DEVELOPMENT OF LABORATORY OXIDATIVE AGING PROCEDURES FOR ASPHALT CEMENTS AND ASPHALT MIXTURES

Ok-Kee Kim
Graduate Research Assistant
Department of Civil Engineering
Oregon State University

Chris. A. Bell
Associate Professor of Civil Engineering
Oregon State University

James E. Wilson
Assistant Engineer of Materials
Oregon Department of Transportation

and

Glenn Boyle
Group Leader - Asphalt Mix Design
Oregon Department of Transportation

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ABSTRACT

This paper presents an evaluation of an oxidative aging procedure for asphalt materials. Test results and the effectiveness of the aging device used are presented. The study was performed by Oregon State University and the Oregon Department of Transportation. This study involved laboratory tests on field core samples as well as laboratory mixture samples and asphalt cements used for three projects constructed in Oregon.

The procedure selected for aging laboratory mixtures involved using a Pressure Oxidation Bomb (POB), a sealed container in which asphalt mixtures and/or asphalt samples were subjected to pure oxygen at 100 psi pressure at 60 C, for periods of up to 5 days. Resilient modulus and fatigue tests were performed to measure the properties of cores and laboratory mixtures (before and after aging). The asphalt samples were aged on a Fraass plaque to achieve minimum disturbance of the sample, and the degree of aging was assessed by changes in the Fraass breaking temperature.

The results of this study showed that the POB was an effective means of producing measurable changes in both mixtures and asphalt samples. However, the mixture properties were substantially different from those measured for the field core samples, while the asphalt properties were similar. As evaluation parameters, the modulus ratio and Fraass breaking temperature are good indicators of aging rate of mixtures and asphalt cement, respectively. The study also indicated that aging rate is a function of the air voids in the mixture and asphalt properties.

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INTRODUCTION

Background

Premature failure or poor performance of asphalt pavements often results from weakening of the adhesive bond between asphalt cement and aggregate particles by the action of moisture and/or mechanical stresses, and/or aging of asphalt cement. Aging is the change of properties of asphalt pavements (1) and usually is accompanied by hardening of the asphalt cement. Petersen (2) indicated that three fundamental composition-related factors govern the changes that could cause hardening of asphalts in pavements:

1) loss of the oily components of asphalt by volatility or absorption by porous aggregates;
2) changes in the chemical composition of asphalt molecules from reaction with atmospheric oxygen; and
3) molecular structuring that produces thixotropic effects (steric hardening).

Oxidation of asphalt is generally considered a major factor contributing to the hardening and embrittlement of asphalt pavement. This oxidation occurs in the preparation and laydown of hot mix pavements as well as due to environmental aging while in service. Excessive hardening of the asphalt cement is undesirable because it often leads to problems associated with pavement embrittlement and cracking. The rate of hardening is affected by the chemical composition of asphalt, light, aggregate properties, and the ambient temperature (3-6). After the development of the recovery method by Abson in 1933 (7) provided a means of recovering the asphalt from hot plant mixtures immediately and after periods of aging in the pavement, numerous methods to evaluate the properties of "aged" asphalt cement have been developed. Many aging methods attempt to correlate short-term laboratory aging with the change of asphalt properties occurring after long exposure in the pavement as well as during mixing operations.

Methods used by various investigators include use of high temperatures, light, chemical oxidation agents and oxidation in solution under oxygen pressure. Reference 8 summarizes the various test conditions, such as temperature and exposure time, used for aging methods along with evaluation parameters. Most of the methods represent the short term aging due to the mixing process rather than the long term aging. Most of the evaluation parameters consist of measurements of consistency of the asphalt cement, such as penetration, viscosity, and ductility. For asphalt mixtures, Pauls and Welborn (9) used the compressive strength of the weathered mixtures as the evaluation parameter. Kemp and Predoehl (10) used the resilient modulus of the weathered briquettes as the evaluation parameter.

Purpose

As discussed above, the majority of aging procedures developed previously are for short term rather than long term effects. The major objective of the study reported in this paper was to develop a laboratory procedure to simulate long term aging effects. The approach selected was one similar to the Lottman test for moisture effects (11), which has been used extensively by the authors (12, 13). This approach is to measure fundamental properties (such as tensile strength, resilient modulus, fatigue life and permanent deformation) of the asphalt mixture before and after conditioning (i.e., either by moisture or oxygen). It was also desired to evaluate asphalt cements as well asphalt mixtures before and after oxygen conditioning, i.e., aging in oxygen.

The purpose of this paper is to (a) present an oxidative aging procedure adopted for a recent aging study by Oregon State University and the Oregon Department of Transportation, and (b) discuss the test results and effectiveness of the aging device.

SELECTION OF AGING AND EVALUATION METHODS

After review of the various aging procedures used previously, it was decided that the method adopted in the aging study should attempt to reproduce oxidative aging occurring after construction of a pavement. The research approach included comparison of artificially aged laboratory prepared samples with cores aged in the field. The extent to which aging of laboratory mixtures could be achieved with the developed methods is emphasized in this paper. Both laboratory mixtures and asphalt samples were subjected to aging. Asphalt sample aging was included in the test program to see if the methods adopted would indicate asphalt aging susceptibility. A major goal of this research was to utilize an aging device suitable for both types of samples.

The pressure oxidation bomb (POB), originally developed in Britain (14) and recently used by Edler, et al. (15) in South Africa, was selected as the most suitable aging device and modified in the aging study. This modified device can contain two mixtures or one mixture and several Fraass samples. As reported by Thenoux, et al.(16), the use of Fraass samples for aging asphalt has the advantage of minimal disturbance to the asphalt which is tested on the "container" on which it is aged.

The POB was operated in the aging study with the samples contained in a pure oxygen environment at 100 psi and at 60 C. This compares to 300 psi and 150 C used by Edler, et al.(15). These levels were arbitrarily selected after consideration of safety concerns regarding the use of pressurized oxygen and in order to preserve the shape of the mixtures.

MATERIALS TESTED

Asphalt cements and aggregates for three projects constructed in Oregon [Idylwood Street (1974) Plainview Road-Deschutes River (1980), Arnold Ice Caves-Horse Ridge (1973)] were used for the laboratory simulation aging study. These projects were 5 to 10 years old and in each project original samples of asphalt and representative aggregate were available. For each of the three projects the mix type was B-mix (Table1) and the grade and optimum content of asphalt cement were as follows: AR 4000 of 7.0% for the Idylwood Street, AR 4000 of 5.5% for the Plainview Road-Deschutes River project, and 120/150 Pen. of 6.5% for the Arnold Ice Caves-Horse Ridge project. Laboratory mixtures were prepared using a kneading compactor, and field cores were obtained for each project.

TEST PROGRAM

Cores

The Oregon Department of Transportation (ODOT) testing program included the tests for aggregate gradation, asphalt cement contents, air voids, and recovered asphalt cement properties. The repeated load diametral test for modulus and fatigue life of cores was performed by Oregon State University.

Laboratory Mixtures

The variables considered in the laboratory mixture preparation were:

1) Compaction level: 94% of maximum density (100 blows at 500 psi after 20 blows at 250 psi and leveling load of 12500 lbs for 15 seconds), and
88% of maximum density (30 blows at 100 psi and leveling load of 1000 lbs

for 15 seconds);

2) Aging period: 0, 1, 2, 3, and 5 days.

