

CHARACTERIZATION AND EVALUATION OF ASPHALT MODIFIED WITH SOME THERMOPLASTIC POLYMERS

* S.A. El-Kholy, **E.A. Hassan, *A.M.M. Abd El-Rahman and *I.M. Nassar

*Egyptian Petroleum Research Institute (EPRI), Nasr City, Cairo, Egypt.

** Faculty of Science, Al-Azhar University, Nasr City, Cairo, Egypt.

ABSTRACT

Some commercial thermoplastic polymers such as styrene-butadiene rubber (SBR), polyacrylonitrile (K), polystyrene (PS), polypropylene (PP) and polychloroprene (PC) are used for the modification of two types of asphalt which are: asphalt 60/70 Suez (L) and asphalt 80/100 Alex (H). The best ratio of modifying polymer to be added by hot mixing method at 150-170°C to asphalt, was determined by measuring the values of penetration, softening point, penetration temperature susceptibility (PTS) and penetration index (PI) for the obtained cooled blended formulations.

For asphalt (L), such optimum ratio was 6% for (SBR and PP), 9% for (PS) and 12% for (PC), while in case of asphalt (H) the optimum ratio was 6% for (SBR), 9% for (PP and K) and 12% for (PS and PC).

Dynamic viscosity tests i.e. shearing in (RV 12) for 5 mins at a high shear rate of $1198.08s^{-1}$ and then for 10 mins at a low shear rate of $149.76s^{-1}$, at different temperatures (30, 40, 50 and 60°C) showed that formulation samples LSBR and HSBR have high yield stress values (τ_0) which give promising indications about the validity of their possible use for pavement. Moreover formulations based on asphalt (H) and modified with SBR gave the highest value of tensile strength as well as thermal stability at 250°C for time period of 150 hours. All the prepared formulations modified with such thermoplastic polymers were resistant to different application media as compared with parent unmodified asphalt.

إستخدام بعض البوليمرات الترموبلاستيكية التجارية مثل: مطاط إستايرين بيوتاديين، مطاط البولي أكريلونيتريل، البولي إستايرين، البولي بروبيلين و البولي كلوروبرين في تحسين نوعين من الأسفلت: أسفلت ٧٠/٦٠ (السويس) و أسفلت ١٠٠/٨٠ (الأسكندرية). و قد تم تحديد أنسب نسبة (بالوزن) من كل من البوليمرات الترموبلاستيكية المناسبة للإمتزاج التام لتكوين بلند مع كل من الأسفلت (L) و (H) عند ١٥٠-١٧٠م، وذلك بقياس خواص الخلطة المبردة مثل درجة الغرز، درجة اللبونة، حساسية الغرز عند التغير في درجة الحرارة و معامل الغرز. وقد أوضحت هذه الخواص أن أفضل نية يمكن إضافتها في حالة الأسفلت (L) هي ٦% من مطاط الإستايرين بيوتاديين & البولي بروبيلين و ٩% من البولي إستايرين و ١٢% من البولي كلوروبرين. أما بالنسبة للأسفلت (H) هي: ٦% من مطاط الإستايرين بيوتاديين و ٩% من البولي بروبيلين & مطاط البولي أكريلونيتريل و ١٢% من البولي إستايرين و البولي بروبيلين.

و بإستخدام اللزوجة الديناميكية عند درجات حراره مختلفه و معدلات قص مختلفه اتضح أن الاسفلتية (H&L) المعدله بمطاط البولي إستايرين لها أعلى نقطة خضوع. و ذلك دليلا على صلاحية استخدام تلك الخلطات في أغرض رصف الطرق. كما إتضح أن جميع الخلطات المحسنة بهذه البوليمرات لها قوة مقاومة عالية لجميع الأوساط الكيماوية مقارنة بالأسفلت الغير محسن.

Keywords: Asphalt, Asphalt modified, Thermoplastic polymers, Dynamic viscosity

INTRODUCTION

The durability of asphalt pavement is greatly influenced by the environmental changes during the year, especially between summer and winter and between day and night; when the daily average temperature change can be considerably large. In summer, the high temperature can soften the asphalt binder and consequently reduce the stiffness of the paving mixture. On the other hand, in winter, the low temperature can stiffen the asphalt binder and reduce

the flexibility of the paving mixture. As a result, thermal cracking that develops may adversely affect the performance and lifetime of the pavement. Thus, high-temperature stiffness and low-temperature flexibility are important properties that increase the lifetime of pavement [1,2].

