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16. Abstract

Asphalt concrete field test pavements were placed in District 19 north of Texarkana on US-59/71 in 1987 and 1988 to evaluate the ability of certain asphalt additives to enhance resistance to cracking and rutting. Two 10-inch thick and 0.9 mile (approx.) long test pavements and a similar untreated control section were constructed in the northbound and southbound lanes for a total of 6 field trials. Asphalt additives were incorporated in both the 8-inch base and the overlying 2-inch surface layers. The additives evaluated included Goodyear LPF 5812, Chemkrete-CTI 102, Exxon Polybilt 102, and Styrelf 13.

Samples of paving materials including aggregates, asphalts, compacted mixes, and pavement cores were collected, conveyed to the laboratory, and tested to provide detailed documentation of their properties. Tests included rheological properties of the binders before and after artificial aging, characterization of aggregate, Hveem and Marshall stability, stiffness as a function of temperature, tensile properties before and after moisture conditioning and artificial aging, air void content, creep, and permanent deformation. Field tests and visual evaluations have been conducted to objectively evaluate field performance. Results of these tests are reported herein.

Within 6 months after construction of the base layers and prior to placement of the surface course, the Chemkrete modified base became severely cracked. As a result, the surface mix placed on this base section was treated with Goodyear latex rather than Chemkrete. All other modified pavements and the control section have performed well and exhibited essentially equivalent performance after 2 1/2 years in service.

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ADDITIVES IN THICK HOT MIXED ASPHALT CONCRETE PAVEMENTS

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Research Report 187-18
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METRIC (SI*) CONVERSION FACTORS

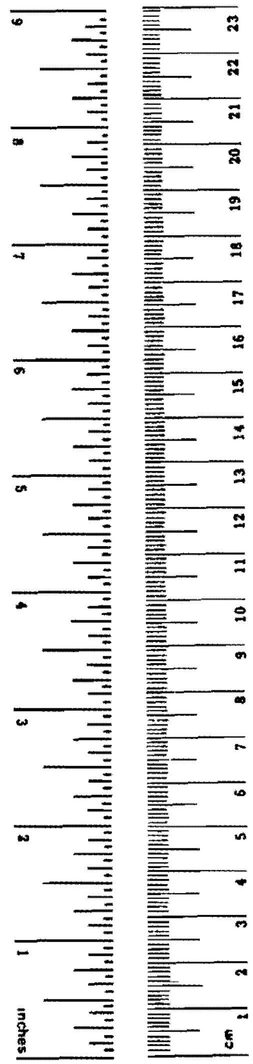
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

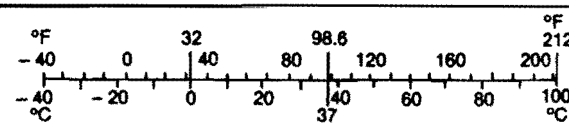


APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

IMPLEMENTATION STATEMENT

Field test pavements composed of 10 inches (8-inch base and 2-inch surface) of modified asphalt concrete were placed in extreme northeast Texas to evaluate the ability of certain asphalt additives to improve pavement performance on a very heavily trafficked roadway. These experiments will provide important information needed to assess cost effectiveness of the particular asphalt additives being studied assuming periodic evaluations of these test sections are continued for the next several years. Results of these field tests can be used to make inferences about performance of other similar polymer-type additives.

For the present time, design of asphalt paving mixtures containing polymeric additives may be accomplished using standard procedures. However, consideration should be given to increasing the mixing and compaction temperatures to accommodate the increased binder viscosity and more closely simulate field operations. It should be pointed out that Hveem stability is not normally sensitive to changes in mixture properties brought about by incorporation of an asphalt additive. Improved mixture design procedures are forthcoming from the National Cooperative Highway Research Program (NCHRP) and the Strategic Highway Research Program (SHRP) and should be investigated.

Pavement thickness design may be performed in the usual manner when modified asphalts are employed. Unless modulus and strength data support reductions in thickness when an additive is used, no attempt should be made to offset the additional cost of the additive by construction of a thinner pavement section. If pavement thickness reductions are not justified, no cost savings will result during the first year; cost-effectiveness must depend on additional service life and reduced maintenance.

When asphalt additives are used, plant operations may or may not need to be modified depending on whether the additive is preblended or blended at the plant site. Generally, mixing and compaction temperatures should be increased to accommodate the higher than usual viscosities of the polymer modified binders to insure adequate coating of the aggregate in the plant and densification of modified paving mixtures. Observations of aggregate coating should be made and compaction test strips should be constructed in order to determine the optimum plant operating temperatures. In addition, extended hot storage of asphalt modified with some polymers may result in degradation of binder properties. Degradation may result from chemical breakdown of the polymer or physical separation of the asphalt and the polymer due to differences in specific gravity.

A compaction cessation temperature of 175°F (79°C) is specified by the Department. If an additive increases the mass viscosity of the mix by a substantial amount without increasing the tensile strength (at the temperature of interest), the normally specified compaction cessation temperature may no longer be valid. This concept needs to be investigated so that appropriate compaction cessation temperatures (or viscosities) can be established for modified asphalt materials.

Until results are available from the SHRP, it appears that specifications will need to be specific for a particular type of asphalt additive since the properties of the commercial additives vary tremendously. Acceptance criteria should be based on fundamental engineering properties and should consider minimum increases in tensile strength, stiffness, resistance to creep and permanent deformation at high service temperatures and compliance at low service temperatures. These tests are designed to simulate real pavement stresses and presently are the most useful in predicting pavement performance using computer software and other predictive methods.

DISCLAIMER

ACKNOWLEDGEMENTS

Special thanks are extended to Texas SDHPT personnel of District 19. Mr. Sawyer R. Wimberly, former District Administrative Engineer, and Mr. Charles W. Armstrong, former District Designing Engineer, were instrumental is setting up this field experiment. The late Mr. Jack L. Smith, Supervising Resident Engineer at Texarkana, managed construction and assisted during short-term evaluation of the test pavements. Mr. John E. Betts, Geologist, furnished much information regarding materials sources, mixture design, and other important items.

Mr. Paul E. Krugler and Mr. A. B. (Brad) Hubbard served as technical coordinators on this study. Their valuable advice and assistance in establishing and evaluating the test pavements is hereby gratefully acknowledged.

Technical information about additives and blending processes was provided by the following additive supplier/manufacturers: Elf Aquitaine Asphalt (Styrelf), Exxon Chemical Company (Polybilt), LBD Asphalt Products Company (Chemkrete), and Fina Oil and Chemical Company (Goodyear 5812). Their participation and cooperation is appreciated.

Laboratory testing at TTI was performed by Messrs. Gene Schlieker, Sidney Greer, Ed Ellis, and Ysidoro Ramirez.

Assistance in preparation of this manuscript was received from Mmes. Lupe Fattorini and Cathy Bryan.

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INTRODUCTION

This work began as HP&R Study 471, "Asphalt Additives for Increased Pavement Flexibility." The overall purpose of the study was to evaluate selected additives or modifiers as economic alternatives to improve resistance to cracking in asphalt concrete paving mixtures. Several asphalt additives have been evaluated in the laboratory and in the field and three reports have been issued (1,2,3).

Near the end of Study 471, plans were in motion to establish side-by-side asphalt additive test pavements on US-59/71 in District 19 North of Texarkana, Texas. Laboratory and field investigations of this work was continued under Study 187. In 1987 and 1988, the test pavements, which contained four different asphalt additives with untreated control sections, were constructed. The asphalt test pavements consisted of a eight-inch base layer and a two-inch surface layer. The additives included:

Goodyear 5812 - styrene butadiene rubber latex (SBR),
Exxon Polybilt 102 - ethylene vinyl acetate (EVA),
Styrelf-13 - SBR vulcanized with asphalt cement, and
Chemkrete - a manganese organic complex in an oil base.

The chief objective of this follow-up work was to document construction procedures and paving materials properties and to evaluate short-term performance of the test pavements.

The primary purpose of the asphalt additives employed in this study is to reduce the probability of cracking and rutting in a thick asphalt concrete pavements subjected to heavy high-volume traffic. Ultimately, long-term performance and cost-effectiveness of the additives will be examined. A laboratory test program was performed to quantify relative strength, stiffness, flexibility, and resistance to permanent deformation and moisture damage of the modified binders and/or paving mixtures. Current performance of the District 19 field test pavements and laboratory experimental findings are reported herein.

This is the fourth in a series of reports that have been produced in this study. Others include Research Report 471-1, "Another Look at Chemkrete", Research Report 471-2F, "Asphalt Additives for Increased

Pavement Flexibility", and Research Report 187-14, "Asphalt Additives in Highway Construction" which are References 1, 2, and 3, respectively.

SUMMARY OF FIELD TRIALS

A 5.6 mile highway construction project MA-F 472(3) composed of designated test pavements containing asphalt additives was built in District 19 on US-59/71 north of Texarkana in 1987 and 1988. The project is located in Bowie County from 1.8 miles north of IH-30 to 0.8 mile south of the Red River. This is a fairly flat rural alluvial area in the Red River bottom. The decision to build test pavements on the construction project was made prior to letting out the project for bids. The project consisted of reconstruction of the existing two-lane pavement and construction of two adjacent lanes to provide a four-lane divided facility. Two test pavements and a control pavement were built in the northbound and the southbound lanes. A map showing the layout of the six pavement sections is shown in Figure A1, Appendix A. The 0.9 mile (approximately) test pavements consist of eight inches of Item 340 Type B (7/8-inch nominal maximum size) and two inches of Item 340, Type D (3/8-inch nominal maximum size) asphalt concrete placed on an 18-inch lime-flyash treated subgrade that had been sealed with an MC-30 prime coat. The Type B mix was placed in three lifts. Specific information about these test pavements is furnished in Table 1. Climatic and traffic data are included in Table 2.

Construction (preparation of the subgrade) of the northbound lanes adjacent to the existing highway began in the fall of 1986. The eight-inch asphalt treated base course was placed in the summer of 1987 and the northbound lanes were turned over to traffic. Reconstruction of the existing two-lane highway (which became the southbound lanes) began in the summer of 1987 and the asphalt treated base course was placed in the fall of 1987. Traffic used these "interim" pavements until the spring of 1988 when the two-inch surface courses were placed in both the northbound and the southbound lanes.

Four different additives were evaluated. These included Chemkrete (CTI-102) supplied by LBD, ethylene vinyl acetate (Polybilt 102) supplied by Exxon, SBR latex (Goodyear 5812) supplied by Fina, and neat synthetic rubber vulcanized with asphalt (Styrelf 13) supplied by Styrelf. The names given to these products are trademarks registered by their suppliers. Both the Type B (base) and Type D (surface) mixes were treated with the same additive in a given test section, with one exception. Chemkrete was removed

Table 1. Summary of Field Project in District 19 North of Texarkana.

General Information

Highway Designation	US 59/71
County	Bowie
Control Section No.	0217-01-018
Construction Project No.	MA-F 472(3)
No. Lanes in each Direction	2
Dates of Construction	
Base (Ultrapave & Chemkrete)	July, 1987
Base (Styrelf & Polybilt)	October, 1987
Surface (all)	May, 1988
Type of Construction	New Construction (Northbound) Reconstruction (Southbound)
Pavement Structure	
Layer 1 (top)	2 in. ACP Type D (3/8" max)
Layer 2	8 in. ACP Type B (7/8" max)
Layer 3	18 in. lime-flyash treated subgrade

Asphalt Paving Mixtures

	Base Course	Surface Course
Asphalt Source		
Ultrapave Latex	Fina AC-10	Fina AC-10
Chemkrete-CTI 102	MacMillan AC-20	Fina AC-10
Polybilt 102 EVA	Lyon AC-20	Lyon AC-20
Styrelf	Exxon	Exxon
Control (no additive)	MacMillan AC-20	MacMillan AC-20
Quantity Additive in Asphalt Cement		
Ultrapave Latex	3.0%	3.0%
Chemkrete	2.0%	3.0% latex*
Polybilt EVA	3.5%	3.5%
Styrelf	3.0%	3.0%
Control	0	0
Aggregate Types		

* Chemkrete was replaced with latex in the surface mix.

Table 2. Traffic and Environmental Data for Test Site in District 19.

Traffic Data	
ADT (1985 & 2005)	8,800/13,000
Trucks in ADT, percent	15.2
ATHWLD	12,900
Tandem Axles in ATHWLD, percent	60
Equivalent 18kip axle loads expected 1985 to 2005	5,670,000
Speed Limit, mph	55
Weather Data	
Climate	
Temperature	
Mean Max, °F	75
Mean Min, °F	54
No. Days/yr 90°F & above	64
No. Days/yr 32°F & below	44
Sharp drops	Yes
Frost Penetration, in.	2
Freeze index	0
Precipitation	
Mean annual precipitation, in.	45.3
Mean annual ice/snow, in.	4

from the market by LBD shortly after construction of the base course. The surface course placed on the Chemkrete treated base course contained three percent Goodyear latex in the asphalt.

Chemkrete was metered into an in-line mixer and blended with the asphalt at the plant site using a special device furnished by LBD Asphalt Products Company. Polybilt was blended at the plant site in a batch-type operation using a low-shear mixer. Styrelf and Goodyear 5812 were blended with asphalt prior to arrival at the asphalt plant. Mixing and placing of the modified mixtures was generally routine and without any additive-related problems. Minor exceptions are listed in the notes pertaining to highway construction using these products (Table 3).

All pavements contained the same aggregates and used basically the same mixture design and construction equipment and procedures. The two control pavements (northbound lanes and southbound lanes) contained MacMillan AC-20. The additive test pavements contained asphalts of various grades from various sources as shown in Table 1. This is not an ideal situation for comparative evaluation of additives but it was necessary to expedite construction of the experimental pavements.

Asphalt paving operations were performed by HMB Construction Company of Texarkana, Texas. The mixes were prepared using a model 8828 ADM Cedar Rapids plant with a capacity of 400 tons per hour. Placing of the mixes was accomplished using BSF541 Cedar Rapids paving machine. A 30 ton pneumatic tired compactor was employed as a breakdown roller followed by an 11 ton steel wheel vibratory roller.

Table 3. Construction Notes From District 19 Test Pavements.

Type Additive	Method of Incorporating Asphalt Additive	Remarks
None (Control Mix)	Not applicable	Plant temperature was about 300°F. All mixes experienced some minor segregation.
Chemkrete	Blended on site using in-line mixer supplied by LBD Asphalt Products Co.	Plant temperature was about 300°F.
Goodyear 5812	Blended at refinery in Port Authur, Tx. and shipped to construction site.	Mix sticky and difficult to place at 350°F, lowered to 310°F and eliminated problems. Mix stuck to pneumatic roller at temperatures above 160°F.
Styrelf 13	Blended and reacted at plant in Baytown, Tx. and shipped to construction site.	Mix stuck to pneumatic roller tires if rolled too hot. Plant temperature was about 310°F.
Polybilt 102 EVA	Blended on site for 30 minutes in a low shear batch-type mixer at 325°F by Cox Paving Co.	Not much different from mixing and compacting control mix. Plant temperature was about 325°F.

FINDINGS

The following paragraphs describe laboratory test results on asphalt-aggregate paving materials collected during and shortly after construction of the projects on US-59/71 in District 19 and subsequent pavement performance after up to three years in service.

LABORATORY TESTS AND RESULTS

Samples of the aggregates, asphalt binders, and paving mixtures, including molded specimens as well as pavement cores, were obtained at the construction site by TTI researchers and tested in the laboratory. This subsection discusses the results of a variety of laboratory tests on these paving materials. Statistical analyses were performed on the test data using one way analysis of variance (ANOVA) and Tukey's multiple range test at a confidence level of 95 percent as contained in the computer software Statgraphics. Statements about significance in this subsection are based on these statistical analyses.

Binders

Samples of unmodified and modified asphalt binders were collected (when possible) during construction of the test pavements. These binders were tested in the laboratory using the standard asphalt specification tests and the force ductility test. Results from the specification tests are recorded in Table 4 and plotted in Figures 1 through 7. It should be pointed out that Lyon AC-20 and Fina AC-10 were not used in the unmodified condition in any test pavements but were tested in the laboratory to provide a comparison with the modified material used in the test pavements. The researchers were unable to obtain a sample of the unmodified Exxon asphalt which was used to produce the Styrelf binder; according to Elf Aquitaine it had a viscosity at 140°F of about 7000 poise.

Typically, the polymers (Polybilt, Goodyear 5812, and Styrelf) increase the consistency of the asphalt at temperatures above 40°F and have little effect at lower temperatures (Table 4). Chemkrete had a softening effect on the neat asphalt. However, a part of the mechanism that Chemkrete depends on to alter asphalt properties is oxidation during plant mixing and early pavement life which had not occurred in the neat material. The Lyon

Table 4. Properties of Binders Used in Test Pavements in District 19.

Test Properties	Type of Binder						
	MacMillan AC-20	Chemkrete MacMillan	Lyon AC-20	Polybilt Lyon	Fina AC-10	Goodyear 5812 Fina	Styrelf Exxon
<u>Original Binder</u>							
Penetration, ASTM D5							
77°F(25°C) 100 gm, 5s	86	118	64	48	90	83	90
39°F(4°C) 100 gm, 5s	10	16	5	2	3	2	6
39°F(4°C) 200 gm, 60s	31	45	14	15	17	23	26
Viscosity, ASTM D2171							
140°F(60°C), poise	2210	1280	2010	2570	825	1770	2350
275°F(135°C), poise	4.46	4.69	4.09	6.19	2.57	9.40	5.95
R&B Soft Pt., °F, ASTM D36	119	120	120	136	119	127	123
Flash Pt., °F, ASTM D92	645	632	670	663	645	643	668
<u>After Thin Film Oven Test</u>, ASTM D1754							
Penetration, ASTM D5							
77°F(25°C), 100 gm, 5s	62	61	46	36	56	55	67
Viscosity, ASTM D2171							
140°F(60°C), poise	3840	4330	3360	3890	1600	2000	3990
Ductility, ASTM D113							
77°F(25°C), 5 cm/min	120+	56	120+	106	120+	120+	120+
Weight Loss, percent	0	0.24	0.23	0	0.22	0.17	0.04

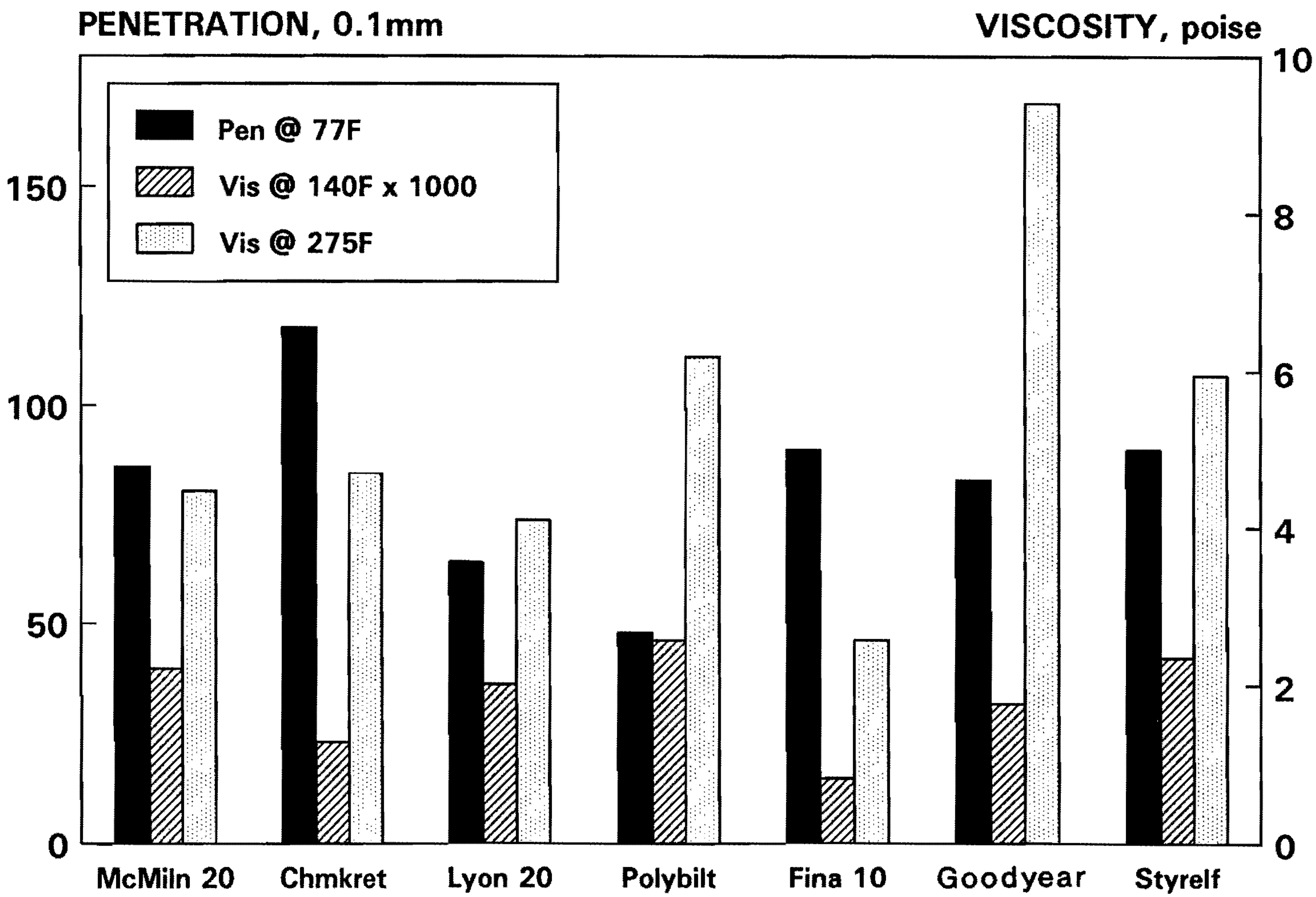

Figure 1. Penetration at 77°F and Viscosity at 140°F and 275°F for Asphalt Binders.

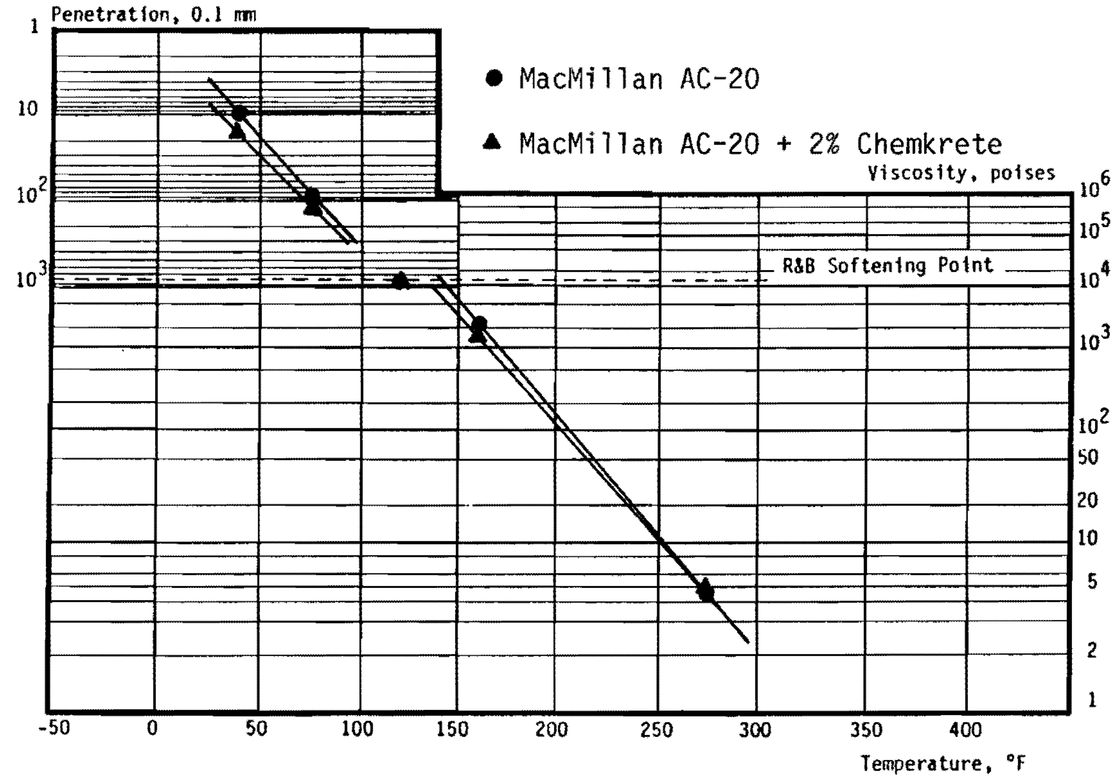

Figure 2. Rheological Properties of Chemkrete - Modified MacMillan AC-20 Compared to the Unmodified Material.

