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SYNTHESIS AND STUDY OF EPOXY RESINS BASED ON DIFFERENT BISPHENOLS FOR IMPROVEMENT OF LOCAL ASPHALT

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

** Faculty of Science, Al-Azhar University, Nasr City, Cairo, Egypt.
*Egyptian Petroleum Research Institute(EPRI), Nasr City, Cairo, Egypt.

ABSTRACT

Four types of bisphenols and their respective low molecular weight epoxy resins (I, II, III and IV) were prepared and characterized. Each of the obtained epoxy resins was applied as an additive (together with high temperature hardener) to two types of local asphalt (L and H types) having different compositions.

The resulting data of the validity of the obtained mixtures concerning the improved properties of asphalt [penetration, softening point, calculated penetration temperature susceptibility (PTI) and penetration index (PI)] are based upon the effect of the quantity and type of epoxy resin, type of the hardener used and also by comparison with the results obtained in presence of the commercial epoxy resin (V) which has a specified low temperature hardener. The optimum conditions obtained for the formulations which lead to the best properties are taken into consideration in the application of such formulations for the improvement of the asphalt to be used in different purposes.

Data obtained revealed that improved asphalt either (H) or (L) type with epoxy III and hardener (1) gave highest values of softening point and penetration grade as compared with unmodified parent asphalt.

تم تحضير و توصيف أربعة أنواع مختلفه من راتنجات الايبوكسى من البيس فينول (I, II, III and IV)، و ذلك لتحضير خلطات اسفلتيه تتكون من كل من مركبات الايبوكسى بالاضافه الى النسبة الملائمة من مادة التصلد عند درجة حرارة عاليه مع نوعين من الاسفلت المحلى: (H)& (L).

أوضحت النتائج أنه تم تحسن في خواص الخلطات الاسفلتيه المحسنه و ذلك بقياس درجة الغرز، نقطة التطرية، حساسية الغرز عند التغير في درجة الحراره و معامل الغرز. كما تم تحديد أفضل نسبه و نوع من مركبات الايبوكسى يمكن إضافته للاسفلت (H) و الاسفلت (L)، و كذلك أفضل نسبه من مادة التصلد التى يمكن إضافتها من وزن راتنج الايبوكسى بالنسبه لنوعى الاسفلت المستخدمين. و قد تم استخدام راتنج ايبوكسى تجارى بغرض المقارنه. كما اتضح أن خلطات الاسفلت (H)& (L) المحسن برا تنج الايبوكسى (III) تعطى افضل النتائج.

Keywords: Asphalt, Epoxy resins, Penetration temperature susceptibility, penetration index.

INTRODUCTION

Asphalt pavements are subjected to a wide range of temperatures at which the asphalt should maintain enough stiffness and strength to prevent failures like cracking (at low temperatures) and rutting or shoving (at high temperatures). Its properties can be controlled using specifications from tests conducted at different temperatures. Grades, according to the location, should be selected depending on the climate [1].

Polymers have traditionally been utilized to improve the temperature susceptibility of asphalt which is thermoplastic; softens when heated and hardens when cooled. It is hypothesized that improving the binder stiffness at high service temperatures and reducing stiffness at low service temperatures develop an overall improved binder. The resulting binder would possess improved resistance to permanent deformation, thermal cracking, and fatigue cracking [2].

A reported mechanism associated with polymers for improving the properties of asphalt cement is that polymers create a lattice within asphalt by combining small molecules. The larger molecule lattice is more stable under high and low temperatures and thus, resists thermally induced cracking at low service temperatures and permanent deformation or rutting at high service temperature.

Extensive research has been conducted on asphalt additives, aiming for example, at the performance of paving grade cement modified by thermosetting, and thermoplastic resins compared with the performance of unmodified asphalt cement. These resins additives increase the mixture's cohesion, lower the temperature susceptibility, improve aggregate retention along with increasing elasticity, and improve the rheological properties of the modified asphalt cement [3-6].

The aim of this work is to determine the optimum compositions of the formulations which result in the best possible penetration, softening point, calculated penetration temperature susceptibility (PTI), penetration index (PI) and thermal susceptibility.

