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16. Abstract

Controlled field experiments were installed in north central and extreme south Texas to evaluate the comparative performance of six different additives in hot mixed asphalt concrete pavements. In north Texas, additives were incorporated in a 3-inch surface course which was applied to rehabilitate a continuously reinforced concrete pavement. In south Texas, additives were used in a 3-inch surface course on a newly constructed pavement. Additives evaluated included styrene butadiene rubber (latex), styrene butadiene styrene block copolymer, ethylene vinyl acetate, finely dispersed polyethylene, and pelletized carbon black. The additives were blended with AC-10; whereas, the control mixtures contained AC-20.

Samples of paving materials were collected during and shortly after construction and tested in the laboratory. Tests included rheological properties of 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 treatment and artificial aging and air void content.

After one year in service all test pavements are performing equally well. The additives had little effect on Hveem and Marshall stability, moisture sensitivity, and oxidative aging of paving mixtures. Additive modified mixtures, carbon black in particular, require more compactive effort and/or higher temperatures to achieve density levels of similar unmodified mixtures. Standard tests used in mixture design do not show benefits of additives as well as tests that measure fundamental materials properties.

17. Key Words
Asphalt additives, paving mixtures, modified asphalts, polymers, carbon black, pavement construction, performance, field trials

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ASPHALT ADDITIVES IN HIGHWAY CONSTRUCTION

by

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Associate Research Engineer

Research Report 187-14
Research Study 1-10-87-187 (Task 5)

Sponsored by
Texas State Department of Highways and
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Federal Highway Administration

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College Station, Texas 77843

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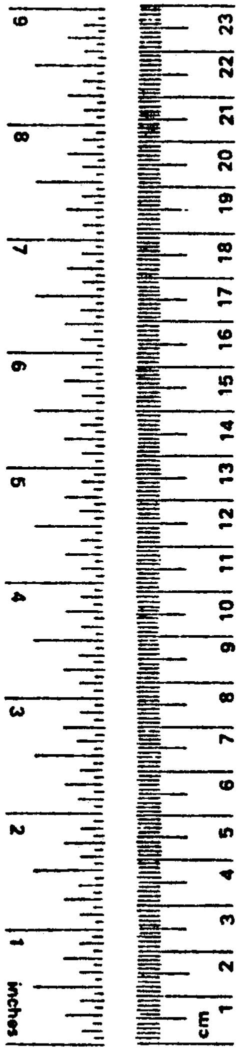
METRIC CONVERSION FACTORS

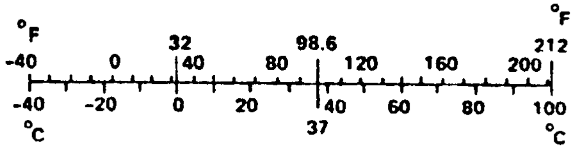
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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IMPLEMENTATION STATEMENT

Controlled field experiments with end-to-end test pavements containing a total of six different asphalt additives have been installed in southern and north central Texas. Evaluation of these and several other isolated test pavements containing these additives will provide essential information to assess cost-effectiveness. Pavement thickness should not be reduced when additives of these types are employed. Therefore, use of these additives will result in no cost savings during the first year. Cost savings should be realized by extended pavement service life and reduced maintenance.

Design of paving mixtures containing polymeric additives or carbon black may be performed in the usual manner. Standard tests employed during mixture design, however, will give little or no indication of changes in fundamental engineering properties of the modified mixtures. Generally, mixing and compaction temperatures should be increased to accommodate the higher than usual binder viscosities to assure adequate coating of the aggregate in the plant and densification of modified paving mixtures.

The use of asphalt additives is greatly simplified when the additive and asphalt are blended prior to arrival at the mix plant. Some asphalt suppliers already have this capability, others are considering addition of such facilities. Extended hot storage of asphalt modified with some polymers may result in degradation of binder properties. Small-scale laboratory tests to simulate storage may over-estimate binder damage. Storage of carbon black or polyethylene modified asphalts without adequate agitation will result in phase separation of asphalt and modifiers unless special blending and/or surfactants are used to keep the additive in suspension.

Presently, it appears that specifications for a particular type of asphalt additive will need to be specific since the properties of the additives vary tremendously. New specifications regarding an asphalt-additive blend should address additive/asphalt ratio and viscosity temperature susceptibility. Acceptance criteria should be based on fundamental engineering properties and should consider minimum increases in tensile strength, stiffness, fatigue properties and/or resistance to creep and permanent deformation at high service temperatures and compliance at low service temperatures.