Each of the above variables was studied relative to a standard mix consisting of the original mix design used for the projects studied. Following the standard ODOT procedure (17) using a kneading compactor, 4-in.(100 mm) diameter by 2.5-in.(63 mm) high specimens were fabricated for three projects [Idylwood Street (ID-ST), Plainview Road-Deschutes River (PR-DR) and Arnold Ice Caves-Horse Ridge (AIC-HR)] by using the same asphalt cement and same mix design employed at the time of construction. A minimum of 10 specimens for each compaction level were prepared for each of the three projects. All 60 specimens were tested for resilient modulus and fatigue life. All diametral tests were run for tensile stress levels of 20 psi and 40 psi for 88% and 94% compaction level, respectively.

Asphalts

Routine asphalt tests were accomplished by ODOT. Fraass samples were prepared and tested by OSU together with chemical composition tests in accordance with ASTM D-4124.

DETAILS OF TEST METHODS

For this aging study the POB was used to simulate oxidative aging occurring after construction. The resilient modulus and fatigue life of cores and laboratory mixture samples as well as the Fraass breaking temperature of asphalt cement were measured. The modulus ratio (the ratio of modulus after aging to the modulus before aging) and the Fraass breaking temperature were adopted to measure the changes in the properties of laboratory mixture samples and asphalt cements, respectively.

Aging Procedure

The modified pressure oxidation bomb, which was developed originally in England, consists of a cylindrical pressure vessel made of stainless steel fitted with a screw-on cover containing an ASME pressure relief for safety, a pressure gauge, and a stopcock. The pressure oxidation bomb (POB) was sealed by using O-rings. Figure 1 shows a diagram of the POB used for this study.

The following are the main steps in the use of the POB:

1) Samples (asphalt mixtures or asphalt cement) are prepared.
2) The samples are placed in a POB.
3) Vacuum [26 in.(66 cm) Hg.] is applied for 20 minutes.
4) The POB is filled via the stop cock from an oxygen cylinder to 100 psi (689.5 kPa). This pressure is held for 30 minutes to ensure leak-free joints.
5) The POB is then placed in an oven maintained at 60 C (140 F) for 1, 2, 3, and 5 days.
6) At the conclusion of the test the stop cock is opened, the cover is removed, and the aged mixtures and/or asphalt cement samples are cooled for one day and one hour under room temperature, respectively.

The Fraass Brittle Test

The Fraass breaking point (18) is the temperature at which an asphalt first becomes brittle as indicated by the appearance of cracks when a thin film of asphalt on a metal plaque is cooled at the rate of 1 C/min. and flexed at a constant rate. This test outlined in Appendix was described by Fraass in 1937, and has been standardized in many countries (16). Figure A in the Appendix shows the component parts of the apparatus.

The following are the main steps used for this study.

1) The sample (0.4 gr) is prepared as described in the Appendix.
2) A standard steel plaque [1.6 in. x 0.8 in.(41 mm x 20 mm)] is coated uniformly with a thin layer of asphalt cement [0.02 in. (0.5 mm)].
3) The steel plaque coated with asphalt cement is in a closed chamber, and the temperature of the plaque is lowered steadily at a rate of 1 C/min (1.8 F/min), adding solid carbon dioxide to the acetone bath which surrounds the chamber where the plaque is located.
4) The steel plaque is repeatedly bent to a given extent in a standard time. The temperature at which one or more cracks appear is recorded as the breaking point ("brittle temperature"). The Appendix gives a more detailed description of the apparatus, the sample preparation and test procedure.

Repeated Load Diametral Test

The resilient modulus and fatigue tests were performed using the repeated load diametral test apparatus. The parameters recorded during the repeated load diametral test were the load applied, the horizontal elastic deformation, and the number of repetitions to failure. During the tests, the dynamic load duration was fixed at 0.1 sec and the load frequency at 60 cycles per minute. The static load 10 pounds (4.5 kg) was applied to hold the specimen in place. The tests were carried out at 70.7± 1.6 F (21.5±0.9 C). For this study, the number of load repetitions to fatigue failure was defined as the number of repetitions required to get a vertical crack approximately 0.25 in (0.64 cm) wide in the specimens. To stop the test at the specified level of specimen deformation, a thin aluminum strip was attached to the sides of the specimen, along a plane perpendicular to the plane formed by the load platen. As the specimen deformation exceeds a certain level, the aluminum strip breaks and opens the relay, which shuts off the test. The test procedures employed are described in detail in Reference 19.

TEST RESULTS AND DISCUSSION

Resilient Modulus

The average moduli values of six cores of each three projects are presented in Table 2 including the thickness, air voids, and asphalt contents. For laboratory mixtures, two specimens were tested as-compacted and the other eight specimens were tested both before and after aging for each compaction level. The aged specimens were cooled for one day before modulus was measured. The modulus test results including bulk specific gravity, air voids, and maximum specific gravity (AASHTO T-209) are summarized in Table 3. The aging effect assessed by the modulus ratio (the ratio of modulus after aging to the modulus before aging) is shown in Figure 2.

The mixtures for the Idylwood Street project (ID-ST) with 88% compaction level aged at a constant rate, while the mixtures for the other two projects aged very rapidly during the first two or three days. The aging rate (slope in Figure 2) of the mixtures for the Plainview Road-Deschutes River project (PR-DR) changed little after the third day while that of the Arnold Ice Caves-Horse Ridge project (AIC-HR) still increased. Even though the same grade of asphalt cement (AR-4000) was used for both the Idylwood Street and the Plainview Road-Deschutes River project the trend of mixture aging is significantly different. The difference is probably because the physical properties of the original and recovered asphalt cement were substantially different as presented in Table 4, i.e., the asphalts were probably from a different source.

The results from the mixtures compacted at 94 % level show a slightly different trend. Unlike the mixtures compacted at 88 % level, the mixtures with 94% compaction level for the Idylwood Street and Plainview Road-Deschutes River projects aged little during the first two days and then aged rapidly between the second and third days. This rapid aging was followed by a period of slow aging between the third and fifth days. This result may show that it takes some time for the oxygen to penetrate into mixtures with low air voids and to react with asphalt cement. If so, the permeability of mixture is an important factor in the aging rate as suggested by Goode (20) and Kumar (21). It is noted that aging rate with 94% compaction level for both the Idylwood Street project and the Plainview Road-Deschutes River project are similar while the aging rate of the mixtures with 88% compaction level for these projects are significantly different.

One unexpected result for the mixtures with 94% compaction level was that the specimens for the Arnold Ice Caves-Horse Ridge project appeared to soften during the first 3 days. This may have been caused by a slight loss of cohesion of the specimens at the high temperature used in the POB (60 C). However, the aging rate (slope) after the second day increases rapidly and then decreases like the other two projects.

Finally it should be noted that the modulus results from the laboratory accelerated aging procedure (POB) performed for five days under 100 psi (688.5 kPa) and 60 C (140 F) were not comparable with the modulus results determined from the cores of each project. Figure 3 shows the moduli of the laboratory aged samples for both compaction levels after 5 days, and the core moduli values. As can be seen, the core moduli values are approximately twice those of the low air void content laboratory samples except the Idylwood Street project. These results are not surprising, since laboratory compacted samples have been found to have lower moduli than field cores (22). The large difference in moduli values between cores and laboratory mixtures for the Idylwood Street project results in part from the difference of asphalt content of cores (5.8%) and laboratory mixtures (7.0%). In general, mixtures with high asphalt content show low modulus.

Fatigue Life

After resilient modulus was measured, the fatigue test was run at fixed tensile stress ranging from 30 psi (207 kPa) to 60 psi (414 kPa) for cores. For the laboratory mixtures the fatigue test was run with applying 20 psi (137.9 kPa) and 40 psi (275.8 kPa) of tensile stress for 88% compaction level mixtures and 94% compaction level mixtures, respectively. Only the test results of the laboratory mixtures are discussed in this paper.