A desirable asphalt mixture is one that is strong and durable, yet flexible. It should resist permanent deformation at high temperature and thermal cracking at low temperature. In order to reduce the

potential for permanent deformation and thermal cracking mixture, tensile strength and flexibility must be simultaneously increased. One-way to achieve a strong and flexible asphalt mixture is to use asphalt additive such as polymer. Polymer-modified asphalt cement increases the level of field performance of asphalt concrete. Polymer modifiers improve thermal cracking resistance, provide resistance to permanent deformation, improve resistance to moisture damage and decrease PTS and increase PI of asphalt [3].

Polymer-modified asphalt is divided into two categories which are thermoplastic and thermoset. Thermoplastic polymers are typically added to asphalt at concentration of 6-8% (w/w). These are especially used with hard asphalt, oxidized asphalt and asphalt that contains a small amount of oil fraction. Asphalts modified by thermoplastic polymers are characterized by low penetration and ductility, high softening temperature, good adhesion and improved resistance to both aging and effect of diesel oil [4,5].

The main objective of this work is to decide the best ratio of modifying polymer to be added to asphalt and to study the rheological and physical characteristics of the improved asphalt with commercial thermoplastic polymers in order to estimate the possible application of these formulations, presenting a comparison between their obtained properties and those of unmodified asphalt.

EXPERIMENTAL WORK

1. Chemicals and Materials Used:

Five types of commercial thermoplastic polymers such as, Styrene Butadiene Rubber (SBR), Polypropylene (PP), Krynac 803 (Rubber acrylonitrile) (K), Polystyrene (PS), and Polychloroprene (PC) (all delivered from Heliopolis Co. for Chemical Industries, Cairo) were employed for the modification of two types of asphalt: asphalt 60/70 (L) provided from Suez Oil Company and asphalt 80/100 (H) from Alexandria Petroleum Company. The physical and chemical properties of the employed asphalts are given in Table 1.

2. Blending of the Asphalt with Polymer:

The blending technique employed involved heating the asphalt sample to 60-80°C followed by through mixing with specified amount of polymer previously swelled for 48 hours in the appropriate solvent. The amount of polymer was added gradually upon stirring with rising the temperature till 170-180°C, for two hours till homogenous blends were obtained.

3. Testing of Obtained Modified Asphalt.

i. Physical Properties:

- **Penetration (0.1m/25°C).**

The standard test was carried out according to ASTM D 5.

- **Softening Point (Ring&Ball).**

The standard test was carried out according to ASTM D 36.

ii. Rheological properties:

- **Dynamic viscosity:-** The dynamic viscosities of asphalt and asphalt polymer mixtures were determined by using RV 12 Viscometer Haake Co., West Germany.

- **Tensile strength:-** To examine adhesion properties of asphalt and asphalt polymer mixtures, tensile strength was measured for standard (10×2cm) plain steel plates covered with the sample (2gm) on the area to be bonded (4 cm²). The tensile strength test was carried out according to ASTM D 638 – 77a.

iii. Chemical resistance of asphalt and asphalt polymer formulations:

- **Resistance to water, acid and alkaline media [4,6,7]:-** The sample was brushed on a steel panel (1-5mm), allowed to drain at nearly vertical position and then left to dry for 48 hours. The steel panel was dipped in paraffin wax to seal the edges. The panel covered with the sample was immersed in a beaker containing about 7cm³ tap water, sea water, NaOH solution (5%), HCl (5%). The panel was removed after the testing period was over, whipped carefully washed and allowed to dry at room temperature. The panel was tested for any changes or defects in appearance according to ASTM D 1947 –59.

iv. Thermal stability:

Asphalt formulations were placed in furnace at 250°C, then withdrawn from the furnace after fixed time intervals, cooled till room temperature, weighed, then replaced in the furnace for another fixed time interval and the process was repeated till the whole time of subjecting the formulations to heat; 150 hours, is reached. The weight loss for cold sample after each time interval was recorded.

