behavior of asphalt mixtures using modified asphalt cement

Conference Paper · December 2000

1 author:

El-sayed Abdelfattah El-kasaby
Benha University

Al-AZHAR UNIVERSITY ENGINEERING JOURNAL

AUEJ

(SPECIAL ISSUE)

Proceedings of Al-Azhar Engineering Sixth International Conference

AEIC 2000

Published by Faculty of Engineering
Al-Azhar University, Cairo- Egypt

BEHAVIOR OF ASPHALT MIXTURES USING MODIFIED ASPHALT CEMENT

سلوك الخلطات الأسفلتية مستخدما الأسفلت الصلب المحسن

" الملخص باللغة العربية"

انتشرت فى الآونة الأخيرة، استخدام المواد المضافة للخلطة الأسفلتية الساخنة بهدف تحسين خصائصها، وكعلاج لمشاكل الرصف المرن المتعددة، ومن المواد التى ذاع انتشارها كمحسن لمادة الأسفلت، وكذلك الخلطات الأسفلتية الساخنة المواد المعاد تصنيعها، والمطاط، والمواد الناعمة، والبوليمرات.

ويهدف هذا البحث إلى تقييم الخلطات الأسفلتية الساخنة المنتجة باستخدام الأسفلت المحسن، بإضافة خام البولى بروبلين،وهو أحد أنواع البوليمرات التى كثر استخدامها فى مصر مؤخرا فى صناعة البلاستيك.

ولتحقيق الهدف من هذا البحث تم تقسيمه إلى قسمين رئيسيين :

القسم الأول: يشتمل على دراسة تأثير خام البولى بروبلين على خصائص أسفلت شركة الإسكندرية للبترول بدرجتى غرز مختلفتين وهما (٨٠-١٠٠) بنسب مئوية هى (١،٢،٣،٤،٦،٨%) و (٦٠-٧٠) بنسبتى (٢،٤%) من وزن الأسفلت لدراسة إمكانية تحسين خصائصه وكذلك مقارنه خصائص الأسفلت (٨٠-١٠٠) قبل وبعد الإضافات، بخصائص الأسفلت (٦٠-٧٠)، وهذه الخصائص هى الغرز والتطرية، واللزوجة الكينماتيكية، واللزوجة المطلقة، والوزن النوعى، واختبار الطبقة الرقيقة.

القسم الثانى : يشتمل على دراسة تأثير خام البولى بروبلين على خصائص الخلطات الأسفلتية المنتجة باستخدام أسفلت القسم الأول، وكذلك مقارنه خصائص الخلطات الأسفلتية (٨٠-١٠٠) قبل وبعد الإضافات بخصائص الخلطات الأسفلتيه (٦٠-٧٠)، وهذه الخصائص هى الثبات، والانسياب، ونسبة الفراغات فى الخلطة، ونسبة الفراغات فى الركام، والوزن النوعى، وذلك عن طريق تصميم مارشال، كما يشتمل هذا القسم أيضاً على دراسة تأثير الأحمال الديناميكية الترددية لقياس التخدد عند درجتى حرارة ٢٥،٦٠ْم وإجهاد ثابت وهو ٦,٢٥ كجم/سم٢، وكذلك تأثير الأحمال الساكنة عند درجة حرارة ثابتة وهى ٢٥ْم و إجهادات مختلفة وهى ٤,٢ ،٦,٢٥،٨,٣،٩ كجم/سم٢ لقياس الزحف على الخلطات الأسفلتية الساخنة المنتجة باستخدام خام البولى بروبلين، ومقارنتها بالخلطات التقليدية، وأخيراً تم إيجاد علاقات تربط بين نتائج اختبارات التخدد والزحف عند درجة حرارة ثابتة وهى ٢٥ ْم وإجهاد ثابت وهو ٦,٢٥ كجم/سم٢.

وأهم الاستنتاجات التى توصلت إليها هذه الدراسة:-

١- إضافة خام البولى بروبلين بنسبتى ٣و ٤% بالوزن للأسفلت (٨٠-١٠٠)، تعدل من خصائصه الفيزيقية وتجعله يدخل فى نطاق الأسفلت (٦٠-٧٠) طبقاً للمواصفات المصرية.

٢- إضافة خام البولى بروبلين حتى نسبه ٤% من وزن أسفلت الإسكندرية، تحسن من قيمة معامل الغرز ، وعلى ذلك يمكن اعتبار النسبة المثلى لإضافة خام البولى بروبلين إلى أسفلت الإسكندرية هى نسبه ٤% حيث أن معدل التحسن فى معامل الغرز يقل بإضافة خام البولى بروبلين فوق هذه النسبة.

٣- بزيادة نسبة البولى بروبلين، يزداد كل من نسبة الفراغات فى الخلطة الأسفلتية، والثبات ومعامل الصلابة لمارشال، ويقل الانسياب للخلطة الأسفلتية، وعند نسبة إضافة ١% تتحسن خصائص الخلطة الأسفلتية (٨٠-١٠٠)، وتصبح افضل من الخلطة الأسفلتية (٦٠-٧٠)، وكذلك يحدث تغير طفيف مع زيادة نسبة الإضافات لكل من الوزن النوعى، ومحتوى الأسفلت الأمثل، ونسبة الفراغات فى الركام.

٤- بزيادة إضافة خام البولى بروبلين فى الخلطة الأسفلتية (٨٠ -١٠٠)، يقل عمق التشكل ويزداد معامل الصلابة الديناميكى مع زيادة زمن وعدد مرات التحميل، وكذلك يقل الزحف ويزداد معلمل الصلابة الاستاتيكى مع زيادة زمن التحميل واقل عمق تشكل واقل زحف ينتج عند إضافة ٤% بولى بروبلين من وزن الأسفلت للخلطة الأسفلتية (٨٠ -١٠٠).

٥- إضافة خام البولى بروبلين إلى الخلطة الأسفلتية (٨٠-١٠٠)، يحسن من قيم معدل عمق التشكل وبالتالى يحسن كل من الثبات والانسياب ومعامل الصلابة لمارشال.

٦- إضافة خام البولى بروبلين، يؤخر من زمن التشكل إلى ٣٥ دقيقه للخلطة الأسفلتية ٣% بولى بروبلين، و٤٥ دقيقه للخلطة الأسفلتية ٤% بولى بروبلين عند ٢٥م° .

وبناء على النتائج السابقة ، نوصى :-

١- بدراسة السلوك الكيميائى لخليط الأسفلت مع خام البولى بروبلين، عند نسب الإضافات المختلفة.

٢- إضافة نسبة ٤% بولى بروبلين من وزن الأسفلت (٨٠-١٠٠) كنسبه مثلى عند إضافته للخلطات الأسفلتية.

٣- بعمل قطاعات رصف تجريبية، لقياس الأداء الحقلى للخلطات الأسفلتية المنتجة، باستخدام خام البولى بروبلين فى ظل ظروف المرور والبيئة المحيطة .

٤- بدراسة مقاومة الخلطة الأسفلتية لإجهاد الكلال.

٥- بعمل دراسة اقتصادية لتكنولوجيا الأضافات مع الأسفلت.

BEHAVIOR OF ASPHALT MIXTURES USING MODIFIED ASPHALT CEMENTS

Badr El-Din A. Mousa*, EL- Sayed A. EL-Kasaby**, and Ahmed G. Mhamoud ***

ABSTRACT

The purpose of this study is to evaluate the effect of adding polypropylene pellets (PP) on the asphalt cements and their asphalt mixtures properties, and the long-term performance.

The variables considered are the effect of adding different ratios of PP on Alex 80/100 and 60/70 A.C properties. The added ratios are 1, 2, 3, 4, 6 and 8% by weight for 80/100 A.C & 2 and 4% by weight for 60/70 A.C. For asphalt mixtures, the variables considered are the effect of the above modified asphalt cements on Marshall properties and on rutting results as evaluated by wheel tracking machine at 25 and 60°C at 6.25 kg/cm^2 stress level and on creep results at 4.2, 6.25 and 9.38 Kg/cm^2 at 25°C. stress levels.

