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Effect of Using Polymers on Bituminous Mixtures Characteristics in Egypt

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Abstract:*Attention has been increasing towards the use of polymer modified asphalt, because conventional asphalt mixtures cannot resist the high axle loads and tire pressures. Several classes of modified binders have been used in asphalt pavements. The main objective of this research was to evaluate the effect of adding several types of polymers on asphalt cement and asphalt concrete mixtures. Experimental program involved two phases. The first phase was modifying the asphalt using six types of polymers then evaluating the properties of the modified asphalt. The second phase was evaluating the effect of binder modification on Marshall mix design characteristics and indirect tensile strength of the asphalt concrete mixtures. It was found that the optimum percentage of PVC, plastic bags and novolac was 4%, and the optimum percentage of HDPE was 5% by weight of asphalt. These percentages caused increase in kinematic viscosity, stability, and indirect tensile strength and caused reduction in penetration.*

Keywords:*Asphalt mixtures, polymers, poly vinyl chloride, novolac, high density polyethylene, waste plastic bags.*

I. Introduction

The increase in road traffic during the last two decades, in addition with an insufficient degree of maintenance, has caused an accelerated deterioration of road structures in many countries[1-7]. The modification of asphalt with polymers is considered one of the best options to improve asphalt properties. Polymers increase considerably the useful temperature range of the binders [2,3]. The added polymer can strongly enhance the binder properties and permit the building of safer roads and the reduction of maintenance costs by increasing the stiffness of the bitumen and improves its temperature susceptibility [3-7].

Roberts et al. reported that low density polyethylene (LDPE) has been used as an asphalt modifier. The LDPE content was typically 4-6 percent by weight of the modified binder[3]. The addition of LDPE to asphalt cement reduces its penetration, and increases its kinematic viscosity, absolute viscosity and softening point [3].

Processed plastic bags (one form of LDPE) were used as an additive with heated bitumen in different proportions[8, 9]. It was observed that the penetration and ductility values of the modified bitumen decreased with the increase in proportion of the plastic additive up to 12% by weight. The softening point of the modified bitumen increased with the addition of plastic additive up to 8%. The optimum percent of plastic bags that gave maximum stability was 8% and above this percent stability decreased [8]. El-saikaly recommended waste plastic bags content of 9.0 % by weight of binder as the optimum content for the improvement of performance of asphalt mix [9].

Mixtures modified with high density polyethylene (HDPE) exhibited higher stability,higher air voids and higher voids in mineral aggregate than conventional mixes. The highest mix stiffness was obtained in creep test for mixes with 4% HDPE (by asphalt weight)[10]. Another research reported that the best results were obtained when polymer concentration was kept below 3% for HDPE and above this percent stability decreased [11].Another research used HDPE to coat the aggregate by using dry process. The recommended proportion of the modifier was 12% by the weight of bitumen content [5].Hinislioglu et al. reported that HDPE modified asphaltic binders provide better resistance against permanent deformation, because of their higher stability and relatively lower flow. As a result, HDPE modified asphaltic binders were considered to be useful in mitigating permanent deformation in hot climate regions [12]. Milk bags and other HDPE based carry bags were used as additives in bituminous mixes. Results revealed that the optimum percent of waste polymeric packaging material (WPPM) was 0.3% to 0.4% by weight of asphalt mix and above this percent stiffness of the mix decreased[9].

Roberts et al. reported PVC as one of the possible asphalt modifiers [3]. However no results were found on the literature for the impact of PVC on asphalt binder and mixtures.

1.1 Study Objectives

The main objective of this research is to study the effect of adding different synthetic polymers on the properties of asphalt cement and bituminous mixes in Egypt.

II. Experimental Consideration

2.1 Materials

In this study one source of asphalt was used. This was Suez asphalt cement, 60/70 penetration grade and 1.02 specific gravity was used in preparing all the investigated asphalt mixtures. The different properties of the used asphalt are shown in Table (1). One source of aggregate and one gradation was used in the study. Coarse aggregate was crushed dolomite stone obtained from Burdein mixer. The fine aggregate was silicous sand obtained from Burdein mixer. The mineral filler was lime stone dust. The Properties of coarse aggregate, fine aggregate and mineral filler are shown in Table (1). Six types of additives were used; five types of polymers and one recycled material. These polymers are:

- Poly vinyl chloride (PVC),
- Phenol formaldehyde solid resin (novolac),
- High Density Polyethylene (HDPE),
- unsaturated polyester dissolved in styrene (Siropol 8340 TPWH-C),
- Phenol Formaldehyde Liquid Resin (Cold Set),
- Waste plastic bags (one of products of LDPE) (recycled material),

These types of polymers were used because other types of polymers were used in other researches. These polymers are considered the most famous and common in Egypt. The properties of polymer materials are shown in Table (2).

