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Study Title: Asphalt Additives for Increased Pavement Flexibility

16. Abstract

Test pavements were constructed in four districts in the mid-1980s to assess the effectiveness of asphalt additives in reducing cracking and rutting in asphalt concrete pavements. Field trails were built in Districts 1, 2, 19, and 21 and their performance has been evaluated. Ride quality of all pavements has proven approximately equivalent and satisfactory. Some pavements exhibit cracking at the surface. EVA modified and control pavements have shown the most cracking. Polyethylene, SBS, SBR, and carbon black appear capable of reducing or delaying cracking in asphalt pavements.

Test pavements in District 19 were cored and the cores were tested in the laboratory. Testing consisted of recovering asphalt to measure penetration and viscosity as well as measurement of Hveem and Marshall stability, indirect tension, resilient modulus at five temperatures, moisture susceptibility, creep, and permanent deformation. Laboratory test results did not reflect the findings from the field condition surveys. Based on the findings of these tests on pavement cores, along with their comparisons to field performance and past experience with these test procedures, it appears that these test methods can identify very bad and very good mixes (regarding cracking and rutting) but cannot detect subtle differences in mixtures properties that can contribute to significant differences in cracking and rutting.

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# EFFECT OF ASPHALT ADDITIVES ON PAVEMENT PERFORMANCE

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Research Report 187-22
Research Study No. 0-187
Study Title: Effect of Asphalt Additives
on Pavement Performance

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# IMPLEMENTATION STATEMENT

Field test pavements composed of 10 inches (254 mm) (8-inch or 203 mm base and 2-inch or 51 mm surface) of modified asphalt concrete were placed in 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 under study, assuming researchers continue periodic evaluations of these test sections for the next several years. The results of these field tests can be used to make inferences about performance of other similar polymer-type additives.

For the present time, one may design asphalt paving mixtures containing polymeric additives using standard procedures. However, designers should consider increasing the mixing and compaction temperatures to accommodate the increased binder viscosity and more closely simulate field operations. One should realize that Hveem stability is not sensitive to changes in binder properties brought about by incorporation of an asphalt additive. Long-term creep and permanent deformation, however, should be sensitive to these changes.

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

When asphalt additives are used, plant operations may or may not need modification, depending on whether the additive is blended at the plant site or preblended with the asphalt prior to arrival. Generally, one should increase mixing and compaction temperatures to accommodate the higher-than-usual viscosities of the polymer-modified binders, thus insuring adequate coating of the aggregate in the plant and densification of modified paving mixtures. One should make observations of aggregate coating and construct compaction test strips 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. Such degradation may result from a chemical breakdown of the polymer or physical separation of the asphalt and the polymer due to differences in specific gravity.

For hot mix containing conventional binders, TxDOT specifies a compaction cessation temperature of 175°F (79°C). If an additive increases the mass viscosity of the mix by a substantial amount, the compaction cessation temperature may also need increasing. This concept needs investigation so that appropriate compaction cessation temperatures (or viscosities) can be established for modified asphalt materials.

Until the Strategic Highway Research Program (SHRP) binder specifications are fully implemented, it appears that modified asphalt specifications will need to be specific for particular categories of asphalt additives since the properties of the commercial additives vary tremendously. Acceptance criteria should be based on fundamental engineering properties of the final product (the asphalt-aggregate mixture) and should stipulate resistance to creep and permanent deformation at high service temperatures and compliance at low service temperatures, as well as minimum increases in tensile strength and stiffness. These tests are designed to simulate stress states in a pavement and are presently the most useful in predicting pavement performance using computer software and other predictive methods.

# DISCLAIMER

This report has been prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

The contents of this report reflects the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation.

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# METRIC (SI*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

### LENGTH

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| 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

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| $in^2$ | 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)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |

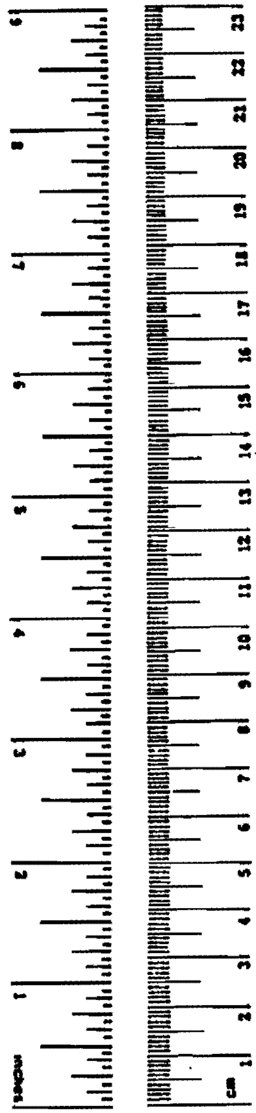
### VOLUME

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| 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)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



## APPROXIMATE CONVERSIONS TO SI UNITS

### LENGTH

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| 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

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| $mm^2$ | 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)

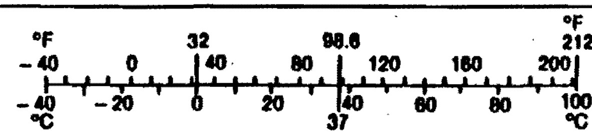
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| g | grams | 0.0353 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams (1 000 kg) | 1.103 | short tons | T |

### VOLUME

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| 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)

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| °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

# SUMMARY

TxDOT initiated this research study in 1984 to evaluate selected asphalt additives or modifiers as economic alternatives to improve flexibility and thus resistance to cracking in asphalt concrete pavements. Since that time, TTI has evaluated several additives in the laboratory and in the field, and four reports describing this work have been issued.

In 1987 and 1988, four asphalt additive test pavements and two control pavements were constructed on US-59/71 in the Texarkana district. The test pavements consisted of an eight-inch (203 mm) base layer and a two-inch (51 mm) surface layer both of which contained additives. Annual field investigations of these pavements and periodic laboratory testing has been continued under TxDOT Study 187 in an attempt to relate performance of the pavements to laboratory properties of the modified binders.

Two laboratory test programs, one soon after construction of these pavements and one about five years after construction (Texarkana pavements only), were performed to quantify relative strength, stiffness, flexibility, and resistance to permanent deformation and moisture damage of the modified binders and/or paving mixtures. Results of the first test program were reported in 1991. Results of the second laboratory test program on 5-year pavement cores and performance of the Texarkana experimental pavements are reported herein.

In 1985 and 1986, additive test pavements were constructed in the Sherman district, the Fort Worth district, and the Pharr district (near San Benito). Current condition of these test pavements is reported herein.

Based on laboratory testing of cores from five-year old test pavements at Texarkana and visual performance evaluations of test pavements near Texarkana, Sherman, Fort Worth, and San Benito, the researchers have concluded:

1. SBR latex, SB block copolymer, finely dispersed polyethylene, and pelletized carbon black may reduce or delay cracking in asphalt concrete pavements. Cost effectiveness of these additives can only be established by monitoring these pavements throughout their life cycles.

2. No significant rutting has been experienced in any of the test pavements, therefore, no inferences can be made regarding the effect of the additives studied on rutting.
3. Creep and permanent deformation tests (as described herein) may identify asphalt mixtures that yield bad and good performance regarding resisting rutting and cracking but cannot detect more subtle differences in binder properties.
4. The additives studied in this experiment will not significantly affect stability, strength, or moisture susceptibility of asphalt paving mixtures.
5. Based on laboratory tests of 5-year old pavement cores and extracted/recovered asphalt binders, it proved difficult to establish the causes of wide differences in cracking performance of the asphalt concrete pavements.

# INTRODUCTION

This research study began in 1984 as HP&R Study 471, "Asphalt Additives for Increased Pavement Flexibility." In general, the original study sought to evaluate selected additives or modifiers as economic alternatives to improve resistance to cracking in asphalt concrete paving mixtures. Researchers have evaluated several asphalt additives both in the laboratory and in the field, and four reports describing this work have been issued (1, 2, 3, 4).

In 1987 and 1988, side-by-side asphalt additive test pavements were constructed on US-59/71 in District 19 just north of Texarkana, Texas. The test pavements consisted of four different asphalt additive sections and two untreated control sections. The asphalt test pavements consisted of an eight-inch (203 mm) base layer and a two-inch (51 mm) surface layer. Annual field investigations of these pavements and some laboratory testing has been continued under TxDOT Study 187. The chief objective of this follow-up work was to attempt to relate performance of the pavements to properties of the materials.

The asphalt additives evaluated in these field studies were designed to reduce cracking and rutting in asphalt concrete pavements subjected to heavy, high-volume traffic. Researchers performed two laboratory test programs (one soon after construction of these pavements and one about five years after construction [Texarkana pavements only]) to quantify relative strength, stiffness, flexibility, and resistance to permanent deformation and moisture damage of the modified binders and/or paving mixtures. Standard ASTM, AASHTO, and/or TxDOT test procedures were performed on laboratory prepared specimens and pavement cores. Results of the first test program were reported in Reference 4. This report presents the results of the second test program on 5-year pavement cores from the Texarkana experiment. Ultimately, researchers will examine long-term performance (and, thus, cost-effectiveness) of the additives. Current performance of the District 19 field test pavements and laboratory experimental findings are reported herein.

In 1985 and 1986, additive test pavements were also constructed in Districts 1 (near Sherman), 2 (in Fort Worth), and 21 (near San Benito) as a part of HP&R Study 471. This report presents information regarding current condition of these test pavements.

This is the fifth in a series of reports. Others include Research Report 471-1, "Another Look at Chemkrete," Research Report 471-2F, "Asphalt Additives for Increased Pavement Flexibility," Research Report 187-14, "Asphalt Additives in Highway Construction," and Research Report 187-18, "Asphalt Additives in Thick Hot Mixed Asphalt Concrete Pavements."

## SUMMARY OF FIELD TRIALS

References 3 and 4 provide details of the design, construction, traffic, and environment of the test pavements. Table 1 and the following paragraphs give a brief summary of these details.

Table 1. Summary of Test Pavements.

| District | 19 | 1 | 21 | 2 |
|---|---|---|---|---|
| Location | Texarkana US 59 | Sherman US 75 | San Benito US 83 | Ft. Worth SH 121 |
| Installed | 1987 | 1986 | 1986 | 1985 |
| Additives | 4 | 5 | 4 | Latex |
| Layer Thickness | 8" + 2" | 3" | 3" | 2" |
| Type Hot Mix | B + D | C | D | D |
| Old Pav | Reconst. | CRCP | New | CRCP |
| ADT @ Const | 13K | 18K | 15K | 63K |
| Trucks | 15% | 17% | 11% | --- |

### TEXARKANA TEST PAVEMENTS

The 5.6 mile (9010 m) project, MA-F 472(3), is located in Bowie County from 1.8 miles (2896 m) north of IH-30 to 0.8 mile (1287 m) south of the Red River. The project consisted of reconstructing 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 adjacent 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 1448 m) test pavements consist of eight inches (203 mm) of Item 340 Type B (7/8-inch [22 mm] nominal maximum size) and two inches (52 mm) of Item 340, Type D (3/8-inch [9.5 mm] nominal maximum size) asphalt concrete placed on an 18-inch (457 mm) lime-flyash treated subgrade that had been sealed with an MC-30 prime coat.

The four different additives evaluated include:

1. Goodyear 5812 - styrene butadiene rubber (SBR) latex, supplied by Fina,
2. Exxon Polybilt 102 - ethylene vinyl acetate (EVA), supplied by Exxon,
3. Styrelf 13 - neat synthetic SB block copolymer vulcanized with asphalt, supplied by Elf Asphalt, and
4. Chemkrete (CTI-102) - a manganese organic complex in an oil base, supplied by LBD.

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. While this is not an ideal situation for comparative evaluation of additives, it was necessary to expedite construction of the experimental pavements.

## SHERMAN TEST PAVEMENTS

Researchers selected a 3.17-mile (5100 m) section of US 75 south of Sherman in Grayson County from construction project CSR 47-13-11 and used it to test five asphalt additives. The five additives included:

1. Novophalt - finely dispersed polyethylene (PE),
2. DuPont Elvax - ethylene vinyl acetate (EVA), polyethylene (PE),
3. Ultrapave latex - styrene butadiene rubber (SBR) latex,
4. Kraton D4460X - styrene-butadiene styrene-block copolymer (SBS), and
5. Microfil-8 - carbon black pelletized using oil as a binder.

The (approximately) one-half mile (805 m) pavements consisted of essentially three-inch (76 mm) overlays of asphalt concrete placed as the surface course in rehabilitation of continuously reinforced Portland cement concrete pavement. All test pavements were built in the southbound travel lane in October of 1986. A map illustrating the layout of the test pavements is furnished in Figure A2, Appendix A.

## FORT WORTH TEST PAVEMENT

Test pavements were built in the outermost northbound lane of SH 121 from IH 35 to IH 820 in Fort Worth in June of 1985 to evaluate Dow latex (SBR) modified hot mixed asphalt and engineering fabric for reducing reflective cracking (5). SH 121 is a very high traffic volume six-lane facility. The existing pavement structure was composed of continuously reinforced concrete pavement. A map of the test pavements is on Table A3. Five 500-foot (152 m) test pavements consisting of two inches (51 mm) of asphalt concrete were originally placed as follows:

Table 2. Description of Test Pavements installed at Fort Worth in 1985.

| Test Section | Percent Binder | Latex | Fabric |
|---|---|---|---|
| 1 | 8.5 | Yes | Yes |
| 2 | 8.5 | Yes | No |
| 3 | 8.5 | No | No |
| 4 | 8.5 | No | Yes |
| 5 | 7.5 | Yes | Yes |
| 6* | 7.2 | No | No |

*Test pavements 3 and 4 failed within two weeks after construction due to rutting, shoving, and flushing and were replaced; the new 1000-foot (305 m) test section was designated section 6.

AC-10 from the Kerr-McGee refinery at Winnewood, Oklahoma, was used in the test sections numbered 1 through 5. AC-20 from the Texaco refinery in Port Authur, Texas, was used in test section number 6. The latex was supplied by Dow Chemical Company. Pavebond antistrip was used in all the paving mixtures for this project. The test sections are located with respect to the Haltom Road bridge, as shown in Table A3. Reference 5 gives details of construction and early performance.

**SAN BENITO TEST PAVEMENTS**

In August, 1986, during construction of Project MA-F-93(40) on US 83/77 in Cameron County, a 2.6-mile (4183 m) segment of the project was used to evaluate four asphalt additives (3). The additives included Exxon Polybilt (EVA), UltraPave latex (SBR), Kraton D4460X (SBS), and Microfil-8 (pelletized carbon black). The work consisted of new construction. To ensure statistical validity, researchers built two ¼-mile (402 m) test pavements three inches (76 mm) thick containing each additive and a control section with no additive. In addition, one ¼-mile (402 m) control section four inches (102 mm) thick was installed. A total of eleven pavement sections were built for the experiment.

Due to subsequent construction of overpasses in the same vicinity in 1990, seven of the test pavements in the middle of the experimental area were totally or partially destroyed. Furthermore, the northernmost surviving test pavements received many more heavy loads during construction of the overpass than the southernmost surviving test pavements. For these reasons, these test sections have been eliminated from further study. A map showing the layout of the experimental sections and those destroyed is provided in Figure A4.

# LABORATORY FINDINGS ON CORES FROM TEXARKANA

This section describes laboratory test results on the pavement cores collected during November, 1992, from the test sections located on US 59/71, just North of Texarkana.

## LABORATORY TESTS AND RESULTS

### Asphalt Binders

Researchers performed standard extraction and recovery procedures separately on the surface course and base course mixtures to obtain samples of the asphalt binders. Viscosity at 140°F (60°C) and penetration at 77°F (25°C) of the binders was measured using standard asphalt specification tests. Table A1 in Appendix A records the results and compares them with properties of virgin materials and TFOT aged materials in Figures 1 and 2. The researchers realize that rubber-modified asphalts are difficult to completely extract and that heating during recovery may affect rheological properties; nevertheless, these values were obtained to identify any inordinately large changes in binder properties which may explain differences in performance within the five-year service period.

Most of the binders exhibited significant increases in viscosity and decreases in penetration, likely due to oxidation. Asphalts from the surface course show more hardening than those from the base course for most of the materials, most probably because the surface has more accessibility to oxygen. The Chemkrete modified material exhibited the largest change in viscosity and penetration. Chemkrete, of course, is designed to harden the asphalt and lower the temperature susceptibility. Penetration and viscosity values after TFOT should indicate the approximate values at construction. Note that the Polybilt/Lyon binder had the lowest penetration asphalt of any of the surface mixtures at construction (as predicted by TFOT), as well as, the highest viscosity of any of the polymer additives after five years.

One should note that each additive is blended with a different asphalt cement, thus confounding direct comparisons of additive performance. Though not ideal for research purposes, this circumstance proved unavoidable.

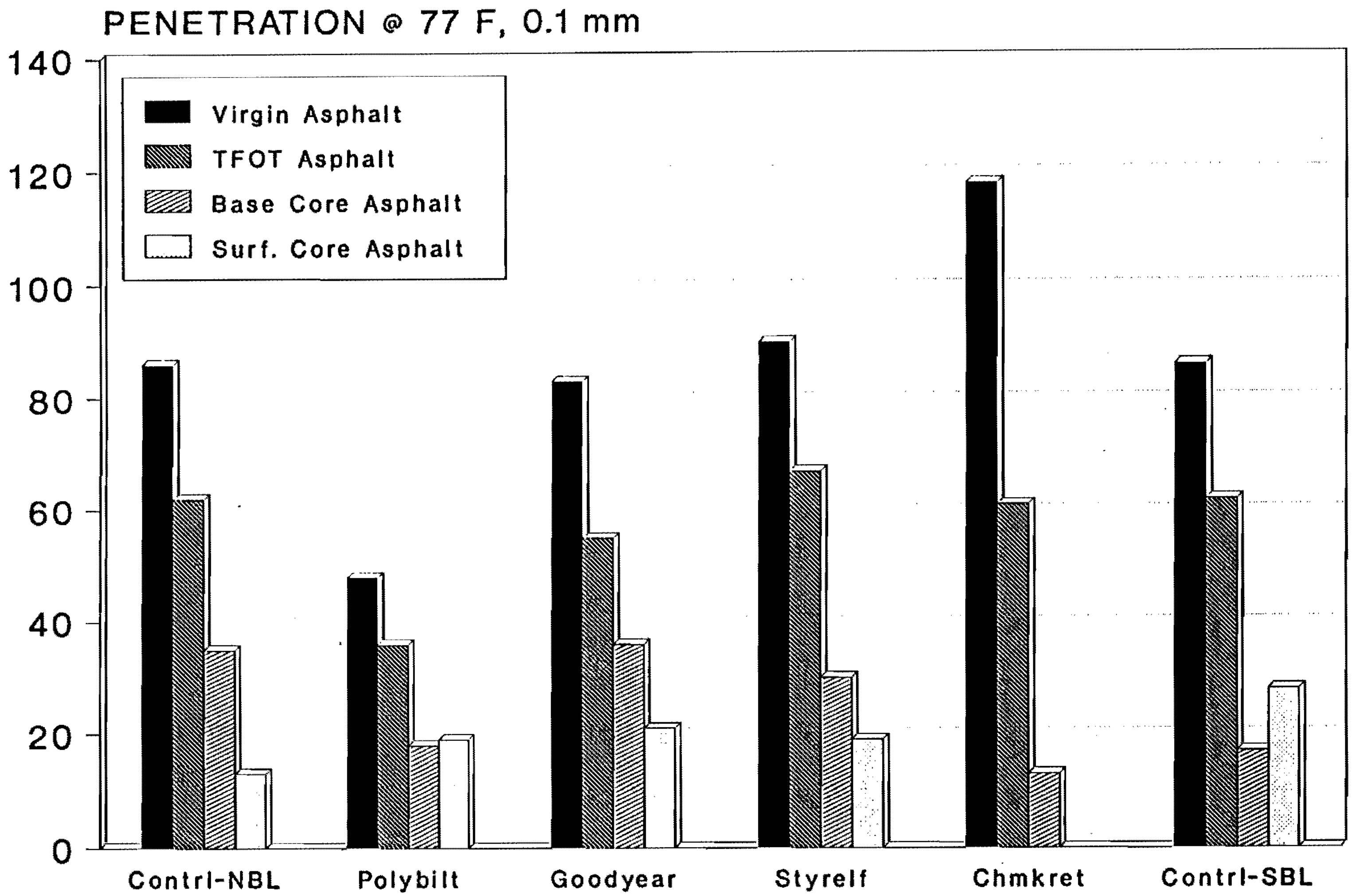



Figure 1. Penetration of Asphalts Extracted from Base and Surface Mixtures after Approximately Five years in Service Compared to Original Properties.