Fatigue results represent the effect of the differences in modulus presented in Table 3 and resulted in a wide variety of fatigue performance as shown in Figure 4. The fatigue results show that the aged mixtures of the Plainview Road-Deschutes River project (PR-DR) obtain the longest fatigue life for both compaction levels, since this project has the highest moduli values as presented in Table 3. In general, the resistance to fatigue failure (slope in Figure 4) of mixtures decreases after the third day regardless of the difference of compaction level.

The fatigue characteristic of mixtures with different compaction levels was changed slightly with aging time. For 88% compaction level, the slopes of each project are relatively constant through time, while slopes of the mixtures compacted at 94% level changed in each time interval. These results show that the air voids of mixtures affect the resistance to fatigue failure through their service period, and that high modulus is an important factor in achieving long fatigue life. The changes of fatigue life of the Idylwood Street and the Arnold Ice Caves-Horse Ridge projects increase slightly during the first two days. This result can be explained by the time for oxygen to penetrate into the mixture as discussed in the modulus section, since the actual air voids of the Idylwood Street (5.5%) and the Arnold Ice Caves-Horse Ridge project (4.0%) are much lower than that of Plainview Road-Deschutes River project (6.6%). The rate of change of fatigue life of each project at both compaction levels (except the Plainview Road-Deschutes River project at 88% compaction level) after the third day decreases, that is, the resistance to fatigue failure of mixtures decreases with oxidative aging time.

Fraass Breaking Temperature

The trends of increased Fraass breaking temperature (i.e., more brittle asphalt) for each project (Figure 5) are similar to those of increased modulus ratio of mixtures with 88% compaction level (Figure 2). For the Idylwood Street project (ID-ST) the breaking temperature of the asphalt cement (AR-4000) increases very slowly as the aging period increases. For the Plainview Road-Deschutes River project (PR-DR) which used the same grade of asphalt cement (AR-4000) the breaking temperature of asphalt cement increases much more rapidly during the first two days aging. The original asphalt cement (120/150 Pen.) used for the Arnold Ice Caves-Horse Ridge project (AIC-HR) has almost the same breaking temperature and a similar aging rate as that for the Idylwood Street project. Also, these asphalt cements have almost the same physical properties except for flash point and loss on heating as presented in Table 4. Again, it can be seen that even though asphalt cements may have the same grade, they show significant differences in behavior such as for the AR-4000 asphalts used for the Idylwood Street and Plainview Road-Deschutes River projects.

The change in Fraass breaking temperature of an asphalt cement indicates a general change in the consistency properties of the asphalt cement which can be estimated from a Bituminous Test Data Chart (BTDC, (23)) as shown Figure 6 for each project. If the temperature susceptibility of asphalt cement changed little after aging (i.e. if the lines drawn through the original and aged property data were parallel), it might be possible to predict the long term asphalt properties with the one point of Fraass breaking temperature of asphalt aged in the POB. Hence, the Fraass breaking temperature may be a valuable indicator of the durability of asphalt cement as well as defining a low temperature consistency.

The rolling thin film oven test (RTFOT, ASTM D-2872) is used to measure the anticipated hardening of the asphalt during hot-mix plant operations in several western States, and therefore will probably not give an indication of hardening due to long term aging. The consistency data for asphalt from each project after RTFOT (Figure 6) are not adequate to predict the long term asphalt properties due to oxidation. The limited data shown in Figure 6 illustrate that asphalt recovered from field cores had higher consistencies to RTFOT aged asphalt, and that POB aging (5 days) may be similar to field aged materials with regard to the Fraass point. Clearly more data is required to support this suggestion.

For the Idylwood Street project the Fraass breaking temperature lies between the projected line (dashed line in Figure 6) of RTFOT and recovered as shown in Figure 6 (a), that is, the asphalt cement aged in the POB for 5 days was aged more than the asphalt from the RTFOT and aged less than that of cores. However, for the Plainview Road-Deschutes River project the Fraass breaking temperature of asphalt aged in the POB for 5 days lies close on the projected line of recovered asphalt in Figure 6 (b). The result of the Arnold Ice Caves-Horse Ridge project is similar to that of the Plainview Road-Deschutes River project as shown in Figure 6 (c).

<u>Effectiveness of POB</u>

In general, a major cause of asphalt cement hardening is oxidation, a process that occurs most readily at high temperature and with thin asphalt films. The POB developed in England (14) was modified to age both asphalt cements and asphalt mixtures for the aging study at OSU. The modified POB was used with 100 psi and 60 C. Previously, higher pressures and temperatures were used (14,15), but the lower levels were adopted because of safety considerations and preservation of the shape of the mixture samples.

The modulus ratios obtained from original mixtures and weathered mixtures after four years aging at four different weathering sites in California (10) are presented in Table 5. The modulus ratio ranges from 0.67 to 1.67, excluding the high air voids (7 to 12 %) mixture using Santa Maria asphalt and non absorbent aggregate. Even though the moduli values of aged laboratory mixtures were substantially different from those of cores tested in the study reported herein, it can be seen that the POB causes similar changes in modulus, i.e., results in similar modulus ratios (Figure 2) to those observed in the California study (Table 5).

The results of asphalt cement chemical composition tests (24) done in cooperation with this aging study, indicate that the use of the POB to age the asphalt cement on Fraass plaques (0.5 mm film thickness) produced a similar chemical composition to that of asphalt extracted from the cores. The results presented in Table 6 show that asphalt cement aged in the POB for 5 days can have a similar composition to that from the cores. However, as with the consistency data, there is a significant difference in the POB and recovered properties for the Idylwood Street project.

The component fractions of asphalt cement samples (aged for 5 days) from the Plainview Road-Deschutes River project were very similar to those obtained for asphalt extracted from the cores. Also, for the Arnold Ice Caves-Horse Ridge project the fractions of asphaltenes and saturates of the asphalt cement aged for 5 days in the POB are close to those of the cores. The chemical composition of the aged asphalt (for 5 days) of the Idylwood Street project shows that the asphalt in the POB was less aged than that of cores as discussed in the previous section. The equivalent aging period in the laboratory to a field may vary with grade and source of asphalt cements as well as mixture properties (particularly air voids and asphalt film thickness) and environmental conditions.

The POB can be used effectively to age asphalt cements in thin films with high pressure and/or temperature to give an indication of the long term asphalt properties with one point of Fraass breaking temperature on the BTDC. However, to effectively evaluate mixture aging, representative mixtures must be tested, and if possible these should be core samples obtained shortly after construction, rather than laboratory compacted mixtures which as shown in this study and others (25, 26) do not represent field mixtures. There may be a large difference between the laboratory mixtures and plant mixtures due to the differences in production method and differences in the compaction method.

Reference 14 indicates that one day's aging of asphalts in the POB at a pressure of 20 atmospheres (300 psi) and at temperatures of 50 to 60 C is equivalent to half a year on the road in Holland. However, it is extremely important to fit an appropriate pressure relief device to the POB when working at these elevated levels. In this study only 100 psi at 60 C was applied after consideration of safety concerns regarding the use of pressurized oxygen and in order to preserve the shape of the mixture samples.

SUMMARY

For the limited number of projects studied, the pressure oxidation bomb (POB) was found to be a very effective device for oxidative aging of both asphalt cements and asphalt mixtures. The test results show that with the exception of one project, and in that case only for modulus, all the properties changed by at least 50 percent after 5 days of POB aging. Higher pressure, temperature and/or longer exposure time could be applied to accelerate the aging, but the user must be aware of safe operating procedures.

