Effect of High Density Polyethylene on the Mechanical Properties of Asphalt Mixture under Dynamic Loads

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ABSTRACT

The effect of waste HDPE (plastic bags) on the rheological and mechanical properties of asphalt binder and mixtures are evaluated in this paper. Waste HDPE ratios are (1-5) % by weight of the asphalt were blended with 40/50 penetration with (PG64-16). By adoption of the (wet Process) in the preparation of mixtures. And by Super pave design of mixtures. It was to find and evaluate the engineering properties of the unmodified and modified asphalt through tests: penetration, softening point, ductility, sensitivity to heat, aging, and examination of homogeneity. Also, the mechanical properties for the unmodified and modified mixtures through conducting numerous test like, the indirect tensile resistance tests, compressive strength, permanent deformations, rutting under the wheel track, flexural strength and fatigue life. The analysis of test results show that rheological and mechanical characteristics of asphalt modified with waste HDPE perform better than conventional mixture. Decrease in penetration and temperature susceptibility, increase in softening points with increase in waste HDPE content. Also, modified mixtures perform better in terms of higher resistance to indirect tensile, best resistance to permanent deformation, the highest values for resilient modulus, better resistance to Rutting under the track wheel, better resistance to flexure and stiffness modulus. And longer Fatigue life in both dry and moisture condition.

Key words: Modified Asphalt, HDPE, ITS, IRS, TSR, Stress Level, Rheological Properties.

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1. INTRODUCTION

During the design life, the concrete pavement is exposed to many of the distortions and damage that lead ultimately to the asphalt pavement failure, and therefore the ability will decrease to carry traffic with increasing distortions when you do not take any measures that would reduce the causes of failure, like high traffic loads, environmental conditions, structural design of pavement and mixing materials. There are several forms of the failures that occur in asphalt concrete such as: permanent deformation (rutting), fatigue, moisture damage and cracks at low temperatures. To prevent the impact of these defects on the asphalt pavement, there are several methods that are used to improve the mix asphalt properties, Firstly, constructing road pavement with higher thickness and secondly using different types of additives as a modifier [1]. But with the increase in the thickness of the pavement, there is an increase in the cost of construction will occur, so the use of additives is the perfect choice to reduce the harmful effects of the distortions that occur in the asphalt pavement.

2-LITERATURE REVIEW

Punith and Veeraragavan, 2007 [2] used reclaimed PE as asphalt modifiers. They found that the basic test properties indicated that the addition of PE content to neat asphalt reduces the penetration and ductility values, whereas increases in softening point and specific gravity values were observed with the addition of PE modifier. A PE content of 5% by weight of asphalt is recommended for the improvement of the performance of asphalt cement.

Ahmadinia et al., 2012 [3] investigated of adding waste plastic bottles PET as an additive in stone mastic asphalt (SMA). Wheel tracking, moisture susceptibility, resilient modulus and drain down tests were carried out on the mixtures that included various percentages of waste PET as 0%, 2%, 4%, 6%, 8% and 10% by weight of asphalt content. Results showed that the MR values of mixtures containing a lower amount of PET were higher than the conventional mix and the addition of waste PET into the mixture could improve the mixture's resistance against

permanent deformation and provide lower binder drain down Also, it was concluded that the mixtures containing PET have lower ITS and TSR value**.**

Moghaddam and Karim, 2012[4] evaluated the ability of using waste (PET) as an additive into asphalt mixture. Different percentages of PET were added into the mixture. Marshall Stability test was carried out. Besides, stiffness modulus and indirect tensile fatigue test were conducted on specimens at optimum asphalt content. Results revealed that PET reinforced mixtures had higher stability value in comparison with the mixtures without PET, and it was noted that 0.4% PET was concluded as the optimum value in case of stability. In addition, flow values increased by adding PET into the mixture. It was also investigated that although stiffness of mixtures decreased by adding a higher amount of PET, fatigue life increased at higher PET content.

3. RESEARCH OBJECTIVE

1- Evaluate the effect OF the modified binder with waste HDPE to the permanent deformation and Cracks for Super-pave mixture.

2- Evaluate the effect of wheel tracking loading test on rutting for Super-pave mixture in dry and wet conditions

3- Evaluate the rheological behave of new blend modified with waste HDPE.

4. EXPERIMENTAL PROGRAM

Materials: The materials which are used in this work are as follows:

Asphalt Cement:

For (40-50) penetration the performance grade is PG24-16 [5]. Brought from AL- Daura refinery in Baghdad Used in this study. The physical properties of asphalt cement done according to ASTM [6].With the specification limits as set by the (**SCRB, 2003)** [7]are summarized in Table (1) .

Table (1): Physical Properties of Asphalt Binder.

Property	Test Condition	Unit	ASTM Designation No	Value	SCRB Specification-03
Penetration	25° C,100gm,5sec	1/10 mm	D-5-**06**	41	40 -50
Softening point	Ring & Ball	∘C	D-36-95	48.7	----
Specific Gravity	25° C	----	D-70-97	1.04	----
Ductility	25° C, 5 cm/min	Cm	D-113-99	151	>100
Flash point	Tag Open- Cup	∘C	D-92-05	275	>232
After Thin Film Oven Test					
Penetration of Residue	25° C,100 gm,5sec	1/10 mm	D-5-26	90%	>55 %
Mass loss	163 ^{o} C, 50 gm,5hr	%	D-1754	0.27	<0.75
uctility of Residue	25° C, 5 cm/min	Cm	D-113-99	95%	>25%

Aggregate Properties:

The coarse and fine aggregate used in this study are crushed aggregate from Al- Nibae Quarry, 80 km north of Baghdad, these aggregates are widely used in the middle areas of Iraq for asphalt pavement. The coarse and fine aggregates used in this work are sieved and recombined [6] in the proper proportions to meet the binder coarse gradation as required by Super pave specification, Routine tests are performed on the Aggregate to evaluate their physical properties which include (Consensus and source properties) [8]. Test done according to ASTM [6].Together with the specification limits as set by the (**SCRB, R9. 2003**)[7]. The results shown in Tables (2), (3) and (4).

Table (2): Consensus properties for coarse and fine aggregate.

Coarse aggregate Angularity	on Fractured % Face	At least 2 Fractured faces %	Designation Test	Super pave Criteria
Coarse 19 mm	98	91	ASTM D5821-01	95/90
Intermediate 12.5m	94	92	ASTM D5821-01	95/90
<Intermediate 9.5mm	95	91	ASTM D5821-01	95/90
	Property	Value		
Flat and elongated particles larger than 4.75 mm	% 1.2		ASTM D4791-05	Max 10%
Clay content for fraction less than 4.75 mm (Sand Equivalent)	67		AASHTO T176 -08	Min 45%
Fine aggregate Angularity	Percent air voids in Loosely compacted fine aggregate			
Manufactured sand	56		AASHTO T304-08	45%Min.
Natural sand	47		AASHTO T304-08	

Table (3) Gradation of Aggregates.