The results of this study indicate that the addition of PP to Alex. A.C and its asphalt mixtures at all ratios improved the all properties. The addition of 3and 4%PP by weight of Alex. 80/100 AC alters its physical properties to be similar to 60/70 A.C. The addition of PP to Alex. A.C improves its thermal characteristics by increasing its penetration index. Increasing the percentages of PP increases stability and Marshall stiffness and decreases the flow of Alex. asphalt concrete mixtures but the unit weight, voids in mineral aggregates and optimum asphalt content are not sensitive. The 80/100 asphalt mixture at 4% PP/A ratio provides much better performance than the others. Moreover this mixture gives the lowest rate of increasing in creep when increasing the stress level. Finally, correlation between wheel tracking test and creep test is developed at 25°C and stress level of 6.25 Kg/cm^2.

KEYWORDS

Polypropylene, Penetration index, Temperature susceptibility, Marshall stiffness, Rutting depth, Rutting stiffness, Creep result and Creep stiffness.

INTRODUCTION

Due to the unexpectedly rapid growth in traffic, particularly of heavy loads, and a continually upward pressure for higher maximum permissible axle loads, many roads that were built during such period are coming to the end of their useful lives. Distress signs take the form of severe rutting of the road, cracking and disintegration of surface materials. Road authorities are looking for materials for maintenance and rehabilitation, which will be capable of giving better performance over longer period [1].

The characteristics of asphalt and asphalt mixtures may be improved by means of using additives [2] such as fly ash[2], carbon black [3], sulfur [4], lime [5], wood fibers [6], rubber [7] and polymers [8].

* Associate Prof. Construction Eng. & Utilities Dep., Faculty of Eng. Zagazig University, Egypt.
** Head of Civil Eng. Department, Benha Higher Inst. of Technology, Egypt.
*** Assistant lecturer, Civil Eng. Department, Benha Higher Inst. of Technology, Egypt.

The main objectives of this study is to evaluate the effect of adding polypropylene materials on the properties of the asphalt cements and their asphalt concrete mixtures and comparing these modified properties with the unmodified properties of the conventional asphalt cements and their asphalt concrete mixtures.

MATERIALS AND STUDY PROGRAM

The materials used in this study composed of aggregate, bituminous and polypropylene. Crushed dolomite obtained from El-Suez used as coarse aggregate. Its engineering properties presented in Table (1). Siliceous sand obtained from Ismailia used as fine aggregate, its bulk specific gravity is 2.65. Cement dust filler of bulk specific gravity 2.868 used as mineral filler. The 60/70 and 80/100 A.C obtained from Alexandria Petroleum Company, their physical properties are found to be as shown in Table (2). Polypropylene pellets were imported from Hanwoo International LTD., Seoul, Korea by the United International Tread Co., Giza City. The size of polypropylene used in this study was passing from sieve No. (4) and retained on sieve No. (8). The physical and engineering properties of polypropylene are shown in Table (3) according to The ASTM specification limits.

The study program was divided into two phases:

Phase1: This phase is concerned with preparing different PP/A samples at ratios 0,1,2,3,4,6 and 8% were added by weight for 80/100 A.C and PP/A= 0,2, and 4% were added by weight for 60/70 A.C to evaluate the effect of adding polypropylene on the physical properties of Alex. 80/100 and 60/70 A.C, and compare the properties of 80/100 A.C before and after modification with Alex. 60/70 A.C without modification. The preparing or heating temperature of the modified asphalt was 190 ± 5°C for one hour, continuous stirring from time to time through the heating time by using an electric mixer is very important to obtain a homogeneous binder. The following tests were performed on the different samples including: Penetration, Softening point, Kinematic viscosity, Absolute viscosity, Flash point, Specific gravity and Thin film oven test.

Phase 2: One gradation was used in this study. This gradation meets the dense gradation as shown in Table (4). The asphalt mixtures designed by using Marshall procedure according to ERBA (T-231). Two groups of the asphalt mixtures were designed, the first group includes the unmodified asphalt mixtures produced by the 60/70 A.C and 80/100 A.C, while the second group includes the modified asphalt mixtures produced by the modified 80/100 and 60/70 A.C under the PP/A ratios as listed before in phase 1. Two tests were conducted on the asphalt mixtures of the first group and on the best PP ratio of Alex. 80/100 asphalt cement in the second group from the analysis of phase 1, these tests are the wheel tracking and the creep tests. To achieve both of the wheel tracking test[9] and the creep test [10] some considered variables were selected; these variables are the temperatures 25°C and 60°C at 6.25kg/cm^2 stress level for wheel tracking test & stress levels 4.2, 6.25 and 9.38Kg/Cm^2 at temperature 25°C for creep test.

RESULTS AND ANALYSIS OF PHASE I

Modification of Alex. Asphalt Cement

Table (5) presents the results of the conventional tests for Alex. AC at different percentages of PP. This table shows that the specific gravity of Alex. AC decreases as PP/A ratio increases. The addition of 3 and 4% PP by weight to Alex.80/100A.C alters its physical properties to be similar to 60/70 AC. The variation rates in Alex. AC due to the addition of PP at the different percentages are presented in Table (6). This table shows that the penetration value of Alex. 80/100 A.C decreases with increasing the PP/A ratio from 0 to 1,2,3,4,6 and 8% by 13.48,19.1,22.47, 25.84,47.19 and 52.81 % respectively, for Alex. 60/70 A.C, increasing the PP/A ratio by 2 and 4% decreases the penetration values by 9.38 and 14.06% respectively. The kinematic viscosity values of Alex. 80/100 A.C increases with increasing the PP/A ratio from 0 to 1,2,3 and 4 % by 3.86,31.27,39.38 and 45.56 % respectively, for 60/70 A.C, increasing the PP/A ratio by 2 and 4% increases the kinematic viscosity by 19.89 and 26.61% respectively. Increasing the PP/A ratio by 1,2,3,4,6 and 8% increases the absolute viscosity by 7.55,16.18,26.22, 40.04,47.56 and 73.73 % respectively, for 60/70 A.C, increasing the PP/A ratio by 2 and 4% increases the absolute viscosity by 3.7 and14.88 % respectively. The softening point values of Alex. 80/100 A.C increases with increasing the PP/A ratio from 0 to 1,2,3,4,6 and 8% by 3.37,5.62, 13.48, 16.85, 21.35 and 23.6 % respectively, for 60/70 A.C, the softening point values increases with increasing the PP/A ratio from 0 to 2 and 4%by 8.33 and 12.5 % respectively.

One test used to evaluate the changes in temperature and other atmospheric factors is the thin-film oven test. The consistency of the material is determined before and after the T.F.O procedure, using the penetration test, and the losses in weight, to estimate the amount of hardening that will take place in the material when used to procedure plant hot-mix. The addition of 1,2,3,4,6 and 8% PP to 80/100 A.C decreases the penetration after T.F.O.T by 22.66,36.00,42.66,50.66,77.33 and 81.33% respectively. The addition of 2 and 4% PP to 60/70 A.C decreases the penetration after T.F.O.T by 15.38 and 28.2%.

The addition of 1,2,3,4,6 and 8% PP to 80/100 A.C decreases the penetration ratio by 10.68,20.52,27.16,33.57,57.09 and 60.46% respectively. The addition of 2 and 4% PP to 60/70 A.C decreases the penetration ratio by 6.72 and 16.56% respectively. The losses in weight values after heating of Alex. 80/100 A.C satisfies the E.R.B.A specification limits of 80/100 A.C at all ratios. The increase of (PP/A) ratio by 1,2,3 and 4% decreases the losses by 25.98,52.76,76.38 and 96.06% respectively. Increasing of PP/A ratio by 2 and 4% decreases the losses by 21.89 and 39.48% respectively.

