Some Aspects of the Effect of Asphalt Chemical Composition on Material Behavior and Pavement Performance

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The purpose of this paper is to look at some aspects of the effect of asphalt chemical composition on the properties and behavior of some fresh asphalt binders, as well as of plant-aged and field-aged samples, and the manner in which long-term aging may be affected by changes in material composition. The asphaltic binders involved are of the straight-run and propane-precipitated asphalt blend types, all of the 60/70 penetration grade. At this stage, data accumulated reflect construction conditions and the beginning of the service life of the test sections. No pavement distress has been reported so far that would warrant linkage to the type and characteristics of the asphalt binder used. However, definite relationships were found among the chemical composition of the asphalt and its physicorheological changes during short- and long-term aging. These relationships were also significant enough to distinguish among the behavior of straight-run asphalts and PPA asphalt blends. As more data become available with time, it is hoped that a more definite relationship can be established among the physicochemical properties of the asphalt and their effect on material behavior and longer-term pavement performance.

Asphalt cements have characteristics and properties significantly determined by the nature of their chemical composition. In general, the chemical character of an asphalt binder is derived from that of the parent crude, although process conditions during production from distillation of the crude may affect the chemistry of the material. Changes in chemical composition, which lead to changes in properties and behavior, may also occur during plant production of asphaltic mixtures, in which heating in the presence of air may cause a substantial level of oxidation of the asphalt binder, or during field service of the asphaltic pavement.

In spite of the link between asphalt chemistry and its behavior, the material is selected for application purposes on the basis of some standard physical rather than chemical tests. In some cases, such standard tests may even fail to differentiate one asphalt type from another, giving the impression of the existence of similarities in products and properties, although in effect, the asphalt materials could be quite different in their chemical composition and in the way they behave and age on production, application and service (*1*).

Examined in this paper are some aspects of the effect of asphalt chemical composition on the properties and behavior of some fresh asphalt binders, as well as of plant-aged and field-aged samples, and the manner in which long-term aging may be affected by changes in material composition. The asphaltic binders involved are of the straight-run and propane-precipitated asphalt (PPA) blend types, all of the 60/70 penetration grade.

ASPHALT CHEMISTRY BACKGROUND

The chemistry of asphalts is not as well defined as those of relatively simple chemical materials and compounds. The link between asphalt chemistry and its behavior has been established directly or indirectly through controlled chemical processes, by which asphalts may be made to acquire some required characteristics (*2–4*), and also through studies modeling aging and changes in asphalt properties by diffusion-controlled oxidation reactions in the material (*5*,*6*).

Because of lack of precise knowledge of asphalt chemistry, most methods for analyzing asphalts chemically are based on separating the material into broad chemical groups with distinct characteristics. Other methods break the various groups into further subgroups in order to improve understanding of the behavior of the material. Considering the complexity of asphalts, however, it is to some extent still doubtful whether the behavior of subgroups can confidently be said to relate to the global behavior of the material. Despite this shortcoming, the present level of knowledge of asphalt chemistry is being used in several ways, such as in supercritical extraction to engineer asphalt materials to have improved quality and better performance predictability.

The work reported here is based on the four-fraction method of chemical analysis of asphalts pioneered by Corbett (*3*,*7*). These fractions are the saturates, the asphaltenes, the naphthene aromatics and the polar aromatics obtained by adsorption-desorption technique on a clay-silica-gel chromatographic column. Ishai et al. (*8*) have adopted the Gaestel Index (I_c) to reflect the relationship between aging and the internal colloidal structure of asphalts. The interpretation of the chemical-group composition of the asphalt, which reflects its internal colloidal structure, was made by the Gaestel Index, as defined in the following equation.

$$I_c = \frac{\text{Asphaltenes} + \text{Saturates}}{\text{Napthene Aromatics} + \text{Polar Aromatics}} \qquad (1)$$

In an earlier work (*9*), it was found that asphalt fractionation obtained by this method strongly correlated with ma-

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terial properties, where the I_c as a single parameter was stronger in relating the asphalt chemical fractions to material rheology and aging than any single fraction, as will be discussed later in this paper.

RESEARCH AND TECHNOLOGY BACKGROUND

In Israel, fresh paving-grade asphalt cements supplied to the asphalt industry may be a straight-run type or vacuum tower bottoms laced with PPA. PPA is a high consistency, high molecular weight asphalt product, obtained as the residue from the refinery production of lubricating oils by solvent (propane) precipitation. It may be blended with other soft asphalt residues (i.e., vacuum tower bottoms), to obtain paving-grade quality. Since their introduction a few years ago, the PPA blends have caused contradictory opinions, caused mainly by the phenomenon of tender mixes, causing construction problems, and to their unknown effects on long-term asphalt durability.

Consequently, a major effort has been devoted to investigate the effect of PPA asphalt cement blends on the chemistry, rheology, and long-term aging of asphalts and bituminous mixtures. The first phase of this work was dedicated to a preparatory laboratory study. Its results were well reported and published in the last five years (*6* and *8*, *9* through *13*).

It was generally found that the PPA blends characteristically had lower viscosity and higher ductility, though better durability and moisture-damage resistance of their mixtures were noted than for the straight runs. No explanation has yet been found for the tenderness and sticky nature of the PPA mixtures, but it is suspected that the lower viscosity and higher ductility have a link with this character. It is also unclear to what extent this property would affect long-term performance.

A study of some asphalt samples by chemical analysis based on the Clay-Gel fractionation method also showed systematic differences between PPA blends and straight-run asphalt samples for same-penetration-grade bitumens. The PPA blends tended to have lower content of asphaltenes, higher polar aromatic fractions, and lower colloidal stability index (Gaestel Index) values than their straight-run counterparts. Unique relationships were established between material viscosity and the colloidal stability index for initial conditions and during aging. Typical examples are given in Figures 1 and 2. On the basis of these relationships, it appears that the relatively high polar aromatic fractions and low content of asphaltenes are a likely explanation for the low viscosity of PPA blends.

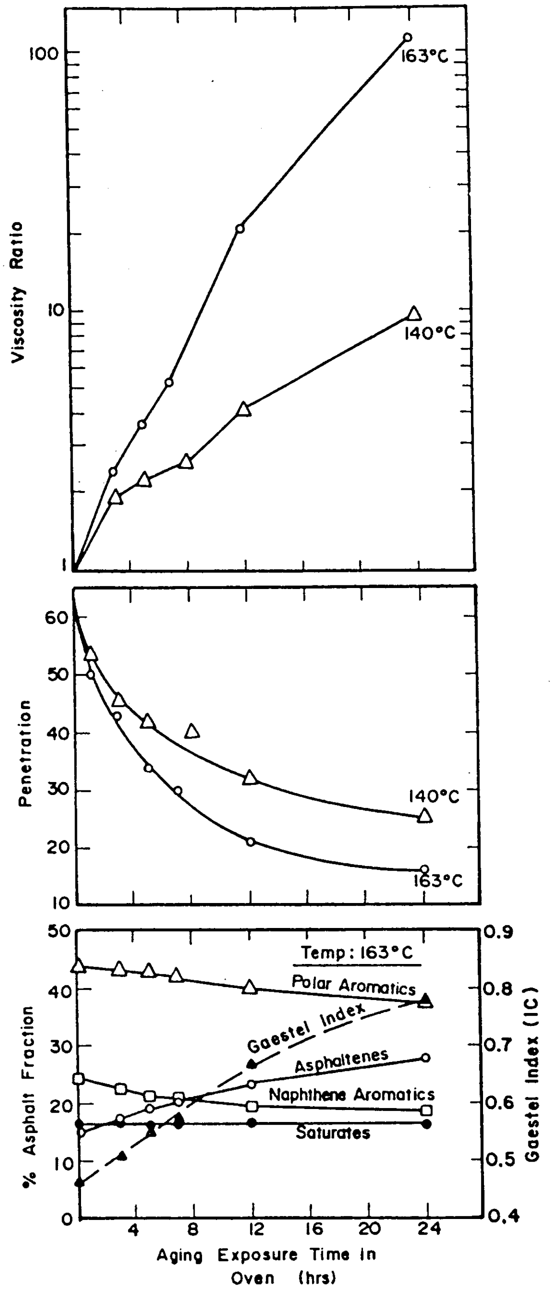

FIGURE 1 Relationship among the changes in asphalt chemical reactions and Gaestel Index and the changes in viscosity and penetration in the laboratory aging process (a straight-run asphalt) (*9*).