EXPERIMENTAL WORK

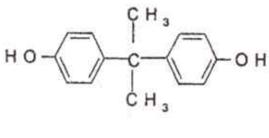
1. Chemicals and Their Properties:

Phenol product of El-Nasr Co. for Coke and Industrial Chemicals, Benzaldehyde of Sigma-Aldrich Co.Ltd. Grade, Acetophenone of Fluka Chemicals Co., Cyclohexanone of El-Nasr Co. for pharmaceutical chemicals. The hardeners for epoxy resin, viz. phthalic anhydride (1), maleic anhydride (2), trimellitic anhydride (3) and also the other used chemicals were of pure grade. Asphalt 60/70 penetration grade (L) supplied from Refinery Suez Co., Egypt, and asphalt 80/100 penetration grade (H) supplied from El-Nasr Petroleum Co., Alex., c. f. Table (1).

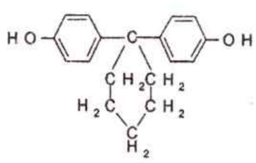
2. Synthesis of Bisphenols:

a. Bisphenols prepared from phenol and acetone (A) and also cyclohexanone (D).

To a mixture of phenol (376 gm) and acetone (58 gm), or cyclohexanone (98gm), at a molar ratio of 4:1, in a conical flask conc. H_2SO_4 (50ml) and conc. HCl gas (100ml) were added and the mixture shaken for 4 hours. The product was then filtered,washed and finally recrystallized [7].



Bisphenol (A)

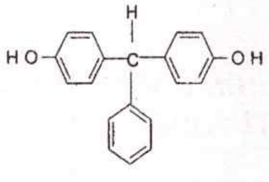


Bisphenol (C)

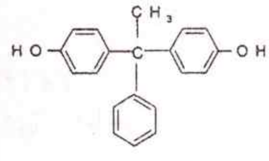
b. Bisphenols prepared from phenol and benzaldehyde (B) and also acetophenone (C) [8].

A mixture of phenol (367 gm) and benzaldehyde (106 gm) or acetophenone (121 gm) at molar ratio of 4 : 1 dissolved in toluene in a conical flask was cooled to -5°C, and then dry HCl gas was bubbled over the mixture for 2 hours followed by shaking for one hour. The obtained products were washed till free of phenol, recrystallized and finally dried at 50°C.

The specifications for all bisphenols (A, B, C, and D) are given in Table (2) and their structures are confirmed with the help of IR, mass spectroscopy, and HNMR analysis. Figures (1-3), illustrate the analysis of the structure of bisphenol A and epoxy resin based on bisphenol A as an example.



Bisphenol (B)



Bisphenol (C)

The IR spectra of the bisphenol A given in Figure (1), show a strong sharp band in the region 3420-3350 cm^{-1} assigned to phenolic (OH) streching vibrations [9]. The bands at 1580 and 1555 cm^{-1} correspond to aromatic C=C streching vibrations, while the band at 1275 cm^{-1} may be assigned to C-OH streching vibrations. The appearance of band at 810 cm^{-1} for all prepared bisphenols is assigned to C-H and of plane bending for P-substituted aromatic ring. This band confirms the condensation of phenol with the corresponding carbonyl compounds at the P-position.

Further confirmation for this structure was obtained from mass spectroscopic investigation (c.f. Figure 3). It is important to recognize the parent peaks because they give the molecular weight of the compound, which agrees with the calculated molecular weight of the produced bisphenols Table (2). It is noted that the produced fragments agree with the base peaks determined from the spectra. The phenolic products produced from condensation of phenol with benzaldehyde were indicated from the base peak at m/e = 276, which represents parent peak of the product.

3. Synthesis of Low Molecular Weight Epoxy Resin [7]:

Bisphenols (A 232 gm), (B 281 gm), (C 295 gm), and (D 287 gm) each was separately mixed with epichlorohydrin (235.9 gm) at molar ratio of (1: 3 w/w) in three-necked flask equipped with stirrer, reflux condenser, and dropping funnel, and placed in water path at 60-70°C. A solution of NaOH (88 gm) in 100ml H_2O was prepared, 60% of this solution was added to the above mixture in a period of 2 hours. The second portion 22% of this solution was added in a period of (15-20 min.), the temperature should not exceed 65-70°C. The third portion 18% was added at once, and stirring continued for another 45min. The obtained resins were separated from the reaction mixture, dissolved in acetone, filtered and then dried at 60-70°C till constant weight.

