The Iraqi Journal For Mechanical And Material Engineering, Special Issue (E)

EFFECT OF ADDITIVE MATERAILS IN MINIMIZING REFLECTIVE CRACKING

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Abstract

Reflection cracks through a road structure is one of the main causes of premature pavement deterioration which which shortens the service life of overlays.

This phenomenon, which often appears when a layer of asphaltic material is placed on top of a discontinuous base, can have many different aspects, in accordance with the large number of factores governing the mechanism of crack initiation and propagation through a road structure.

A number of additives appear to be promising in plying an important role in improving the properties and performance of paving mixtures.

Wheel tracking testing techniques were developed to examine one type with different contents of asphalt modifier additives (High-density polyethylene) overlays for situations where reflection cracking may normally developed.

The prime objective of this research is to investigate the potential role of High-Density Polyethylene as additive in retarding or minimizing reflective cracking.

A total of 120 Marshall Specimens is prepared and tested by Marshall, Indirect tensile and Creep tests at different temperature decrease. To simulate the overlay performance under a rolling tire, 18 compacted asphalt concrete beam samples are tested using wheel tracking apparatus after modification.

It can be concluded that modified mixes with 9% of High-Density Polyethylene (by wt. of asphalt) gives the maximum resistance to reflection cracking.

تأثير المواد المضافة في تقليل الشقوق الانعكاسية

الخلاصـــــــــــــــــــــة

أن انعكاس الشقوق خلال منشأ الطريق هو احد الأسباب الرئيسية المؤدية إلى التلف الأولي للتبليط والذي يقصر العمر الخدمي لطبقة الاكساء. هذه الظاهرة التي غالبا تظهر عند أكساء طبقة من المواد الإسفلتية فوق أساس غير مستمر , تمتلك عدد من السمات المختلفة بموجب عدة عوامل متعلقة بميكانيكية نشوء و نمو الشقوق خلال منشأ الطريق.

هناك عدد من المضافات ظهرت لتلعب دورا مهما في تحسين خصائص ومستوى أداء الخلطات الإسفلتية.

تم تطوير جهاز العجلة المتحركة وذلك لفحص طبقة الاكساء الجديدة المحسنة بنوع من المضافات و بنسب مختلفة من البولي اثلين عالي الكثافة لمناطق طورت فيها الشقوق الانعكاسية.

ان الهدف الرئيسي لهذا البحث هو التحري عن الدور الكامن للبولي أثلين عالي الكثافة كمضاف في تأخير أو إعاقة الشقوق الانعكاسية.

تم تحضير120 نموذج مارشال وفحصت باستخدام الفحوصات (فحص مارشال، فحص قوة الشد غير مباشر والزحف) بعدة درجات حرارة. . تم فحص18 نموذج عتبة مرصوصة من الإسفلت الكونكريتي باستخدام جهاز العجلة المتحركة بعد أجراء عملية التحوير للجهاز من اجل تمثيل مستوى أداء طبقة الاكساء الجديدة تحت تأثير دوران العجلة.

ويمكن ألاستنتاج بان أفضل خلطة ذات أعلى مقاومة للشقوق الانعكاسية هي خلطة ذات نسبة 9% من البولي اثلين عالي الكثافة (من وزن الإسفلت).

Keywords:

Reflecion cracks, High-density polyethylene, Wheel tracking apparatus, additives.

1-Introduction

The phenomenon of propagation of cracks in bituminous overlays directly at locations where cracks or joints exist in the underlying cracked bituminous or concrete pavements is called reflective cracking [1,2] .

The basic mechanisms generally assumed to lead to reflection cracking are the vertical and horizontal movements of the pavement being resurfaced. Vertical movements are differential deflections at the joint or cracks in the underlying pavement and are caused by moving wheel loads [3,4] .

Strengthening by overlay has the advantages that it enhances any residual life in the existing pavement. As compared with the reconstruction approach, it is quicker, and is less sensitive to weather conditions; it also reduces traffic delays [5].

Construction of HMA overlays over old concrete pavements is the most common concrete pavement rehabilitation strategy, and a major concern associated with using HMA overlays on (PCC, AC) pavements is reflection cracking [6]. These cracks represented a major and difficult problem in the design of HMA overlays on (AC or PCC) pavements [7].

The justification or the reason for using an additive or extender is to solve or alleviate a pavement problem and to realize some benefits like: economic, environmental, energy, application and performance.[8]

Jew and Woodhams[9] reported that polyethylene is a potentially useful modifier for increasing the low temperature fracture toughness of asphalt concrete and may also confer additional pavement stability at elevated temperatures to minimize rutting distortion due to creep.

Lee, Morrision and Hesp[10] found that the addition of polyethylene to asphalt binders does significantly increase their low temperature fracture and fracture energy.

