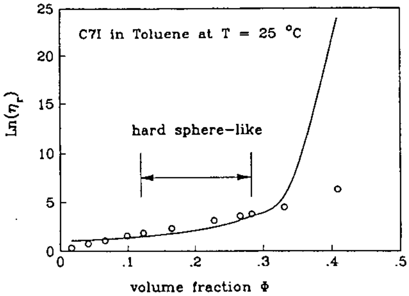

Fig. 2c. Comparison of asphaltene solution with hard sphere model.

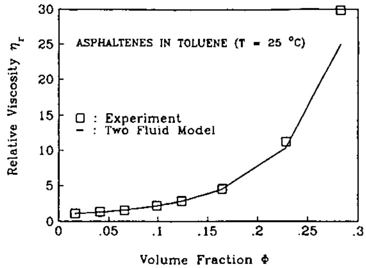

Fig. 2d. Interaction model for asphaltene solution.

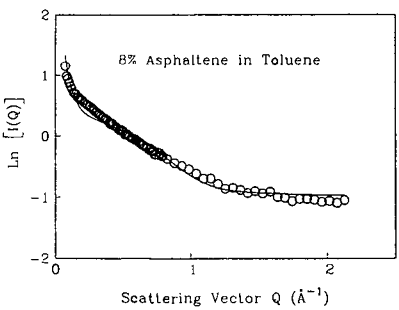

Fig. 3a. SANS dat and the analysis.

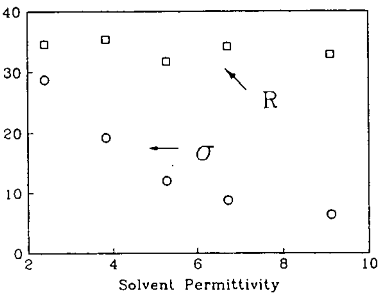

Fig. 3b. Radius and the interragne parameter, as a function of ϵ.

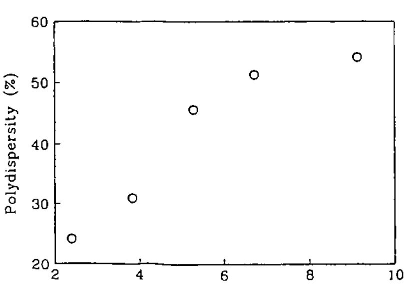

Fig. 3c. Polydispersity as a function of solvent permittivity.

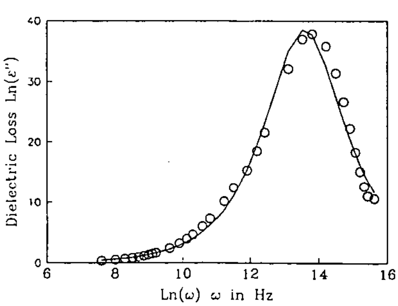

Fig. 4. Dielectric loss for asphaltene solution and the Cole-Cole analysis.

Improved Asphalt Specification
Based on Physicochemical Properties

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INTRODUCTION

Current specifications for asphalt cement contain limits on physical properties based on correlations established in the past with field performance of asphalt pavements. Recently, however, concerns have arisen that although current asphalts in use meet these specifications, they are not consistently providing the service life once achieved.

There are a number of logically possible explanations of this situation:

[1] A considerable concern is associated with the recent world crude oil supply and the economic climate after the 1973 oil embargo which may have affected the properties of asphalt of certain origin (1). Blending several crudes, as routinely practiced in refineries to produce asphalts meeting current specifications, may have upset certain delicate balances of compatibility among various asphaltic constituents, which may manifest itself in their long-term field performance but not in original physical properties specified in the specifications (2,3).

[2] The increased volume and loads of traffic on highways.

[3] Inadequate mixture design, poor gradation of aggregates, changing construction practices, and improper use of additives (1,4).

[4] Specifications based only on physical properties of asphalts do not guarantee adequate performance.

While the performance of the asphalt pavements could be improved by judicious application of improved mix design techniques, more rational thickness design procedures, better construction methods and quality control measures, selection of asphalts based on performance-related properties, tests, and specifications is the key to durable asphalt pavements.

Asphalt samples were analyzed by high performance liquid chromatography (HPLC), thermomechanical analysis (TMA), differential scanning calorimetry (DSC), X-ray diffraction (XRD), and nuclear magnetic resonance (NMR). The results were correlated with properties known to affect field performance. On the basis of the correlations, performance-based trial specifications for the state of Iowa were developed.

EXPERIMENTAL

Materials

Three sets of asphalt samples were used in this study as follows:

1. A total of 12 virgin asphalts obtained from two local suppliers and their thin film oven test (TFOT) residues (ASTM D1754),
2. Two sets of asphalt samples recovered from two pavements of known performance (total 6 recovered asphalts from Sugar Creek and Wood River), and
3. Asphalt samples used in 10 hot mix field pavement projects in Iowa and their field and lab aged samples.