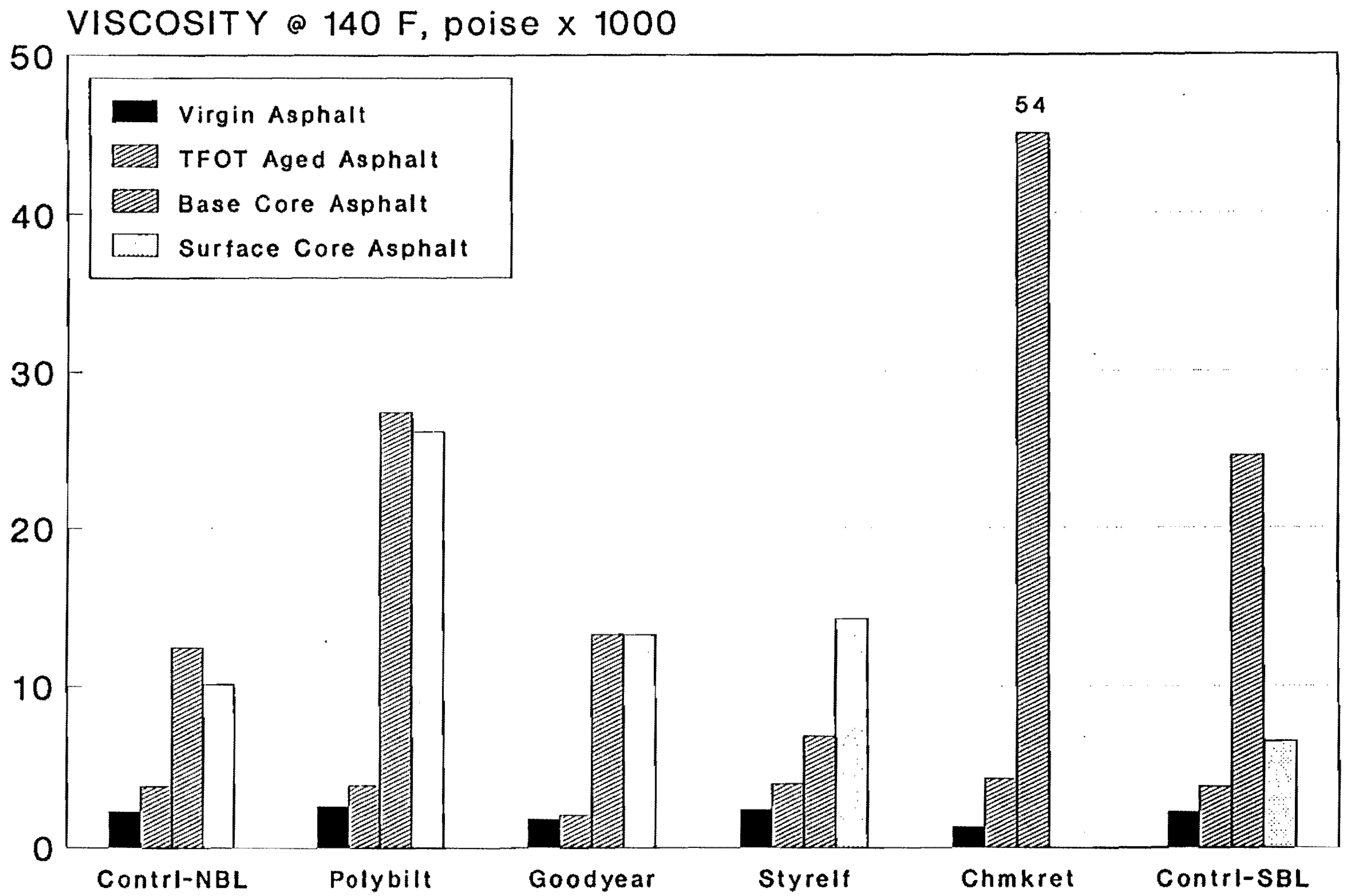



Figure 2. Viscosity of Asphalts Extracted from Base and Surface Mixtures after Five Years in Servie Compared to Original Viscosity.

**Results of Tests on Pavement Cores**

Researchers drilled fifteen four-inch (102 mm) diameter cores from each of the four test pavements and two control pavements in the northbound and southbound lanes. A total of 90 cores were obtained. Each core was cut at the interface of the surface and base layer to accommodate separate testing of the 8-inch (203 mm) Type B base mixtures and the 2-inch (51 mm) Type D surface mixtures. Creep and permanent deformation testing of the base course mixtures was performed on approximately 8-inch (203 mm) tall cores. Researchers performed all other tests on core samples cut to two inches (approximately) tall. Figure 3 shows how the specimens were tested. Data for the two-inch (51 mm) specimens is tabulated in Tables A2 and A3, Appendix A.

*Base Cores.* Resilient moduli of the two-inch (51 mm) high base cores (Type B) were measured at five different temperatures, and the resulting data is plotted in Figure 4. Resilient modulus values increased from the corresponding values at the construction reported in Reference 4 with the exception of Chemkrete. Resilient moduli of Chemkrete decreased and was lower than all other mixtures at all temperatures, with the exception of 104°F (60°C). The high viscosity and low modulus of Chemkrete may indicate a high propensity for fatigue damage. (One should note that thermal (transverse) and load related (longitudinal) cracks occurred in the Chemkrete base before placement of the surface course.) The Control mixtures exhibited the highest moduli at all temperatures, while the Goodyear/Fina (latex) exhibited a significantly lower modulus at 104°F than the other mixtures.

Hveem stability values of the base cores are plotted along with the stability values of the as-constructed cores in Figure 5. Values for all the latex, Polybilt, and Control-SBL cores showed consistent and significant increases. Stability of the Styrelf cores exhibited the smallest increase with time. Although Hveem stability is quite sensitive to binder content, it is not normally sensitive to changes in binder viscosity. These increases in stability may be partly due to steric hardening of the asphalt which is not detected by tests on extracted and recovered asphalts.

Figure 6 shows that Marshall stability for the mixtures increased with time for each mix except Chemkrete. The Control sections show the largest increase. The Chemkrete mix

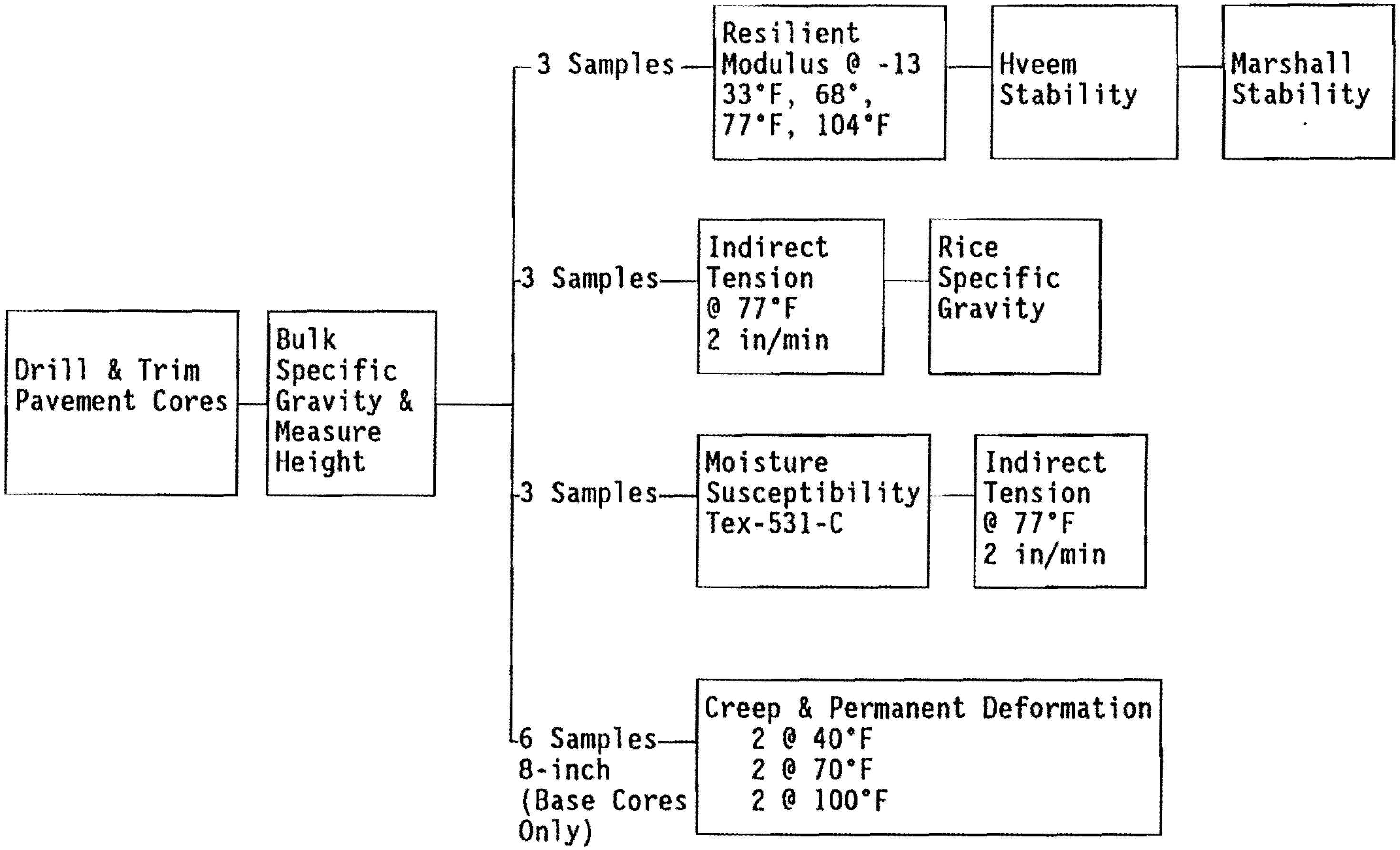



Figure 3. Laboratory Test Program for Paving Cores.

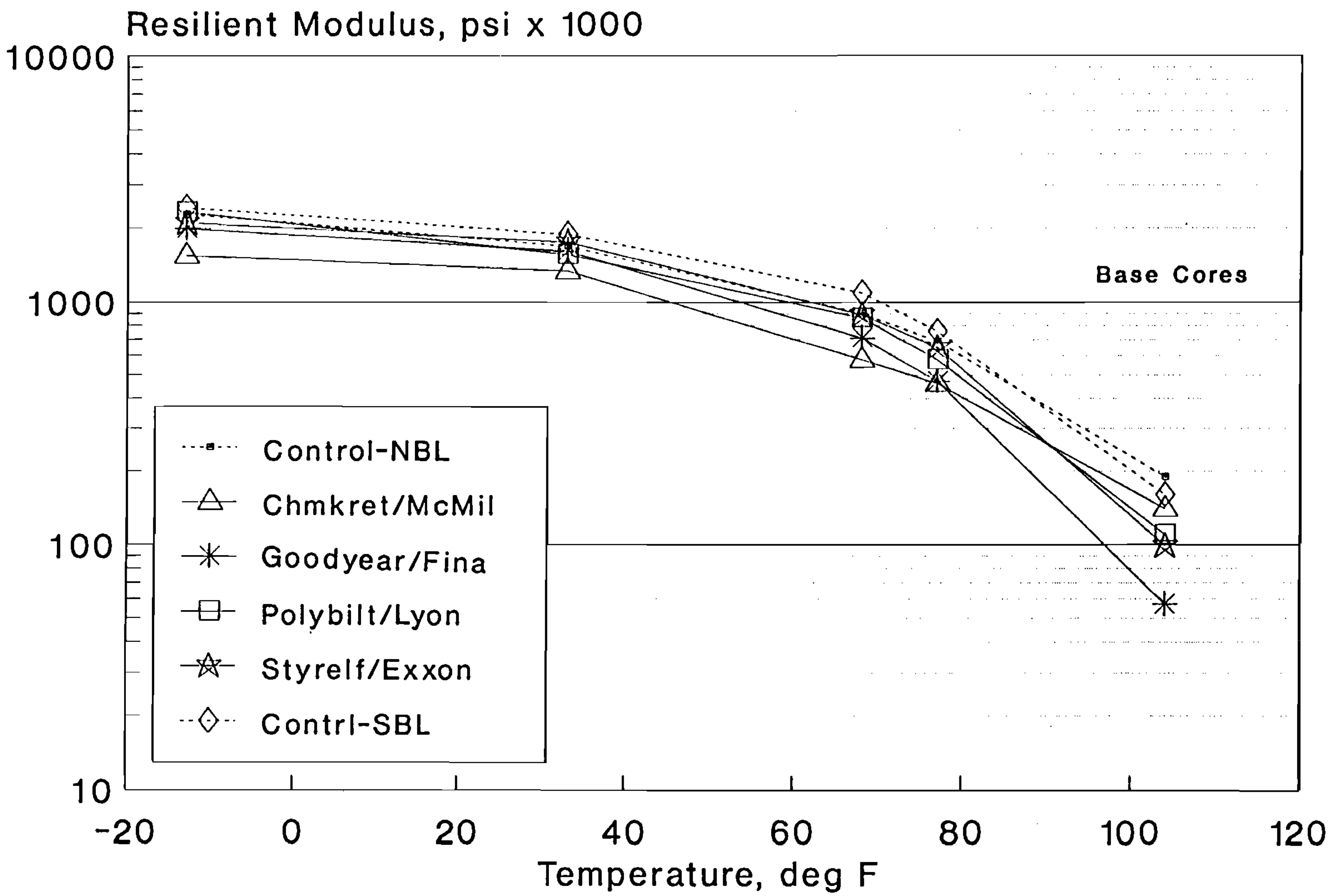



Figure 4. Resilient Modulus as a Function of Temperature for 5-Year Base Cores.

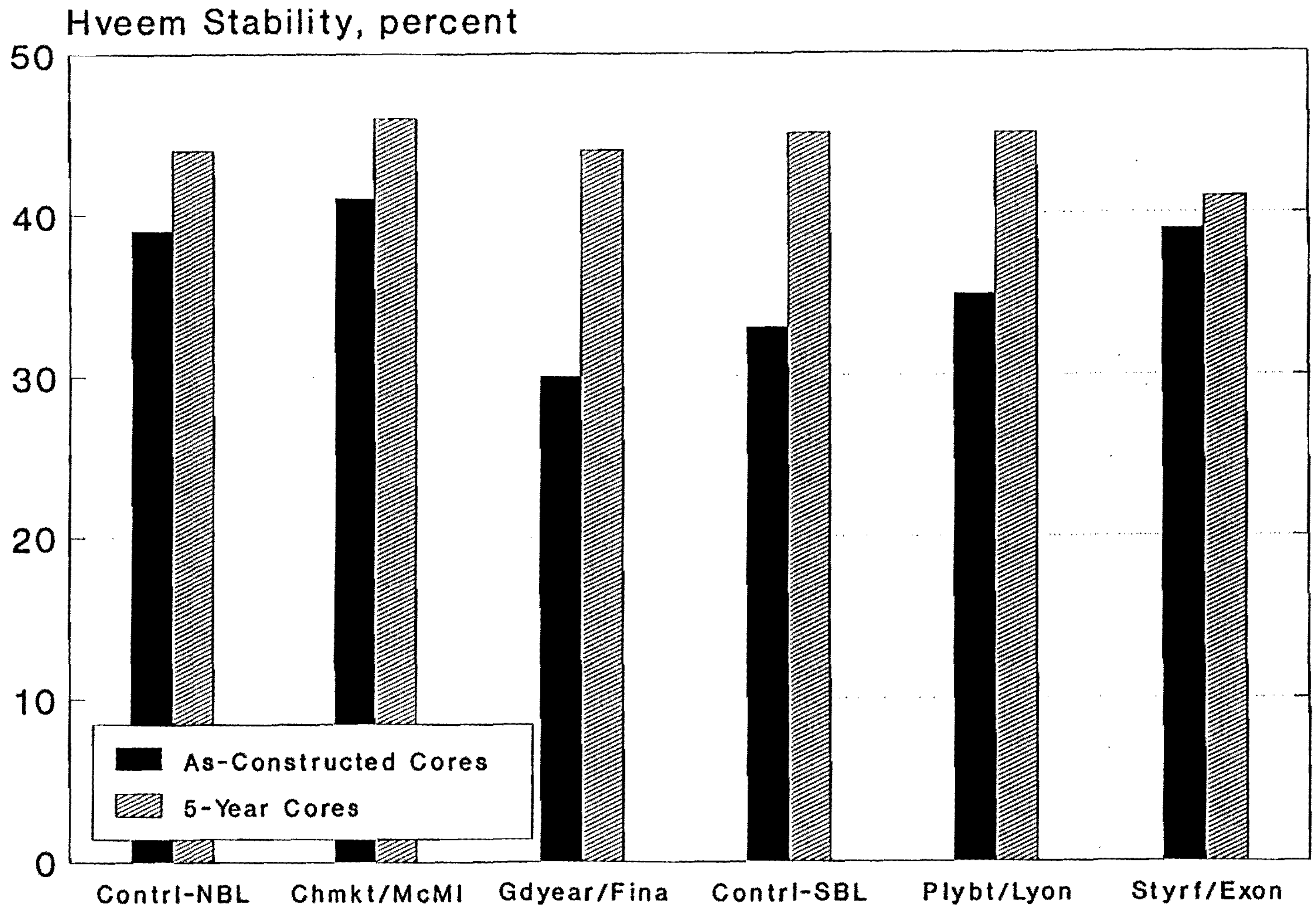



Figure 5. Hveem Stability of As-Constructed and 5-Year Base Cores.