Abdellatif, Brahim and Mosto(11) studied the effect of addition of both high-density polyethylene (HDPE) and a blend of HDPE and ethylene-propylene-diene-monomer (EPDM) to the asphalt binder for specific end-use applications. It was found that addition of (HDPE/EPDM) to the straight asphalt results in materials with enhanced overall properties, and most important, dispersed phase much more stable than the equivalent HDPE modified asphalt, mainly before TFOT aging.

Mohammad T. Awwad and Lina Shbeeb[12] studied two types of polyethylene were added to coat the aggregate [High Density Polyethylene (HDPE) and Low Density

Polyethylene (LDPE)]. The polymers were introduced to the mixture in two states (Grinded and not Grinded) to determining the best type of polyethylene to be used and its proportion. The results indicated that grinded HDPE polyethylene modifier provides better engineering properties. The recommended proportion of the modifier is 12% by the weight of bitumen content. It is found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate.

2-The Research Objectives

1-To evaluate the effect of High-Density Polyethylene with different contents to resist and minimize reflective cracking.

2- To simulate the performance of modified overlay using modified wheel tracking test in tikrit university, and obtaining the best percentage of High-Density Polyethylene depending on conventional and wheel tracking test results.

3-Materials and Testing

The asphalt cements used in this study include (40-50) Penetration grade from Daurah Refinery. The physical properties for this grade is shown in table No. (1).

Aggregates from Al- Nibaee quarry with ordinary Portland cement (from Kubaisa factory) as filler are used in preparing the various mixtures, and their properties are presented in Table No. (2 and 3). The combined gradation of aggregates and filler Table No. (4) are selected to be within the limits of the State Commission of Roads and Bridges (S.C.R.B) for dense graded paving mixtures of finer surface course (13).

High-Density Polyethylene is by product of state Company for Petrochemical Industries at Basrah and available in local market. The particle gradation is shown in Table No. (5) with a unit weight of 0.94 gm/cm^3.It has regular linear chaines ($-CH_2-CH_2-)_n$ which acquire high density and good mechanical properties. Table (6) shows the physical properties of H.D.Polyethylene.

In order to determine the optimum asphalt content for this type of mixture Five different percentages of asphalt cement are used (4.25, 4.75, 5.25, 5.75, 6.25) % of Daurah (40-50).The asphalt-High-Density Polyethylene blend consisting of (0, 0.5, 1, 1.5, 3, 6, 9, 12) % High-Density Polyethylene by weight of asphalt are added to asphalt which are prepared by heating the asphalt to (150-160)°C and adding the High-Density Polyethylene while stirring for (25-30) minutes until obtaining a homogenous consistency. The asphalt- High-Density Polyethylene blend is then mixed with the heated aggregate which is represented by 160°C for about 2 minutes in order to prepare the required mixture.

The various mixtures were tested according to ASTM (14) standards for resistance to plastic flow using Marshall apparatus with recorder (D 1559) The bulk specific gravity and density ASTM (D 2726) (14), theoretical (maximum) specific gravity of voidless mixture are determined in accordance with ASTM (D 2041) (14)

$$Gse= (Pmm-Pb)/[(Pmm/Gmm)-(Pb/Gb)] \quad \text{..(1)}$$

Where:

Gse= effective specific gravity of the aggregate.

Pmm=t total loose mixture percent by weight of mixture.

Pb = as asphalt percentage by total weight of mixture.

Gmm=specific gravity of paving mixture.
Gb= specific gravity of Asphalt.

Marshall Stiffness is determined as the ratio between maximum load resistances (Stability) of the standard specimen to the corresponding flow at temperatures of 60°C. The indirect tensile strength is determined according to ASTM (D 4123) [14] at (0, 25, 40°C).The temperature susceptibility of mixture is calculated, as below [15]:

$$TS = [(I.T.S)_{t0} - (I.T.S)_{t1}] / (t_1 - t_0) \quad \text{.....(2)}$$

where: $(I.T.S)_{t0}$ = Indirect tensile strength at t_0 (˚C) , $(I.T.S)_{t1}$ = Indirect tensile strength at t_1 (˚C), t_0 = 25˚C, t_1 = 40 ˚C.

The diametric-indirect tensile creep test has been done at Asphalt Labortary of Al-Mustansiria University to determine the stiffness of asphalt mixture by measuring strain-time values at the desired temperature of (25̊C) the results of this test shown in Figures (3-6). The specimen is loaded to a static stress of 0.141 Mpa for 1 hours, and the deformation is recorded at certain time increments (0.1,0.25,0.5,1,2,4,8,15,30,45,and 60 min.). The load is then released, and the recovered strain for 1 hour is recorded, at the same periods. The vertical strain is calculated by using the following formula:

$$\varepsilon_{mix}=\Delta H/D_0 \text{ (mm/mm)} \quad \text{.....(3)}$$

where: - ΔH = The total measured vertical deformation at a certain loading time (mm), D_0 = The original diameter of specimen (mm).
The stiffness modulus of the mixture is calculate by:

$$S_{mix} = \sigma / \varepsilon_{mix} \quad (N/mm^2) \quad \text{.....(4)}$$

where: - S_{mix} = Stiffness modulus (N/mm^2), σ = Applied stress (N/mm^2),and ε_{mix} = Vertical strain in the mix.