Most asphalt extraction methods currently practiced are unsuitable for use with the additives discussed herein as these materials are insoluble or only partially soluble in typical solvents. This problem may be ameliorated by using the nuclear method to determine binder content.

DISCLAIMER

The contents of this report reflect 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. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

ACKNOWLEDGEMENTS

Special thanks are extended to Texas SDHPT personnel, Mr. Howard Smith in District 1 and Mr. Richard Buchen in District 21 for their cooperation with the research agency and the extra effort put forth in establishing the additive test pavements described in detail in this report. Personnel in Districts 2, 10, 16, 17 and 19 were very helpful in furnishing information on individual additive test pavements.

Several additive suppliers provided their products without cost to the state to be evaluated in this study. They are Cabot Corporation, E.I. DuPont de Nemours and Company, Exxon Chemical Company, Novophalt America Corporation, Shell Development Company, and Textile Rubber and Chemical Company. Mono-Chem Corporation of Atlanta, Texas, furnished manpower and equipment for blending carbon black and asphalt used in the test in San Benito.

Mr. Paul Krugler, the technical coordinator on this study, provided valuable advice and assistance in establishing the test pavements which is acknowledged and appreciated.

Laboratory testing was performed by Messrs. Sidney Greer, Ysidoro Ramirez and Steve Phillips. Typing of the manuscript was accomplished by Mmes. Carolyn Ramirez, Linda Millhollon, Stacey Rodgers, Bea Cullen, Connie Fox and Ofelia Gonzales.

INTRODUCTION

Highway engineering is a field which requires the judicious use of materials manufactured by nature. Naturally occurring soils serve as the foundation for highway pavements. Some serve faithfully and well while others crack and swell and wreak havoc on expensive pavement structures. Nature's products are also used in pavement bases and asphalt mixtures, often with relatively minor refinements. Many of these products are remarkably well suited to meet our needs. It is the duty and responsibility of paving engineers to optimize the use of these materials to the maximum benefit of the taxpayers and the driving public. A host of man-made products are now available which can be used to improve the rheological and/or adhesive properties of nature's own asphalt cement. Full-scale evaluation of six of these asphalt additives is the primary thrust of this report.

The overall purpose of this research study is to evaluate economic alternatives to reduce premature pavement cracking. In order to reduce the potential for cracking of asphalt concrete mixtures, at least one of two objectives must be accomplished: (1) increase mixture tensile strength or (2) increase mixture flexibility. Both of these objectives can be accomplished by simply increasing the mixture's asphalt content; however, mixture stability will be adversely affected. Mixture tensile strength can be increased by using harder asphalt, but flexibility will suffer. Softer asphalts will, of course, improve flexibility at the expense of tensile strength and stability which may fall below specified values. In the past, these objectives have not been possible simultaneously. However, the advent of new, economical additives may eliminate the need for this historical compromise.

This research project began as HP&R study 471 which culminated with a report of laboratory findings on asphalt additives (1). The primary objective of this study was to evaluate performance of materials added to or techniques applied to asphalt concrete mixtures for the purpose of reducing pavement cracking potential. In reaching this goal, it was necessary to compare performance of modified paving mixtures in the laboratory and in the field. The interest was chiefly in products that would, immediately upon addition to asphalt concrete, alter the mechanical production to improve the properties and/or the performance of the resulting binder and/or mix.

A request was made by File D-9 personnel for suitable sites to evaluate several asphalt additives in adjacent pavement sections with the additive being the only variable. District 1 and 21 responded favorably. A description of the proposed tests was made available to those bidding on the two selected paving projects. Once successful bidders were chosen, several months of preparatory work were required before the additive modified mixtures were placed. Researchers were on site during construction to collect material samples, prepare test specimens and record observations.

A total of five products were evaluated in two different climatic and geologic regions of the state. The products included four polymers, ethylene vinyl acetate, polyethylene, styrene butadiene rubber as latex and styrene butadiene styrene block copolymer, and a pelletized HAF grade carbon black. This report presents findings from field and laboratory experiments designed to evaluate these additives during mixture design and preparation, pavement construction and early service life. Methods for implementation of the findings in paving applications and recommendations regarding further study are discussed. The findings at this stage are not overwhelmingly in favor of widespread use of asphalt additives; however, the data indicate that certain additives can be used to improve mixture properties and have the potential to provide cost-effective extensions to pavement service life.