2.2 Sample Preparation

Modified binders were prepared using melt blending(wet process) technique. The bitumen was heated in oven till fluid condition. The target percentage of the polymer (as percent of binder weight) was slowly added and temperature was kept between 160°C and170°C. Mixing by hand was continued for 1 hour to produce homogenous blend. Mixing was performed at sixperiods, each period was 10 min. In each period temperature dropped from 170°C to 160°C. After each period of mixing, oven was closed to reach to 170°C.Unfortunately, high shear mixer is not currently available in our labs.

2.3 Testing

2.3.1 Asphalt Cement Testing

The experimental work was divided into two phases. The first phase was modifying the asphalt cement by using six types of additives,then measuring the different properties of asphalt and modified asphalt cement. The measured properties of asphalt and modified asphalt cement were penetration at 25°C and kinematic viscosity at 135°C.

2.3.1.1 Penetration Test

Penetration test was performed by standard needle loaded to a total weight of 100 gm is left to penetrate the sample of asphalt for the prescribed time of exactly 5 sec. The penetration is given as the distance in units of 0.1 mm that the needle penetrates the sample(according to AASHTO Designation T49).

2.3.1.2Kinematic Viscosity Test

Kinematic viscosity in units of centistokes (Cst) was obtained by multiplying the time in seconds (that the asphalt cement takes to flow between two timing marks on viscometer) by a calibration factor for the viscometer used (according to AASHTO Designation T201).

2.3.2 Hot Mix Asphalt (HMA) Testing

The second phase was obtaining the properties of the modified asphalt mixtures. Four types of additives from six types were used. The four types of additives were PVC, novolac, HDPE and waste plastic bags. The unsaturated polyester dissolved in styrene (Siropol 8340 TPWH-C) and phenol formaldehyde liquid resin had negative impact on asphalt penetration and kinematic viscosity. So that (Siropol 8340 TPWH-C) and phenol formaldehyde liquid resin were not used in HMA testing.

2.3.2.1 Marshall Test

Marshall test at a temperature of150°C (according to AASHTO Designation T245) was used to define the optimum asphalt content (OAC). The reason for using Marshall is that it is the current methods for mix design used in Egypt. The OAC was defined following asphalt institute method as the average of three values (asphalt content at 4% air voids, asphalt content at maximum stability and asphalt content at maximum density).

2.3.2.2 Indirect Tensile Strength Test

After OAC was defined samples were prepared for indirect tensile strength (ITS) test according to manual of testing procedures, 1966 (Texas high way department) [13]. Indirect tensile strength test was conducted on two samples that were prepared at the OAC for each additive percentage.Fig. (1) presents the overall experimental program.

III. Results And Discussion

3. 1 Effect of Additives on Asphalt Cement (AC) Properties

3.1.1Penetration Test Results

Table (3) shows penetration results for AC virgin and modified with different types of additives.Fig.(2-a) shows the penetration values for AC modified with different types of additives.Fig.(2-a) shows that adding PVC reduces penetration up to four percent then adding more PVC has a negative effect on the penetration.

Fig.(2-a) shows that adding HDPE reduced penetration up to four percent then adding more HDPE has a negative effect on the penetration. This agrees with previous study, where the addition of HDPE reduced the penetration up to specific percentage (5% by AC weightin [11] and 4% by asphalt weight [12]).

Fig.(2-a) shows that adding phenol formaldehyde solid resin(novolac) reduced penetration up to four percent then adding more novolac has a negative effect on the penetration.

Fig.(2-a) shows that adding plastic bags reduced penetration for all percents beginning with two percent and ending with eight percent. This agrees with previous research where adding plastic bags reduced penetration [14]. Fig.(2-a) shows that adding (Siropol 8340 TPWH-C) or phenol formaldehyde liquid resin (Cold Set)increased penetration up, meaning thatthis additive did not enhance the properties of asphalt cement. Waste plastic bags was the best additive to enhance penetration then HDPE then PVC then novolac.