Comparison between Modified and unmodified 80/100 A.C and unmodified 60/70 A.C

A comparison between Alex. 80/100 A.C before and after the addition of different PP/A ratio and Alex. 60/70 A.C is presented in Table (7). The penetration value of Alex. 60/70 A.C is lower than the penetration value of Alex 80/100 A.C at PP/A =0 ,3 and 4% by 39.06, 7.81 and 3.13 % respectively. The kinematic viscosity value of Alex. 60/70 A.C is better and higher than the values of Alex. 80/100 A.C at PP/A = 0 % by 27.45%, and is lower than the kinematic viscosity values of Alex. 80/100 A.C at PP/A = 3 and 4 % by 1.12 and 5.6 % respectively. The absolute viscosity values of Alex. 80/100 A.C at PP/A =0, 3 and 4% is lower than the value of Alex. 60/70 A.C by 44.83, 30.38 and 25.75% respectively. The softening point value of Alex.60/70 A.C is higher than the softening point values of 80/100 A.C at PP/A = 0 % by 7.29 % and is lower than the softening point values of Alex. 80/100 A.C at PP/A = 3 and 4% by 5.21and 8.33 % respectively. The penetration value after T.F.O.T of Alex. 60/70 A.C is lower than the values of Alex. 80/100 A.C at PP/A = 0 and 3% by 92.31 and 10.26 % respectively, while the penetration value after T.F.O.T of Alex. 60/70 A.C is higher than the value of Alex. 80/100 A.C at PP/A = 4% by 5.13%. The penetration ratio value of Alex. 60/70 A.C is lower than the values of 80/100 A.C at PP/A = 0 and 3% by 38.2and 0.66% respectively, and is higher than the value of 80/100 A.C at PP/A= 4% by 8.2 %. The losses in weight values of Alex. 80/100 A.C at PP/A = 0, 3 and 4% is lower than the losses in weight value of Alex. 60/70 A.C by 45.5, 87.12 and 97.85% respectively.

Temperature Susceptibility

Penetration index (PI) is used as a parameter in this study to describe the temperature susceptibility of the modified and unmodified AC. The penetration index (PI), has been expressed, by Pfeiffer and Van Doormaal .

$$(\text{Log } 800 - \text{Log Pen.})/(T_{R+B} - T) = (20-PI)/[50(10+PI)]$$

Where Log pen. is the logarithm to base10 of the measured penetration, T_{R+B} is the softening point in degrees Celsius and T is the temperature at which the penetration test was carried out (25°C).

For simplicity, SHEEL researchers have developed a simple measure of temperature susceptibility to obtain the PI. Table (8) shows values of PI by using the above equation, these values satisfy the normal asphalt range ($-2.0 < PI < +2.0$). Also, Table (8) shows that, the penetration index of 80/100 A.C increases with increasing the PP/A ratios from 1 % to 8 % by 4.65,13.18, 78.29, 98.45, 69.77 and 66.66 % respectively. The penetration index of 60/70 A.C increases with increasing the PP/A ratios by 2 and 4% by 68.42 and 98.25 % respectively. Table (9) and Fig. (1) present a comparison between PI values of Alex. 80/100 A.C at all ratio of PP/A and the PI value of Alex. 60/70 A.C, the results show that, the PI value of Alex. 60/70 A.C is higher than the PI values of Alex. 80/100 A.C at (PP/A = 0 and 1%) by 13.16 and 7.9 % respectively, and is lower than the PI values of Alex. 80/100 A.C at (PP/A = 2,3,4,6 and 8%) by 1.75, 75.44, 98.25, 65.79 and 62.28 % respectively. The higher increasing ratio at (PP/A = 3 and 4 %) in PI values indicates the best improvement in the temperature susceptibility of 80/100 A.C.

RESULTS AND ANALYSIS OF PHASE 2

This Phase presents the results of different asphalt mixtures produced by different asphalt cement types at different PP/A ratio. This phase includes Marshall test results, rutting test results and creep test results.

Marshall Test Results

Table (10) presents a summary to the engineering properties for all asphalt mixtures at their optimum asphalt contents (O.A.C). The optimum asphalt content, unit weights and voids in mineral aggregates are approximately the same after the addition of polypropylene. The addition of polypropylene improves the air voids stability, flow and Marshall stiffness, the improvement rates are shown in Table (11). The stability values of Alex. asphalt mixtures satisfy the ERBA specification limits of a minimum 1500 Ib at all PP/A ratio. For 80/100 asphalt mixtures, the increase of PP/A ratio by 1,2,3,4,6 and 8 % increases the stability value by 10.64, 21, 26.21, 47.33, 79.27 and 130.25 % respectively. For 60/70 asphalt mixtures, the increase of PP/A ratio by 2 and 4 % increases the stability value by 63.45 and 110.41 % respectively. The flow of Alex. asphalt mixtures satisfy the ERBA specification range (0.08-0.16 in). For 80/100 asphalt mixtures the increase of PP/A ratio by 1,2,3,4,6 and 8% decreases the flow value by 5.5,9.15,22.34, 23.08, 26.74 and 30.4 % respectively. For 60/70 asphalt mixtures the increase of PP/A ratio by 2 and 4% decreases the flow value by 15.13 and 24.72 % respectively. The air voids of Alex. asphalt mixtures satisfy the ERBA specification range (3-5%). For 80/100 asphalt mixtures the increase of PP/A ratio by 1,2,3,4, 6 and 8% improves the air voids by 1.64, 3.28, 6.56, 8.2, 27.87 and 44.26 % respectively. For 60/70 asphalt mixtures the increase of PP/A ratio by 2 and 4% improves the air voids by 12.12 and 30.30% receptively. The unit weight, voids in Mineral Aggregates and O.A.C of the all asphalt mixtures are approximately the same and do not significantly affected by changing the polypropylene percent.

Comparison between Modified and unmodified 80/100 asphalt mixtures and unmodified 60/70 asphalt mixtures.

A comparison to Marshall results between of Alex. 80/100 asphalt mixtures at different polypropylene ratio and Alex. 60/70 asphalt mixtures are shown in Table (12). This Table shows that the stability value of Alex.60/70 asphalt mixture is higher than the stability value of Alex. 80/100 asphalt mixture by 9.39 % and is lower than the stability values of

Alex. 80/100 asphalt mixtures at PP/A = 1,2,3,4,6 and 8% by 0.25, 9.64, 14.73, 33.5, 62.44 and 108.63 % respectively. The flow value of Alex. 60/70 asphalt mixtures is lower than the flow value of 80/100 asphalt mixture at PP/A = 0% by 0.74 %, and the flow values of Alex. 80/100 asphalt mixtures at PP/A= 1,2,3,4,6 and 8% are higher than the flow value of Alex. 60/70 asphalt mixture by 4.8, 8.5, 21.77, 22.51, 26.20 and 29.89 % respectively. The air voids of Alex. asphalt mixtures satisfy the ERBA specification range (3-5%). For 80/100 asphalt mixtures the increase of PP/A ratio by 1,2,3,4, 6 and 8% improves the air voids by 1.64, 3.28, 6.56, 8.2, 27.87 and 44.26 % respectively. For 60/70 asphalt mixtures the increase of PP/A ratio by 2 and 4% improves the air voids by 12.12 and 30.30% receptively.

Marshall Stiffness Results

The values of Marshall stiffness that are shown in Table (10) are calculated by using this equation [11]:

$$S_M \text{ (psi)} = \text{Marshall Stability (lb)/[Marshall Flow (0.01 in) * Specimen Height (in)]}$$

For 80/100 asphalt mixtures the increases of PP/A ratio by 1,2,3,4,6 and 8 % increases the Marshall stiffness value by 17.07, 33.21, 63.03, 91.53, 144.7 and 230.82% respectively. For 60/70 asphalt mixtures the increases of PP/A ratio by 2 and 4 % increases the Marshall stiffness value by 92.61 and 179.54% respectively. Table (12) shows that, the Marshall stiffness value of Alex. 80/100 asphalt mixture at PP/A = 0 % is lower than the Marshall stiffness value of Alex. 60/70 asphalt mixture by 10.04%, and the Marshall stiffness values of Alex. 80/100 asphalt mixtures at PP/A = 1,2,3,4,6 and 8 % is better and higher than the value of 60/70 asphalt mixture by 5.31, 19.83, 46.65, 72.3, 120.12 and 197.6 % respectively.

Evaluation of asphalt mixes deformation resistance using rutting and creep tests

In this part of the study, rutting and creep specimens were duplicated for Alex. 60/70 asphalt mixtures without modification and Alex. 80/100 asphalt mixtures at PP/A =0, 3 and 4 % at their O.A.C. The PP/A ratio at 1,2,6 and 8 % for 80/100 asphalt mixtures & PP/A ratio at 2 and 4% for 60/70 asphalt mixtures were ignored because the penetration values of these ratios did not satisfy the ERBA specification limits of penetration for both 80/100 A.C and 60/70 A.C.

Rutting Results: Twelve specimens of Alex. 80/100 asphalt mixture at PP/A= 0,3 and 4% and four specimens of Alex. 60/70 asphalt mixture were used in rutting test according to the temperature of the test. The testing temperatures were 25 and 60°C, these temperatures represents the laboratory temperature and the maximum temperature of the asphalt concrete surface in summer. All specimens were tested in wheel tracking machine under a constant repeated stress equal to 6.25 Kg/ Cm^2 (90 psi) and also were cured for three days before testing. The rutting depth deformation was record with time.