A unique opportunity was afforded this study in that a companion study by TTI sponsored by the Federal Highway Administration (FHWA) (2) evaluated the same five additives in the laboratory in a very rigorous experimental program. The overall objectives of the FHWA study were to (1) identify through laboratory testing, the most promising types of additives or admixtures for reducing rutting and cracking in hot-mixed asphalt pavements, (2) develop guidelines showing how the additives can be incorporated into actual pavements and (3) develop procedures for evaluating additives. Some of the results from that study are summarized herein. These complementary studies were a cooperative effort between the Texas State Department of Highways and Public Transportation (SDHPT) and the FHWA. The FHWA study was essentially a comprehensive laboratory study of the physical and chemical properties of additive-modified asphalt binders. Fatigue and creep properties and resistance to crack propagation of paving mixtures were also quantified and resistance to crack propagation of paving mixtures were also quantified over a range of service temperatures and selected mixture properties were used in mathematical models to predict pavement performance. The SDHPT study was primarily a field study. However, certain laboratory tests on binders and paving mixtures were necessary to initiate the field work. In addition, materials identical to those tested in the FHWA research program were used to study the utility of the force ductility, investigate heat stability of modified binders and evaluate tensile properties of paving mixtures over a wide range of temperatures and loading rates (1).

SUMMARY OF FIELD PRODUCTS

GENERAL

Construction projects containing designated test sections to evaluate asphalt additives for improving asphalt concrete pavement structural properties were installed at several locations in Texas (Figure 1). Two construction projects, one in District 1 near Sherman and one in District 21 near San Benito, included several one-half mile test pavements placed side-by-side to comparatively evaluate selected asphalt additives under similar conditions. Specific information about these test pavements is furnished in Table 1. Climatic and traffic data are included in Table 2 to indicate the types of environments to which these pavements are exposed.

DESCRIPTION OF ASPHALT ADDITIVES

Five types of additives which appear likely to improve resistance to rutting and cracking were selected for study. The five types were:

1. Pelletized carbon black microfiller,
2. Styrene-butadiene rubber (SBR), added to asphalt as latex,
3. Thermoplastic block copolymer rubber,
4. Polyethylene finely dispersed in asphalt, and
5. Copolymers of ethylene and vinyl acetate (EVA).

To the best of the author's knowledge there is presently only one carbon black product produced specifically for asphalt modification, Microfil-8, supplied by Cabot Corporation. Microfil-8 is a mixture of approximately 92 percent high-structure HAF grade carbon black plus approximately 8 percent oil similar to the maltenes portion of asphalts, formed into soft pellets dispersible in asphalt.

Styrene-butadiene latexes are available with a wide variety of monomer proportions, molecular weight ranges, emulsifier types and other variables. The product selected for use in this field investigation was Ultrapave 70 from Textile Rubber and Chemical Co. It is an anionic emulsion and contains about 70 percent rubber solids and 30 percent water.

Thermoplastic block copolymer rubber was supplied from Shell Development Company in the form of Kraton 4460X (a blend of equal parts styrene-butadiene-styrene polymer and rubber extender oil). The oil added is a