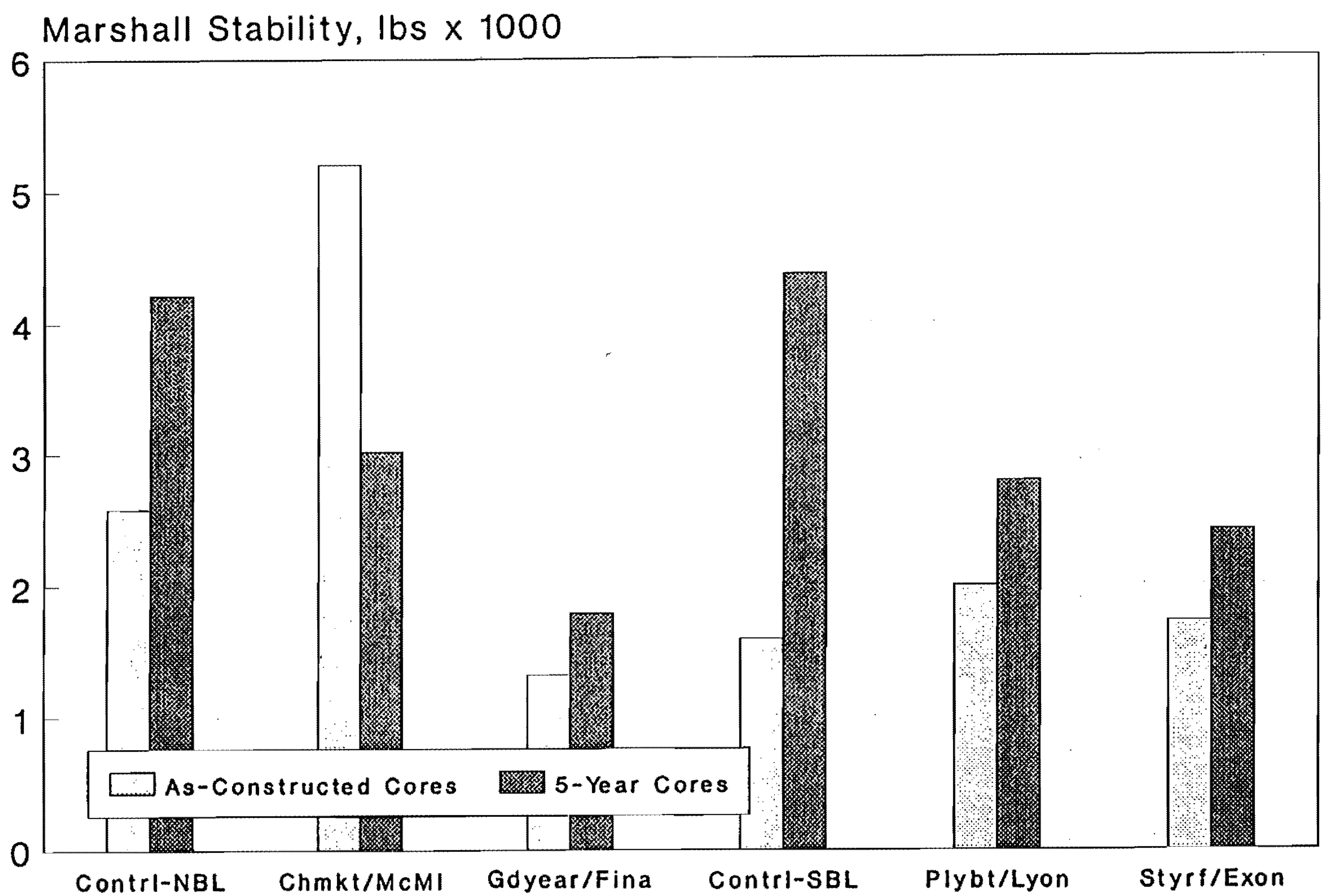



Figure 6. Marshall Stability of As-Constructed and 5-Year Base Cores.

exhibited a substantial decrease in stability.

Test Method Tex-531-C was used to determine tensile properties before and after moisture treatment for the base cores and is compared to the as-constructed base core in Figure 7. Polybilt and Control-NBL exhibited a decrease in tensile strength compared to the as-constructed values. For the 5-year cores, Chemkrete, Polybilt, and Control-NBL exhibited the lowest tensile strengths (about 150 psi [1.03 x $10^6$ pascal]), while Control-SBL exhibited the highest tensile strength and the greatest increase in strength. Since the tensile strength of the control mixtures essentially bracket those of the modified mixtures, it appears that the additives have little effect on tensile strength after five years.

The tensile strength ratio (TSR), which gives an indication of the relative effect of moisture on the mixtures, declined after five years for all mixes except Control-NBL, which exhibited a significant increase in TSR. The 5-year base cores for Control-SBL, Polybilt, Styrelf, and Chemkrete had TSR values of 0.7 or below. None of the additives improved tensile strength or resistance to moisture damage.

*Surface Cores.* Resilient modulus values for the 1992 surface cores (Type D) are plotted in Figure 8. For all mixtures, the modulus values increased over the as-constructed values, with the exception of latex at 33°F (0.6°C) and 104°F (40°C). At 104°F, modulus of the latex mix decreased by about 14 percent. The latex mix exhibited a significantly lower modulus value than the other mixes at 104°F and 33°F. No significant differences existed in the resilient modulus of the other mixtures at the other temperatures. No evidence exists that any of the additive mixtures exhibit greater load carrying capacity than the Control mixtures.

Hveem stability of the surface cores is plotted along with the as-constructed values in Figure 9. Stability values increased with time for the Control-NBL, Polybilt, and Styrelf mixes. Stability of the 5-year cores measured lowest for the latex cores and highest for the Polybilt cores, as it was for the as-constructed cores. When one considers stability of the base cores and surface cores together, no consistent evidence exists that any additive will offer significant improvements.

Marshall stability was determined for the 5-year cores and compared to the as-constructed values in Figure 10. Stability values of all the mixtures increased significantly

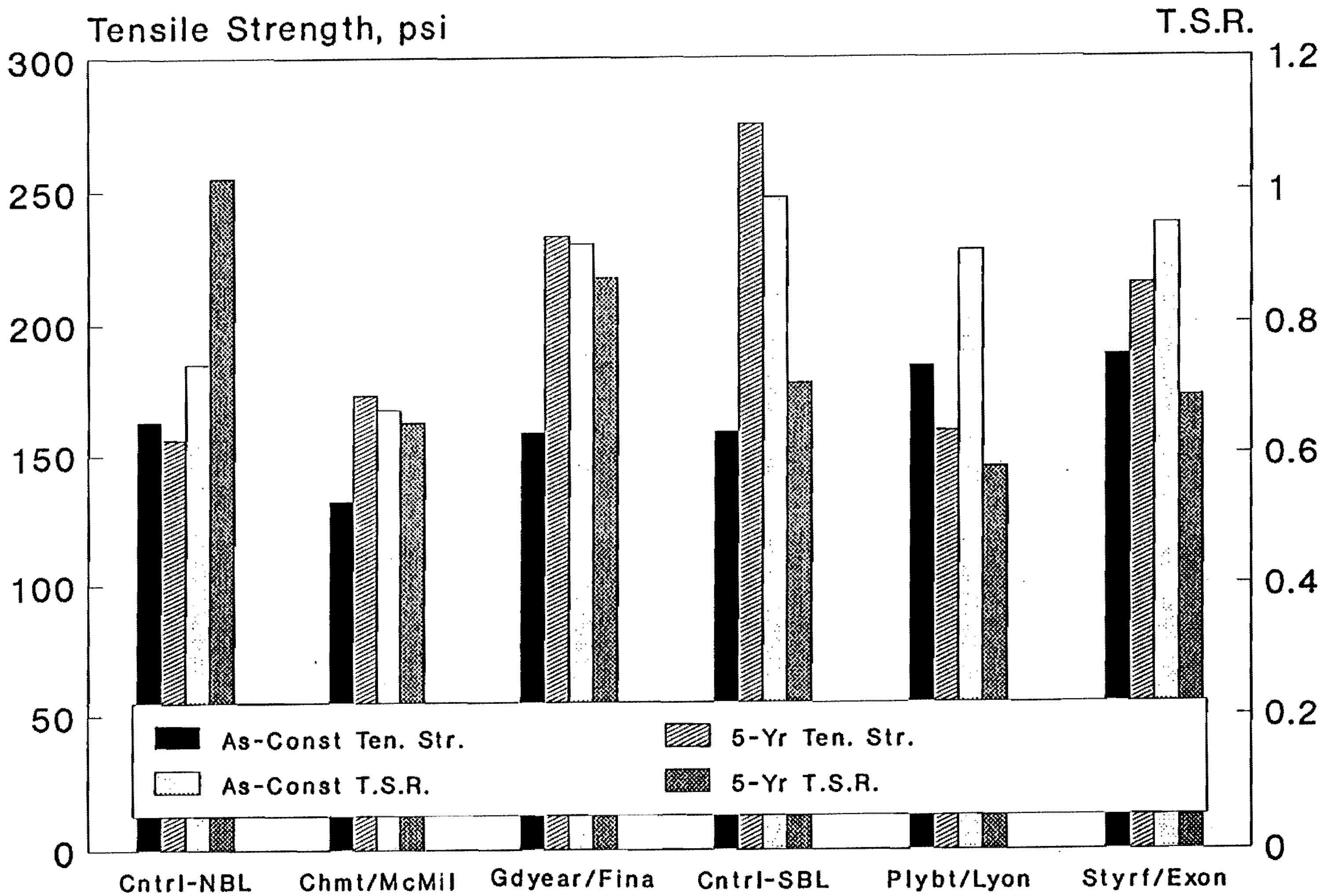



Figure 7. Tensile Properties of As-Constructed and 5-Year Base Cores.

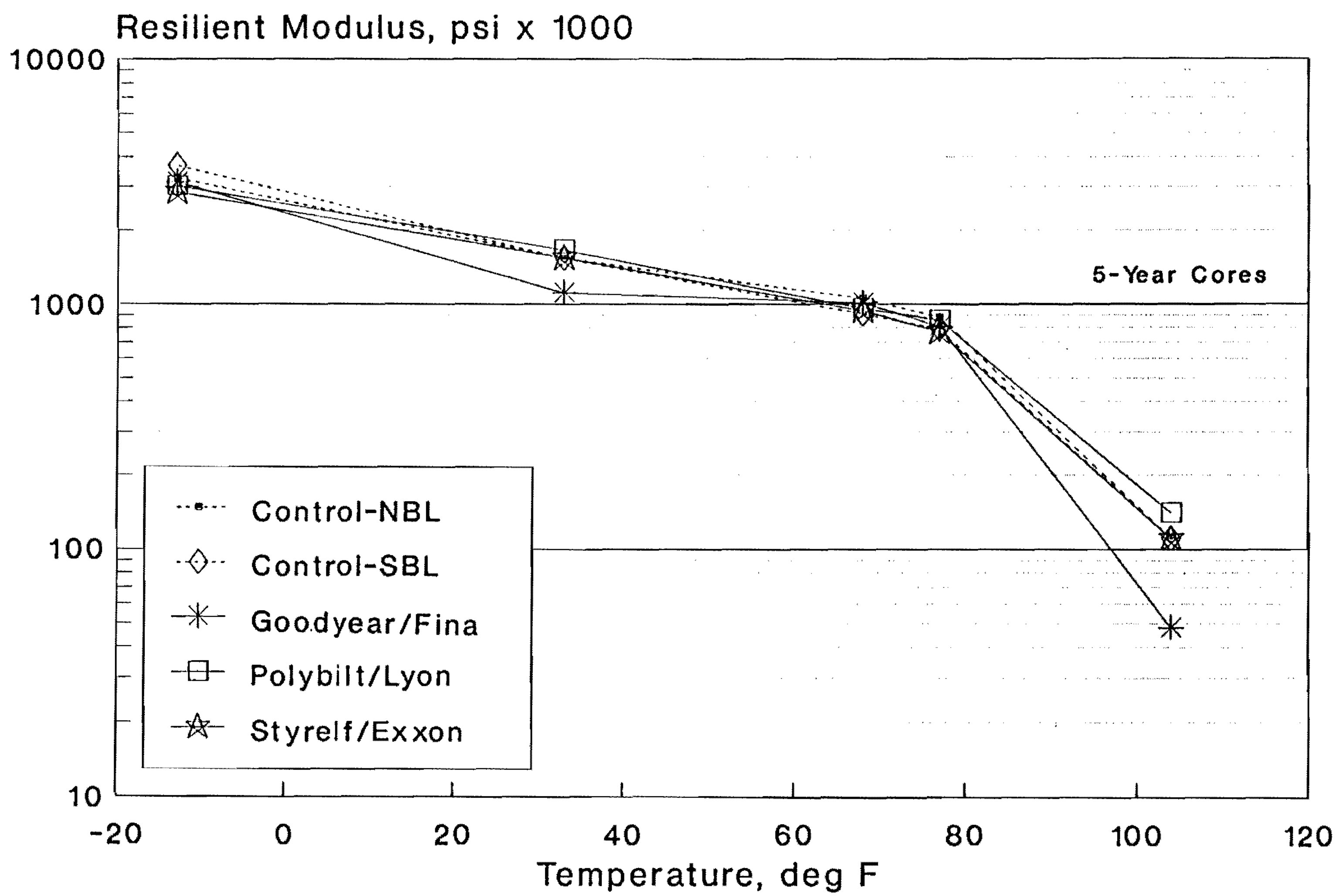



Figure 8. Resilient Modulus as a Function of Temperature for 5-Year Surface Cores.

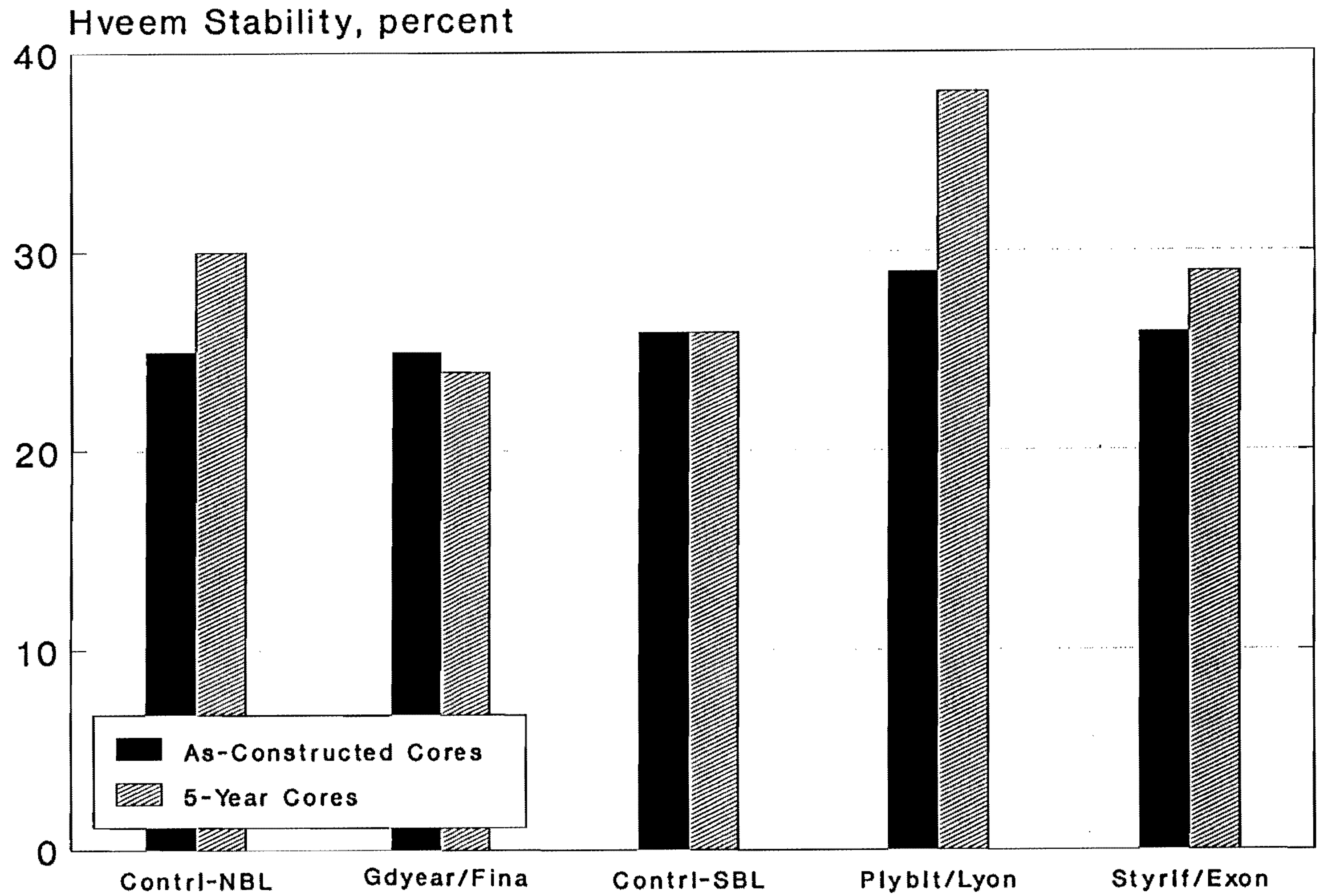



Figure 9. Hveem Stability of As-Constructed and 5-Year Surface Cores.

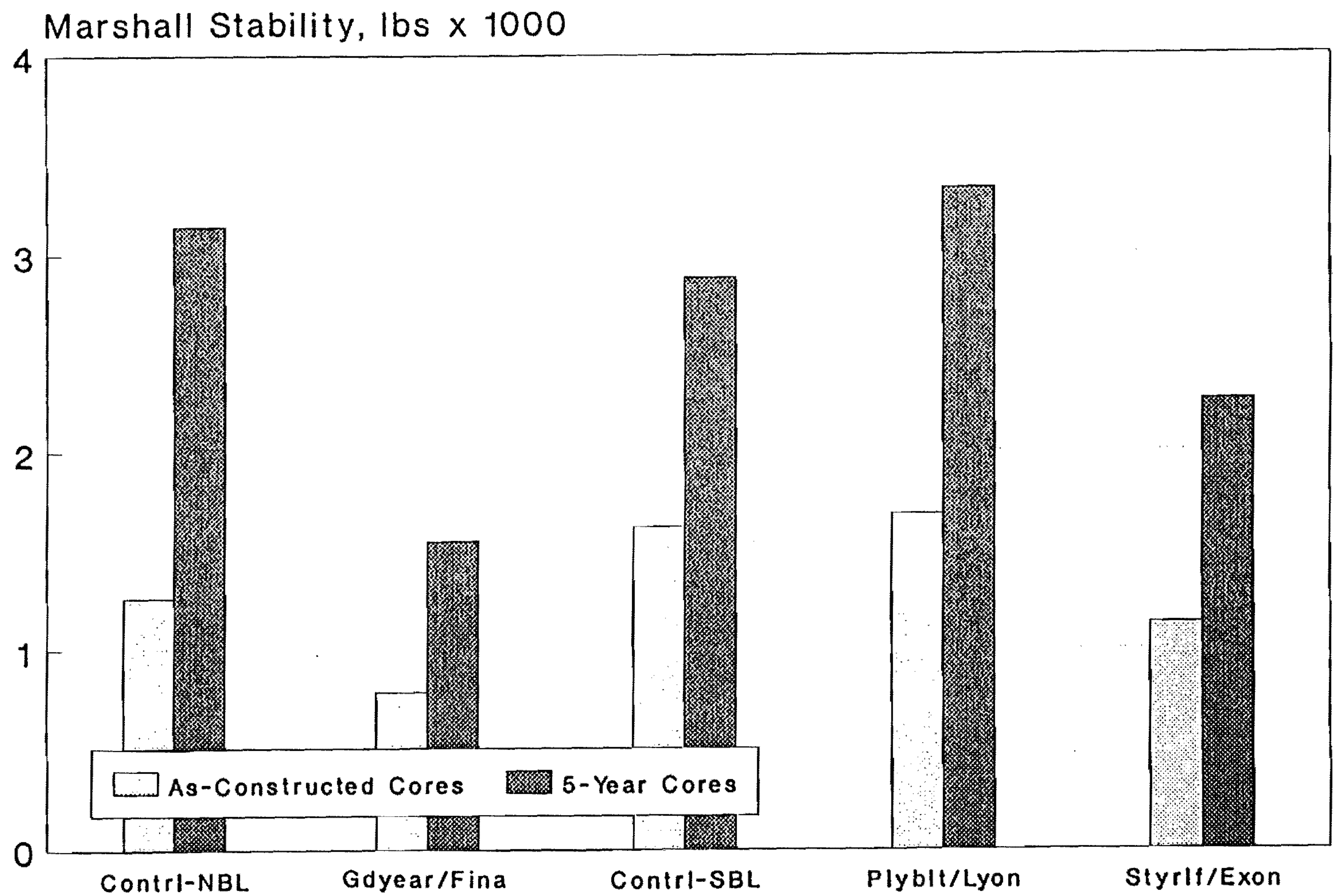



Figure 10. Marshall Stability of As-Constructed and 5-Year Surface Cores.

with time. As with Hveem stability (for both base and surface cores), the latex mix exhibited the lowest overall Marshall stability both for the 5-year and as-constructed cores.