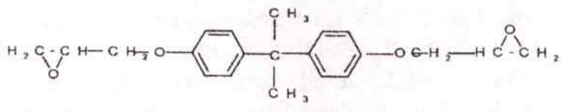
The specifications of the obtained epoxy resins are given in Table (3).

4. Determination of the specifications of the prepared epoxy resins.

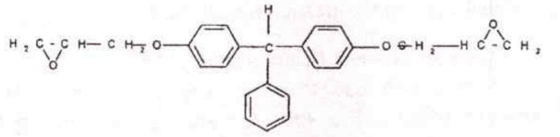
- Values of epoxy group content, hydroxyl group content and drop falling temperatures (by

Ubbeblode method) were determined according to the cited methods in the literature [10,11].

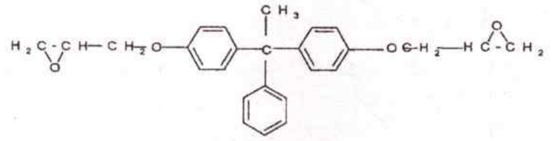
- The Dynamic viscosity of the obtained resin was measured using RV 12 Viscometer Haake Co., West Germany.



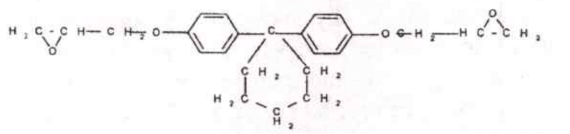
Epoxy Resin(I)



EpoxyResin(II)



Epoxy Resin (III)



Epoxy Resin(IV)

5. Blending of Asphalt with Epoxy Resin [5].

The blending technique employed involved heating the asphalt sample to 60-80°C followed by thorough mixing with specified amount of epoxy resin and calculated amount of molten hardener in a beaker till homogenous blend was obtained and then placed in an oven at 150-170°C. The curing time, resin concentration and hardener concentration, % of the weight of resin were estimated.

6. Determination of the physical properties of asphalt blends.

- ***Softening Point (Ring&Ball).*** The standard test method was carried out according to ASTM D 36.

- ***Penetration (0.1m/25°C).*** The standard test method was carried out according to ASTM D 5.

RESULTS AND DISCUSSIONS

The synthesized four types of low molecular weight epoxy resins (I, II, III, and IV) were added separately to each of the studied local asphalt samples (L and H) together with individually calculated amounts of high temperature hardener (1, 2, and 3) for asphalt modification. The obtained results of softening point, penetration, calculated PTS and PI were determined and compared with those of unmodified asphalt and of the used commercial epoxy resin (V) and its specified low temperature hardener.

The Factors Affecting the Characteristics of the Obtained Asphalt-Epoxy Resin Mixture, are:

i. Mixing temperature.

Since the used viscous medium, like bitumen can minimize the possibility of interaction between the molecules of the resin and hardeners, i.e. it reduces their chance of collision, the only way to offset such behaviour and produce homogeneity of the mixtures; it was necessary to increase the temperature in order to accelerate the reaction velocity [3]. Consequently, the asphalt, polymer-mixing temperature was around 150-170°C which is the asphalt workability temperature.

ii. Curing time.

In order to find out the suitable time which is necessary for the curing, of the studied asphalt-epoxy mixtures, 24 different types of mixtures were prepared, the compositions of the mixtures of asphalt 60/70 (L) or 80/100 (H) is 90% asphalt, plus one of the used types of low molecular weight epoxy resins (10%), based on [bisphenol A (I), Bisphenol of benzaldehyde (II), bisphenol of acetophenone (III), and bisphenol of cyclohexanone (IV)]. Each of the used hardeners, [phthalic anhydride (1), maleic anhydried (2), and trimellitic anhydried (3)] was added separately at a ratio of 10% of the weight of the used epoxy resins. Therefore the symbols for compositions of the studied mixtures; (H I 1), (H II 1), (H III 1), (H IV 1), (H I 2), (H II 2), (H III 2), (H IV 2), (H I 3), (H II 3), (H III 3), and (H IV 3) specify asphalt 80/100, while for asphalt 60/70 mixtures the respective abbreviations are (L I 1), (L II 1), (L III 1), (L IV 1), (L I 2), (L II 2), (L III 2), (L IV 2), (L I 3), (L II 3), (L III 3), and (L IV 3). The studied physical properties of the samples after curing at different time intervals (5, 10, 15, 20, and 25 hours) were penetration, 0.01mm, and softening point, °C.