The wheel-tracking apparatus, shown in plate (1), is modified to simulate the effect of traffic loading on asphalt concrete overlay. This test is done at Asphalt Labortary of Tikrit University.

The following modifications have been done on the sample and apparatus.

- Increasing the samples mold thickness from 2.5 cm to 5 cm.
- Increasing the loading capacity of the apparatus from 40 Ib (18.14 Kg) to 187.4 Ib (85Kg).
- Strengthening the apparatus base plate to bear the extra loads applied to the wheel.

The test is carried out on prepared asphalt mixture beams 12x3.5x2 in.(30x9x5cm) which are rigidly restrained by their four sides, placed over a support (two pieces of high quality plywood) with the same dimensions and (10mm) gap to simulate the existing cracks in old pavement. The two layers are joined with a tack coat. The quasi-elastic behavior of the subgrade is simulated by a solid rubber, as shown in Plate (2) [16,17].

To obtain an asphalt beam with the mentioned dimensions, approximately 3206.25 gm of asphalt mixture is prepared using laboratory mixer. The required amount is placed in the slightly oiled (ferrous) iron mould uniformly and spaded vigorously with a heated spatula. The beam is formed by static compacting using compression machine with (300 KN) capacity applied to steel plate that coveres the asphalt mixture to get uniform load. The applied pressure is maintained at (300KN) for 2 minutes to achieve the same Marshall bulk density and the load is released slowly.

A loaded (soild) rubber tired wheel is driven over a compacted beam sample of bituminous material. The essential features of the machine are as given in Table (7). The motor and the reciprocating device provide a motion to the platform of 50 passes in minute with a distance of travel over the sample of 9 in.(22.5cm), and with a contact stress equal to $4.58*10^5$ N/m2 which represents 76% out of the contact stress of W18 (single axle duel wheel).

The test was considered as complete when the crack appears on the surface of overlay painted with a white paint, as shown in Plate (3).

4- Result and Discussion

The effect of asphalt content on Marshall and density-air voids properties involved in this research is shown in Tables (8). From Marshall Test result the 5.37% was selected as optimum asphalt content.

The effect of High-Density Polyethylene addition on binder characteristics illustrated in Table (9) and the effect of resultant binder at (O.A.C, 5.37%) on engineering properties such as Marshall, indirect tensile and creep tests will be discussed below.

It can be noticed from this table that the penetration of modified binder increases up to 0.5% then it decreases as High-Density Polyethylene added to asphalt cement increases while the softening point decreases up to 2% High-Density Polyethylene then increases with the increase in High-Density Polyethylene, this type of binder is considered more preferable in hot climates. This significant fact demonstrates that High-Density Polyethylene will lead to make this binder less susceptible to temperature changes.

The addition of High-Density Polyethylene to asphalt concrete mixture up to (9%) (by weight of asphalt) shows an increase in Marshall stability, Marshall Stiffness, Indirect tensile strength, temperature susceptibility, recoverable strain and stiffness moduluse with a decrease in flow, strain values and permanent strain as shown in Table (10) and Figures (1-6). Therefore, it can be concluded that using modified mix which contains (9%) of High-Density Polyethylene in the construction of surface course will increase the resistance of this course to tensile stresses, increase the resistance of these mixtures to deformation and reflection cracking which may be developed within this layer due to various traffic loadings and climatic conditions.

Wheel Tracking Test:- Six High-Density Polyethylene contents (0,1.5,3,6,9,12)% are used to evaluate the modified beams under wheel tracking test. Table (11) presents the wheel tracking test results as average of three beams.

. The percent of air voids is then calculated. The effective specific gravity of the aggregate (Gse) is calculated, as below.

Figure (7) illustrates the relationship between High-Density Polyethylene content and the total number of wheel passing required to crack the whole thickness of asphalt beam. It is shown that number of wheel passes increase rapidly as High-Density Polyethylene content increases up to 9%. The number of wheel passes for 9% increases by 161% compared with conventional beam and decreases slightly after it. This is due to the improved asphalt mixture properties such as increase in Marshall Stiffness, tensile stresses, stiffness modulus, and the decrease in the permanent deformation. This result confirms the results of I.T. and creep tests.

