Percent air voids*** |
| .min ١٤ | ١٥,٢٠ | ***Percent VMA*** |

Table (8) : Marshall test results for control mixture & asphalt mixtures modified by Polyethylene (PE) with two different densities .

| ***Sample*** | ***Polymer Percent %*** | ***Marshall Stability (KN)*** | ***Marshall Flow (mm)*** | ***Bulk Density gm\|cm³*** | ***Stiffness (KN/mm)*** | ***Air void %*** |
|---|---|---|---|---|---|---|
| ***Control ((Unmodified*** | ---- | ٩,٤٩ | ٢,٠٨ | ٢,٣٨٠ | ٤,١٨١ | ٤,١٠ |
| ***Modified with HDPE*** | ٢ | ٢٧,٢٠ | ٣,٣٥ | ٢,٣٤٣ | ٨,١١٩ | ٤,٠٣ |
| | ٥ | ١٦,٠٠ | ٣,٦٤ | ٢,٣٣٠ | ٤,٣٩٦ | ٤,٣٥ |
| | ٧ | ١٣,٦٣ | ٢,٩٨ | ٢,٣٢١ | ٤,٥٧٤ | ٤,٥٥ |
| ***Modified with LDPE*** | ٢ | ١٤,٧٦ | ٢,٤٥ | ٣,٣٣٢ | ٦,٠٢٤ | ٤,١٦ |
| | ٥ | ١٢,١٠ | ٣,١٠ | ٢,٣٢٨ | ٣,٩٠٣ | ٤,٤٢ |
| | ٧ | ١١,١٥ | ٣,٠١ | ٢,٣١٨ | ٣,٧٠٤ | ٤,٦٤ |

Table (9) : Wheel track test results at 40 Cº & 50 Cº for control mixture & asphalt mixtures modified by Polyethylene (PE) with two different densities .

| *Sample* | *Polymer Percent %* | *Case 40 Cº at 6000 cycles(12000 passes)* | *Case 50 Cº at 3000 cycles(6000 passes)* |
|---|---|---|---|
| | | *Rutting Depth (mm)* | *Rutting Depth (mm)* |
| *Control (Unmodified)* | ---- | 4.55 | 6.25 |
| *Modified by HDPE* | ٢ | ٦,٤٧ | 2.08 |
| | ٥ | ٢,٠٥ | 2.52 |
| | ٧ | ٢,٥٠ | 3.04 |
| *Modified by LDPE* | ٢ | ٢,٩٨ | 2.45 |
| | ٥ | ٢,٤٥ | 2.97 |
| | ٧ | ٢,٩٦ | 3.30 |

Table (10) : Wheel track test results (rutting depth) after 6000 passes at 40 Cº & 50 Cº for control mixture & asphalt mixtures modified by Polyethylene (PE) with two different densities .

| *Sample* | *Polymer Percent%* | *Case 40 Cº at 3000 cycles(6000 passes)* | *Case 50 Cº at 3000 cycles(6000 passes)* |
|---|---|---|---|
| | | *Rutting Depth (mm)* | *Rutting Depth (mm)* |
| *Control (Unmodified)* | ---- | 4.55 | 6.25 |
| *Modified by HDPE* | 2 | 1.61 | 2.08 |
| | 5 | 2.04 | 2.52 |
| | 7 | 2.50 | 3.04 |
| *Modified by LDPE* | 2 | 2.02 | 2.45 |
| | 5 | 2.47 | 2.97 |
| | 7 | 2.89 | 3.30 |