	Agg.C 19 mm	Agg.C 12.5mm	Agg.C 9.5mm	Min. Sand	Na Sand	Gradation of mix 1	Gradation of mix 2	Gradation of mix 3	C. points Min	C. points Max	R. zone Min	R. zone Max	SCRB-2003 Min	SCRB-2003 Max
Trail No 1	%23	%12	%30	%20	%15									
Trail No 2	%8	%12	%22	%25	%33									
Trail No 3	%22	%18	%20	%20	%20									
Sieve Size	Gradation passing %								Min	Max	Min	Max	Min	Max
25 mm	100	100	100	100	100	100	100	100	100	-	-	-	100	100
19mm	100	100	100	100	100	97	99	96	90	100	-	-	90	100
12.5mm	57	91	100	100	100	85	93	82	-	90	-	-	70	90
9.5mm	49	57	92	100	100	71	82	65	-	-	-	-	56	80
4.75mm	23	26	31	95	93	38	56	40	-	-	-	-	35	65
2.36mm	10	11	12	64	71	25	39	28	23	49	34.6	34.6	23	49
1.18mm	4.4	2	3	35	60	18	30	21	-	-	22.3	28.3	-	-
0.6mm	4	2.2	2.5	22	45	13	21	15	-	-	16.7	20.7	-	-
0.3mm	4	2.1	2.3	14	33	10	15	11	-	-	13.7	13.7	5	19
0.15mm	4	2	2.3	7	23	7	10	7	-	-	-	-	-	-
0.075mm	3	2	2.3	6	11	5	6	6	2	8	-	-	3	9

Table (4): source properties results

Property	Value	Designation Test	Super-pave Criteria
Toughness (loss Angeles abrasion) %	27	AASHTO T 96-06	Max 35%
Soundness%	12.6	AASHTO T 104-11	Max 18%(Sodium Sulfate)
Deleterious Materials %	0.023	AASHTO T 112-08	0.2-10 %

Filler

In this study, one type of mineral fillers is used, lime stone dust. Passing sieve, no 200, Bulk specific gravity and Specific surface area are: 96%, 2.165 m^3/kg and 393, respectively.

Modifiers

Waste HDPE (Plastic bags) collected from domestic waste is used in this study to modify the conventional 40/50 bitumen to evaluate the performance of asphalt mixture. The density, melting point, tensile strength, elongation at break and water absorption of waste plastic (HDPE) are: 0.941gm/cm3, 139 oC, 2.65 Mpa,> 500% and 0%, respectively.

5. TEST METHOD AND SAMPLE PREPARATION

Super-pave mix design for Optimum Aggregate Gradation Selection and optimum asphalt con

Optimum Aggregate Gradation Selection

Selection of the design aggregate structure consists of determining the aggregate stockpile proportions and corresponding combined gradations of the mix design. The design aggregate structure, when blended at the optimum binder content, should yield acceptable volumetric properties based on the established criteria [9]. Three trial aggregate were established and the initial binder content determine for each trial aggregate gradation. Five stockpiles of materials consisting of (3) coarse materials and two (2) fine materials are employed. Representative samples of the materials are obtained, and washed sieve analysis is performed for each aggregate. The specific gravities (bulk Gsb and apparent Gsa) are determined for each aggregate, table (5), in addition to priory, Super pave requires certain consensus and source aggregate tests be performed to assure that the combined aggregates selected for the mix design are acceptable. The aggregate gradation was plotted followed by Super pave requirements on the (0.45power) chart, which is developed by (FHWA, this chart also content (Nominal Maximum Size, which is 19mm for binder coarse, and control points). Figure (1). And Figure (2) shows a flow chart of the experimental design Procedure used in this study.
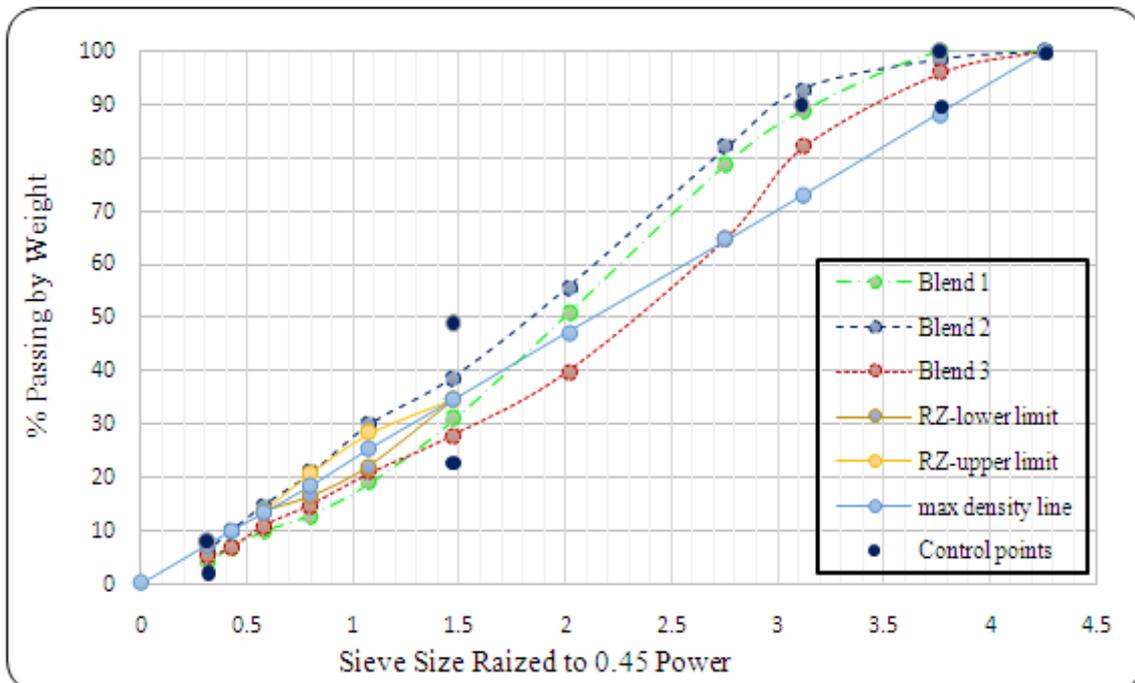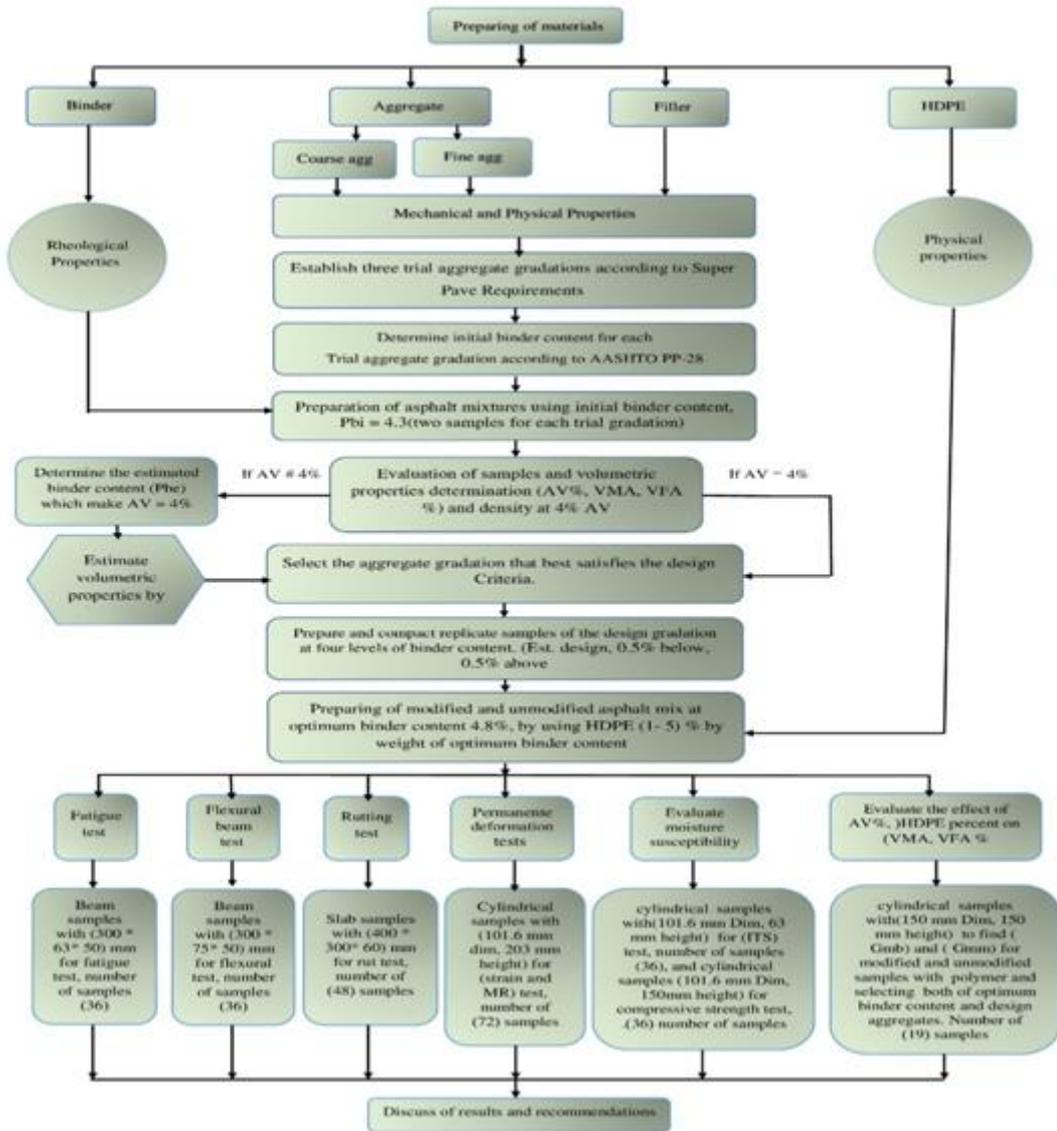