FIELD TEST SECTIONS

The peculiar characteristics of the PPA blends and the merits of using one type of asphalt rather than another required field performance indicators. As a follow-up to the preparatory laboratory study, the Israel Public Works Department, in cooperation with the Technion Transportation Research Institute, in 1991 constructed a series of actual field-controlled test sections. These sections included separate stretches for straight-run asphalts and for PPA blends, with a view to obtaining firsthand information about material and pavement performance as related to basic rheological and chemical properties of the asphalts under field conditions (*14*). Among other parameters, pavement performance and material properties are monitored from time to time and correlated with chemical composition of cored samples taken at those instances.

To date, data accumulated so far reflect construction conditions and the beginning of the service life (up to 9 months) of the test sections. Data accumulated on properties of asphalts extracted from plant mixtures are found to tie in with those for fresh and oven-aged samples to show a clear correlation between asphalt properties and changes in chemical composition.

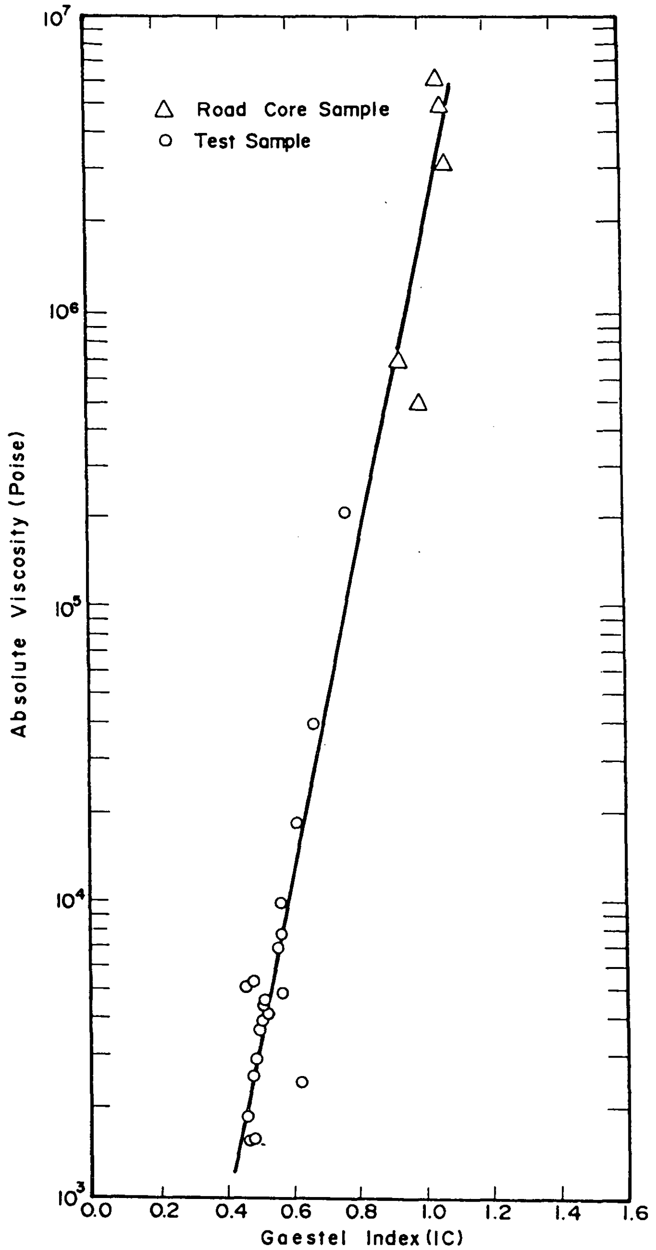

FIGURE 2 Relationship among viscosity and Gaestel Index at different laboratory and field aging levels for different types of asphalts (*9*).

SITES, MATERIALS, AND TESTING PROGRAM

Controlled test sections were constructed at three sites in southern Israel in the vicinity of Ashdod and Beersheva. This construction was part of maintenance and rehabilitation activities on two major highways of the Israeli rural network. The sites were

1. Ramat Hovav (RH): Highway No. 40, 6 km south of Beersheva;
2. Beit-Kama (BK): Highway No. 40, 10 km north of Beersheva;
3. Nachshon (NA): Highway No. 32, 10 km west of Ashdod.

All bituminous mixtures were produced in a central asphalt plant located between Sites 2 and 3.

The experimental investigation that followed each construction site was based on a comprehensive testing system that included (see also Figure 3)

1. Tests on fresh asphalt cements;
2. Tests on recovered asphalt from plant produced mixtures;
3. Tests on aggregates and laboratory-produced bituminous mixtures;
4. Tests on plant-produced bituminous mixtures;
5. Tests on asphaltic concrete and recovered asphalt cement from samples cored soon after construction; and
6. Long-term followup on bituminous concrete and recovered asphalt under long service conditions.

Two types of asphalt cements were used: a straight-run and a PPA blend, each obtained from a different producer. The fresh asphalt samples were monitored from production source to destination [i.e., samples were taken right after production (*A*), from delivery tanks before unloading at the site (*B*), and finally, from site storage facilities before entry into the asphalt plant (*C*)]. The idea behind sampling at those stages was to ascertain whether, during the transportation and storage stages, any variables were introduced into the material behavior. In the past, some contractors claimed (albeit without any tangible evidence) that asphalt cements arriving at their facilities had their properties somehow changed as a result of the transportation process from the production source. Tests carried out on these samples included comprehensive "fingerprinting" tests and clay-gel compositional analysis, as shown in Figure 3.

For plant-produced bituminous mixtures, samples were taken during each work day and for each bitumen type during laying of the test sections. The mixtures were used for recovering the asphalt binder for testing, as previously described. The blends were also used for preparing specimens for mechanical tests, which are not discussed in this paper. All materials belonging to this type of sample have been designated (*E*). Cores were also taken from the test sections at around 3 and 9 months after construction, the time periods representing the state of the test sections shortly after construction and 9 months of field aging. All asphalts recovered from the road core samples have been designated (*G*3) and (*G*9) for 3 and 9 months of field aging, respectively.

Two types of aggregates were used. For the sections at Ramat Hovav and Nachshon, the composition was totally dolomitic aggregates, whereas for Beit Kama it was + #4 sieve-basalt aggregates and − #4 sieve-dolomitic aggregates.

RESULTS AND DISCUSSION

Asphalt Cement Properties During Construction

Comparison Among Populations

Results of average physical and rheological properties of the asphalt cements during construction are summarized in Table 1. The table represents averages of 45 samples of fresh bitumen from the three sites and from A, B, and C groups, and