6- Conclusions

For the type of asphalt, aggregate, and mixture compositions investigated in this study and within the limitations of the tests(18), the following points are concluded:

1. The best content of H.D.Polyethylene that minimizing reflection cracks is (9%), it leads to the following: -

- Penetration values at 25°C decrease by 38% than that of pure asphalt, while ring and ball softing point increases by 4%.
- Increasing overlay Marshall Stiffness by 40% as compared with the conventional mixture.
- Tensile strength of overlay increasing by 62.5%,
- Temperature susceptibility increasing by 71% and stiffness modulus by 62% as compared with the conventional mixture.
- The maximum number of wheel passes which causes reflection cracking to appear increases by 161% as compared with conventional mixture.

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Table (1): Physical Properties of Asphalt Cement.

Test	**Units**	**Penetration-Grade (40-50)**
Penetration (25 °C, 100g, 5 sec.) ASTM D5.	1/10mm	43
Ductility (25°C, 5 cm/min). ASTM D 113*	Cm	100^+
Softening Point (Ring and Ball). ASTM D 36	°C	54
Specific Gravity at 25 °C. ASTM D 70*	….	1.047
Flash Point (cleaveland open cup) ASTM D 92*	°C	325
After Thin-Film Oven Test ASTM D 1754		
Penetration of Residue.	1/10 mm	31
Ductility of Residue*	cm	100^+
Loss in Weight (163 °C, 50g, 5h).	%	0.175

Table (2): Physical Properties of Nibaee Aggregates.

Property	***Coarse Aggregate***	***Fine Aggregate***	
		Crushed	***River Sand***
Bulk Specific Gravity (ASTM C127 and C128)	2.614	2.629	2.617
Apparent Specific Gravity (ASTM C 127 and C 128)	2.644	2.652	2.649
Percent Water Absorption (ASTM C127 and C 128)	0.435	0.562	1.40
Percent Wear (Los-Angeles Abrasion) (ASTM C131).	19.69	…	…

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

Physical Properties	
% Passing Sieve No. 200	98
Specific Gravity	3.13
Specific Surface area (m^2/kg)	356

Table (4): Gradation of the Aggregate for Surface Course.

Sieve Size	**Sieve Opening (mm)**	**Percentage Passing by Weight of total Aggregate**	
		Finer Surface Course	
		Specification limit [13]	**Mid Point Gradation**
1/2"	12.5	100	100
3/8"	9.5	80-100	90
No.4	4.75	46-76	61
No.8	2.36	28-58	43
No.50	0.3	8-24	16
No.200	0.075	4-12	8

Table (5): Gradation of High-Density Polyethylene.

Sieve Size	Percentage of Passing by weight of total H.D.Polyethylene
No. 20	100
No.50	36
No.100	25
No.200	0

Table (6):Physical Properties of High-Density Polyethylene.

Property	Unit	Value
Density	Gm/cm3	0.94*
Thermal degradation temperature	°C	407*
Color	-	Yellow

* From private factory.

Table (7): Essential Features of Test Machine.

	Before* modification	After modification
Width of rubber Tire, in	2	2
Load exerted by wheel on sample, Ib.	40 ± 0.5	187
Stroke on wheel, in.	9	9
Speed of electric motor driving wheel r.p.m.	25	25
Dimensions of sample		
Length, in.	12	12
Width, in.	3.54	3.54
Thickness, in.	1	2

* From catalogue of apparatus.

Table (8): Result of Mixtures with DAMS 12.5mm, (40-50) A.C.

Asphalt Content %	Marshall Stability, (KN)	Marshall Flow, (mm)	Unit Weight (gm/cm^3)	Gse*	Air Void (%)	V.F.A. (%)	V.M.A. (%)	Marshall stiffness KN/mm
4.25	12.23	2.450	2.290	2.6448	7.81	55.32	17.48	5.00
4.75	13.15	2.475	2.340		5.109	68.31	16.12	5.31
5.25	13.48	2.950	2.370		3.27	78.88	15.49	4.57
5.75	12.30	3.200	2.390		1.85	87.68	15.02	3.84
6.25	10.80	3.500	2.378		1.53	90.40	16.09	3.09

* Gse= effective specific gravity of the aggregate .

Table (9): Physical Properties of High-Density Polyethylene-Asphalt Mix*.

H.D.Polyethylene Content,%	Penetration25ºC 100gm,5 sec.	Softening Point ºC	Ductility25ºC 5cm/min.
0.0	43.0	54.0	112
0.5	56.0	52.0	>155
1.0	54.0	51.5	>155
1.5	52.3	51.0	>155
3.0	43.3	53.0	>155
6.0	33.0	54.5	>155
9.0	26.5	56.0	>155
12.0	23.0	60.0	140
S.C.R.B Specification For (40-50) grade	40-50	51-62	≥100