Figure 1: Aggregate gradation for 19 mm nominal max size

Figure 2: Flow Chart of the Experimental Design Procedure for the Study

Table (5): Aggregate Specific Gravity Results

Aggregate	19 mm	12.5 mm	9.5 mm	Min.and	Nat.sand
Gsb	2.615	2.61	2.63	2.61	2.625
Gsa	2.672	2.688	2.67	2.65	2.7

Using the equations of the volumetric properties to find initial binder content for each trail aggregate gradation (Pbi), then at (Pbi) content prepare and compact (2) samples for each trail aggregate gradation using Super-Pave Gyratory compactor (SGC). The volumetric properties of the compacted samples were measured and estimated at (0.4) % air voids. Table (6), for this study trial blend No. (1) Were selected for its best design criteria. According to super pave requirements the air voids accede (4 %), [8]therefore the volumetric properties evaluated again by estimating the binder content (Pbe) which make air voids equal to 4 (AV=4%). table (7).

Table (6): Volumetric Properties for Trial Blends

Trial blend	Gse	Vba	Ws (gm)	Pbi	%G_{mm} @ N_{des}	%G_{mm} @ N_{ini}	Va %	VMA %
1	2.649	0.010402	2.298	4.31	95.25	83.4	4.75	14.17
2	2.654	0.010175	2.301	4.29	95.52	84.1	4.53	13.99
3	2.649	0.011018	2.298	4.33	95.5	84	4.5	13.76

Table (7): Volumetric Properties for Trial Blends at AV= 4%

Blend No	$Pb_{ini \%}$	VFA %	VMA%	Va%	$Pb_{es \%}$	D_P	G_{mm} @ Nini% (Est)
1	4.3	71.44	14.01	4	4.59	1.08	84.15
2	4.3	71.18	13.88	4	4.31	1.31	84.63
3	4.3	70.71	13.66	4	4.31	1.31	84.5

Optimum Asphalt Content Selection:

Selection of the design (optimum) asphalt binder content consists of varying the amount of asphalt binder in the design aggregate structure to obtain acceptable volumetric properties when compared to the established mixture criteria. It also provides a feel for the sensitivity of the design properties to changes in the asphalt binder content during production of super pave mix design [9]. For select of optimum binder content for a given aggregate Source, binder source and optimum aggregate. Based on the specification (4% air voids, >13 % VMA, 65-75 VFA, 0.6-1.2 dust). Two samples were Prepared and compact of the design gradation (blend No .1) at four levels of binder Content. (Est. design: 4.6 %, 0.5% below, 0.5% above and 1.0% above) using (SGC). Volumetric properties were measured for all the samples, table (8). By drawing the relationship between asphalt content and (AV, VMA, VFA AND Dp). The optimum asphalt content evaluated at (4) % air voids which was (4.8) %. Then checking of volumetric properties at (4.8) % asphalt content, which was fulfill the design criteria. After that tow samples were prepared and compacted at Nmax, the purpose of this step is to checking (%Gmm @Ndes) it should not be greater than (98) % according to Super pave requirements. Table (9).

Table (8): Volumetric Properties at Ndes

AC %	VA%	VFA%	VMA%	$D_{P\%}$	G_{mm} @Ndes%	G_{mm} @Nini%
4.1	5.52	62.52	14.72	0.96	94.48	81.73
4.6	4.51	68.64	14.44	0.99	95.49	83.13
5.1	3.5	75.31	14.2	1.03	96.50	83.82
5.6	3.27	77.60	14.58	1.077	96.73	83.87

Table (9): Volumetric Properties at Optimum Binder Content at Nmax

Property of mix	Air voids %	VMA % at N_{des}	VFA % at N_{des}	$D_{P \%}$	G_{mm} @ N_{ini}	G_{mm} @ N_{des}	G_{mm} @ N_{max}
Result	4 %	14.23 %	71.89 %	0.97	82.71	94.1	96.66
Super pave Requirements %	4	13 or more	65-75	0.6-1.2	Less than 89	96 max range	98 max range

6- PREPARATION OF MODIFIED BINDERS

For preparation of HDPE blends, bitumen was heated to a Temperature 170°C, the percentage (1-5) % of plastic bags by weight of bitumen in shredded form (2*2) mm were add. The temperature was maintained between 165°C to 175°C and mixing using a high-speed stirrer rotating at a speed of 1800 rpm, and blending was done for a period of 90 minute to obtain a homogeneous binder. The uniformity of dispersion of HDPE was confirmed by passing the bitumen at 170°C through an ASTM 100 sieve. It was found that the bitumen thus prepared can be stored for future use [2].

Preparation of modified and unmodified mixtures:

All the asphalt mixes in the study were prepared by super pave mix design procedure, the modified and unmodified binder is heated to produce kinematic viscosity of 170 ± 20 x 10-6 m^2/s and 280 ± 30x10-6 m^2/s. [10].The viscosity temperature relationship was developed to determine the mixing and compaction temperatures. The rotational viscosity was determined by measuring the torque required to maintain a constant rotational speed (20 rpm) of a cylindrical spindle (LV21) while submerged in bitumen binder at constant temperature by Brookfield viscometer. So the result of compaction and mixing temperature are (167 °C -163 °C), (143 °C -150 °C) respectively. The aggregates are then heated to a temperature of 160 °C before mixing with asphalt cement which has already been heated to a temperature that produce a kinematic viscosity. Then, the asphalt cement is weighed to the desired amount and added to the heated aggregates and mixed until all aggregate particles are coated with asphalt.