The modulus ratio and the Fraass breaking point are good indicators to measure the aging rate of mixtures and asphalt cement, respectively. The aging rate of mixtures varies with the air voids of mixtures. The mixtures with higher air voids are aged more rapidly, although the aging rate depends on asphalt properties.

The limited testing done in this study showed that asphalts aged in the POB for 5 days had similar composition to those recovered from field cores of five to ten years old. This lends some confidence to the use of the Fraass samples for oxidative aging procedures.

RECOMMENDATIONS FOR FUTURE WORK

Although not evaluated in this study, the POB approach for oxygen conditioning could be combined with a Lottman moisture conditioning approach to approximate very harsh environmental conditions. There is some evidence to suggest that mixtures suffering oxidative aging are moisture susceptible (2) and therefore subjecting a mix to cycles of oxidation and moisture conditioning with modulus and fatigue tests are very appropriate.

Clearly, the data collected in this study were insufficient to fully evaluate the aging procedures used. More data should be collected, therefore, to improve confidence in their effectiveness.

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DISCLAIMER

The contents of this paper reflects the views of the authors who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or polices of either the Oregon State Highway Division or Federal Highway Administration.

LIST OF TABLES

Table 1. Aggregate Gradation, Class B Mix

Sieve Size	Aggregate Gradation, % Passing		
	Idylwood Street	Plainview Road-Deschutes River	Arnold Ice Caves-Horse Ridge
1 in.	–	–	100
3/4 in.	100	100	97
1/2 in.	87	87	84
3/8 in.	78	74	74
1/4 in.	63	60	60
No. 4	52	52	53
No. 10	30	31	32
No. 40	12	14	15
No. 200	5	5	5

Table 2. Summary of Core Data

Projects	Thickness (in.)	Max. Sp. Gr.	BSG	Air Voids (%)	Asphalt Content (%)	Resilient Modulus (ksi)
Idylwood St.	1.9	2.459	2.17	11.8	5.9	772
Plainview Rd.-Deschutes River	1.4	2.497	2.29	8.3	5.8	569
Arnold Ice Caves-Horse Ridge	1.6	2.444	2.34	4.3	6.7	244

Table 3. Laboratory Mixture Aging Test Data

Project	Asphalt Content (%)	Max. SP. Gr.	Bulk Sp. Gr.	Air Voids (%)	Days	Resilient Modulus (ksi)
Idylwood Street	7.0	2.407	2.275 *	5.5 *	0	74
					1	80
					2	81
					3	110
					5	118
			2.137 **	11.2 **	0	52
					1	53
					2	58
					3	59
					5	68
Plainview Road-Deschutes River	5.5	2.455	2.292 *	6.6 *	0	237
					1	241
					2	265
					3	366
					5	373
			2.160 **	12.0 **	0	149
					1	158
					2	214
					3	238
					5	242
Arnold Ice Caves-Horse Ridge	6.5	2.447	2.349 *	4.0 *	0	105
					1	72
					2	73
					3	105
					5	128
			2.202 **	10.0 **	0	53
					1	69
					2	82
					3	83
					5	94

Pure Oxygen Pressure = 100 psi
Aging Temperature = 60 C
* Samples prepared to approximately 94% of max. density
** Samples prepared to approximately 88% of max. density

Table 4. Physical Properties of Asphalt Cement

	Idylwood Stet			Plainview Road-Deschutes River			Arnold Ice Caves-Horse Ridge		
	O	RTFOT*	R	O	RTFOT	R	O	RTFOT	R
Penetration									
at 25 C (77 F)	139	66	10	80	46	22	140	66	63
at 4 C (39.2 F)	50		9	20		14	46		32
Penetration Ratio (4 C/25 C)	0.36		0.90	0.25		0.64	0.33		0.51
Absolute Viscosity (60 C, Poises)	1169	4306	225129	1504	3858	13584	762	2524	5542
Kinematic Viscosity (135 C, C.S.)	353	608	3952	368	494	885	236	393	745
Flash Point (Closed Cup, C)	199			252			229		
Loss on Heating (%)	1.77			0.34			0.20		

*RTFOT: After Rolling Thin Film Oven Test
O: Original
R: Recovered

Table 5. Modulus Ratio of Field Weathering Mixtures (original and 4 year field weathering, Ref. 10)

A. Non Absorbent Aggregate

Asphalt Source	Air Voids	Original*	Weathering Site** A	B	C	D
	3-5	950	0.86	0.76	1.16	0.81
Valley	7-9	880	0.85	0.84	1.05	0.82
	10-12	1000	0.73	0.76	0.81	0.62
LA Basin	7-9	740	0.78	0.73	1.11	0.96
	3-5	330	1.21	1.21	1.24	1.67
Santa Maria	7-9	160	2.31	2.13	2.44	3.13
	10-12	150	1.93	2.47	2.13	3.40

B. Absorbent Aggregate

Asphalt Source	Air Voids	Original*	Weathering Site A	B	C	D
	3-5	810	0.79	0.80	1.12	0.86
Valley	7-9	590	1.09	0.83	1.20	1.07
	10-12	730	0.92	0.70	1.11	0.95
Santa Maria	3-5	430	1.28	1.00	1.28	1.61
	10-12	270	1.37	1.44	1.63	2.07

Original*: Resilient Modulus of Original Mixture, ksi
Weathering Site**: A; Fort Bragg B; Sacramento
C; So Lake Tahoe D; Indio

Table 6. Chemical Composition of Asphalt Cement

	Idylwood Street				Plainview Road-Deschutes River				Arnold Ice Caves-Horse Ridge			
	0	2 days*	5 days**	R	0	2 days	5 days	R	0	2 days	5 days	R
Asphaltenes	22.7	27.2	29.0	37.3	16.1	22.4	24.3	25.3	24.9	25.6	27.8	28.0
Saturates	8.4	8.2	7.2	5.6	8.6	7.6	7.6	6.6	10.2	10.3	9.8	10.8
Naphthene-Aromatics	24.5	23.0	23.4	24.7	26.8	25.8	25.1	25.8	25.5	27.4	26.8	19.7
Polar Aromatics	43.3	39.4	37.9	32.4	47.0	42.6	40.8	41.8	38.1	36.0	33.7	39.7
Total	98.9	97.8	97.5	100.0	98.5	98.4	97.7	99.5	98.7	99.3	98.1	98.2