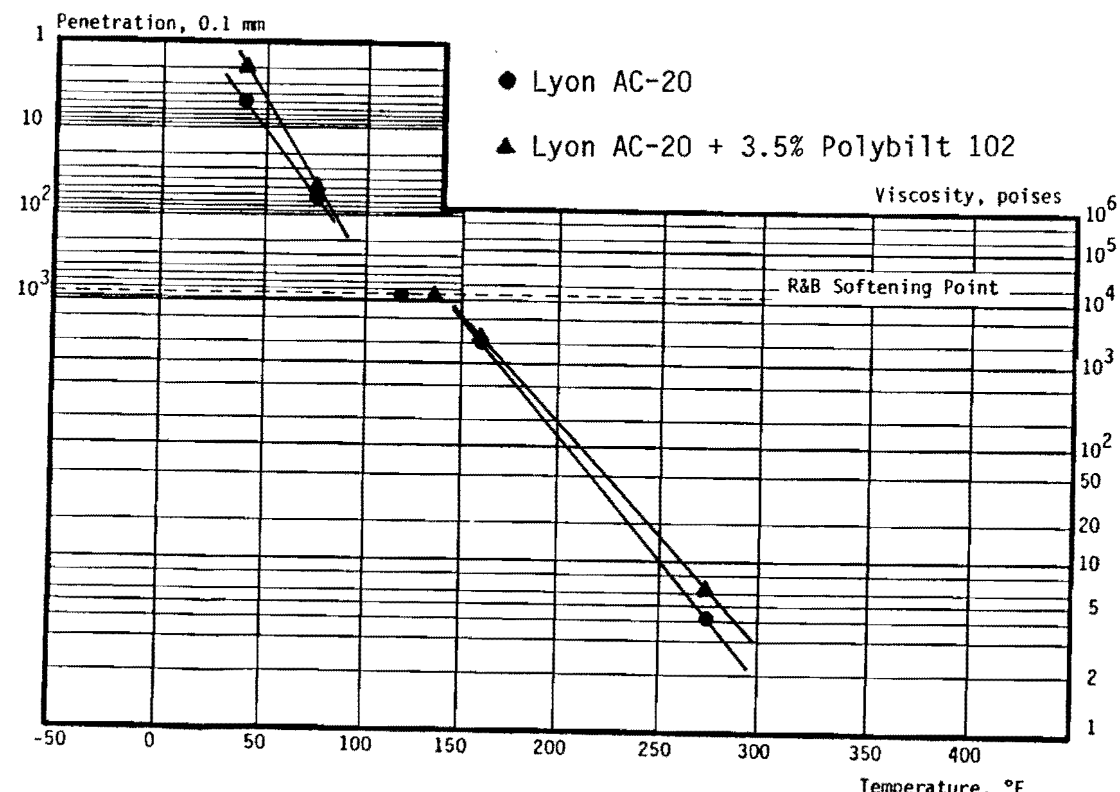

Figure 3. Rheological Properties of Polybilt - Modified Lyon AC-20 Compared to the Unmodified Material.

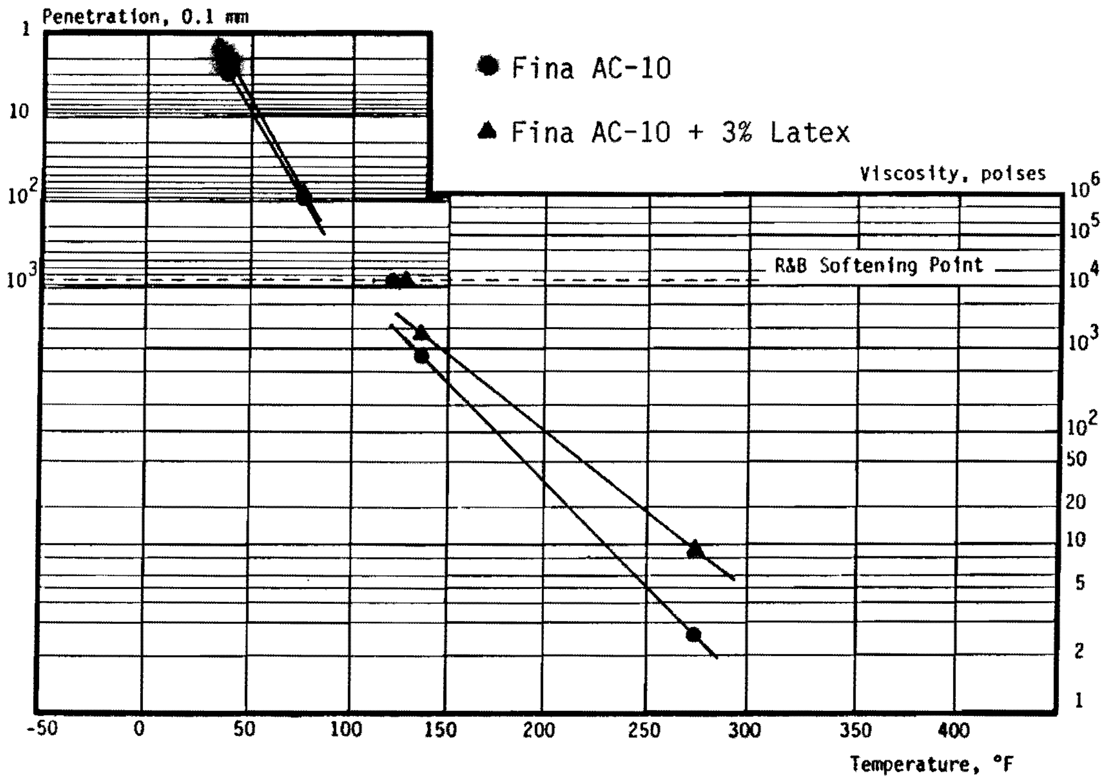

Figure 4. Rheological Properties of Latex-Modified Fina AC-10 Compared to the Unmodified Material.

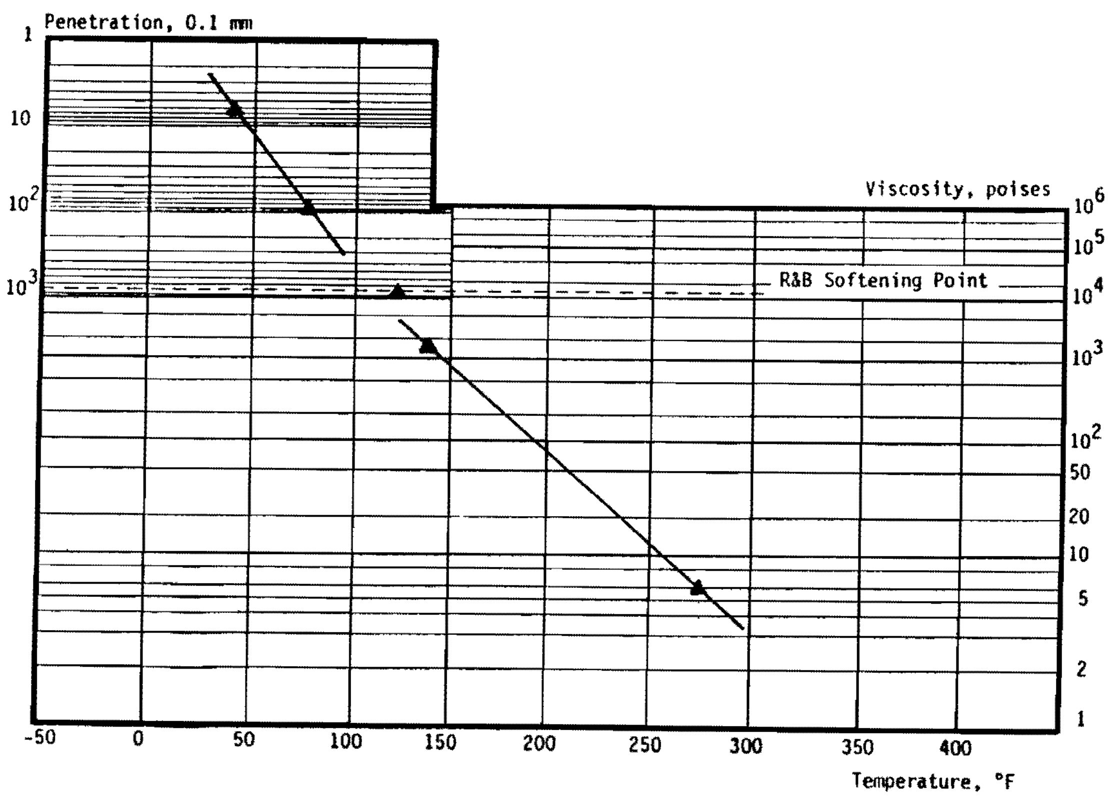

Figure 5. Rheological Properties of Exxon Asphalt Modified with Three Percent Styrelf Polymer.

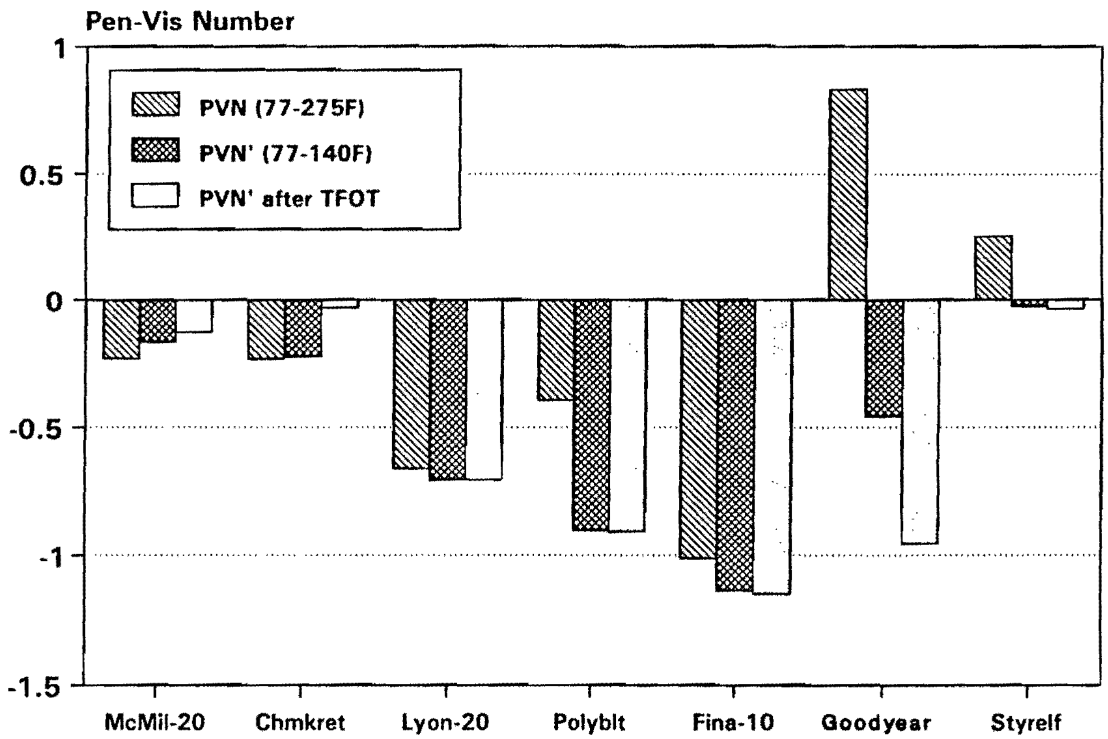

Figure 6. Temperature Susceptibility of Binders based on Pen-Vis Number.

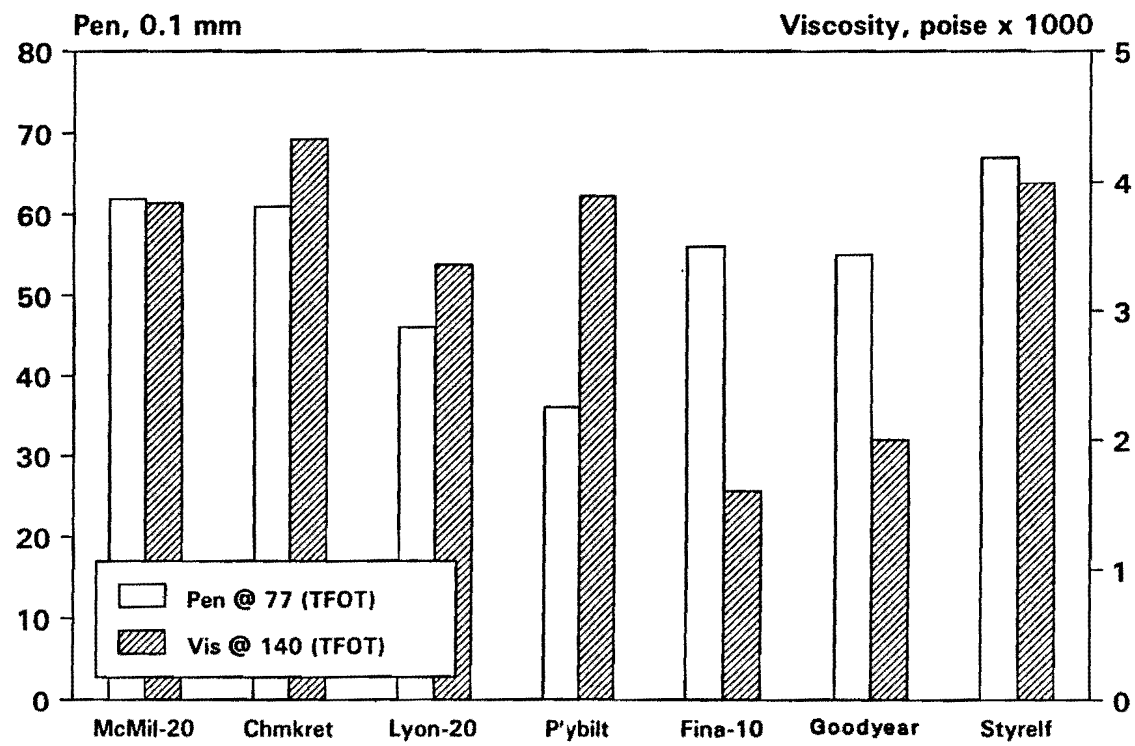

Figure 7. Penetration at 77°F and Viscosity at 140°F After the Thin Film Oven Test.

AC-20 is a fairly low penetration material and, when modified with Polybilt, it exhibited the lowest penetration at 77°F. In fact, the penetration fell below the specified value of 55 (Texas SDHPT) for an AC-20. Rheological properties of the neat binders are plotted on bitumen test data charts in Figures 2 through 5.

To compare differences in temperature susceptibility of the neat binders, penetration-viscosity numbers were computed using McLeod's (4) equations and the results are plotted in Figure 6. Temperature susceptibility increases as the value of pen-vis number decreases. The polymers exhibit the ability to reduce temperature susceptibility, particularly in the range of pavement service temperatures (77°F-140°F). Chemkrete, of course, depends on plant and in-place aging to accomplish the reduction in temperature susceptibility. Latex shows, by far, the largest reduction in temperature susceptibility from that of the original asphalt (Fina AC-10); that reduction practically disappeared, however, after the thin film oven test (TFOT).

Results after the TFOT (Tex-510-C) show significant hardening of the Chemkrete modified product, as expected, and very little hardening of the latex modified material as measured by viscosity at 140°F (Table 4 and Figures 1 and 7). All the binders met the Texas SDHPT ductility specifications.

The force ductility test is a modification of the asphalt ductility test (ASTM D113) (5) and is used to compare tensile load-deformation characteristics of modified asphalt binders. The test is typically performed following the TFOT. Data and associated plots from the force ductility tests are shown in Table 5 and plotted in Appendix A. Maximum engineering strain was much greater for the latex and Styrelf modified products than for the other materials; however, maximum engineering stress was greatest for the Polybilt modified Lyon asphalt and the unmodified Fina AC-10. Area under the stress-strain curve could be considered analogous to total work or energy required to produce failure or toughness. Force ductility data indicate the polymer additives have the ability to increase the amount of energy required to deform and ultimately fail an asphalt cement specimen (Figure A12, Appendix A).

Table 5. Summary of Forced Ductility Test at 39.2°F and 5 cm/min After Thin Film Oven Tests District 19*.

Sample Type	Maximum Engineering Stress, psi	Maximum Engineering Strain, in/in	Area Under Stress-Strain Curve	Initial Slope of True Stress-Strain Curve	Total Deformation at Specimen Rupture, cm
MacMillan AC-20	7.2	5.0	13.6	40.7	18
Chemkrete/ MacMillan	6.7	3.1	10.2	28.8	12
Lyon AC-20	20.2	5.0	37.5	140	7
Polybilt 102/ Lyon	27.4	4.3	51.2	104	15
Fina AC-10	23.9	3.4	37.8	86.7	8
Latex/Fina	18.1	17.8	76.1	56.5	49
Styrelf/Exxon	14.1	13.5	86.6	55.8	40

* Each value represents an average from two different tests.

Aggregates

Crushed sandstone and flume sand were combined to produce the hot mixed asphalt concrete used in both the base course and the surface course. The sandstone was a very hard, well cemented siliceous material with a low absorption capacity. The flume sand was also siliceous and composed of clean, rounded to subrounded, smooth-textured particles. Job mix gradations for the base course and the surface course are given in Table B1, Appendix B and Table C1, Appendix C, respectively. Identical aggregate types and gradations, within normal tolerances, were used in all test pavements and control pavements.

Mixture Design

All mixtures were designed by District 19 personnel in accordance with Texas SDHPT standard design procedures. Hot mixed asphalt concrete mixture designs for the base course control mixture and the surface course control mixture are provided in Table B2, Appendix B and Table C2, Appendix C, respectively. Optimum binder contents (in percent by weight of total mix) for the various Type B base course mixes were as follows:

MacMillan AC-20 - 4.1,
MacMillan AC-20 + Chemkrete - 4.3,
Lyon AC-20 + Polybilt - 4.2,
Fina AC-10 + latex - 4.6, and
Styrelf - 4.3.

The optimum binder content used in all the Type D surface course mixtures (modified or unmodified) was 4.8 percent.

Field Mixed-Laboratory Molded Mixtures

Base Mixes. During construction of the base layer, samples of each test mixture were obtained from selected haul units. The mixtures were immediately conveyed to the Department laboratory at the plant site where eighteen four-inch diameter and two-inch high cylindrical specimens were compacted using the standard Texas gyratory molding procedure. Average air void content of these Type B mixture specimens ranged from 3.8 percent to 5.1 percent. These specimens were tested in accordance with the test program outlined in Figure 8. Results from tests on these base mixtures are tabulated in Tables B3 through B7.

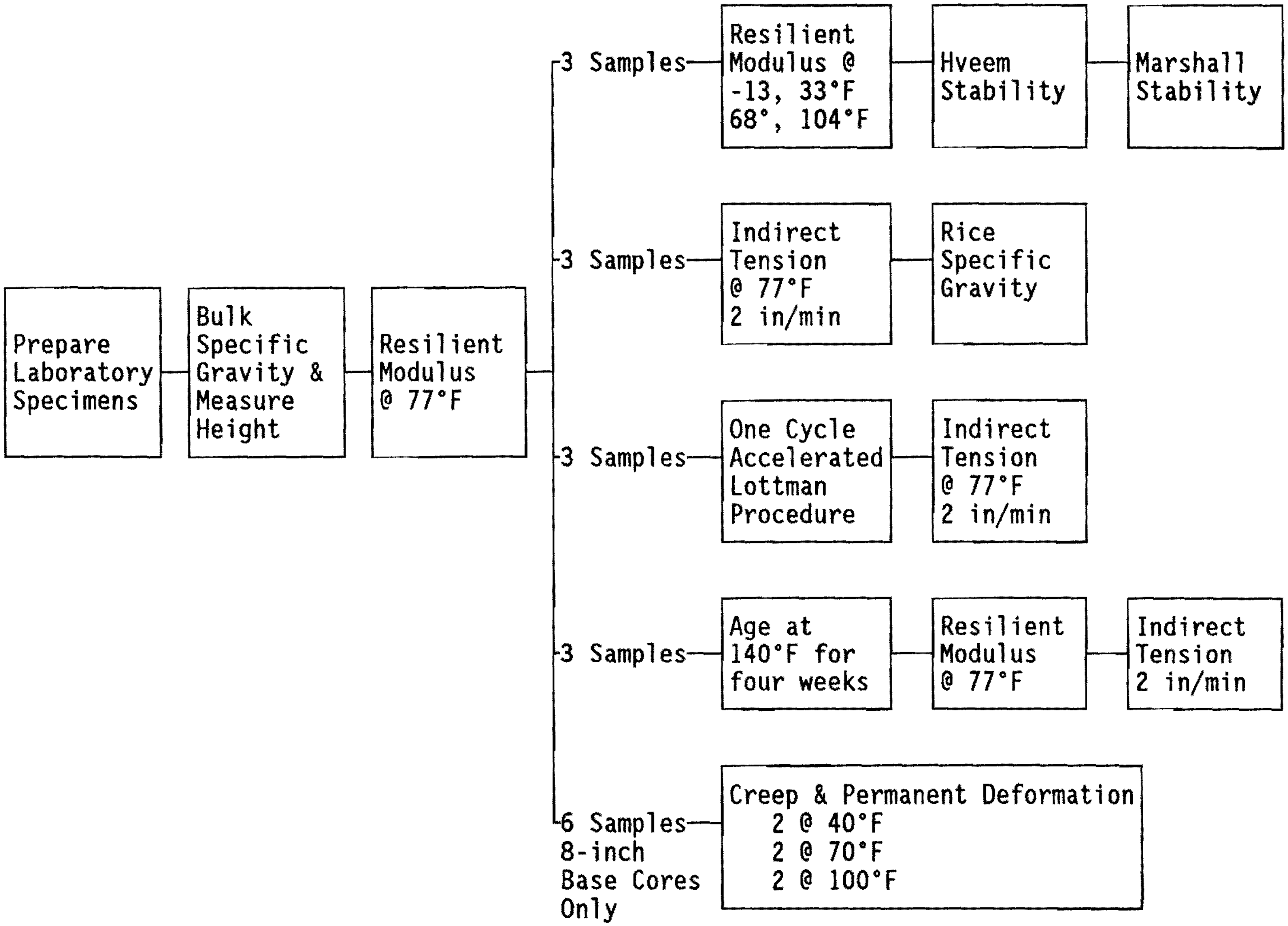

Figure 8. Laboratory Test Program for Paving Mixtures (field mixed-laboratory compacted base mixes, cores from base, and cores from surface).

Mixture stiffness as a function of temperature was measured using the Mark III resilient modulus device in accordance with ASTM test method D4123. Typically, a diametral load of approximately 72 pounds was applied for a duration of 0.1 seconds while monitoring the diametral deformation perpendicular to the loaded plane. The load is normally reduced to about 20 pounds for tests performed at 100°F or higher to prevent damage to the specimens. Resilient modulus measured over a range of temperatures is used to provide comparative estimates of the load spreading capacity of the different mixtures at various temperatures. Resilient modulus data are plotted in Figure 9.

Generally, the modified binders are shown to produce stiffer laboratory molded mixtures than the unmodified MacMillan (control) asphalt. At the lowest temperature (-13°F), Tukey's multiple range test places the mean resilient moduli into two groups within which the values are not significantly different. The two groups contain (1) Chemkrete, control, Polybilt, and Goodyear and (2) control, Polybilt, Goodyear, and Styrelf. Only Chemkrete and Styrelf have significantly different means. At 68°F, there are four groups of two each within which the values are not significantly different; they are (1) control and Chemkrete, (2) Chemkrete and Goodyear, (3) Goodyear and Styrelf, and (4) Styrelf and Polybilt. At 77°F, resilient modulus of the control mixture is significantly lower than the other mean values and resilient modulus of the Polybilt which is significantly higher. At 104°F, resilient modulus of only the Goodyear and Polybilt are significantly different from each other but they are not significantly different from the other mean values. In summary, resilient modulus of the Chemkrete mixture was not significantly different from the control mixes at any temperature. Polybilt mixtures exhibited the lowest mixture temperature susceptibility and Goodyear mixtures exhibited the highest temperature susceptibility. These findings would not have been predicted based on results of binder tests.