After mixing, short term aging of (4 hours at 135o C) is used to simulate what is happening in the hot mix plant during the mixing according to AASHTO-PP2 [10], storage and placement operations. During compaction by super pave gyratory compactor (SGC) a vertical force of 600 KPa is applied, and the mold is tilted to an angle of 1.25 °. The SGC

forces the tilt of the mold to rotate at a rate of 30 rpmaccording to AASHTO-T312 [11]. All of the test samples were compacted at the design number of gyrations using the Super pave procedures. The gyrations selected for the present study are given below.

Ninitial = 8 gyrations, Ndesign = 100 gyrations, Nmaximum = 160 gyrations.

7. PERFORMANCE TESTS

A number of performance tests in the laboratory were adopted. These tests were: moisture susceptibility, permanent deformation, resilient modulus, rutting, flexural strength and fatigue tests. For all the tests the dry and wet conditions were evaluated. The moisture susceptibility test according to AASHTO T283 [11] procedure was performed on the five HMA mixes, which were compacted to an average air-void content of 7.0%. Three specimens (101.5mm in dim*63.5mm height) were prepared and used for the dry group and three specimens for the wet group were prepared for modified and unmodified mixture. From this test the indirect tensile strength test and tensile strength ratio were determined for the two groups at test temperature (25°C and 60°C). Also, compressive strength was evaluated according to ASTM-D1074on specimens with diameter 101.6mm and 150mmheight. Both of Permanent deformation and resilient modulus was done on Super pave cylindrical testing specimen with dimensions of 101.6 mm in diameter and 203±3 mm in height, and an air-void content of 7.0%. Which required approximately 3800 g of asphalt mixture. The specimens were placed in testing chamber for two hours at the desired temperature. The axial repeated load test was conducted using the Pneumatic Repeated Load System [12], with a compressive stress (0.138 Mpa) test temperatures (25°C, 40°C and 60°C) in this test, repetitive compressive loading was applied to the specimen and the axial deformation was measured under the different loading repetitions. Compressive loading was applied in the form of rectangular wave with a constant loading frequency of 60 cycles per minute (1 HZ) including 0.1 sec loading time and 0.9 sec rest period. The experiment is commenced by application of repeated axial stress and recording the vertical deformation. Upon completion of test after 4000 load repetitions or any number for load repetition when the specimen failed earlier. The permanent deformation is expressed as vertical micro strain and calculated by using Eq. (1);

$$\varepsilon p = \frac{\Delta H}{H} \qquad \ldots\ldots.. \text{Eq. (1)}$$

Where:
εp = vertical micro strain, mm/mm
ΔH = vertical deformation at the specified load repetition, mm
H = original height of the specimen, 203.2 mm.

The resilient modulus of asphalt mixture, ASTM D-4123[6], can be applied as indicator of flexible pavement ability to resist the harmful effects of high axle loading and elevated temperature conditions. According to Huang, 2004[13], the resilient modulus is the elastic modulus based on recoverable strain in repeated load test and can be expressed by Eq.

(2);
$$MR = \sigma d / \varepsilon r \qquad \ldots\ldots\ldots.. \text{Eq. (2)}$$
Where:
MR = resilient modulus of asphalt mixture, Mpa.
σd = deviator stress, which is the axial stress for unconfined compression test, 20 psi= 0.137 MPa.
εr = recoverable vertical strain corresponding to the 200th repetition of load application.

The test of rutting was performed according to EN 12697-22[14] test method using Wheel Tracking Device. The susceptibility of bituminous material to rut under wheel load is determined using the wheel tracking test. Specimens prepared in laboratory with dimensions (400mm*300mm*60mm). Compacted to an average air-void content of 7.0%. Test temperature was 40°C and 55°C and the slabs were kept 2 hours at that temperature before the actual start of the test. The wheel loads of 700 N, which moves back and forth in harmonic motion at 10000 passes or 26.4 cycles per min or as long as it takes for a 15-mm deformation to occur in the specimen, whichever comes first. Flexural test was done according to ASTM C-78[6] on small beams of the dimension (300mm * 75mm * 60 mm) cutting from a compacted square slab specimen (300 * 400 * 60 cm). Three series of beam specimens were prepared and tested at 0 °C and -10 °C temperature for modified and unmodified specimens using a universal testing machine. 36 specimens were prepared for this test. From this test the flexural modulus (MR) and stiffness modulus (ST) were determined by:

$$MR = \frac{PL}{6\Delta b^2 d^2} \qquad \ldots\ldots.. \text{Eq. (3)}$$

Where MR is flexural modulus (modulus of rupture), P is load at break, N MPa. Δ is deflection at the beam center, mm; and b is av. beam width, mm. d is av. Beam depth, mm.

$$ST = \frac{PL}{bd^2} \qquad \ldots\ldots \text{Eq. (4)}$$

Where St is the stiffness modulus, MPa. P is load at break, N. L is beam span, mm. b is av. beam width, mm. d is av. Beam depth, mm. St is a measure of the stiffness modulus. The specimens of flexural fatigue test used (300*63*60) mm which catted from the slab with dimension (400*300*60) mm prepared by same procedure in preparing wheel tracking specimens. The test was conducted according to (constant stress method) at temperature 20 °Cwith frequency of 120 cycles per minute (2 HZ), including 0.1 sec loading time and 0.4 sec rest period. Through (Third Point Loading Test), [13] using Pneumatic Repeated Load System. The stresses used (0.45 Mpa, 0.65Mpa and 0.85 Mpa). Repetitive compressive loading was applied to the specimen and the vertical deformation was measured at the center of each beam.

8. RESULTS AND DISCUSSION

Rheological tests:

The rheological properties of waste HDPE–asphalt binders were evaluated on SGC specimens (150mm in diameter and 115 ± 5mm in height). The results are presented in table (10). The results indicate that waste HDPE is effective in improving the rheological properties of asphalt cement. At the 5% of HDPE the penetration decreases by 35.8 which indicates improvements in resistance to deformation [15], While the softening point increase by 26.6, otherwise 3% 0f waste HDPE keeping the ductility value above 100^{+}.

Temperature susceptibility:

The penetration index relationship was used to investigate the influence of Waste HDPE addition on temperature susceptibility of asphalt cement using the following Eq. (1) mentioned by [16].

$$pentrationindex(P.I) = \frac{20 - 500A}{1 + 50A} \qquad ......\text{Eq. (1)}$$

$$A = \frac{\log(Pen.@T) - \log 800}{T - T_{R\&B}} \qquad ......\text{Eq. (2)}$$

Where T is the testing temperature, **25 °C**.TR2B is the ring and ball softening point, **°C**.

The relationship between the penetration index and HDPE contents illustrates in fig (3). A higher value of P.I. indicates the lower temperature susceptibility of binder [14]. it can be observed that the values of P.I. for virgin and 5% waste HDPE modified bitumen samples are (-1.95 and 0.74) respectively. It can be said that P.I for useful materials should be between the rang (-2, +2) as mentioned by researchers.