The rutting stiffness of the mixture was calculated by using an equation developed by J.F. Hill [12] for the wheeal tracking test as follows:

$$S_{r\ mix} = (Z * \sigma_o * H_o) / (RD)$$

Where; $S_{r\ mix}$: Rutting stiffness modulus of mixture in Kg/Cm^2, Z: Dimensionless parameter equal to 0.5 for wheel tracking machine where the asphalt layer rested on a steel base plate, σo: Contact stress at the surface of the specimen in the rutting test (6.25Kg/Cm^2), Ho: Initial thickness of specimen in the rutting test (5cm) and RD: Rutting depth (cm) for the wheel tracking machine with rigid steel plate.

The rate of tracking in the rutting depth was expressed in mm/hour by using the following formula:

$$ROT = 4\ (RD_{45} - RD_{30})$$

Where; ROT: Rate of tracking mm/hour, RD_{45}: Rutting depth after 45 min., (mm) and RD_{30}: Rutting depth after 30 min., (mm).

The results of these tests are given in Table (13) and Figures (2) through (5). Table (14) shows the values of the rutting depth and the rutting stiffness at 25°C and 60°C after 45 min. and also the rate of tracking depth for different asphalt mixtures. This table shows that increasing the temperature from 25°C to 60°C for all asphalt mixtures increases the rutting depth and decreases the rutting stiffness of 80/100, 80/100 at PP/A =3%, 60/70 and 80/100 at PP/A= 4% by 20.7, 63.5, 66.8 and 270 times respectively. The higher increasing ratio in the rutting depth and rutting stiffness of 80/100 asphalt mixture at PP/A = 4% from 25°C to 60°C shows that the effect of polypropylene is better in the low temperature than in the high temperature. At 25°C, the increases of PP/A ratio from 0% to 3% and 4% for 80/100 asphalt mixture decreases the rutting depth and increases the rutting stiffness by a factor of 5.35 and 40 respectively. The rutting depth of 60/70 asphalt mixture is more than 6 times the rutting depth of 80/100 asphalt mixtures at PP/A = 4%. While the rutting depth of 80/100 asphalt mixture at PP/A = 0% and 3% is more than the rutting depth of 60/70 asphalt mixture by a factor of 6.68 and 1.25 respectively. At 60°C, the increase of PP/A ratio from 0% to 3% and 4% for 80/100 asphalt mixture decreases the rutting depth and increases the rutting stiffness by a factor of 1.74 and 3.1 respectively. The rutting depth of 60/70 asphalt mixture is more than 1.48 time the rutting depth of 80/100 asphalt mixture at PP/A=4 %, while the rutting depth of 80/100 asphalt mixture at PP/A =0% and 3% is more than the rutting depth of 60/70 asphalt mixture by a factor of 2.1 and 1.19 respectively.

Table (14) indicate that the rate of tracking increases with increasing the temperature for all different asphalt mixtures. The 80/100 asphalt mixture at PP/A= 4% shows the lowest rate of tracking followed by 60/70, 80/100 at PP/A= 3% and 80/100 asphalt mixtures at 25°C. At 60°C 80/100 asphalt mixture shows the lowest rate of tracking followed by 80/100 at PP/A= 3%, 80/100 at PP/A= 4% and 60/70 asphalt mixtures respectively.

The relations between the time and the rutting depth for different asphalt mixtures are presented in Figure (2) for 25°C, and Figure (3) for 60°C, these figures show that, the rutting depth increases with increases the loading time for different asphalt mixtures. The 80/100 asphalt mixture at PP/A= 4% shows the best resistance to permanent deformation, i.e. the lowest rutting depth along the all loading times, followed by 60/70, 80/100 at PP/A=3% and 80/100 asphalt mixtures respectively. The addition of polypropylene pellets by weight of asphalt to 80/100 asphalt mixture results in shifting the rutting time from 0 to 35 minutes at PP/A=3% and from 0 to 45 minutes at PP/A=4% at 25°C. The relations between the time and the rutting stiffness for different asphalt mixtures are presented in Figure (4) for 25°C, and Figure (5) for 60°C, these figures show that the rutting stiffness of the mixtures decreases with increases the loading time for different asphalt mixtures. The 80/100 asphalt mixtures at PP/A= 4% shows the highest rutting stiffness modulus, followed by 60/70, 80/100 PP/A= 3% and 80/100 asphalt mixtures respectively.

The equation that satisfies Figures (2) and (3) take the form of:

$$Ln\,(RD) = A_r * Ln\,(T) + B_r \qquad (1)$$

The equation that satisfies Figures (4) and (5) take the form of:

$$Ln\,(S_{r\,mix}) = C_r * Ln\,(T) + D_r \qquad (2)$$

Where; RD: Rutting depth (mm), $S_{r\,mix}$: Rutting stiffness of mixtures (Kg/Cm^2) T: Time, (min) and A_r ,B_r, C_r and D_r: are constants, the values of the constants for different asphalt mixtures are shown in Tables (15) and (16).

Table (17) shows the relations between the stability, the flow and the Marshall stiffness versus the rutting depth for different 80/100 asphalt mixtures at 60 °C and after 45 min. As shown in this table the higher rutting resistance was attained by increasing the stability and the Marshall stiffness and decreasing the flow for different 80/100 asphalt mixtures.

Creep Results: A series of creep testes were carried out on the Marshall specimens for 60/70 asphalt mixture and 80/100 at PP/A = 0 , 3and 4% asphalt mixtures at their O.A.C, to determine the creep results and the creep stiffness of the mixture and to study the effect of loading time and the change in stress levels on the creep result and on the creep stiffness of the mixtures. Three groups of test specimens were used in creep test according to the stress level of the test. The stress levels were 4.2, 6.25 and 9.38 Kg/Cm^2 (60, 90 and 120 psi) for a period of one hour at an ambient temperature of 25°C. These stress levels represents the cases of low, medium and heavy traffic loads. The creep stiffness of mixtures ($S_{c\,mix}$) was calculated from the following equation:

$$S_{c\,mix} = (\text{Applied stress } (\sigma)) / (\text{Strain in mix } (\varepsilon))$$

The results of these tests are given in Table (18). Table (19) shows that, the increase of stress level from 4.2 Kg/Cm^2 to 6.25 Kg/Cm^2 increases the creep result by 1.66, 1.68, 1.72 and 1.56 times respectively and decreases the creep stiffness by 1.11,1.13,1.16 and 1.05 times respectively of 80/100, 60/70, 80/100 at PP/A= 3% and 80/100 at PP/A= 4% asphalt mixtures. The increase of the stress level from 6.25 Kg/Cm^2 to 9.38 Kg/Cm^2 increases the creep result by 1.56,1.6,1.7 and 1.53 times respectively and decreases the creep stiffness by 1.04,1.06,1.14 and 1.02 times respectively of 80/100,60/70,80/100 at PP/A=3% and 80/100 at PP/A= 4% asphalt mixtures. At 4.2 Kg/Cm^2 the increase of PP/A ratio from 0% to 3% and 4% for 80/100 asphalt mixtures decreases the creep result by factor of 1.43 and 1.75 respectively and increases the creep stiffness by a factor of 1.26 and 1.89 respectively. The creep result of 60/70 asphalt mixture is less than 1.12 times the creep result of 80/100 asphalt mixture and is more than the creep result of 80/100 asphalt mixtures at PP/A= 3 and 4% by 1.28 and 1.56 times respectively and the vise is versa for creep stiffness. At 6.25 Kg/Cm^2, the increase of PP/A ratio from 0% to 3% and 4% for 80/100 asphalt mixture decreases the creep result by a factor of 1.38 and 1.86 respectively and increases the creep stiffness by a factor of 1.26 and 1.89 respectively. The creep result of 60/70 asphalt mixture is less than 1.1 times the creep result of 80/100 asphalt mixture and is more than the creep result of 80/100 asphalt mixtures at PP/A= 3 and 4% by 1.25 and 1.70 times respectively and the vise is versa for creep stiffness. At 9.38 Kg/Cm^2, the increase of PP/A ratio from 0% to 3% and 4 % for 80/10 asphalt mixture decreases the creep result by a factor of 1.26 and 1.89 respectively and increases the creep stiffness by a factor of 1.26 and 1.89 respectively. The creep result of 60/70 asphalt mixture is less than 1.08 times the creep result of 80/100 asphalt mixture and is more than the creep result of 80/100 asphalt mixtures at PP/A= 3 and 4% by 1.17 and 1.76 times respectively and the vise is versa for creep stiffness. The lowest increasing ratio in the creep result and the lowest decreasing ratio in the creep stiffness of the 80/100 asphalt mixture at PP/A= 4% shows the best resistance to the increasing in the stress levels.