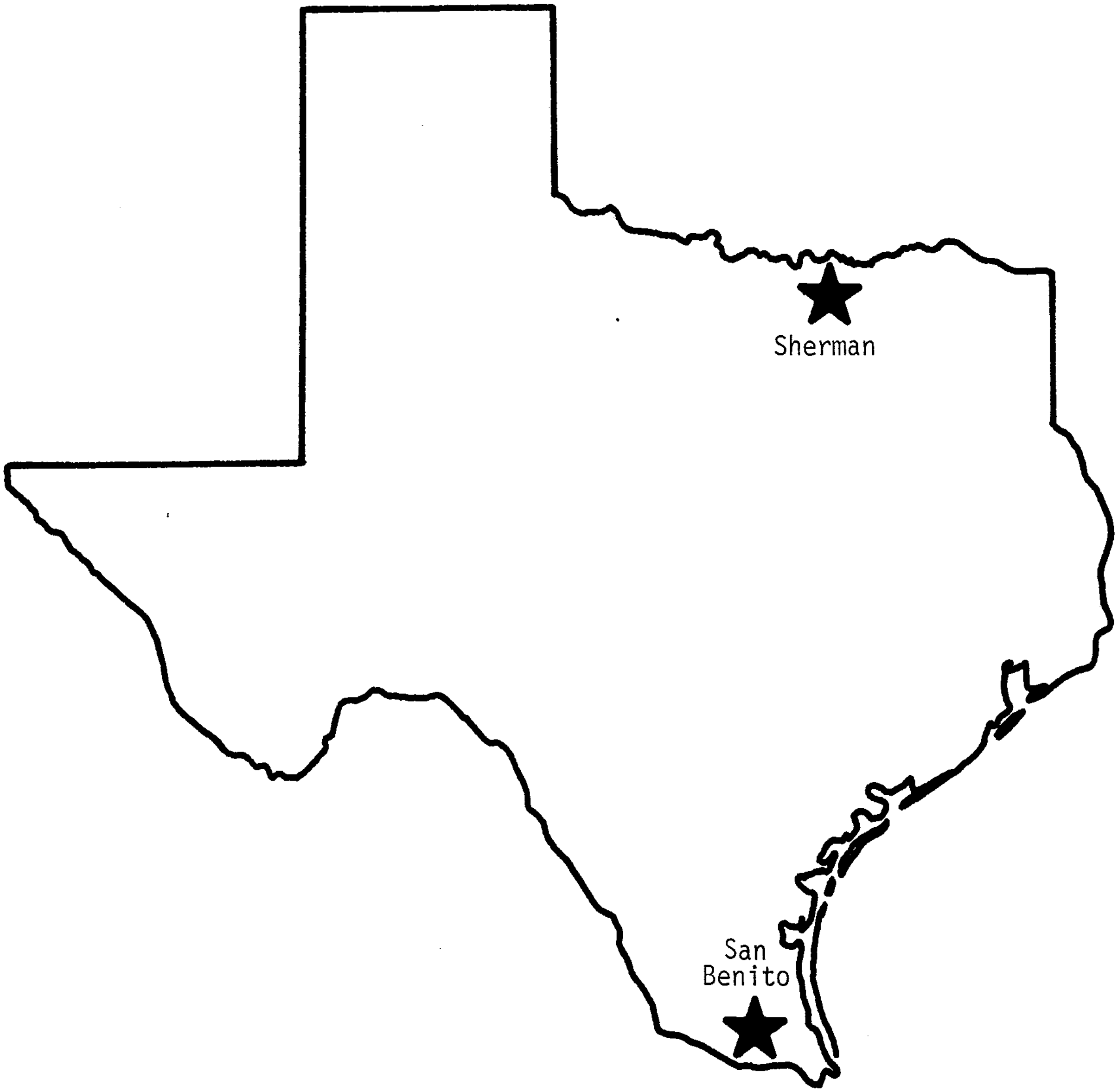

Figure 1. Location of Field Test Sections.

Table 1. Summary of Texas Field Projects in Districts 1 and 21.

Item	Location South of Sherman	South of San Benito
General Information		
Highway Designation	US75	US 83/77
District Number	1	21
County and Number	Grayson (92)	Cameron (31)
Control-Section Number	0047-13	39-8
No. of Lanes each Direction	2	2
Existing Pavement		
Layer 1 (Top)	8" CRCP	NA (New Const.)
Layer 2	6" Flex Base/Lime	NA
Layer 3	6" Subgrade/Lime	NA
Construction Project No.	CSR 47-13-11	MA-F-93 (40)
Date of Construction	October 1986	August 1986
Type of Construction	HMAC* Overlays	New HMAC*
Construction Sequence	Sealcoat+2" Type B + Test Pavement	12" Lime-Subgrade+ +12" Flex Base+4" Black Base+test pvmt.
Description of Test Pavements		
Mix type	Type C	Type D
Asphalt Source	Total Asphalt Co.	Texas Fuel & Asphalt
Asphalt Type & Grade w/Additives	AC-10	AC-10
Asphalt Type & Grade Control	AC-20	AC-20
Aggregate Type	Crushed Limestone and Field Sand	Crushed Gravel and Field Sand
Antistrip Additives	1/2% Pave Bond LP	1% Hydrated Lime (slurry)
Test Pavement Thickness	3-inch	3-inch
Control Pavement Thickness	3 and 4-inch	3 and 4-inch
Asphalt Additives Tested		
Carbon Black	Microfil-8	Microfil-8
Ethylene Vinyl Acetate	Elvax 150	Polybilt 102
Polyethylene	Novophalt	None
SBR Latex	Ultrapave	Ultrapave
SBS Block Copolymer	Kraton D	Kraton D

*HMAC - Hot mix Asphalt Concrete

Table 2. Traffic and Environmental Data for Test Sites.