Aging of asphalts

Age hardening characteristics of the project asphalt samples were studied in the laboratory by use of three different aging procedures; TFOT, Iowa durability test (IDT), and mix aging. TFOT simulates age hardening due to the conventional batch mixing (5). The IDT or pressure-oxidation procedure consists of two aging stages: TFOT to simulate hardening during hot-plant mixing followed by pressure-oxidation under 20 atm of oxygen at 65 °C for oxidative hardening during field pavement service (6). In this study, two different durations of pressure-oxidation, 5 and 46 hour, were used. These are, based on the previous study, equivalent to 1 and 5 year field aging under Iowa climate, respectively (6).

The hardening of asphalt in a mix is believed to be affected by air void content, asphalt film thickness, characteristics of aggregate, and the durability of the asphalt. Marshall specimens were prepared by use of the same materials and job mix formula used at each project. To simulate asphalt aging in pavement of high and low void levels, mixes were compacted by 35 blows per side and 75 blows per side, respectively, and oven-aged at 60 °C for 12 days, equivalent to eight years of in-service asphalt aging in pavement (7). The asphalts were extracted and recovered.

Rheological properties

Penetrations at 5 °C and 25 °C (100g, 5sec), penetration at 4 °C (200g, 60sec), viscosities at 25, 60, and 135 °C, and ring-and-ball softening point tests were performed on the original asphalts, the lab aged asphalts, and asphalts recovered from plant mix and cores (0 and 1 year old). From these data, penetration ratio (PR), penetration index (PI), pen-vis number (PVN), viscosity temperature susceptibility (VTS), cracking temperature (CT), critical stiffness at -23 °C and 10,000 sec loading time (S23), stiffness at -29 °C and 20,000 loading time (S29), and critical stiffness temperature at 20,000 psi and 10,000 sec (TES) were calculated. Based on viscosity data at 25 °C, shear index (SI) and complex flow (CF) were also determined.

To correlate with low temperature field performance, the dependence of viscoelastic properties of selected five asphalt samples on their thermal history was studied at a low temperature. Newtonian viscosities and elastic shear moduli of these samples were determined using modified cone and plate viscometer at 5 °C after cooling from 25 °C and warming from a quenching temperature of -30 °C. Before cooling or warming, samples were allowed to be conditioned for 24 hours or 1 hour at the specified temperature (25 °C or -30 °C). Instrumentation, procedure, and the theory were described elsewhere (8).

High performance gel permeation chromatography (HP-GPC)

Waters' HP-GPC system was used during this study. It included three "Ultrastyragel" columns, one 1000Å followed by two 500Å units and a UV absorbance detector (Waters model 481) set at 340nm. Asphalt samples of 0.02 to 0.05 grams were dissolved in HPLC grade tetrahydrofuran (THF) to be 0.5% (w/v) solution. Before injection, sample was centrifuged to remove foreign particles capable of plugging columns. The delay time between sample dissolution and injection was kept constant from sample to sample (approximately 30 minutes). Sample size was 100μl and THF was used as a solvent with 0.9 ml/min flow rate at 27°C.

Thermal analysis

Differential scanning calorimetry (DSC) analysis was performed on the first two sets of asphalts, scanning from -80°C to 80°C at a rate of 5°C/min. Precooling rate was 10°C/min. Thermomechanical analysis (TMA) was performed on the second and the third sets of asphalts. Samples were prepared having 3mm thickness. By using an expansion probe, samples were scanned from -70°C to 25°C at a rate of 5°C/min.

Nuclear magnetic resonance (NMR) and X-ray diffraction

Four samples from the first two asphalt sets were subjected to ^{13}C and ^{1}H NMR analysis, using a home-built solid state NMR spectrometer operating at 100MHz for ^{1}H and 25MHz for ^{13}C. This unit has extensively been used for studies of pyrolyzed pitches and coals. Solution ^{13}C NMR was also employed for two recovered asphalts, two original asphalts and their n-pentane asphaltenes (Bruker WM-200, 50MHz).

The first set of asphalts, 12 original asphalt and their TFOT residues were subjected to X-ray diffraction analysis by θ-2θ scanning, using monochromatized CuK_α beam with 1.54Å wavelength. The samples were molded in circular Plexiglas holders exactly flush with their brim.

RESULTS AND DISCUSSION

Rheological properties

The rheological properties of all asphalts studied were reported elsewhere (8,9,10). Among the rheological properties, temperature susceptibility may be the most important property determining pavement performance. Asphalt cements of high temperature susceptibility may contribute to rutting at high pavement temperatures and cracking at low pavement temperatures. The results of this study indicates that within each viscosity grade of asphalt cements available in Iowa meeting the current specifications, there were differences in temperature susceptibility between suppliers and between samples from the same supplier over time.

The viscoelastic properties of five asphalt samples measured at 5°C show the large differences among the responses of these sample to temperature conditioning and the lapse of time. Figures 1 and 2 show viscosities and elastic shear moduli of two recovered asphalts, Sugar Creek asphalt (SC) and Wood River asphalt (WR). Both were recovered from the surface courses after 80 months of field services. The viscoelastic properties of SC asphalt show large dependence on thermal history. Performance evaluation of these asphalts indicated that SC asphalt developed more cracks in much shorter time than WR asphalt (Mark and Huisman, 1985).