Hveem and Marshall stability of these gyratory molded specimens are shown in Figure 10. Hveem stability was measured in accordance with test method Tex-208-F, Test for Stabilometer Value of Bituminous Mixtures. Differences in Hveem stability are small. As is usually the case, the quality of the binder has little effect on Hveem stability. Statistical analyses showed that Hveem stability fell into two groups within which the

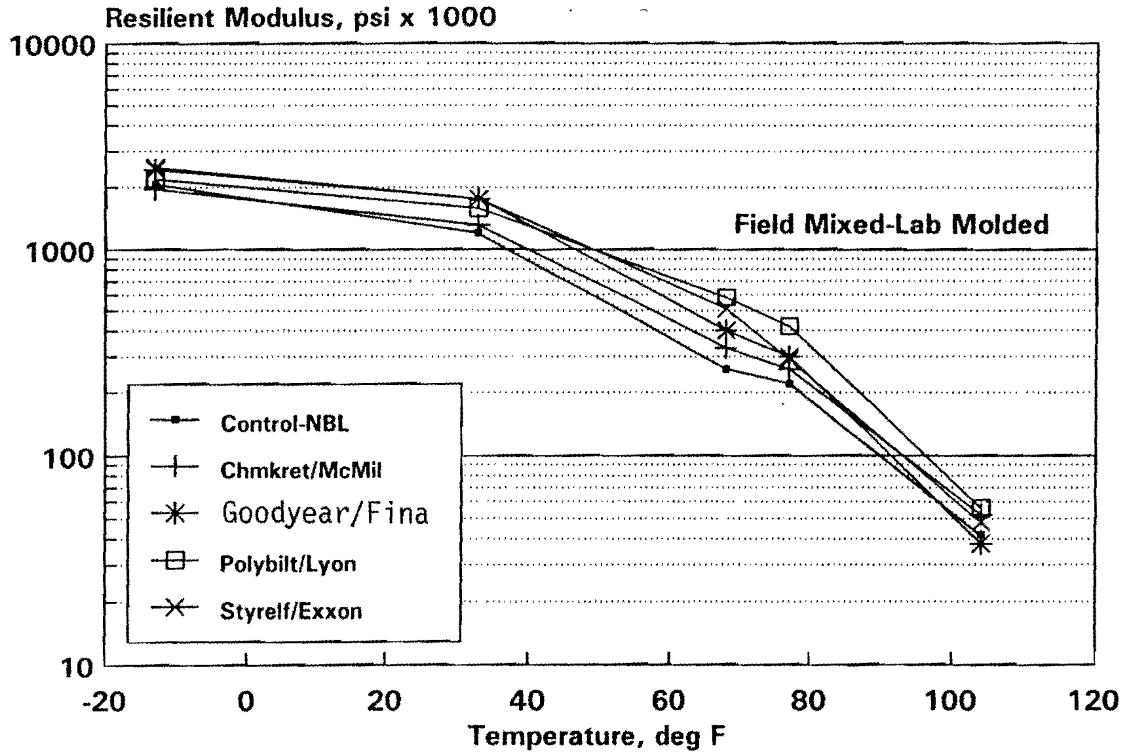

Figure 9. Resilient Modulus of Field Mixed-Lab Compacted Base Mixtures as a Function of Temperature.

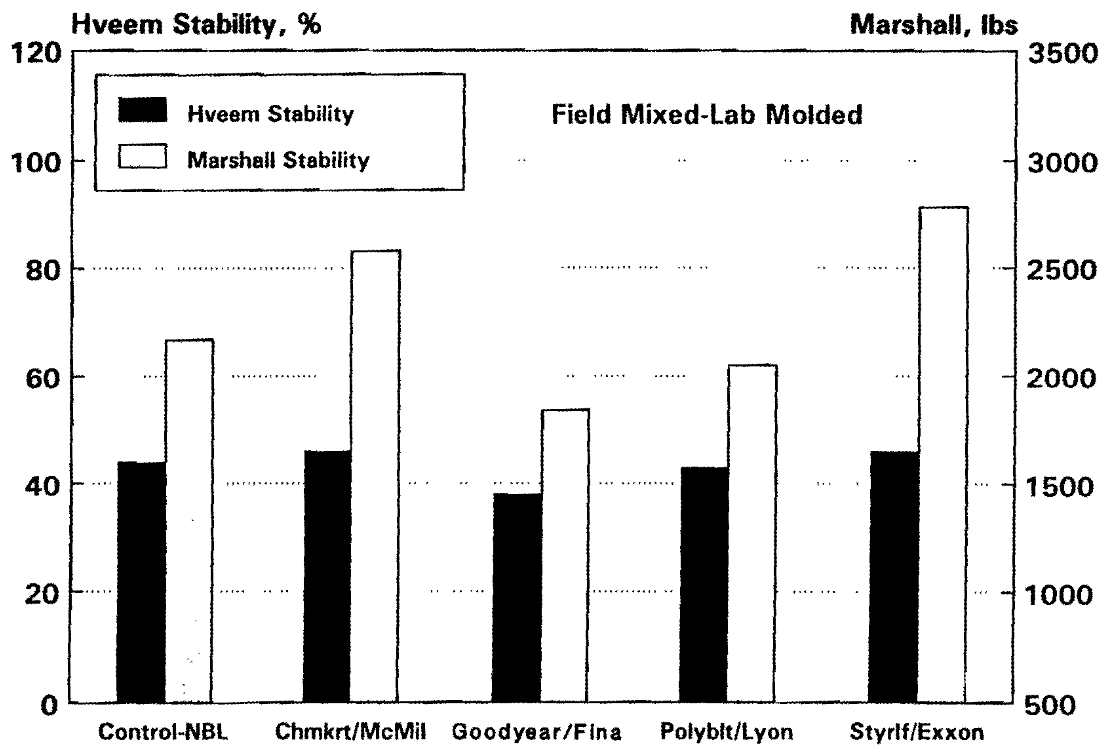

Figure 10. Hveem and Marshall Stability of Field Mixed-Laboratory Compacted Base Mixtures.

values are not significantly different. The two groups consist of (1) Goodyear and Polybilt and (2) Polybilt, Chemkrete, Styrelf, and Control. That is, only Goodyear is significantly different (lower) from the control.

Marshall stability, on the other hand, was significantly affected by the viscosity of the modified binders (See Table 4). Statistical analyses showed that Marshall stability fell into three groups within which the values are not significantly different. The three groups are (1) Styrelf and Chemkrete, (2) Chemkrete and Control, (3) Control, Polybilt, and latex. Only Styrelf is significantly different (higher) from the control.

Indirect tension tests (Table B4) were performed at 77°F and two inches per minute in accordance with test method Tex-226-F. All the modified asphalts produced mixtures with significantly higher tensile strengths than the control mixture (Figure 11) at a confidence level of 95 percent. It is also noted that the Chemkrete specimens exhibited comparatively low strain at failure indicating a low tolerance for tensile strains. Tensile strength and Marshall stability are usually influenced by binder viscosity as is the case here.

Moisture sensitivity was estimated by applying Tex-531-C. Indirect tension tests were performed following an accelerated moisture treatment procedure similar to that prescribed by Lottman (6) to facilitate computation of tensile strength ratios (TSR) (Figure 11). If a minimum TSR of 0.74 is applied, then all the mixtures exhibit acceptable resistance to moisture damage. It should be pointed out that the mixtures were prepared using standard compaction and air voids were below the specified seven percent in Tex-531-C. Additionally, all the polymer (latex, Polybilt, and Styrelf) modified mixtures were mixed in the plant at temperatures higher than the control and Chemkrete modified mixtures. Higher mixing temperatures have been shown to have positive effects on resistance to moisture damage (7). In other words, these data do not show conclusively that any of these additives reduce moisture damage.

Indirect tension tests were again performed following a thermal aging treatment of the specimens (Table B5). Conditioning of the specimens consisted of exposure to 140°F in air for a period of four weeks. In almost every case, the tensile strength increased and the tensile strain at failure decreased. Resilient modulus at 77°F of the specimens before and after the

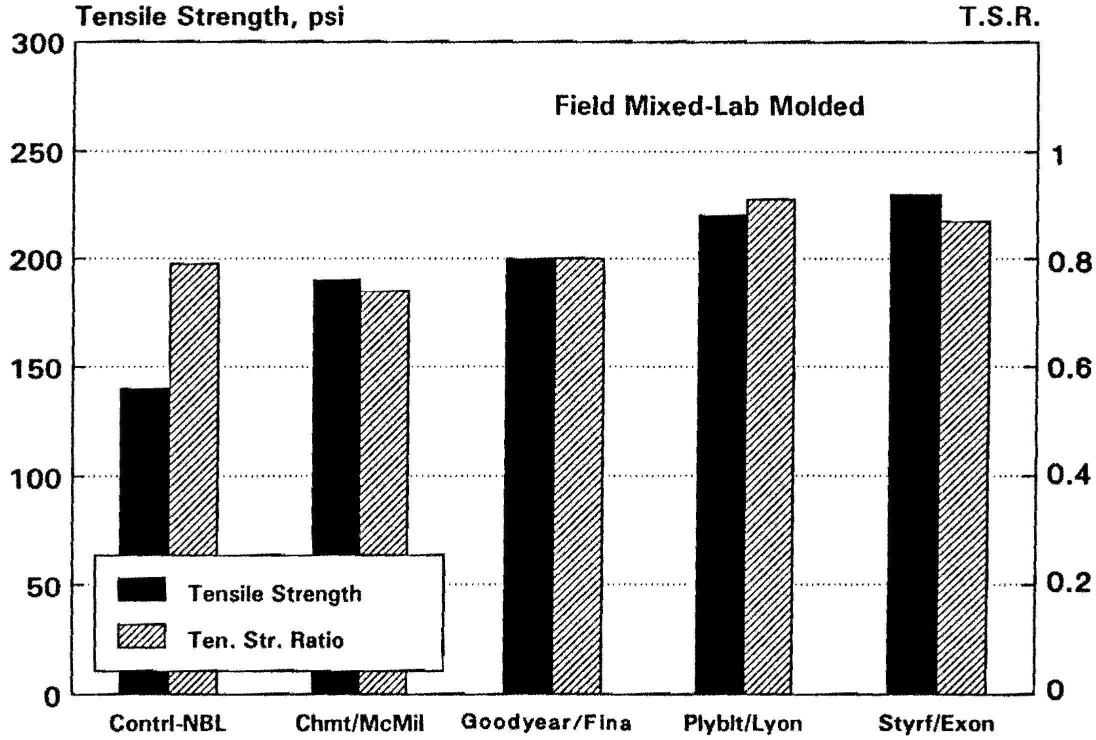

Figure 11. Tensile Strengths and Tensile Strength Ratios (after accelerated Lottman moisture treatment) of Field Mixed-Lab Compacted Base Mixtures.

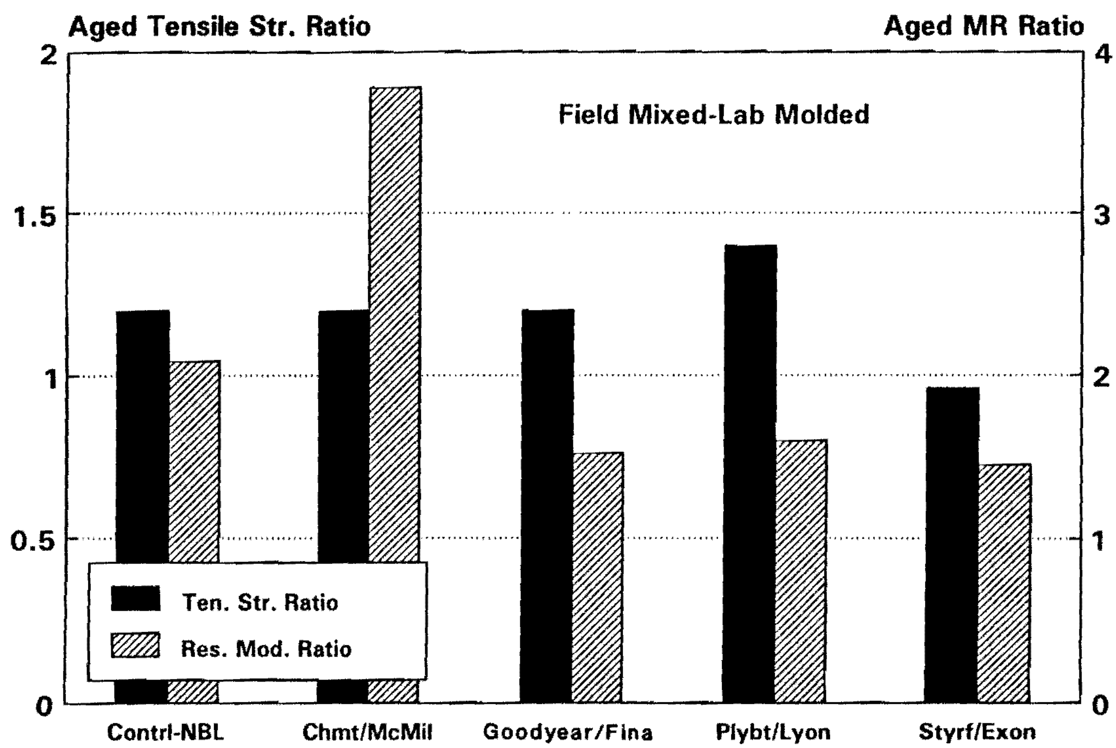

Figure 12. Tensile Strength Ratios and Resilient Modulus Ratios for Field Mixed-Lab Molded Specimens after Thermal Aging.

aging treatment was also measured and resilient modulus ratios were computed (Figure 12). Tensile strain at failure after aging is higher for the polymer modified materials. Overall, these limited tests indicate that the polymer modified specimens retain desirable properties after thermal aging better than the control or the Chemkrete modified materials.

Surface Mixes. The researchers were unable to be at the field test site during placement of the Type D surface mixtures. Therefore, no field mixed-laboratory compacted specimens were prepared for the surface mixes. However, pavement cores were collected shortly after completion of construction.

Results of Tests on Pavement Cores

Twelve four-inch diameter pavement cores were drilled from each test pavement and from the control pavements in the northbound and southbound lanes after all asphalt paving was completed. A total of six pavements were cored. The surface mixtures were separated from the base mixtures by sawing. Since the base layers were approximately eight inches thick, some of the base cores were tested intact to measure creep and permanent deformation properties. Results from these tests will be discussed in a subsequent subsection. Other base cores were sawed to produce three specimens approximately two inches in height. These two-inch base core specimens and the surface cores were tested separately in accordance with Figure 8 except for the thermal aging portion. The data are presented in Appendices B and C for the base and surface cores, respectively.

Base Cores. Resilient moduli of the two-inch height base cores (Type B) were measured at five temperatures as described above. Resulting data are plotted in Figure 13. Based on statistical analyses (ANOVA and Tukey's multiple range test), the resilient moduli of the various mixtures at -13°F, 68°F, and 77°F are not significantly different. However, at 104°F, the resilient moduli fell into two groups within which the values are not significantly different. These two groups contain the following: (1) Control-NBL and SBL, latex, Styrelf, Polybilt and (2) Control-NBL and SBL, Chemkrete, and Polybilt. Resilient modulus of the Chemkrete mixture is shown to be significantly higher than that of the Goodyear and Styrelf mixtures but none are significantly different from the control mixtures. Based on these modulus test results, it does not appear that any of the

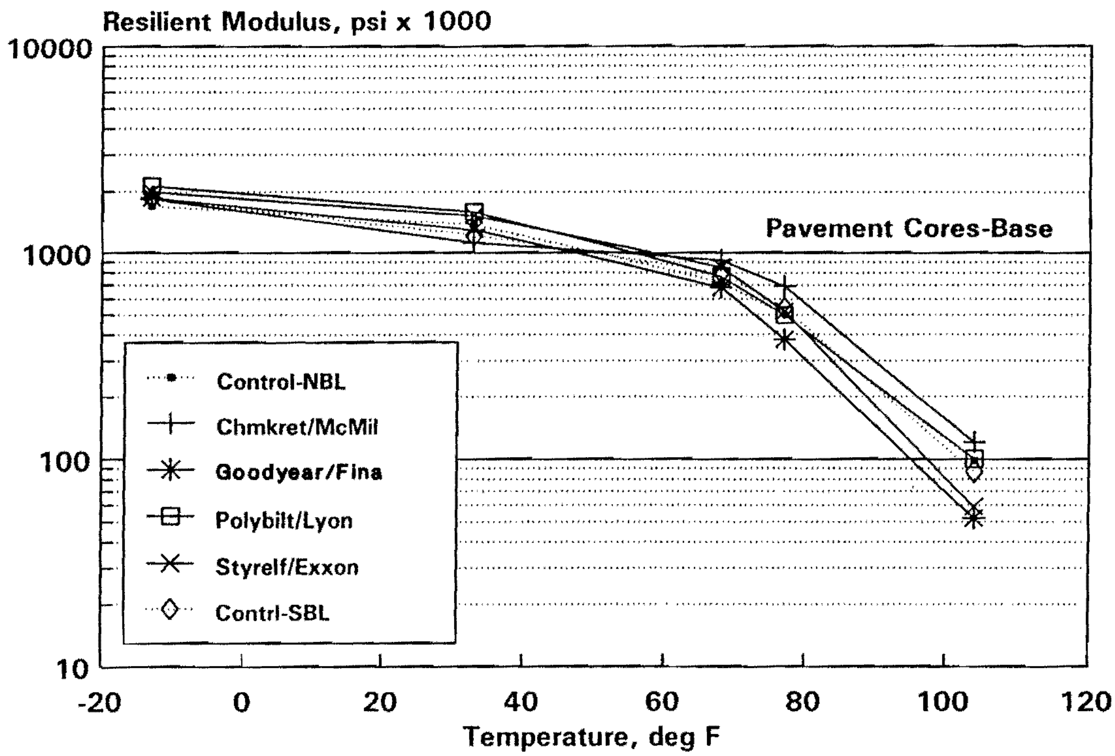

Figure 13. Resilient Modulus as a function of Temperature for Pavement Cores-Base Mixtures.

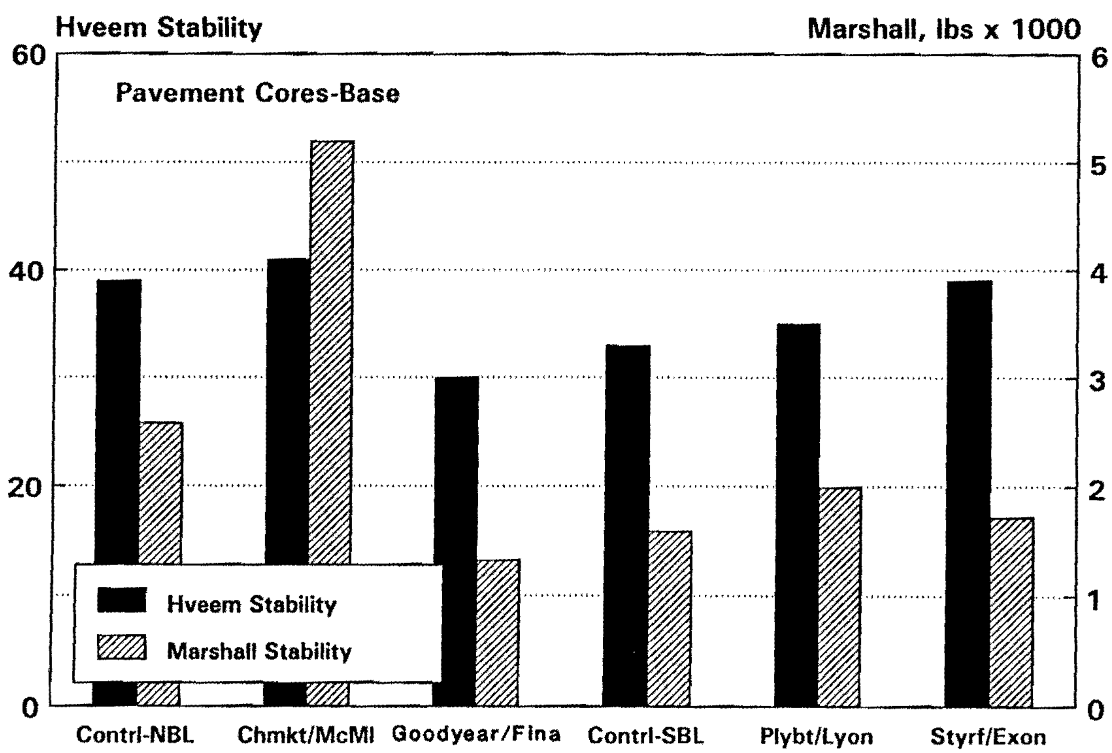

Figure 14. Hveem and Marshall Stability of Pavement Cores-Base Mixture.

additives significantly increased the load carrying capacity of this paving mixture above that of the control.

Hveem stability values of the base cores are plotted in Figure 14. Although the mean values ranged from 29 to 43, a statistical analysis indicated that there are no significant differences between the means.

Marshall stability (Figure 14) appeared to decrease when using the polymer modified asphalts. The mixture stiffening effect of the Chemkrete was beginning to be evident at the time of these tests. Marshall stability of these cores fell into two groups within which the values are not significantly different. The groups consist of the following: (1) Control-NBL and SBL, latex, Styrelf, and Polybilt and (2) Control-NBL and Chemkrete. Air voids content of these specimens ranged from 6.1 percent to 7.4 percent but showed no correlation with stability. Marshall stability and flow of the pavement cores were within the range of values normally specified for standard specimens compacted using the Marshall hammer.

Tensile properties of the cores were quantified before and after moisture treatment using the indirect tension test (Tex-531-C) (Figure 15). Specimens modified with Chemkrete exhibited the lowest tensile strengths both before and after moisture treatment (Table B7). However, statistical analysis revealed that the tensile strength values within each series were not significantly different. Tensile strength ratios were computed to estimate sensitivity of the mixtures to moisture. Only the Chemkrete specimens yielded values below 70. All the modified mixtures yielded values between those of the two control mixtures. It is concluded, therefore, that polymer additives had no effect on the mixture's resistance to moisture damage.

Surface Cores. Resilient moduli of the pavement surface cores (Type D) are shown in Figure 16. At -13°F and 33°F, the resilient modulus values are not significantly different. Resilient modulus of Goodyear mix is significantly higher than the controls at 68°F and 77°F but not at 104°F. Resilient modulus of Polybilt mix is significantly higher than the controls at 77°F and 104°F but not at 68°F. At 104°F, resilient modulus of the latex modified specimens is significantly lower than all the other specimens. When resilient modulus values from the laboratory molded specimens as well as the surface and base core specimens are considered, Polybilt, on the average, offers the largest increase in layer stiffness or load spreading

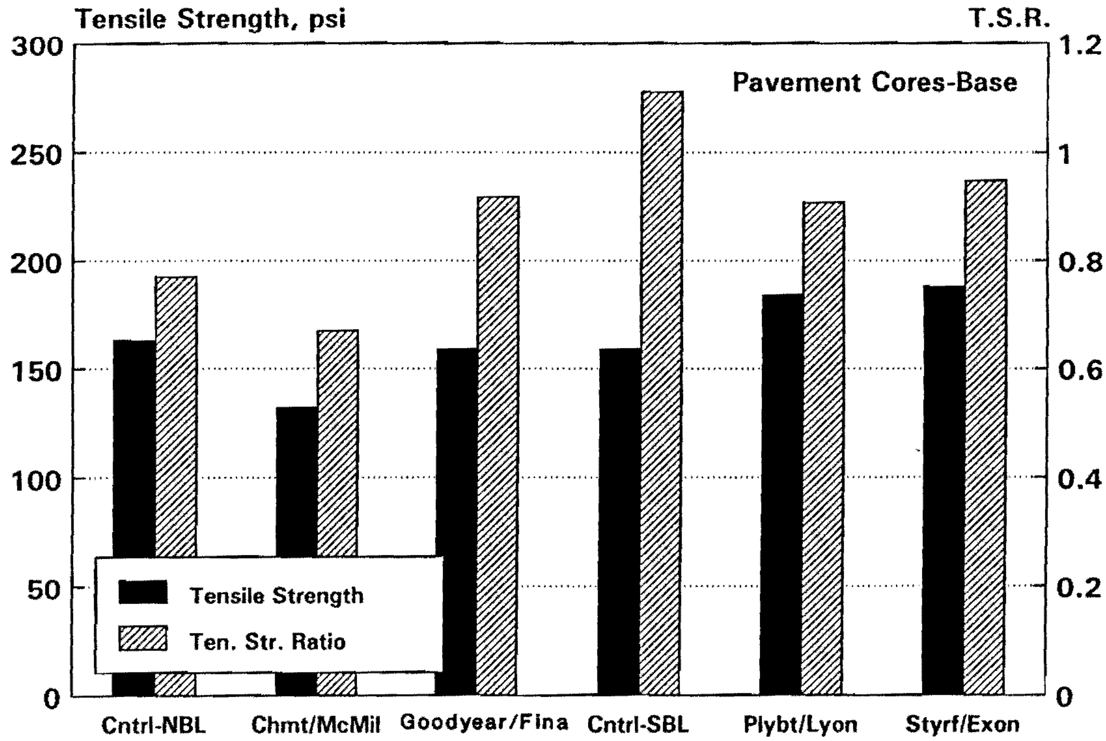

Figure 15. Tensile Strength and Tensile Strength Ratio (after accelerated Lottman moisture treatment) of Pavement Cores-Base Mixtures.