Item	Location	
	South of Sherman	South of San Benito
<u>Traffic Data</u>		
ADT (1985 & 2005)	17,700/28,800	14,900/26,700
Trucks in ADT, %	17.1	10.7
ATHWLD	13,100	12,400
Tandem Axles in ATHWLD, %	80	60
Equivalent 18kip axle loads expected 1985 to 2005	21,377,000	5,796,000
<u>Weather Data</u>		
Climate	Humid, subtropical with hot summers	Tropical with dry winters and hot, humid summers
Temperature		
Mean & Record Max, °F	96/109	97/107
Mean & Record Min, °F	31/-2	50/14
No. Days/yr 90°F & above	94	146
No. Days/yr 32°F & below	55	4
Sharp drops	Yes	No
Frost Penetration, in.	1	0
Freeze Index	0	0
Precipitation		
Mean annual precip, in.	40	26
Mean annual ice/snow, in.	5.1	Trace

select blend of aromatic and naphthenic/paraffinic oils designed to facilitate incorporation of the polymer into asphalt and improve the properties of the final modified product.

Polyethylene was supplied and blended with asphalt by the Novophalt America Corporation. Information on the Novophalt process indicated that normally low density polyethylene (LDPE) is used. Preparation of Novophalt (asphalt and polyethylene) involves a high shear blending process which breaks down the polyethylene into very fine particles, stores the blend in a heat-controlled, agitated tank and transfers the material directly to the mixing plant. Polyethylene is a linear nonpolar polymer.

Two ethylene vinyl acetate (EVA) resins differing in monomer ratio, solubility, softening point and melt index were studied. These included Elvax 150 from DuPont Company and Polybilt 102 from Exxon Chemical Americas. EVA has permanent polarity associated with the acetate group.

These additives were characterized in two comprehensive laboratory test programs (1,2) sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. A summary of the work accomplished and the conclusions from these laboratory investigations are presented in Appendix A.

It should be pointed out that the names given these polymers are trademarks registered by the associated companies.

ASPHALT/ADDITIVE BLENDS

Current laboratory data (1,2) indicate that, for best results in cold as well as warm weather, additives should be used with asphalt at least one grade softer than that normally used in a paving mixture. The additives discussed herein will significantly increase the viscosity of an asphalt cement at high service temperatures (greater than 100°F) but have little effect on asphalt consistency at lower service temperatures (less than 40°F). The soft asphalt provides flexibility to reduce cracking at the lower temperatures and the additive increases the viscosity at higher temperatures to reduce the potential for rutting. Optimum viscosities of modified binders will, of course, depend upon climate, traffic and characteristics of the aggregate with which they are used.

FINDINGS

The two field trials in Districts 1 and 21 are described in detail in the following paragraphs. Discussions include field installation, laboratory test results on paving materials collected from the construction projects and performance after one year in service.

DISTRICT 1

General

A 3.17 mile section of US 75 South of Sherman, Texas, in Grayson County was selected from construction Project CSR 47-13-11 and used to test five asphalt additives. The five additives included four polymers, ethylene vinyl acetate (EVA), polyethylene (PE), styrene butadiene rubber (SBR) latex and styrene butadiene styrene block copolymer (SBS), and carbon black. The one-half mile (approximately) pavements consisted of essentially three inch overlays of asphalt concrete placed as the surface course in rehabilitation of a continuously reinforced Portland cement concrete pavement. Construction details are given later. Control pavements, three inches and four inches in depth, were similarly placed. All test pavements and control pavements were installed in October 1986 in the southbound travel lane. A map showing the exact location of the different test and control sections is provided in Figure B1, Appendix B.