Results given in Table (5) show that the penetration of the mixtures decreases at first with increasing time of curing, and reach their lowest values of penetration at curing time between 10-15 hours. These values increase with further increasing time of curing. On the other hand the values of softening point increase with increasing time of curing till reaching their highest values of softening point for curing time between 10-15 hours for all mixtures after which they decrease. This means that the suitable time for curing for all mixtures ranged between 10-15 hours.

Values of penetration index (PI) and penetration susceptibility (PTS) which give indications about the hardness, and plastic flow to the prepared formulations, were calculated with help of the obtained values of penetration and softening point for the above mentioned mixtures according to the following equations [3,4]:

PTS = Log 800 – Log penetration / Softening point at 25°C

PI = (30 / 1 + 90 PTS) – 10

Results given in Table (6) show that the lowest values of PTS accompanied by highest values of PI for the same sample are recorded for curing times between 10-15 hours, means that the mixtures with the highest rheologic properties acquire the highest values of PI and lowest values of PTS, such mixtures acquire higher hardness as compared with other mixtures [4].

iii. Curing agent, %.

For the selected local asphalt samples AC 60/70 Suez (L), and 80/100 Alex. (H), each was mixed with 10% w/w of the prepared low molecular weight epoxy resin (I, II, III, and IV) to give the previously mentioned mixtures. Each of these mixtures was cured at 150-170°C for 15 hours using different percentages by weight of the specified hardener, phthalic anhydride (1), (10, 20, 30, 40, and 50% respectively relative to fixed weight of the epoxy resin). The same procedure was applied on the other two hardeners, maleic anhydride (2), and trimellitic anhydride (3). The physical tests such as penetration, and softening point were estimated for the obtained cured mixtures to investigate the suitable ratio of used hardeners needed to give the highest hardness as predicted from the values of low penetration and high softening point [3,4].

Results given in Table (7) show that the values of penetration decrease with increasing the percentage of hardener up to 40% which gives the lowest values of penetration and the highest values of hardness for all the studied mixtures of asphalt 80 /100 Alex. (H).

The respective values of softening point increase with increasing the ratio of hardener till 40% after which the respective softening point decreases.

The values of penetration for all mixtures based on asphalt 60/70 Suez (L), give the lowest values of penetration and highest values of softening point in presence of hardener quantity of 30% of the weight of the epoxy-resin [12].

It is probable that the difference in the values of quantities of added hardeners which are equal to 40% of the weight of the epoxy resin for asphalt 80/100 (H), as compared to 30% of the weight of the epoxy resin for asphalt 60/70 (L), could be attributed to the different constitutions of the studied asphalt which together with the added epoxy resin could be reflected on the studied property.

Moreover further higher values of hardeners than the optimum values for each of the studied asphalt formulations which are accompanied by increase in the values of penetration and decrease of the softening point, could be accompanied by an increase in the acidity of the mixtures obtained from excess acidic hardeners at the such workability temperature which could lead to the destruction of the formed bonds between the hardener and the resin [13].

iv. Optimum ratio of added epoxy resin.

It was also essential to investigate the suitable amount of epoxy resin necessary for obtaining the best possible improvement (lowest penetration and highest softening point) for the selected two asphalt samples (L&H).

Each of the prepared epoxy resins were added in different percentages to the asphalt sample (10, 20, 30, 40, and 50% respectively), each was mixed with 40% of used high temperature curing agent (1), (2), and (3) in case of asphalt 80/100 (H) and 30% in case of asphalt 60/70 (L) and cured at the previously determined curing temperature for the respective curing time. Also, the commercial epoxy resin was added to asphalt with the same different ratios with its specified hardener. After that, the values of penetration, and softening point were measured.

The obtained data listed in Table (8) show that all tested mixtures based on asphalt 80/100 (H) gave the lowest values of penetration and highest values of softening point at quantities of epoxy between 30-40% of the weight of the asphalt [13].

According to the type of hardener the lowest values of penetration and consequently the highest values of softening point proceed in the following order 1 > 3 > 2.