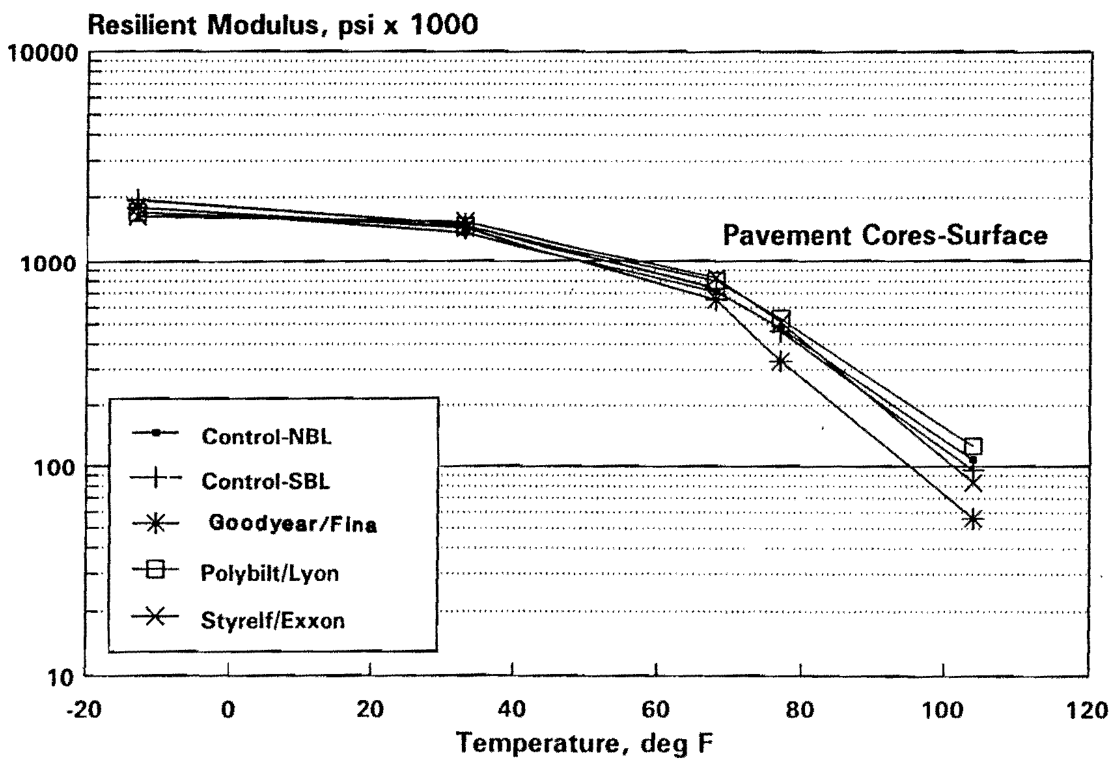

Figure 16. Resilient Modulus as a Function of Temperature for Pavement Cores-Surface Mixtures.

ability. However, resilient modulus of even the Polybilt modified mixtures were not consistently significantly larger than the corresponding unmodified mixtures. Therefore, these data show no evidence that these additives can be used to justify thinner pavement layers to offset the initial cost of the additives.

Hveem stability of the surface cores (Figure 17) were not significantly different from each other. When all of the Hveem stability data from the base and surface mixtures are considered collectively, they indicate that Hveem stability is not an adequate test to evaluate the effects nor justify the use of asphalt additives assuming the additives affect mixture performance. As has been pointed out previously (2), Hveem stability is very sensitive to asphalt quantity but not to asphalt quality.

Marshall stability (Figure 17) of the Goodyear modified surface cores was significantly lower than all the other mixtures. This probably reflects the low viscosity of the Goodyear modified binder (Table 4). The mixtures exhibiting the lowest Marshall stability (Goodyear and Styrelf) also contained the highest air voids. Marshall stability of the Styrelf and Polybilt modified mixtures were not significantly different from the control specimens.

Dry tensile strength of the surface core specimens (Figure 18) fell into three groups within which the values are not significantly different. These groups are as follows: (1) Control-NBL, Goodyear, and Styrelf, (2) Goodyear, Styrelf, and Polybilt, (3) Styrelf, Polybilt, and Control-SBL. Tensile strengths of all the modified mixtures were between those exhibited by the two control mixtures. Although air voids ranged from 7.0 percent to 9.3 percent, tensile strength ratios for all the mixtures exceeded 90 percent indicating these mixtures are exceptionally resistant to moisture damage (Figure 18).

Creep/Permanent Deformation Tests on Full-Length Base Cores

Description of Tests. Time dependent deformation behavior of the asphalt concrete paving mixtures was evaluated by conducting a series of laboratory tests on four-inch diameter by eight-inch high field cores. The accumulation of permanent strain was evaluated by conducting both incremental static loading and repeated haversine loading. Creep compliance was evaluated by developing a 1000 second response curve for two replicates

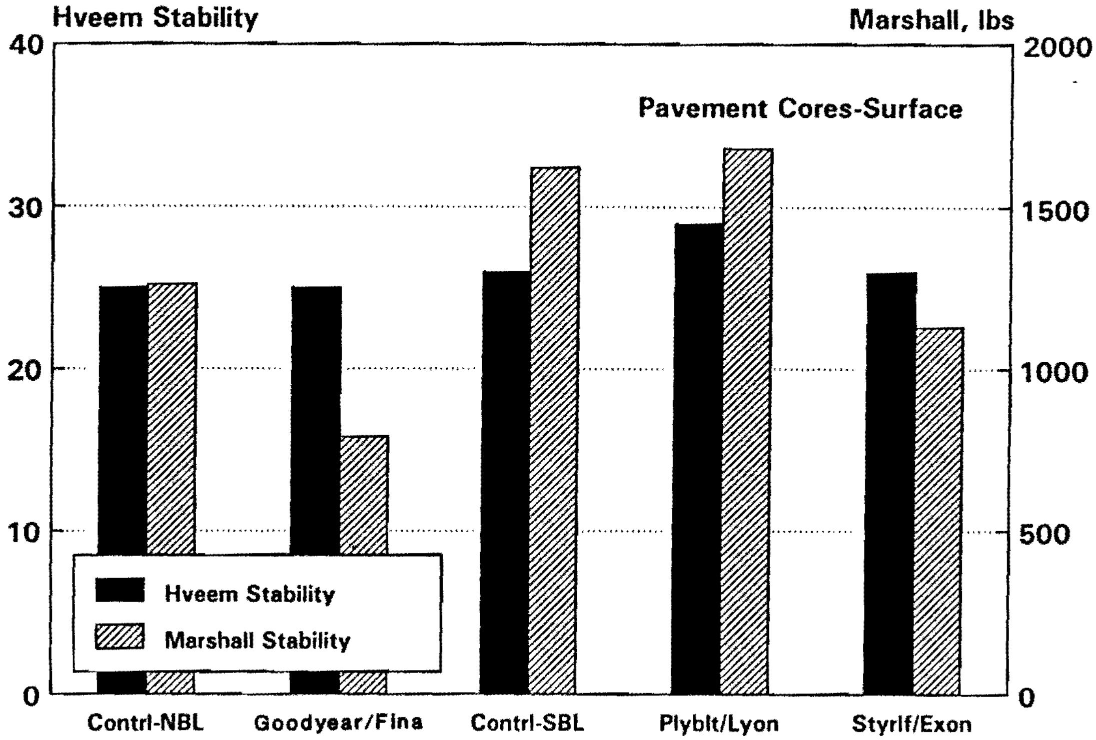

Figure 17. Hveem and Marshall Stability of Pavement Cores-Surface Mixtures.

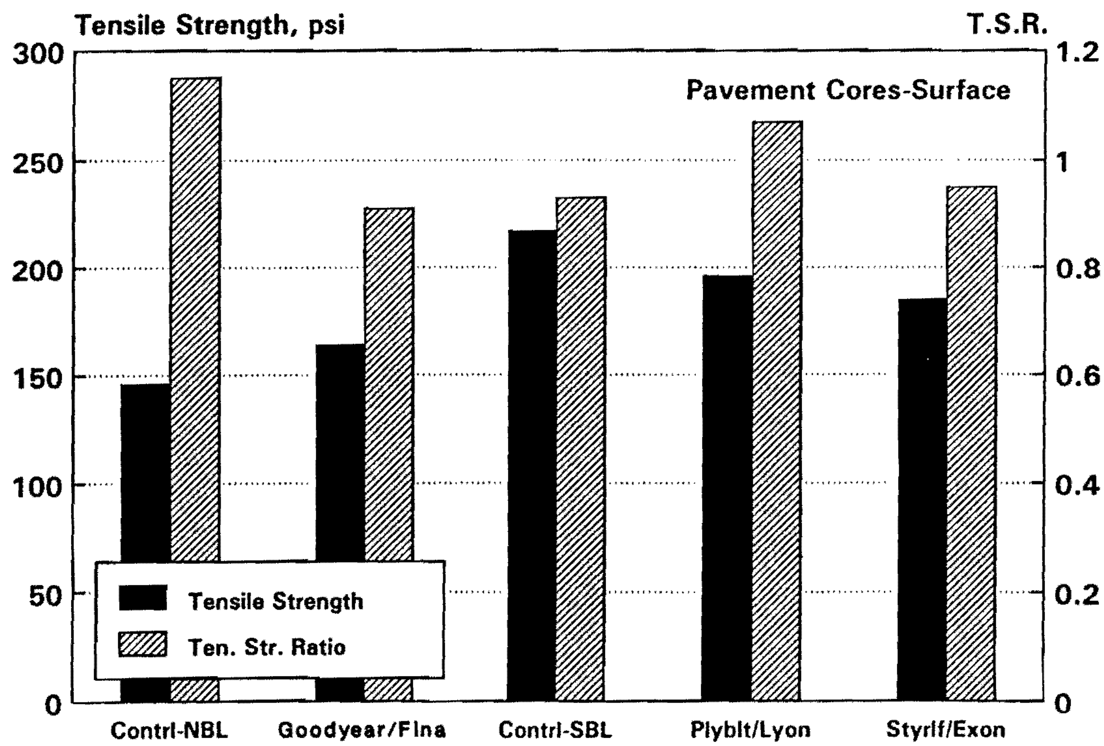

Figure 18. Tensile Strength and Tensile Strength Ratio (after accelerated Lottman moisture treatment) of Pavement Cores-Surface Mixtures.

of each mix at temperatures of 40°F, 70°F, and 100°F. All these tests were performed on an MTS-810 with a controlled environmental chamber.

Creep tests were conducted in accordance with the VESYS (8) procedure. At 40°F and 70°F, tests were conducted using a load level of 20 psi. At 100°F, this load level caused more than 2500 microunits of strain in the specimens, therefore, the test load was reduced to 15 psi, in accordance with the specified procedure. After a test specimen reached the appropriate test temperature, it was placed in the controlled temperature cabinet and centered under the loading apparatus. The LVDT's were attached and the electronic measuring equipment was adjusted and balanced. Standard preconditioning of the specimens requires three ramp loads at the specified level to be applied and held for ten minutes duration. Ten minutes after unloading, the electronic measuring equipment was readjusted to zero.

Incremental static loading consisted of applying an axial test load to the cores for periods of 0.1, 1, 10, 100, and 1000 seconds. For the 0.1, 1, and 10 second loading tests, permanent deformation was measured two minutes after unloading. For the 100 second loading test, permanent deformation was measured four minutes after unloading. During the 1000 second loading period, creep deformation is measured after 0.03, 0.1, 1, 3, 10, 30, 100, and 1,000 seconds. Additionally, permanent deformation is measured eight to twelve minutes after unloading.

Dynamic testing, to simulate moving traffic, consisted of repeated axial haversine loading of the eight-inch pavement base cores. The applied load followed a haversine wave form consisting of a 0.1 second loading period followed by a 0.9 second rest period. A minimum of 1000 load cycles are applied to each specimen and the accumulated permanent deformations are recorded periodically throughout the test. Resilient moduli of the specimens were calculated by using the recovered strain at 200th cycle. Values from two replicates of the above tests were averaged and plotted in the figures shown below.

Creep compliance. Creep compliance, usually denoted by D(t), characterizes deformation as a function of time under an applied unit stress. Higher compliance at high temperatures represents higher permanent deformation which indicates a higher propensity for rutting in a pavement during service. Higher compliance values at low temperatures indicate a mixture that is better suited to relieve stresses and thus resist fracturing. Figures 19, 20, and 21 are plots of the creep compliance at the three test temperatures.

At 40°F, the data indicates that Styrelf and Goodyear may provide slightly more resistance to cracking than the control mixes or the other modified mixtures, particularly at the longer loading times (Figure 19). Data at 40°F for the Chemkrete mixture could not be obtained because of the early failure of the samples during testing.

At 70°F, all the mixtures except Goodyear exhibit about the same compliance values at times greater than one second (Figure 20). The Goodyear mixture shows significantly higher compliance.

At 100°F, test results indicate that the Goodyear and Polybilt modified mixes have the highest tendency to permanently deform (Figure 21). The Chemkrete mix showed the least compliance. The two Control mixes and Styrelf modified mix showed very similar compliance values at 100°F.

<u>Permanent Deformation</u>. Figures 22 through 24 show permanent deformation resulting from the incremental static loading tests. In these plots, the curves for the Control NBL and SBL mixtures are always near the top and bottom and generally bracket the other data. It is impossible, therefore, to state convincingly that one mix is greatly different from another. This variability is probably due to the fact that the specimens are field cores (less quality control during specimen preparation) and that different asphalts were used during construction of the different test pavements. Furthermore, when a high quality aggregate system containing hard, angular stones with good surface texture is utilized (as was the case here), the rheological properties of the binder should have relatively little influence on creep and permanent deformation of the asphalt paving mixture. It is noticeable, however, that the Goodyear and Styrelf mixtures usually exhibit the higher permanent deformations while the Chemkrete mixture exhibits the lower permanent deformations at all three test temperatures.

Accumulated permanent strains due to repeated dynamic loading are shown in Figures 25, 26, and 27 at 40°F, 70°F and 100°F, respectively. At 40°F, Polybilt shows the least permanent deformation. At 70°F and 100°F, Chemkrete generally shows the least permanent deformation while Goodyear and Styrelf exhibit the highest permanent deformation. Polybilt also displays fairly high permanent deformations at 100°F. Resilient moduli at three temperatures obtained from the dynamic tests are plotted in Figure 28.

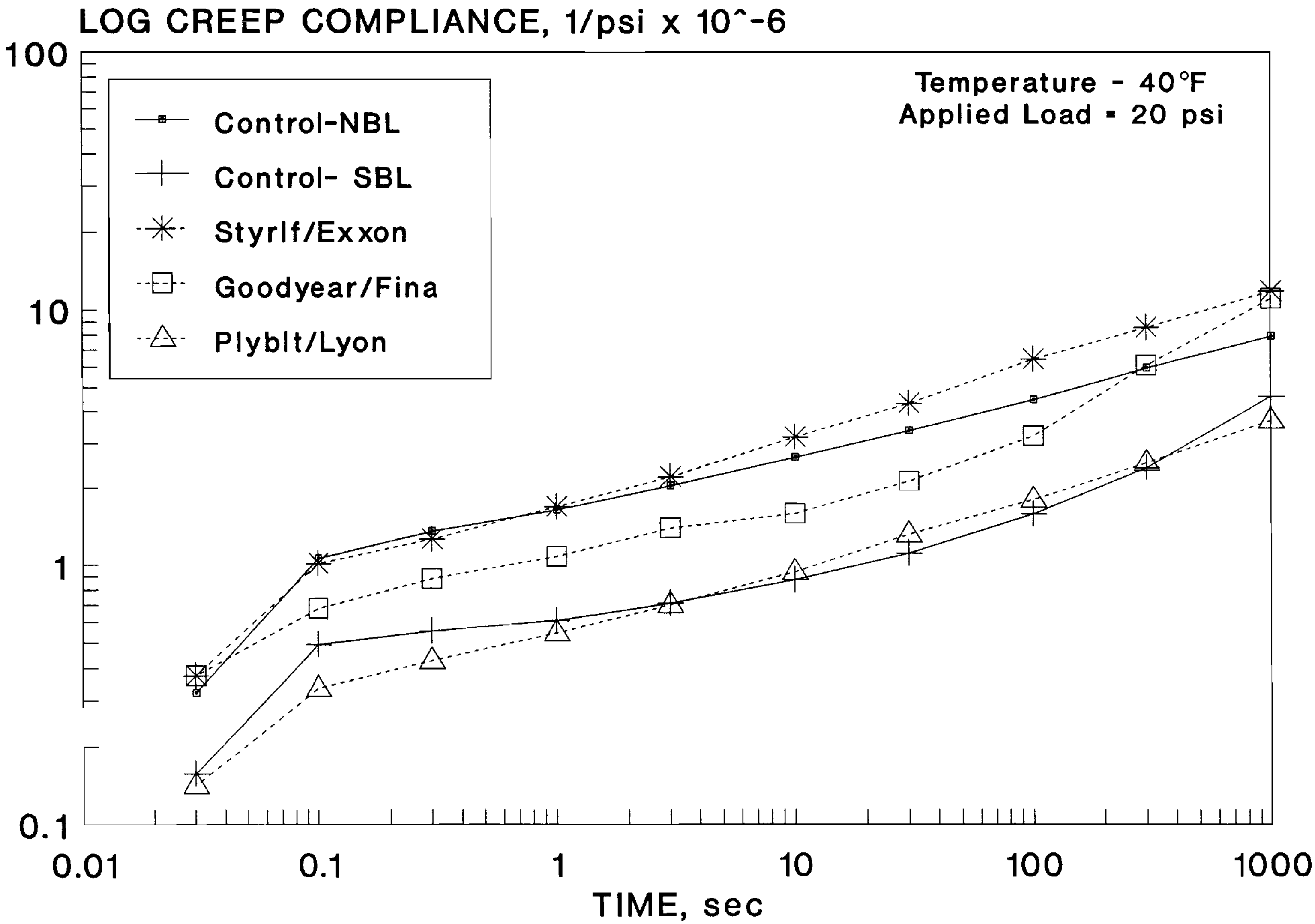

Figure 19. Creep Compliance Curves at 40°F (4°C) for Base Cores from District 19.

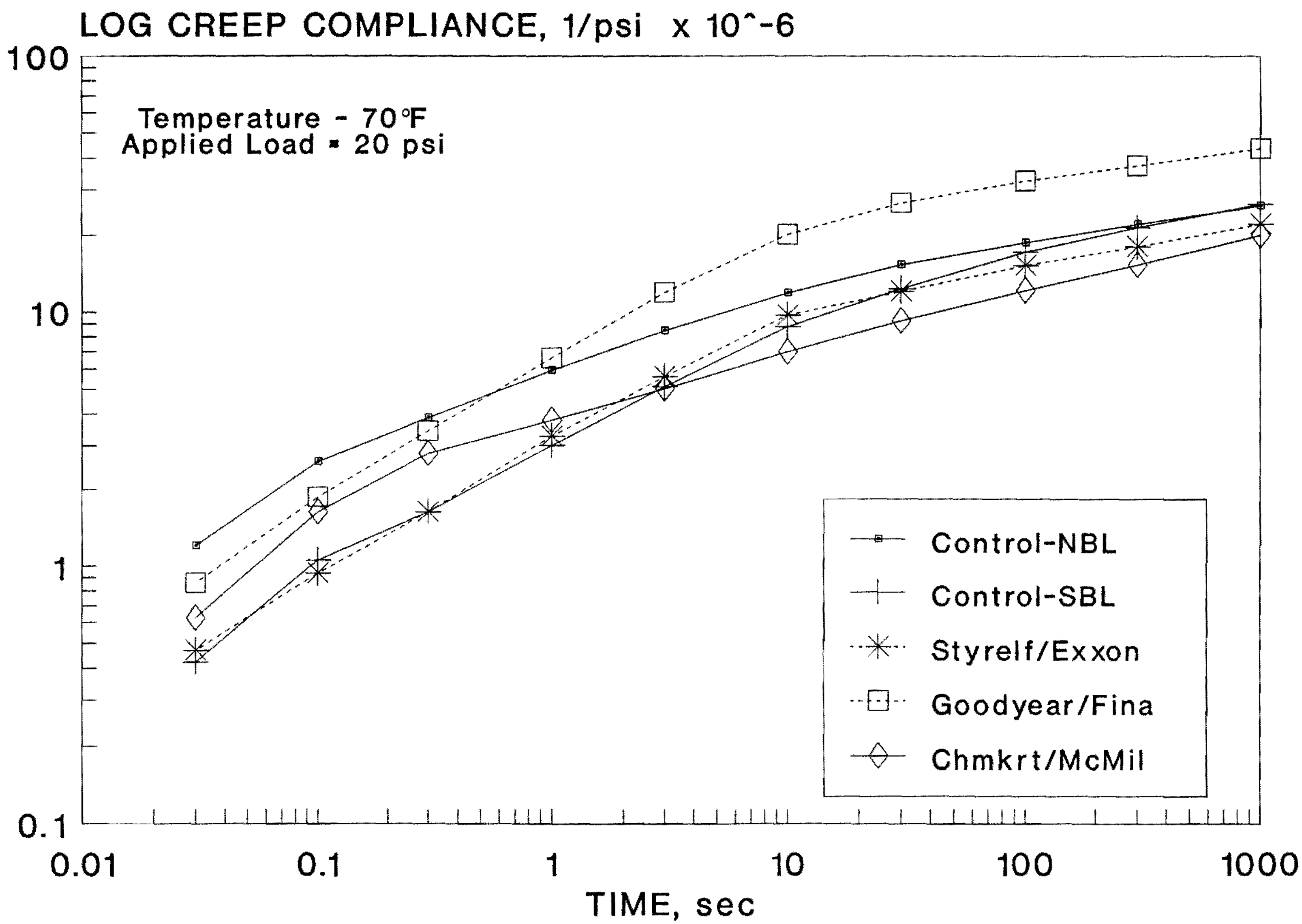

Figure 20. Creep Compliance Curves at 70°F (21°C) for Base Cores from District 19.

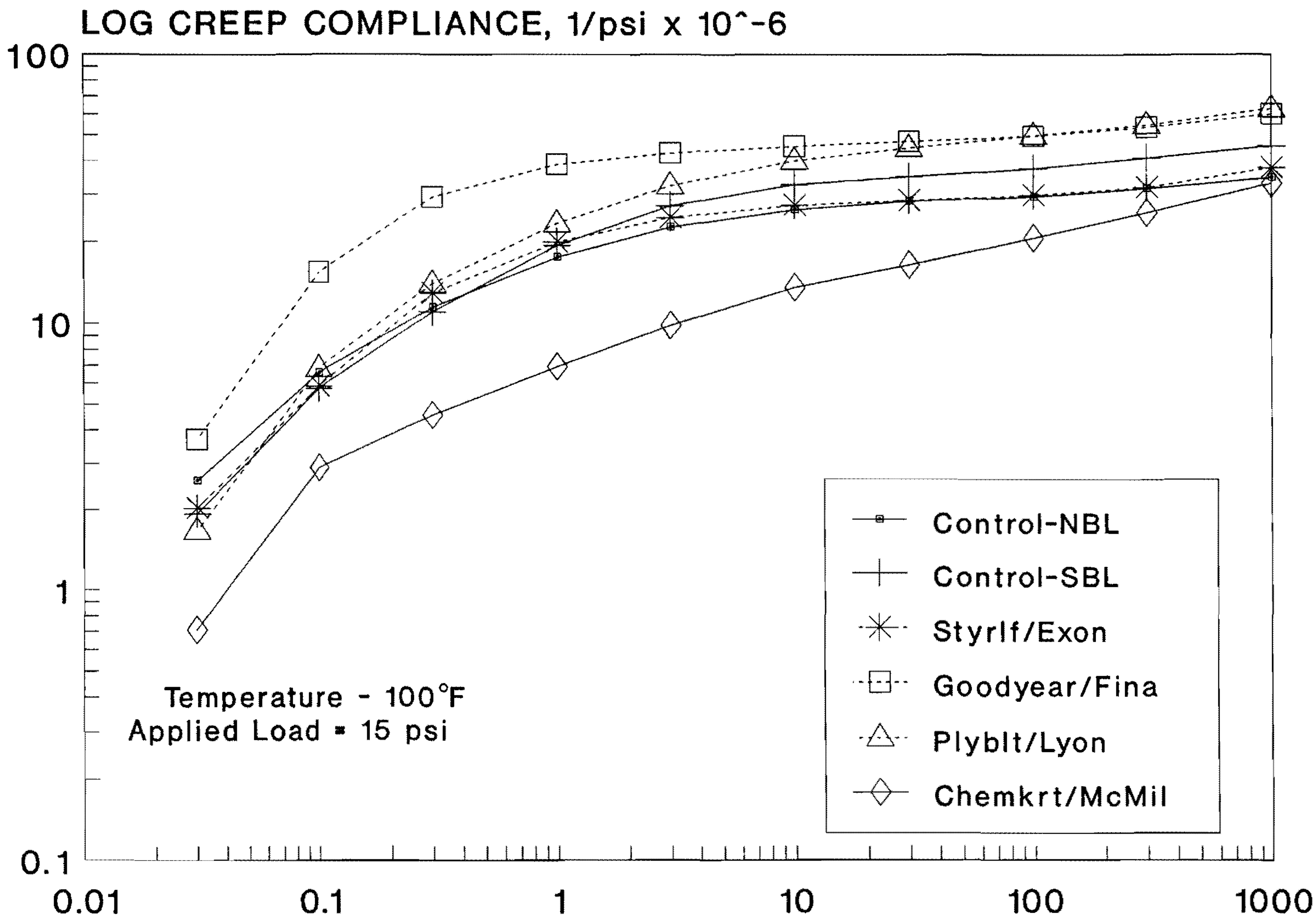

Figure 21. Creep Compliance Curves at 100°F (37°C) for Base Cores from District 19.