*aged with POB for 2 days
**aged with POB for 5 days
O: Original
R: Recovered

LIST OF FIGURES

Figure

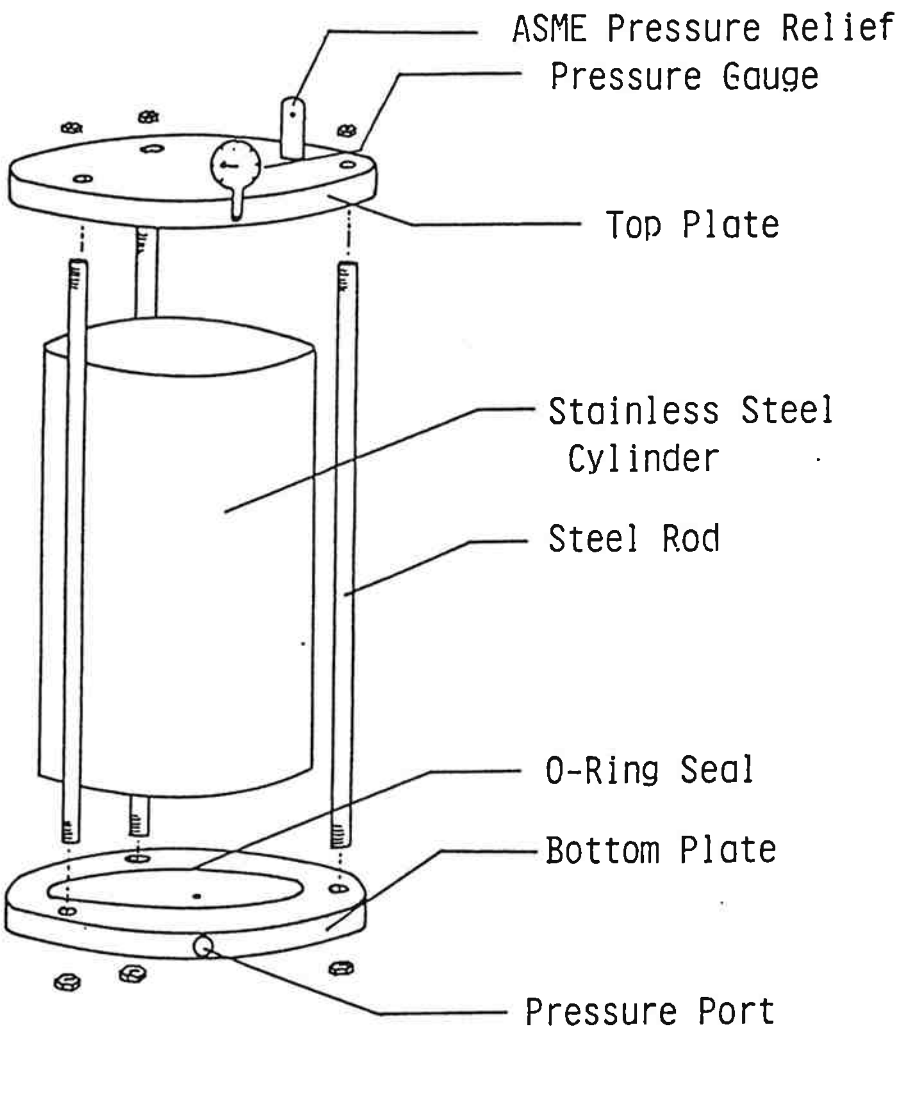
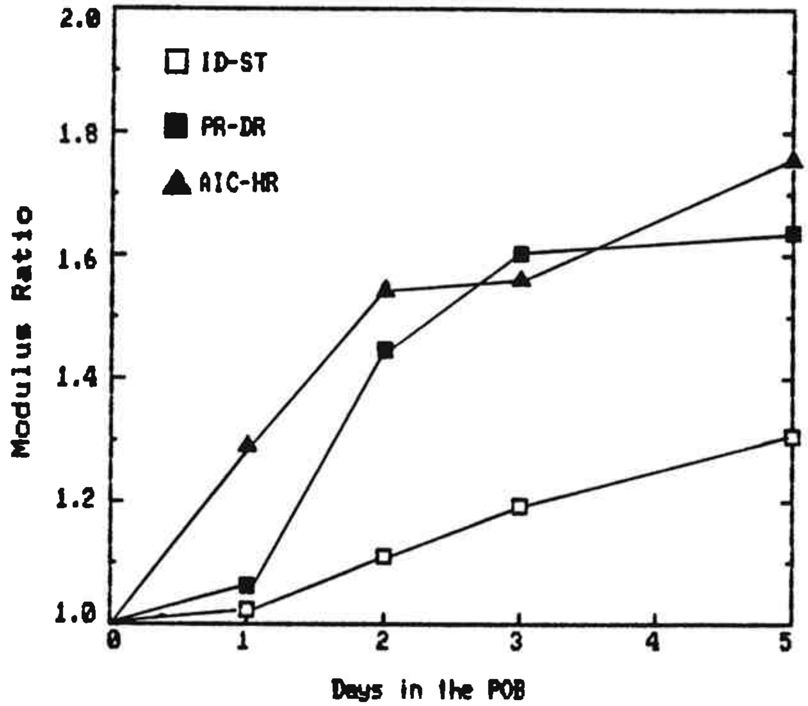
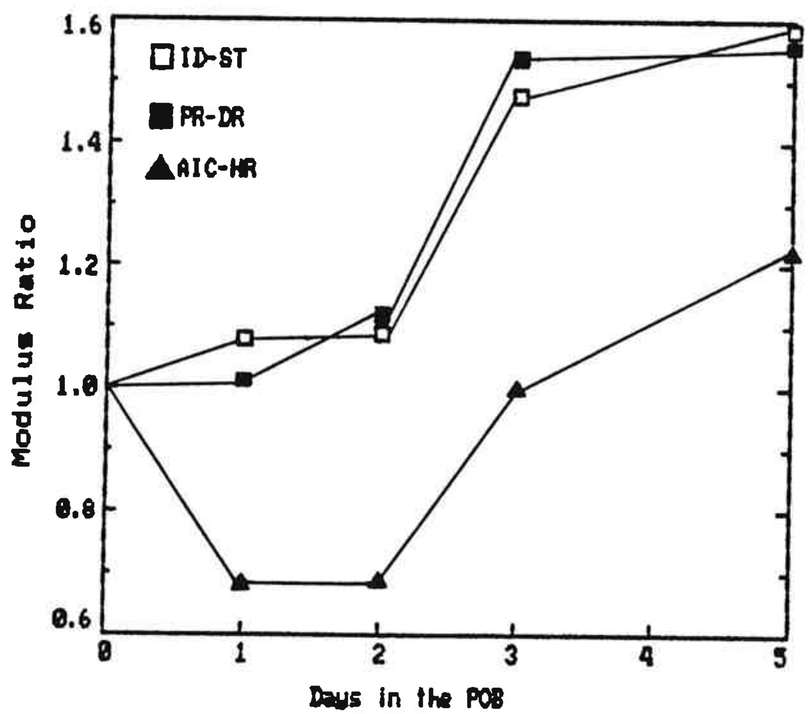


Figure 1. Pressure Oxidation Bomb (POB)