HP-GPC

Figure 3 shows typical HP-GPC chromatograms of original, TFOT residue, and asphalt pressure-oxidized for 46 hours (IDT). The amount of large size molecules is unidirectionally sensitive to aging, i.e., as the asphalt ages the amount of large molecules increases. Therefore, the HP-GPC technique can be used to monitor and predict aging.

To better characterize the molecular size distribution of the asphalts and to be used in statistical analysis, the HP-GPC profile were divided into three, four and eight slices following Montana State (11), Iowa State (8), and Purdue (12) procedures respectively. The elution cut-off times used in the three slice method were 22.5 and 30.5 minutes. The four slice method is a modification of the three slice method, in which the first fraction (earliest-eluted fraction) is further divided into two using a cut-off elution time of 18.125 minutes. The first and the second eluted fractions is denoted as LMS (large molecular size) and MMS1 (medium molecular size 1), respectively. In the 8-slice method, the cut-off times used were 19.875, 21.875, 23.875, 25.375, 26.875, 28.875, and 30.875 minutes and the eight slices were denoted as X1 ··· X8.

Results of regression analysis between the physical properties and HP-GPC parameter defined as above are listed in Table 1. The first two columns show one-parameter correlations using the first fractions in the 3-slice and 4-slice methods. LMS fraction which ranges from 1% to 11% has weak correlations with physical properties. LMS+MMS1 fraction ranges from 20% to 43% and shows significant correlations with all the rheological properties, some temperature susceptibility parameters and low temperature cracking properties. Molecular size distribution is best characterized by the 8-slice method thus correlating well with almost all physical properties. Among the 8 slices, the second slice (X2) and the seventh slice (X7) most predominantly control the rheological and low-temperature properties as indicated by results from stepwise regressions (the last column in Table 1 and Table 3).

Effects of aging on physical properties and on physicochemical properties are not the same. For example, the asphalt used in one of the ten projects had a large percent increase in LMS due to aging, but not reflected by changes in viscosity ratio. This implies that the chemical composition of the asphalt results in excess amount of oxidation products determined by molecular size but the increase of viscosity is also prevented by its chemical composition. The opposite was also observed. The asphalt used in another project showed high increase in viscosity after TFOT, but not reflected in LMS increase, suggesting the opposite chemical composition.

Thermal analysis

It has long been attempted to correlate some low temperature transitions in asphalts, which are believed to affect their low-temperature rheology, such as glass transition and phase transformations to their field performance. A typical DSC thermogram obtained in this study is shown in Figure 4. The low temperature inflection points on the thermograms interpreted as glass transition points (13,14), Tg, were determined. The rest of the thermograms consist of two shallow endothermic peaks. The two peak temperatures were determined. These regions were analyzed to determine the enthalpies of transformation. These endothermic transformations are referred to as melting of the crystallized asphaltic components (13) or dissolution of these components in the matrix (14). The DSC data shows no significant correlation with physical properties determined in this study. However, the enthalpies of transformation for asphalts from one supplier are significantly different from asphalts from the other supplier (the enthalpy values are on the average 24% higher).

The effect of aging on the DSC parameters appears to be in random directions. This might be due to overshadowing the gel to sol transition in thermal analysis by the large thermal effect of dissolution of the crystallized components as treated by Albert et al. (14).

Four parameters were determined from the TMA thermograms as shown in Figure 5:

1. The slope of the initial straight line (ML) which measures the low temperature thermal coefficient of expansion of the sample at the glassy state.
2. The slope of the nearly straight adjacent section of the plot at higher temperature (MH), which measures the coefficient of expansion after the glass transition.
3. The glass transition temperature (Tg) graphically determined as shown in the Figure 5.
4. The softening temperature (Tsp) at which the displacement of the TMA probe reaches a maximum.

The glass transition temperature, Tg, of the original asphalts ranges from -34 °C to -22.5 °C, increasing with viscosity from AC-5 to AC-20. In general, aging at high temperature (TFOT or hot mixing) reduced the TMA parameter values and the following low temperature aging (pressure-oxidation or field aging) increased the thermal responses. In other words, a different aging mechanism seemed to result in different trend of thermal responses.

Correlations between the TMA parameters and physical properties are listed in Table 2. Tg correlates well with low temperature properties, while Tsp and ML correlates well with both rheological and low-temperature properties. Among the temperature susceptibility parameters only penetration ratio (PR) and pen-vis number at 60 °C (PVN60) significantly correlate with Tsp and ML.

Nuclear magnetic resonance (NMR)

Based on the limited experiments, the following conclusions are drawn:

1. Oven treatment (TFOT) decreases the amount of aliphatic quaternary carbon in the original asphalt.
2. The quaternary carbon content of the Sugar Creek (SC) sample is strikingly less than those of all other samples subjected to NMR.