The relations between the time and the creep result for different asphalt mixtures at different stress levels are presented in Figures (6) up to (8),these Figures show that, the creep result increase with increases the loading time for different asphalt mixtures at all stress levels. At stress levels 4.2, 6.25 and 9.38 Kg/Cm^2 the 80/100 asphalt mixture at PP/A = 4% shows the lowest creep results along all the loading times, followed by 80/100 at PP/A= 3%, 60/70 and 80/100 asphalt mixtures respectively. The relations between the time and the creep stiffness for different asphalt mixtures are presented in Figures (9) through (11) at different stress levels, these figures show that the creep stiffness of the mixture decreases with increases the loading time for different asphalt mixtures at all stress levels. The 80/100 asphalt mixture at PP/A= 4% shows the highest creep stiffness modulus, followed by 80/100 at PP/A =3%, 60/70 and 80/100 asphalt mixtures respectively for all stress levels.

The equation that satisfies Figures (6) up to (8) takes the form:

$$Ln\,(CR) = A_c * Ln\,(T) + B_c \qquad (3)$$

The equation that satisfies Figures (9) up to (11) takes the form:

$$Ln\,(S_{c\,mix}) = C_c * Ln\,(T) + D_c \qquad (4)$$

Where: CR: Creep results (mm), $S_{c\,mix}$: Creep stiffness of mixture (Kg/Cm^2), T: Time (min), and A_C, B_c, A_c and D_c: Are constants the values of the constants for different asphalt mixtures are shown in Tables (20) and (21).

Relation between the Rutting Test and the Creep Test

The relation between the rutting test and the creep test can be expressed at a temperature of 25°C and a stress level equal to 6.25 Kg/Cm^2 for the all asphalt mixtures types as in the following subsections.

Relation between the Rutting Depth and the Creep Result at the Same Time: This relation can be obtained from equation (1) and (3) for every asphalt mixture type through a certain time interval. The equations and the time intervals, which satisfy the results of the different asphalt mixtures, are shown in Table (22).

Relation between the Creep Stiffness and the Rutting Stiffness at the Same Time: This relation can be obtained from equation (2) and (4) for every asphalt mixture type through a certain time interval. The equations and the time intervals, which satisfy the results of the different asphalt mixtures, are shown in Table (22)

CONCLUSIONS AND RECOMMENDATIONS

The analysis of test results led to the following conclusions and recommendations:

1- The addition of PP to Alex. 80/100 A.C reduces the penetration, penetration ratio, losses in weight and specific gravity, also, increases the kinematic viscosity, absolute viscosity and softening point, and improves its thermal characteristics. The addition of 3and 4% PP by weight to Alex. 80/100 A.C alters its physical properties to be similar to 60/70 A.C.

2- Increasing the percentages of PP increases stability and Marshall stiffness and decreases the flow of Alex. asphalt concrete mixtures. The addition of 1% PP by weight to 80/100 A.C used in asphalt concrete mixtures improves the stability, flow and Marshall stiffness and modifies them to be better than the same characteristics of the 60/70 asphalt concrete mixtures.

3- The Alex. 80/100 asphalt mixture at 4% polypropylene by weight to asphalt shows the best resistance to permanent deformation, also the highest rutting and creep stiffness, compared with 60/70, 80/100 at 3% polypropylene and unmodified 80/100 asphalt mixtures at all studied temperatures.

4-The relation between the rutting test and the creep test can be expressed by using the following equations:

a- $CR = A*(RD)^B$ b- $S_{c\,mix} = C*(S_{r\,mix})^D$ Where A, B, C and D are constants.

5-It is recommended to study the chemical behavior of polypropylene and asphalt cement mixture in relation of physical and mechanical properties, and the fatigue resistance of the modified mixes, also construct a field test section using polypropylene to predict the performance of the modified mixtures under different traffic and environmental conditions.

REFERENCES

1-Shell Chemicals. Cariflex TR in Bituminous for Road Constriction and Maintenance. Technical Manual, TR 6.6 Reprinted December 1989.

2-F. L. Roberts, P. S. Kandhal, E. R. Brown, D. Lee, and T.W. Kennedy. Hot Mix Asphalt Materials, Mixture Design, and Construction. First Edition, 1991.

3-Park T., Coree B. J., and Lovell C. W.. Evaluation of Pyrolized Carbon Black from Scrap Tires as Additive in Hot Mix Asphalt. TRR No. 1530, 1996.

4-Adli H. Al-Balbissi, Dallas N. Little, Chuck Greogry, and Barry Richey. Modulus Properties of Plasticized sulfur Mixtures. TRR No.1323, 1991.

5-Mohamed EL-Said. Effect of Mixing Technology on Hot Asphaltic Mixtures Properties. M.Sc. Thesis, Zagazig University 1996.

6-Sonbol B. R. Feasibility of Using Eichhornia Plants and Wood-Saw Dust as Rein- forcing Agents for Hot Mix Asphalt. M.Sc., Thesis, Benha High Inst. of Tech., 1998.

7-Ghassan I. Ashqar. Thermoplastic Rubber for Modification of Bitumen for Road Construction. Shell Chemicals Distributing Co, Middle East Shell Center, Amman Jordan, December 1994.

8-Barsoom M. F. Effect of Polyethylene on the Physical and Engineering Properties of Ameria. A C 60/70. M. Sc., Thesis, Cairo University-Fayoum Branch, 1994.

9-Procedure for the Manufacture and Testing of Wheel Tracking Test Specimens, Materials Division, TRRL, London March, 1976.

10-Bolk, H. J. N. A. and Van de Loo, P.J., The Creep Test: a Routine Method for the Design of Stable Asphalt Mixes, European Seminar 1978, the Challenge of the Future for asphalt Roads, London, 14&15 Nov., 1978.

11-Brown, S. F. and Cooper, K.E. The Mechanical Properties of Bituminous Materials for Road Bases and Base Courses. Proceedings, AAPT, Vol.53, 1984.

12-J. F. Hill, D. Brient and P.J. Van De Loo. The Correlation of Rutting and Creep Tests on Asphalt Mixes. Journal Institute of Petroleum, January 1974.

NOTATION

A. C	: Asphalt cement.	S_m	: Marshall stiffness
Alex.	: Alexandria.	RD	: Rutting depth
P. I	: Penetration index.	CR	: Creep results
PP	: Polypropylene.	$S_{r\ mix}$	: Rutting Stiffness
PP/A	: Polypropylene /asphalt.	$S_{c\ mix}$	: Creep stiffness

Table (1) Physical and Engineering Properties of Coarse Aggregate.

Test No.	Test	ERBA Designation Test No.	Result		Specification Limits
			Size 2	Size 1	
1	Bulk specific gravity	T- 108	2.488	2.471	-
2	Bulk specific gravity Saturated surface dry	T- 108	2.546	2.536	-
3	Apparent specific gravity	T- 108	2.647	2.642	-
4	Water absorption (%)	T- 108	2.3	2.6	≤ 5
5	Los Angeles abrasion:	T-106			
	- Loss After 100 rev. (%)		5.2	5.42	≤10
	- Loss After 500 rev. (%)		26.62	26.32	≤40

Table (2) Physical Properties of Bituminous Materials.

Test No.	TEST	ERBA Designation No.	60/70 A.C	Specification Limits	80/100 A.C	Specification Limits
1	Penetration	T-205	64	60-70	89	80-100
2	Softening point	T-208	48	45-55	44.5	42-52
3	Flash point	T-204	+270	≥250	+270	≥250
4	Kinematic viscosity	T-227	357	≥320	259	≥300
5	Absolute viscosity	T-228	4079	-	2250	-
6	Specific gravity	ASTM - (D 70-82)	1.0359	-	1.0381	-

Table (3) Physical and Engineering Properties of Polypropylene.