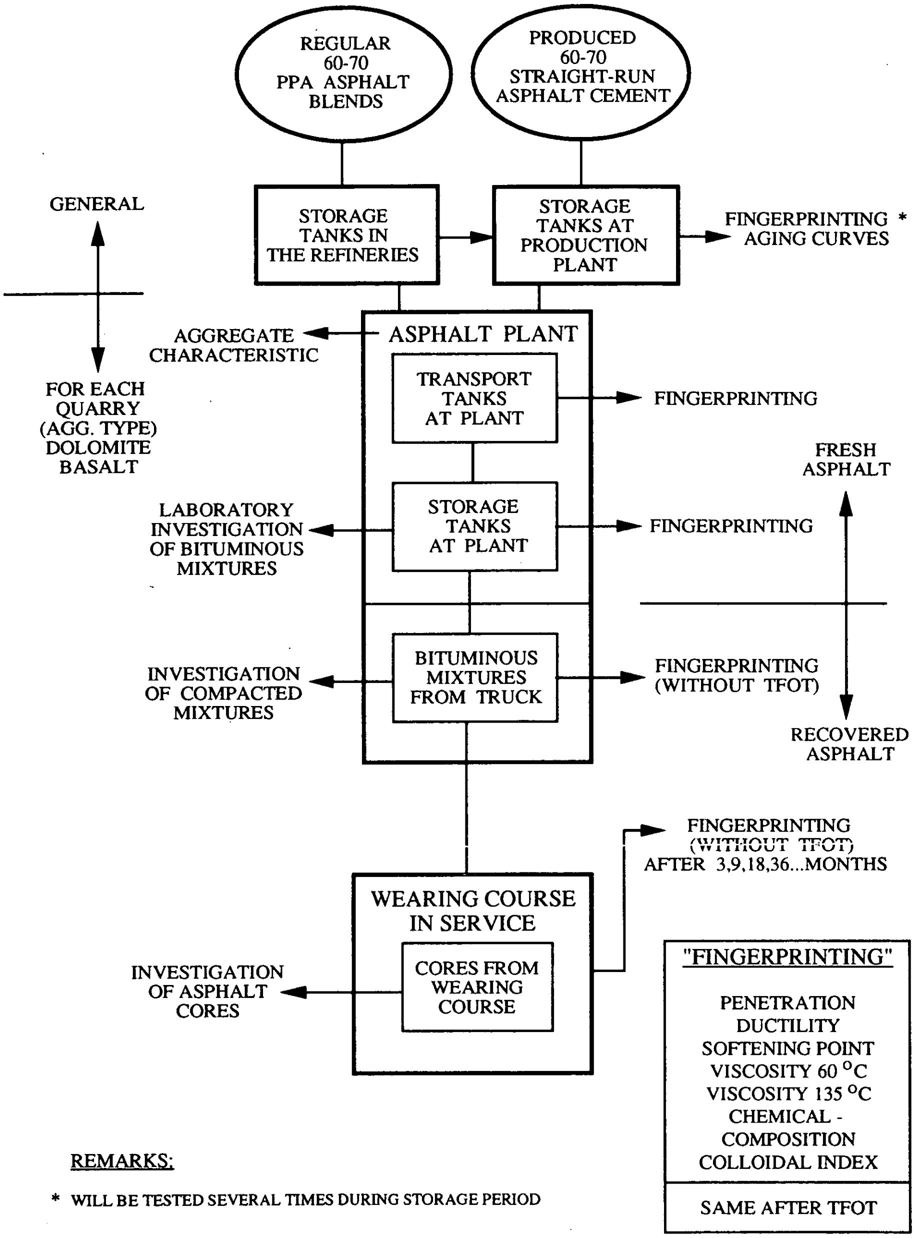

FIGURE 3 **Schematic description of experimental investigation that follows each construction site.**

31 samples of recovered asphalt from plant mixtures directed for the three sites. For the fresh asphalts, fingerprinting tests were made before and after thin-film oven testing (TFOT). In general, the tests included 54 straight-run samples and 21 PPA asphalt cement blends.

Before any conclusions can be reached about the effects of asphalt type and its chemical properties on material behavior, an examination should be made about the effect of the construction site (RH, BK, NA) and the asphalt group (*A*,*B*, and *C*). A statistical "Student-t" analysis was performed to check the significance of the differences among these various populations.

The results of the analysis showed that within the given sites there are no significant differences in asphalt properties among the various asphalt groups (*A*,*B*,*C*), and within each group there are no significant differences among the various sites (RH,BK,NA).

In general, it can be concluded that this comparative investigation is significant with respect to the comparison between the two types of asphalt (straight-run versus PPA blends), and with respect to the trends resulting from these comparisons, such as the effect of the chemical composition and behavior on aging. It is also evident that the properties of the asphalts did not change during the handling process (produc-

TABLE 1 General summary of average asphalt cement properties during construction (*A*, *B*, and *C* samples)

Asphalt condition	Type of asphalt Site	PPA blends				Straight-run			
		RH	BK	NA	General average	RH	BK	NA	General average
	No. of samples	5	3	5	Total 13	13	6	13	Total 32
Fresh Asphalt Cement (A, B, C)	Penetration (1/10mm)	65	63	61	63	66	66	68	67
	Ductility (cm)	104+	100+	100+	101+	100+	100+	100+	100+
	Softening Point (°C)	47.5	50.1	49.9	49.0	49.0	50.3	50.3	50.0
	Absolute Viscosity (Poise)	1232	1291	1369	1298	1611	1552	1588	1591
	Kinematic Viscosity (Centistokes)	289	291	305	295	321	303	316	316
Fresh Asphalt Cement (A, B, C) After TFOT	Penetration (1/10mm)	38	38	40	39	43	44	45	44
	Ductility (cm)	80	100+	100+	92+	56	51	53	54
	Softening Point (°C)	53.8	54.2	53.5	53.8	53.5	54.8	55.2	54.4
	Absolute Viscosity (Poise)	3675	3225	3375	3456	4901	4966	4572	4717
	Kinematic Viscosity (Centistokes)	426	406	424	421	450	453	443	448
	No. of Samples	3	1	5	Total 9	7	5	10	Total 22
Asphalt Recovered from Plant Mixtures (E)	Penetration (1/10mm)	38	40	43	41	41	48	43	44
	Ductility (cm)	81	100+	95+	91+	44	63	40	47
	Softening Point (°C)	61.4	50.8	52.8	55.4	55.6	55.1	55.0	55.2
	Absolute Viscosity (Poise)	6677	3098	4058	4824	9247	4570	7791	7522
	Kinematic Viscosity (Centistokes)	542	423	459	483	553	472	535	526
	Mixing Temperature (°C)	175	165	178	175	174	167	180	175

tion storage, transportation, and plant storage), and during the time gap (several months) between construction of the different testing sites.

Physical and Rheological Properties

In order to investigate the effect of asphalt chemical composition on material behavior and pavement performance, consideration should be given to the physicorheological behavior of the asphalts. The average value of the detailed data base is shown in Table 1. The correlative statistical analysis of this data base leads to the following trends in the relationship among major asphalt properties and the effect of the PPA on fresh and recovered asphalts during the construction process (see also Tables 2 and 3):

1. In most cases, almost no correlations exist among the different properties of fresh asphalts before and after TFOT. This is true for all relationship combinations of the straight-run asphalts. Only for the PPA asphalt blends were good correlations obtained between the kinematic and absolute viscosity (Table 2).
2. The low correlations among penetration and viscosity (Table 2) indicated that the standard specified range of penetration does not ensure any well-defined values or ranges of viscosity. Despite the fact that the two types of asphalt are from the same penetration grade, they differ significantly in viscosity for a wide range of testing temperatures. The differences are especially significant for the asphalts recovered from the plant mixes (Table 1).
3. In contrast to the fresh asphalts, the correlations among properties of asphalts recovered from plant mixes are much higher (Table 3). Very high correlations were obtained among the viscosities, but good correlations were also obtained among the penetration and the two viscosities. The improvement in the correlation is mainly caused by the increasing range of asphalt parameter values of the recovered asphalt, because of different behavior under plant aging.
4. As for the comparison among the two types of asphalt, it can be seen that PPA asphalt blends possess lower pene-

TABLE 2 Statistical correlations among fresh asphalt properties (all sites and groups): (a) linear relationship $Y = A + BX$ for PPA asphalt blends ($N = 14$), and (b) linear relationship $Y = A + BX$ for straight-run asphalt ($N = 31$)

Y / X	Before TFOT			After TFOT		
	Penetration	Softening Point	Absolute Viscosity at 60°C	Penetration	Softening Point	Absolute Viscosity at 60°C
Softening Point	A = 119.88 B = -1.147 R^2 = 0.18	-	-	A = 35.31 B = 0.071 R^2 = 0.00	-	-
Absolute Viscosity at 60°C	A = 74.57 B = -0.008 R^2 = 0.10	A = 41.04 B = 0.06 R^2 = 0.40	-	A = 45.77 B = -0.002 R^2 = 0.16	A = 53.00 B = 0.000 R^2 = 0.01	-
Kinematic Viscosity at 135°C	A = 107.52 B = -0.149 R^2 = 0.20	A = 30.27 B = 0.064 R^2 = 0.27	A =-1792.15 B = 10.509 R^2 = 0.69	A = 58.93 B = -0.047 R^2 = 0.26	A = 52.26 B = 0.004 R^2 = 0.01	A =-4213.99 B = 18.348 R^2 = 0.87