According to the type of epoxy resin, the values of the above mentioned properties proceed in the following order of the prepared formulations, H III 1 > H II 1 > H I 1 > H IV 1 > H V. It is probable that such values proceed according to the possibility of the rotation of the central carbon atom of the prepared bisphenol in resulting epoxy resin with temperature. This means that the easier rotation around the central carbon atom leads to the higher penetration and lower softening point, the difficult rotation leads to lower penetration and higher softening point values.

For mixtures based on asphalt 60/70 (L), data given in Table (8) revealed that, all mixtures gave the lowest values of penetration and highest values of softening point at epoxy resin content of 20% of the weight of asphalt. This percent is correlated with the experimentally added quantities of epoxy resins in the cited literature.

According to the type of epoxy resin, the obtained lowest penetration and highest softening point proceed according to the following order of the prepared formulations, L III 1 > L II 1 > L I 1 > L IV 1 > L V.

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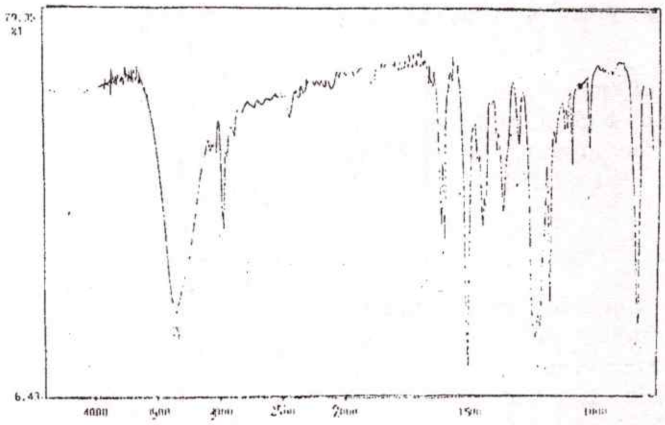

Figure 1. IR Spectrum of Bisphenol Based on Acetone.

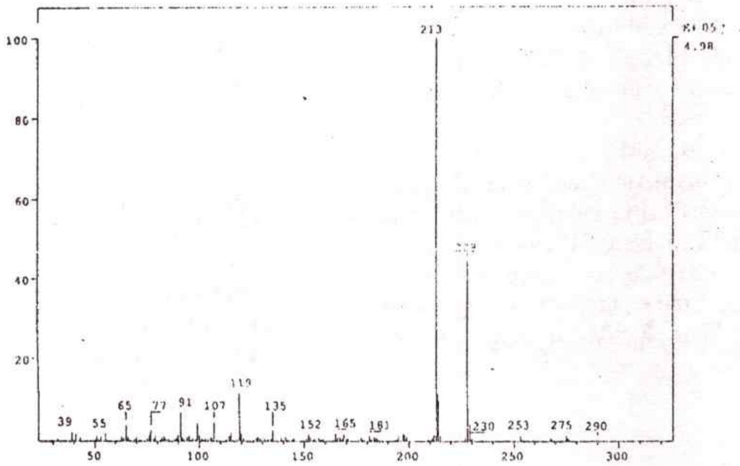

Figure 2. Mass Spectrum of Bisphenol Based on Acetone.

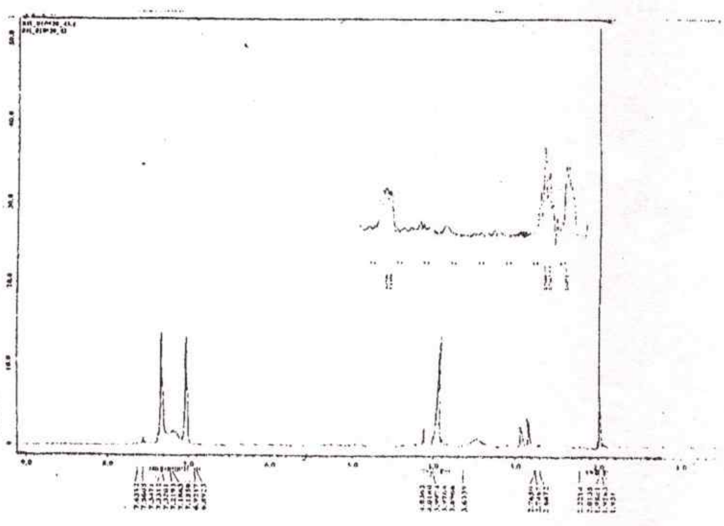

Figure 3. HNMR Spectrum of Epoxy Resin Based on Bisphenol A.