3.1.2 Kinematic Viscosity Test Results

Table (3) shows kinematic viscosity results for AC virgin and modified with different types of additives.Fig.(2-b) shows the effect of the kinematic viscosity values for AC modified with different types of additives.Fig.(2-b) showsthat adding PVC, HDPE and Novolac increased the kinematic viscosity up to four percent then adding more of the additive caused negative effect on kinematic viscosity. Fig.(2-b) shows that adding waste plastic bags increased the kinematic viscosity for all percents beginning with two percent and ending with eight percent. This agrees with previous research where the addition of plastic bags caused increase in absolute viscosity [13]. Fig.(2-b) shows that adding Siropol 8340 TPWH-C or Cold set additives reduced the kinematic viscosity.Waste plastic bags was the best additive to enhance kinematic viscosity followed by HDPE, PVC then novolac.

Waste plastic bags was the best additive to enhance asphalt cement properties followed by HDPE, PVC then novolac.

Reduction in penetration and increase in kinematic viscosity up to specified percentage of additivesindicates an increase in the consistency of asphalt which might be due to two factors. One is the maltene penetrated into additive and it swells and disperses thoroughly in the asphalt phase. Another factor is the interaction between additive and polar molecules of asphaltene which makes the molecules of asphaltene larger with a higher molecular weight. A lower penetration and higher viscosity values mean high resistance to permanent deformation (rutting) at high service temperature [15, 16].

3.2 Effect of Additives on Hot Mix Asphalt (HMA) Properties

In the first phase of the research, it was found that four out of the six evaluated polymers improved the asphalt kinematic viscosity and penetration. Those four polymer modified binders were used in the second phase of the research.

3.2.1Effect of Poly Vinyl Chloride (PVC) on Marshall Test Results

It was found that addition of PVC improved stability, flow and density of HMA. Fig.(3-a) and (3-b) present the effect of PVC on the stability and flow values for all HMAsamples. Fig.(3-a) shows an increase of stability up to 4% PVC additive and above this percent the stability decreased. Fig.(3-b) shows a decrease of flow for all percents of PVC modified HMA. Fig.(3-c) and (3-d) present the stability and flow values at OAC for all PVC ratios. Fig.(3-c) shows an increase of stability up to 4% PVC additive and above this percent the stability decreased. Fig.(3-d) shows a decrease of flow up to 4% PVC additive and above this percent the flow increased.

This agrees well with the results of the penetration and kinematic viscosity for the PVC modified binder presented in earlier sections.

3.2.2Effect of novolac on HMA Marshall Test Results

It was found that addition of novolac improves stability, flow and density of MMA. Fig.(4-a) and fig.(4-b) present the effect of novolac on the stability and flow values for all HMAsamples modified with novolac. Fig.(4-a) shows an increase of stability up to 4% novolac and above this percent stability decreased. Fig.(4-b) shows a decrease for all percents of novolac modified HMA. Fig.(4-c) and (4-d) present the stability and flow values at OAC for HMA samples modified with novolac. Fig.(4-c) shows an increase of stability for all percent of novolac additive except the 3% novolac shows a decrease of stability. Fig.(4-d) shows a decrease of flow up to 3% novolac and above this percent the flow increased.

3.2.3Effect of HDPE on HMA Marshall Test Results

It was found that addition of HDPE improves stability, flow and density of HMA. Fig.(5-a) and (5-b) present the effect of HDPE on the stability and flow values for all HMA modified with HDPE). Fig.(5-a) shows an increase of stability for all percents of HDPE modified HMA. Fig.(5-b) shows an increase of flow values for all percents of HDPE modified HMA. Fig. (5-c) and fig. (5-d) present the stability and flow values at OAC and HDPE ratio for HMA. Fig. (5-c) shows an increase of stability for all percents of HDPE up to 6%. Fig. (5-d) shows a decrease of flow for all percents of HDPE except the percents of (3% HDPE and 6% HDPE) show an increase of flow results.This agrees well with the results of the penetration and kinematic viscosity for the HDPE modified binder presented in earlier sections. These results agrees with previous research that HDPE can improve the stability and flow of the HMA up to certain percentages then, negative impact starts to appear [3, 5, 12].