Figure 11 compares tensile properties (tensile strength and TSR) of the 5-year cores with the as-constructed cores. During five years of service, tensile strengths increased while TSRs decreased. Since the aggregates are the same in all mixes, researchers attribute the increase in tensile strength to asphalt hardening. Air voids content for all mixes was remarkably close to seven percent, except for two mixtures (Table A4, Appendix A). While the as-constructed mixes showed exceptionally high resistance to moisture damage (TSR all above 0.9), only Polybilt and Control-SBL retained TSR values above 0.7 for the 5-year cores. Since the TSR of the control mixtures bracket those of the modified mixtures, the additives appear to have little effect on moisture susceptibility.

**Creep/Permanent Deformation Tests on Full-Depth Base Cores**

*Description of Tests.* Time dependent deformation behavior of the pavement base cores (4-inch diameter by 8-inch tall or 102 mm diameter by 203 mm tall) was evaluated by conducting a series of axially loaded creep and permanent deformation tests. The tests, conducted in accordance with the VESYS procedure, were identical to those performed on the as-constructed cores (shown in Reference 4). These included incremental static loading, 1000 second creep, and dynamic repetitive haversine loading. To ensure continuity in the test program, the same loads were used and the same data were obtained as on the as-constructed cores. Tests were conducted on an MTS closed-loop servo-hydraulic system equipped with a Gardner Systems controller/data acquisition unit.

Creep compliance data at 40°F, 70°F and 100°F (4.4°C, 25°C, and 37.8°C) for the 5-year base cores is plotted in Figures 12, 13 and 14, respectively. Permanent deformation data obtained from incremental static loading tests for 5-year base cores is depicted in Figures 15, 16 and 17. The values in the plots represent averages of tests on two different specimens.

*Creep Compliance.* Higher compliance at low temperatures is normally considered indicative of better resistance to cracking; whereas, lower compliance at higher temperatures

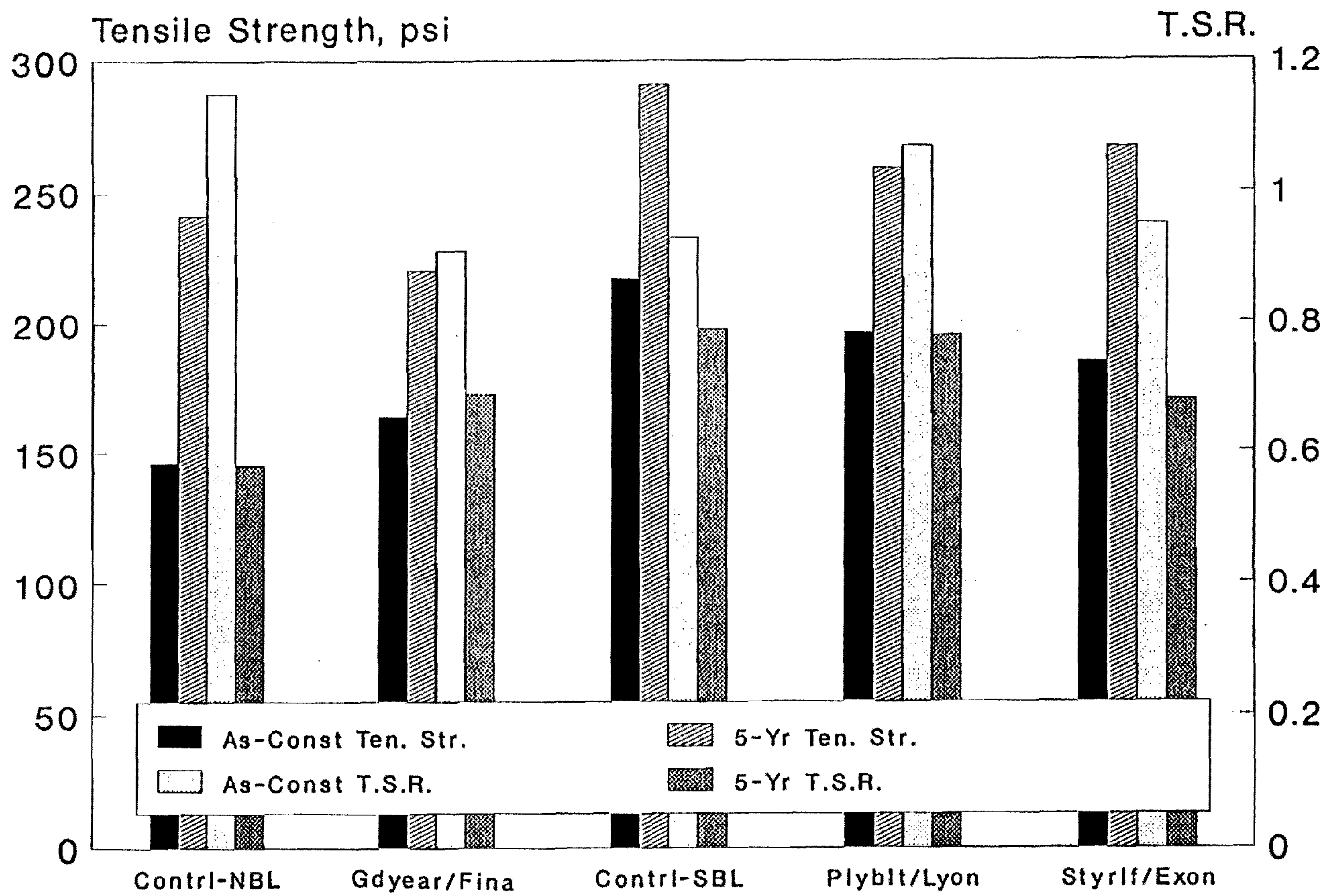



Figure 11. Tensile Properties of As-Constructed and 5-Year Surface Cores.

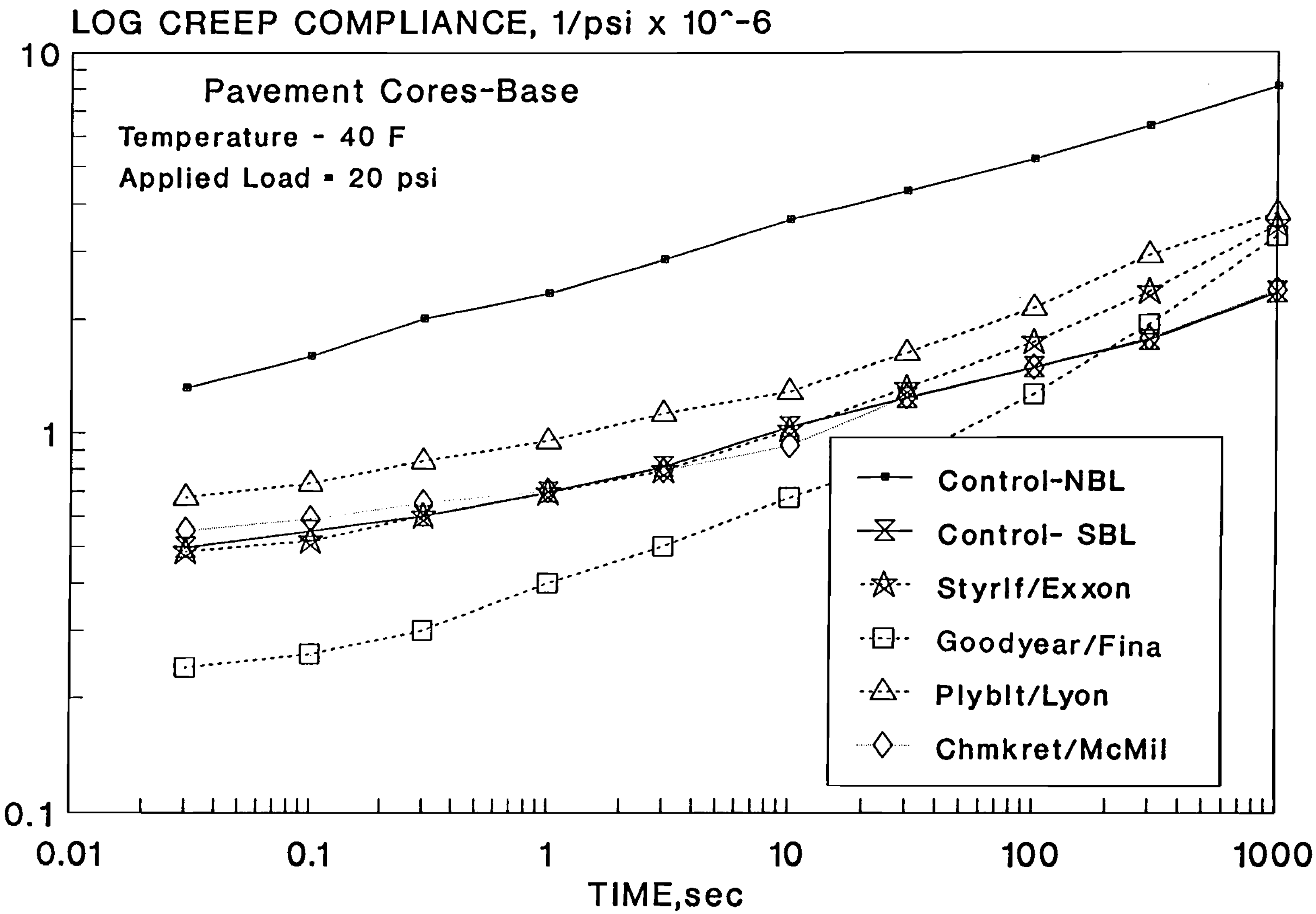



Figure 12. Creep Compliance of 5-Year Base Cores at 40°F.

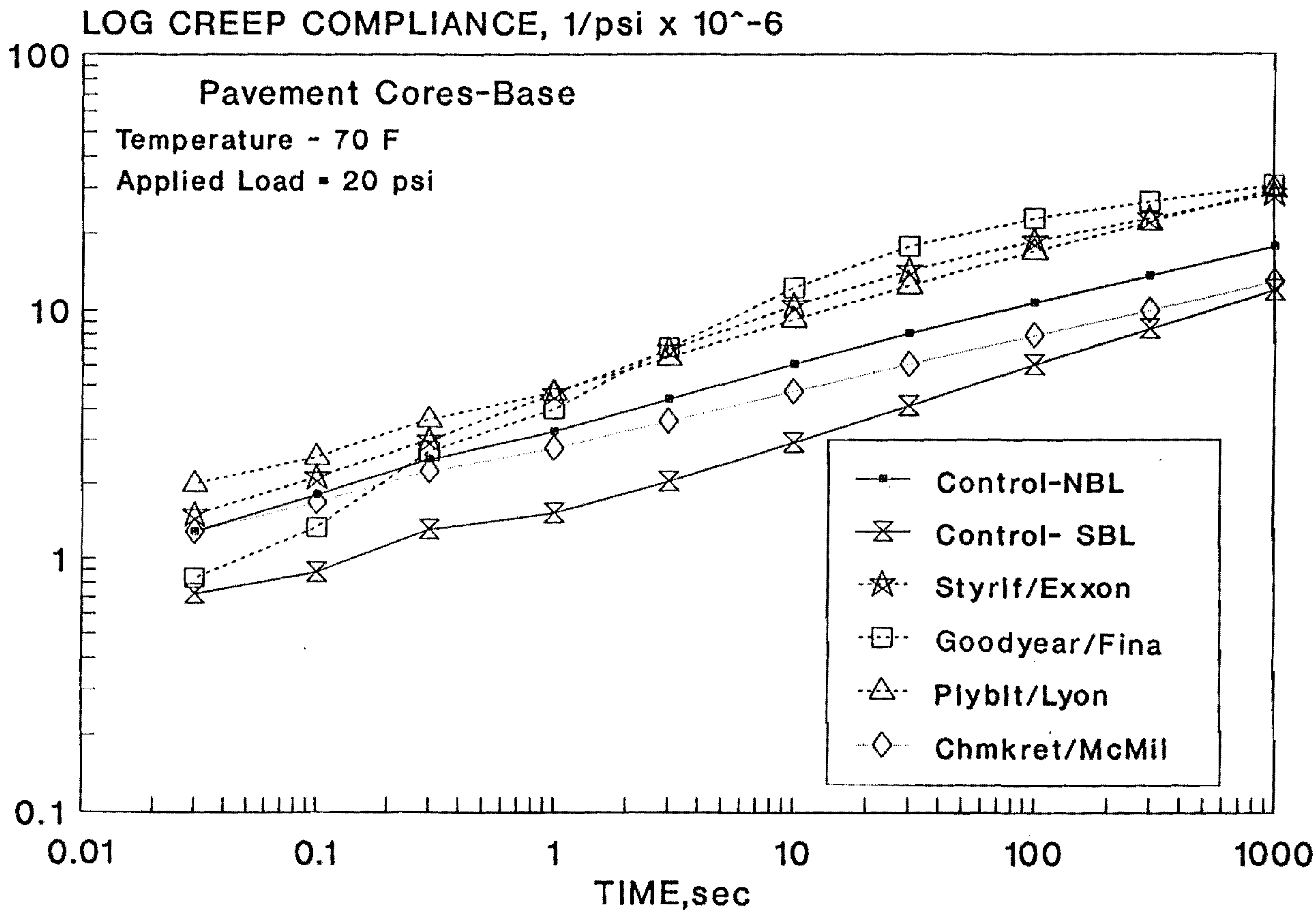



Figure 13. Creep Compliance of 5-Year Base Cores at 70°F.

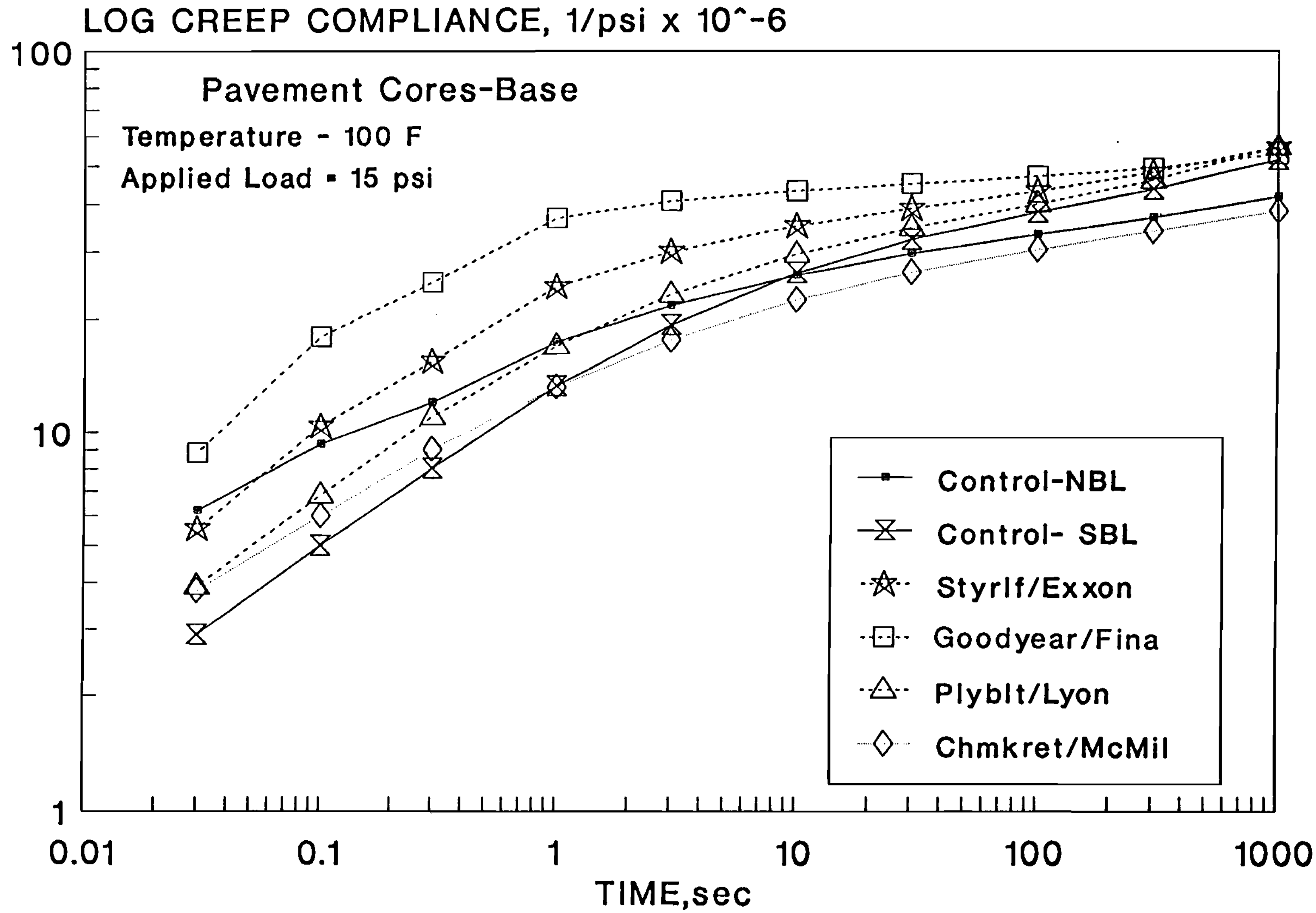



Figure 14. Creep Compliance of 5-Year Base Cores at 100°F.

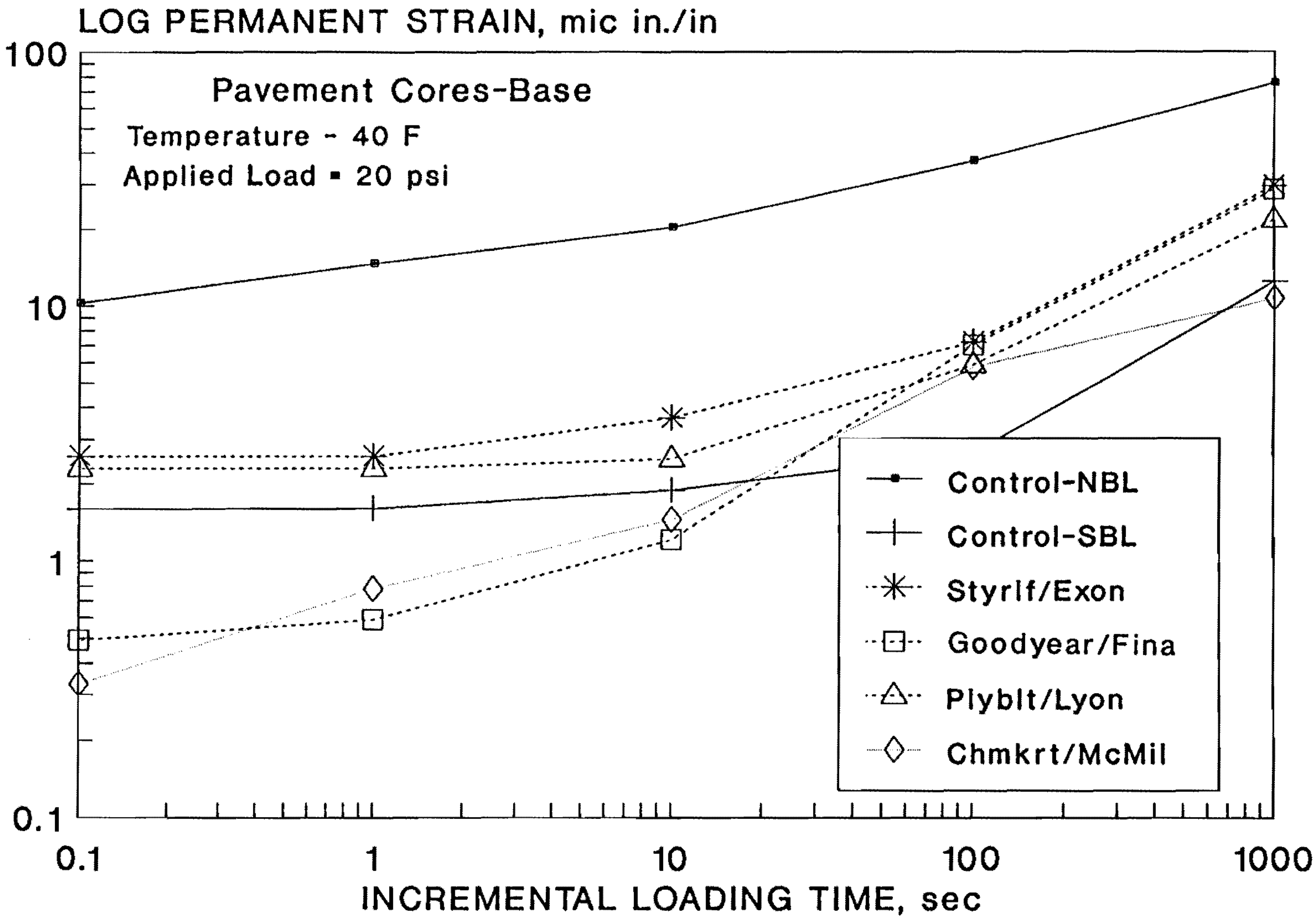



Figure 15. Permanent Deformation Versus Time of 5-Year Base Cores at 40°F.