(a)

Y / X	Before TFOT			After TFOT		
	Penetration	Softening Point	Absolute Viscosity at 60°C	Penetration	Softening Point	Absolute Viscosity at 60°C
Softening Point	A = 59.05 B = 0.160 R^2 = 0.01	-	-	A = 41.39 B = 0.044 R^2 = 0.00	-	-
Absolute Viscosity at 60°C	A = 66.79 B = 0.000 R^2 = 0.00	A = 52.91 B = -0.002 R^2 = 0.02	-	A = 52.12 B = -0.002 R^2 = 0.21	A = 56.53 B = -0.000 R^2 = 0.04	-
Kinematic Viscosity at 135°C	A = 84.82 B = -0.056 R^2 = 0.04	A = 37.51 B = 0.039 R^2 = 0.06	A = 275.18 B = 4.104 R^2 = 0.11	A = 59.51 B = -0.035 R^2 = 0.12	A = 58.00 B = -0.007 R^2 = 0.02	A =-1672.78 B = 14.415 R^2 = 0.29

(b)

TABLE 3 Statistical correlation among recovered asphalt properties (all sites): (a) linear relationship $Y = A + VX$ to PPA asphalt blends ($N = 10$), and (b) linear relationship $T = A + BX$ for straight-run asphalt ($N = 21$)

Y X	Penetration	Softening Point	Absolute Viscosity at 60°C
Softening point	A = 67.55 B = -0.488 R^2 = 0.35	-	-
Absolute Viscosity at 60°C	A = 49.46 B = -0.0017 R^2 = 0.72	A = 44.63 B = 0.0022 R^2 = 0.71	-
Kinematic Viscosity at 135°C	A = 68.35 B = -0.057 R^2 = 0.76	A = 26.45 B = 0.059 R^2 = 0.56	A = -9635.50 B = 29.880 R^2 = 0.94

(a)

Y X	Penetration	Softening Point	Absolute Viscosity at 60°C
Softening point	A = 72.67 B = -0.526 R^2 = 0.09	-	-
Absolute Viscosity at 60°C	A = 50.38 B = -0.0008 R^2 = 0.73	A = 52.66 B = 0.0003 R^2 = 0.32	-
Kinematic Viscosity at 135°C	A = 71.92 B = -0.054 R^2 = 0.72	A = 44.24 B = 0.021 R^2 = 0.33	A = -23090.94 B = 58.323 R^2 = 0.93

(b)

tration and lower viscosity values than straight-run asphalts. This is true for the fresh asphalt before and after TFOT and also for the recovered asphalts. It should be noted that this trend is contradictory for asphalt consistency because lower penetration indicates harder asphalt, whereas lower viscosity indicates softer asphalt. Again, attention should be given to the physical meaning of the viscosity and the realistic meaning of its testing temperature for construction and service conditions, as compared with the empirical character of the penetration test and its meaningless test temperature.

5. The difference between the two types of asphalt is also reflected in their ductility. Although adequate high values of ductility were obtained for the two types of fresh unaged asphalts, the difference among the straight-runs and the PPA blend asphalts is manifested in the aging process. The PPA blends maintain their high ductility values both after TFOT and plant mixing, whereas a severe drop in the ductility, down to values of less than 20 cm, characterizes the straight-run asphalts. This result stresses the inferiority of local straight-run asphalts in flexibility and adhesion.

Comparison with Other Populations

It will be interesting to compare the results of asphalt properties obtained during the construction of the test sections with properties of asphalt cement of other different and wider populations. During the preparatory laboratory research (*6*, *8*, and *9* through *13*), a daily sampling of asphalt cements was taken at the refineries. Within two years (1987–1989), more than 650 asphalt specimens were sampled and tested for a comprehensive fingerprinting (*12*,*13*). The second population represents asphalt cement fingerprinting taken during the quality control of overlaying jobs constructed in 1991 in northern Israel. This population includes 170 samples of fresh and recovered asphalt cements.

The comparison among the populations is summarized in Figures 4–6. These figures present the comparative variability in the different populations in the relationship between the penetration and absolute viscosity at 60°C. They also reflect the characteristics of the fresh asphalts before and after TFOT and asphalts recovered from plant mixes.

In the penetration-viscosity relationship, it can be seen that the PPA asphalt blends of the current investigation generally coincide with other wide-range practical populations tested between 1987–1991. On the other hand, the straight-run asphalts represent different populations characterized by a higher level of age hardening, as reflected in the absolute viscosity tested under realistic service temperature (60°C). This trend is more significant in the population of asphalts recovered from plant mixes (Figure 6).

Long-Term Aging

The effect of temperature and time on changes in the physical and rheological properties of asphalt under accelerated conditions is commonly used to characterize the durability and aging potential of the asphalt. Long-term aging curves at different temperatures were used to differentiate among dissimilar asphalt types in the laboratory investigation (*10,13*). A typical long-term aging comparison among straight runs and different PPA blends is given in Figure 7 (*11*).

Similarly, about 50 aging curves were formed in this investigation, based on extensive accelerated long-term aging tests. The aging curves were based on penetration, two viscosities, and softening point. Typical test results for asphalt (*A*) from the BK site at two different exposure temperatures are presented in Table 4 and Figure 8.

On the basis of the comprehensive results, it was found that PPA asphalt blends are characterized by much lower viscosities in the long-term aging process as compared with straight-run asphalts. This is mainly reflected by the absolute viscosity, with up to three times difference, seen in Figure 8. This may indicate the higher aging sensitivity of the straight-run asphalt cements. It also conformed with the results obtained for the asphalts recovered from plant mixes.

Chemical Composition

Summarized in Table 5 are the average values of the asphalt chemical composition during construction at all three sites. Also presented in the table are the values of the Gaestel Index (I_c), which reflect the colloidal stability of the asphalt. Based on the detailed results and those of the table, the following trends are observed:

1. There is a significant difference in the chemical composition among the straight-run and the PPA blend asphalts. This difference lies mainly in the saturates and polar aromatic fractions. PPA asphalt blends contain less saturates (a difference of 3–4 percent) and more polar aromatics (a difference of 3–6 percent). The differences in the asphaltene and the naphthene aromatic fractions are much smaller (1–2 per-