Incorporation of Asphalt Additives

About 6000 gallons (one tanker load) of modified and unmodified asphalt were used to construct each test pavement. The additives were mixed with AC-10 from Total Asphalt Company. The control pavements (no additive) were made using AC-20. All binders contained one-half percent PaveBond LP as an antistrip additive. The antistrip was added by simply pouring into the tank truck while it was unloading at the mix plant. This method leaves questions regarding uniform mixing. Three of the additives, SBS, latex and EVA, were blended with the asphalt cement prior to arrival at the mixing plant site. Each additive was blended with Total AC-10 by different agencies using different procedures (Table 3).

Table 3. Construction Notes from District 1 Test Pavements.

Type Additive	Additive Dosage, wt. percent	Source and Grade of Asphalt	Date Pavement Placed	Method of Incorporating Asphalt Additive*	Plant Used	Comments
Polyethylene (Novophalt)	5%	Total AC-10	10/14/86	Truck mounted high-shear blending device at plant site.	Small	First ∿ 2000 gal of Novophalt not sufficiently blended = 700' of pavement.
Control - 3"	None	Total AC-20	10/14/86	N/A	Large	None
SBS/Oil (Kraton D4460X)	8.6%**	Total AC-10 + Exxon 120/150	10/15/86	Preblended by Texas Emulsions in Mt. Pleasant using low shear at 340°F.	Large	Mix color was brown.
Latex (Ultrapave)	3%	Total AC-10	10/15/86	Preblended by Trumbull in Dallas using low shear at 380°F.	Large	None
Carbon Black (Microfil-8)	12.5%	Total AC-10	10/15/86	Initially, 25 lb plastic bags of carbon black placed directly into pugmill and blended with dry aggregate; last 1/4, black added after asphalt.	Small	Noted carbon blace atop water in settling tank from scrubber.
EVA (Elvax 150)	2%	Total AC-10	10/16/86	Preblended at Texas Fuel and Asphalt in Corpus Christi using low shear at 330°F.	Large	None
Control - 4"	None	Total AC-20	10/16/86	N/A	Large	Placed in 1 lift, as all others
Control - 3"	None	Total AC-20	10/16/86	N/A	Large	None

*One-half percent Pave Bond LP was added to all binders by pouring into tanker truck at plant site.

**Kraton D4460X is composed of 50% SBS black copolymer + 50% extender oil. Blending difficulties necessitated the use of about 15% Exxon 120/150 per asphalt in the modified binder.

When attempting to blend the SBS/Oil (Kraton) with the Total AC-10 asphalt, there was an insufficient quantity of material in the large vat to facilitate mixing by recirculation. It was necessary, therefore, to add about 1000 gallons more asphalt. All that was available was Exxon 120/150 grade, so it was added resulting in a 6 to 1 Total-Exxon mixture. This will adversely affect the data analysis from a statistical standpoint but was necessary from a practical standpoint to allow construction.

Polyethylene pellets were incorporated into the asphalt at the mix plant site using a truck-mounted blending device capable of mixing, heating and storing while agitating 2000 gallons of modified asphalt (Novophalt). The heart of the system is a Siefer mixer which ideally "grinds" the polyethylene pellets into almost microscopic size particles. Initially, the Microfil-8 was added to the dry aggregate and after approximately 5 seconds mixing time, the asphalt was added and mixed for an additional 35 seconds. Carbon black began to accumulate on the surface of the settling pond from the wet scrubber system. In an attempt to avoid this problem, the bag of Microfil-8 was placed in the pug mill immediately after the asphalt was added with no adjustments in mixing times. This was done during construction of the southernmost 25 percent of the carbon black test pavement.

Construction of Test Pavements

The existing pavement consisted of a transversely cracked and deteriorating eight inch continuously reinforced concrete pavement. After repair of localized failures, a seal coat was placed using 1 cubic yard per 100 square yards of Grade 4 precoated crushed stone with 0.29 gallons per square yard AC-5. This was followed by a level-up course consisting of 2-inches of Item 340, Type B hot-mixed asphalt concrete. The test pavements in which the asphalt additives were incorporated consisted of 3-inches of Item 340, Type C hot mixed asphalt concrete placed in one lift. Similar 3-inch control sections with no additive were built and, in addition, a 4-inch control section was built to provide data regarding thickness equivalency factors. This field test project is located on US 75 south of Sherman, Texas, on a fairly straight section of a rural 4-lane divided highway in rolling hills. A summary of the test pavements is given in Table 1. Mixture design data is presented in Table B1.