(a) At 88% Compaction Level



(b) At 94% Compaction Level

Figure 2. Aging Modulus Ratio

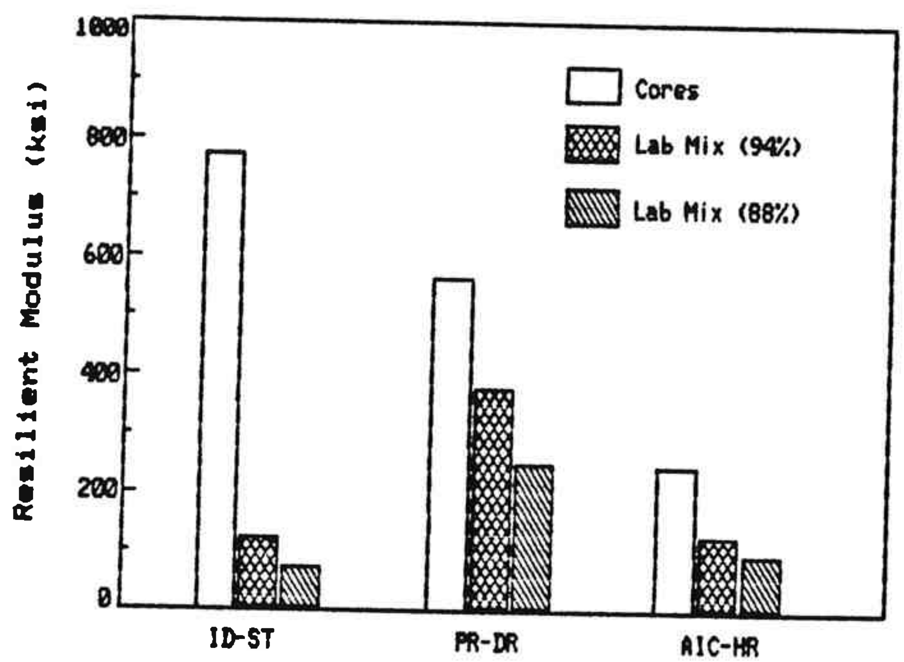
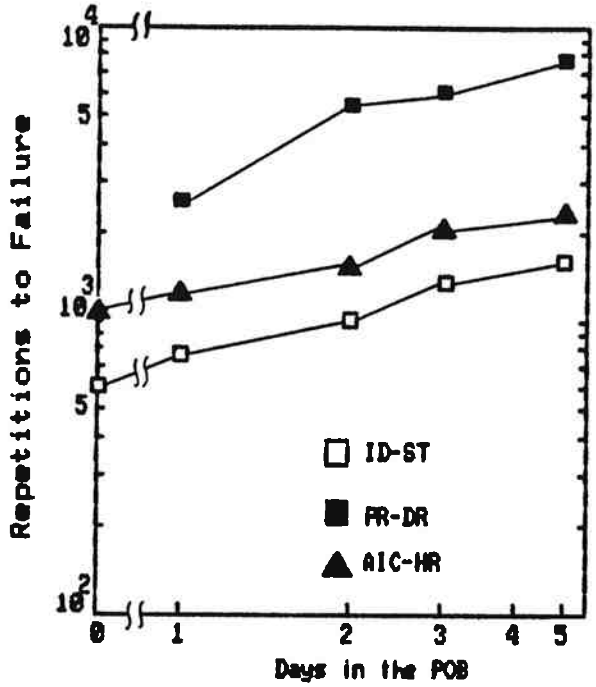
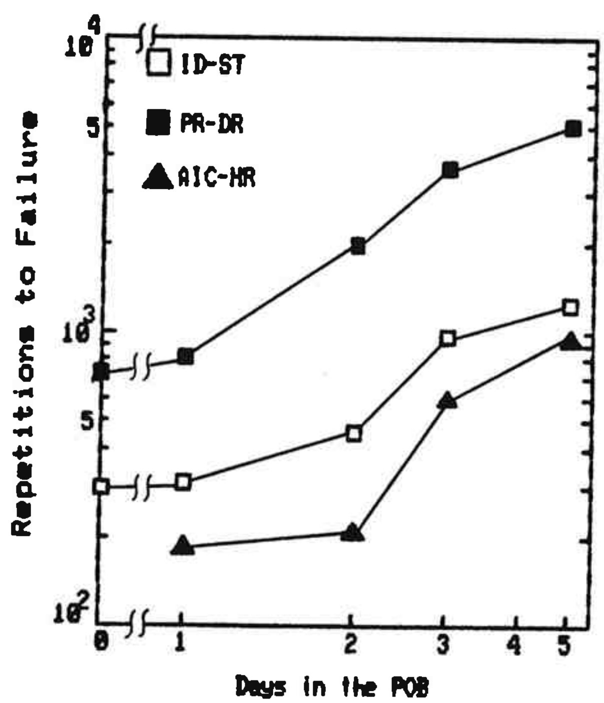