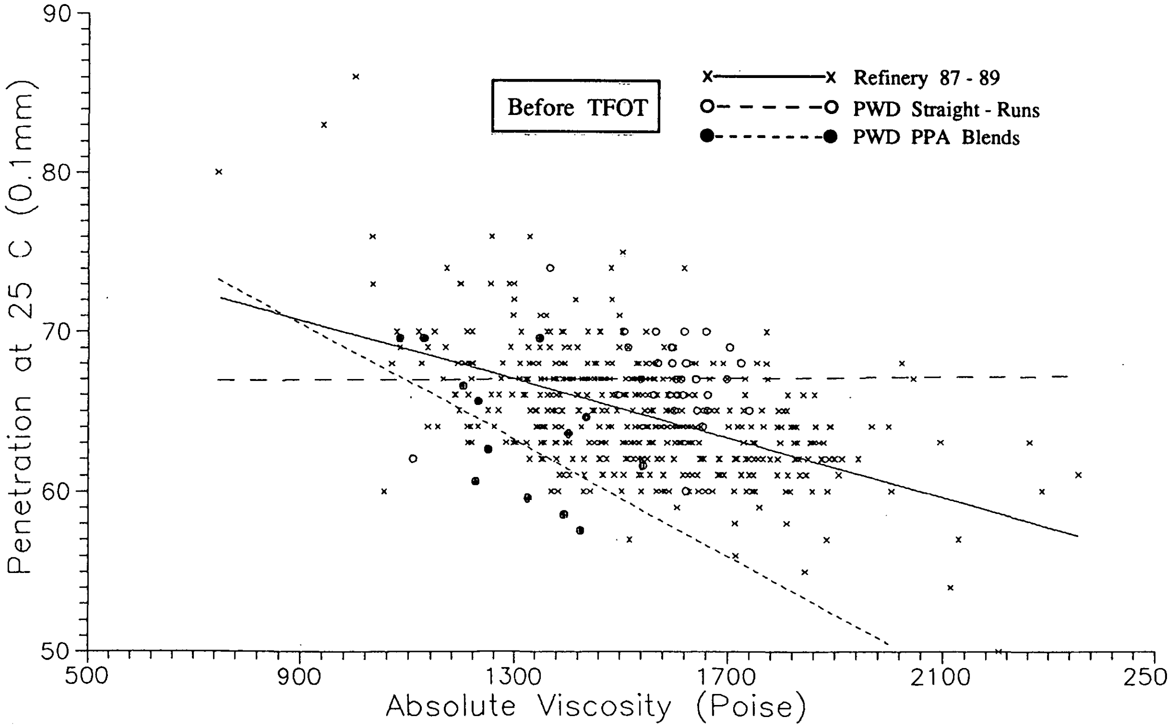

FIGURE 4 Comparison among asphalt populations by relationship between penetration and absolute viscosity (at 60°C) for fresh asphalts.

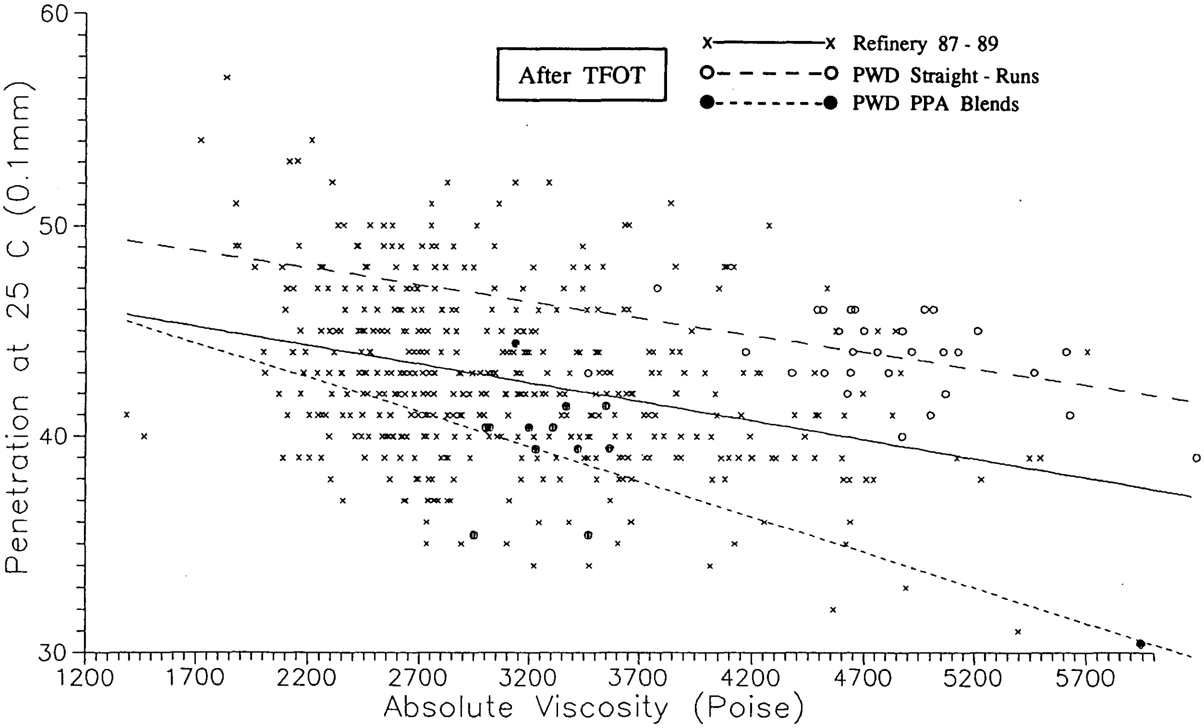

FIGURE 5 Comparison among asphalt populations by the relationship between penetration and absolute viscosity (at 60°C) for fresh asphalts after TFOT.

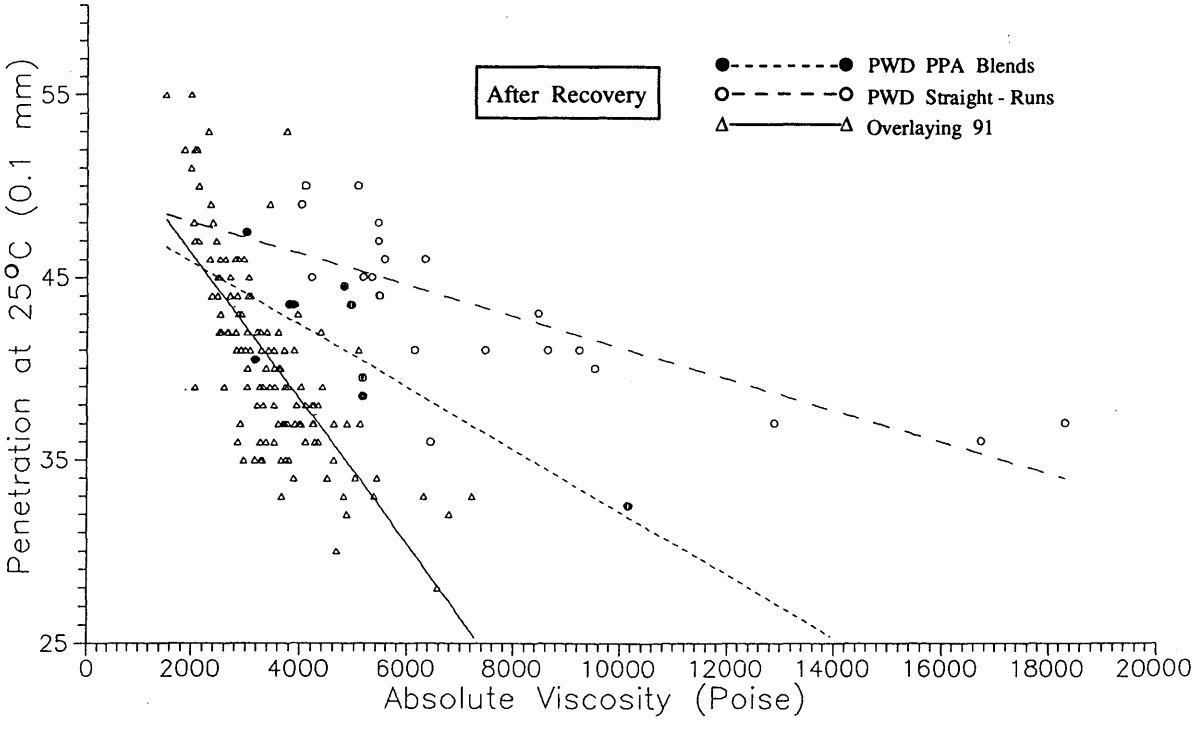

FIGURE 6 Comparison among asphalt populations by the relationship between penetration and absolute viscosity (at 60°C) for recovered asphalts.

NOTATION	SAMPLE	PPA/VTB/EXT	TYPE OF EXT OR VTR
□——□	C	43/57/0	240 Pen
○------○	E	83/0/17	BRIGHT STOCK EXTRACT
×—·—×	F	85/0/15	SAE-30 EXTRACT
●— —●	CONTROL	0/100/0	60-70 STRAIGHT RUN A.C.