Asphalt paving operations were performed by Rushing Paving Company. The general contractor was Lattimore Materials of Denison, Texas. Two different batch plants at the same location were used in preparing the paving mixtures. The smaller plant was 5000 pound capacity gas-fired Standard Havens 32 years old with a wet scrubber. The larger plant was an 8000 pound capacity gas fired Cedarapids 8 years old with a wet scrubber. All test pavements (3-inch and 4-inch) were placed in a single lift using a Cedarapids BSF-520 paving machine. Compaction was accomplished using a Bomag 12-ton steel wheel roller followed by a Ferguson SP-1118 25-ton pneumatic roller.

All mixtures except the carbon black modified mixture contained 5.3 percent asphalt by total weight of mixture. When carbon black was used, the binder content was increased to 5.5 weight percent to account for the higher specific gravity of the carbon black (1.7). This resulted in equivalent design volume percentages for all binders used in the study.

Placing of the modified mixtures was generally routine and without additive-associated problems. There was some concern by the paving crew about the brown color of the SBS-modified mix. They thought the mix was "scorched." The brown color is typical when SBS polymer is used.

Construction Evaluations

Samples of asphalt binders, aggregates and paving mixtures, including gyratory molded specimens as well as pavement cores, were obtained and tested in the laboratory. Paving mixtures were tested in accordance with Figure 2. Results from these tests are tabulated in Appendix B.

Laboratory Tests on Binders. A summary of the binder test results is given in Table B2, Appendix B. Figures 3 through 7 compare the rheological properties of the modified asphalts with the unmodified asphalts. Figure 3 shows that upon addition of Microfil-8, the increase in viscosity is substantially greater than the corresponding decrease in penetration. This likely results from the presence of the oil in the Microfil-8 which remains liquid at relatively low temperatures. The result is a significantly harder binder with a lower temperature susceptibility. Based