Table 2. Characteristics of the Prepared Bisphenols.

Type of Bisphenol	Des.	Theore-tical yield, gm	Obtained yield, g/mole of c. group	Yield %	Melting point, °C	M.wt	Elemental analysis					
							Calculated			Found		
							C	H	N	C	H	N
4,4-dihydroxy diphenyl propane	A	232	219	94.3	157	228	79	7	---	79	7	---
4,4-dihydroxy triphenyl methane	B	281	259	92.1	189	290	82.7	6.2	---	82.7	6.2	---
4,4-dihydroxy triphenyl methyl methane	C	295	255	86.4	168	276	83.2	5.8	---	83.2	5.8	---
4,4-dihydroxy diphenyl cyclohexanone	D	287	194	67.6	139	268	80.5	7.4	---	80.5	7.4	---

Table 3. Characteristics of the Prepared Epoxy Resins.

Parent bisphenol.	Prepared epoxy resins (symbols).	Yield, gm.	Epoxy group content, %.	Epoxy, g/g eq. Epoxy resins.	Hydroxyl group content, %.	Drop-falling temp.°C	Viscosity, m. Ps.	M.wt	Elemental analysis, %					
									Calculated			Found		
									C	H	N	C	H	N
A	I	354	24.2	4.1	58	58	457	382	76.9	6.2		76.9	6.2	-
B	II	396	20.1	0.45	31.8	51	489	438	79.9	5.4	-	79.9	5.4	-
C	III	380	21.8	0.41	42.4	52.4	521	454	80.1	5.7	-	80.1	5.7	-
D	IV	340	22.3	0.44	34.4	48.2	429	428	78.5	6.5	-	78.5	6.5	-

Table 4. Physical Properties and Calculated PTS, and PI Values of LV and HV Mixtures at 70% Asphalt + [3V : 1Hardener (w/w)].

Formulations	Penetration 0.01mm, 25°C	Softening point, °C	PTS	PI
LV	63	43	0.0613	-5.3978
HV	78	40	0.0613	-5.7542

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 5. Effect of Curing Time on the Values of Penetration and Softening Point for Formulations Consisting of 90 % Asphalt + 10 % [resin + 10% hardener] Cured at 150-170°C.

Formulations	Specifications	Curing time, (hrs)									
		5		10		15		20		25	
		H	L	H	L	H	L	H	L	H	L
H/L I 1	Penetration	72	45	61	42	50	46	53	46	54	50
	Sof. point	48	53	52	59	51	57	46	53	52	50
H/L II 1	Penetration	63	43	49	40	48	40	54	44	52	45
	Sof. point	51	56	50	56	58	60	51	55	53	52
H/L III 1	Penetration	42	40	62	34	61	36	59	37	56	41
	Sof. point	54.5	55	52	61	52	56	52	53	50	51
H/L IV 1	Penetration	67	44	59	41	52	43	53	45	56	45
	Sof. point	47	59	54	61	52	58	52	54	50	51
H/L I 2	Penetration	65	47	59	44	62	40	64	43	67	48
	Sof. point	52	55	58	58	55	58	51	54	49	51
H/L II 2	Penetration	60	44	56	41	59	40	62	42	65	45
	Sof. point	51	52	57	54	53	54	50	51	48	47
H/L III 2	Penetration	63	42	57	40	57	39	60	39	64	41
	Sof. point	51	51	55	53	56	56	50	52	48	49
H/L IV 2	Penetration	66	48	61	45	61	41	64	43	68	47
	Sof. point	54	50	60	52	60	53	57	51	53	50
H/L I 3	Penetration	62	51	59	48	57	48	57	52	60	55
	Sof. point	56	57	56	60	59	58	57	55	53	53
H/L II 3	Penetration	59	48	56	45	52	47	52	50	57	52
	Sof. point	61	60	61	62	64	59	63	56	59	55
H/L III 3	Penetration	60	50	57	47	53	49	56	51	59	54
	Sof. point	58	59	59	61	61	61	57	58	52	56
H/L IV 3	Penetration	63	52	61	49	59	49	62	51	64	56
	Sof. point	56	56	58	59	63	58	59	55	55	52

Where: H is asphalt 80/100, and L is asphalt 60/70.