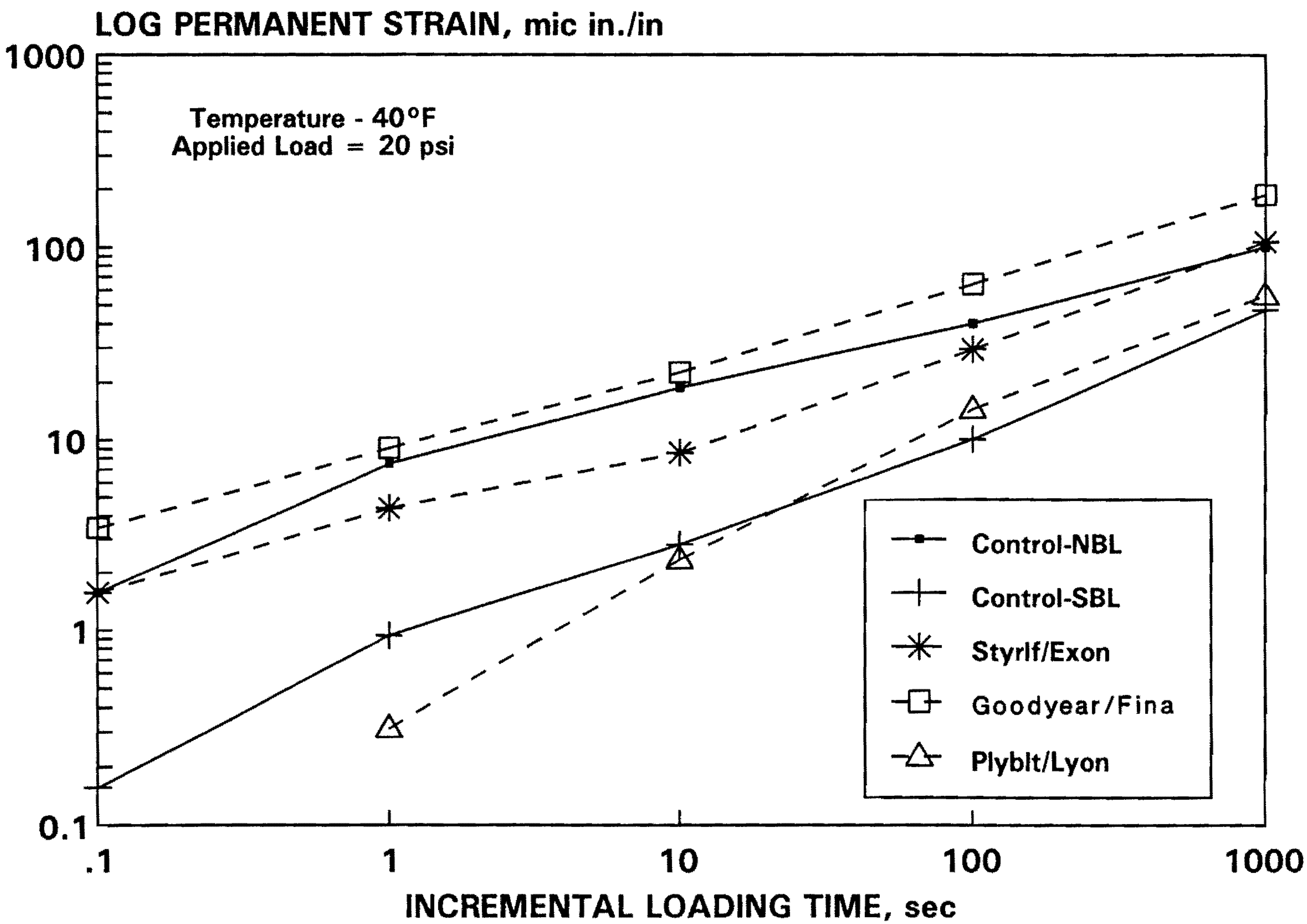

Figure 22. Permanent Strain from Incremental Static Loading Tests at 40°F (4°C) for Base Cores.

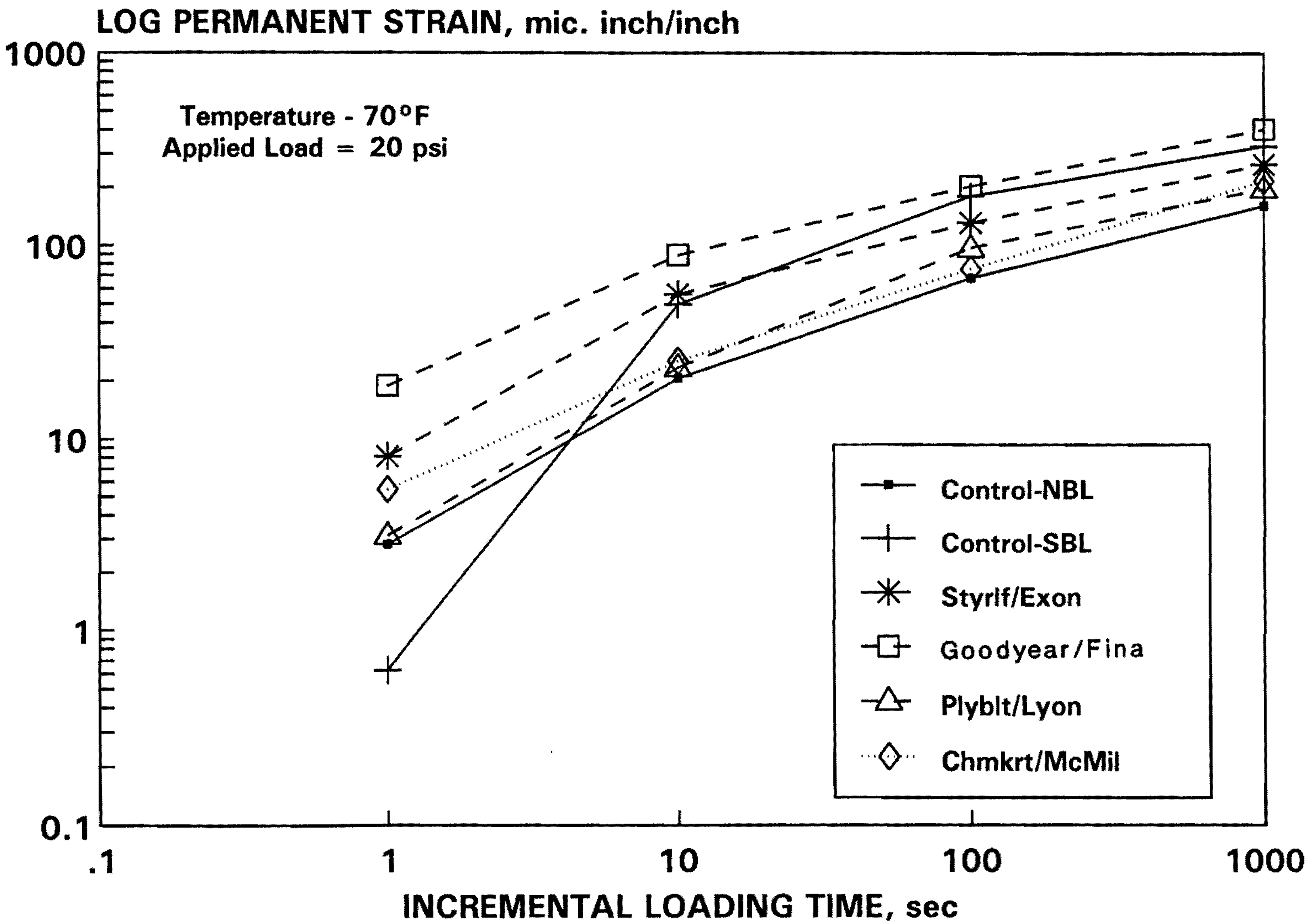

Figure 23. Permanent Strain from Incremental Static Loading Tests at 70°F (21°C) for Base Cores.

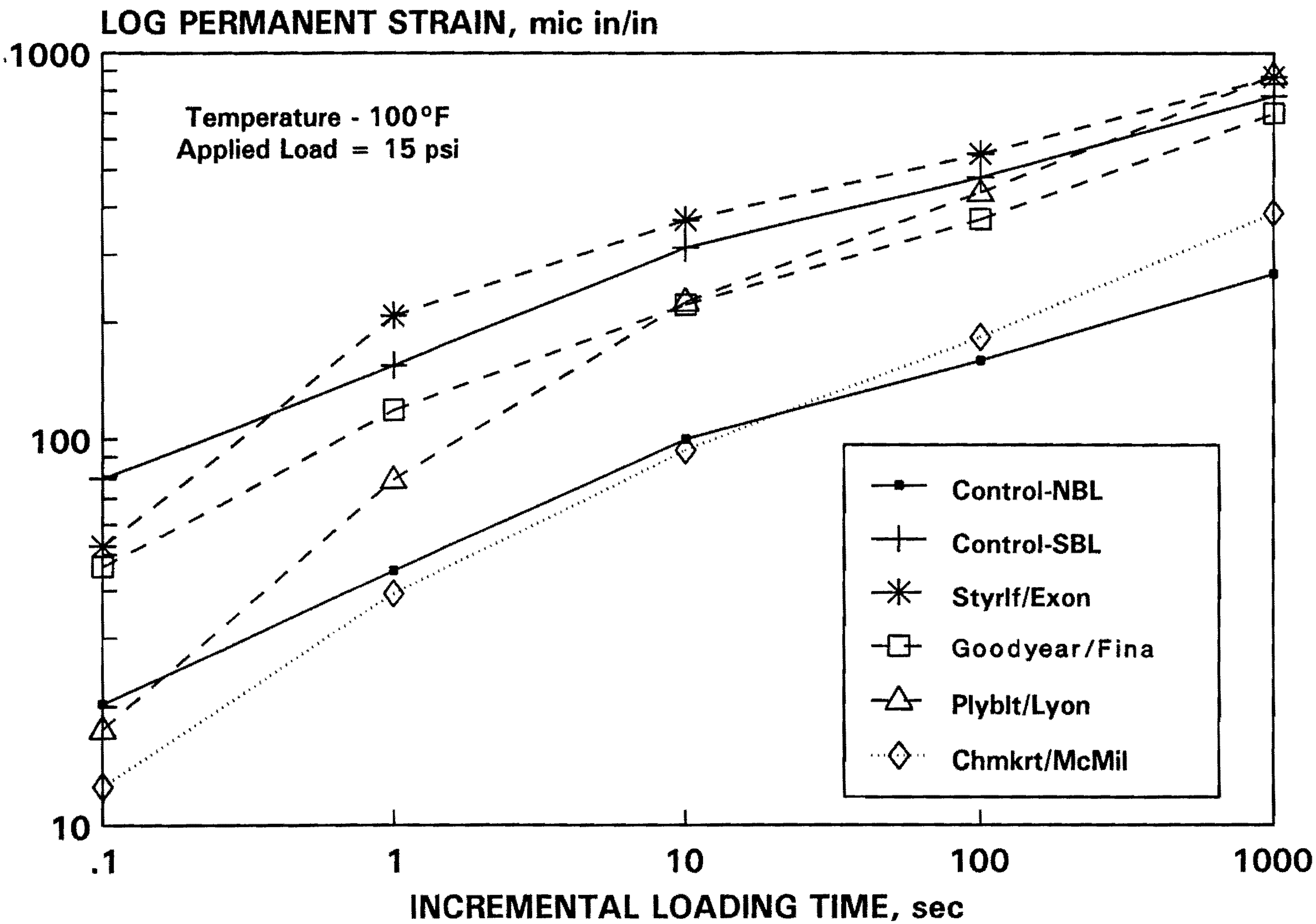

Figure 24. Permanent Strain from Incremental Static Loading Tests at 100°F (37°C) for Base Cores.

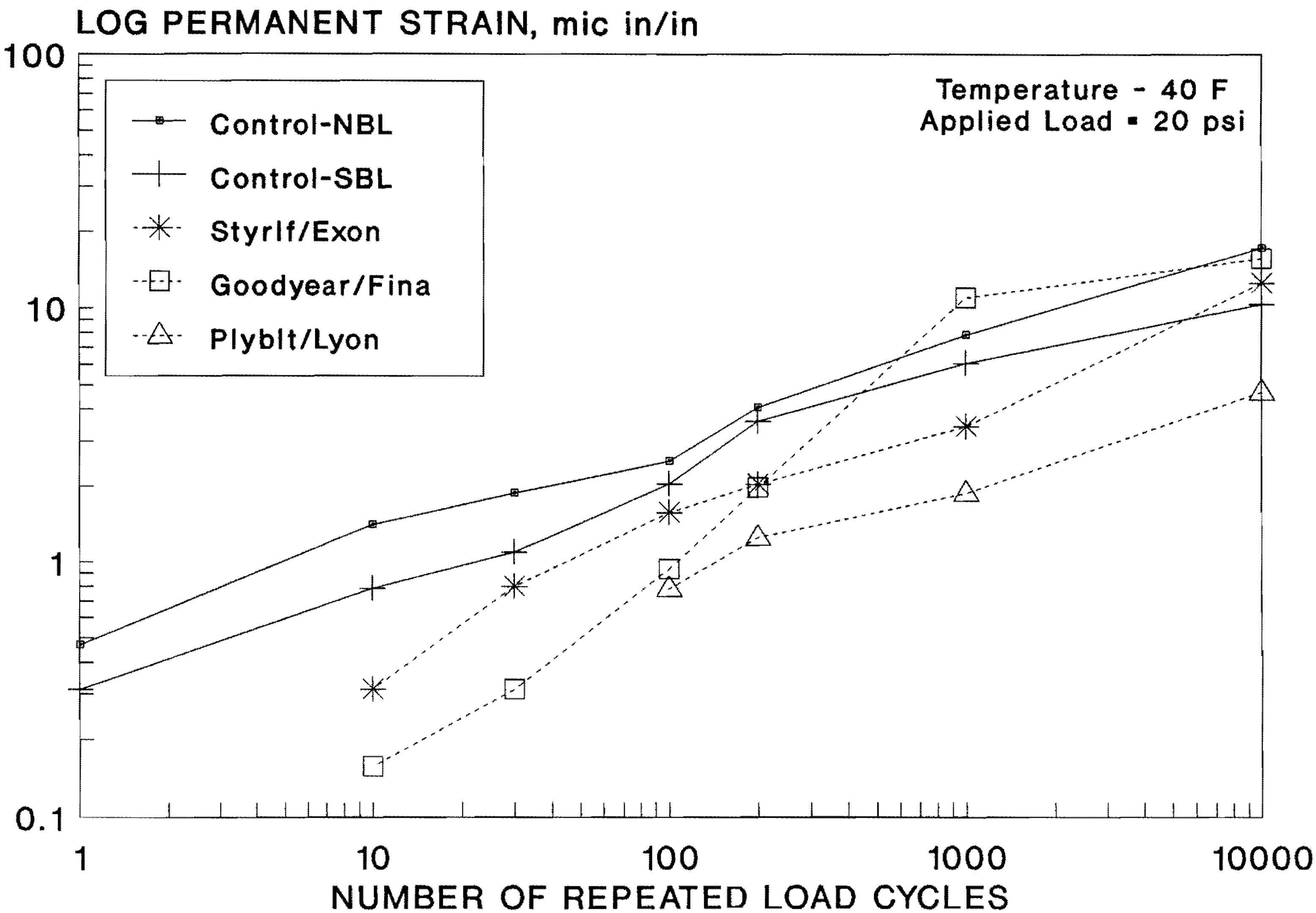

Figure 25. Accumulated Strain Versus Load Cycles For Base Cores Tested At 40°F (4°F).

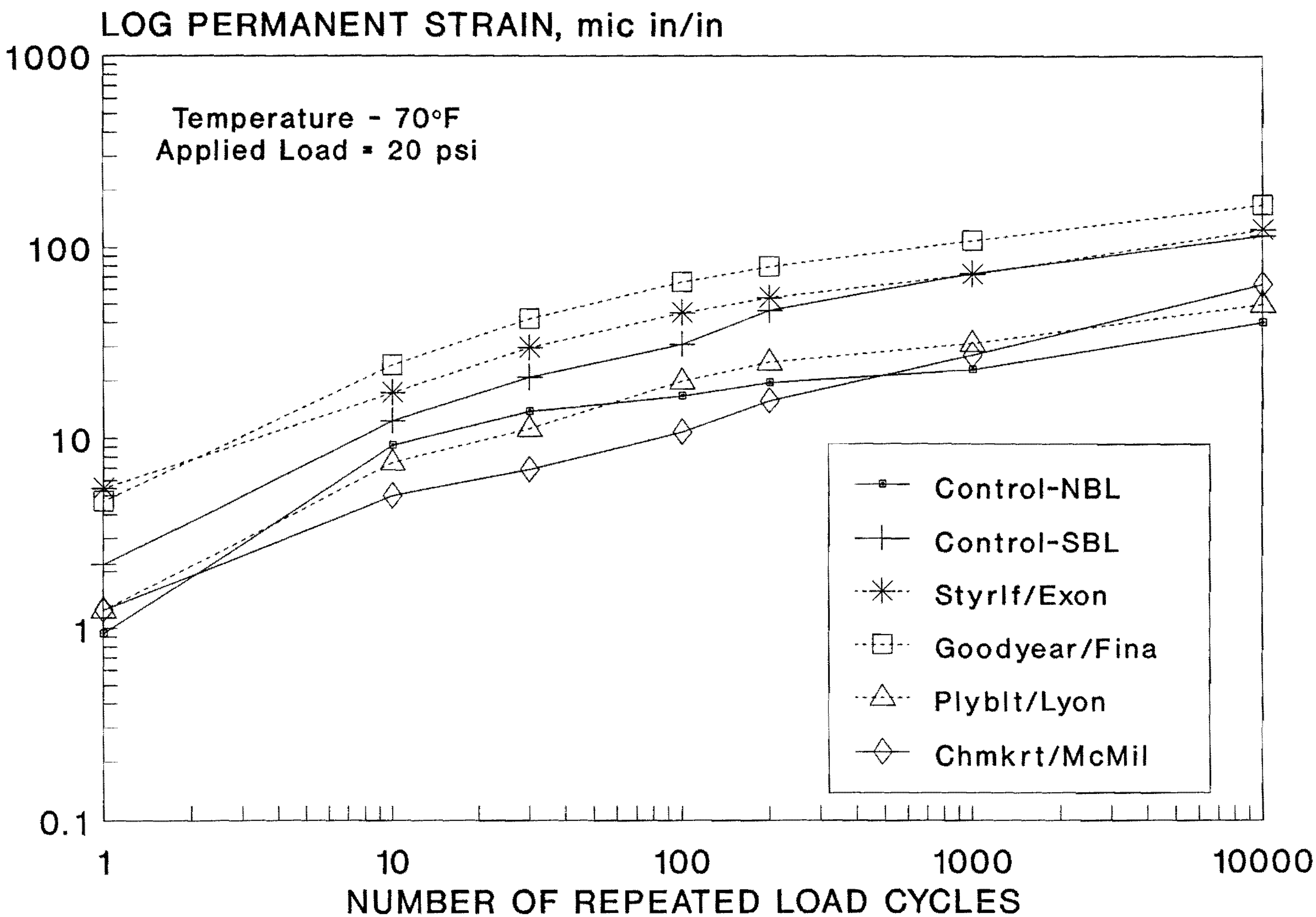

Figure 26. Accumulated Strain Versus Load Cycles for Base Cores Tested at 70°F (21°C).

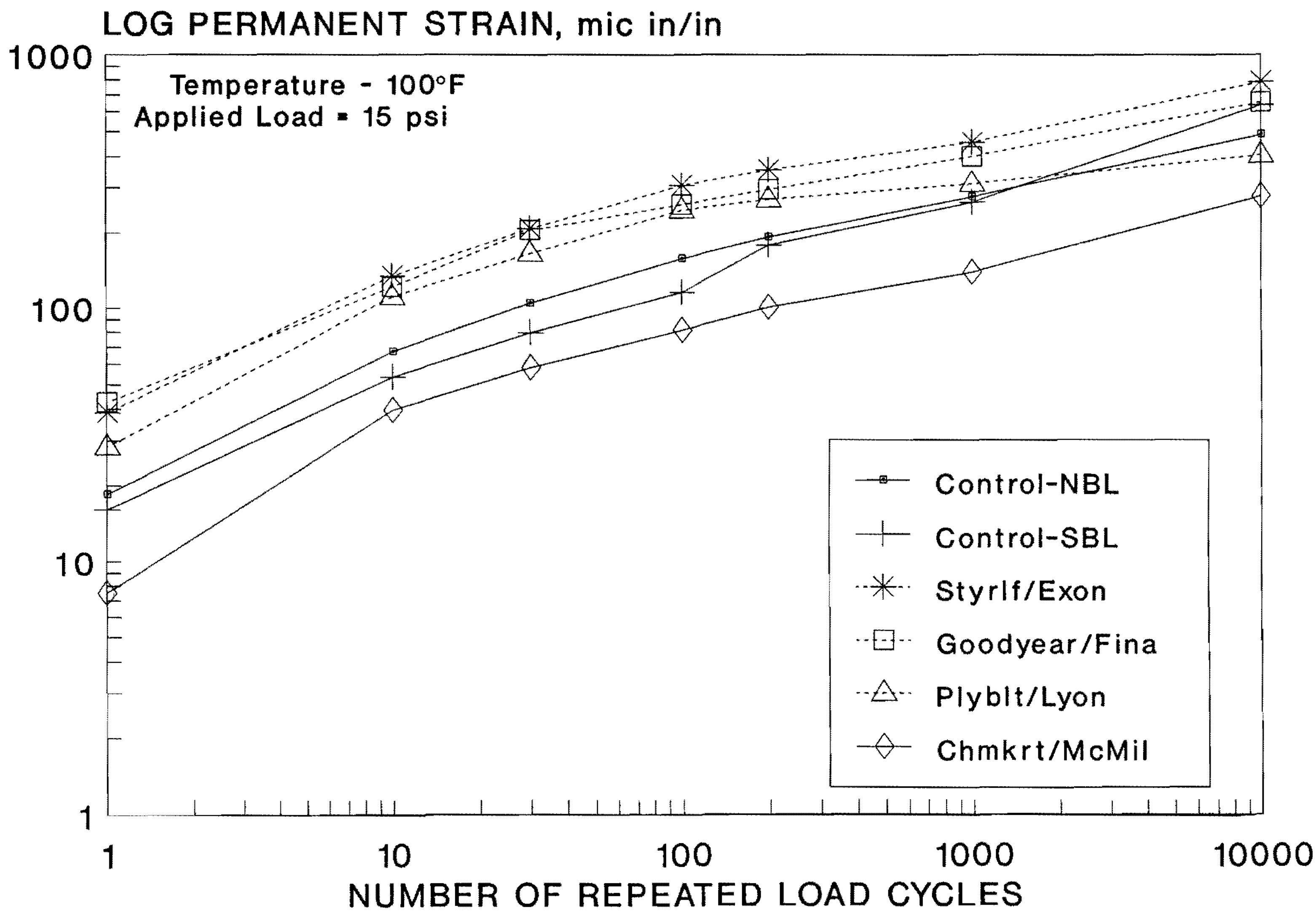

Figure 27. Accumulated Strain Versus Load Cycles for Base Cores Tested at 100°F (37°C).