3.2.4 Effect of waste plastic bags on Marshall Test Results

It was found that addition of plastic bags improves stability, flow and density of HMA. Fig.(6-a) and fig. (6-b) present the effect of plastic bags on the stability and flow values for all HMA unmodified and modified (0, 2, 4 and 6% plastic bags). Fig. (6-a) shows an increase of stability up to 4% plastic bags and above this percent stability decreased. Fig. (6-b) shows an increase of flow for all percents of plastic bags modified HMA. Fig. (6-c) and (6-d) present the stability and flow values at OAC and plastic bags ratio for HMA. Fig. (6-c) shows an increase of stability up to 4% plastic bags and above this percent the stability decreased. Fig. (7-d) shows a decrease of flow for the two percents (2% and 6% plastic bags) and a constant flow for 4% plastic bags.These results agrees with previous research that LDPE can improve the stability and flow of the HMA up to certain percentages then, negative impact starts to appear [8,9,13]. When modified binder was evaluated, the viscosity kept increasing for all percentages of the plastic bags, this was not the case for the mix. One possible reason was that mixing and compaction temperature was kept the same for all mix designs in this research. For up to 4% plastic bags, the viscosity at 135°C was reasonable (514 centistokes (Cst) compared to 370 Cst for unmodified binder). For higher percentage of plastic bags, the viscosity at 135°C increased significantly reaching 791 Cst. Unfortunately, rotational viscometer is not currently available in our labs, and future research should cover the effect of mixing and compaction temperature on polymer modified asphalt.

IV. Effect of Polymers on Indirect Tensile Strength (ITS) Test Results

Indirect tensile test was conducted on two samples that were prepared at the OAC for each additive percentage. Fig.(7) presents the effect of different additives on the indirect tensile strength.

The addition of PVC increased the indirect tensile strength up to 4% PVC, and above this percent the indirect tensile strength remained constant up to 5%, then ITS decreased at 6% PVC. The addition of HDPE caused increase in the indirect tensile strength up to 5% and above this percent the indirect tensile strength decreased.

The addition of novolac increased the indirect tensile strength up to 4% and above this percent the indirect tensile strength decreased. It is noticed that novolac did not show clear effect on ITS up to 2% then it started to show clear effect at when novolac increased to 4%.

The addition of plastic bags increased the indirect tensile strength up to 4% and above this percent the ITS decreased. It is noticed that 2% plastic bags had same impact on indirect tensile strength as 4%. It is also noted that this results differs than that obtained based on stability results.

Plastic bags gave the best improvement in the mix properties followed by HDPE, followed by novolac and then PVC.

Increasing in stability and indirect tensile strength results and decreasing in flow results up to optimum percentage of additivescan be explained by the increase in kinematic viscosity and the decrease in penetration. Above this percentage, stability and indirect tensile strength results decreased while flow results increased, this can be explained by the high percent of additive which reduced the full contact between bitumen and aggregate so the failure of the specimen occurred rapidly.

The added polymers enhanced the binder properties which would permit the building of safer roads and the reduction of maintenance costs by increasing the stiffness of the bitumen and improves its temperature susceptibility.Increased stiffness improves the rutting resistance of the mixture in hot climates.

MEPGD was used to evaluate the expected gain in pavement life. It was found that using different types of additives increased pavement design life. This part of research regarding pavement life is under revise [17].

V. Summary And Conclusion

The most common distresses appeared on Egyptian roads are rutting and fatigue cracking. Under these situations, it is essential to modify the asphalt cement using polymers to improve its physical properties. On other hand, the environmental problem is major concern. To overcome this problem waste plastic bags was used.

The main objective of this research was to evaluate the effect of adding several types of polymers on asphalt cement and asphalt mixtures in Egypt.

Experimental program involved two phases. The first phase was modifying the asphalt using six types of additives then evaluating the properties of the modified asphalt. These additives are: poly vinyl chloride (PVC), phenol formaldehyde solid resin (novolac), high density polyethylene (HDPE), unsaturated polyester dissolved in styrene (Siropol 8340 TPWH-C), phenol formaldehyde liquid resin (cold set) and waste plastic bags). The second phase was evaluating the effect of binder modification on Marshall mix design and indirect tensile strength of the asphalt concrete mixtures.

It was found that the optimum percentage of PVC, plastic bags and novolac was 4%, and the optimum percentage of HDPE was 5% by weight of asphalt. These percentages caused increase in kinematic viscosity, increase in stability, increase in indirect tensile strength and reducing penetration. When those additives were used above these percentages, the stability and indirect tensile strength values decreased while the flow values increased.The unsaturated polyester dissolved in styrene (Siropol 8340 TPWH-C) and phenol formaldehyde liquid resin had negative impact on asphalt penetration and kinematic viscosity.