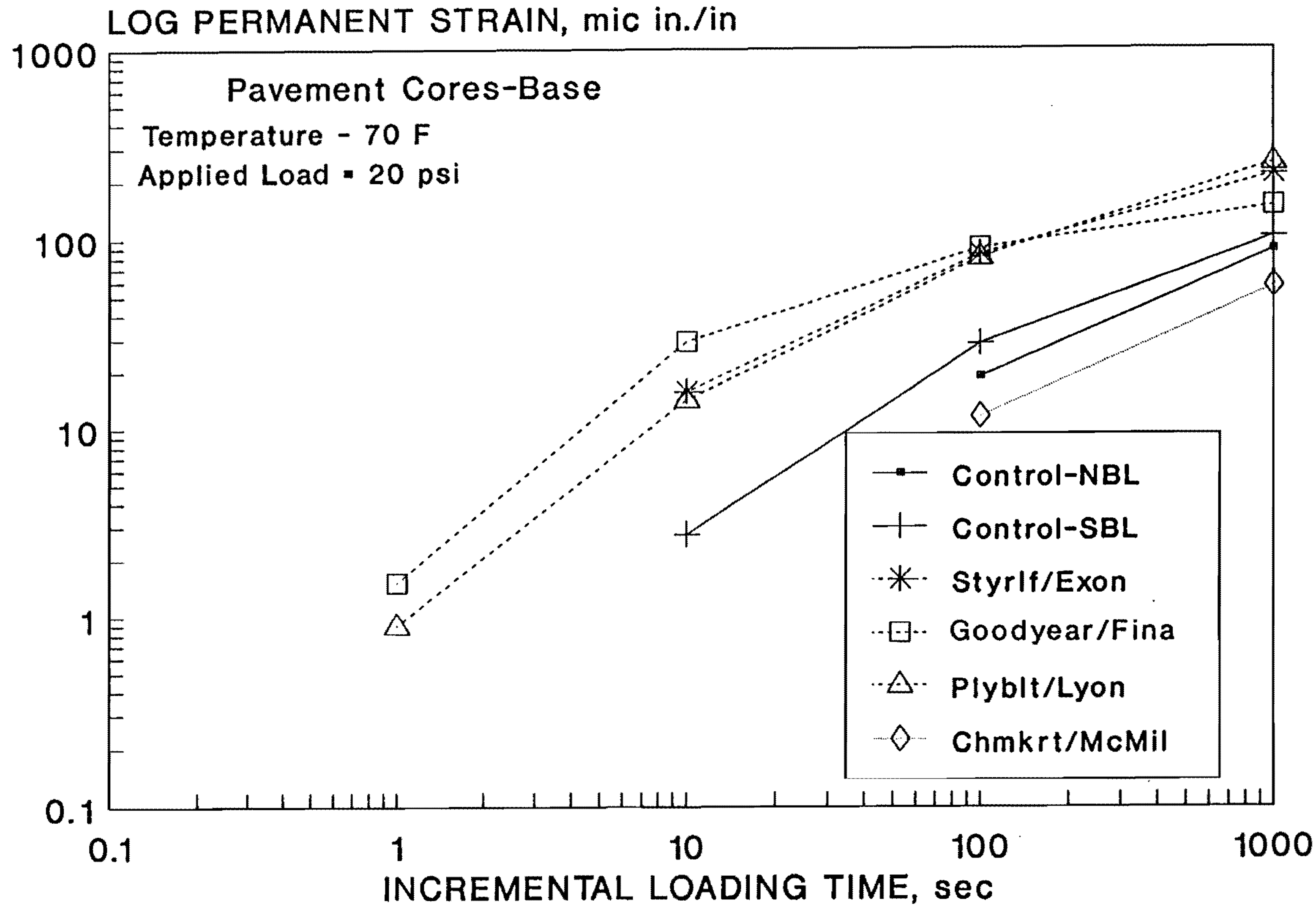



Figure 16. Permanent Deformation Versus Time of 5-Year Base Cores at 70°F.

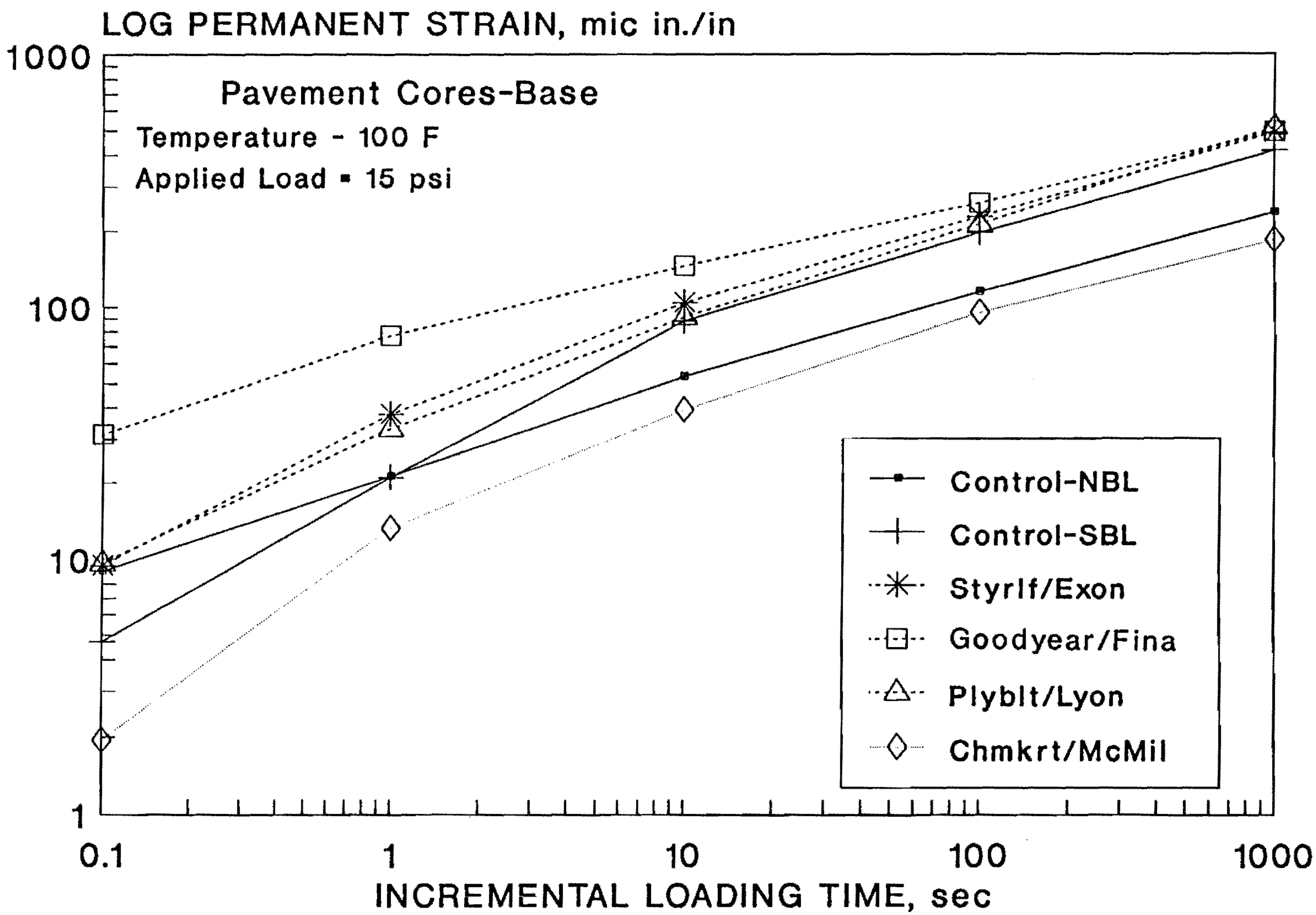



Figure 17. Permanent Deformation Versus Time of 5-Year Base Cores at 100°F.

is normally considered indicative of better resistance to rutting. One may infer from Figure 12 that the Control-NBL mix at 40°F (4.4°C) has the most resistance to cracking. Goodyear/Fina (latex) shows the least initial deformation but the highest overall rate of deformation, such that over longer periods the compliance is comparable to that of the other mixes.

Examination of compliance at longest loading times indicates that all the additive mixtures lie between the two control mixes with Polybilt displaying comparatively good resistance to cracking. This is in direct contrast to field observations that the Polybilt section shows significantly more cracking than any of the other sections. (See Field Performance Section.)

Comparison of the 5-year core data with the as-constructed core data reveals that creep compliance has decreased for all mixtures, indicating mix hardening and possibly an increased propensity for cracking. The effect of the additives on resistance to cracking at low temperatures is difficult to determine at the applied stress level, as no consistent correlations exist between the 5-year and as-constructed data. Increasing the test load may have given a better indication of a mixture's ability to resist cracking.

One may compare the compliance properties of the 5-year cores at 70°F (25°C) (Figure 13) to the as-constructed compliance values. The Goodyear/Fina mix exhibited the highest compliance for the 5-year and as-constructed cores at 1000 seconds. Control-NBL displays median compliance while Control-SBL and Chemkrete exhibited the least compliant mixes for the 5-year cores at 70°F.

A comparison of the creep compliance data sets at 100°F (37.8°C) for the 5-year cores (Figure 14) with compliance for the as-constructed cores indicates a fairly good correlation. For both sets of data, the Goodyear/Fina mix generally proves the most compliant, and the Chemkrete mix is the least compliant. The two control mixes exhibited approximately median compliance for both data sets.

*Permanent Deformation.* At 40°F (4.4°C), permanent deformations of the 5-year cores did not prove significant until after the 100 and 1000 second loading intervals. Deformation of the two control mixes bracketed deformations for the modified mixes with the exception of Chemkrete at 1000 seconds; therefore, these results are inconclusive until researchers obtain more performance data.

Comparison of test data from the 5-year cores with the as-constructed cores at 70°F (25°C) and 100°F (37.8°C) reveals that, due to hardening, the permanent deformations accumulated during incremental static loading measured smaller for the 5-year cores. Although permanent deformations proved less for the 5-year cores, the relative deformations for each mix are similar to the as-constructed cores, with the Polybilt mix exhibiting the greatest deviation (with an increase in relative deformation).

The Goodyear, Styrelf, and Polybilt mixes generally exhibited the highest permanent deformations, as compared to the control and Chemkrete mixes at 70°F and 100°F. This agrees closely with the findings on the as-constructed cores with the exception of the relative deformations of the Polybilt mix.

Figures 18, 19, and 20 graphically portray the cumulative permanent strains of the 5-year base cores due to repeated dynamic haversine loading at 40°F, 70°F and 100°F, (4.4°C, 25°C, and 37.8°C) respectively. The stress level (20 psi or $1.38 \times 10^5$ pascal) used at 40°F proved too low to accurately indicate true pavement performance and susceptibility to fatigue cracking. In this series of tests, the Chemkrete mix continues to exhibit a comparatively low ability to relieve stresses at low temperatures, as indicated by the low strains generated. While field observations indicate that the Polybilt pavement has accumulated significant cracking at the surface, the low temperature fatigue analysis on the base cores does not predict this result.

Cumulative permanent deformations due to dynamic loading at 70°F (25°C) and 100°F (37.8°C) for the 5-year base cores decreased in comparison to the data on the as-constructed cores. As with the incremental static loading data presented earlier, the highest permanent deformations at 70°F and 100°F were accumulated by the Goodyear, Styrelf, and Polybilt mixtures (Figures 19 and 20). The Chemkrete mix again showed the highest resistance to deformation at elevated temperatures. Relative deformation due to dynamic loading of the 5-year cores at 70°F and 100°F showed good correlation with the as-constructed data with the exception of the Polybilt mix. Relative deformation of the Polybilt mixture increased at both temperatures.

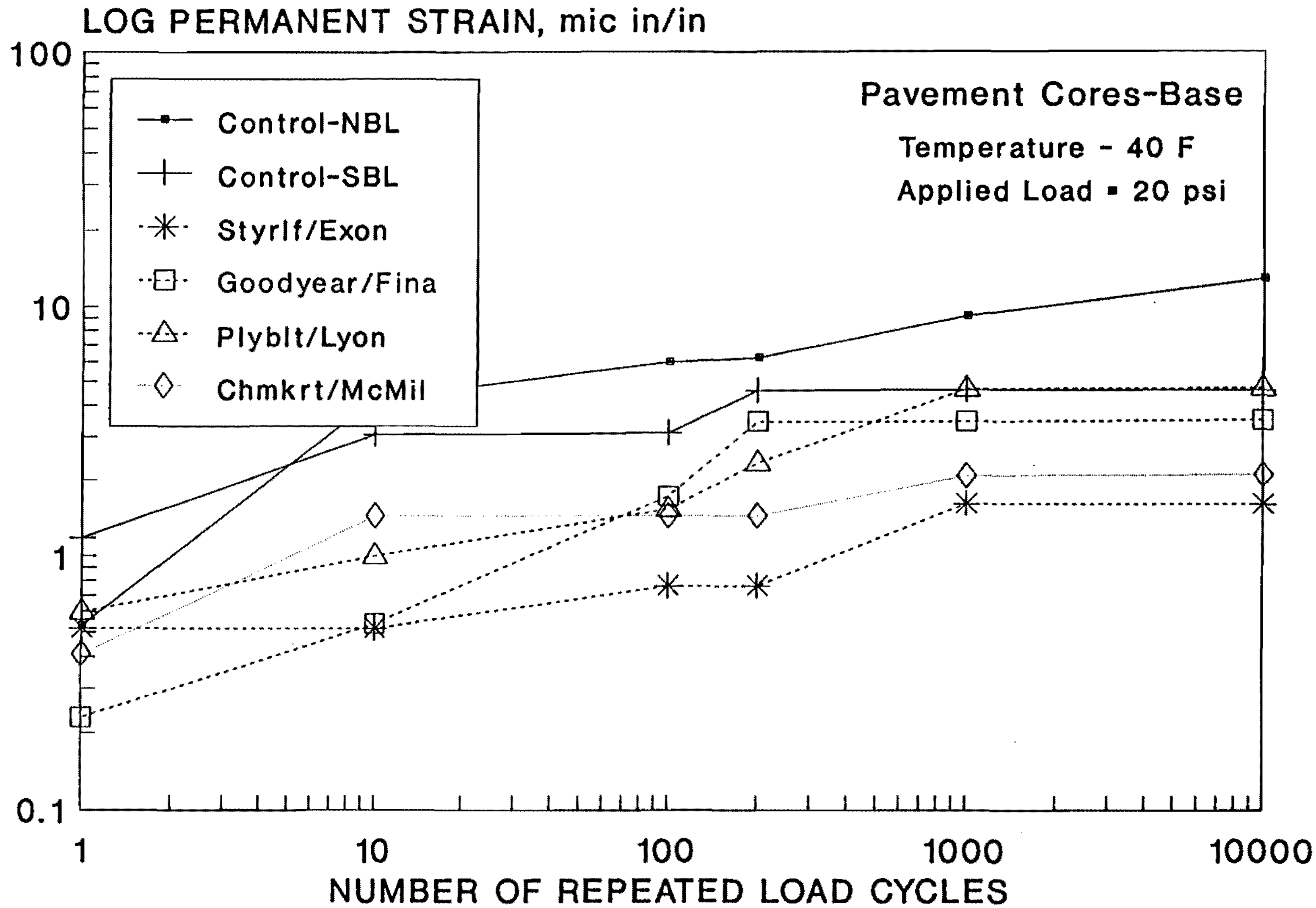



Figure 18. Permanent Deformation Versus Load Cycles of 5-Year Base Cores at 40°F.

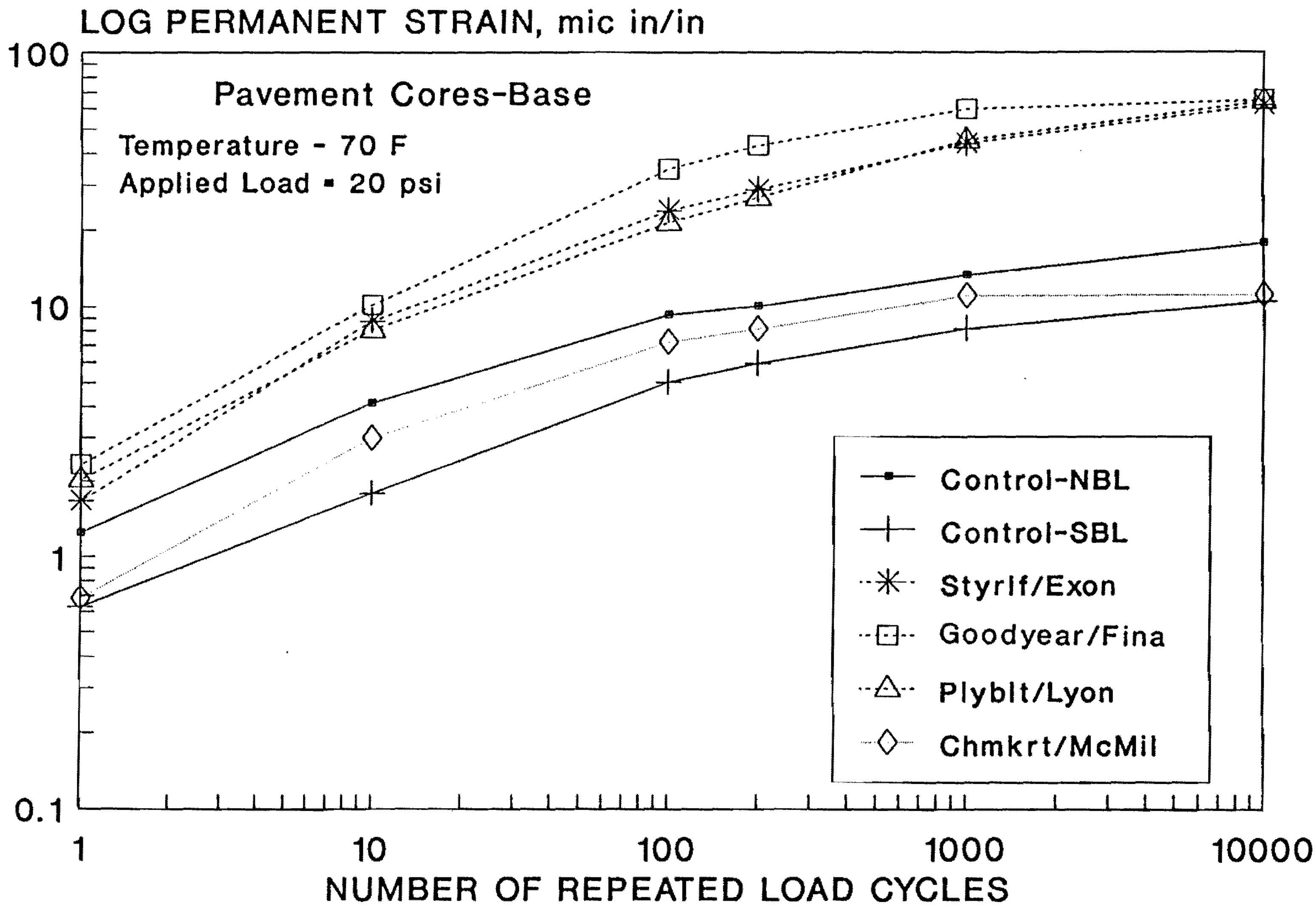



Figure 19. Permanent Deformation Versus Load Cycles of 5-Year Base Cores at 70°F.