X-ray diffraction

As associative interaction between asphaltenes or polar molecules promote a structural order in the system, such an interaction is also expected to reflect on X-ray diffraction spectra of the sample.

According to Williford (15), the height of the shoulder of the spectral curve at low angles is a measure of the quality of the asphalt. This height above the background (at 2θ = 4.83 °) for the original asphalts and their TFOT residues were determined. No regular trend was found in these X-ray spectra regarding the viscosity grade, the sample source, and the effect of aging.

Correlation

In this section, the discussion will be confined to correlations among physical properties, TMA, and HP-GPC parameters of all samples related to the 10 field projects.

TMA parameters and HP-GPC parameters had less significant correlation with each other than their correlations with physical properties. For this reason, it was decided to treat these two sets of parameters as independent but complementary variables to correlate with the physical properties. Table 3 gives a summary of regression analyses performed as such on physical properties against TMA and HP-GPC parameters combined. These regression analyses give considerably higher values of coefficients of determination (r^2) than the regression analyses using TMA or HP-GPC parameters alone. Figures 6 and 7 compare the measured viscosities at 25°C and 135°C with the predicted values from regression analyses.

PROPOSED TRIAL ASPHALT SPECIFICATIONS FOR IOWA

The selection of the proper grade of asphalt for a given paving project must be based on consideration of climate (temperature), traffic, thickness of the layer, and the prevailing construction conditions. The selection of asphalt within a grade must be based on temperature susceptibility and durability. The temperature susceptibility of asphalt influences the mixing, placing and compaction of paving mixture as well as the high and low temperature performance of the pavement. Durability of asphalt or asphalt's resistance to hardening and aging, during construction and in-service, affect the pavement life. Current specifications, while containing requirements for indirect control of temperature susceptibility and asphalt hardening during hot-plant mixing (short-term durability), have no control over long-term durability.

A trial specification based on Iowa pressure oxidation test is proposed. The Iowa pressure oxidation test is a realistic durability test for asphalt developed by consideration of the two stages of hardening processes of asphalt in their logical order and of their differences in mechanisms and effects. Furthermore, good correlations between field hardening and IDT exist (6). Results of this and more recent other studies confirm that chemical or compositional factors have a major impact on the performance of asphalt. While specification based solely on chemical composition would be costly and difficult to implement, a rational specification based on both short-term and long-term accelerated aging tests, containing time-honored physical tests and temperature susceptibility control, coupled with minimum chemical and low-temperature requirements is both desirable and feasible. HP-GPC and TMA parameters are determined to be included in the proposed specification.

Many researchers have proposed physical properties of asphalts and their critical limits for acceptable pavement performance. Some of these properties are penetration at 4°C and 25°C, Ring-and-Ball softening point, viscosity at 25°C, shear index, pen-vis number, and stiffness at a low temperature as summarized in Table 4.

Due to insufficient field performance data correlated with HP-GPC ant TMA parameters, critical values of HP-GPC an TMA parameters were indirectly estimated from correlation with the performance related properties as given in Table 4. Aging characteristics of asphalts are commonly expressed by a hyperbolic functions of time and changes of asphalt properties after 5 years of aging become very small. For this reason, the critical values discussed above are recommended as limiting values in specification for an asphalt pressure oxidized for 46 hours at 65°C and 20 atm oxygen.

Limiting values for penetration at 5°C were determined to meet the cracking temperature criteria to prevent a low-temperature asphalt transverse cracking. Long-term aging index, ratio of viscosity at 60°C after pressure oxidized for 46 hours to viscosity at 60°C after TFOT was introduced to assure long term durability. Based on observation of IDT data, a tentative critical long-term aging index was proposed.

The proposed specification, based on the pressure oxidation test and existing AASHTO M226, Table 2, is given in Table 5. Some of the limiting values can be refined as more field performance data become available.

CONCLUSIONS

Conclusions of a general natures are summarized as follows:

1. The strikingly different effect of thermal history on the viscoelastic properties at 5°C of the Sugar Creek core sample might have an important bearing on its poor field performance.
2. HP-GPC parameters are conclusively and unidirectionally sensitive to aging and can be used to predict behavior and performance of asphalts.
3. Both TMA and HP-GPC parameters correlates well with physical properties.
4. For some asphalts, aging characteristics during high temperature (short-term) and service temperature (long-term) were very different. Physical reponses to aging could be very different from physicochemical responses.
5. Improved asphalt specification should include evaluation methods for short-tenn and long-term aging characteristics in terms of both physical and physicochemical methods.