(I, II, III, and IV) are the four different prepared epoxy resins.

(1, 2, and 3) are the used hardeners.

Table 6. Effect of Curing Time on the Values of (PTS) and (PI) for Formulations Consisting of 90 % Asphalt + 10 % [resin + 10% hardener] Cured at 150-170°C.

Formulations	Specifications	Curing time, (hrs)									
		5		10		15		20		25	
		H	L	H	L	H	L	H	L	H	L
H/L I 1	PTS	0.0217	0.0235	0.0214	0.0216	0.0236	0.0217	0.0256	0.0234	0.0225	0.0240
	PI	0.159	0.369	0.252	0.190	0.396	0.159	0.920	0.341	0.082	0.506
H/L II 1	PTS	0.0216	0.0236	0.0242	0.0232	0.0219	0.0216	0.0229	0.0229	0.0223	0.0240
	PI	0.190	0.396	0.560	0.284	0.380	0.190	0.199	0.199	0.0232	0.506
H/L III 1	PTS	0.0234	0.0236	0.0213	0.0224	0.0214	0.0240	0.0217	0.0251	0.0230	0.0253
	PI	0.341	0.396	0.280	0.053	0.250	0.506	0.082	0.794	0.228	0.845
H/L IV 1	PTS	0.0229	0.213	0.0209	0.0211	0.0219	0.0218	0.0226	0.0231	0.0230	0.0245
	PI	0.0232	0.284	0.506	0.348	0.198	0.128	0.224	0.256	0.231	0.639
H/L I 2	PTS	0.020	0.0223	0.019	0.0217	0.020	0.0224	0.021	0.0235	0.021	0.0239
	PI	0.714	-0.023	1.070	0.159	0.714	-0.05	0.0380	-0.369	0.380	-0.479
H/L II 2	PTS	0.022	0.024	0.020	0.0238	0.021	0.024	0.022	0.025	0.022	0.0265
	PI	0.067	-0.50	0.714	-0.45	0.380	-0.50	0.067	-0.769	0.067	-1.13
H/L III 2	PTS	0.021	0.025	0.020	0.0248	0.020	0.023	0.022	0.0252	0.022	0.026
	PI	0.380	-0.769	0.714	-0.717	0.714	-0.228	0.067	-0.82	0.067	-1.01
H/L IV 2	PTS	0.020	0.0244	0.0188	0.024	0.0185	0.0243	0.0199	0.0248	0.020	0.0246
	PI	0.714	-0.61	1.140	-0.50	1.257	-0.58	0.748	-0.717	0.714	-0.66
H/L I 3	PTS	0.0198	0.0206	0.020	0.0203	0.0194	0.021	0.020	0.0215	0.021	0.0214
	PI	0.783	0.511	0.714	0.611	0.924	0.38	0.714	0.221	0.380	0.252
H/L II 3	PTS	0.0185	0.0203	0.0189	0.0201	0.0185	0.0208	0.0188	0.0215	0.0194	0.0215
	PI	1.257	0.611	1.106	0.679	1.257	0.445	1.140	0.221	0.924	0.221
H/L III 3	PTS	0.0193	0.0201	0.0194	0.0209	0.0193	0.019	0.020	0.0208	0.021	0.0202
	PI	0.960	0.679	0.924	0.413	0.960	1.07	0.714	0.445	0.380	0.645
H/L IV 3	PTS	0.0197	0.0211	0.0192	0.0205	0.0179	0.0209	0.0188	0.0217	0.0199	0.0222
	PI	0.810	0.348	0.997	0.544	1.48	0.413	1.140	0.159	0.748	0.006

Where: H is asphalt 80/100, and L is asphalt 60/70.
(I, II, III, and IV) are the four different prepared epoxy resins.
(1, 2, and 3) are the used hardeners.

Table 7. Effect of Curing agent of the wt. of Epoxy Resin on the Values of Penetration and Softening Point for Formulations Consisting of 90% Asphalt + 10 % [resin + 10-50% hardener] Cured at 150-170°C for 15 hrs.