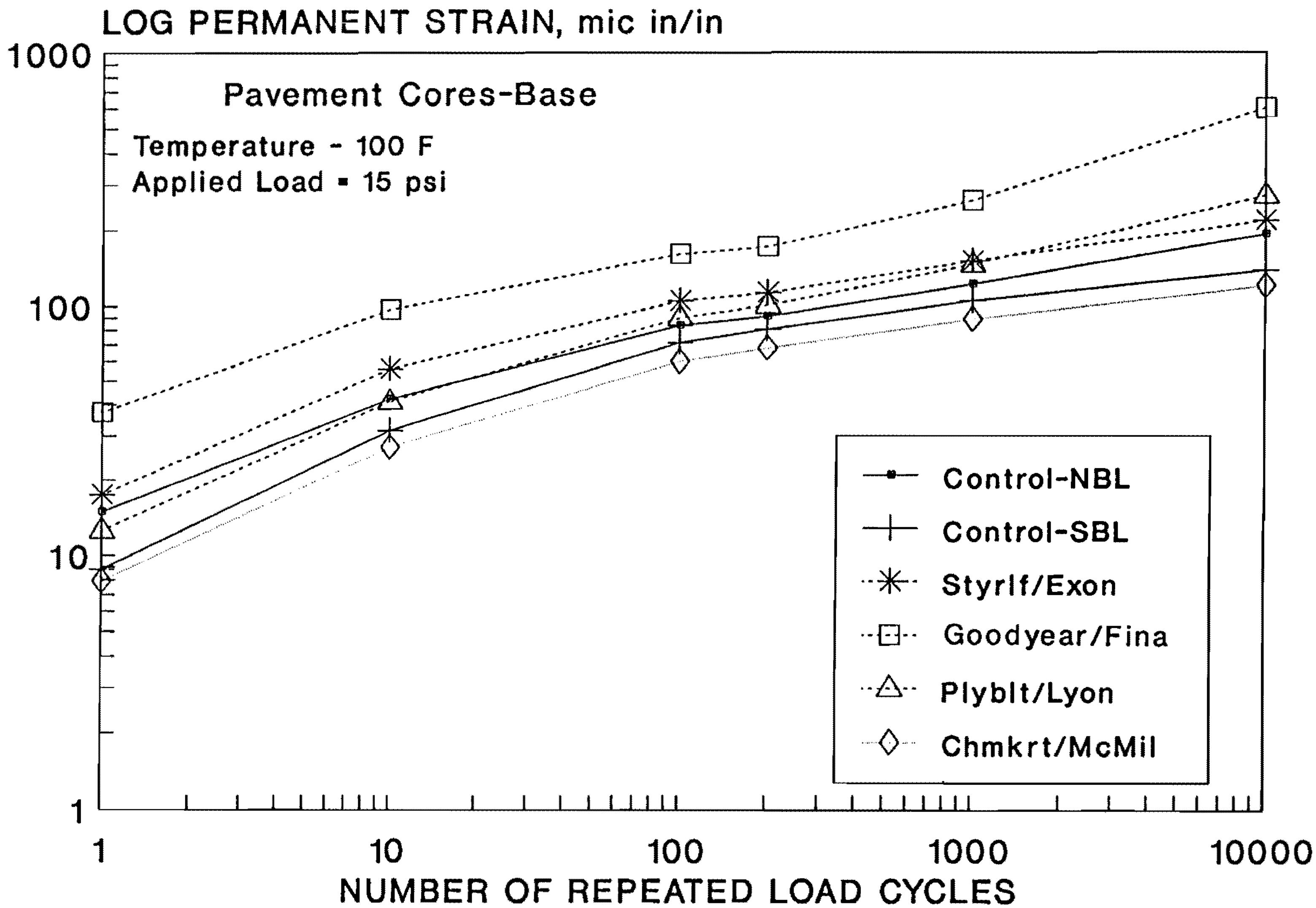



Figure 20. Permanent Deformation Versus Load Cycles of 5-Year Base Cores at 100°F.

Rationale for the cracking observed on the surface of the Polybilt pavement may be indicated by a relatively large decrease in the axially loaded dynamic resilient modulus for the 5-year base cores at 40°F (4.4°C) (Figure 21) when compared to the as-constructed base cores (Reference 4). The 5-year Control-NBL base cores exhibited the lowest resilient modulus at 40°F, which corresponds with the modulus of the as-constructed base cores. The 5-year Goodyear cores showed the greatest increase as well as highest axial resilient modulus at 40°F. All 5-year mixtures experienced a decrease in axial resilient modulus at 100°F (37.8°C) as compared to the corresponding as-constructed modulus values.

## GENERAL COMMENTS

Based on findings of these tests on pavement cores along with their comparisons to field performance and past experience with these test procedures, it appears that these test methods can identify very bad and very good mixes (regarding cracking and rutting) but cannot detect subtle differences in mixture properties that can contribute to significant differences in cracking and rutting.

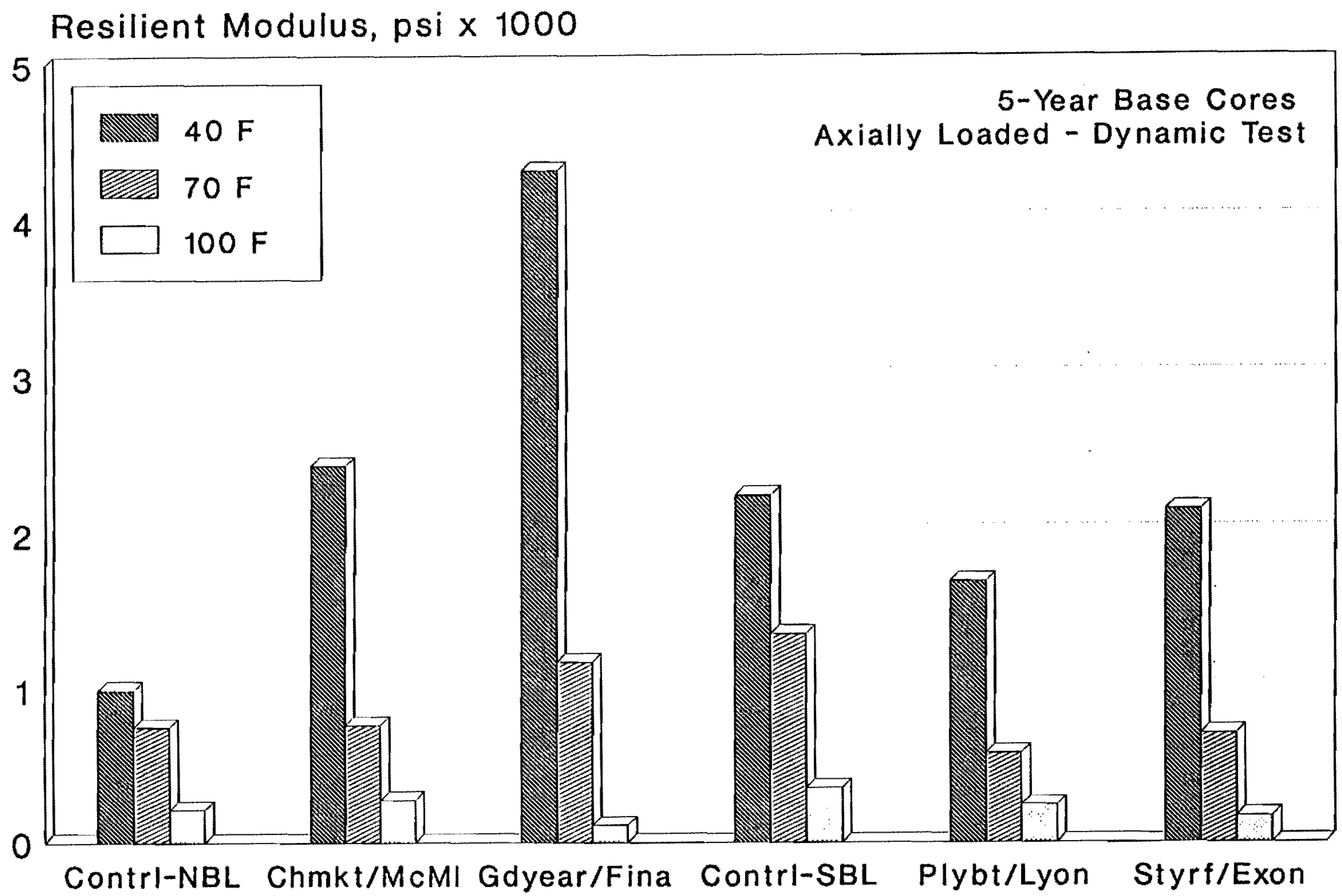



Figure 21. Resilient Modulus of Axially Loaded 8-inch Base Cores at 40°F, 70°F, and 100°F (4°C, 21°C, and 38°C).

# FIELD PERFORMANCE

## TEXARKANA TEST PAVEMENTS

After five years in service, all the test pavements at Texarkana have good ride quality. No visible evidence exists of rutting, flushing, patching, or alligator cracking. Slight raveling in isolated areas may be associated with aggregate segregation during construction. Extensive longitudinal, transverse, and random cracking existed in the Polybilt section, and some similar cracking was evident in the control sections. Researchers categorized the random cracks, as well as possible, as either transverse or longitudinal cracks to facilitate plotting (Figures 22 and 23) and comparative analysis. There was also significant transverse cracking in the Chemkrete/Latex section which, based on earlier observations, had reflected through the Goodyear latex modified surface mix from the Chemkrete modified base. Researchers observed no signs of pumping at the cracks even though rainfall had occurred a few days before the visual evaluation.

## SHERMAN TEST PAVEMENTS

After seven years of service, the ride quality of the test pavements near Sherman was essentially equivalent. There was no rutting, alligator cracking, or patching. However, transverse and longitudinal cracks were observed. These are probably reflective cracks from the underlying CRCP. The relative severity of these cracks is depicted in Figures 24 and 25. DuPont EVA currently exhibits the highest amount of transverse cracking per station (100 feet or 30.48 m). For two consecutive years (1991 and 1992), DuPont EVA exhibited the most longitudinal cracking, but the Control-3" section caught up with it in 1993 (Figure 25). Though it is too soon to tell for sure, it appears that Kraton, Microfil, SBR latex, and the thicker overlay (Control-4") are suppressing crack growth. No evidence existed of pumping at the cracks.

Raveling varied from very slight to moderate and, at this time, cannot be associated with any additive or lack of additive. Raveling often seemed associated with longitudinal cracks and, further, longitudinal cracks often appear associated with aggregate segregation during construction. The longitudinal cracks are almost always near the center of the lane.

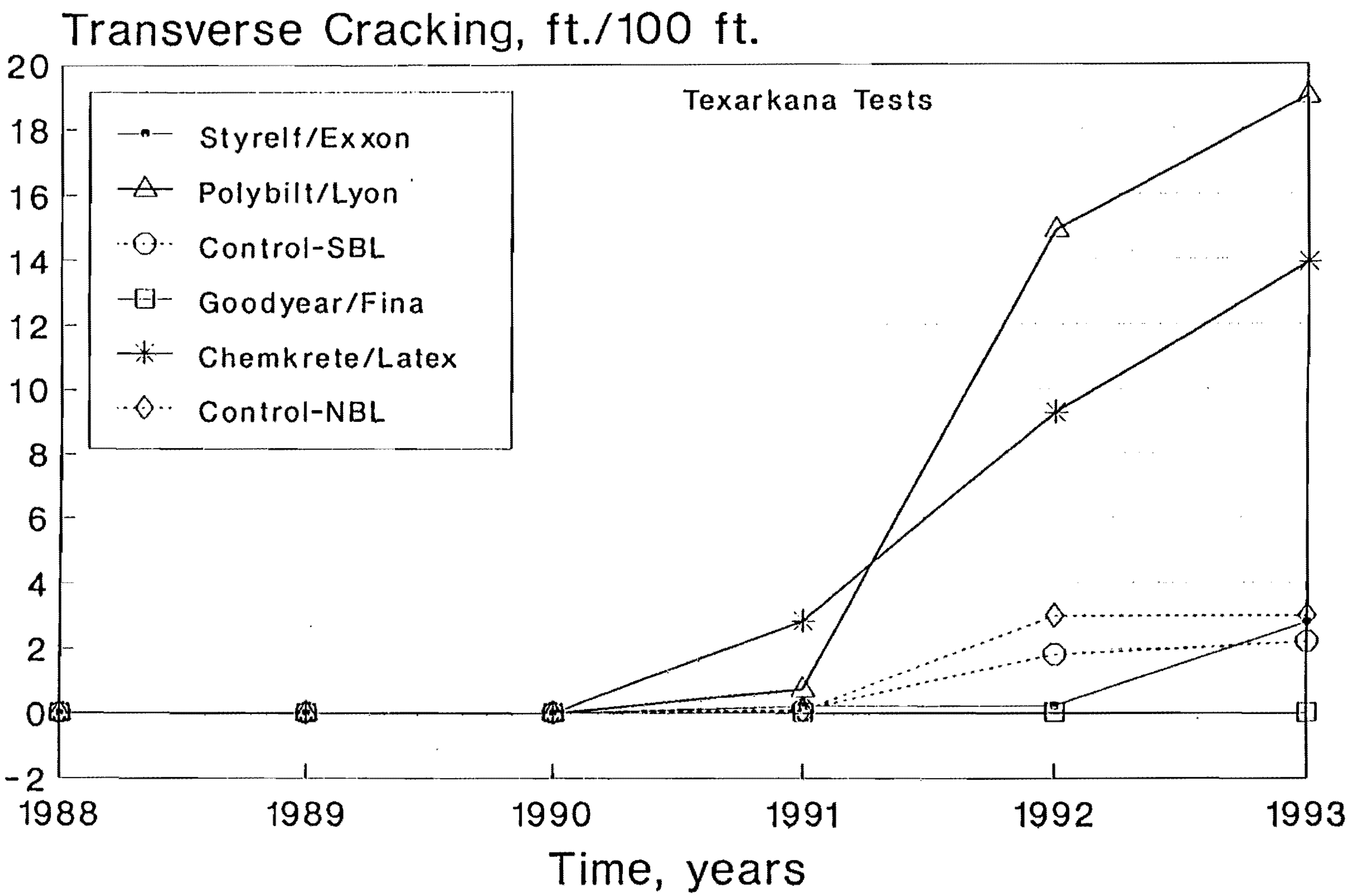



Figure 22. Transverse Cracking as a Function of Time for Texarkana Test Pavements.

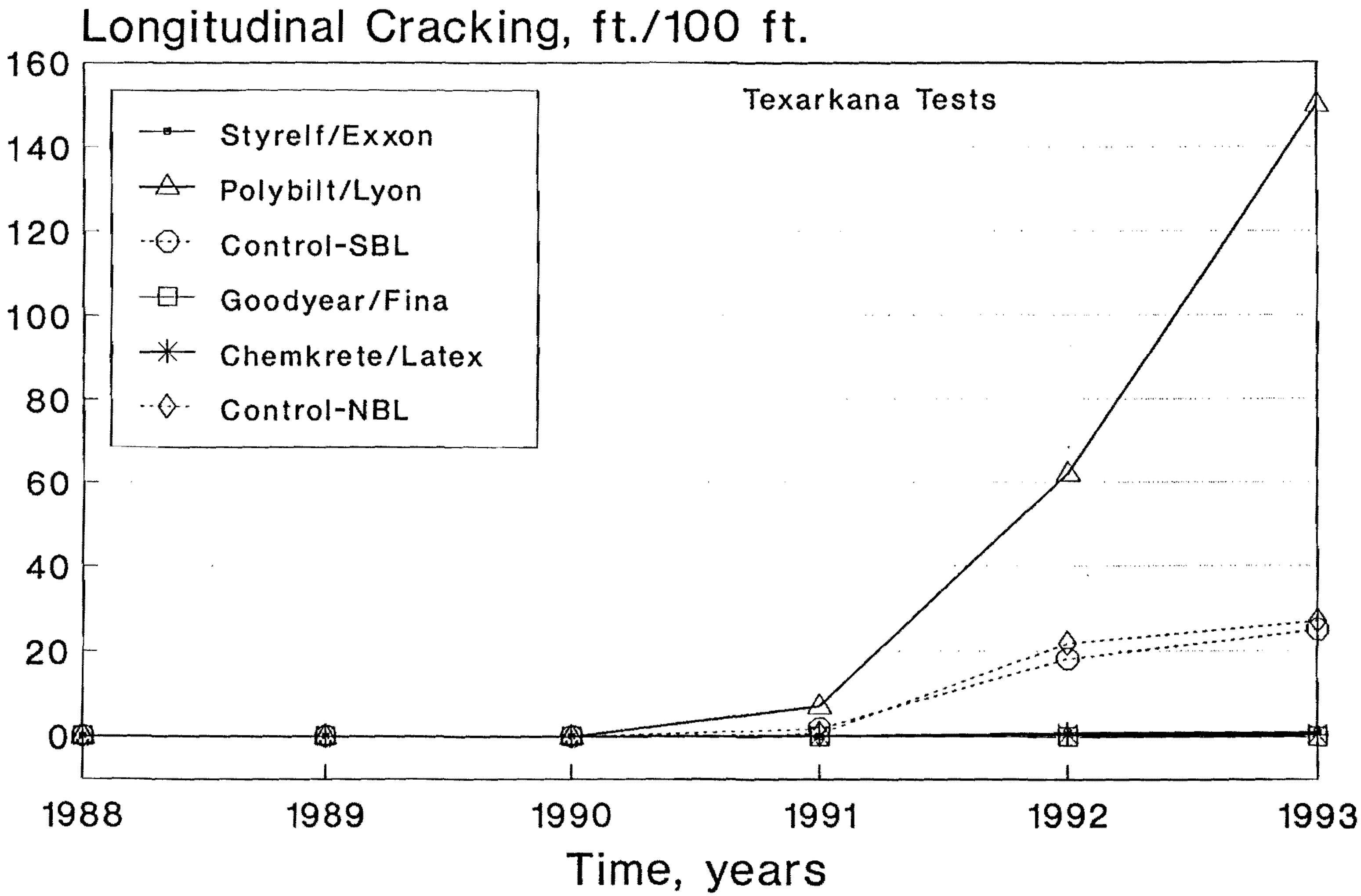



Figure 23. Longitudinal Cracking as a Function of Time for Texarkana Test Pavements.