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Table 1. Regression Analyses between Physical Properties and HP-GPC Parameters (n=73)

Dependent Variables	LMS P-value	LMS R**2	LMS+MMS1 P-value	LMS+MMS1 R**2	3-SLICE P-value	3-SLICE R**2	4-SLICE P-value	4-SLICE R**2	8-SLICE P-value	8-SLICE R**2	Selected variables from stepwise reg
Rheological properties											
P5	0.0004	0.161	0.0001	0.245	0.0001	0.333	0.0001	0.356	0.0001	0.568	X2,X4,X5,X7,X8
P25	0.0001	0.248	0.0001	0.385	0.0001	0.432	0.0001	0.429	0.0001	0.549	X4,X6,X7,X8
P4	0.0001	0.191	0.0001	0.298	0.0001	0.378	0.0001	0.389	0.0001	0.560	X2,X7
VIS25	0.0012	0.139	0.0001	0.253	0.0001	0.302	0.0002	0.278	0.0001	0.462	X4,X6,X7,X8
CF	0.0500	0.053	0.0001	0.283	0.0001	0.339	0.0001	0.475	0.0001	0.546	X2
SI	0.0173	0.077	0.0001	0.311	0.0001	0.369	0.0001	0.457	0.0001	0.509	X2,X4
VIS60	0.0421	0.057	0.0001	0.185	0.0006	0.221	0.0006	0.249	0.0001	0.325	X2
VIS135	0.0036	0.113	0.0001	0.361	0.0001	0.416	0.0001	0.475	0.0001	0.588	X7,X8
SP	0.0001	0.208	0.0001	0.353	0.0001	0.391	0.0001	0.367	0.0001	0.505	X4,X6,X7,X8
Temperature susceptibility											
PR	0.0004	0.161	0.0001	0.258	0.0001	0.278	0.0001	0.307	0.0001	0.420	X5
PI	0.2533	0.018	0.1021	0.037	0.0523	0.105	0.0282	0.146	0.0366	0.218	X3,X4,X6
CN	0.1110	0.035	0.0208	0.073	0.1480	0.074	0.1827	0.086	0.1447	0.166	X5
VTS	0.1798	0.025	0.6095	0.004	0.8754	0.010	0.4803	0.049	0.2465	0.142	X3
PVN60	0.2874	0.016	0.0099	0.090	0.0700	0.097	0.0061	0.188	0.0076	0.268	X2,X8
PVN135	0.7255	0.002	0.0619	0.048	0.2190	0.062	0.0001	0.301	0.0001	0.433	X2,X8
Low-temperature cracking properties											
CT	0.2700	0.017	0.2242	0.021	0.0515	0.106	0.0103	0.174	0.0001	0.311	X1,X2,X7
TES	0.0001	0.205	0.0001	0.273	0.0001	0.317	0.0001	0.354	0.0001	0.432	X2,X7
S23	0.0032	0.116	0.0001	0.236	0.0001	0.334	0.0001	0.326	0.0001	0.411	X2,X7
S29	0.0099	0.090	0.0001	0.211	0.0001	0.319	0.0001	0.316	0.0001	0.467	X1,X2,X7,X8

Table 2. Regression Analyses between Physical Properties and TMA Parameters (n=80)

Dependent Variables	Tg P-value	Tg R**2	Tsp P-value	Tsp R**2	ML P-value	ML R**2	MH P-value	MH R**2	ALL 4 PARAMETERS P-value	ALL 4 PARAMETERS R**2	Selected variables from stepwise reg.
Rheological properties											
P5	0.0003	0.152	0.0001	0.228	0.0106	0.081	0.6021	0.004	0.0001	0.357	ALL
P25	0.0125	0.077	0.0001	0.207	0.0027	0.110	0.9885	0.000	0.0001	0.292	Tsp
P4	0.0016	0.121	0.0001	0.246	0.0057	0.094	0.8209	0.001	0.0001	0.340	ALL
VIS25	0.0037	0.103	0.0001	0.399	0.0003	0.157	0.7735	0.001	0.0001	0.474	Tsp
CF	0.9515	0.000	0.0001	0.249	0.0001	0.173	0.7922	0.001	0.0001	0.487	ALL
SI	0.9571	0.000	0.0001	0.249	0.0013	0.125	0.5032	0.006	0.0001	0.465	ALL
VIS60	0.2055	0.020	0.0001	0.297	0.0009	0.133	0.6978	0.002	0.0001	0.430	Tsp, ML, MH
VIS135	0.0520	0.048	0.0001	0.358	0.0001	0.173	0.7772	0.001	0.0001	0.508	Tsp, ML, MH
SP	0.0372	0.054	0.0001	0.336	0.0003	0.158	0.8249	0.001	0.0001	0.426	Tsp, ML, MH
Temperature susceptibility											
PR	0.5794	0.004	0.0004	0.150	0.0008	0.135	0.4413	0.008	0.0002	0.249	ALL
PI	0.1248	0.030	0.1208	0.031	0.3939	0.009	0.6061	0.003	0.0569	0.114	Tg, Tsp
CN	0.8330	0.001	0.0376	0.054	0.0960	0.035	0.6208	0.003	0.0497	0.118	Tsp
VTS	0.9091	0.000	0.5999	0.004	0.6046	0.003	0.8512	0.000	0.9374	0.011	None
PVN60	0.9802	0.000	0.0107	0.081	0.0413	0.052	0.7488	0.001	0.0083	0.165	Tsp
PVN135	0.9441	0.000	0.0970	0.035	0.2008	0.021	0.8359	0.001	0.2380	0.070	Tsp
Low-temperature cracking properties											
CT	0.0036	0.104	0.2035	0.021	0.9654	0.000	0.2546	0.017	0.0125	0.155	Tg, MH
TES	0.0016	0.120	0.0022	0.114	0.0216	0.066	0.8811	0.000	0.0008	0.221	Tg, Tsp
S23	0.0002	0.161	0.0001	0.280	0.0006	0.140	0.9183	0.000	0.0001	0.402	ALL
S29	0.0009	0.133	0.0001	0.211	0.0009	0.133	0.9954	0.000	0.0001	0.345	ALL