RESULTS AND DISCUSSION

Five commercial thermoplastic polymers; styrene butadiene rubber (SBR), polyacrylonitrile (krynac K), polypropylene (PP), polychloroprene (PC) and polystyrene(PS), were used for the modification of asphalt 60/70 (L) and asphalt 80/100 (H).

1. Characterization of Asphalt Modified with Thermoplastic Polymer:

Each of the above mentioned five types of commercial thermoplastic polymers was mixed individually with each of the two types of asphalt (H) and also (L) in different percentages (w/w) 3, 6, 9, 12, and 15 % respectively to form series of mixtures. The first series is (HSBR), (HPP), (HK), (HPS), (HPC) and the second is, (LSBR), (LPP), (LK),

(LPS), and (LPC). These mixtures were evaluated through the determination of penetration, and softening point.

Data given in Table (2), show that the lowest values of penetration and the highest values of softening point for (LSBR), (LPP), (LK), and (HSBR) were obtained at polymer content of 6% (w/w) of the weight of asphalt. On the other hand the lowest values of penetration and the highest values of softening point in case of (LPS), (HPP), and (HK) were obtained at polymer content of 9% (w/w) of the weight of asphalt. It is interesting to mention that polychloroprene gave lowest values of penetration and highest values of softening point when introduced in quantities of 12%(w/w) of either the two types of asphalt (LPC) and (HPC). With polystyrene, the lowest values of penetration and highest values of softening point were obtained for added quantities of 12 % (w/w) of asphalt (HPS).

The calculated values of PTS and PI for the previous tested mixtures are correlated with the values of penetration, and softening point for these mixtures, and consequently correlated with the hardness of these mixtures.

Data listed in Table (2) show that the lowest values of PTS, and highest values of PI are recorded for (LSBR), (LPP), (LK), and (HSBR) at 6% (w/w), while the lowest values of PTS and highest values of PI are recorded for (LPS), (HPP), and (HK) at 9% (w/w), and also the lowest values of PTS and the highest values of PI are recorded for (LPC), (HPS), and (HPC) at 12% (w/w) [8].

2. Evaluation of Asphalt Modified with Thermoplastic Polymers:

i. Rheological properties:

Rheology can be defined as the science that deals with the flow and deformation of any material. This property is very important from the practical point of view since it helps in defining, and estimating the behaviour of our investigated asphalt formulation [4].

Accordingly this study is divided into three series; the first evaluates the variation of the viscosity with shearing time, the second deals with the estimation of the relation between viscosity and shear rate and the third is concerned with a study of the relation between shear rate and shear stress.

a. Relation Between Viscosity and Shearing Time:-

The studied samples were those based on: 94 % (L) + 6 % (SBR, K, and PP, each was used separately), 91 % (L) + 9 % (PS) and 88 % (L) + 12 % (PC), while in case of asphalt (H), the constitutions were:

94 % (H) + 6% (SBR), 91% (H) + 9 % (in case of PP and also K) and 88 % (H) + 12 % (in case of PS and also PC).

The mixing temperature for all the added polymers was 150-170°C for two hours upon stirring the prepared formulations previously dissolved by immersion in xylene [50 % (w/w)] for 24 hours to achieve complete dissolution [9]. The prepared solutions were subjected to high shear rate of 1198.08 s⁻¹ in RV-12 rheometer for 5 mins and also to low shear rate of 149.76 s⁻¹, for 10 mins, at different temperatures (30, 40, 50, and 60°C) in the two cases.

Data given in Tables (3,4) show that the viscosity of the studied formulations increases gradually with time and when the shear rate was switched to its low value, the viscosity decreased to its initial value (which was recorded within the first minute of high shear rate evaluation) and then became constant [4].

All the above-mentioned formulations are found to follow such same behavior at the studied temperatures. Such behaviour is very important from the practical point of view. The increase in viscosity with shearing time at high shear rate (high shear stress or high load) gives an indication that such formulations can resist the high stress or high loads which the samples could suffer during heavy traffic or during parking for long time on the highway [9].