Property	ASTM Specification No.	Results
1- Density, g/cm^3	A.S.T.M (D-792)	0.9
2- Tensile strength, kg f/cm^2	A.S.T.M (D-638)	350
3- Elongation, %	A.S.T.M (D-638)	>500
4- Flexural modulus, kg f/cm^2	A.S.T.M (D-785)	18500
5- Melting point, °C	A.S.T.M (D-3418)	182
6- Softening point, °C	A.S.T.M (D-4625)	153

Table (4) The Percent of Aggregate Components and the Designed Gradation

Sieve No	1	3/4	1/2	3/8	#4	#8	#30	#50	#100	#200
Combined Aggregate Grading	100	99.34	85.14	71.42	48.37	41.25	27.21	14.38	7.25	5.99
Spec. Limits (4-C)	100	80-100	67-88	60-80	48-65	35-50	19-30	13-23	7-15	3-8

Table (5) Effect of Polypropylene on the Physical Properties of A.C.

Asphalt Cement Type	80/100 + PP/A%							60/70 + PP/A%		
Polypropylene Percent, (%)	0	1	2	3	4	6	8	0	2	4
Penetration, (1/10 mm)	89	77	72	69	66	47	42	64	58	55
Kinematic viscosity, (Cskc.)	259	269	340	361	377	-	-	357	428	452
Absolute viscosity, (Poise)	2250	2420	2614	2840	3151	3320	3909	4079	4230	4686
Softening point, (°C)	44.5	46	47	50.5	52	54	55	48	52	54
Thin film oven test										
* Penetration after heating	75	58	48	43	37	17	14	39	33	28
* Penetration ratio, (%)	84.30	75.30	67.00	61.40	56.00	36.17	33.33	61.00	56.9	50.9
* Losses after heating, (%)	0.127	0.094	0.060	0.030	0.005	-	-	0.233	0.182	0.141
Specific gravity	1.038	1.037	1.035	1.033	1.032	1.03	1.027	1.036	1.033	1.03
Flash point, (°C)	+270	+270	+270	+270	+270	+270	+270	+270	+270	+270

Table (6) Improvement Rates in A.C Due to the Addition of Polypropylene

Asphalt Cement Type	80/100 + PP/A%							60/70 + PP/A%		
Polypropylene Percent, (%)	0	1	2	3	4	6	8	0	2	4
Improvement in penetration, (%)	0.0	13.48	19.10	22.47	25.84	47.19	52.81	0.0	9.38	14.06
Improvement in kinematic viscosity, (%)	0.0	3.86	31.27	39.38	45.56	-	-	0.0	19.89	26.61
Improvement in absolute viscosity, (%)	0.0	7.55	16.18	26.22	40.04	47.56	73.73	0.0	3.70	14.88
Improvement in softening point, (%)	0.0	3.37	5.62	13.48	16.85	21.35	23.60	0.0	8.38	12.50
Improvement in penetration (T.F.O.T), (%)	0.0	22.66	36.00	42.66	50.66	77.33	81.33	0.0	15.38	28.20
Improvement in losses (T. F.O.T), (%)	0.0	25.98	52.76	76.38	96.06	-	-	0.0	21.89	39.48

Table (7) Comparison between 80/100 A.C at Different PP/A Ratio and 60/70A.C.

Asphalt Cement Type	60/70	80/100 + PP/A%						
Polypropylene Percent. (%)	0	0	1	2	3	4	6	8
Penetration. (%)	0.00	+39.06	+20.31	+12.50	+7.81	+3.13	-26.56	-34.38
Kinematic viscosity. (%)	0.00	-27.45	-24.65	-4.76	+1.12	+5.60	+13.17	+21.00
Absolute viscosity. (%)	0.00	-44.83	-40.67	-35.92	-30.38	-25.75	-18.61	-4.17
Softening point. (%)	0.00	-7.29	-4.17	-2.10	+5.21	+8.33	+12.50	+14.58
Penetration (T.F.O.T). (%)	0.00	+92.31	+48.72	+23.10	+10.26	-5.13	-56.41	-64.10
Losses (T.F.O.T). (%)	0.00	-45.50	-59.66	-74.25	-87.12	-97.85	-	-

Table (8) Penetration Index and its Improvement Rates of Alex. Asphalt Cement due to Polypropylene Addition.

Asphalt Cement Type	80/100+PP/A%							60/70+PP/A%		
Polypropylene percent. %	0	1	2	3	4	6	8	0	2	4
Penetration index	-1.29	-1.23	-1.12	-0.28	-0.02	-0.39	-0.43	-1.14	-0.36	-0.02
Improvement rates. %	0.0	4.65	13.18	78.29	98.45	69.77	66.66	0.00	68.42	98.25

Table (9) Comparison between PI of Alex. 80/100 A.C at Different PP/A ratios and Alex. 60/70 A.C.

Asphalt Cement Type	60/70	80/100+PP/A%						
Polypropylene percent. %	0	0	1	2	3	4	6	8
Penetration index	0.00	-13.16	-7.90	+1.75	+75.44	+98.25	+65.79	+62.28

Table (10) Marshall Properties for the Investigated Mixtures.

Asphalt Cement Type	PP (%)	O.A.C (%)	Unit Weight g/cm^3 (lb/ft^3)	Stability (lb)	Flow (0.01 in)	A.V (%)	V.M.A (%)	Marshall Stiffness (psi)
80/100 A.C + PP/A%	0	5.95	2.265 (141.40)	1785	13.65	3.05	15.37	5231
	1	5.95	2.266 (141.47)	1975	12.90	3.10	15.38	6124
	2	5.95	2.266 (141.47)	2160	12.40	3.15	15.39	6968
	3	6.05	2.267 (141.53)	2260	10.60	3.25	15.77	8528
	4	5.7	2.270 (141.72)	2630	10.50	3.30	15.02	10019
	6	5.65	2.250 (140.47)	3200	10.00	3.90	15.88	12800
	8	5.63	2.245 (140.16)	4110	9.50	4.40	16.15	17305
60/70 A.C + PP/A%	0	6.05	2.258 (140.97)	1970	13.55	3.30	15.74	5815
	2	5.93	2.249 (140.41)	3220	11.50	3.70	15.95	11200
	4	5.75	2.242 (139.97)	4145	10.20	4.30	16.10	16225

Table (11) Improvement Rates in Alex. Asphalt Mixtures due to the Addition of Polypropylene.

Asphalt Cement Type.	80/100+PP/A%							60/70+PP/A%		
Propylene percent. (%)	0	1	2	3	4	6	8	0	2	4
Improvement rates in stability. (%)	0.00	10.64	21.00	26.61	47.33	79.27	130.25	0.0	63.45	110.41
Improvement rates in flow. (%)	0.00	5.50	9.15	22.34	23.08	26.74	30.40	0.0	15.13	24.72
Improvement rates in Marshall stiffness. (%)	0.00	17.07	33.2	63.03	91.53	144.7	230.82	0.0	92.61	179.54
Improvement rates in air voids. (%)	0.00	1.64	3.28	6.56	8.2	27.87	44.26	0.0	12.12	30.30

Table (12) Comparison to Marshall Results of Alex. 80/100 A.C Mixes at Different PP/A ratio and Alex. and Alex.60/70A.C Mixes.

Asphalt Cement Type	60/70	80/100+PP/A						
Polypropylene percent. %	0	0	1	2	3	4	6	8
Stability. %	0.00	-9.39	+0.25	+9.64	+14.73	+33.50	+62.44	+108.63
Flow .%	0.00	-0.74	+4.80	+8.50	+21.77	+22.51	+26.20	+29.89
Marshall stiffness. %	0.00	-10.04	+5.31	+19.83	+46.65	+72.30	+120.12	+197.6
Air voids. %	0.00	-7.58	-6.06	-4.55	-1.52	0.00	+18.18	+33.33

Table (13) Rutting Results for different Paving Mixtures at Temperature 25°C, Curing Time 3 days and Contact stress 6.25 Kg /Cm^2.