Short-Term Aging in the Thin Film Oven Test (TFOT)

The short-term aging test for modified asphalt with waste HDPE was carried out by thin film oven test (TFOT) and the loss of weight was conducted after that. From the figure (3), the percent loss of weight by heat and air decreases as the PET content increase this is related to that the HDPE was occupied a space of total mix, and cause reduction in asphalt volume, which leads to decrease in loss by dehydrogenation and oxidation of asphalt in the mix (durability increased slightly with the addition of Plastic bags content in the mix) [15].
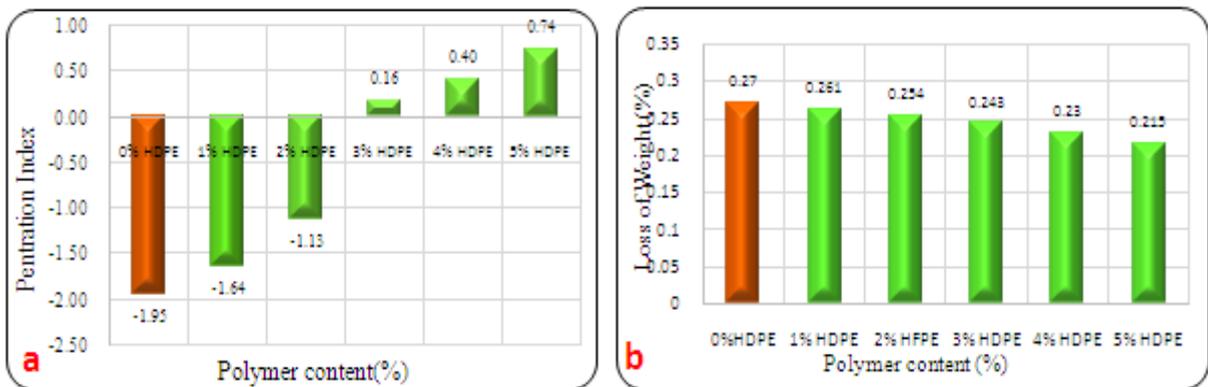

Figure (3): Relationship between HDPE Content and: (a) Penetration Index, (b) Percentage Loss of Heat and Air.

Volumetric Properties of Modified Mixtures:
Air voids (AV)

An air void in the mixture is an important parameter because it permits the physical properties and performance of the mixture to be predicted for the service life of the pavement [2]. As shown in figure (4) the air voids of conventional mix decrees as the revolution of gyratory test machine (GTM) Increase. Also, it's observed from the test result of super pave specimen that the percentage air voids decrease with increase in plastic bags in the mixture. The result illustrated in Table (10).

Table (10): Rheological Properties Results

% waste HDPE	Penetration (25 °C,1/10, 100g, 5sec	Ductility (25 °C, cm)	Softening Point (°C)
0	41	151	66.4
1	38.4	142	63.5
2	33.4	119	61.3
3	30.7	104	54
4	28.4	75	50.5
5	26.3	61	48.7

Voids in Mineral Aggregates (VMA)

In general, the VMA percentage of the modified asphalt concrete mixtures is higher than the conventional asphalt concrete mixture. as shown in and Table (10) and figure (4).

Voids Filled with Asphalt (VFA)

The VFA percentage of the modified asphalt concrete mixtures is higher than the conventional asphalt concrete mixture. The modifiers here work as a microscopic frame within the voids which allow the absorption of more asphalt cement to be in the mixture. as shown in figure (4) and Table (11).
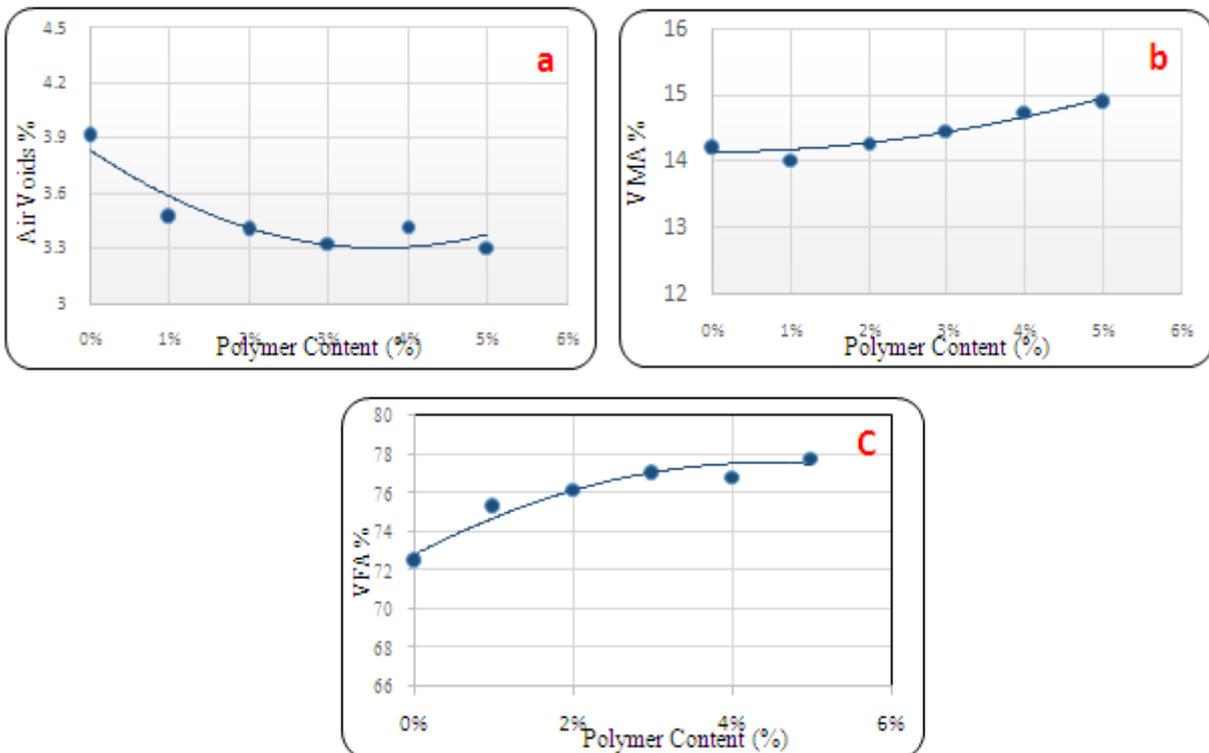

Fig. (4). Relationship between waste HDPE content and volumetric properties (a – AV, b – VMA, and c – VFA).

Table (11): Volumetric Properties for Modified and Unmodified Mixtures

% waste HDPE	Gmb	Gmm	*%Gmm*	AV%	VMA	VFA
0%	2.36	2.456	*0.960*	3.908	14.21	72.50
1%	2.365	2.45	*0.965*	3.469	14.03	75.27
2%	2.358	2.441	*0.965*	3.400	14.28	76.20
3%	2.353	2.434	*0.966*	3.327	14.46	77.0
4%	2.345	2.428	*0.965*	3.418	14.75	76.83
5%	2.341	2.421	*0.966*	3.304	14.90	77.83

Performance Test Results
Moisture Susceptibility:

Figure (5) shows the relation between indirect tensile strength (ITS) and Tensile strength ratio (TSR) with waste HDPE–asphalt mixtures. The results indicate that indirect tensile strength and tensile strength ratio increased for both testing temperatures. This reason due to increase the adhesion between aggregate and bitumen, which leads to a decrease in the stripping of HMA). [15]. the results indicated that the increase in (ITS) values were (47.28) % and (61/25) %, respectively. While (TSR) values were 92.69 % for Super pave modified mixtures containing 3%HDPE. And for the compressive strength (CS), the results show that (Cs) increase with increase of waste HDPE content. The percent of increase (76.8) % and (65.3) % at 5% of polymer content. While higher value of Index of Retained Strength (IR) was (88.17). (It can be seen that the waste HDPE-modified bitumen improves the resistance to moisture susceptibility of the asphalt mixtures.
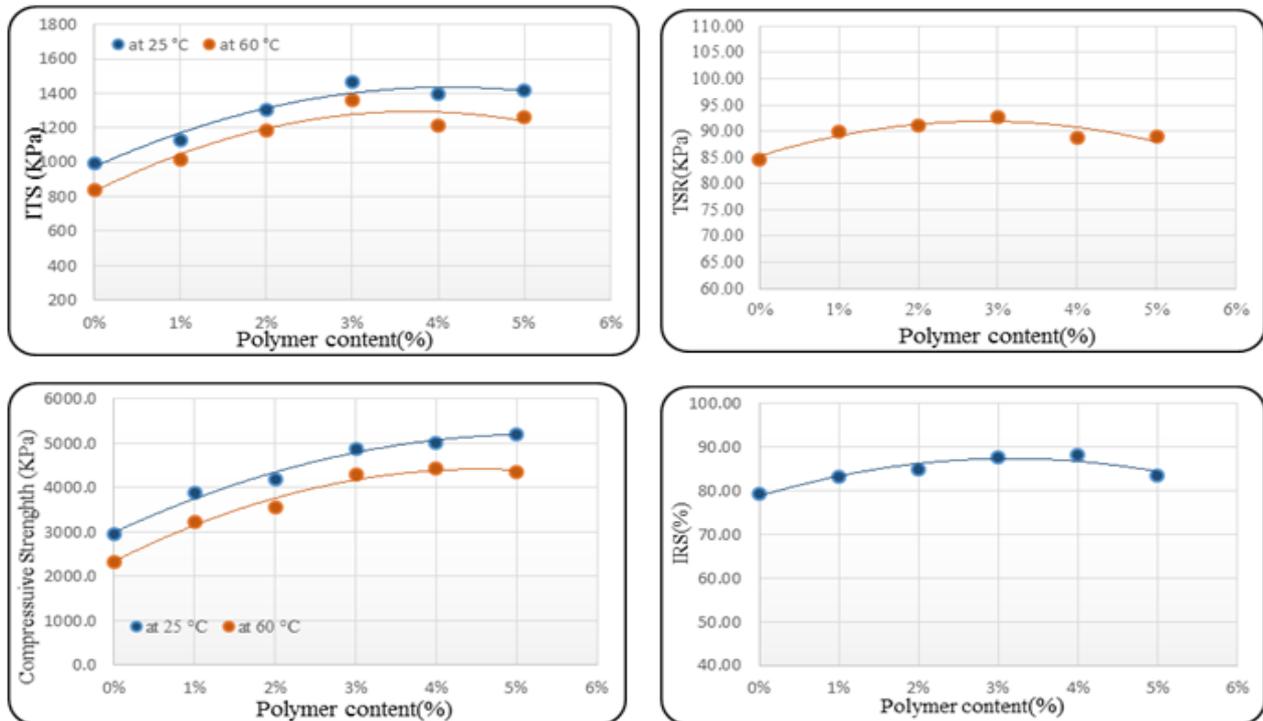

Figure (5) relationship between waste HDPE content and (a) ITS, (b) TSR, (c) CS, and (d) IRS.

Permanent Deformation Results:

It is invariably found that, the plastic bags used in this study succeed in improving the ability of asphalt mixture to resist the permanent deformation expressed in micro strain. However, the degree of success varies from the dry condition to moisture condition. The reduction of micro strain in dry condition by 35.4%,35.2 and 32.5% at testing temperatures 25 °C, 40 °C and 60 °C, respectively. While in moisture condition reduction by 24.1%, 25.5% and 28.9% at the same testing temperatures, respectively. at the same polymer content of 5 % by weight of bitumen. The temperature has a significant influence on permanent deformation of asphalt mixture. Increasing the test temperature from 25 °C to 40 °C produce an increase in micro strain by 7.8 %, and 6.3%. These two percentages became 9 % and

2.9 % respectively when the temperature raised from 40 °C to 60 °C for dry and wet condition respectively at 5% by weight of bitumen. This behavior is quite understood and logically accepted because the stiffness of asphalt binder is adversely affected by the temperature increasing and moisture condition. But the increment of permanent deformation decreases gradually by increment of plastic bags in mixtures. This beaver due to increase in softening point and the mixtures become more stiffness. Fig (6).
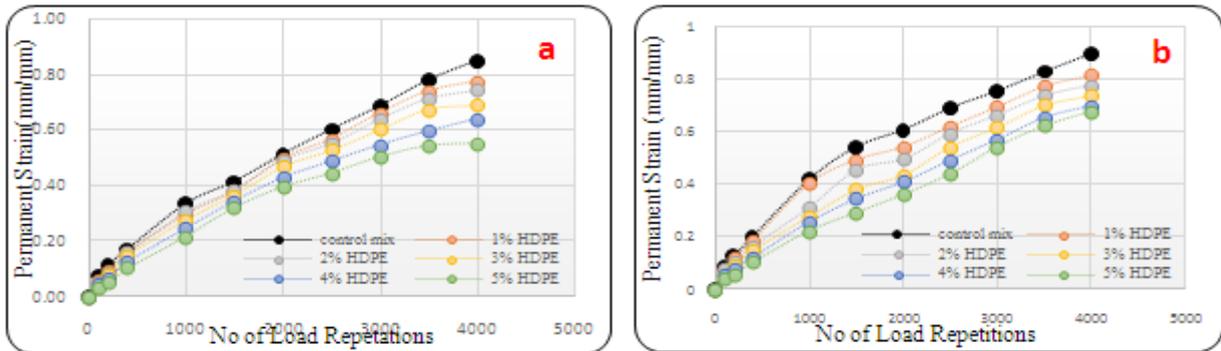
Figure (6): Effect of Waste HDPE on Permanent Deformation (@ Stress Level= 0.138 MPa, T=40 °C, (a) Dry Condition, (b)Wet Condition)