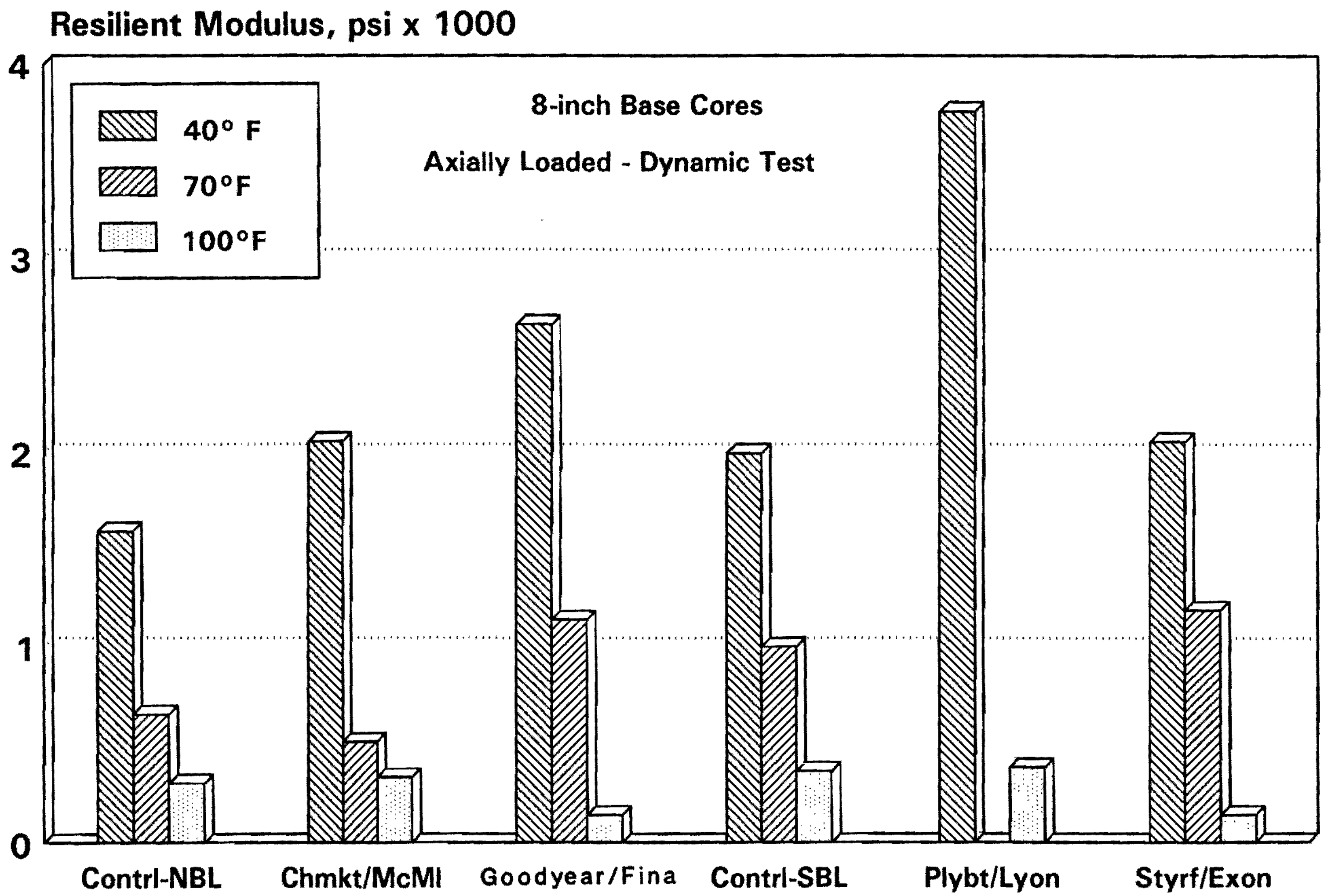

Figure 28. Resilient Modulus at 3 Temperatures of Axially Loaded 8-inch Base Cores.

A comparison of results from the three sets of data indicate reasonable uniformity. The Chemkrete mixture is the least resistant to permanent deformation at high service temperatures but unacceptable due to its susceptibility to cracking at low temperatures. The Goodyear and Styrelf mixtures have a greater capacity to relieve stresses at low temperatures than the control mixtures but are also subject to as much or more permanent deformation as the control mixtures at high temperatures. The Polybilt mixture displays the least capacity to relieve stresses at low temperatures but good resistance to permanent deformation at high temperatures.

PREDICTED LONG-TERM PERFORMANCE

There are several analytical tools available to analyze and predict long-term performance of pavements with respect to permanent deformation (rutting) and fatigue (cracking). One is a nonlinear finite element program called MICH-PAVE. MICH-PAVE was developed by Baladi (9) at Michigan State University for the design of flexible pavements. It is capable of calculating the stresses, strains, and surface deflections developed in a pavement section due to a passing vehicle. An empirical approach was used rather than a phenomenological model for the prediction of fatigue life. The approach considers the following parameters: compacted asphalt mix, magnitude of the applied load, test temperature, tensile strains of the asphalt courses, and the moduli of the different pavement layers. Ten existing pavement sections in the state of Michigan with known cross-sections and fatigue lives were used to calibrate the fatigue equation. MICH-PAVE was used with the appropriate traffic to predict performance of the test pavements in District 19 (Table 6).

Fatigue cracking is, of course, the most critical at the low temperature (40°F). Table 6 indicates the unmodified asphalt mixes, represented by Control-NBL and SBL, sustained the highest number of equivalent single axle loads (ESAL's) thus giving the best fatigue performance. The Goodyear modified mix would have failed after the lowest number of ESAL's. The Styrelf and Polybilt modified mixes gave superior fatigue performance in comparison to the other modified mixes.

In comparing rutting at the high temperature (100°F) at the end of 20 years of service life, the Goodyear modified mix was found to be superior to the other mixes. The Controls and the Chemkrete modified mixes showed

Table 6. Predicted Pavement Performance after 20 Years in Service.

Mixture ID	40°F	100°F	
	Fatigue, No. of ESAL to failure	Rut Depth, in.	Fatigue, No. of ESAL to failure
Control-SBL	2.35E + 07	3.0	8.96E + 07
Control-NBL	1.36E + 07	3.1	8.96E + 07
Chemkrete/MacMillan	No Data	3.0	8.52E + 07
Polybilt/Lyon	8.98E + 06	2.4	5.99E + 07
Goodyear/Fina	4.43E + 06	1.6	3.25E + 07
Styrelf/Exxon	9.68E + 06	2.5	7.19E + 07

the highest rutting. These findings were unexpected, based on observation of the plots of creep compliance and permanent deformation at 40°F.

In summary, considering the actual design traffic level for U.S. 59, MICH-PAVE predicts all the pavement sections will fail due to rutting before the 20 year design life. The Chemkrete section will fail due to cracking.

OBSERVED SHORT-TERM PERFORMANCE

As discussed previously, the eight-inch asphalt stabilized base courses were placed on US-59/71 north of Texarkana in the northbound lanes in the summer of 1987 and turned over to traffic. Placement of the asphalt stabilized base layers in the southbound lanes was completed in the fall of 1987. Traffic used these "interim" pavements until the spring of 1988 when the two-inch surface courses were placed in both the northbound and the southbound lanes. These pavements have been visually evaluated periodically since construction of the base layers in 1987.

By April, 1988, prior to placement of the surface courses, the base layer containing Chemkrete was exhibiting severe cracking. Continuous longitudinal cracks were present at each construction joint. Meandering (generally transverse) cracks were spaced at about 5 to 15 feet apart. Coring revealed the longitudinal cracks had progressed completely through the eight-inch layer; whereas, the transverse cracks were progressed only about two-thirds of the way through the layer. The Chemkrete pavement surface also appeared older than the other test pavements as it had a dull finish. At this time, there were no visible cracks in the base layers of any of the other five pavements. With the exception of the Chemkrete pavement, all the pavements were performing equally well with no visible signs of distress. Cracks in the Chemkrete section were sealed with a rubberized asphalt and the decision was made to use the latex-modified asphalt concrete mix as the surface for this Chemkrete section.

Shortly after this evaluation of the base layers, the surface layers were placed in the spring of 1988. A visual evaluation in September, 1988 revealed no cracking or raveling at the surface of any of the six test pavements. Rut depths were less than 1/8 inch for all test pavements. Performance appeared to be equivalent for all pavements.

In May, 1990, the pavements were generally performing equally well with no signs of serious distress. One exception was the appearance of minor transverse cracking (about 40 feet) in the Goodyear/Chemkrete test section. It was assumed these cracks were reflected from the previously cracked Chemkrete-modified base. Rut depths measured using a five-foot straight edge yielded an average of 3/16-inch ruts in all pavements except the Polybilt pavement which exhibited a rut depth of 1/8 inch. There were no other signs of distress at the pavement surface.

In August, 1991, about 3¼ years after placement of the surface courses, the 0.9-mile pavements were beginning to show significant differences (Table 7). Significant longitudinal cracking had occurred in the Polybilt-modified section. Transverse cracks from the cracked Chemkrete-modified base began to reflect through the surface of the Goodyear latex-modified surface. The Goodyear latex pavement and the Styrelf sections exhibited less cracking than the other sections. Rutting was essentially the same as it was in May, 1990 and should be considered insignificant.

Dynaflect data were obtained on each test pavement in June, 1989. Readings were taken in the outside wheelpath. The data are summarized in Table 8. Maximum deflections are about the same for all the pavements except the Goodyear/Chemkrete section. This may be due to excessive hardening of the asphalt in the Chemkrete-modified base which stiffened the base layer.

Surface curvature index (SCI) is the difference in deflection between geophones 1 and 2 and is an indicator of stiffness of the upper pavement

Table 7. Field Performance of Test Sections as of August, 1991, 3 1/4 Years after Placement of the Surface Courses.

Test Pavement Identification	Longitudinal Cracking, ft.	Transverse Cracking, ft.	Alligator Cracking	Rut Depth, in.	Raveling	Patching	Other[2]
Control-NBL	35	3	None	3/16	None	None	-
Goodyear/ Chemkrete[1]	10	140	None	3/16	None	Minor	-
Goodyear/Fina	None	1	None	3/16	None	None	-
Styrelf/Exxon	None	12	None	3/16	None	None	-
Polybilt/Lyon	340	35	None	1/8	None	None	-
Control-SBL	84	4	None	3/16	None	None	-

[1]Chemkrete was used in the base mix and Goodyear latex was used in the surface mix of this test pavement.
[2]All sections contained spots of segregated aggregate in the surface course.

layers. The Goodyear/Chemkrete test pavement exhibited the lowest average SCI value. The next lowest SCI value was for the Goodyear/Fina section. From a statistical standpoint, the SCI values fell into two groups within which they are not significantly different; these two groups are comprised of (1) the two latex (Goodyear) modified pavements and (2) Goodyear/Fina, Control-NBL, Styrelf/Exxon, Polybilt/Lyon, and Control-SBL. Values of maximum deflection and SCI are fairly typical for a thick pavement designed for high traffic.

The average stiffness coefficient of pavement for the Goodyear/Chemkrete section is shown to be greater than the others (Table 8). This is consistent with previous results. However, a statistical analysis shows the values of stiffness coefficient of pavement fell into two groups within which they are not significantly different. These two groups are (1) Control-SBL, Polybilt/Lyon, Styrelf/Exxon, Control-NBL, and Goodyear/Fina and (2) Control-NBL, Goodyear/Fina, and Goodyear/Chemkrete. As one may expect, values of SCI and stiffness coefficient of pavement vary in an opposite manner.

Load spreadability of the pavement was calculated by dividing the average deflection by the maximum deflection. These data show only minor differences in the ability of these pavements to spread a load. All the above data indicate that, except for the Chemkrete, the asphalt additives are having only subtle effects on the structural capacity of this particular pavement.

Stiffness coefficients of subgrade for the various test sections are not significantly different. This is to be expected, since the substrates of all the pavements are equivalent and consist of 18 inches of lime-flyash treated subgrade.

Table 8. Dynaflect Data for Additive Test Pavements in District 19 - June 1989.

Test Pavement Identification	Maximum Deflection, Mils	Surface Curvature Index	Stiffness Coefficient of Subgrade	Stiffness Coefficient of Pavement	Spreadability of Pavement	Number Points in Averages
Control-NBL	0.362 0.069	0.035[1] 0.006[2]	0.22 0.01	0.73 0.03	0.836	16
Goodyear/ Chemkrete[3]	0.306 0.032	0.028 0.006	0.22 0.01	0.77 0.05	0.827	16
Goodyear/ Fina	0.387 0.041	0.033 0.007	0.21 0.01	0.75 0.04	0.836	13
Polybilt/Lyon	0.354 0.044	0.039 0.007	0.22 0.01	0.71 0.03	0.807	16
Styrelf/Exxon	0.384 0.044	0.038 0.006	0.22 0.00	0.72 0.02	0.827	13
Control-SBL	0.384 0.064	0.041 0.009	0.22 0.01	0.70 0.04	0.816	14

[1]Average of values measured
[2]Standard deviation of average value
[3]Chemkrete was used in the base mix and Goodyear latex was used in the surface mix of this test pavement.

REVIEW OF ADDITIVES

ROLE OF ASPHALT ADDITIVES

In this study, a bituminous binder additive is defined as a material which would normally be added to or mixed with the bitumen before or during production of the paving mixture, to improve the properties and/or performance of the resulting paving product. The justification for using an additive falls into one or both of two categories: (1) it solves or alleviates a pavement problem which is likely to occur in the area in which unmodified asphalt paving mixtures are used or (2) it produces an environmental, energy, construction and/or performance benefit. In either case, the improvement must ultimately be cost-effective. One must understand the problems and their causes and the alternative treatments that might be available (including additives) and be able to effectively match problems with treatments.

The most important and most widespread asphalt pavement problems in the United States are: (1) stripping, (2) rutting, (3) thermal cracking, (4) reflection cracking through overlays, (5) hardening of the binder through aging, and (6) flushing. Additives of primary interest in this study are those designed to improve pavement flexibility or structural properties.

Additives are often applied to solve a specific pavement problem. Indiscriminate use of additives may well be self defeating. Design guidelines or pavement materials specifications are needed that will enable the pavement designer to select the particular additive or narrowed list of candidates that have the highest probability of ameliorating his particular problem without causing another problem. The guidelines should allow the designer to consider, as a minimum, the following:

1. The Anticipated Problem
    a. Cracking - reflection, thermal, fatigue
    b. Plastic deformation - high traffic, intersection
    c. Stripping - moisture susceptible mix
    d. Raveling - surface deterioration due to poor adhesion
    e. Hardening or aging of binder - desert, high voids
    f. Flushing - soft binder, high traffic

2. Chemical composition and physical properties of bitumen
3. Aggregates available and economically acceptable
4. Traffic factors
    a. Weight/tire or contact pressures
    b. Quantity
    c. Duration of loads - average traffic speed
    d. Turning maneuvers
    e. Stopping/skidding frequency
5. Environmental factors - temperature, rainfall
6. Substrate - new base or old pavement, subgrade
7. Exposure of pavement surface to fuel or oil
8. Mixture design and method of design

In any case, for the present time, additives proposed for use in a bituminous paving mixture should be tested with the particular bitumen and aggregate to be used. Performance of various additives will be affected in different ways by the physical properties of a bitumen depending on its chemical composition (2, 10). In addition, additive degradation at asphalt mixing temperatures and compatibility of the additive with the source and grade of asphalt cement must be considered.

ASPHALT ADDITIVES AVAILABLE

Most of the known asphalt additives available in today's market have been categorized by generic name in Table 9. Some of these products are used routinely in bituminous paving mixtures; whereas, others are still in the experimental stage. This list is provided merely as a convenient source of information.

Additives of primary interest to this study are those designed to alter the physical properties of the bituminous binder which, in turn, improves (ostensibly) the pavement's resistance to distress such as cracking and/or rutting. Polymers including neat rubbers are the most versatile and probably hold more promise in improving structural and adhesive properties of bituminous pavements than any other single category of additives. Some polymers like EVA, SBR, and some polypropylenes are quite miscible with many bitumens while others like polyethylene must be dispersed in the bitumen using special high-shear processes. Generally, the polymer-type additives are shown to reduce binder temperature susceptibility and brittleness and increase ductility, toughness, and tenacity. [Toughness and tenacity are computed from areas under stress-strain plots derived from a unique tensile test (11) on the modified binder]. Polymers in asphalt mixtures have exhibited moderate improvements in Marshall stability and tensile properties but generally no significant increase in Hveem stability. It has been pointed out that although Hveem stability is quite sensitive to binder content, it is not very sensitive to binder properties (2,10).

Table 9. Bitumen Additives Currently Being Used or Tested in Pavements.

1. Polymers
    a. Styrene Butadiene Rubber (SBR) (Latex)
    b. Block Copolymers
        i. Triblock Styrene-Butadiene-Styrene (SBS)
        ii. Radial Block SBS
        iii. Vulcanized (SBR)
        iv. Styrene-Isoprene-Styrene (SIS)
        v. Styrene-Ethylene-Burylene-Styrene (SEBS)
        vi. Styrene-Ethylene-Propylene-Styrene (SEPS)
    c. Polyethylene (PE)
    d. Ethylene Vinyl Acetate (EVA)
    e. Polypropylene (PP)
    f. Crumb Tire Rubber
    g. Polychloroprene latex
    h. Polychloroprene solids
    i. Natural Polyisoprene
    j. Synthetic Polyisoprene
    k. Ethylene Propylene-Diene-Monomer (EPDM)
    l. Polyisobutylene
    M. Polyethlene Tetrathiolate (PET)
2. Extenders
    a. Sulfur
    b. Fillers

(Continued)

Table 9. (Continued)

3. Mineral Fillers
    a. Carbon Black
    b. Hydrated Lime
    c. Flyash
    d. Silica Fines
    e. Baghouse Fines
4. Natural Asphalts
    a. Trinidad
    b. Gilsonite
5. Antistripping Agents
    a. Amidoamines
    b. Imidazolines
    c. Polyamines
    d. Hydrated Lime
    e. Organo-metallics
6. Antioxidants
    a. Diethyldithio carbamates
        i. Lead
        ii. Zinc
    b. Carbon Black
    c. Hydrated Lime
    d. Phenols
7. Hydrocarbons
    a. Tall Oil
    b. Aromatics
    c. Naphthenics
    d. Paraffinics/Wax
    e. Vacuum Gas Oil
    f. Petroleum/Plastic Resins
    g. Asphaltenes
8. Fibers
    a. Polypropylene
    b. Polyester
    c. Natural
    d. Glass
9. Others
    a. Gelling Agents
    b. Viscosity Modifiers

POTENTIAL PROBLEMS WITH ASPHALT ADDITIVES

The primary disadvantage of the increased viscosity of the modified binders at high temperatures is that it extends into the temperature range at which asphalt concrete is mixed (275°F-325°F or 135°C-165°C). It is, therefore, often necessary to increase the operating temperature of the mixing plant to achieve adequate coating of aggregate and provide for satisfactory compaction of the paving mixture. Plant temperature increases from 0°F to 70F° (0°C to 39C°) have been reported with about 30°F (17C°) being most usual. Obviously, the required temperature increase will depend upon the type and quantity of additive used. This is, nevertheless, an important consideration for the paving contractor from an economic standpoint, in that more fuel will be required to operate his plant at a higher than normal temperature. It should also be considered when selecting the type and quantity of additive since economic trade-offs may present themselves.

Crude petroleums from various parts of the world vary significantly in chemical composition. Various refining processes also cause variation in the chemical make-up of asphalt cement. When a given quantity and type of polymer is added to an asphalt product, the resulting physical properties of the modified binder will also vary with asphalt source. In some cases, a polymer which normally mixes well with some asphalts will not mix uniformly with a given asphalt. This problem is usually referred to as poor compatibility.

Compatibility is a rather poor choice of words, but is routinely used by the asphalt paving industry to describe the ability of a polymer to be incorporated into an asphalt and remain in suspension during static, hot storage. A more descriptive and less ominous sounding term is "storage stability." Most polymers are not really "soluble" in any bitumen. O'Connor (12) pointed out that even though the SBR latex may appear to blend satisfactorily with a given asphalt, if the mixture is unstable, the rubber may separate from the asphalt by settling or floating out. He further stated that some asphalt suppliers can produce an asphalt that is compatible with rubber by selection of crudes. A polymer-asphalt blend that exhibits poor storage stability will physically separate and form lumps of polymer-rich binder or merely phase separate due to the difference in specific gravity of the two materials. These products must be continuously agitated to avoid phase separation. Special extender oils can be incorporated at additional cost to improve storage stability of asphalt-polymer blends. Some chemists have indicated that certain chemical species can be reacted with polymers to improve compatibility with asphalt.

Many agencies specify an extraction procedure to verify the presence of the design quantity of bituminous binder. Some of the polymers are only partially soluble or insoluble in the conventional solvents and, as a result, interfere with the extraction process and may cause erroneous results. Some agencies go a step further and periodically recover the bituminous binder from the extraction solvent in order to determine its physical properties. Properties of polymer modified binders recovered after the extraction process are questionable because, even if all the modified binder is recovered, the additive and bitumen have been intimately blended in the extraction procedure which, in all probability, significantly changed the rheological properties.

Tests to verify the quantity of polymer in the neat binder are not difficult but are time consuming and expensive. Fourier Transform Infrared Analysis (FTIR), with careful calibration, using mixtures of known quantities of bitumen and polymer, can readily be used to determine polymer content of a modified binder (13, 14). However, the difficultly factor rises sharply if the modified binder must be first extracted from an aggregate mixture as completeness of the extraction is dependent upon the aggregate composition and gradation.

Heat stability of polymer modified binders has been evaluated in an attempt to predict problems that might occur during prolonged hot storage (2, 10). After exposure to 325°F (163°C) for 24 hours while protected from oxidation, SBR and SBS products exhibited a significant decrease in viscosity. This drop in viscosity is apparently due to a breakdown of the molecular structure of the polymer. Similar findings have been reported from the field after prolonged hot storage in a tank. In one case, the user agency rejected the modified binder because it no longer met viscosity specifications. In another case, the damaged binder was used but significant mixture tenderness was noted during construction. One highway district in Texas specifies that SBR latex be added to the asphalt mixture in the mixing plant to avoid hot storage and possible damage to the modified asphalt.

FUTURE OUTLOOK FOR ADDITIVES

Vehicle weights, traffic volume, and tire pressures are steadily increasing and demanding more and more from pavement structures. Engineers are faced with serious problems regarding quality of paving material. Quite often materials are shipped long distances at high cost because local material supplies of adequate quality have been depleted. The public is better informed now than in times past and demands more for its tax dollars. As a result, bituminous binder additives have been widely accepted by the paving industry for the present time. The concept of additives is logical and results from laboratory testing look positive. Even though field test results using many additives are incomplete, those responsible for pavement quality are willing to gamble because the odds appear to be in their favor.

The bituminous binder additive industry and associated technology is advancing at a very rapid rate. By the time results from the field are available for the additives being currently marketed, it is reasonable to assume that a whole new generation of bitumen additives will be on the market. It is, therefore, postulated that asphalt additives will provide viable alternatives for pavement designers in the foreseeable future.

CONCLUSIONS

Based on performance evaluations of full-depth asphalt concrete pavement test sections near Texarkana, Texas which contain Chemkrete, Goodyear 5812 latex, Styrelf-13, or Polybilt 102 and laboratory evaluations of associated paving materials, the following conclusions appear warranted. The reader is reminded that no two additives were incorporated into the same asphalt and, therefore, direct comparisons of laboratory and field performance should made with caution.

1. After approximately 4 years in service under heavy traffic, the test pavements containing either Goodyear latex or Styrelf-13 showed less cracking than similar unmodified pavements and less cracking than pavements containing Polybilt 102 or Chemkrete (with latex surface). The pavement modified with Exxon Polybilt 102 began to show significantly more cracking than the other sections during the fourth year of service. The Chemkrete modified pavement exhibited extreme cracking after less than one year in service. No other signs of distress were visible at the pavement surfaces.

2. Chemkrete caused excessive hardening of the asphalt after placement of the paving mixture. The severe hardening effects of Chemkrete were not observed using standard laboratory tests on asphalt binders and mixtures.

3. Field tests using the Dynaflect and laboratory testing of field mixes consisting of resilient modulus at a series of temperatures indicates only minor differences in stiffness or load spreading ability of the polymer modified and unmodified paving mixtures. It is, therefore, concluded that incorporation of a polymer modifier should not be used to justify construction of pavement layers thinner than those required by conventional design methods.

4. Acceptable polymer modified asphalt concrete paving mixtures were produced using standard Texas SDHPT mixture design procedures.

5. Hveem stability was not sensitive to changes in mixture properties effected by the asphalt additives. Hveem stability is quite sensitive to binder quantity but not to binder quality. It, therefore, is not a suitable test to evaluate the effects of nor justify the use of asphalt binder additives.

6. All mixtures exhibited excellent resistance to moisture damage. None of the polymer additives had any significant effect on resistance to moisture damage. Chemkrete appeared to have a slight negative effect.

7. Changes in mixture properties cannot be readily predicted from changes in binder properties effected by the asphalt additives. That is, certain changes in binder properties produced by an additive did not necessarily produce the anticipated change in mixture properties.

8. The polymers tested (Goodyear latex, Polybilt EVA, and Styrelf 13) increased the consistency of the asphalt at temperatures above 40°F and had little effect on consistency at lower temperatures. The net effect was lowering of temperature susceptibility.