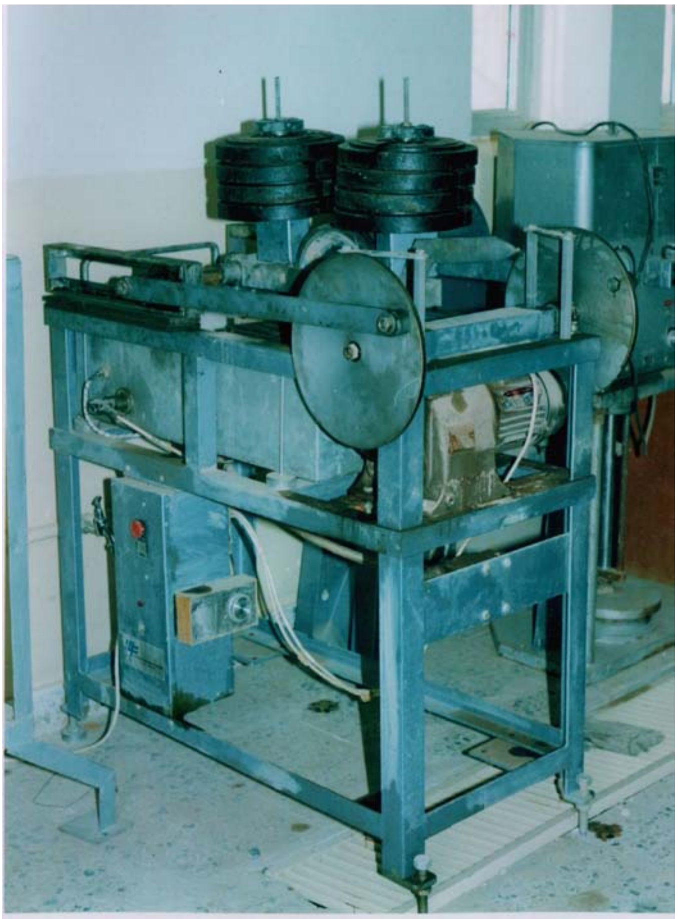
* The tests were done in cooperation with National Center for Construction and laboratories.

Table (10): Marshall Results of High-Density Polyethylene Mixture at Optimum Asphalt Content (as average of three Marshall Specimens).

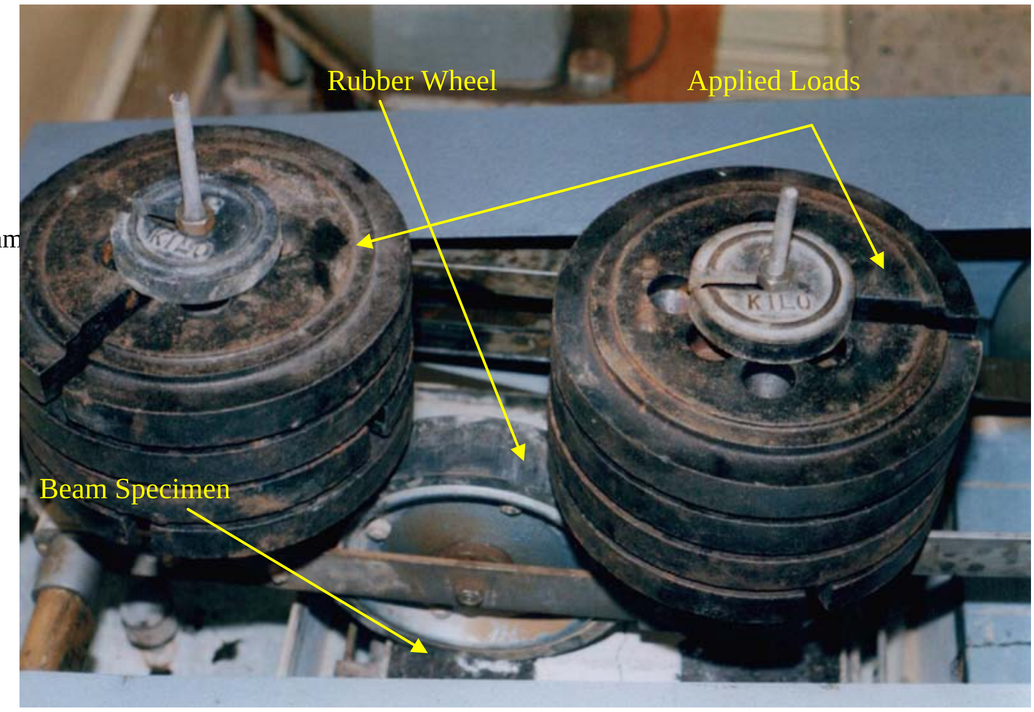
Marshall properties	H.D.Polyethylene Content %								S.C.R.B Specification Limits
	0	0.5	1.0	1.5	3.0	6.0	9.0	12.0	
Stability, KN	13.25	9.63	10.00	10.75	13.76	18.4	20.1	16.0	8.0 (min.)
Flow, mm	3.00	4.74	4.00	3.53	3.50	3.35	3.25	4.3	2-4
Unit Weight, gm/cm^3	2.375	2.363	2.362	2.360	2.358	2.356	2.350	2.325	_
Gse	2.666								-
Air Voids %	3.36	3.708	3.788	3.860	3.950	3.915	3.92	5.03	3-5
V.M.A. %	15.54	15.95	15.82	15.74	15.33	15.0	14.66	15.06	14.0 (min.)
V.F.A. %	78.38	76.75	76.06	75.48	74.23	73.9	73.87	66.69	65-85
Stiffness, KN/mm	4.42	2.03	2.50	3.05	3.93	5.49	6.18	3.72	_