The obtained data show in general show that the viscosities for formulations based on asphalt (L) type are higher as compared with those of formulations based on asphalt (H). This may be due to the difference in chemical composition and physical properties between the two asphalt types (*c.f* Table 1) which shows that asphalt (L) (having higher values of asphaltene and resin content, and lower values of oil and wax content) is characterized by higher values of kinematic viscosity, and lower values of penetrations,

The formulations based on thermoplastic commercial polymers (SBR, K, PP, PS, and PC) each together with asphalt (L and H) gave higher viscosity values with different shear rates as compared with the parent unmodified asphalt (L and H), at all tested temperatures. The viscosity values for all tested formulations proceeds in the following order of the added best quantity of the respective polymers:

(L SBR, 933.8 mPa s) > (L K, 884.5 mPa s) > (L PS, 860.8 mPa s) > (LPC, 832.9 mPa s) > (L PP, 796.4 mPa s) > (L, 751.4 mPa s), while for (H), formulations follow the order:
(HSBR, 828.6 mPa s) > (H K, 792.1 mPa s) > (H PS, 753.5 mPa s) > (HPC, 732 mPa s) > (H PP, 723.4 mPa s) > (H, 687 mPa s).

The information obtained from the recorded data show that the formulations with such polymer additives have increasing values of viscosity with shearing time which means that such modified

formulations when applied in pavements can resist plastic flow which results from high traffic load in highway and in the parking [9].

b. Shear Rate - Viscosity Relationship.

Figures (1,2) show that the values of dynamic viscosities for the prepared formulations decrease as the shear rate increases. This behavior is known as shear thinning or (rheopetic) [4]. This result means that all formulations acquire a decreasing flow with increasing shear rate, as mentioned above, depending on the asphalt type and polymer compositions.

c- Shear Rate - Shear Stress Relationship.

For a-Newtonian fluid, the shear stress is directly proportional to the shear rate with proportionality constant called dynamic viscosity. If the fluid is non-Newtonian, a plot of the shear stress against shear rate is not a straight line but a curve. The third kind of non-Newtonian behavior follows the Bingham plastic behavior. Here, the curve for shear stress versus shear rate is linear but it does not pass through the origin, the value of the intercept on the shear stress axis is called the yield stress (τ_0). The slope of the shear stress curve at the chosen value of the shear rate is known as the consistency (η_0).

Figures (3,4) show that formulations of thermoplastic commercial polymers give values of yield stress, in case of the series of asphalt (L) formulations, proceeding in the following order: (LSBR, 71.1 s^{-1}) > (L K, 67.2 s^{-1}) > (L PS, 63.7 s^{-1}) > (L PC, 60.8 s^{-1}) > (L PP, 60.5 s^{-1}) > (L, 59.9 s^{-1}).

In case of formulations involving asphalt (H), the order is:

(H SBR, 62.7 s^{-1}) > (H K, 59.8 s^{-1}) > (H PS, 57.3 s^{-1}) > (H PC, 55.5 s^{-1}) = (L PP, 55.5 s^{-1}) > (H, 53.2 s^{-1}).

It follows therefore, from the obtained order, that the values of yield stress (τ_0) for formulations based on asphalt (L) have higher values as compared with formulations based on asphalt (H). This may be due to the difference in chemical composition of the two types of the used asphalt (L&H) as previously mentioned. Values of yield stress (τ_0) are found to be inversely proportional to the values of plastic flow of the material, such that by increasing the values of yield stress, the values of plastic flow decrease. Such results present conformations about behaviour of the prepared formulations since they appear to be suitable for application in pavement at high traffic loads.

3. Adhesive Properties:

The selected formulations were (L, H, HSBR, H PC 1, LSBR and L PC). For each experiment, five samples were prepared and the average results were calculated. Data given in Table (5) show that the introduction of polymer to asphalt results in an increase in the values of tensile strength (N/mm^2)

[10], as compared with unmodified asphalt (L and H). The obtained values of tensile strength for asphalt (H) formulations proceed in the order: (H SBR, 2.5 N/mm^2) > (H PC, 1.6 N/mm^2) > (H, 0.86 N/mm^2).

On the other hand, the values of tensile strength for asphalt (L) formulations proceed in order: (L SBR, 2.9 N/mm^2) > (L PC, 2.0 N/mm^2) > (L, 1.4 N/mm^2).

The values of elongation, % for such formulations proceed in the same order. Moreover, the obtained results show also that formulations based on asphalt (L) give tensile strength values higher than those of formulations based on asphalt (H).