Table 3. Regression analyses: Physical Properties against TMA and HP-GPC Parameters (n=73)

Dependent Variables	TMA & HP-GPC parameters P-value	TMA & HP-GPC parameters R**2	Selected variables from stepwise reg. TMA parameters	Selected variables from stepwise reg. HP-GPC parameters
Rheological properties				
P5	0.0001	0.666	**Tsp**	**X2**,X6,**X7**
P25	0.0001	0.669	Tsp,ML,MH	**X4**,X6,**X7**
P4	0.0001	0.667	Tsp	**X2**,X4,X6,**X7**,X8
VIS25	0.0001	0.766	**Tsp**	X2,**X4**,X6,**X7**,MWT,PIDX
CF	0.0001	0.741	Tg,Tsp,**ML**,MH	**X2**
SI	0.0001	0.719	Tg,**Tsp**,ML,MH	**X2**
VIS60	0.0001	0.583	**Tsp**	X8
VIS135	0.0001	0.773	Tsp,ML,MH	X7
SP	0.0001	0.715	**Tsp**,ML,MH	X1,**X3**,**X6**,MWT
Temperature susceptibility				
PR	0.0001	0.636	Tsp	X2,**X4**,X5
PI	0.0517	0.309	Tg,Tsp	**X4**,PIDX
CN	0.2076	0.246	Tsp	X5
VTS	0.5121	0.187		X3
PVN60	0.0098	0.368		X2,X8
PVN135	0.0001	0.496		**X2**,**X8**
Low-temperature cracking properties				
CT	0.0008	0.438	Tg	X2,**X5**,**X7**,X8
TES	0.0001	0.564	Tg	X2,**X7**
S23	0.0001	0.655	**Tsp**,ML,MH	**X2**,X4,**X7**,PIDX
S29	0.0001	0.588	Tsp,ML,MH	X2,X5,**X7**

Bold face indicates significantly correlated variable.

Table 4. Critical Values for Performance Related Parameters

Parameter	Critical Value	Reference	Corresponding X2,%	Corresponding X7,%	Corresponding Tg, °C	Corresponding Tsp, °C	Corresponding ML, μm/°C
P4	>5	10	<18.5	>4.5	<-9.5	<32.9	<0.51
P25	>20	17	<18.0	>5.0	<-18.5	<31.0	<0.39
SI	<0.55	18	<18.1	>4.6		<36.0	<0.60
R&B SP	<65.5 °C	17	<18.7	>4.6		<31.2	<0.45
VIS25	<2MPa·s	17	<18.2	>5.2	<-17.5	<28.0	<0.42
PVN60	>-1.3	5	>9.8	<13.6			
PVN135	>-1.0	19	>11.1	<12.7			
S23	>20ksi	20	<19.5	>3.7	<-17.0	<32.5	<0.47

Table 5. Proposed Trial Specification for Asphalt Cement

Test	AC-5	AC-10	AC-20
Original Asphalt:			
Viscosity @ 60 °C, poise[1]	500±100	1,000±200	2,000±400
Viscosity @ 135 °C, cSt, min[1]	175	250	300
Penetration @ 25 °C, min[1]	140	80	60
Flash point, °C, min[1]	177	219	232
Solubility in TCE, %, min[1]	99.0	99.0	99.0
Residue from TFOT:			
Viscosity @ 60 °C, poise, max[1]	2,000	4,000	8,000
Residue from Pressure-Oxidation, 46 hrs, 65 °C, and 20 atm:			
Viscosity @ 60 °C, poise, max	10,000	20,000	40,000
Penetration, 25/100/5, min	20	20	20
Penetration, 4/200/60, min	5	5	5
Penetration, 5/100/5, min	10	8	7
R&B softening point, °C, max	71	71	71
Stiffness, -23 °C, 10,000 sec, psi	20,000	20,000	20,000
Viscosity, 25 °C, megapoise, max	20	20	20
Shear susceptibility, max	0.55	0.55	0.55
X2 (HP-GPC), %, max	20	20	20
X7 (HP-GPC), %, min	5	5	5
Tg (TMA), °C, max	-20	-20	-20
Tsp (TMA), °C, max	28	28	28
ML (TMA), max	0.4	0.4	0.4