The ranking of the polymers for their effect on asphalt mix properties would depend on the ranking criterion. The minimum flow was obtained by modification of asphalt by novolac, followed by PVC, followed by HDPE, then waste plastic bags. Waste plastic bags gave the best improvement in both the indirect tensile strength and Marshall stability followed by HDPE, followed by novolac and then PVC.

Finally plastic bags was the best additive followed by HDPE followed by novolac and then PVC. Mixtures modified with any type of these additives exhibited higher stability, higher indirect tensile strength and lower flow than virgin mixtures.

Table (1): aggregate gradation and properties of asphalt cement (AC).

Aggregate gradation

Type		Coarse Aggregate		Fine Aggregate	Mineral Filler	Design mix gradation	Specification limits
Sieve size (inch)	Sieve size (mm)	% passing					
		Pin 2	Pin 1				
1	26.5	100	100			100	100
¾	19	92.7	100			97.8	80-100
½	13.2	37	100			81.1	--
3/8	9.52	6	84			66.2	60-80
No.4	4.75	0.5	38.14	100		48.5	48-65
No.8	2.36		2	100		35.7	35-50
No 30	0.6			83	100	29.9	19-30
No 50	0.3			39.8	98.5	16.8	13-23
No 100	0.15			8.7	94	7.31	7-15
No 200	0.075				82	4.1	3-8

Properties of aggregate

Test No.	Test	Type of aggregate	AASHTO Designation No.	Results	Specification Limits
1	Abrasion value after 500 revolution	Pin 2	T-96	34%	≤ 40%
		Pin1		33%	
2	Water absorption values	Pin 2	T-85	3.2%	≤ 5%
		Pin1		4.7%	

Asphalt cement (AC) properties

Test no	Test	AASHTO Designation No	Results	Specification Limits
1	Penetration (0.1mm)	T-49	67	60-70
2	Softening point (º C)	T-53	53	45-55

3	Flash point (° C)	T-48	+265	+250
4	Kinematic viscosity (Cst)	T-201	370	+320

Table (2): properties of polymeric materials.

properties	Types of additives					
	PVC	HDPE	Novolac	Waste plastic bags	Siropol 8340 TPWH-C	Cold set
Molecular formula	$(C_2H_3CL)_n$	(CH2=CH2)n	$(C_6H_6O - CH_2O)x$	(-CH2-CH2-)n	R-COO-R	C8 H10 O2
Density (g/cm^3)	1.3 – 1.45	0.943-0.949	1.2 - 1.4	0.910 - 0.940	1 - 1.3	1.12 – 1.16
Melting point (°C)	160	130	75 - 85	110	--	--
Physical state	Clear white powder	White pellets	Clear white – yellow – crushed lumps	--	Yellow to orange liquid	Clear (from yellow to dark red) liquid
Elongation at break (%)	20 – 40	700	--	400	--	--
Dynamic viscosity at 30°C (Mpa.s) (Cp)	--	--	--	--	400 - 600	200 - 400
Max shelf life @25°C (months)	--	--	--	--	6	6

Table (3):results of penetration and kinematic viscosity testing for virgin and modified asphalt cement.

Additive number	Additive name	Penetration, (1/10mm) Additives ratio						
		0%	2%	3%	4%	5%	6%	7%	8%
1	PVC	67	65	53	40	59	66	--	--
2	HDPE		38	32	25	37	42	--	--
3	Novolac		56	55	45	58	70	--	--
4	Siropol 8340 TPWH-C		72	--	75	--	--	--	--
5	Cold set		70	--	72	--	--	--	--
6	Plastic bags		37	--	20	--	15	--	10
Additive number	**Additive name**	**Kinematic Viscosity, (centistokes) Additives ratio**							
		0%	2%	3%	4%	5%	6%	7%	8%
1	PVC	370	456	543	607	560	515	--	--
2	HDPE		554	568	582	530	474	--	--
3	Novolac		475	475	514	467	467	--	--
4	Siropol 8340 TPWH-C		340	--	312	--	--	--	--
5	Cold set		360	--	340	--	--	--	--
6	Plastic bags		475	--	514	--	791	--	830