4. Thermal Stability:

Asphalt formulations based on L and H with thermoplastic polymers added according to their previously determined optimum quantities were also evaluated and compared with the unmodified asphalt samples (L and H).

Data given in Table (6) show that the addition of polymer additives to asphalt improved the thermal stability properties (wt. loss %) as compared with the unmodified parent asphalt. This may be due to the fact that the added polymers having higher molecular weight can withstand higher temperature for a longer lifetime and consequently destruction occurs after a longer time, as compared with the parent asphalt [9].

The obtained results of heating the samples till 250°C show that the recorded values of wt. loss % for commercial thermoplastic polymer added to asphalt (L) formulations is within the range of 1.759-8.968. In case of asphalt (H) formulations, the range is 2.01-10.598.

Formulations based on asphalt (L) were more thermally stable as compared with formulations based on asphalt (H). This may be due to the difference in initial chemical composition and physical characteristics of the two types of used asphalt.

5. Resistance to External Media:

For the study of the resistance to external media, the studied samples were similar to the formulations previously tested for thermal stability. The studied chemical resistance for the formulations was compared with that of the unmodified parent asphalt. The obtained data given in Table (7) show that the used polymer additives greatly improved the chemical resistance of the prepared asphalt formulations, as compared with the unmodified parent asphalt [8].

Asphalt formulations modified with thermoplastic polymers gave higher chemical resistance towards all tested media.

Generally, modified asphalt formulations based on asphalt (L) gave higher resistance towards all tested

media as compared with modified asphalt formulations based on asphalt (H).

CONCLUSIONS

The most important conclusions reached in our investigation are:

1. The modification of the selected two types of locally produced asphalt, (low penetration grade asphalt 60/70 Suez, L) and (high penetration grade asphalt 80/100 Alex., H), with some commercial thermoplastic polymers improved physical properties, rheological properties, adhesion, aging and chemical resistance as compared with unmodified asphalt.
2. For modified asphalt L, the studied characteristics are apparently higher as compared with those for modified asphalt H due to the difference in the characteristics of the two parent asphalts.
3. Modified formulations of a sphalt (L and H) with PC gave higher physical, rheological, thermal and chemical properties as compared with formulations modified with SBR, and those formulations showed better performance than the rest of the formulations modified with PS, K, and PP.
4. Such modifications have been reached for hot mix asphalt together with new characteristics, which include lower plastic flow, resistance to deformation, and increase in yield stress values (τ_0), which are important for their use in pavement and traffic.

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Table1. Physical and Chemical Characteristics of the Selected Two Asphalts (L and H).

Physical Properties(ASTM D-946)	Asphalt 60/70 Suez (L)	Asphalt 80/100 Alex. (H)
Solubility in trichloroethylene,%	99.0	99.0
Flash Point ,°F(Cleveland open cup)	450	250
Kinematic viscosity at 135 °C, C.st.	357	257
Absolute viscosity at 60°C, poise	2560	973
Softening Point, Ring and Ball ,°C	47	41
Penetration at 77°F(25°C) 100g, 5 S	65	94
Ductility at 77°F(25°C), 5 cm/min., cm	+ 150	< 150
Chemical Constituents, Wt%		
Oil	25.5	35.62
Wax Content of oil portion	4.4	9.32
Asphaltene	20.8	18.26
Resins	53.6	36.8

Table 2. Penetration, Softening Point, PTS and PI for the Prepared Formulations Using Asphalt (L and H types) with Different Concentration, % from Different Thermoplastic Polymers.