[1]AASHTO M226, Table 2

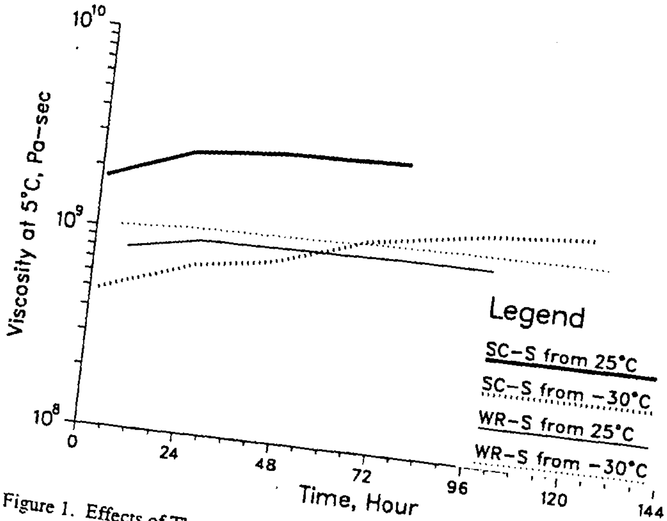

Figure 1. Effects of Thermal History on Viscosity at 5°C for SC and WR asphalts

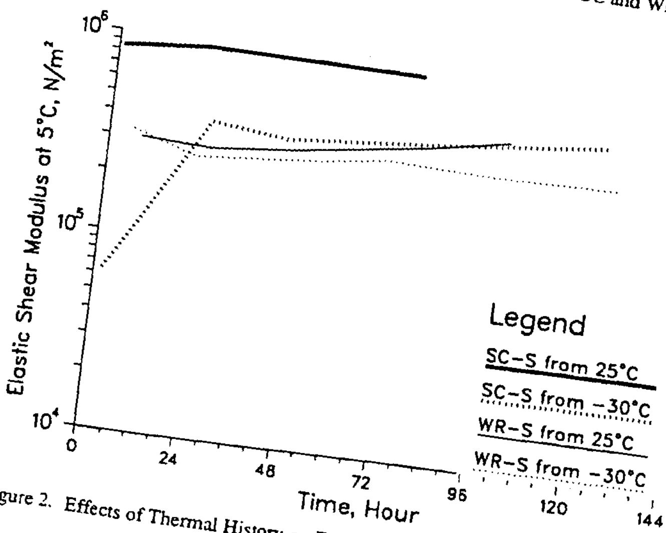

Figure 2. Effects of Thermal History on Elastic Shear Moduli at 5°C for SC and WR asphalts