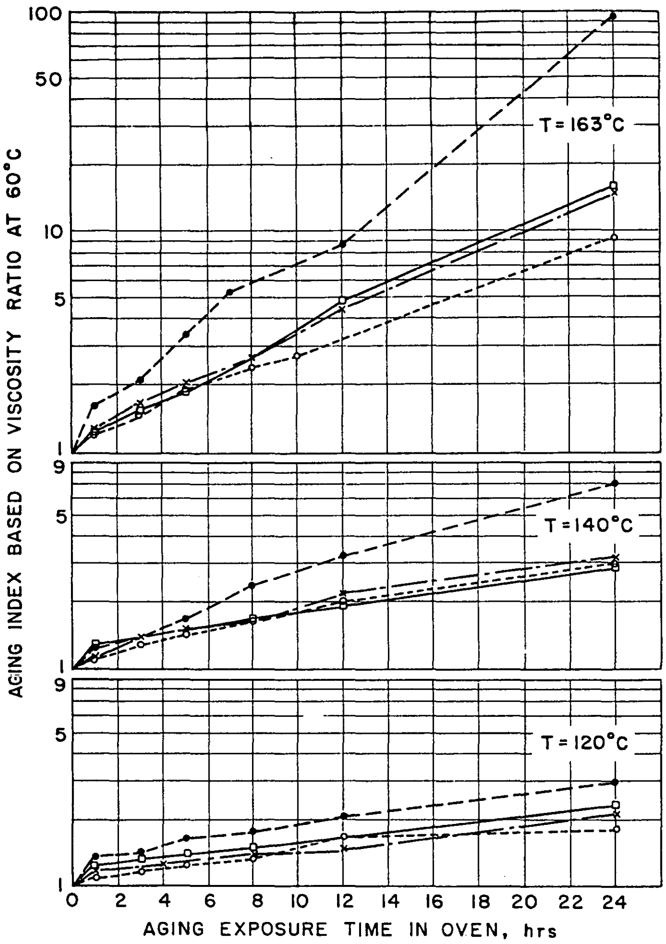

FIGURE 7 Typical long-term aging curves, based on absolute viscosity, for comparison among straight-run asphalts and different PPA asphalt blends (*11*).

cent), where the amount of asphaltenes in the PPA asphalts is less than in the straight runs. Accordingly, the value of the Colloidal Stability Index (I_c) in PPA asphalt blends is smaller.

2. During the aging and hardening process, the following colloidal changes occur: In PPA asphalt blends, the polar aromatic fraction content is decreasing while transforming into asphaltenes with an increase in the latter's fraction content. This transformation is accompanied by minor changes in the content of the saturates and naphthene aromatic fractions only. In straight-run asphalts, the increase of the asphaltenes fraction is probably caused by the transformation of both aromatic fractions, whereas the saturates fraction remains unchanged (as in the PPA blends), and does not contribute to the aging and hardening process. A similar trend in chemical composition changes in the aging process is illustrated in Figure 1.

3. Because the colloidal changes in PPA asphalt blends occur mainly in the dissolvent phase (polar aromatics → asphaltenes), and very seldom in the solvent phase, they are accompanied by smaller changes in the viscosity compared with straight asphalt, in which the colloidal changes are also caused by the transformation of solvent fractions into dissolvent ones (naphthene aromatics → asphaltenes). This leads to more significant increases in viscosity during the aging process.

4. An expression of the difference between the two types of asphalt with respect to their chemical composition-viscosity relationship, is presented in Figure 9 (based on Tables 1 and 5). This figure reflects again, in the given range, the significant relationship between asphalt aging and its chemical composition. It should be noted that asphalt aging is based on the realistic and physical viscosity parameter, which is measured at realistic service temperature. The figure stresses again the contrasts between the two types of asphalt and relates them to the chemical compositions. These differences are expressed either by the difference in the Colloidal Stability Index (I_c) or by the higher sensitivity of the straight-run asphalt to aging and hardening in the weathering process; and

5. No significant relation whatever was found among the chemical composition of the asphalt and its changes and among the penetration values, either in the difference among the asphalts or the aging process.

Asphalt Cement Properties During Early Service Time

As mentioned previously, the changes in the asphalt cement from actual test-section wearing causes were monitored after construction. At this stage, cores were taken from the asphaltic surfaces 3 and 9 months after their construction (samples *G*3 and *G*9, respectively). Physical and rheological fingerprinting and also chemical composition analyses were performed on asphalt cements recovered from the pavement cores.

A summary of the physical, rheological and chemical composition changes that occurred in the asphalt cements during the early service time are presented in Tables 6 and 7. These results indicate the following trends:

The Aging Process

As can be observed from Table 7, and also expressed in Figure 10, the aging process of the asphalts continued even during the early service time immediately after construction. The process was reflected in all physico-rheological parameters tested. The evolution of these parameters during the beginning of service life (3 and 9 months) is described in Figure 10, and compared with the properties of the fresh asphalts and asphalt recovered from fresh plant mixes (0 months).

It can be seen that both asphalts age substantially during the short service time. This aging is more pronounced when

TABLE 4 **Typical table summarizing results of long-term aging tests (PPA asphalt blend, Beit Kama site)**

TFOT Exposure Temperature 163°C

Time (hrs.)	0	1	3	5	8	12	18	24
Penetration (25°C), 1/10mm)	68	59	52	45	40	35	28	25
Absolute Visc., (Poise)	1,623	2,340	3,395	4,698	8,870	20,470	50,980	203,350
Kinematic Visc., (cSt)	321	369	383	446	558	708	1053	1792
Softening Point, (°C)	50.1	52.0	54.1	54.0	56.2	60.5	64.3	69.6

TFOT Exposure Temperatue 140°C

Time (hrs.)	0	1	3	5	8	12	18	24
Penetration (25°C), 1/10mm)	68	62	61	54	44	42	40	38
Absolute Visc., (Poise)	1,623	2,090	2,479	2,874	4,294	5,780	9,416	15,680
Kinematic Visc., (cSt)	321	355	368	388	437	481	547	662
Softening Point, (°C)	50.1	51.2	51.8	53.1	53.0	57.1	57.1	57.9

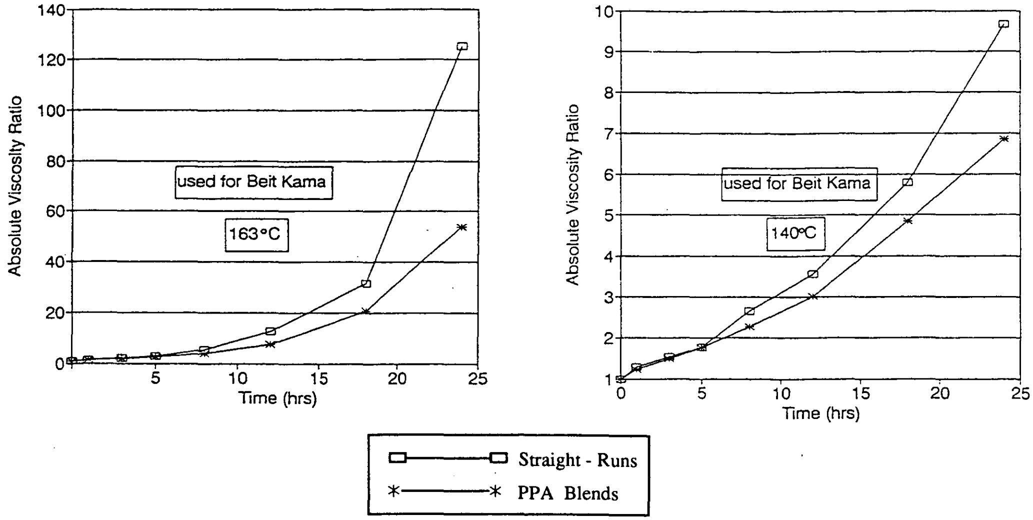

FIGURE 8 Typical aging curves based on absolute viscosity that reflects the difference between the two types of asphalt for long-term durability (Asphalt *A* from Beit Kama site).