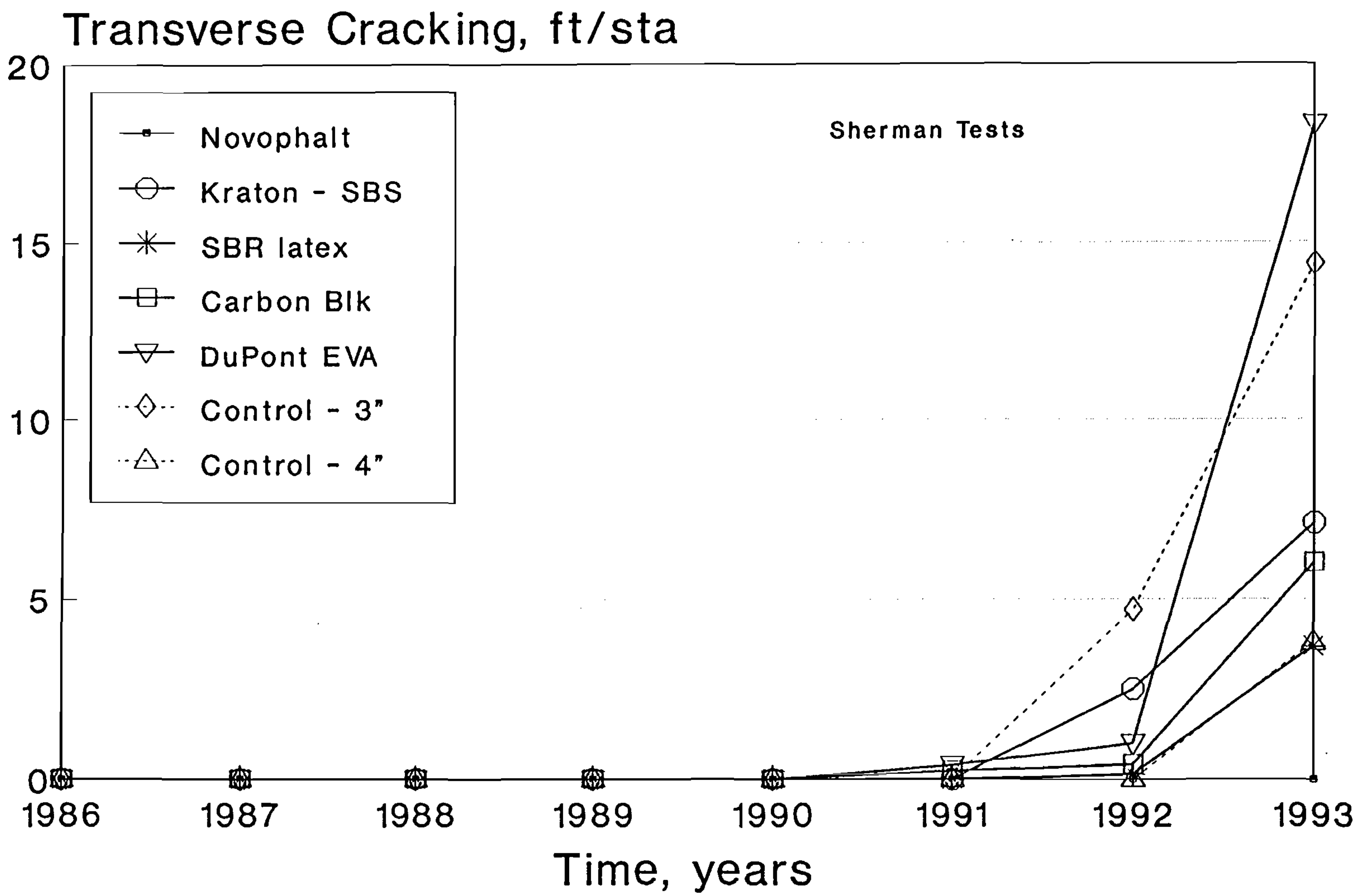



Figure 24. Transverse Cracking as a Function of Time for Sherman Test Pavements.

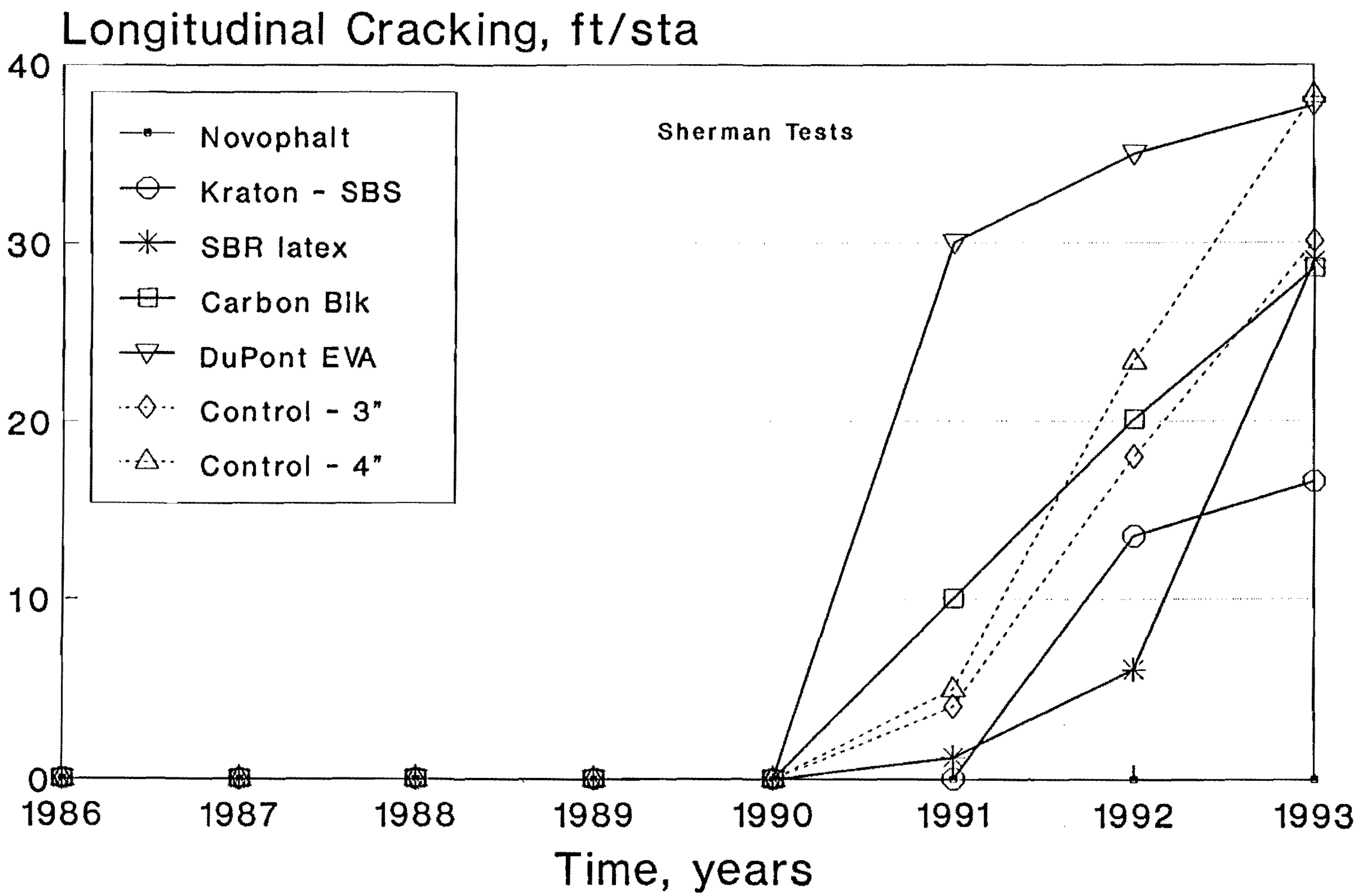



Figure 25. Longitudinal Cracking as a Function of Time for Sherman Test Pavements.

## FORT WORTH TEST PAVEMENTS

After eight years in service, all four test pavements are performing essentially equivalently. No significant signs of distress exist in any of the test pavements. In one small area near the Haltom Road Bridge, three 12-foot (3.66 m) transverse cracks are located in test section number 6 (control section). Rut depths measured less than one-fourth inch (6.4 mm). There is no evidence of raveling, longitudinal cracking, alligator cracking, pumping, or patching.

## SAN BENITO TEST PAVEMENTS

In the fall of 1989, just before subsequent construction destroyed most of the test pavements, all pavements in the experiment were performing identically.

Table 3 shows the relative performance of the surviving test pavements in 1992. No rutting, no flushing, no alligator cracking, and only slight raveling in the surviving test pavements occurred. The control sections and the carbon black section demonstrated approximately equivalent performance; whereas, the Kraton section exhibited significantly more severe longitudinal cracking. These deep, wide cracks probably result from poor base or subgrade preparation in this area and have little to do with the presence or type of additive in the 3-inch (76 mm) surface course of asphalt concrete.

Table 3. Performance data for Surviving Test Pavements near San Benito.

| Section | Rut Depth, inches | Longitudinal Cracking, ft | Transverse Cracking, ft | Raveling |
|---|---|---|---|---|
| Control-3" < 1/8 | 270 | 0 | Slight | |
| Control-4" < 1/8 | 210 | 0 | Slight | |
| Carbon Black | < 1/8 | 60 | 0 | Slight |
| Kraton | < 1/8 | 450 | 10 | Slight |
| Control-3" < 1/8 | 0 | 0 | Slight | |

# CONCLUSIONS AND RECOMMENDATIONS

## CONCLUSIONS

Based on laboratory testing of cores from five-year old test pavements at Texarkana and visual performance evaluations of test pavements at Texarkana, Sherman, Fort Worth, and San Benito, researchers have made the following inferences. The reader should consider these as interim conclusions until the test pavements have reached the end of their useful lives and final conclusions can be established.

1. SBR latex, SB block copolymer, finely dispersed polyethylene, and pelletized carbon black may reduce or delay cracking in asphalt concrete pavements. Cost effectiveness, however, has not yet been established.
2. Since no significant rutting has been experienced in any of the test pavements, no inferences can be made regarding the effect of the additives studied on rutting.
3. Creep and permanent deformation tests (as described herein) can identify asphalt mixtures that yield both bad and good performance in resisting rutting and cracking but cannot detect more subtle differences in binder properties.
4. The additives studied in this experiment will not significantly affect stability, strength, or moisture susceptibility of asphalt paving mixtures.
5. Based on standard laboratory tests of extracted/recovered binder and pavement cores, it sometimes proves difficult to establish the causes of wide differences in cracking performance of asphalt concrete pavements.

## RECOMMENDATIONS

It is recommended that monitoring of the test pavements in the Texarkana, Sherman, and Fort Worth districts be continued throughout the life-cycle of these pavements. Cost effectiveness of these additives can only be established by monitoring these pavements through their life cycles.

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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. Button, J. W. and Prapnnachari, S., "Asphalt Additives in Thick Hot Mixed Asphalt Concrete Pavements," Research Report 187-18, Texas Transportation Institute, Texas A&M University, College Station, Texas, 1991.

5. Epps, J. A., Hughes, C. H., and Bass, D. A., "A Study of Long-Term Performance of Latex-Modified Hot Mix Asphalt Concrete on SH-121 in Fort Worth, Texas," Report 4-708-2, University of Nevada-Reno, Civil Engineering Department, Reno, Nevada, April, 1989.

# Appendix

Table A1. Properties of Binders Extracted from Selected Pavement Cores.

| Test Section ID | Sample Number* | Viscosity @ 140 F, poise | Pen. @ 77 F, 0.1 mm | Asphalt Content, percent |
|---|---|---|---|---|
| Control-NBL (McMillan AC-20) | 2S<br>8B3 | 12,500<br>10,100 | 13<br>35 | 4.2<br>4.0 |
| Chemkrete/ McMillan NBL | -<br>17B1 | -<br>54,000 | -<br>13 | -<br>4.2 |
| Latex/ Fina NBL | 17S/39S<br>33B3 | 13,200<br>13,300 | 21<br>36 | 3.9<br>4.5 |
| Styrelf/ Exxon SBL | 50S<br>47B1 | 14,200<br>6,950 | 19<br>30 | 4.2<br>3.8 |
| Polybilt/ Lyon SBL | 69S<br>68B2 | 26,200<br>27,400 | 19<br>18 | 3.6<br>3.7 |
| Control-SBL (McMillan AC-20) | 16S<br>81B2 | 5,700<br>24,600 | 28<br>17 | 4.4<br>4.0 |

* Note: Labels with an "S" were extracted from surface coarse, labels with a "B" were extracted from base coarse.

Table A2. Data from 5-Year Texarkana Test Pavement Cores - Base Layer.

| Type Mixture | Test Label | 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. | Flow, .01 in. |
|---|---|---|---|---|---|---|---|---|---|---|
| Control-NBL | 8B1 | 6.19 | 2550 | 1790 | 970 | 660 | 200 | 46 | 4490 | 18 |
| | 11B1 | 7.33 | 2050 | 1800 | 820 | 650 | 170 | 49 | 3550 | 17 |
| | 14B1 | 6.39 | 2250 | 1480 | 930 | 740 | 210 | 39 | 4610 | 18 |
| | Average | 6.64 | 2280 | 1690 | 910 | 680 | 190 | 45 | 4220 | 18 |
| Chemkrete/MacMillan | 17B3 | 6.45 | 1640 | 1420 | 690 | 560 | 160 | 46 | 4540 | 19 |
| | 21B2 | 9.42 | 1490 | 1270 | 530 | 400 | 120 | 48 | 2310 | 18 |
| | 27B1 | 10.3 | 1530 | 1330 | 530 | 420 | 130 | 45 | 2200 | 16 |
| | Average | 8.72 | 1550 | 1340 | 580 | 460 | 140 | 46 | 3020 | 18 |
| Goodyear/Fina | 33B3 | 4.62 | 1940 | 1740 | 680 | 480 | 39 | 47 | 1680 | 24 |
| | 41B2 | 5.89 | 1870 | 1410 | 670 | 450 | 51 | 40 | 2110 | 19 |
| | 42B3 | 6.30 | 2150 | 1660 | 770 | 480 | 82 | 44 | 1600 | 16 |
| | Average | 5.60 | 1990 | 1600 | 710 | 470 | 57 | 44 | 1800 | 20 |
| Styrelf/Exxon | 47B1 | 5.93 | 2180 | 1620 | 1000 | 710 | 90 | 44 | 2470 | 19 |
| | 48B1 | 6.46 | 1960 | 2050 | 830 | 640 | 100 | 39 | 2320 | 18 |
| | 58B2 | 7.92 | 2160 | 1620 | 840 | 600 | 100 | 41 | 2430 | 23 |
| | Average | 6.77 | 2100 | 1760 | 890 | 650 | 97 | 41 | 2410 | 20 |
| Polybilt/Lyon | 68B2 | 9.74 | 2000 | 1520 | 880 | 530 | 98 | 36 | 2580 | 26 |
| | 73B2 | 8.40 | 2480 | 1500 | 870 | 610 | 110 | 50 | 2900 | 21 |
| | 75B1 | 8.28 | 2500 | 1660 | 830 | 610 | 120 | 50 | 2900 | 21 |
| | Average | 8.81 | 2330 | 1560 | 860 | 580 | 110 | 45 | 2790 | 23 |
| Control-SBL | 77B2 | 5.21 | 3040 | 2400 | 1070 | 800 | 160 | 48 | 4950 | 18 |
| | 81B2 | 7.74 | 1910 | 1430 | 980 | 680 | 140 | 46 | 3580 | 19 |
| | 90B1 | 6.11 | 2320 | 1830 | 1220 | 820 | 180 | 40 | 4590 | 18 |
| | Average | 6.35 | 2420 | 1890 | 1090 | 770 | 160 | 45 | 4370 | 18 |

Pascal = psi x 6894, kg = lb x 0.4535, mm = in x 25.40

Table A2. Continued

| Type Mixture | Before Moisture Treatment | | | | After Moisture Treatment | | | Tensile Strength Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | Tensile Properties | | | Tensile Properties | | |
| | Test Label | Air Void Content, percent | Tensile Strength, psi | Strain @ Failure, in/in | Test Label | Tensile Strength, psi | Strain @ Failure, in/in | |
| Control-NBL | 4B2 | 7.61 | 155 | 0.0029 | 4B1 | 172 | 0.0032 | 1.11 |
| | 10B1 | 6.88 | 199 | 0.0023 | 9B1 | 191 | 0.0023 | 0.96 |
| | 13B3 | 6.47 | 114 | 0.0036 | 11B3 | 114 | 0.0024 | 1.00 |
| | Average | 6.99 | 156 | 0.0029 | Average | 159 | 0.0026 | 1.02 |
| Chemkrete/MacMillan | 20B1 | 6.57 | 247 | 0.0028 | 23B1 | 81 | 0.0031 | 0.33 |
| | 25B1 | 10.2 | 150 | 0.0025 | 25B2 | 148 | 0.0021 | 0.99 |
| | 27B2 | 5.18 | 123 | 0.0026 | 28B3 | 76 | 0.0049 | 0.62 |
| | Average | 7.32 | 173 | 0.0026 | Average | 102 | 0.0034 | 0.64 |
| Goodyear/Fina | 39B2 | 5.88 | 238 | 0.0034 | 33B2 | 243 | 0.0026 | 1.02 |
| | 41B3 | 6.59 | 228 | 0.0041 | 36B2 | 162 | 0.0037 | 0.71 |
| | -- | -- | -- | -- | -- | -- | -- | -- |
| | Average | 6.24 | 233 | 0.0038 | Average | 203 | 0.0032 | 0.87 |
| Styrelf/Exxon | 47B2 | 7.92 | 194 | 0.0036 | 48B2 | 83 | 0.0033 | 0.43 |
| | 51B1 | 5.89 | 248 | 0.0037 | 57B2 | 104 | 0.0031 | 0.42 |
| | 56B1 | 6.50 | 202 | 0.0032 | 58B1 | 245 | 0.0036 | 1.21 |
| | Average | 6.77 | 215 | 0.0035 | Average | 144 | 0.0033 | 0.69 |
| Polybilt/Lyon | 64B2 | 8.16 | 228 | 0.0026 | 64B3 | 129 | 0.0027 | 0.57 |
| | 72B2 | 9.78 | 125 | 0.0036 | 71B3 | 74 | 0.0021 | 0.59 |
| | 76B2 | 8.69 | 125 | 0.0042 | -- | -- | -- | -- |
| | Average | 8.88 | 159 | 0.0035 | Average | 102 | 0.0024 | 0.58 |
| Control-SBL | 78B2 | 5.30 | 289 | 0.0015 | 79B2 | 182 | 0.0020 | 0.63 |
| | 83B2 | 5.99 | 312 | 0.0018 | 84B2 | 245 | 0.0016 | 0.79 |
| | 90B2 | 7.37 | 225 | 0.0019 | 91B2 | 154 | 0.0019 | 0.68 |
| | Average | 6.22 | 275 | 0.0017 | Average | 194 | 0.0018 | 0.70 |

Table A3. Data from 5-Year Texarkana Test Pavement Cores - Surface Layer.

| Type Mixture | Test Label | 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, .01 in. |
|---|---|---|---|---|---|---|---|---|---|---|
| Control-NBL | 2 | 6.34 | 2980 | 1640 | 1000 | 890 | 140 | 32 | 3570 | 18 |
| | 12 | 6.55 | 3390 | 1600 | 1040 | 890 | 96 | 33 | 3230 | 18 |
| | 14 | 5.56 | 3380 | 1350 | 1110 | 870 | 95 | 25 | 2640 | 16 |
| | Average | 6.15 | 3250 | 1530 | 1050 | 880 | 110 | 30 | 3150 | 17 |
| Goodyear/ Fina (Latex on Chemkrete) * | 17 | 8.84 | 3490 | 1260 | 940 | 810 | 47 | 35 | 1670 | 17 |
| | 20 | 6.71 | 3540 | 1370 | 870 | 710 | 48 | 24 | 1970 | 16 |
| | 26 | 7.21 | 3960 | 1120 | 900 | 710 | 41 | 27 | 1930 | 19 |
| | Average | 7.59 | 3660 | 1250 | 900 | 740 | 45 | 29 | 1860 | 17 |
| Goodyear/ Fina (Latex on Latex) | 32 | 7.08 | 3040 | 1110 | 1040 | 870 | 45 | 25 | 1700 | 16 |
| | 39 | 7.49 | 3340 | 1080 | 1170 | 850 | 53 | 22 | 1400 | 14 |
| | 44 | 7.94 | 3040 | 1150 | 830 | 720 | 46 | 25 | 1600 | 16 |
| | Average | 7.50 | 3140 | 1110 | 1010 | 810 | 48 | 24 | 1570 | 15 |
| Styrelf/ Exxon | 50 | 8.18 | 2710 | 1530 | 820 | 700 | 90 | 27 | 2210 | 20 |
| | 54 | 8.78 | 2910 | 1500 | 990 | 850 | 110 | 30 | 1880 | 17 |
| | 59 | 9.22 | 2920 | 1590 | 1020 | 760 | 130 | 30 | 2710 | 23 |
| | Average | 8.73 | 2850 | 1540 | 940 | 770 | 110 | 29 | 2270 | 20 |
| Polybilt/ Lyon | 63 | 6.08 | 3130 | 1520 | 1050 | 810 | 150 | 36 | 3680 | 20 |
| | 69 | 7.10 | 2940 | 1660 | 860 | 830 | 130 | 38 | 2940 | 20 |
| | 74 | 10.0 | 3020 | 1760 | 980 | 930 | 130 | 39 | 3360 | 21 |
| | Average | 7.73 | 3030 | 1650 | 960 | 860 | 140 | 38 | 3330 | 20 |
| Control-SBL | 80 | 6.22 | 3940 | 1610 | 1020 | 830 | 110 | 30 | 3020 | 17 |
| | 85 | 8.63 | 3680 | 1540 | 870 | 760 | 110 | 21 | 2920 | 20 |
| | 91 | 7.60 | 3380 | 1430 | 850 | 760 | 110 | 25 | 2710 | 24 |
| | Average | 7.48 | 3670 | 1530 | 910 | 780 | 110 | 25 | 2880 | 20 |

* Note: The Latex surface on the Chemkrete base was not analyzed graphically in this report.