Resilient Modulus Test

The resilient modulus test was conducted at the same conditions of testing permanent deformation and (same specimens). The influence of blending asphalt binder with HDPE polymer (plastic bags) is portrayed in from fig (7). Which declare that, this Plastomers polymer increase the resilient modulus by 108%, 116.5% and 123.6% at testing temperature 25 °C, 40 °C and 60 °C, respectively in dry condition. While in moisture condition, resilient modulus increase 89.8%, 100% and 100% respectively, at 5% polymer. In other side, increasing the test temperature from 25 °C to 40 °C produce a reduction in resilient modulus by 20% and 17.2% these two percentages became 10.3% and 10.1 % when the temperature raised to60 °C for dry and wet condition, respectively. The temperature has a significant influence on resilient modulus of asphalt mixture. As demonstrated in Figure (7) for both dry and wet condition. Increasing the test temperature from 25 °C to 40 °C produce reduction in resilient modulus by 20% and 17.2% for dry and wet condition, respectively. These two percentages became 10.3% and 10.1% this behavior is quite understood and logically accepted because the stiffness of asphalt binder is adversely affected by the temperature increasing. [12].
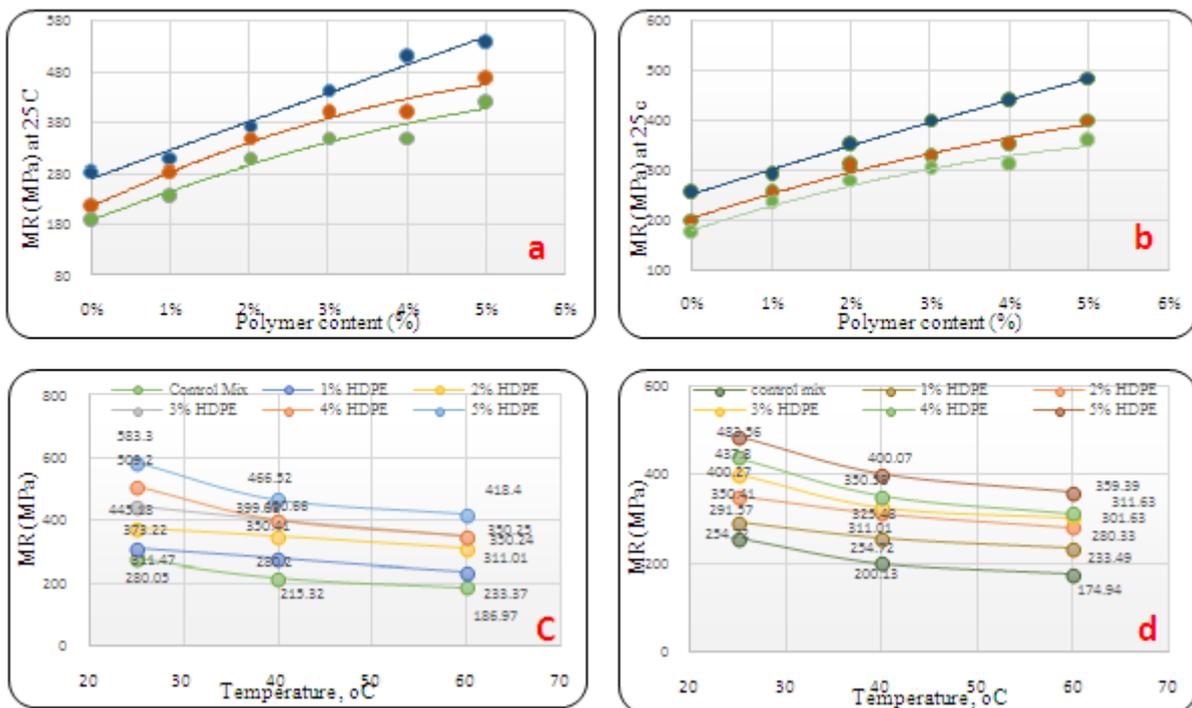

Figure (7): Relationship between Waste HDPE and MR (a) Dry Condition (b) Wet Condition. And Relationship between MR and Temperature (c) Dry Specimens (d) Wet Specimens.

Wheel Tracking Test

Roller compacted slab were tested in both dry and wet condition at temperatures 40 °C and 55 °C. The effect of waste HDPE (plastic bags) on rutting resistance for mixtures is displayed in Figure (8) the results indicate that mixtures containing waste HDPE have better rutting resistance compared to the conventional mixture. The rut depth decreases with increase of plastic bags in the mix. Resistance to rutting of bituminous mixes depends upon several factors such as volumetric composition, shape of aggregate and characteristics of binders [17] It can be seen from data plotted in Figure (8) that incorporation of 5% plastic bags reduced rutting by 78.7% and 78.9% at 40ºC for dry and wet condition, respectively. This percent became 81.5% and 79.3% respectively at 55ºC after 10,000 passes. This behave of modified mixtures with waste HDPE achieved can contribute to the formation of a stiffer mixture, which improves the rutting resistance of the mixture [3].
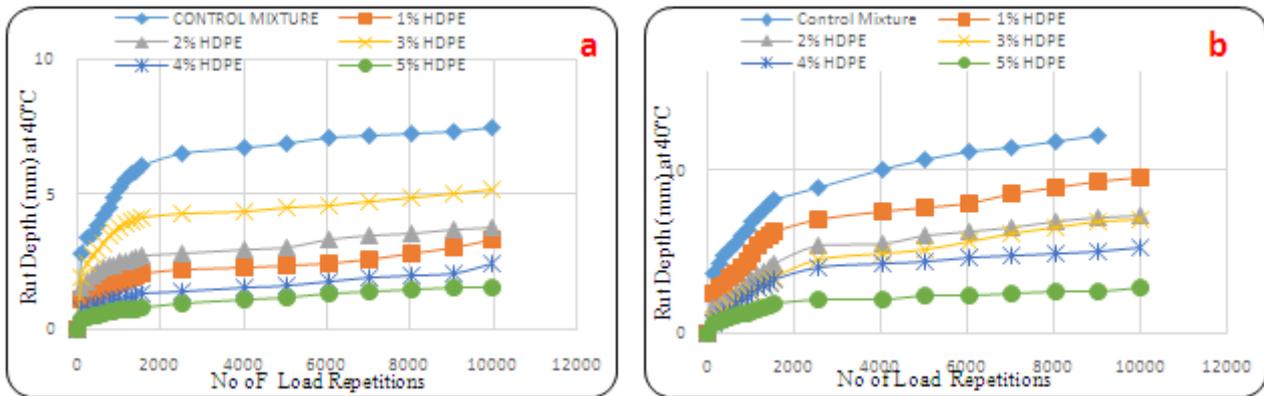

Figure (8): Relation between Rut Depth and Wheel Pass Repetitions (a)Dry Condition, (b)Wet Condition

Low Temperature Test Results

Figure (9) show the test results for the conventional and modified mixtures with waste HDPE. The testing was conducted at 0 °C and -10 °C. Stiffness modulus and flexural modulus for waste HDPE-modified asphalt mixtures is slightly higher than for conventional asphalt mixtures because the viscosity of waste HDPE-modified asphalt is higher than that of conventional asphalt. Test results indicated that the inclusion of waste HDPE content in asphalt mixtures reduces the cracking potential at low temperatures [15]. The higher value of both Stiffness modulus and flexural modulus obtained for mixtures with 4% of waste HDPE, but these values were closer to the modified mixtures with 5% HDPE, for both testing temperatures.
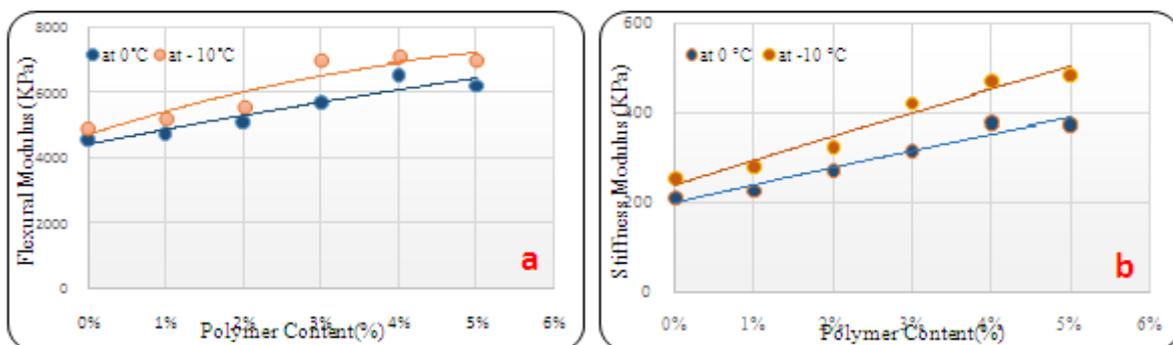

Figure (9): Relationship between Waste HDPE Content and (a) Flexural Modulus, (b) Stiffness Modulus.