Table (11):Number of Wheel Passes for Conventional and Modified Beam at Corresponding Optimum Asphalt Content under an Application Contact Stress 4.58*10^5 N/m2 (as average of three beams).

	High-Density Polyethylene Content %					
	0	1	3	6	9	12
No. Of Wheel Passes	15700	25300	32500	38100	41000	35050



*Wykeham



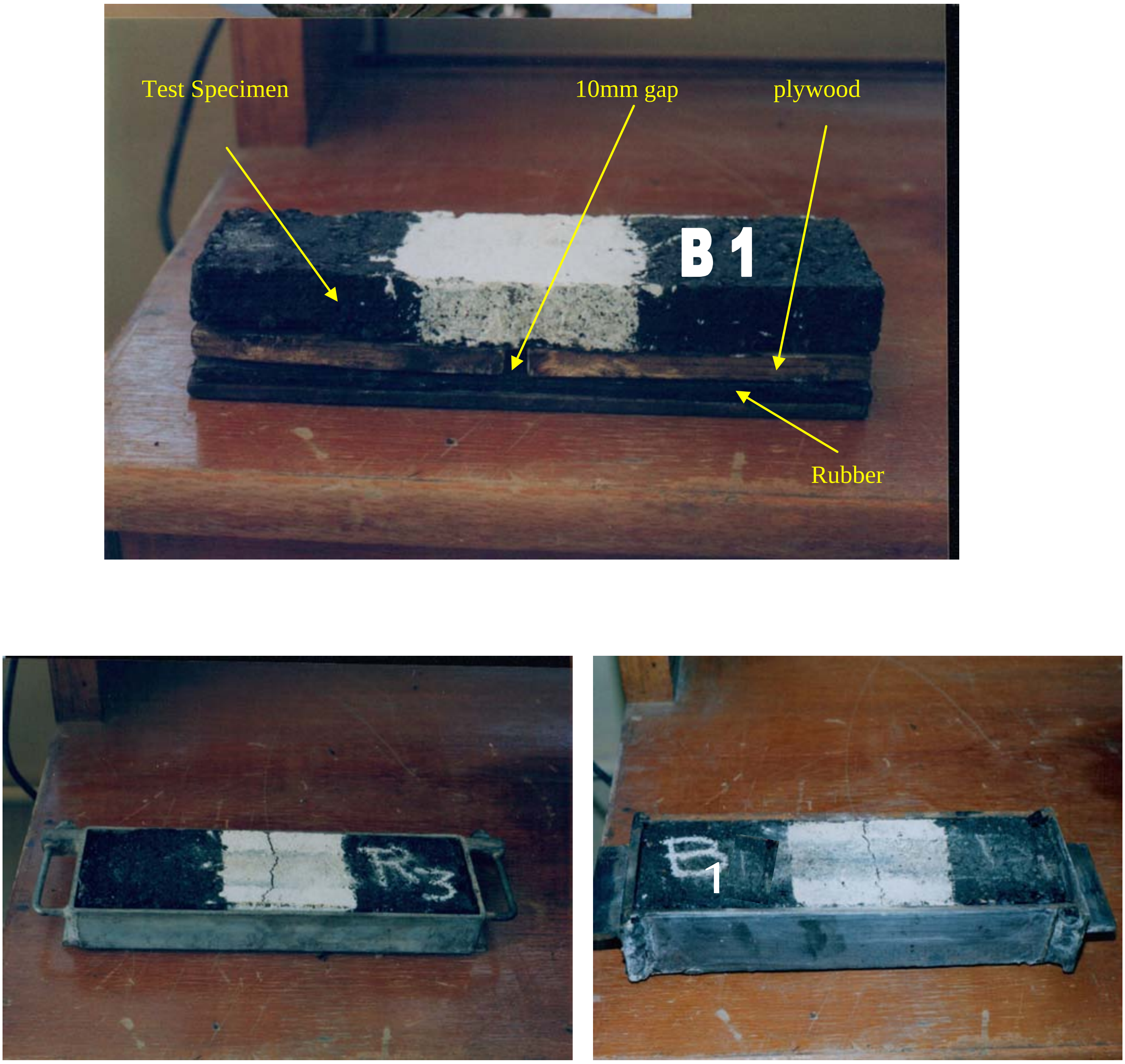
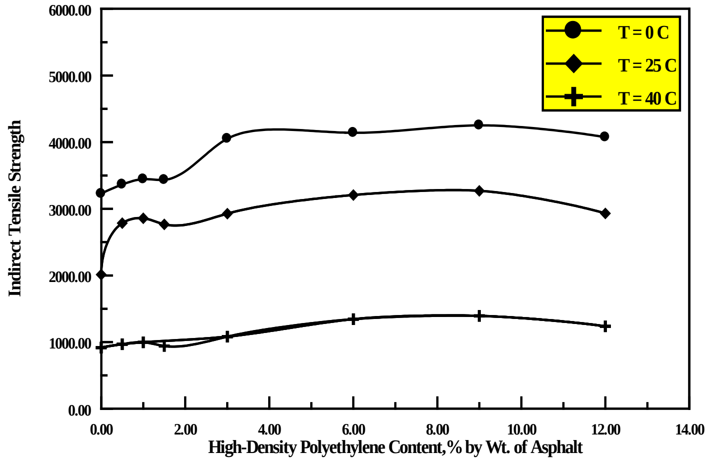