Pascal = psi x 6894, kg = lb x 0.4535, mm = in x 25.40

Table A3. Continued

| Type Mixture | Before Moisture Treatment | | | | After Moisture Treatment | | | Tensile Strength Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | Tensile Properties | | | Tensile Properties | | |
| | Test Label | Air Void Content, percent | Tensile Strength, psi | Strain @ Failure, in/in | Test Label | Tensile Strength, psi | Strain @ Failure, in/in | |
| Control-NBL | 9 | 6.17 | 288 | 0.0020 | 5 | 191 | 0.0021 | 0.66 |
| | 10 | 6.24 | 221 | 0.0015 | 11 | 88 | 0.0023 | 0.40 |
| | 15 | 5.79 | 214 | 0.0013 | 15 | | 0.0042 | |
| | Average | 6.07 | 241 | 0.0016 | Average | 140 | 0.0029 | 0.53 |
| Goodyear/ Fina (Latex on Chemkrete) * | 18 | 8.71 | 255 | 0.0013 | 19 | 122 | 0.0019 | 0.48 |
| | 24 | 6.54 | 217 | 0.0023 | 21 | 246 | 0.0029 | 1.13 |
| | 27 | 6.98 | 240 | 0.0020 | 28 | 123 | 0.0031 | 0.51 |
| | Average | 7.41 | 237 | 0.0019 | Average | 164 | 0.0026 | 0.71 |
| Goodyear/ Fina (Latex on Latex) | 34 | 7.18 | 194 | 0.0018 | 35 | 129 | 0.0039 | 0.66 |
| | 40 | 8.16 | 228 | 0.0018 | 38 | 124 | 0.0026 | 0.54 |
| | 42 | 7.66 | 191 | 0.0018 | 46 | 153 | 0.0023 | 0.80 |
| | Average | 7.67 | 204 | 0.0018 | Average | 135 | 0.0029 | 0.67 |
| Styrelf/ Exxon | 47 | 9.06 | 281 | 0.0018 | 49 | 173 | 0.0032 | 0.62 |
| | 52 | 8.19 | 296 | 0.0023 | 56 | 169 | 0.0024 | 0.57 |
| | 55 | 8.67 | 223 | 0.0020 | 61 | 191 | 0.0026 | 0.86 |
| | Average | 8.64 | 267 | 0.0020 | Average | 178 | 0.0027 | 0.68 |
| Polybilt/ Lyon | 65 | 6.12 | 307 | 0.0018 | 67 | 208 | 0.0013 | 0.68 |
| | 70 | 7.14 | 207 | 0.0013 | 72 | 226 | 0.0013 | 1.09 |
| | 75 | 9.70 | 264 | 0.0008 | 76 | 147 | 0.0013 | 0.56 |
| | Average | 7.65 | 259 | 0.0013 | Average | 194 | 0.0013 | 0.78 |
| Control-SBL | 78 | 9.60 | 251 | 0.0015 | 79 | 209 | 0.0023 | 0.83 |
| | 82 | 5.99 | 337 | 0.0023 | 84 | 211 | 0.0023 | 0.63 |
| | 87 | 7.37 | 286 | 0.0018 | 88 | 258 | 0.0023 | 0.90 |
| | Average | 7.65 | 291 | 0.0019 | Average | 226 | 0.0023 | 0.79 |

* Note: The Latex surface on the Chemkrete base was not analyzed graphically in this report.

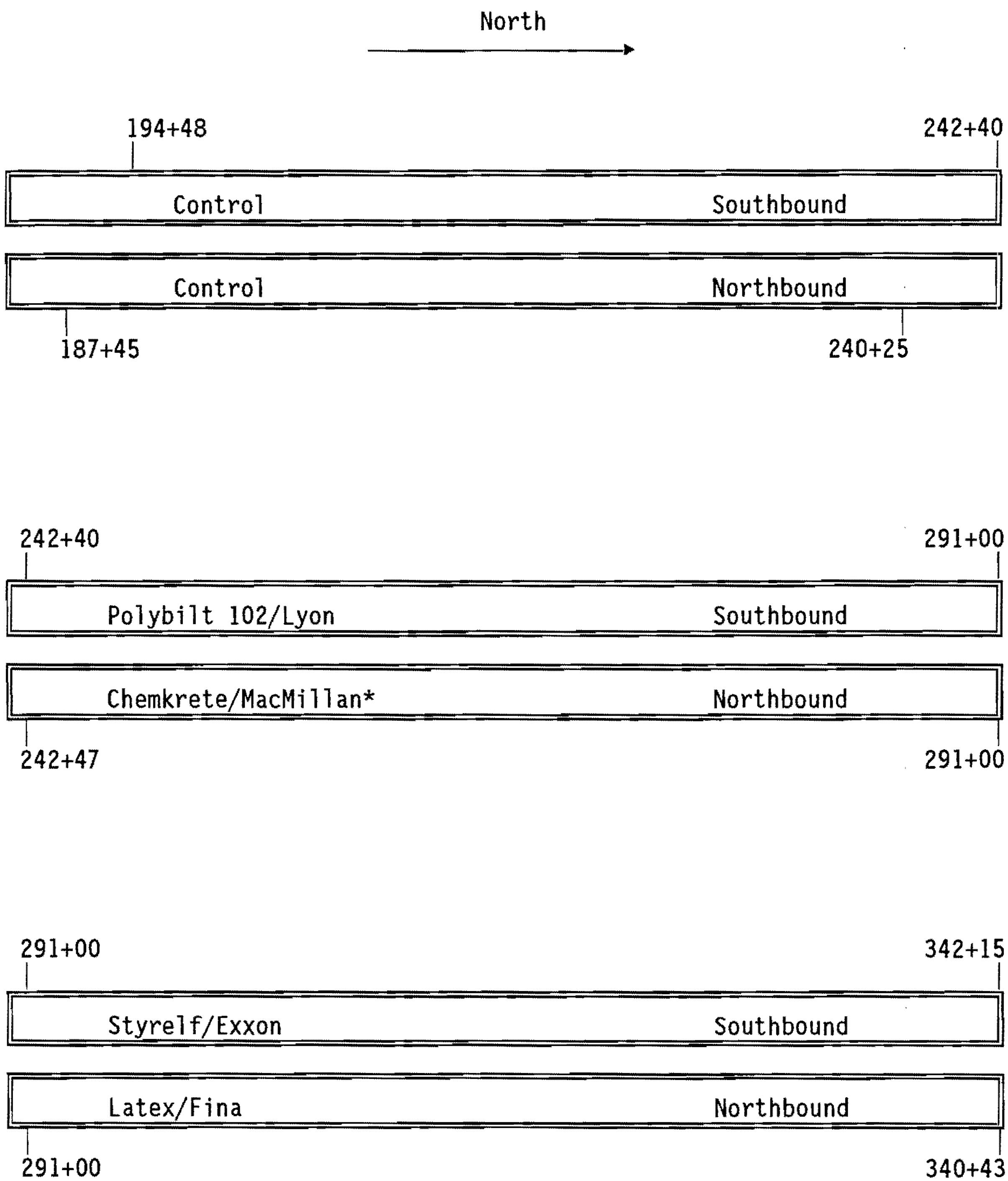


Figure A1. Schematic Showing Test Pavement Locations.

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

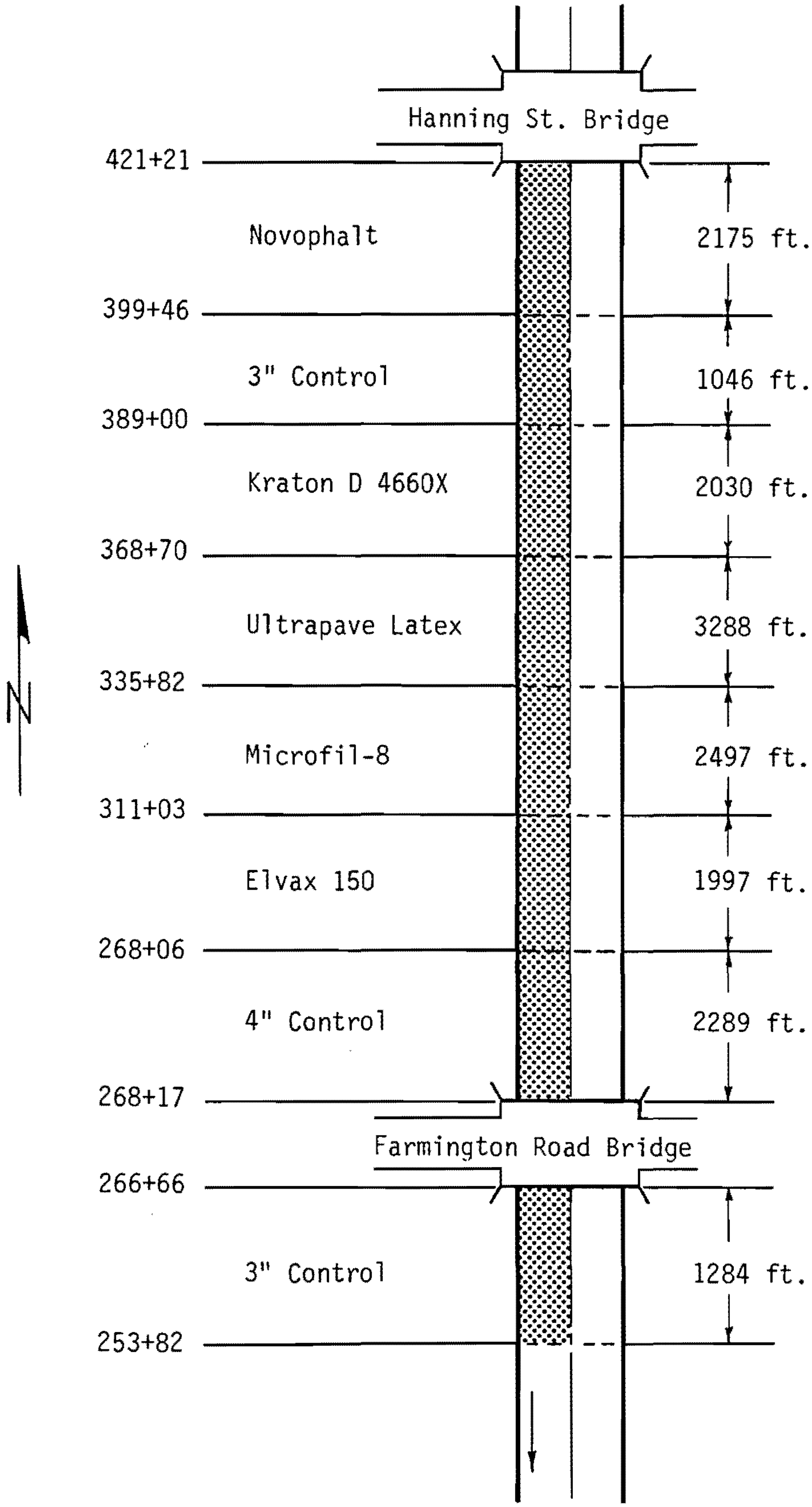


Figure A2. Limits of Additive Test Pavements in District 1.

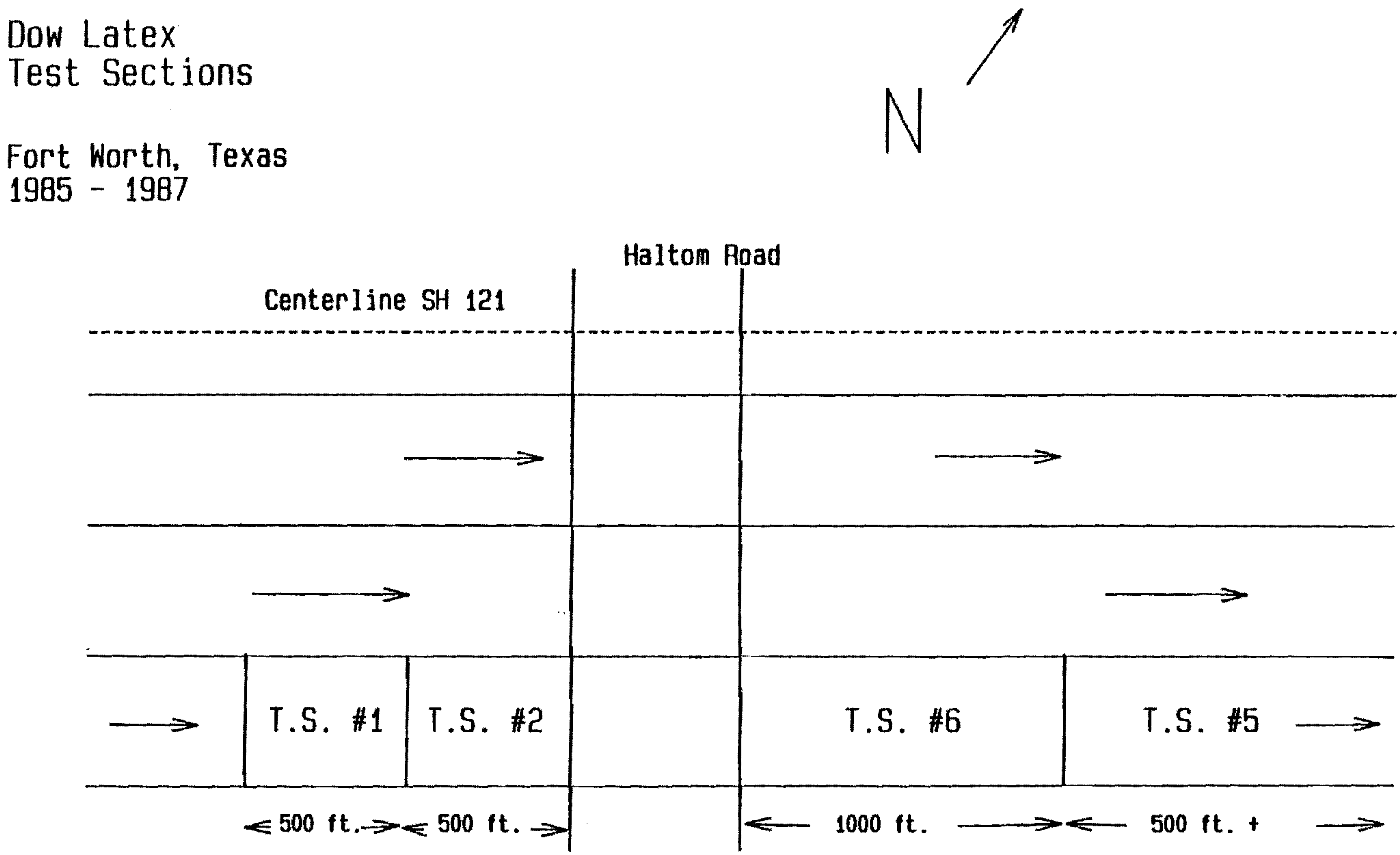


Figure A3. Limits of Additive Test Pavements in District 2 (Ft. Worth).

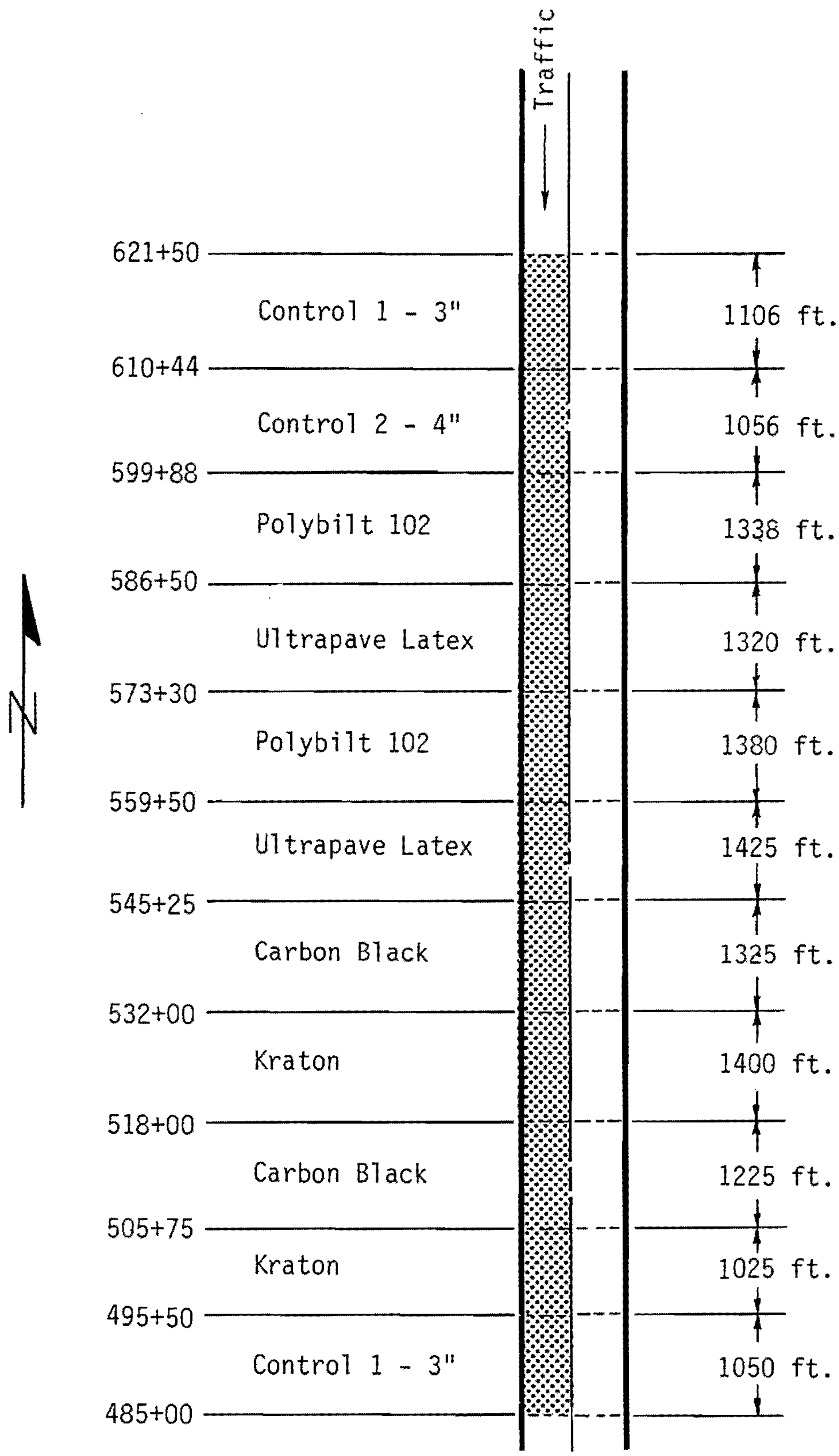


Figure A4. Limits of Additive Test Pavements in District 21.