Flexural Fatigue Test Result

Results of fatigue tests that performed at 20ºC have been shown in Figure (10), at various stress level (0.45 Mpa, 0.65Mpa and 0.85 Mpa). Its display that the addition of waste HDPE percent (1-5) % by weight of bitumen to the Super pave mixtures improved the fatigue life and reduced the accumulated strain. At stress of 0.45 Mpa, 0.65 Mpa, and 0.85 MPa, the fatigue life increased by about 2.98 times, 2.39times, and 2.16 times, respectively for dry specimens with the addition of 5% waste HDPE. While for wet specimen fatigue life increased by 2.92times, 2.41 times and 1.05 times respectively, mixtures containing higher percentages of waste HDPE appeared to experience longer fatigue life. Also it can be seen that stiffness increases with increase of polymer content. as shown in Table (12) the Super pave mixtures

tend to have lower fatigue lives and stiffness at higher stress levels and when the specimens are moisture. It is obvious from the analysis of the results of dry specimens that fatigue life reduces 69.4 % a stress increases from 0.45 MPa to 0.65 MPa, and decreases 64.5 % when stress change from 0.65 MPa to 0.85 Mpa, and for moisture specimens fatigue life reduces 70.4 % a stress increases from 0.45 MPa to 0.65 MPa, and decreases 77.6 % when stress change from 0.65 MPa to 0.85 Mpa. Also, the fatigue parameters, the coefficient K1and K2, K2 increases with increase of polymer content. in this study coefficient K2 takes on the values (2.427-2.661) for moisture specimens. While for dry specimens (2.363- 30.98). It's noted the values of K1 at dry and moisture condition were (1.00E-05-3.090E-06) and (1.630E-05-6.920E-08) respectively.
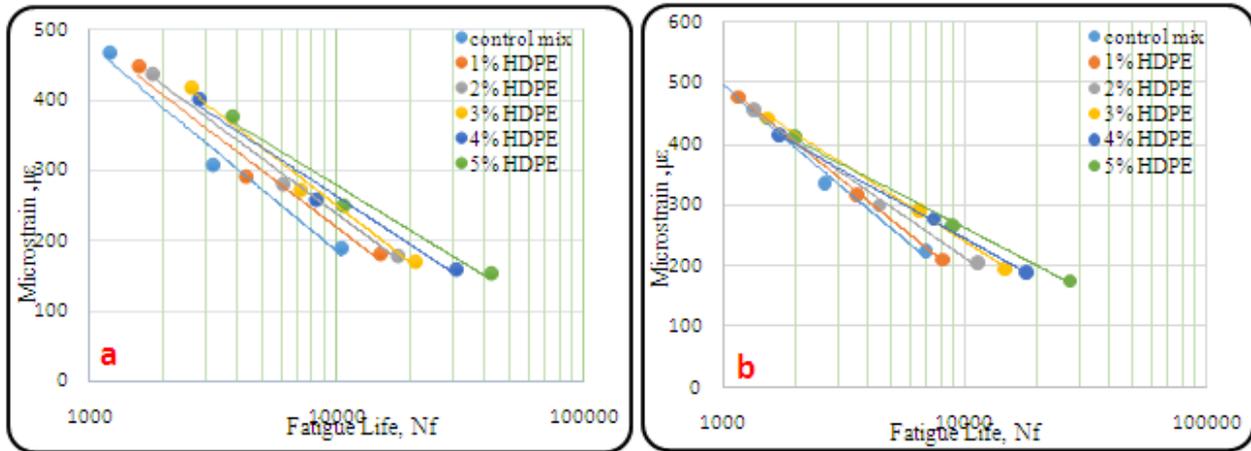

Figure (10): Fatigue Life for Modified and Unmodified Specimens. (a) Dry Condition, (b) Wet Condition

Table (12): Beam Flexural Fatigue Test Results:

Mix Type	Stress level (Mpa)	Dry specimens			Wet specimens		
		Initial strain (μ)	Flexural stiffness (Mpa)	Fatigue life, Nf	Initial strain	Flexural stiffness (Mpa)	Fatigue life, Nf
Control Mix	0.45	0.000192	2349.68	10529	0.000222	2031.08	6897
	0.65	0.000308	2110.66	3154	0.000334	1945.13	2629
	0.85	0.00047	1810.86	1202	0.000507	1676.72	981
1% HDPE	0.45	0.000184	2445.59	14998	0.00021	2139.89	8156
	0.65	0.000293	2218.90	4304	0.000316	2060.91	3622
	0.85	0.000451	1886.31	1584	0.000477	1782.34	1178
2% HDPE	0.45	0.00018	2496.54	17798	0.000203	2219.14	11388
	0.65	0.000282	2307.66	6050	0.000301	2163.96	4411
	0.85	0.00044	1934.68	1821	0.000455	1870.72	1357
3% HDPE	0.45	0.000173	2605.08	20754	0.000195	2304.49	14900
	0.65	0.000274	2370.88	7186	0.000289	2248.27	6605
	0.85	0.000421	2021.05	2611	0.000443	1918.28	1554
4% HDPE	0.45	0.000162	2786.83	30550	0.000188	2396.67	18113
	0.65	0.000259	2508.32	8312	0.000278	2339.41	7390
	0.85	0.000402	2115.49	2798	0.000413	2057.79	1722
5% HDPE	0.45	0.000154	2922.77	41944	0.000177	2549.65	27088
	0.65	0.000252	2583.20	10703	0.000263	2473.09	9005
	0.85	0.00038	2241.16	3800	0.00041	2076.67	2011

CONCLUSION

Based on the testing and analysis presented herein, the conclusions of the study are summarized as follows:

1- Penetration at 25 °C will generally decrease as waste HDPE content increases, which indicates an improved shear resistance in medium to high temperatures;
2- The addition of HDPE kept the ductility values at a minimum range of ASTM specifications of 100+ cm up to 3% Waste HDPE content;

3- Softening point tend to increase with the addition of waste HDPE content, which indicates improvement in resistance to deformation;

4- Penetration index values indicated that waste HDPE reduced the temperature susceptibility of asphalt;

5- The percentage loss of air and heat decreases with the addition of waste HDPE. The result indicates that waste HDP Easphalt mixture will be more resistance to the change in temperature and action of air;

6- The uniformity test results indicated that waste HDPE and asphalt are compatible to an extent.

7- The modification of asphalt binder increased the ITS, TSR values and the mixture stiffness. This indicates that this type of modifier does not cause the mixture to weaken when exposed to moisture;

8- The inclusion of HDPE increases the stiffness and modulus of rupture values of the asphalt mixtures at low temperature 0 °C and -10 °C which may reduce the cracking potential of pavements at low temperatures;

9- The use of waste HDPE in asphalt concrete mixtures caused an increase in resilient modulus values at temperatures, 25 °C, 40 °C and 60 °C. and it was found that the resilient modulus of asphalt mixture clearly effected by temperature increasing, but the effect of polymer was noted;

10- Waste HDPE succeed in improving the ability of asphalt mixture to resist the permanent deformation (strain);

11- Wheel tracking test showed that waste HDPE had greater resistance of asphalt concrete against permanent deformation (rutting) compared to conventional mixtures.

12- Cycle numbers to failure of asphalt mixture modified by waste HDPE can be increased at all stress levels tested, and this improvement to fatigue resistance is more significant at lower stress levels, and

13- The appropriate amount of Waste HDPE was determined to be 5% by weight of optimum bitumen content.

ACKNOWLEDGEMENTS

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