Formulations	Specifications	Concentration, %									
		3		6		9		12		15	
		L	H	L	H	L	H	L	H	L	H
L/H SBR	penetration	42	51	39	48	41	48	43	52	46	55
	Sof. point	51	58	54	61	52	60	52	58	49	57
	PTS	0.025	0.021	0.024	0.020	0.025	0.019	0.024	0.02	0.025	0.021
	PI	-0.76	0.445	-0.56	0.714	-0.71	0.889	-0.61	0.645	-0.84	0.544
L/H PP	penetration	46	52	43	50	45	47	48	51	50	54
	Sof. point	55	57	58	60	54	63	51	59	51	57
	PTS	0.023	0.021	0.022	0.02	0.023	0.02	0.024	0.02	0.024	0.02
	PI	-0.082	0.511	0.128	0.714	-0.25	0.611	-0.47	0.578	-0.396	0.611
L/H K	penetration	46	52	43	50	44	49	47	51	49	54
	Sof. point	59	60	60	61	58	63	56	61	53	59
	PTS	0.021	0.019	0.021	0.019	0.022	0.019	0.022	0.019	0.023	0.019
	PI	0.348	0.818	0.38	0.818	0.159	0.997	0.097	0.889	-0.17	0.783
L/H PS	penetration	47	54	42	52	38	49	41	48	45	51
	Sof. point	57	61	59	63	59	65	54	65	51	62
	PTS	0.023	0.019	0.023	0.019	0.022	0.019	0.024	0.019	0.025	0.019
	PI	-0.082	1.03	-0.112	1.14	-0.053	1.106	-0.451	1.18	-0.639	0.997
L/H PC	Penetration	45	56	41	53	40	50	37	49	42	52
	Sof. point	50	60	53	61	55	63	58	64	54	59
	PTS	0.025	0.019	0.024	0.019	0.024	0.019	0.023	0.019	0.024	0.02
	PI	-0.743	0.997	-0.586	0.96	-0.369	1.03	-0.228	1.106	-0.424	0.679

Table 3. Effect of Time on Dynamic Viscosity at Low and High Shear Rate for the asphalt (L) and the Modified Formulations with Different Polymers at Different Temperatures.

Formulations	Temp °C	Dynamic Viscosity, η mPa.s at														
		D = 1198.08 s ⁻¹					D = 149.76 s ⁻¹									
		1	2	3	4	5	1	2	3	4	5	6	7	8	9	10
L	30	751	756	761	768	774	751	751	751	751	751	751	751	751	751	751
L SBR		934	938	946	951	958	934	934	934	934	934	934	934	934	934	934
L K		884	890	895	899	903	884	884	884	884	884	884	884	884	884	884
L PC		833	838	846	852	860	833	833	833	833	833	833	833	833	833	833
L PS		861	865	871	880	884	861	861	861	861	861	861	861	861	861	861
L PP		796	801	809	816	820	796	796	796	796	796	796	796	796	796	796
L	40	622	629	635	638	643	622	622	622	622	622	622	622	622	622	622
L SBR		764	769	676	681	687	764	764	764	764	764	764	764	764	764	764
L K		719	725	731	739	746	719	719	719	719	719	719	719	719	719	719
L PC		683	687	693	699	704	683	683	683	683	683	683	683	683	683	683
L PS		702	709	716	722	729	702	702	702	702	702	702	702	702	702	702
L PP		663	668	671	678	684	663	663	663	663	663	663	663	663	663	663
L	50	217	221	230	238	244	217	217	217	217	217	217	217	217	217	217
L SBR		401	409	413	421	426	401	401	401	401	401	401	401	401	401	401
L K		350	358	366	371	378	350	350	350	350	350	350	350	350	350	350
L PC		303	308	315	421	429	303	303	303	303	303	303	303	303	303	303
L PS		320	328	332	340	343	320	320	320	320	320	320	320	320	320	320
L PP		296	301	307	311	319	296	296	296	296	296	296	296	296	296	296
L	60	172	177	183	190	195	172	172	172	172	172	172	172	172	172	172
L SBR		303	308	315	320	323	303	303	303	303	303	303	303	303	303	303
L K		283	289	297	301	307	283	283	283	283	283	283	283	283	283	283
L PC		283	288	296	301	305	283	283	283	283	283	283	283	283	283	283
L PS		258	261	268	275	280	258	258	258	258	258	258	258	258	258	258
L PP		227	231	238	246	251	227	227	227	227	227	227	227	227	227	227

Table 4. Effect of Time on Dynamic Viscosity at Low and High Shear Rate for the asphalt (H) and the Modified Formulations with Different Polymers at Different Temperatures.