Formulations	Specifications	Curing agent, wt%									
		10		20		30		40		50	
		H	**L**	**H**	**L**	**H**	**L**	**H**	**L**	**H**	**L**
H/L I 1	Penetration	50	42	48	38	46	35	46	39	49	44
	Sof. point	51	57	53	61	55	61	59	57	53	53
H/L II 1	Penetration	48	40	45	36	42	33	42	37	46	41
	Sof. point	58	58	58	62	59	64	61	58	56	54
H/L III 1	Penetration	42	34	40	32	37	30	34	33	43	36
	Sof. point	54	59	57	62	58	65	60	60	55	56
H/L IV 1	Penetration	59	41	55	38	53	34	49	38	54	43
	Sof. point	52	58	54	60	61	63	61	60	56	52
H/L I 2	Penetration	59	57	56	54	54	54	51	56	55	58
	Sof. point	58	59	58	59	59	61	59	58	56	56
H/L II 2	Penetration	56	52	53	49	51	47	49	50	54	53
	Sof. point	57	64	59	65	61	65	61	62	58	60
H/L III 2	Penetration	57	53	55	51	52	49	52	52	54	55
	Sof. point	55	61	58	62	60	64	57	61	54	59
H/L IV 2	Penetration	61	59	58	56	54	52	54	54	57	57
	Sof. point	60	63	61	64	63	66	64	63	59	61
H/L I 3	Penetration	57	48	53	46	51	44	51	44	55	47
	Sof. point	59	60	59	61	62	63	64	62	58	59
H/L II 3	Penetration	52	45	50	41	45	41	45	42	49	45
	Sof. point	64	62	65	62	65	64	66	61	61	58
H/L III 3	Penetration	53	47	51	45	48	42	46	45	52	48
	Sof. point	61	61	63	63	65	65	65	60	62	57
H/L IV 3	Penetration	59	49	56	46	53	43	50	45	57	49
	Sof. point	63	59	64	61	66	61	66	58	60	54

Where: H is asphalt 80/100, and L is asphalt 60/70.

(I, II, III, and IV) are the four different prepared epoxy resins.

(1, 2, and 3) are the used hardeners.

Table 8. Effect of Epoxy Content, % on The Values of Penetration and Softening Point for Formulations Consisting of 90-50% Asphalt +10-50 % [resin + 40% hardener] Cured at 150-170°C for 15 hrs.

Formulations	Specifications	Epoxy content, %									
		10		20		30		40		50	
		H	L	H	L	H	L	H	L	H	L
H/L I 1	Penetration	45	35	44	31	39	31	42	34	46	37
	Sof. point	54	61	55	64	57	62	60	59	56	56
H/L II 1	Penetration	43	33	40	30	36	34	37	37	41	38
	Sof. point	51	64	53	65	56	61	58	59	54	57
H/L III 1	Penetration	39	30	36	28	31	32	31	35	37	35
	Sof. point	51	65	54	66	56	66	59	62	55	58
H/L IV 1	Penetration	44	34	41	31	38	33	40	36	42	37
	Sof. point	53	63	55	64	58	64	59	59	54	56
H/L I 2	Penetration	51	54	49	51	49	51	52	53	54	55
	Sof. point	59	61	59	61	61	59	58	57	56	56
H/L II 2	Penetration	49	47	49	45	47	48	50	52	53	56
	Sof. point	61	65	63	67	63	64	59	61	58	58
H/L III 2	Penetration	52	49	48	49	46	52	49	54	52	57
	Sof. point	57	64	59	65	59	61	56	61	54	59
H/L IV 2	Penetration	54	52	51	50	51	50	53	53	56	55
	Sof. point	64	66	65	67	67	65	63	63	60	60
H/L I 3	Penetration	57	44	53	41	51	43	54	46	59	49
	Sof. point	59	63	62	63	62	60	58	57	54	55
H/L II 3	Penetration	52	41	50	39	47	42	51	45	55	48
	Sof. point	64	64	64	65	66	61	61	59	57	54
H/L III 3	Penetration	53	42	50	42	49	44	49	47	54	50
	Sof. point	61	65	63	66	64	62	62	59	59	53
H/L IV 3	Penetration	59	43	56	40	52	40	55	42	58	45
	Sof. point	63	61	64	61	66	60	61	57	56	52

Where: H is asphalt 80/100, and L is asphalt 60/70.

(I, II, III, and IV) are the four different prepared epoxy resins.

(1, 2, and 3) are the used hardeners.