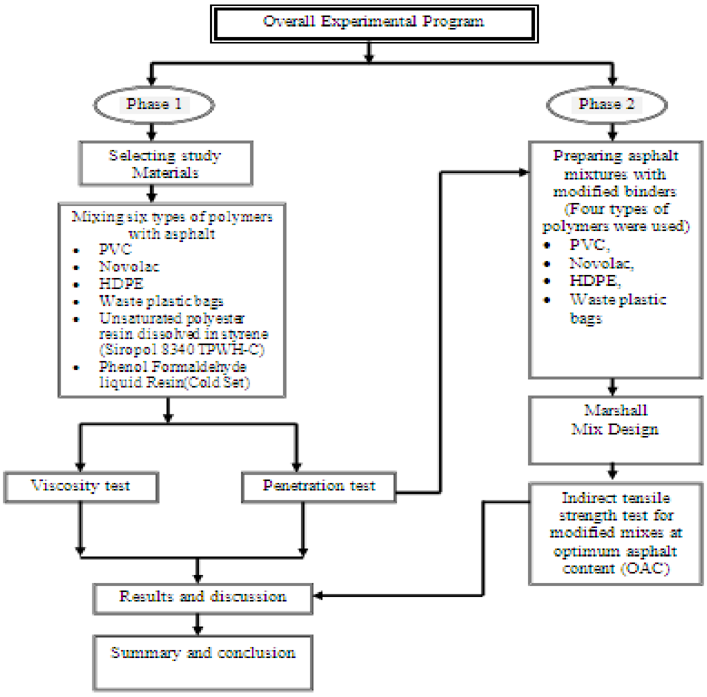

Figure (1):overall experimental program.

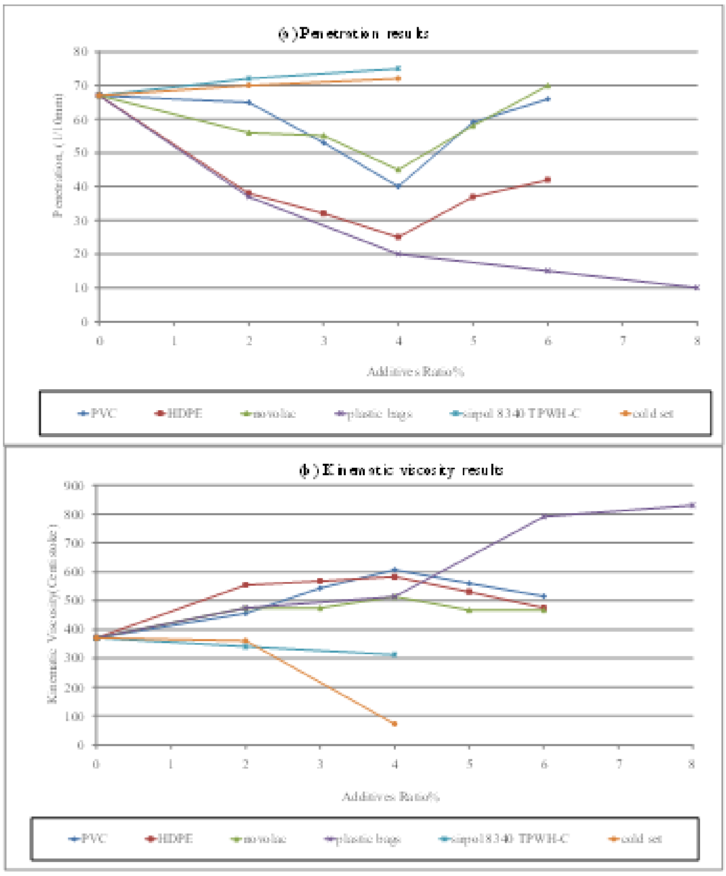

Figure (2): effect of different polymers on the penetration and kinematic viscosity of AC.