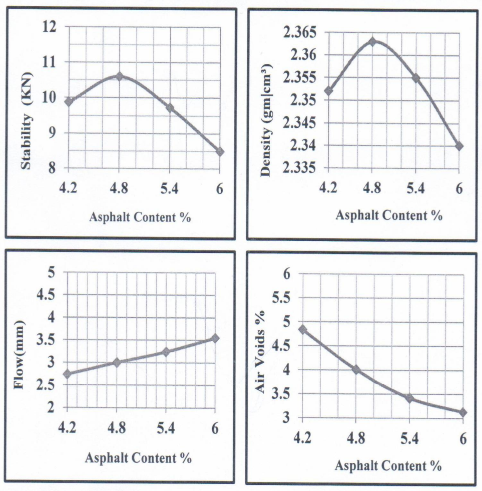
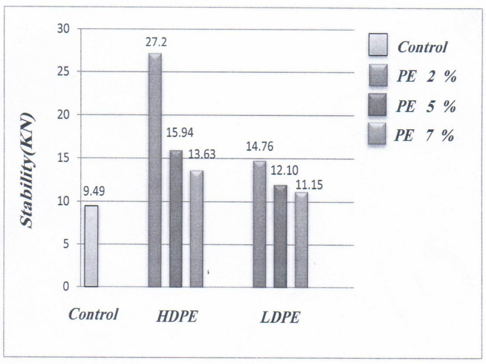
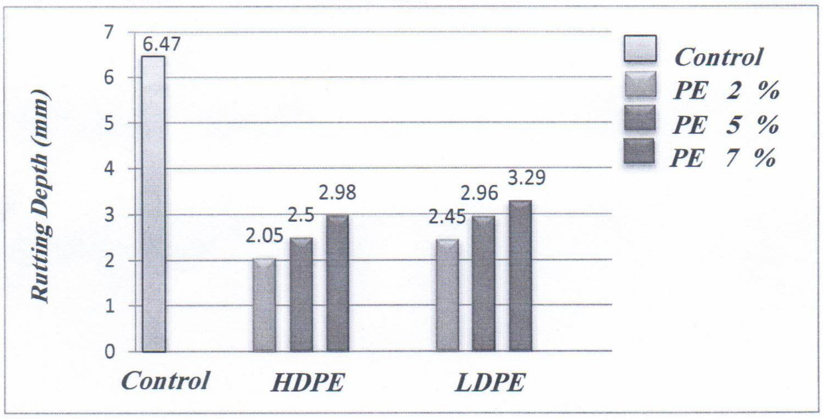


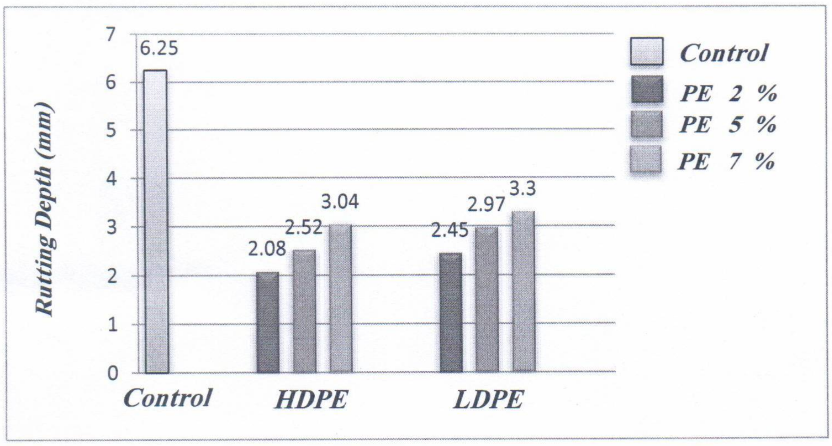

Figure (1): Marshall mix design curves for optimum asphalt content.



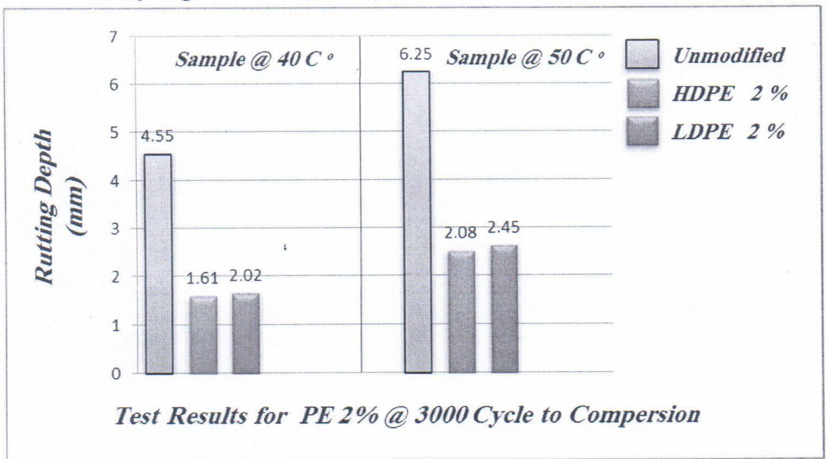

Figure(2) : Effect of Density of Polyethylene Polymer (PE) on Stability of Asphalt Concrete Modified Mixture .




Figure(3) : Effect Density of Polyethylene Polymer (PE) on Permanent Deformation(Rutting Depth @ 40 C° Test) of Asphalt Concrete Modified Mixture .




Figure(4) : Effect Density of Polyethylene Polymer (PE) on Permanent Deformation(Rutting Depth @ 50 C° Test) of Asphalt Concrete Modified Mixture .




Figure(5) : Effect of Temperature on the Rutting Depth for the Asphalt Mixtures Modified by Polyethylene(PE) with Different Densities