TABLE 5 General summary of average values of asphalt cement chemical composition during construction

Asphalt Condition	Site	Straight-run					PPA Blends				
		AS	SA	NA	PA	I_C	AS	SA	NA	PA	I_C
Fresh Asphalt Cement (A)	RH	22.10	17.18	18.84	41.65	0.65	23.37	19.86	20.56	35.74	0.77
	BK	21.52	16.53	19.09	42.50	0.62	22.58	19.85	20.47	36.33	0.75
	NA	20.76	16.36	19.06	42.53	0.60	21.96	18.65	20.30	38.07	0.75
	Average	21.46	16.69	19.00	42.23	0.62	22.64	19.45	20.44	36.71	0.76
Fresh Asphalt Cement (A) After TFOT	RH	23.36	14.80	18.31	42.83	0.63	24.17	19.04	20.60	35.39	0.77
	BK	23.83	15.45	19.98	39.99	0.65	24.12	19.66	20.49	34.63	0.81
	NA	23.21	16.83	18.42	41.48	0.66	24.20	17.60	19.25	36.73	0.75
	Average	23.47	15.59	18.90	41.43	0.65	24.16	18.77	20.11	35.55	0.78
Asphalt Recovered from Plant Mixes (E)	RH	27.75	15.34	18.04	37.09	0.78	27.45	17.45	17.76	34.91	0.84
	BK	25.16	14.63	20.77	38.76	0.67	24.89	20.01	18.22	35.31	0.84
	NA	24.77	16.35	18.04	38.69	0.72	37.00	19.47	18.51	34.52	0.88
	Average	25.89	15.44	18.95	38.18	0.72	26.45	18.97	18.16	34.91	0.85

NA - Naphthene Aromatics
PA - Polar Aromatics
AS - Asphaltenes
SA - Saturates

$$I_C = \text{Gaestel Index} = \frac{AS + SA}{NA + PA}$$

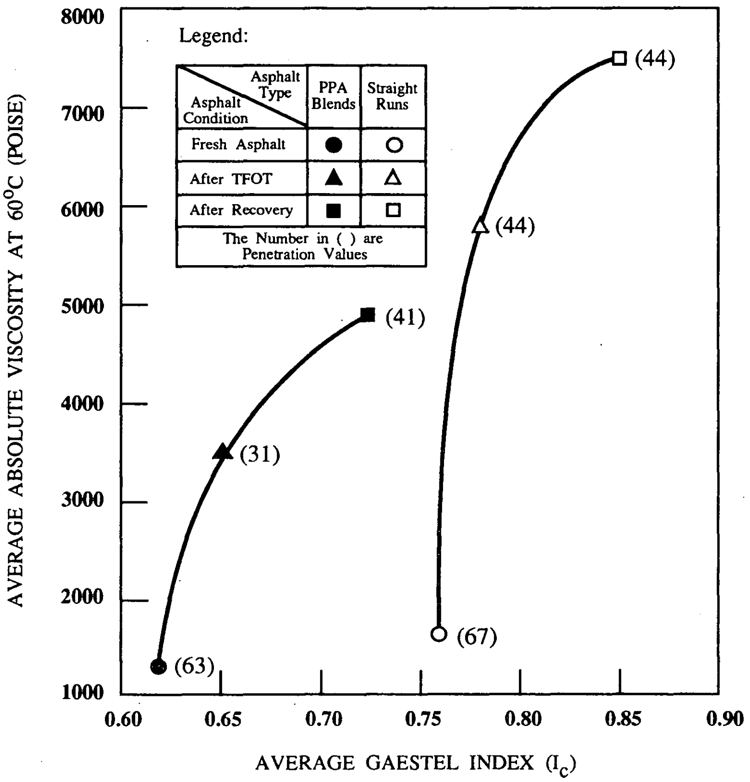

FIGURE 9 **Difference between two types of asphalt as expressed by viscosity-chemical composition relationship (fresh and recovered asphalts during construction).**

expressed by the absolute viscosity and ductility, rather than by the penetration, softening-point or kinematic viscosity. The absolute viscosity increases up to 4.0–5.5 times its value after mixing, and the ductility decreases down to 5.8 times. Because the absolute viscosity is measured at critical service temperature (typical to the Israel Negev where the test sections are located), its aging trend seems to be most realistic to the hardening expected to occur during the longer service time. As related to flexibility and adhesion, the ductility could also be an important indicator of the expected pavement distress after long-term exposure to the specific semiarid climate.

The difference between the two types of asphalt still follows the same trends when the fresh asphalt and that recovered after mixing are compared. Here again, the rate of aging was much higher for the straight-run asphalts than for the PPA blends. This is reflected in all the aging parameters, as shown in Figure 10. On the basis of absolute viscosity, the straight-run asphalt aged about 25 times from the fresh state up to 9-month field service, whereas the PPA blends aged only 15 times. Also, on the basis of ductility, a drop of about 12 times from the fresh asphalt state up to 9 months' service was found for the straight runs, whereas the drop was only 6 times for the PPA blend. It should be noted that the ductility level of the straight-run asphalts reached a critical level of values less than 10 cm.

It would be interesting to compare the aging level in the standard TFOT exposure with the aging occurring under real mixing and service conditions. As shown in Table 1 and Figure 10, the hardening occurring in the standard TFOT is even less than that under routine plant mixing. In this sense, if the methodology suggested by Ishai (*10*) is used, together with the values of the aging curves in Figure 8 and similar ones, it can be seen that the aging level after 9 months' service is equivalent, on the average, to 16 hours of exposure in the TFOT (under 163°C). In this way, the laboratory aging curves can be calibrated to reflect and predict the aging under real service conditions.

Aspects of Chemical Composition

As shown in Table 8, and also expressed in Figure 11, the aging occurring during the early service time was also reflected by the changes in chemical composition. As distinct from the aging during the mixing process, in which the asphalt hardening was reflected mainly by the increase of asphaltene fraction with the saturates being constant, during the aging under service conditions, both the asphaltene and saturate fractions increased, whereas the polar aromatic fraction remained fairly constant.

Despite this difference in the relative changes in the chemical composition fractions, the Colloidal Stability Index (I_c) continued to increase with the physical hardening (as expressed in Figure 10 by its relation to service time). A long-term relationship between I_c and absolute viscosity, similar to the short-term one expressed in Figure 9, is presented in

TABLE 6 General summary of asphalt cement property changes during early service time (*G*3 and *G*9 samples)

ASPHALT CONDITION	TYPE OF ASPHALT	STRAIGHT-RUN				PPA BLENDS			
	SITE	RH	BK	NA	General	RH	BK	NA	General
	No. of Samples	7	5	7	Total 19	3	1*	4	Total 7
Asphalt recovered from road cores after 3 months (G3)	Penetration (1/10mm)	30	33	32	32	26	-	24	25
	Ductility (cm)	11	15	12	12	27	-	26	26
	Softening Point (°C)	59	57.6	58.5	58.4	57.5	-	59.0	58.4
	Absolute Viscosity (Poise)	21,117	14,348	15,517	17,272	11,737	-	10,488	11,023
	Kinematic Viscosity (Centistokes)	772	670	717	725	664	-	618	638
Asphalt recovered	No. of Samples	7	5	5	Total 17	3	1*	4	Total 7
Asphalt recovered from road cores after 9 months (G9)	Penetration (1/10mm)	26	25	28	26	24	-	24	24
	Ductility (cm)	8	7	8	8	14	-	18	16
	Softening Point (°C)	61.8	61.7	63.2	62.2	58.0	-	60.5	59.4
	Absolute Viscosity (Poise)	42,130	43,859	35,706	40,749	17,425	-	21,948	20,010
	Kinematic Viscosity (Centistokes)	944	998	911	950	729	-	774	755

* Tests on a single sample were omitted due to insufficient statistical verification

TABLE 7 General summary of average values of asphalt cement chemical composition changes during early service time (*G*3 and *G*9 samples)

ASPHALT CONDITION	TYPE OF ASPHALT	STRAIGHT-RUN					PPA BLENDS				
	FRACTION SITE	AS	SA	NA	PA	I_C	AS	SA	NA	PA	I_C
Asphalt recovered from road cores after 3 months (G3)	RH	29.46	16.09	16.27	36.41	0.86	27.00	17.16	21.05	34.63	0.79
	BK	27.36	20.39	15.34	36.67	0.92	–	–	–	–	–
	NA	27.83	19.49	16.88	35.48	0.90	28.74	16.44	17.04	37.38	0.83
	Average	28.22	18.66	16.16	36.19	0.89	27.87	16.80	19.04	36.01	0.81
Asphalt recovered from road cores after 9 months (G9)	RH	30.27	20.89	14.44	33.29	1.07	28.59	19.05	13.81	38.26	0.91
	BK	28.61	21.50	14.64	35.13	1.01	-	–	–	–	-
	NA	30.02	19.21	16.02	34.72	0.97	28.77	16.44	15.33	38.72	0.84
	Average	29.63	20.53	15.05	34.38	1.02	28.68	17.74	14.57	38.49	0.87