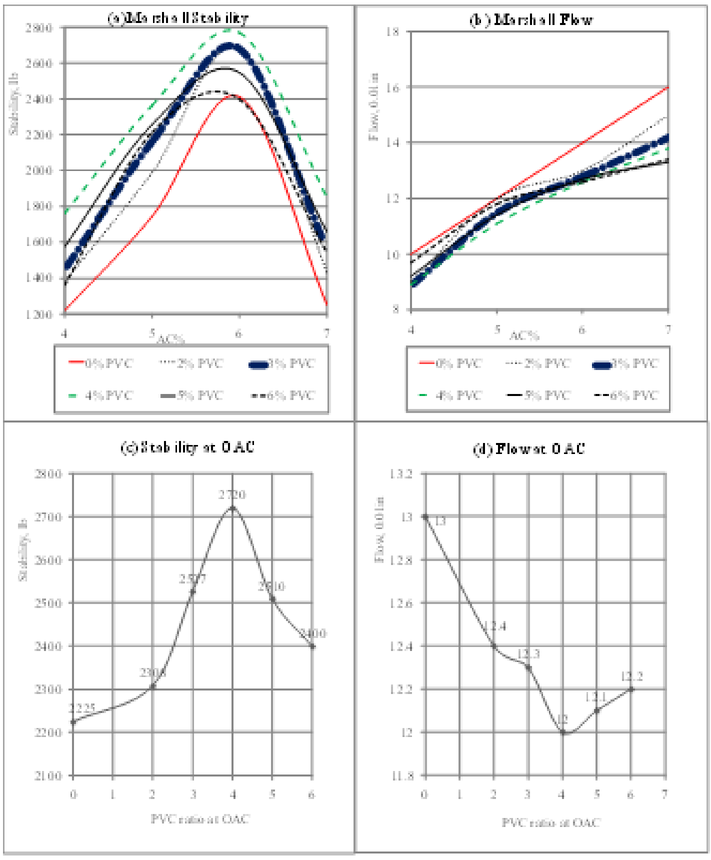

Figure (3):effect of PVC on the stability and flow of HMA.

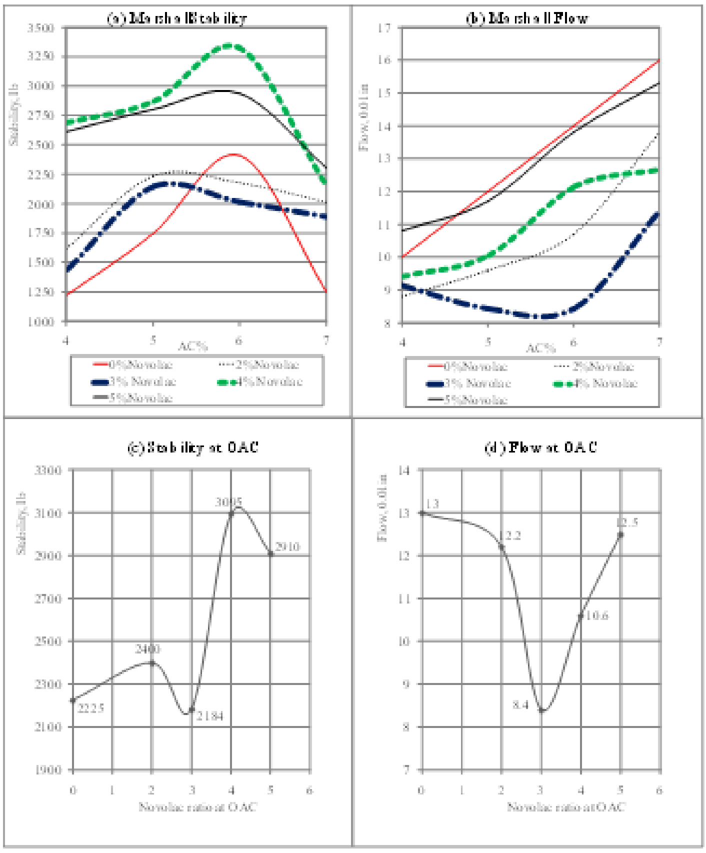

Figure (4):effect of novolac on the stability and flow of HMA.