Plate (3): Propagation of Reflection Cracks



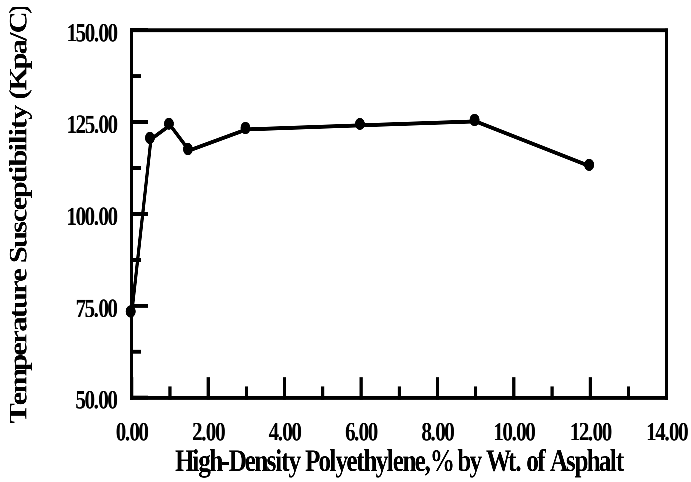


Figure (1): Effect of High-Density Polyethylene Content on Indirect Tensile Strength

Figure (2): Effect of High-Density polyethyleneContent on Temperature Susceptibility

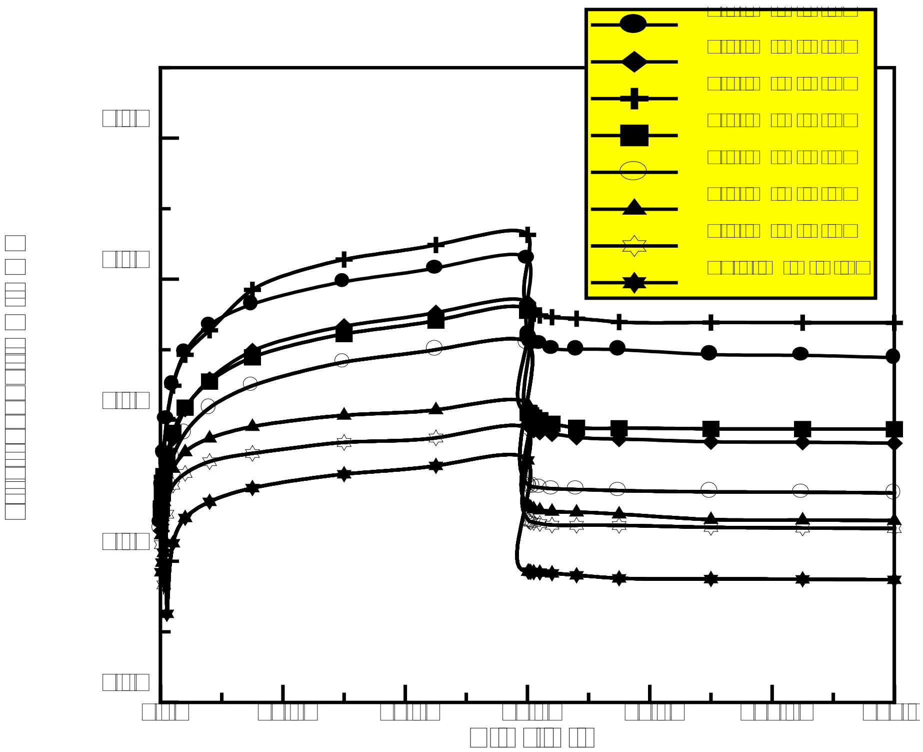


Figure (3): Effect of High-Density Polyethylene Content on Strain-Time Relationship Corresponding to Optimum Asphalt Content (Stress =0.141 Mpa, Testing Temp. =25ºC).