NA - Naphthene Aromatics
PA - Polar Aromatics
AS - Asphaltenes
SA - Saturates

$$I_C = \text{Gaestel Index} = \frac{AS + SA}{NA + PA}$$

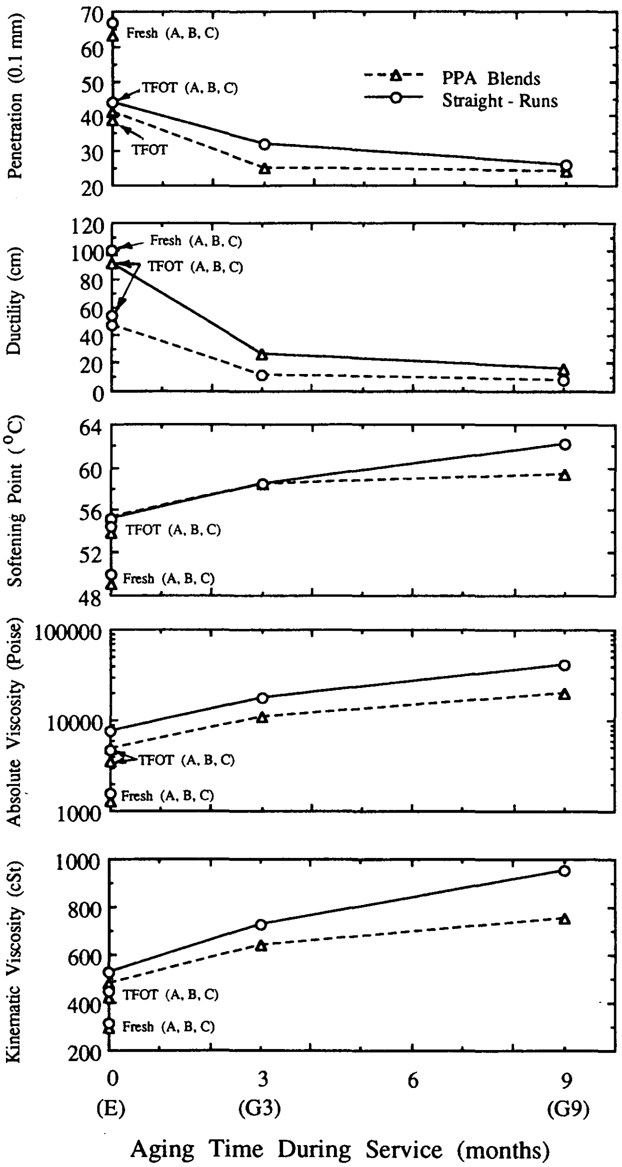

FIGURE 10 Evolution of physico-rheological asphalt parameters during early service aging.

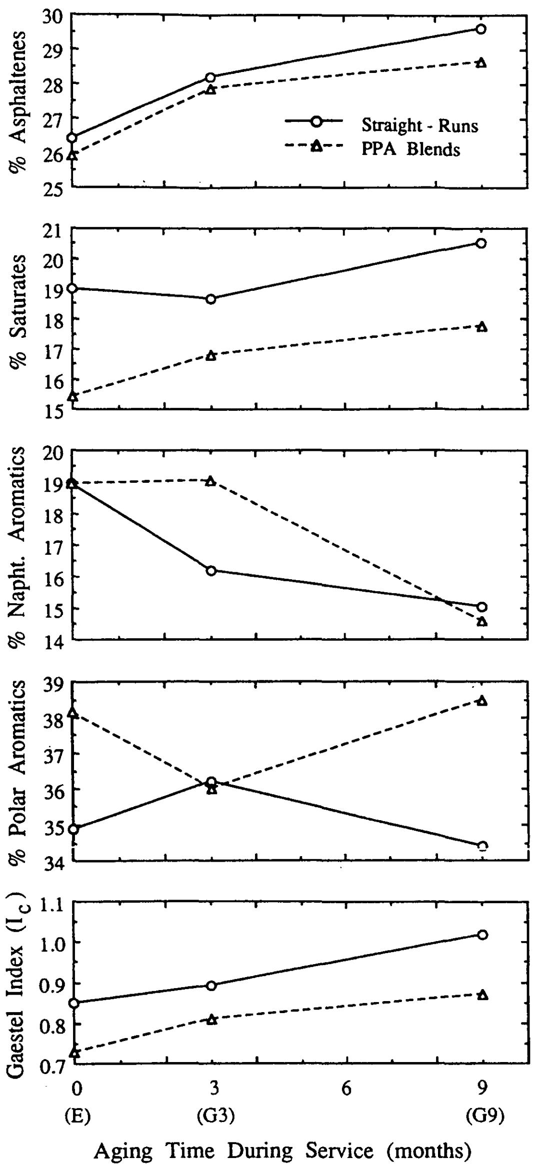

FIGURE 11 Chemical composition changes during early service time.

Figure 12. As is also seen in Figure 2, the Colloidal Stability Index adequately reflected and correlated with long-term age hardening.

This quantitative relationship among physical hardening and changes in the chemical composition also reflected the difference between the two types of asphalt with respect to their sensitivity to aging and the relative advantage of the PPA asphalt blends.

SUMMARY

Presented in this paper are some aspects of the effect of asphalt chemical composition on the properties and behavior of some fresh asphalt binders, as well as of plant-aged and field-aged samples, and the manner in which long-term aging may be affected by changes in material composition. The asphalt binders involved were of the straight-run and PPA blend types, all of the 60/70 penetration grade.

At this stage, data accumulated reflect construction conditions and the beginning of the service life of the test sections. No pavement distress has been reported so far that would warrant linkage to the type and characteristics of the asphalt binder used. However, definite relationships were found among the chemical composition of the asphalt and its physicorheological changes during short- and long-term aging. These relationships were also significant enough to distinguish among the behavior of straight-run asphalts and PPA asphalt blends.

As more data become available with time, it is hoped that a more definite relationship can be established between the physicochemical properties of the asphalt and their effect on material behavior and longer-term pavement performance.

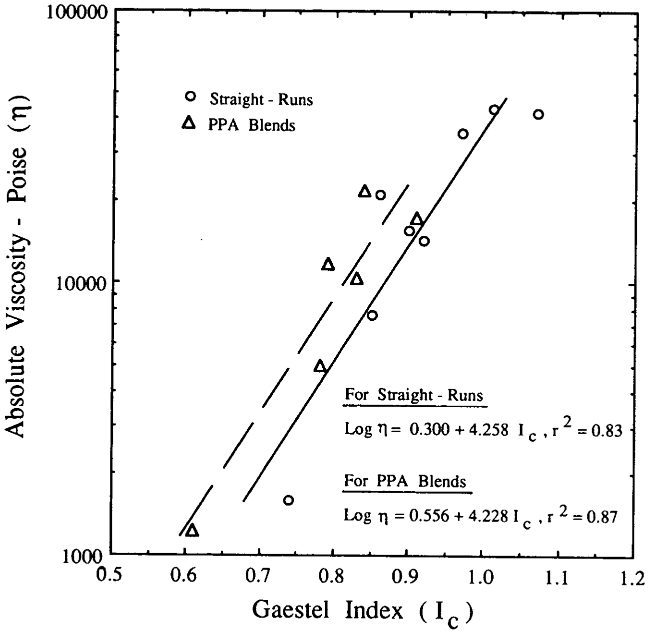

FIGURE 12 Long-term relationship between Colloidal Stability Index and asphalt viscosity during aging in mixing and in early service.

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