9. Although latex produced the largest decrease in asphalt temperature susceptibility when all the additives are considered, thin film oven aging (which simulates plant aging) of the latex modified asphalt negated most of the positive effects.

10. Force ductility data indicate the polymer additives have the ability to increase the amount of energy required to deform and ultimately fail an asphalt cement specimen.

11. Creep/permanent deformation testing indicated that the Chemkrete mixture was the most resistant to rutting but was unacceptable due to its high susceptibility to cracking at low temperatures. The Goodyear latex and Styrelf mixtures exhibited greater capacity than the control mixtures to resist cracking at low temperatures but exhibited as much or more propensity for rutting as the control mixtures at high temperatures. The Polybilt mixture exhibited the least capacity to resist cracking at low temperatures but showed good resistance to rutting at high temperatures.

REFERENCES

1. Adams, C. K. and Button, J. W., "Another Look at Chemkrete", Research Report 471-1, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1986.
2. Button, J. W. and Little, D. N., "Asphalt Additives for Increased Pavement Flexibility," Report No. FHWA/TX-87/471-2F, Texas State Department of Highways and Public Transportation, Austin, Texas, November, 1986.
3. Button, J. W., "Asphalt Additives in Highway Construction," Research Report 187-14, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1987.
4. McLeod, N. W., "Asphalt Cements: Pen-Vis Number and Its Application to Moduli of Stiffness," ASTM Journal of Testing and Evaluation, Vol. 4, No. 4, July 1976, pp. 275-282.
5. Annual Book of ASTM Standards, Vol. 4.03, "Road and Paving Materials: Bituminous Materials for Highway Construction, Waterproofing and Roofing and Pipe; Skid Resistance," American Society for Testing and Materials, 1913 Race Street, Philadelphia, PA 19103, 1987.
6. Lottman, R. P., "Laboratory Test Method for Predicting Moisture-Induced Damage to Asphalt Concrete," Transportation Research Record 843, Transportation Research Board, National Research Council, Washington, D. C., 1982.
7. Kennedy, T. W., Roberts, F. L., and Anagnos, J. N., "Texas Boiling Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," Research Report 253-5, Center for Transportation Research, University of Texas, Austin, Texas, 1984.
8. Kenis, W. J., "Predictive Design Procedures, VESYS Users Manual," Report No. FHWA-RD-77-154, Federal Highway Administration, January, 1978.
9. Baladi, G. Y., "Fatigue Life and Permanent Deformation Characteristics of Asphalt Concrete Mixes," Paper Presented at the 68th Annual Meeting, Transportation Research Board, January, 1989.
10. Little, D. N., Button, J. W., White, R. M., Ensley, E. K., Kim, Y., and Ahmed, S. J., "Investigation of Asphalt Additive," Report No. FHWA/RD-87/001, Federal Highway Administration, Washington, D. C., November, 1986.

11. Benson, J. R., "Tentative Standard Method of Test for Toughness and Tenacity of Rubberized Asphalts," Bituminous Consultants, Denver, Colorado, February, 1955.
12. O'Connor, D. L., "Recent Experience with Latex Modified Asphalts," Presented at 62nd Annual Texas A&M Highway Short Course, Texas State Department of Highways and Public Transportation, October, 1988.
13. Button, J. W., and He, L. Y., "FTIR and Gravimetric Methods to Determine Polyethylene Content of Modified Asphalt," Research Report No. 393-1F, Texas Transportation Institute, Texas A&M University, May, 1989.
14. Malek, A. E., "The Determination of SBS Block Co-Polymer Concentration in Bitumen/Polymer Blends in Infra-Red Spectroscopy," Research Report No. AIR286-10, Australian Road Research Board, Vermont South, Victoria, Australia, December, 1984.

Appendix A

Schematic of Pavement Locations
Force Ductility Data

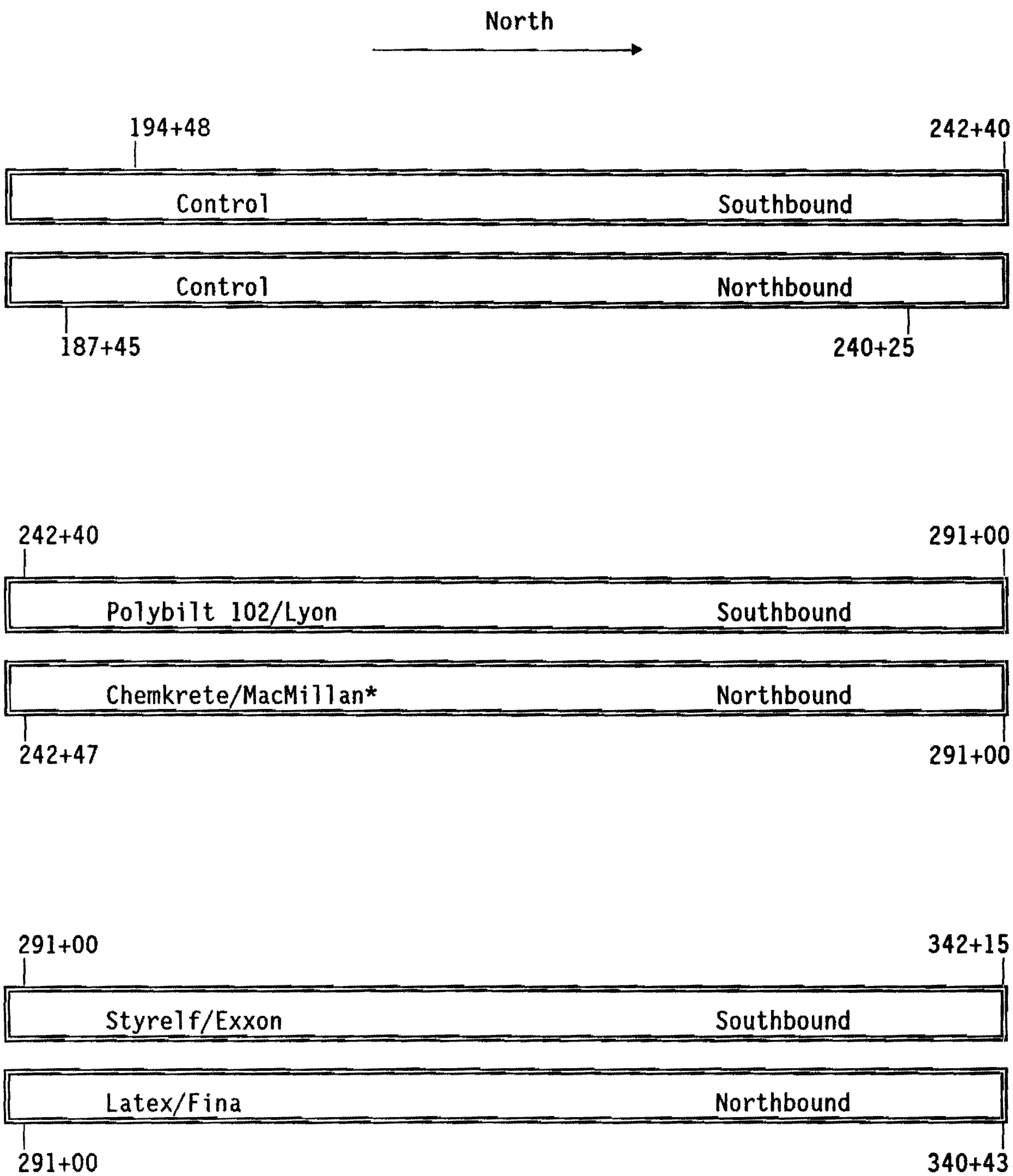

Figure A1. Schematic Showing Test Pavement Locations.

*Chemkrete/McMillan was replaced with Latex/Fina in the surface mixture.

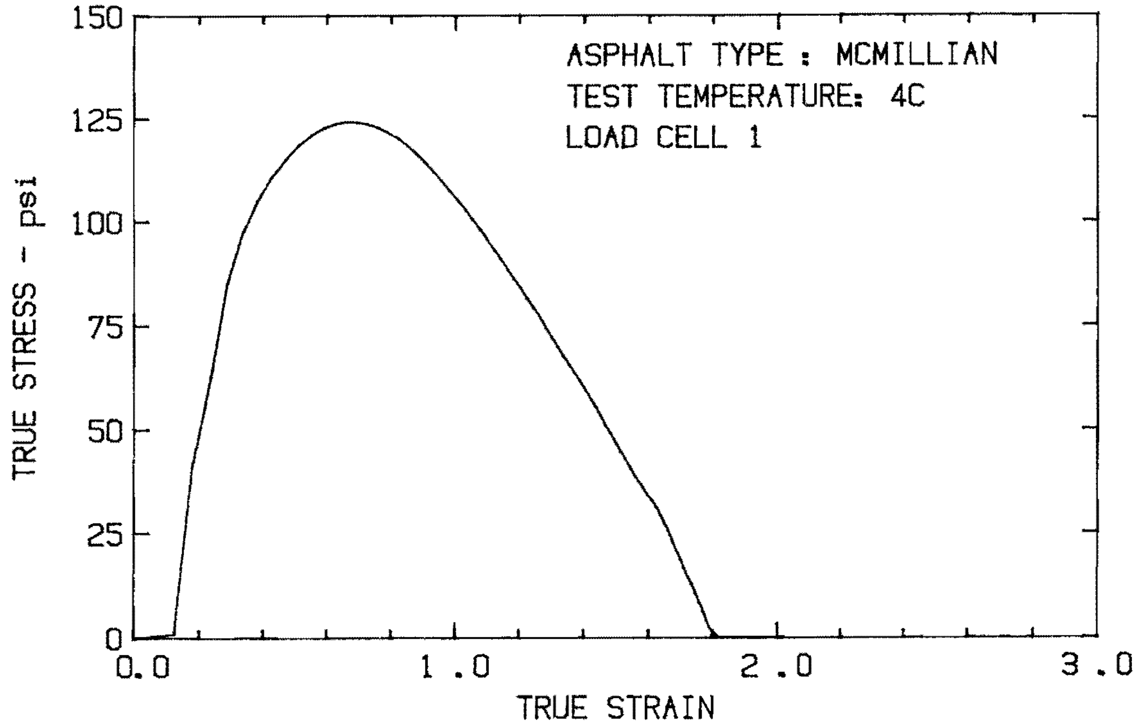

Figure A2. Force Ductility Test Result for MacMillan AC-20.

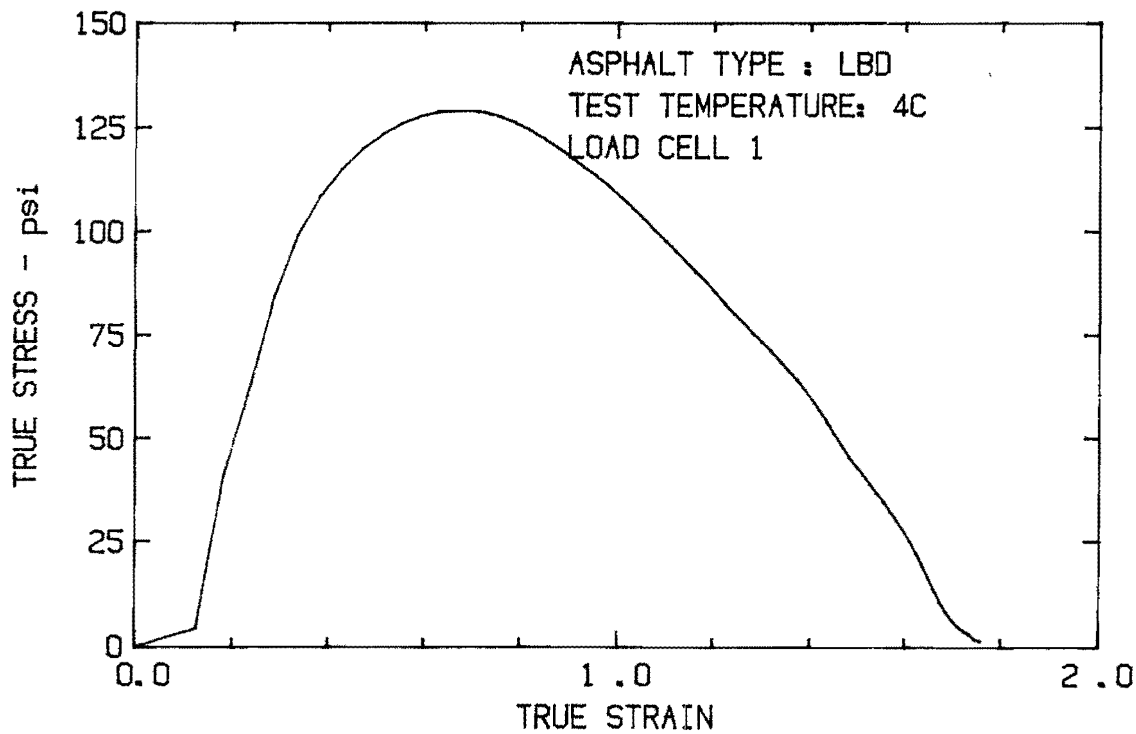

Figure A3. Force Ductility Test Result for Chemkrete Modified MacMillan Asphalt.

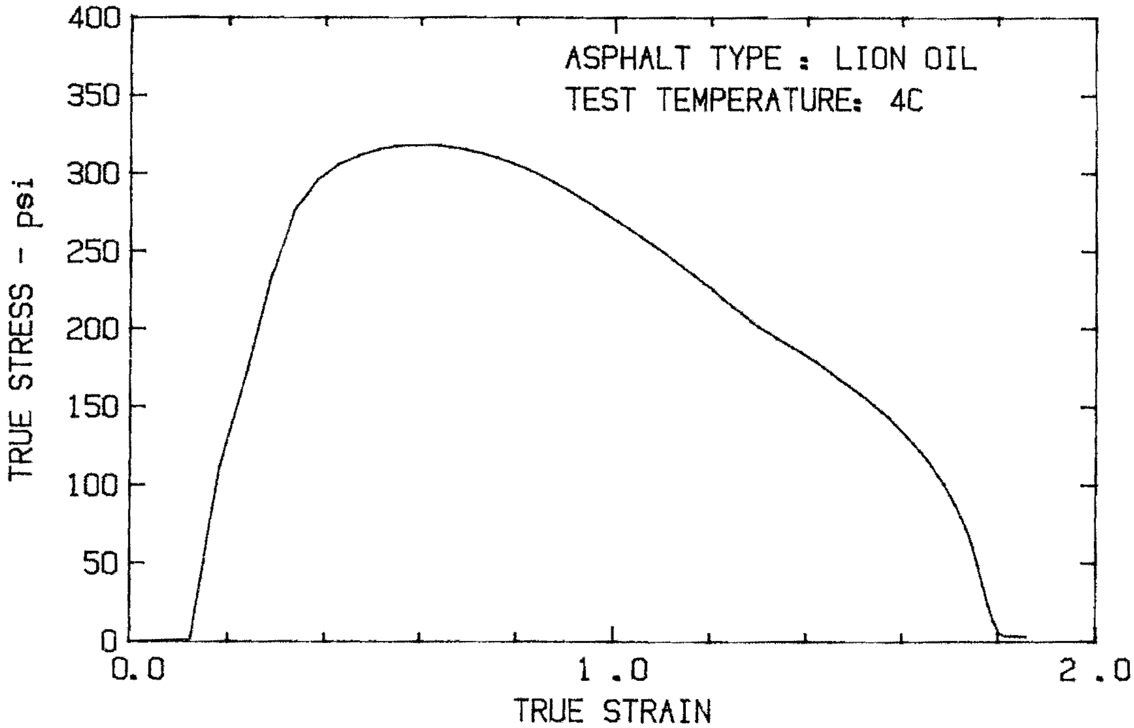

Figure A4. Force Ductility Test Result for Lyon AC-20.

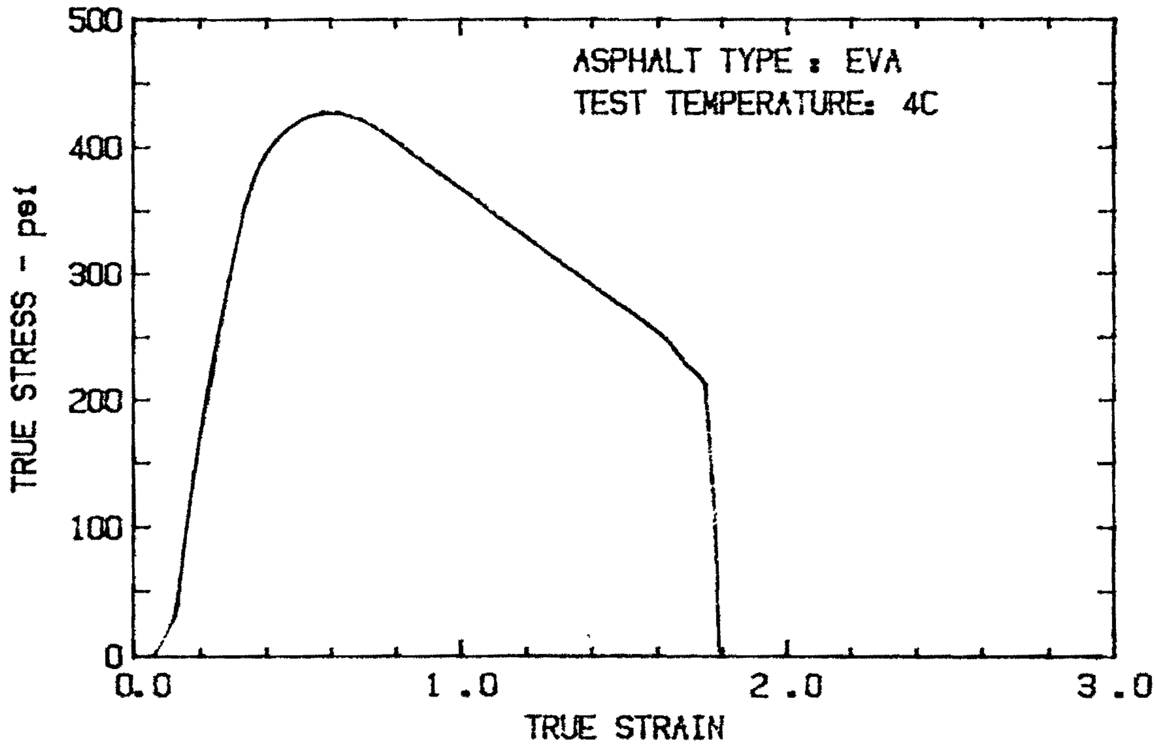

Figure A5. Force Ductility Test Result for Polybilt Modified Lyon Asphalt.

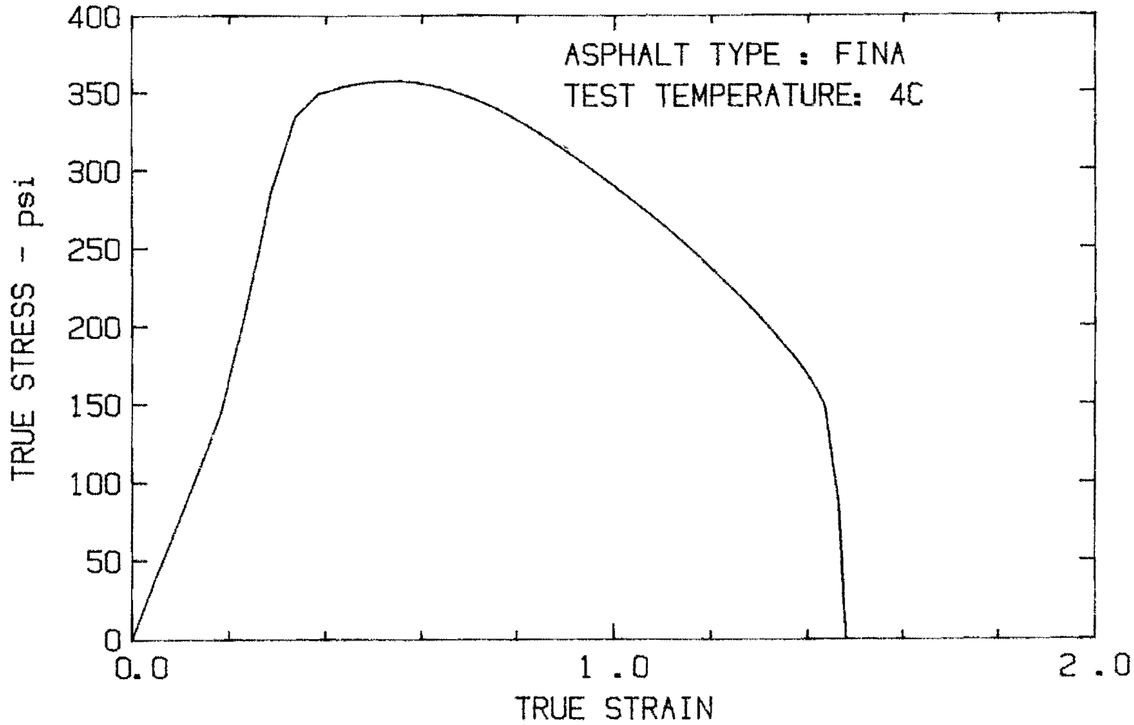

Figure A6. Force Ductility Test Result for Fina AC-10.

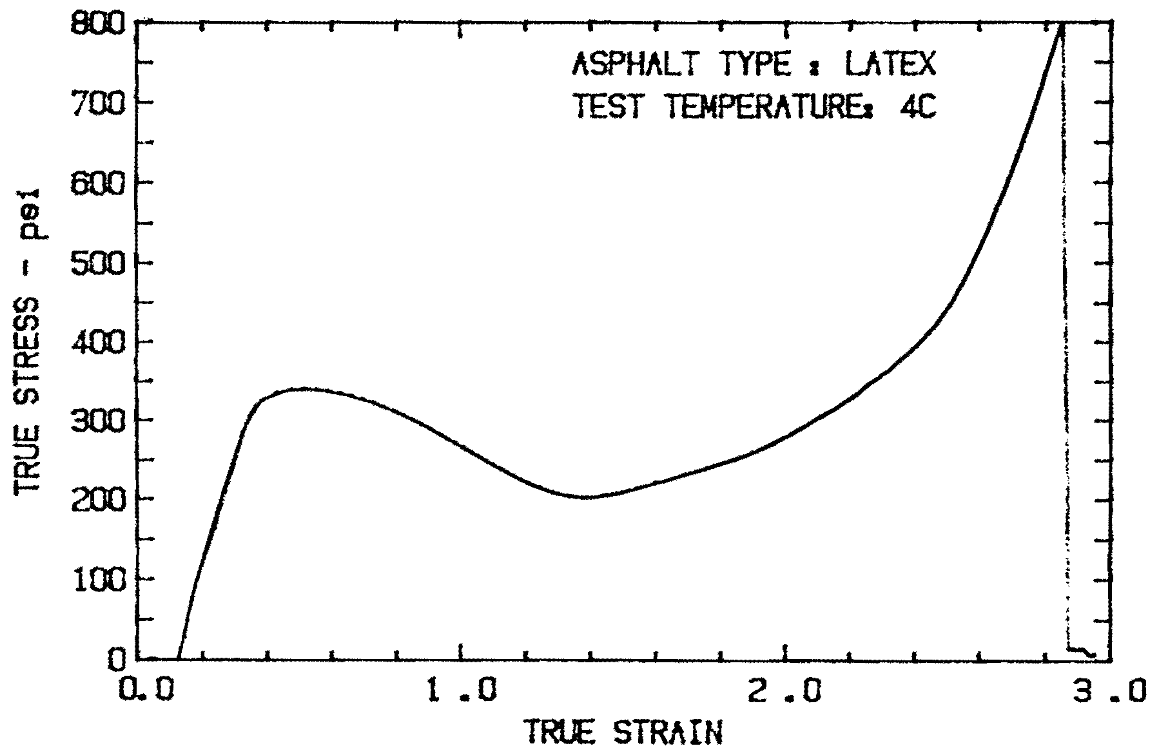

Figure A7. Force Ductility Test Result for Latex Modified Fina Asphalt.