Figure 3. Comparison of Modulus Between Cores and Aged Mixtures



(a) At 88% Compaction Level



(b) At 94% Compaction Level

~~Figure 4. Fatigue Life of Aged Specimens~~

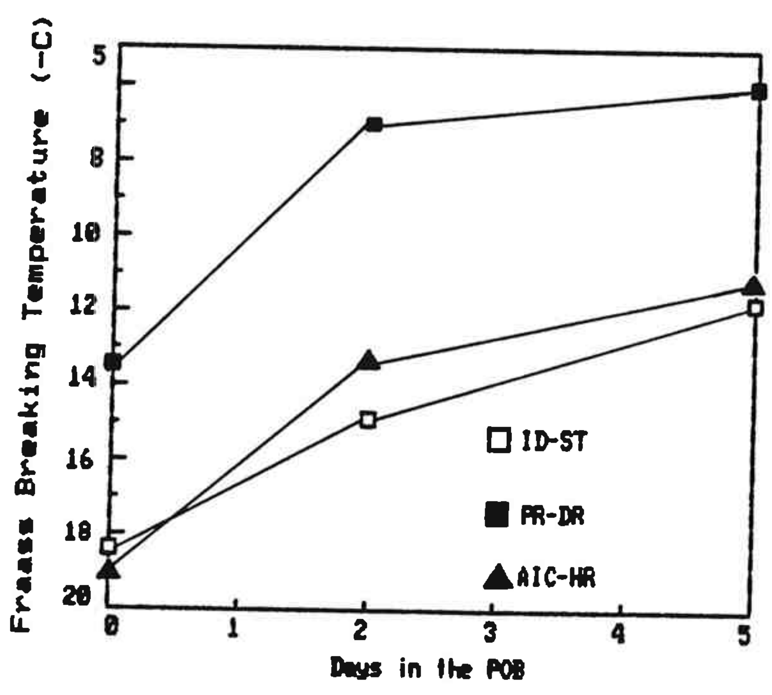
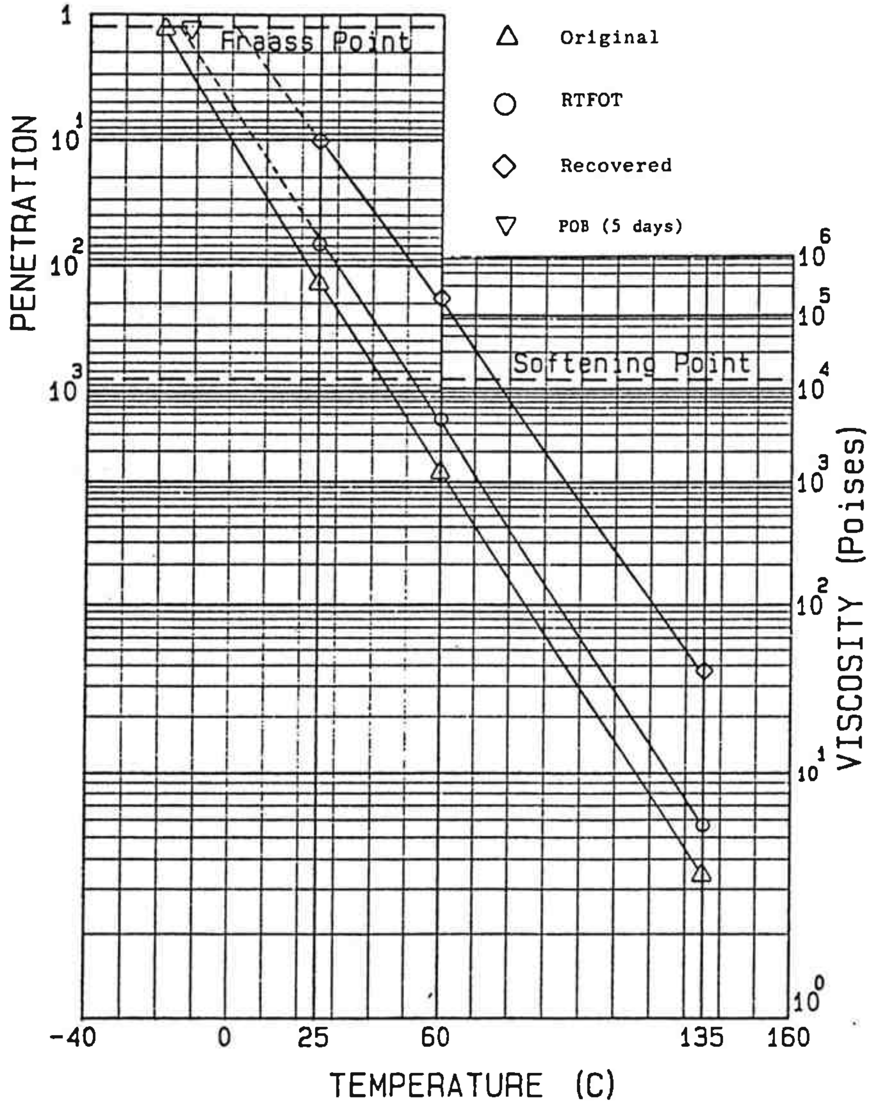
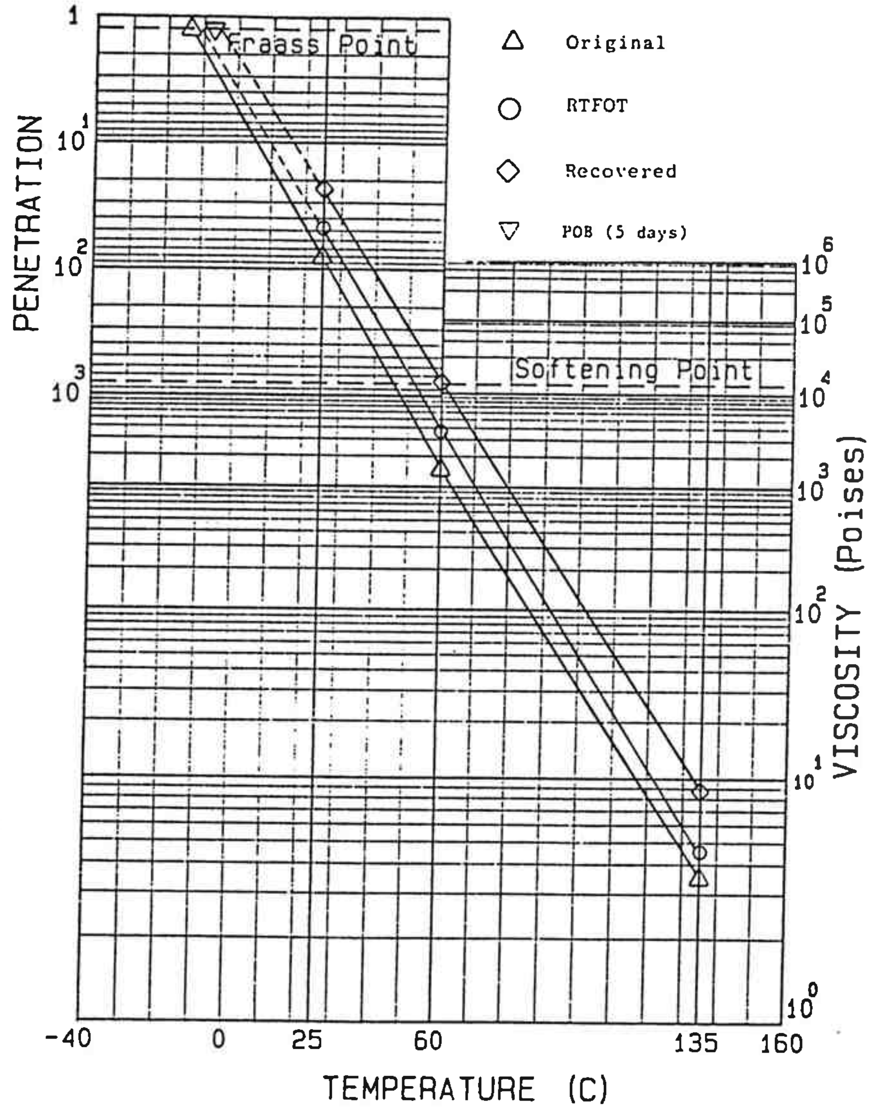


Figure 5. Effect of POB Aging on Fraass Temperature of Asphalt Cement



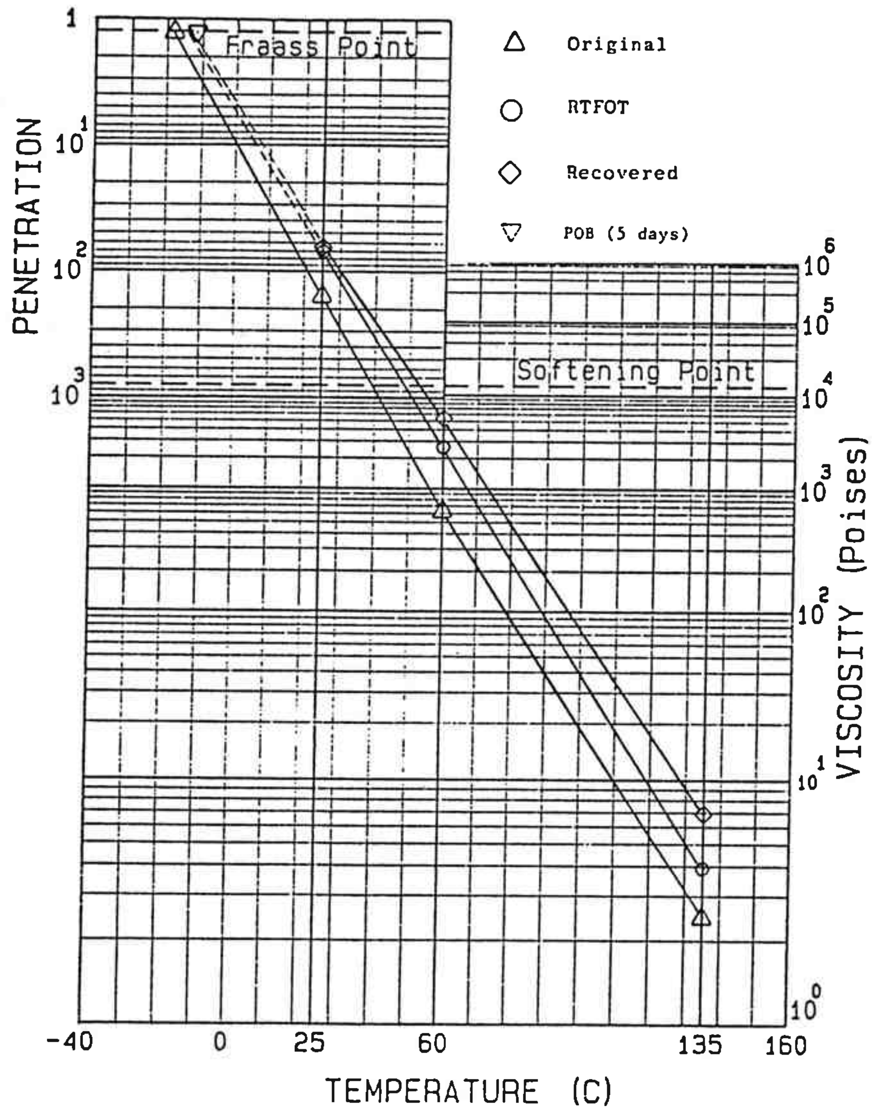
(a) Idylwood Street

Figure 6. Asphalt Consistency Data



(b) Plainview Road-Deschutes River

Figure 6. Asphalt Consistency Data (Continued)



(c) Arnold Ice Caves-Horse Ridge

Figure 6. Asphalt Consistency Data (Continued)

APPENDIX

SAMPLE PREPARATION AND TESTING PROCEDURE OF FRAASS BRITTLE TEST

Figure A gives a general description of the component parts of the Fraass apparatus. The following describes the sample preparation procedure and test procedure. Throughout these procedures temperature and preparation times should be controlled very carefully.