Time min	Dial gauge reading 0.005 in				Rutting depth deformation mm				Rutting stiffness Kg/cm^2			
	80/100+PP/A%			60/70	80/100 +PP/A%			60/70	80/100 +PP/A%			60/70
	0	3	4		0	3	4		0	3	4	
1	0.10	0	0	0	0.013	0	0	0	12311	∞	∞	∞
2	0.25	0	0	0	0.025	0	0	0	4924	∞	∞	∞
3	0.40	0	0	0	0.038	0	0	0	3078	∞	∞	∞
4	0.60	0	0	0	0.064	0	0	0	2052	∞	∞	∞
5	0.75	0	0	0	0.095	0	0	0	1642	∞	∞	∞
10	1.50	0	0	0	0.191	0	0	0	820.7	∞	∞	∞
15	1.85	0	0	0	0.235	0	0	0	665.5	∞	∞	∞
20	2.40	0	0	0	0.305	0	0	0	513	∞	∞	∞
25	2.75	0	0	0	0.349	0	0	0	447.7	∞	∞	∞
30	3.10	0	0	0	0.394	0	0	0	397.1	∞	∞	∞
35	3.45	0.20	0	0.10	0.438	0.025	0	0.0127	356.8	6156	∞	12311
40	3.75	0.50	0	0.35	0.476	0.064	0	0.0444	328.3	2462	∞	3517.4
45	4.00	0.75	0.10	0.60	0.508	0.095	0.0127	0.0760	307.8	1642	12311	2051.8
50	4.25	1.00	0.15	0.85	0.539	0.127	0.0191	0.1080	289.7	1231	8208	1448.4
55	4.50	1.15	0.20	1.00	0.572	0.146	0.0254	0.1270	273.6	1071	6156	1231.1
60	4.75	1.25	0.25	1.10	0.603	0.159	0.0318	0.1397	259.2	985	4924	1119.2

Table (14) Summary Results of Rutting Depth, Rutting Stiffness (at 25 & 60°C and after 45 min.) and Rate of Tracking Depth for Different Asphalt Mixture.

Temperature	Rutting Depth, mm				Rutting Stiffness, Kg/Cm^2				Rate of Tracking Depth, mm/hour			
	80/100+PP/A%			60/70	80/100 +PP/A%			60/70	80/100 +PP/A%			60/70
	0	3	4		0	3	4		0	3	4	
25 °C	0.508	0.095	0.0127	0.076	307.8	1642	12311	2051.8	0.456	0.38	0.051	0.304
60 °C	10.509	6.033	3.429	5.08	14.9	25.9	45.6	30.8	2.412	5.336	3.048	5.84

Table (15) The Values of the Constants A_r and B_r for Rutting Tests.

Temperature	25°C			60°C		
Asphalt Mixture	A_r	B_r	R^2	A_r	B_r	R^2
80/100	0.9318	-4.1367	0.980	0.727	-0.2511	0.994
80/100 +3% PP	3.2825	-15.0547	0.898	0.8231	-1.305	0.996
60/70	4.2419	-19.0255	0.884	0.7739	-1.3325	0.999
80/100 +4% PP	3.1833	-16.4516	0.991	0.7494	-1.6031	0.998

Table (16) The Values of the Constants C_r and D_r for Rutting Tests.

Temperature	25 °C			60°C		
Asphalt Mixture	C_r	D_r	R^2	C_r	D_r	R^2
80/100	-0.8899	+9.0352	0.992	-0.7271	+5.3033	0.998
80/100 +3 % PP	-3.2638	+20.0331	0.901	-0.8259	+6.3688	0.999
60/70	-4.2404	+24.0713	0.884	-0.7718	+6.3756	0.995
80/100 +4% PP	-3.1810	+21.4956	0.980	-0.7499	+6.6567	0.994

Table (17) Stability, Flow, Marshall Stiffness and Rutting Depth for 80/100 Asphalt Mixtures at 60°C and after 45 min.

Polypropylene percent	Stability (lb)	Flow (0.01 in)	Marshall Stiffness (psi.)	Rutting depth (mm)
0%	1785	13.65	5231	10.509
3%	2260	10.6	8528	6.033
4%	2630	10.5	10019	3.429

Table (18) Creep Test Results for Different Paving Mixture at 25°C under Contact Stress 6.25kg/Cm^2, Height of Sample 6.35 cm and Diameter of Sample 10.16 cm.

Time min	Creep results (mm)				Creep Strain (%)				Creep Stiffness (kg/Cm^2)			
	80/100+PP/A%			60/70	80/100 +PP/A%			60/70	80/100 +PP/A%			60/70
	0	3	4		0	3	4		0	3	4	
1	1.400	0.845	0.611	1.200	2.205	1.331	0.961	1.890	283.800	470.200	650.810	331.100
2	1.540	0.960	0.689	1.330	2.425	1.512	1.085	2.094	258.000	413.874	576.661	298.736
3	1.628	1.030	0.740	1.425	2.564	1.622	1.165	2.244	244.054	385.747	537.281	278.821
4	1.688	1.085	0.774	1.485	2.658	1.709	1.218	2.339	235.379	366.193	513.665	267.555
5	1.732	1.129	0.810	1.530	2.728	1.804	1.275	2.409	229.400	351.922	490.821	259.686
10	1.890	1.262	0.915	1.685	2.976	1.987	1.441	2.654	210.222	314.958	434.229	235.798
15	1.984	1.372	0.986	1.778	3.124	2.161	1.552	2.800	200.262	289.591	403.165	223.464
20	2.055	1.438	10.40	1.850	3.236	2.265	1.637	2.913	193.343	276.300	382.222	214.767
25	2.110	1.489	1.082	1.900	3.323	2.346	1.704	2.992	188.303	266.747	367.208	209.116
30	2.152	1.535	1.121	1.945	3.389	2.417	1.765	3.062	184.628	258.840	354.591	204.277
35	2.194	1.571	1.153	1.982	3.455	2.473	1.816	3.121	181.094	252.989	344.596	200.464
40	2.226	1.606	1.183	2.012	3.506	2.528	1.862	3.169	178.490	247.474	336.000	197.475
45	2.255	1.636	1.211	2.041	3.551	2.576	1.906	3.214	176.195	242.860	328.228	194.669
50	2.280	1.662	1.235	2.065	3.591	2.617	1.944	3.252	174.263	239.133	321.847	192.407
55	2.308	1.686	1.257	2.086	3.635	2.655	1.979	3.285	172.149	235.658	316.211	190.470
60	2.328	1.710	1.280	2.106	3.666	2.693	2.015	3.317	170.670	232.351	310.527	188.661

Table (19) Summary Results of Creep Depth and Creep Stiffness Values for Different Stress Levels at 25°C and after 45 min.

Stress Kg/cm^2	Creep result mm				Creep stiffness Kg/Cm^2			
	80/100+PP/A%			60/70	80/100 +PP/A%			60/70
	0	3	4		0	3	4	
4.20	1.362	0.950	0.7775	1.216	195.983	280.977	343.317	219.514
6.25	2.255	1.636	1.2105	2.041	176.195	242.06	328.228	194.669
9.38	3.51	2.789	1.856	3.260	169.592	213.678	321.179	182.806

Table (20) the Values of the Constants A_c and B_c for Creep Tests.

Stress Level	4.2Kg/Cm^2			6.25 Kg/Cm^2			9.38 Kg/Cm^2		
Asphalt Mixture	A_c	B_c	R^2	A_c	B_c	R^2	A_c	B_c	R^2
80/100	0.1345	-0.1951	0.992	0.1227	0.3486	0.999	0.1341	0.7581	0.978
60/70	0.1073	-0.2079	0.996	0.1360	0.1992	0.998	0.1169	0.7499	0.938
80/100+3% PP	0.1638	-0.6635	0.990	0.1717	-0.1592	0.999	0.1986	0.2697	0.999
80/100+4% PP	0.1561	-0.8434	0.998	0.1812	-0.5012	0.999	0.1837	-0.0826	0.999

Table (21) the Values of the Constants C_c and D_c for Creep Tests.

Stress Level	4.2Kg/Cm^2			6.25 Kg/Cm^2			9.38 Kg/Cm^2		
Asphalt Mixture	C_C	D_C	R^2	C_C	D_C	R^2	C_C	D_C	R^2
80/100	-0.1345	5.7821	0.998	-0.1227	5.6362	0.999	-0.1341	5.6321	0.999
60/70	-0.1073	5.7949	0.990	-0.1360	5.7856	0.999	-0.1169	5.6400	0.999
80/100+3% PP	-0.1638	6.2505	0.996	-0.1717	6.1439	0.997	-0.1986	6.1204	0.937
20/100+4% PP	-0.1561	6.4304	0.992	-0.1812	6.4860	0.999	-0.1837	6.4727	0.978

Table (22) The Equations and the Time Intervals That Satisfy the Relations between the Creep and the Rutting tests.