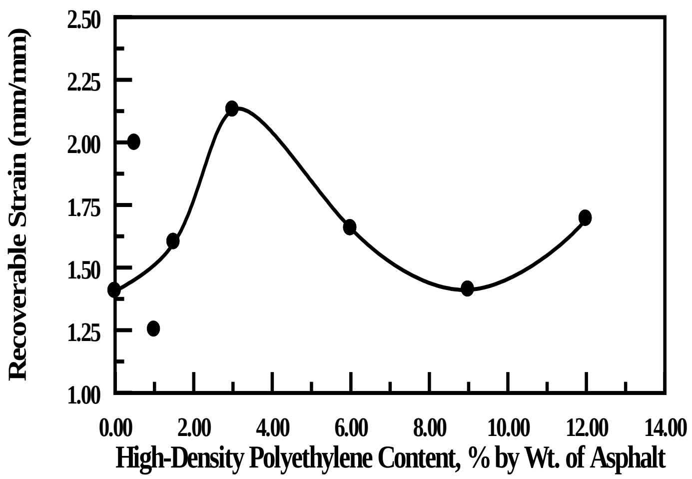


Figure (4): Recoverable Strain at Different High-Density Polyethylene Content.

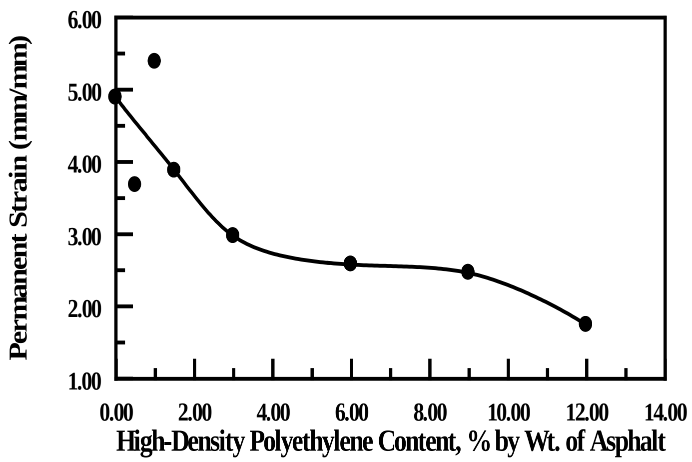


Figure (5): Permanent Strain at Different High-Density Polyethylene Content.

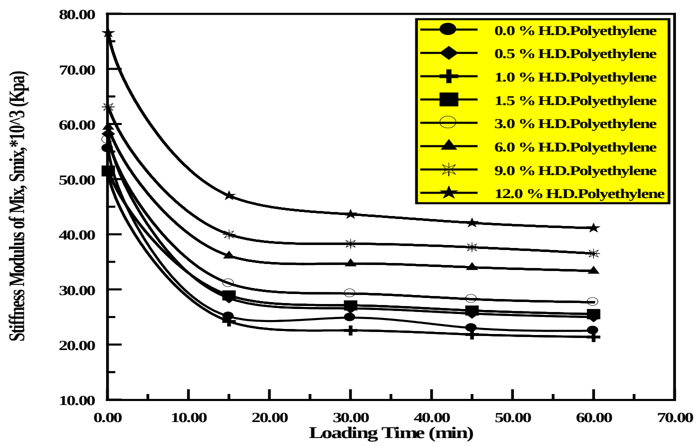


Figure (6): Stiffness Modulus, S_{mix} in Kpa at Different High-Density Polyethylene Content.

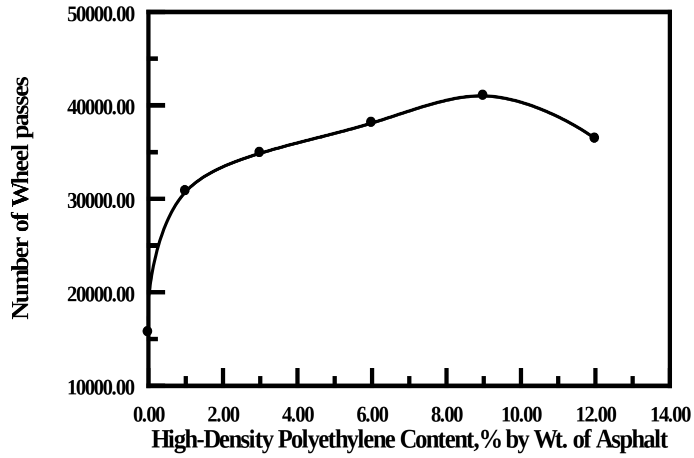


Figure (7): Relationship between No. of Wheel Passes and High-Polyethylene Content, %.