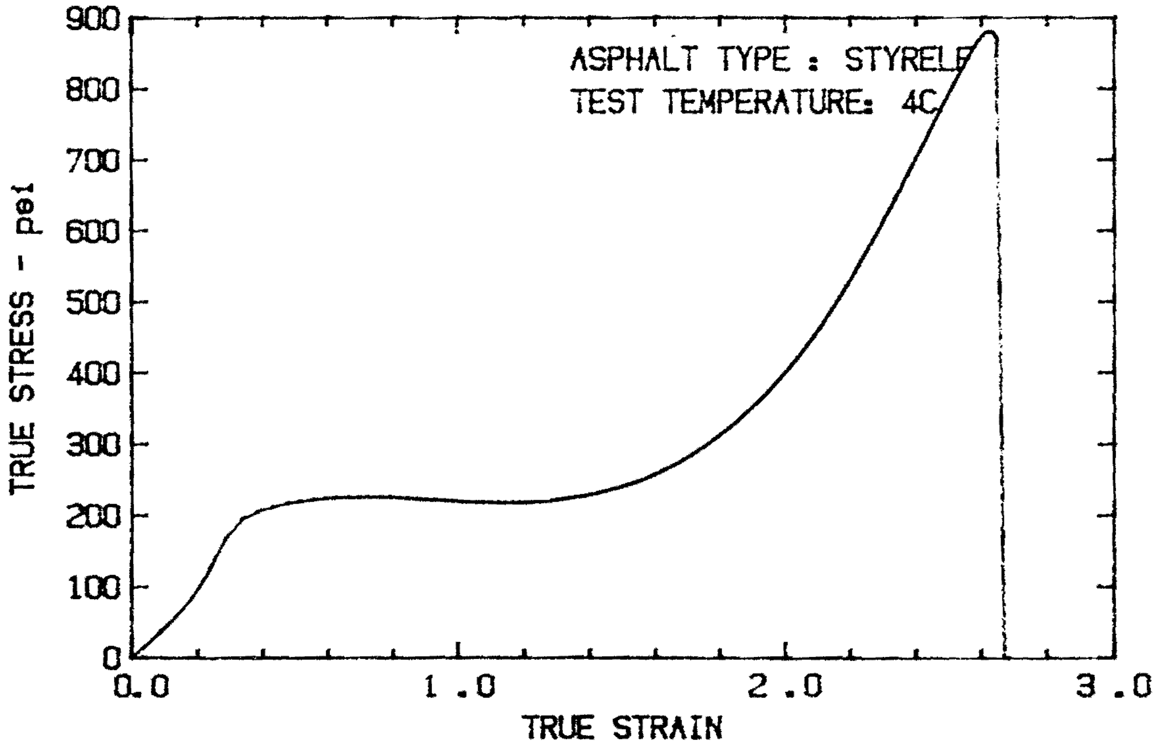

Figure A8. Force Ductility Test Result for Styrelf Modified Exxon Asphalt.

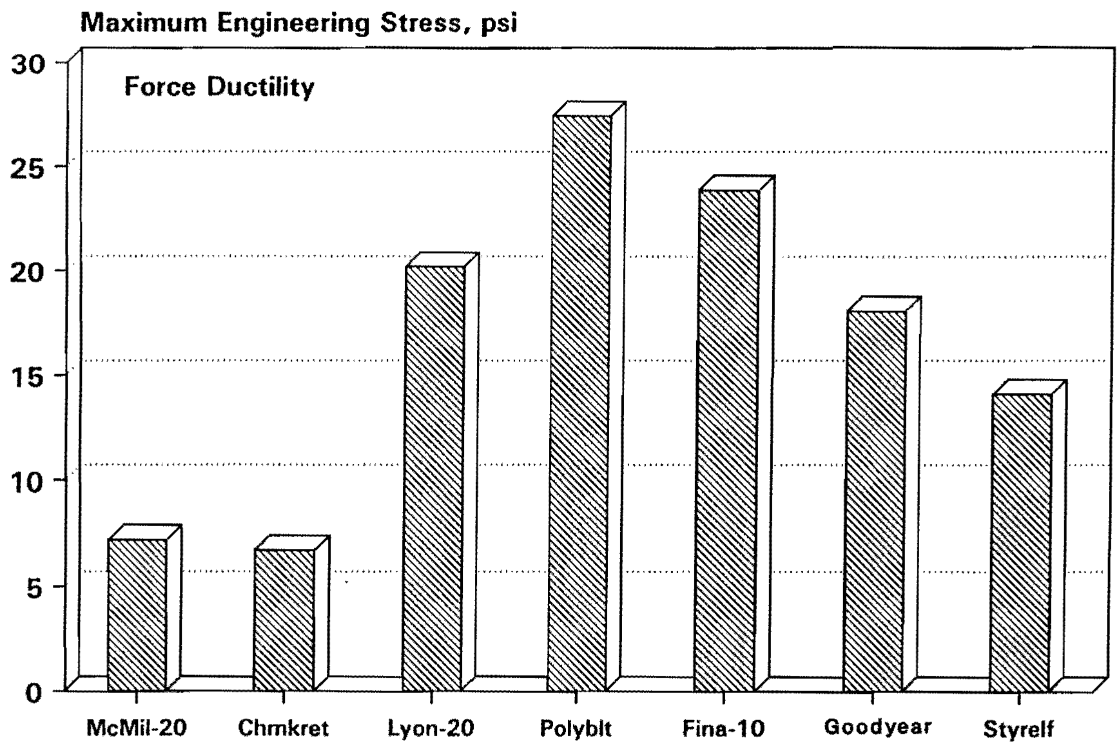

Figure A9. Maximum Engineering Stress from Force Ductility Test.

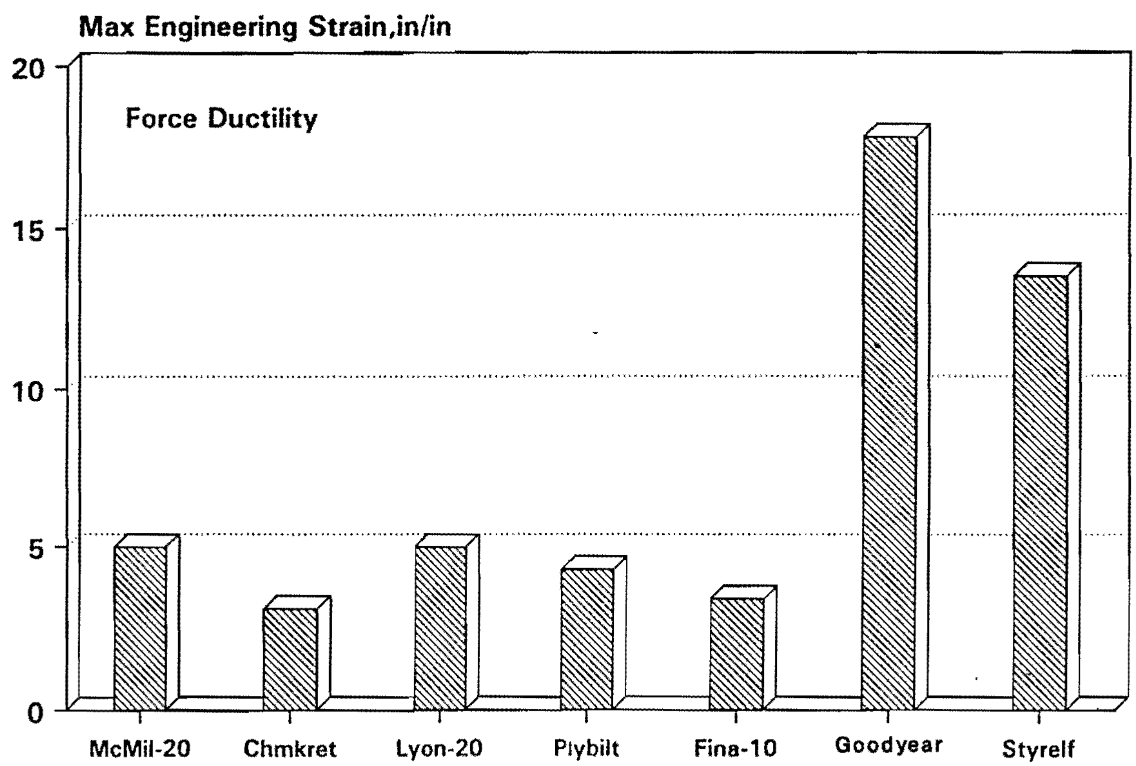

Figure A10. Maximum Engineering Strain from Force Ductility Test.

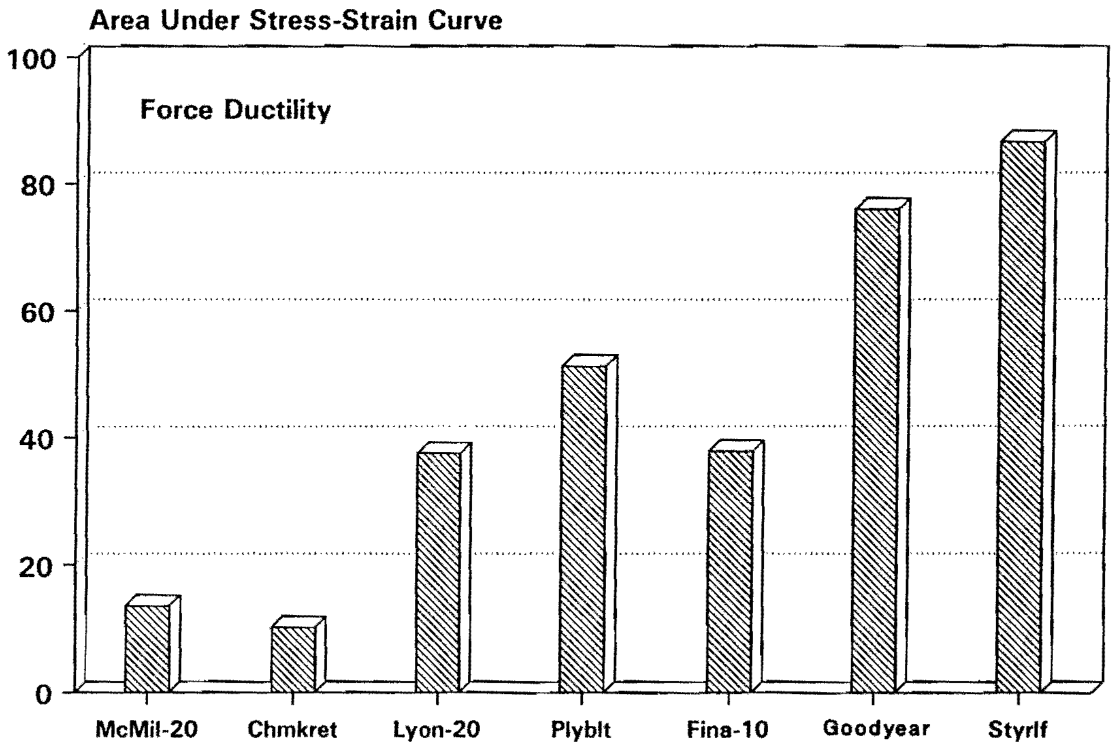

Figure A11. Areas Under Stress-Strain Curve from Force Ductility Test.

APPENDIX B

Data For Base Course Mixtures

Table B1. Aggregate Data For Hot Mix Asphalt Concrete - Base Course.

	Individual Aggregate Gradations			
	HMB C A - 7/8 (% by wt.)	HMB C A - 1/2 (% by wt.)	HMB Screenings (% by wt.)	G-H Hoot Flume Sand (% by wt.)
Retained 1"	0.0	0.0	0.0	0.0
Retained 7/8"	0.0	0.0	0.0	0.0
7/8" - 3/8"	88.5	20.8	0.0	0.0
3/8" - No. 4	11.5	62.2	0.6	0.8
No. 4 - No. 10	0.0	12.6	13.2	5.5
No. 10 - No. 40	0.0	1.2	39.9	42.6
No. 40 - No. 80	0.0	0.7	19.3	45.3
No. 80 - No. 200	0.0	1.1	16.3	5.1
Pass No. 200	0.0	1.4	10.7	0.7
TOTAL	100.0	100.0	100.0	100.0

	Combined Gradation Components									
	HMB C A - 7/8		HMB C A - 1/2		HMB Screenings		G-H Hoot Flume Sand		Combined Gradation	SDHPT Specs.
Retained 7/8"	0.0		0.0		0.0		0.0		0.0	0-5
7/8" - 3/8"	26.5		6.2		0.0		0.0		32.7	21-53
3/8" - No. 4	3.5		18.7		0.1		0.2		22.5	11-42
No. 4 - No. 10	0.0		3.8		2.6		1.1		7.5	5-26
Retained No. 10									62.7	58-74
No. 10 - No. 40	0.0		0.4		8.0		8.5		16.9	6-32
No. 40 - No. 80	0.0		0.2		3.9		9.1		13.2	4-21
No. 80 - No. 200	0.0		0.3		3.3		1.0		4.6	3-21
Pass No. 200	0.0		0.4		2.1		0.1		2.6	1-8
TOTAL	30.0	+	30.0	+	20.0	+	20.0	=	100.0	

Table B2. Design Data For Control Hot Mix Asphalt Concrete - Base Course.

Size	Specific Gravities			
	HMB C A - 7/8	HMB C A - 1/2	HMB Screenings	G-H Hoot Flume Sand
7/8" - 3/8"	2.574			
3/8" - No. 4	2.559	2.559		
No. 4 - No. 10		2.509		
No. 10 - No. 80			2.472	2.631
Pass No. 80			2.669	2.664

Specific Gravity of Asphalt = 1.018
Combined Bulk Specific Gravity = 2.567

Asphalt Content (% by wt.)	Density (Corrected For Asphalt Absorption)		
	Actual Sp. Gr. of Specimens (Ga)	Theo. Sp. Gr. of Specimens (Gt)	Corrected Density (Ga/Gt) X 100%
4.0	2.341	2.433	96.2
5.0	2.365	2.399	98.6
6.0	2.365	2.365	100.8
7.0	2.350	2.332	100.8

Optimum Asphalt Content (at 97% Density) = 4.3%
Stability at Optimum Asphalt Content = 46%
Effective Specific Gravity (GE) = 2.583
Asphalt Absorption = 0.2%

Table B3. Resilient Modulus, Hveem and Marshall Stability of Field Mixed-Laboratory Molded Test Specimens From District 19 - Base Course.

Type Mixture	Air Void Content[1], percent	Resilient Modulus, psi x 10^3					Hveem Stability[2]	Marshall Test[2]	
		-13°F[2]	33°F[2]	68°F[2]	77°F[1]	104°F[2]		Stability, lbs.	Flow, 0.01"
Control - NBL	4.4	2070	1200	260	220	42	44	2170	15
Chemkrete/ MacMillan	4.5	1960	1310	330	260	52	46	2576	13
Goodyear/ Fina	4.3	2450	1760	400	300	38	38	1840	13
Polybilt/ Lyon	4.7	2200	1580	580	420	56	43	2050	13
Styrelf/ Exxon	3.9	2510	1760	510	290	48	46	2780	15

[1] Average of tests on twelve different specimens.
[2] Average of tests on three different specimens.

Table B4. Properties of Field Mixed-Laboratory Molded Specimens From District 19 Base Course Before and After Accelerated Lottman Freeze-Thaw Procedure.

	Before Moisture Treatment					After Moisture Treatment			
			Tensile Properties[1,2]			Tensile Properties[1,2]			
Type Mixture	Air Void Content, percent	Resilient Modulus at 77°F[3], psi x 10^3	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi,	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Tensile Strength Ratio
Control NBL	4.4	220	140	0.0036	39,700	110	0.0055	19,300	0.79
Chemkrete/ MacMillan	4.5	260	190	0.0025	75,500	140	0.0044	31,600	0.74
Goodyear/ Fina	4.7	300	200	0.0049	41,400	160	0.0073	22,200	0.80
Polybilt 102/ Lyon	4.3	420	220	0.0033	67,400	200	0.0043	43,200	0.91
Styrelf/ Exxon	3.9	290	230	0.0052	44,500	184	0.0076	24,400	0.87

[1] Indirect tension tests were performed at 77°F and 2-inches/minute before and after moisture treatment.
[2] Average of tests on three different specimens.
[3] Average of tests on twelve different specimens.

Table B5. Properties of Field Mixed-Laboratory Molded Specimens From District 19 Base Course After Thermal Aging Treatment[1].

Type Mixture	Resilient Modulus at 77°F psi x 10^3	Tensile Properties[2]: Tensile Strength, psi	Tensile Properties[2]: Strain @ Failure, in/in	Tensile Properties[2]: Secant Modulus, psi	Resilient Modulus Ratio (Aged)	Tensile Strength Ratio (Aged)
Control/ NBL	460	170	0.0023	72,200	2.09	1.2
Chemkrete/ MacMillan	980	230	0.0023	100,200	3.78	1.2
Goodyear/ Fina	455	230	0.0039	58,400	1.52	1.2
Polybilt/ Lyon	670	300	0.0027	104,200	1.60	1.4
Styrelf/ Exxon	420	220	0.0045	49,200	1.45	0.96

[1] Aging consisted of exposure to 140°F for a period of four (4) weeks.
[2] Indirect tension tests were performed at 77°F and 2 inches/minute after aging.

Table B6. Resilient Modulus, Hveem, and Marshall Stability of Pavement Cores From District 19 Base Course.

Type Mixture	Lift Tested	Air Void Content, percent	Resilient Modulus, psi x 10^3 -13°F	33°F	68°F	77°F	104°F	Hveem Stability, percent	Marshall Test Stability, lbs.	Marshall Test Flow, 0.01"
Control-NBL	Top	6.4	1200	1410	810	570	140	40	2740	28
	Center	6.9	2010	1310	660	480	95	38	2430	16
	Bottom	6.2	1920	1420	680	450	61	--	--	--
	Average	**6.4**	**1710**	**1380**	**720**	**500**	**98**	**39**	**2580**	**17**
Chemkrete/ MacMillan	Top	6.1	1870	1470	1240	990	160	53	6950	11
	Center	8.0	1730	1130	920	620	110	24	6240	17
	Bottom	6.3	1940	1020	590	450	89	45	2421	23
	Average	**6.8**	**1850**	**1120**	**920**	**690**	**120**	**41**	**5202**	**17**
Goodyear/ Fina	Top	5.7	1960	1180	720	430	67	27	1350	17
	Center	5.1	1870	1350	740	420	53	33	1700	18
	Bottom	7.6	1820	1380	580	280	36	29	914	18
	Average	**6.1**	**1880**	**1300**	**680**	**380**	**52**	**30**	**1320**	**18**
Control-SBL	Top	6.8	1560	1060	710	510	83	--	--	--
	Center	7.2	1940	1200	830	580	92	34	2010	16
	Bottom	8.3	2100	1390	860	520	86	32	1160	16
	Average	**7.4**	**1860**	**1220**	**800**	**540**	**87**	**33**	**1590**	**16**
Polybilt/ Lyon	Top	7.6	2220	1530	820	530	120	35	1970	15
	Center	4.5	2180	1760	850	590	100	35	2860	16
	Bottom	7.9	1990	1500	650	370	75	33	1140	18
	Average	**6.7**	**2130**	**1600**	**770**	**500**	**100**	**35**	**1990**	**16**
Styrelf/ Exxon	Top	7.2	1900	1610	910	590	68	43	1910	19
	Center	7.3	2100	1450	780	460	50	34	1540	19
	Bottom	--	--	--	--	--	--	--	--	--
	Average	**7.3**	**2000**	**1530**	**850**	**520**	**59**	**39**	**1720**	**19**

Table B7. Properties of Pavement Cores From District 19 Base Course Before and After Accelerated Lottman Freeze-Thaw Procedure.

Type Mixture	Lift Tested	Air Void Content, percent	Before Moisture Treatment: Tensile Properties[1,2] Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi,	After Moisture Treatment: Tensile Properties[1,2] Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Tensile Strength Ratio
Control-NBL	Top	6.5	173	0.0035	50,000	126	0.0031	38,500	
	Center	6.9	154	0.0043	35,800	114	0.0047	24,000	
	Bottom	6.2	--	--	--	--	--	--	
	Average	**6.5**	**163**	**0.0039**	**42,900**	**120**	**0.0039**	**31,500**	**0.74**
Chemkrete/ MacMillan	Top	6.1	--	--	--	51	0.0028	18,500	
	Center	8.0	148	0.0021	71,000	81	0.0041	19,700	
	Bottom	6.3	117	0.0033	35,700	132	0.0048	27,600	
	Average	**6.8**	**132**	**0.0026**	**53,300**	**88**	**0.0039**	**21,900**	**0.67**
Goodyear/ Fina	Top	5.7	171	0.0056	30,300	151	0.0040	35,600	
	Center	5.1	181	0.0064	28,400	187	0.0068	27,700	
	Bottom	7.6	125	0.0068	18,300	105	0.0066	16,000	
	Average	**6.1**	**159**	**0.0063**	**25,700**	**147**	**0.0058**	**26,400**	**0.92**
Control-SBL	Top	6.8	120[3]	0.0042	28,300	--	--	--	
	Center	7.2	175	0.0033	53,100	234	0.0040	59,200	
	Bottom	8.3	183	0.0036	53,000	121	0.0052	23,800	
	Average	**7.4**	**179**	**0.0037**	**45,000**	**177**	**0.0046**	**41,500**	**0.99**
Polybilt/ Lyon	Top	7.6	195	0.0039	52,400	156	0.0035	44,500	
	Center	4.5	197	0.0038	51,600	238	0.0056	42,500	
	Bottom	7.9	158	0.0046	34,400	110	0.0061	18,100	
	Average	**6.7**	**184**	**0.0041**	**46,100**	**168**	**0.0051**	**35,900**	**0.91**
Styrelf/ Exxon	Top	7.2	202	0.0033	61,900	195	0.0046	42,600	
	Center	7.3	175	0.0040	44,000	164	0.0060	27,300	
	Bottom	--	--	--	--	--	--	--	
	Average	**7.3**	**188**	**0.0038**	**53,000**	**179**	**0.0053**	**35,000**	**0.95**

[1] Indirect tension tests were performed at 77°F and 2 inches/minute before and after moisture treatment.
[2] Average of tests on three different specimens.
[3] Not included in average.

APPENDIX C

Data For Surface Course Mixtures

Table C1. Aggregate Data For Hot Mix Asphalt Concrete - Surface Course.

Size	Individual Aggregate Gradations		
	HMB C A - 7/8 (% by wt.)	HMB Screenings (% by wt.)	G-H Hoot Flume Sand (% by wt.)
Retained 1/2"	0.0	0.0	0.0
Retained 3/8"	1.3	0.0	0.0
3/8" - No. 4	62.4	0.6	0.8
No. 4 - No. 10	34.9	13.2	5.5
No. 10 - No. 40	0.6	39.9	42.6
No. 40 - No. 80	0.2	19.3	45.3
No. 80 - No. 200	0.2	16.3	5.1
Pass No. 200	0.4	10.7	0.7
TOTAL	100.0	100.0	100.0

	Combined Gradation Components				
	HMB C A - 7/16	HMB Screenings	G-H Hoot Flume Sand	Combined Gradation	SDHPT Specs.
Retained 1/2"	0.0	0.0	0.0	0.0	0
Retained 3/8"	0.7	0.0	0.0	0.7	0-15
3/8" - No. 4	34.3	0.1	0.2	34.6	21-53
No. 4 - No. 10	19.3	2.6	1.3	23.2	11-32
Retained No. 10				58.5	54-74
No. 10 - No. 40	0.3	8.0	10.7	19.0	6-32
No. 40 - No. 80	0.1	3.9	11.3	15.3	4-27
No. 80 - No. 200	0.1	3.3	1.3	4.7	3-27
Pass No. 200	0.2	2.1	0.2	2.5	1-8
TOTAL	55.0	20.0	25.0	100.0	

Table C3. Resilient Modulus, Hveem and Marshall Stability of Pavement Cores from District 19 Surface Course.

Type Mixture	Air Void Content[1], percent	Resilient Modulus, psi x 10^3					Hveem Stability[2], Percent	Marhall Test[2]	
		-13°F[2]	33°F[2]	68°F[2]	77°F[1]	104°F[2]		Stability, lbs	Flow, 0.01"
Control-NBL	8.0	1810	1370	710	480	108	25	1260	15
Goodyear/MacMillan	9.0	1790	1440	650	330	56	25	790	14
Control-SBL	7.3	1940	1500	740	460	96	26	1620	15
Polybilt/Lyon	7.0	1700	1470	800	530	126	29	1680	20
Styrelf/Exxon	9.3	1630	1543	830	510	83	26	1130	15

[1] Average of tests on twelve different specimens.
[2] Average of tests on three different specimens.

Table C4. Properties of Pavement Cores from District 19 Surface Course Before and After Accelerated Lottman Freeze-Thaw Procedure.

Type Mixture	Before Mositure Treatment				After Moisture Treatment			
		Tensile Properties[1,2]			Tensile Properties[1,2]			
	Air Void Content, percent	Tensile Strength, psi	Strain @ Failure, in/in	Secanat Modulus, psi	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Tensile Strength Ratio
Control-NBL	8.0	146	0.0033	44,400	168	0.0050	33,700	1.15
Goodyear/MacMillan	9.0	164	0.0073	25,000	149	0.0066	22,600	0.91
Control-SBL	7.3	217	0.0043	50,500	202	0.0057	35,400	0.93
Polybilt/Lyon	7.0	196	0.0035	56,900	209	0.0043	49,600	1.07
Styrelf/Exxon	9.3	185	0.0037	59,800	175	0.0049	35,800	0.95

[1] Indirect tension tests were performed at 77°F and 2 inches/minute before and after moisture treatment.
[2] Average of tests on three different specimens.