Asphalt Mixture	The Equations		The Time Interval
80/100	$CR = 2.443 \cdot RD^{0.1317}$	$S_{c\ mix} = 80.67 \cdot S_{r\ mix}^{0.1378}$	0 – 60 min
60/70	$CR = 2.246 \cdot RD^{0.0321}$	$S_{c\ mix} = 150.43 \cdot S_{r\ mix}^{0.0321}$	35 – 60 min
80/100 + 3% PP	$CR = 1.874 \cdot RD^{0.0523}$	$S_{c\ mix} = 175.78 \cdot S_{r\ mix}^{0.0526}$	35 – 60 min
80/100 + 4% PP	$CR = 1.545 \cdot RD^{0.0569}$	$S_{c\ mix} = 192.78 \cdot S_{r\ mix}^{0.057}$	45 – 60 min

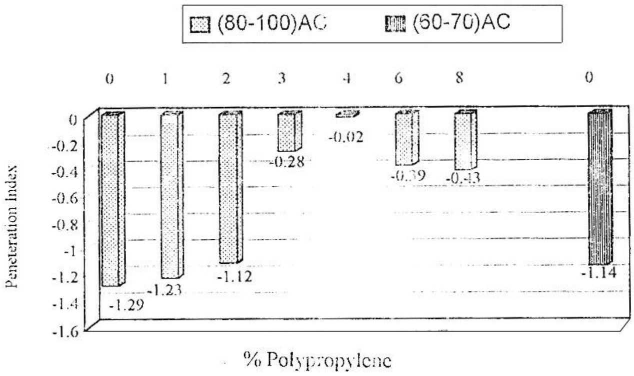
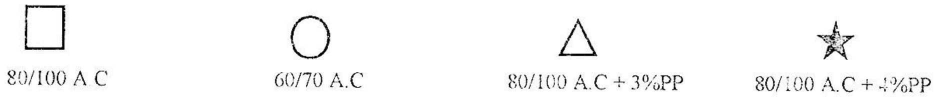


Fig. (1) Penetration Index Comparison between 80/100 A.C and 60/70 A.C without modification.



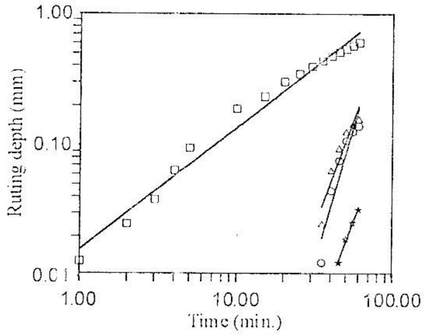


Fig. (2) Rutting Depth as a Function of Time for Different Paving Mixtures at 25°C.

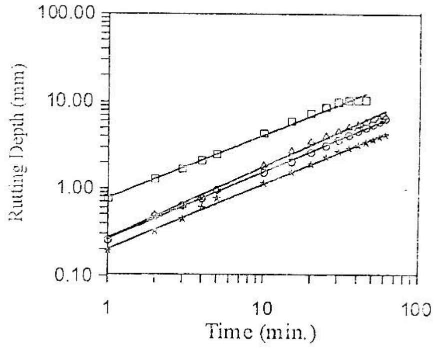


Fig. (3) Rutting Depth as a Function of Time for Different Paving Mixtures at 60°C.

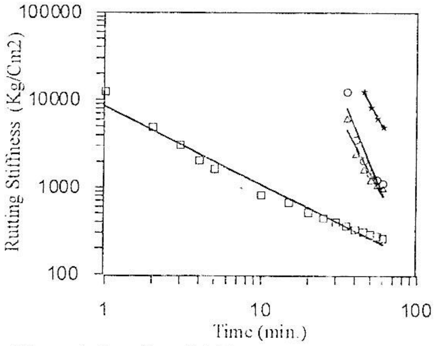


Fig. (4) Rutting Stiffness as a Function of Time for Different Paving Mixtures at 25°C.

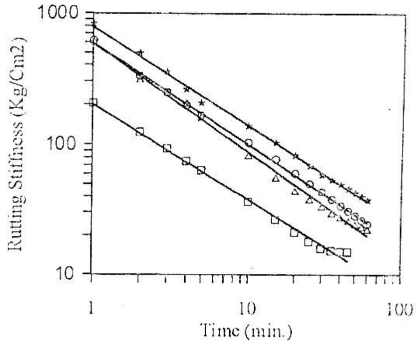


Fig. (5) Rutting Stiffness as a Function of Time for Different Paving Mixtures at 60°C.

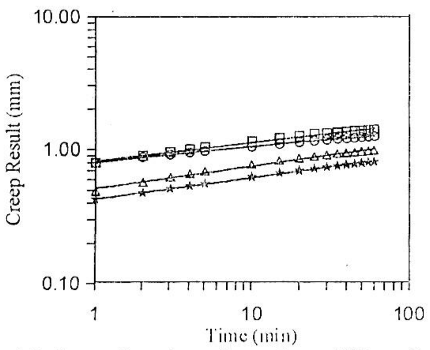


Fig. (6) Creep Result as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 4.20 Kg/Cm^2.

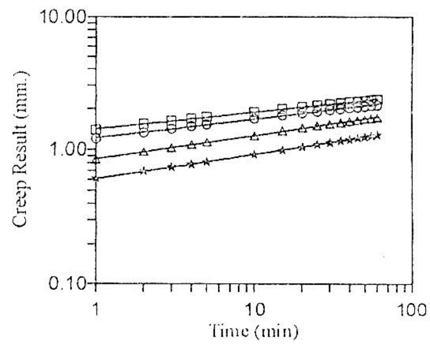


Fig. (7) Creep Result as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 6.25 Kg/Cm^2.

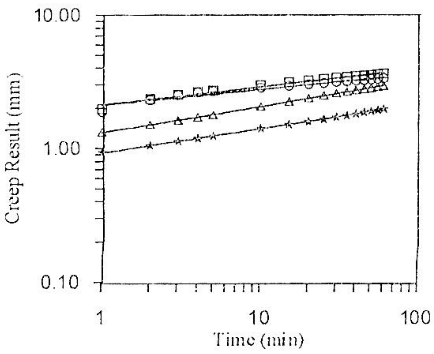


Fig. (8) Creep Result as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 9.38 Kg/Cm^2.

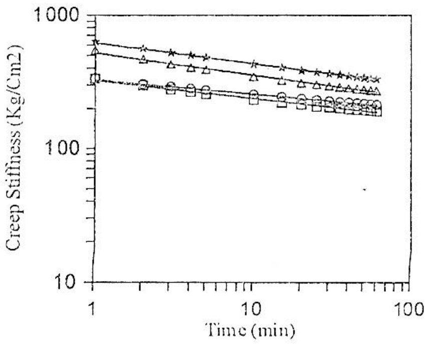


Fig. (9) Creep Stiffness as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 4.20 Kg/Cm^2.

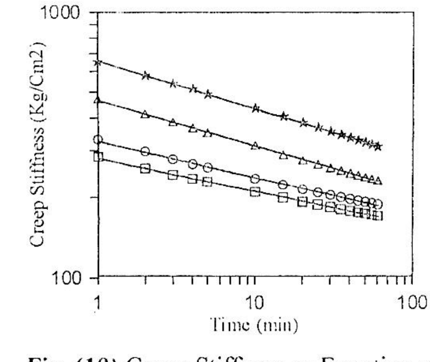


Fig. (10) Creep Stiffness as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 6.25 Kg/Cm^2.

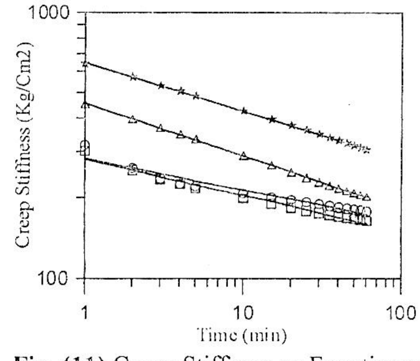


Fig. (11) Creep Stiffness as Function of Time for Different Paving Mixtures at 25°C under Contact Stress Equal 9.38 Kg/Cm^2.