Formulations	Temp °C	Dynamic Viscosity, η mPa.s at														
		D = 1198.08 s ⁻¹					D = 149.76 s ⁻¹									
		1	2	3	4	5	1	2	3	4	5	6	7	8	9	10
H	30	687	693	698	703	707	687	687	687	687	687	687	687	687	687	687
H SBR		829	831	837	843	860	829	829	829	829	829	829	829	829	829	829
H K		792	796	800	808	815	792	792	792	792	792	792	792	792	792	792
H PC		732	736	742	749	753	732	732	732	732	732	732	732	732	732	732
H PS		753	759	763	769	776	753	753	753	753	753	753	753	753	753	753
H PP		723	729	736	742	750	723	723	723	723	723	723	723	723	723	723
H	40	593	598	601	607	612	593	593	593	593	593	593	593	593	593	593
H SBR		713	719	726	732	734	713	713	713	713	713	713	713	713	713	713
H K		672	679	684	690	694	672	672	672	672	672	672	672	672	672	672
H PC		627	630	636	642	650	627	627	627	627	627	627	627	627	627	627
H PS		653	658	663	670	675	653	653	653	653	653	653	653	653	653	653
H PP		640	647	653	659	664	640	640	640	640	640	640	640	640	640	640
H	50	189	194	200	206	211	189	189	189	189	189	189	189	189	189	189
H SBR		339	346	350	357	361	339	339	339	339	339	339	339	339	339	339
H K		266	271	279	285	290	266	266	266	266	266	266	266	266	266	266
H PC		242	249	255	258	263	242	242	242	242	242	242	242	242	242	242
H PS		255	300	305	310	319	255	255	255	255	255	255	255	255	255	255
H PP		236	241	245	250	255	236	236	236	236	236	236	236	236	236	236
H	60	148	153	156	165	171	148	148	148	148	148	148	148	148	148	148
H SBR		255	261	270	276	285	255	255	255	255	255	255	255	255	255	255
H K		232	238	246	251	256	232	232	232	232	232	232	232	232	232	232
H PC		208	215	219	227	231	208	208	208	208	208	208	208	208	208	208
H PS		217	221	229	235	241	217	217	217	217	217	217	217	217	217	217
H PP		204	210	219	226	232	204	204	204	204	204	204	204	204	204	204

Table 5. The Values of Tensile Strength N/mm² for Some Selected Formulations.

Formulations	Tensile Strength, N/mm ²
H	0.86
H SBR	2.5
H PC	1.6
L	1.4
L SBR	2.9
L PC	2.0

Table 6. Thermal Stability at 250° C for Samples Based on Asphalt L (80% by wt) and, asphalt H (70% by wt) modified with different types of polymers.

Time of curing, hrs	5	10	20	30	60	120	150
Weight Loss, %							
H	2.534	2.968	3.264	4.562	6.353	8.659	12.364
H PP	2.106	2.745	3.021	3.954	5.867	7.995	10.857
H SBR	2.010	2.638	2.997	3.824	5.495	7.152	10.629
H K	2.115	2.824	3.219	4.216	6.134	8.105	11.254
H PC	2.317	2.852	3.104	4.214	5.958	8.125	11.352
H PS	2.013	2.695	3.018	3.748	5.369	7.014	10.598
L	2.015	2.624	3.249	5.107	7.224	9.016	12.101
L PP	1.684	1.924	2.568	3.105	5.524	6.549	9.264
L SBR	1.597	1.724	2.129	2.957	3.854	5.264	8.968
L K	1.758	1.995	2.548	3.256	4.106	6.257	9.426
L PC	1.995	2.534	3.121	4.267	6.847	8.354	10.528
L PS	1.827	2.324	2.864	3.751	5.761	6.852	10.189

Table 7. Resistance of Asphalts (L, H) Both Modified with Some Commercial Polymers to External Media.

Solvent	Boiling water	Water	artificial					Toluene					5% NaOH					5% H ₂ SO ₄				
			6	12	24	48	72	96	6	12	24	48	72	96	6	12	24	48	72	96		
L	15	4 weak	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+		
L SBR	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
LK	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
LPP	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
LPS	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
LPC	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
H	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+		
H SBR	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
HK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
HPP	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		
HPS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
HPC	-	-	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-		