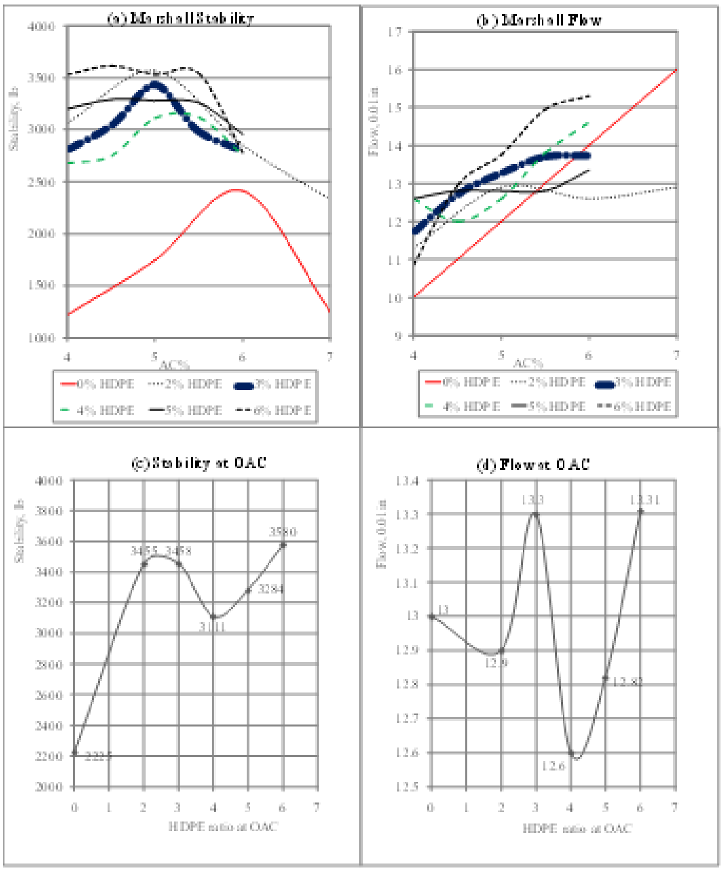

Figure (5):effect of HDPE on the stability and flow of HMA.

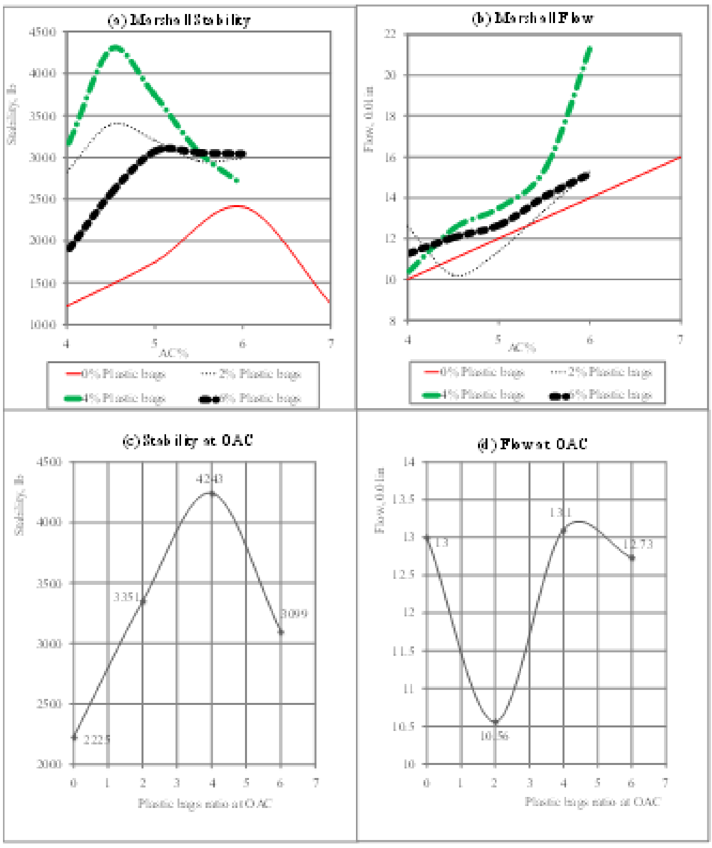

Figure (6):effect of waste plastic bags on the stability and flow of HMA.

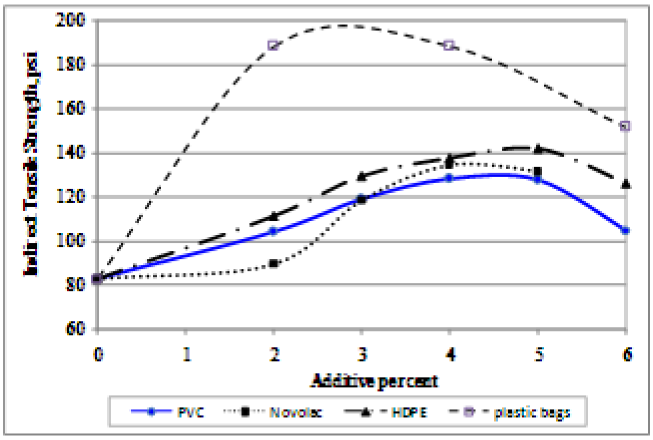

Figure (7):effect of additives percent on the indirect tensile strength.

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