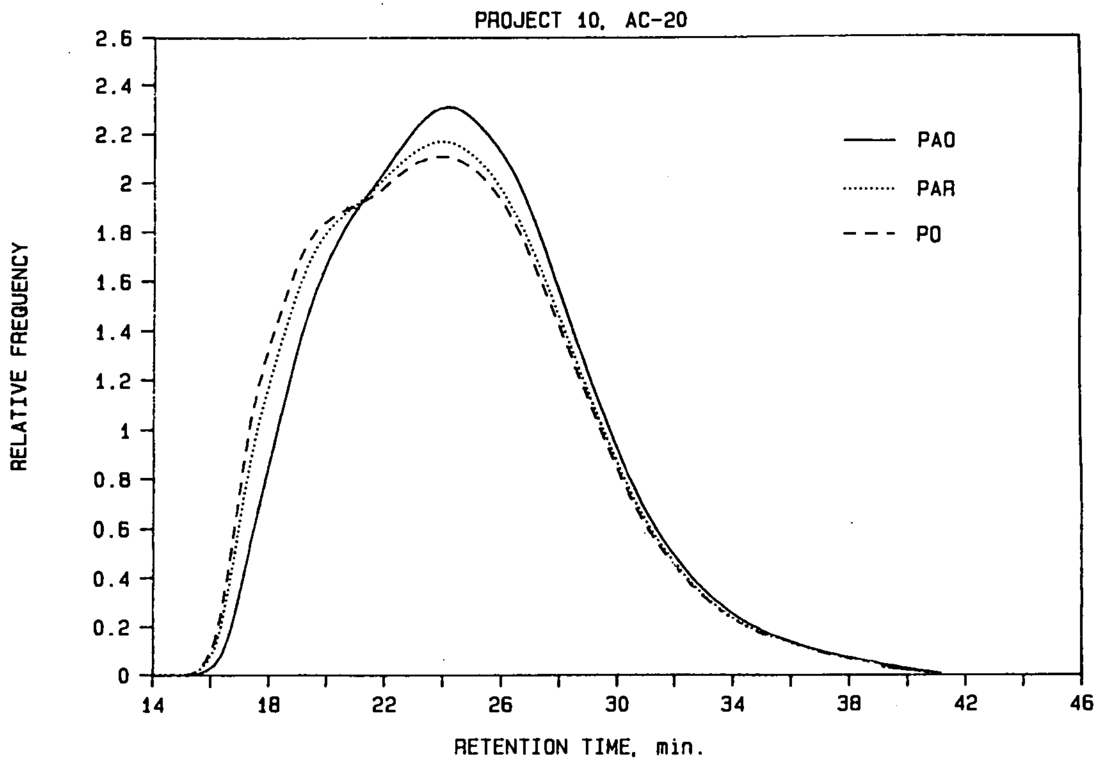

Figure 3. Effects of Aging on HP-GPC Chromatogram of Project 10 asphalt

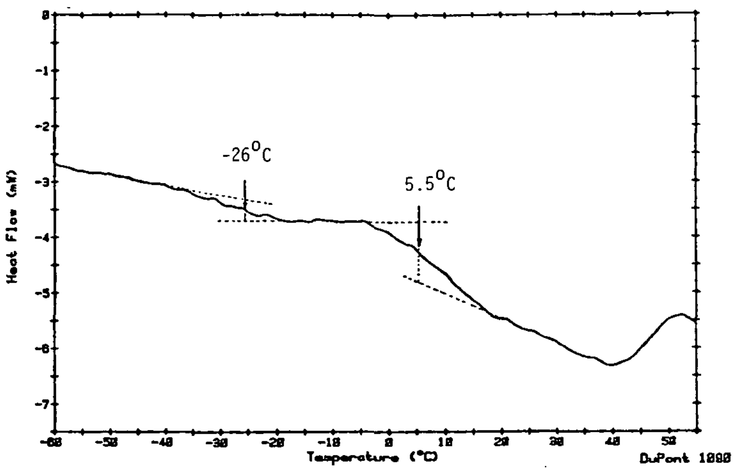

Figure 4. DSC thermogram of Asphalt B2975

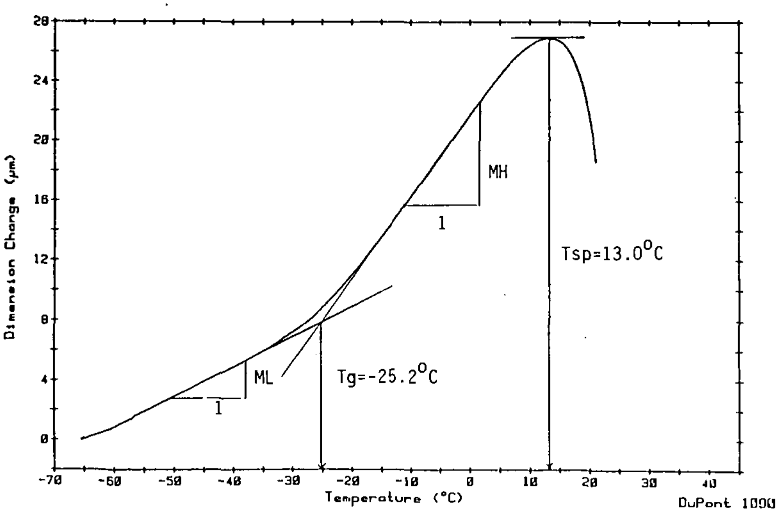

Figure 5. Typical TMA thermogram (K20-01-O)

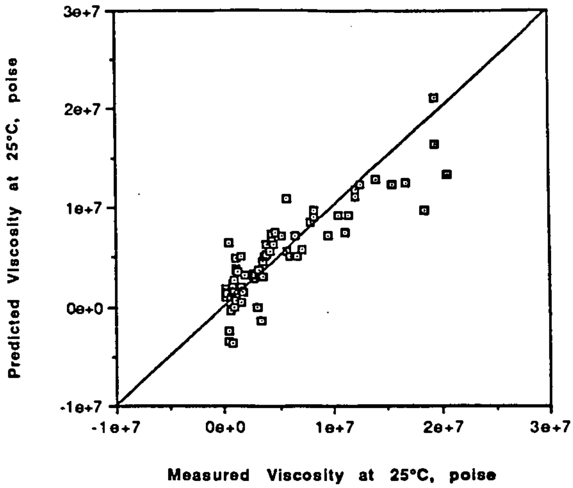

Figure 6. Measured Viscosity at 25 °C and Predicted from TMA and HP-GPC Parameters

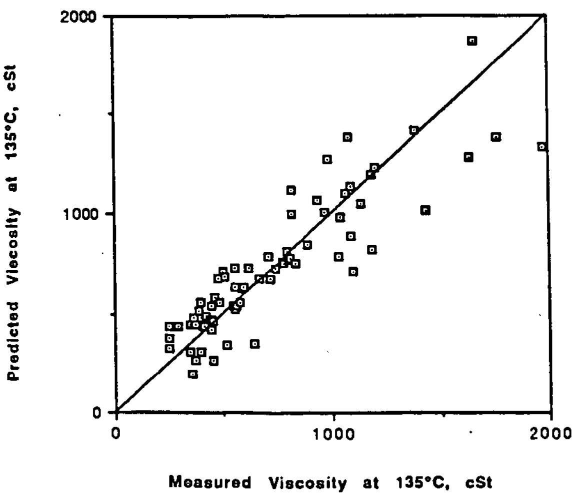

Figure 7. Measured Viscosity at 135 °C and Predicted from TMA and HP-GPC Parameters