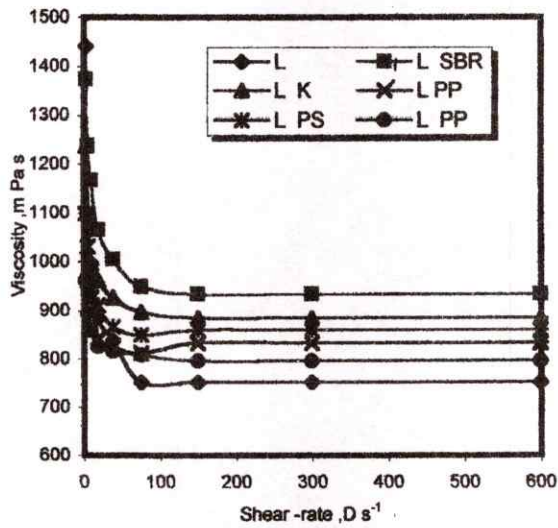


Figure 1. Shear rate against dynamic viscosity m Pa.s for blank sample(L) and for those modified with polymers at 50% asphalt at 30°C in xylene.

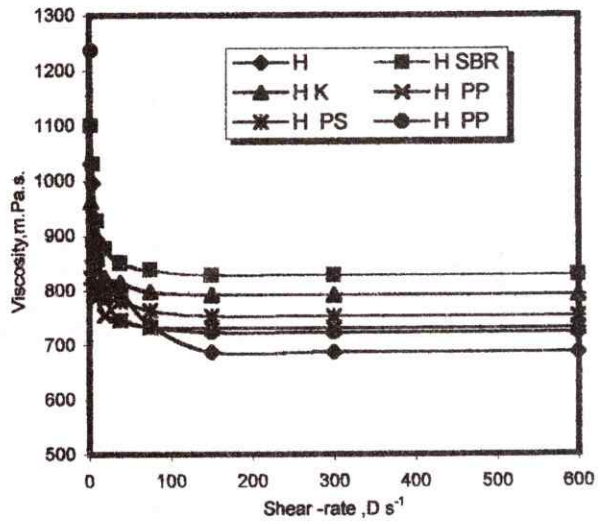


Figure 2. Shear rate against dynamic viscosity m Pa.s for blank sample(H) and for those modified with polymers at 50% asphalt at 30°C in xylene.

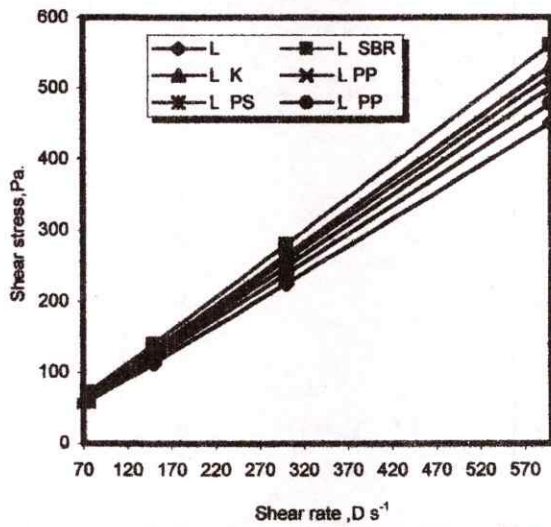


Figure 3. Shear stress against shear rate at 30 °C in xylene for blank sample(L) and for those modified with polymers at 50% asphalt .

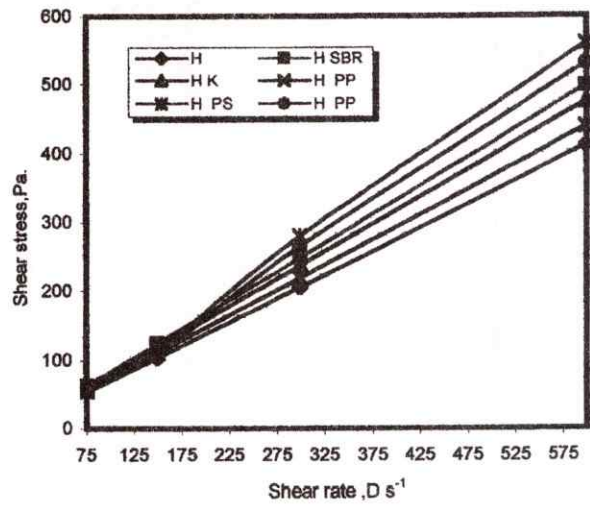


Figure 4. Shear stress against shear rate at 30 °C in xylene for blank sample(H) and for those modified with polymers at 50% asphalt .