A. Sample Preparation

The following are the steps used for the sample preparation:

1. Heat the asphalt cement until it has become fluid enough to pour from the container in which it is supplied. The temperature required to heat the asphalt cement to this consistency should correspond to a viscosity of 100 ± 10 Poises obtained from a plot of viscosity versus temperature, such as a BTDC. Do not heat the container for more than one hour.
2. Pour the asphalt on waxed paper and spread as thin as possible. Cool the asphalt at 10 C for one hour.
3. Place an amount of the asphalt corresponding to 0.40 ± 0.01 gr. in the solid state on a standard Fraass steel plaque (41 mm x 20 mm) of known tare weight. For each test, prepare at least eight plaques. This process is done at temperature below 10 C, such that the asphalt cement can be cut with a razor.

4. After placing the sample on a steel plaque, heat the plaque on the baffle plate (Figure B) cautiously. The temperature on the heating plate at the edge is the temperature used in step 1. Before heating, the level of the heating plate should be checked and maintained.
5. Place no more than three plaques around the edge (Figure B) of the heating plate. Using a very thin needle, after the sample has softened, induce the sample towards the edge of the plaque by breaking the surface tension. This step should be done as soon as possible (within 3 minutes).
6. Cool the plaques at room temperature for about one hour then place in a refrigerator until executing the Fraass test.

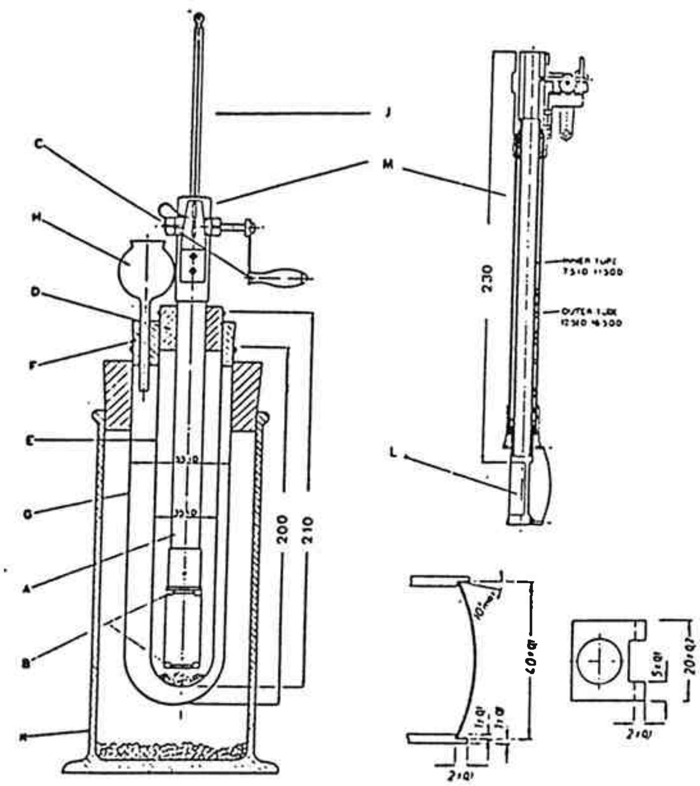
B. Testing Procedure

The steps of testing are the following:

1. Check the bending apparatus and the distance between the plaque hinges. The distance should be 40 ± 0.1 mm as shown in Figure A.
2. Place a small quantity of calcium chloride or anhydrone in the test tube E and the cylinder K (Figure A).
3. Assemble the test tubes as shown in Figure A, and fill the annular space between E and G to about half its height with acetone.
4. Attach a thermistor behind the plaque and place the plaque between the clips of the bending apparatus,

bending the plaque gently to do so, and mount the bending apparatus in the tube E.

5. Add solid carbon dioxide to the acetone at such rate that the temperature falls at rate of 1 C per minute.
6. When the temperature reaches 0 C, start to turn the handle "C" at a rate of one revolution per second for 11 or 12 turns and then unwind the handle at the same rate.
7. Repeat step 6 until one or more cracks appear on the sample. Record the temperature at this point as the Fraass breaking point.



(dimensions in mm)

KEY

A: Concentric cylinder

B: Plaque hinges

C: Rotating handle

D: Supporter rubber bung. Seals chamber one.

E: Test-tube. Air chamber one. Contains small quantity of calcium chloride to absorb moisture.

F: Supported rubber bung

G: Test tube containing acetone

H: Funnel

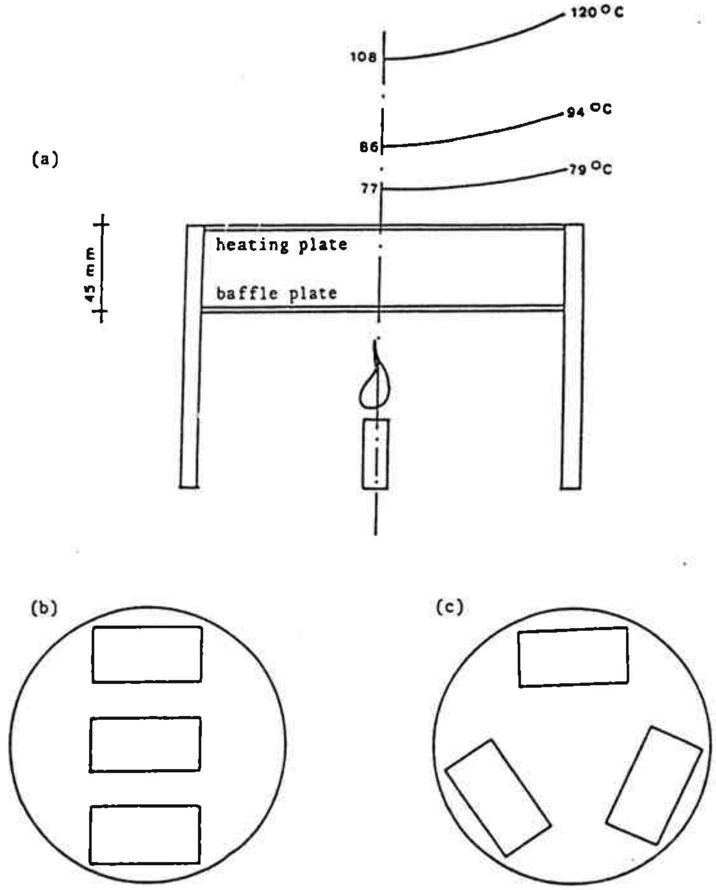
J: Mercury thermometer

K: Glass cylinder. Air chamber two contains small quantity of calcium chloride to absorb moisture.

L: Location of the thermometer bulb

M: Bending apparatus

Figure A. Schematic of Fraass Apparatus (After Ref. 16)



(a) Temperature Gradients on Plate for Three Different Flame Intensities

(b) Plaque Positioned the Wrong Way

(c) Better Way of Placing Plaques during Preparation

Figure B. Schematic of Fraass Sample Preparation (After Ref. 16)