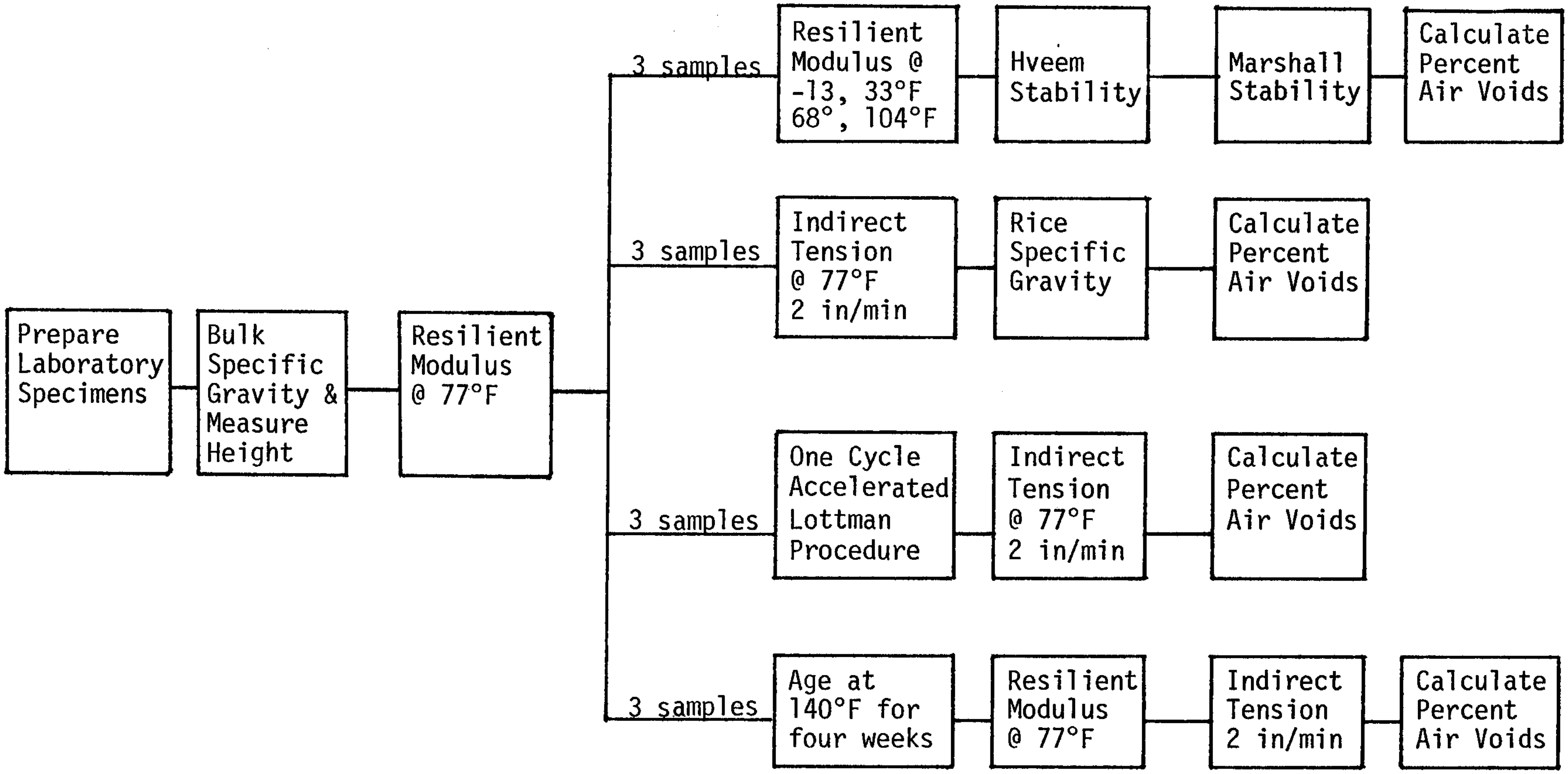

Figure 2. Laboratory Test Program for Paving Mixtures.

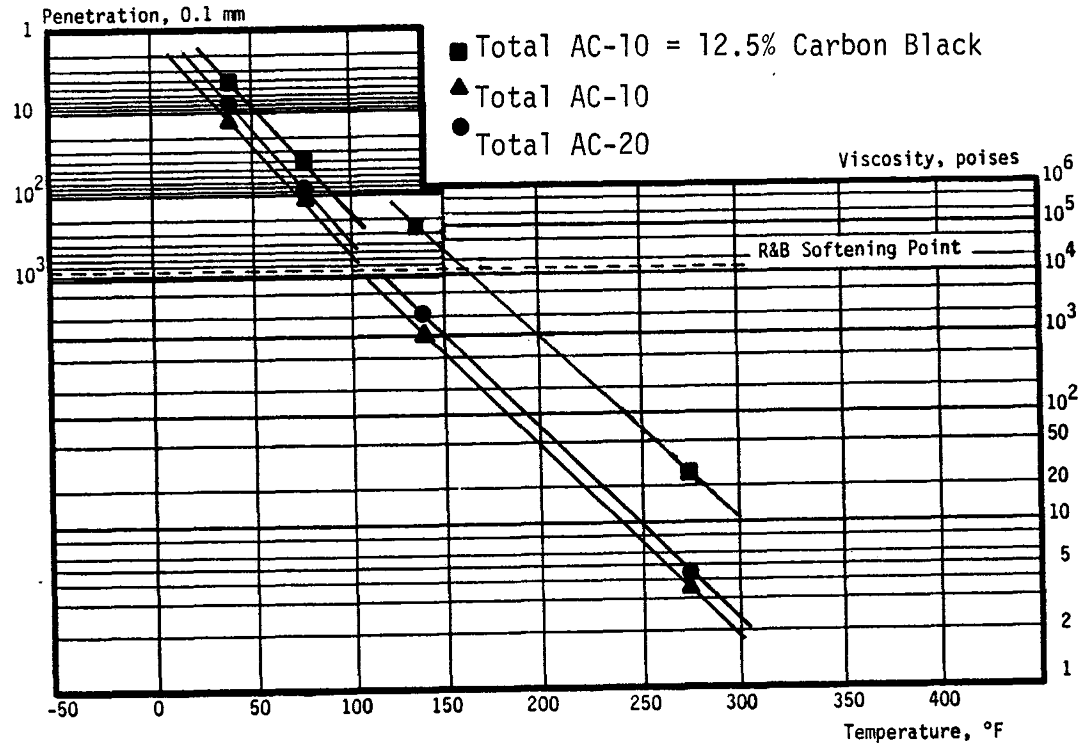

Figure 3. Rheological Properties of Carbon Black Modified AC-10 Compared with Unmodfied AC-10 and AC-20.

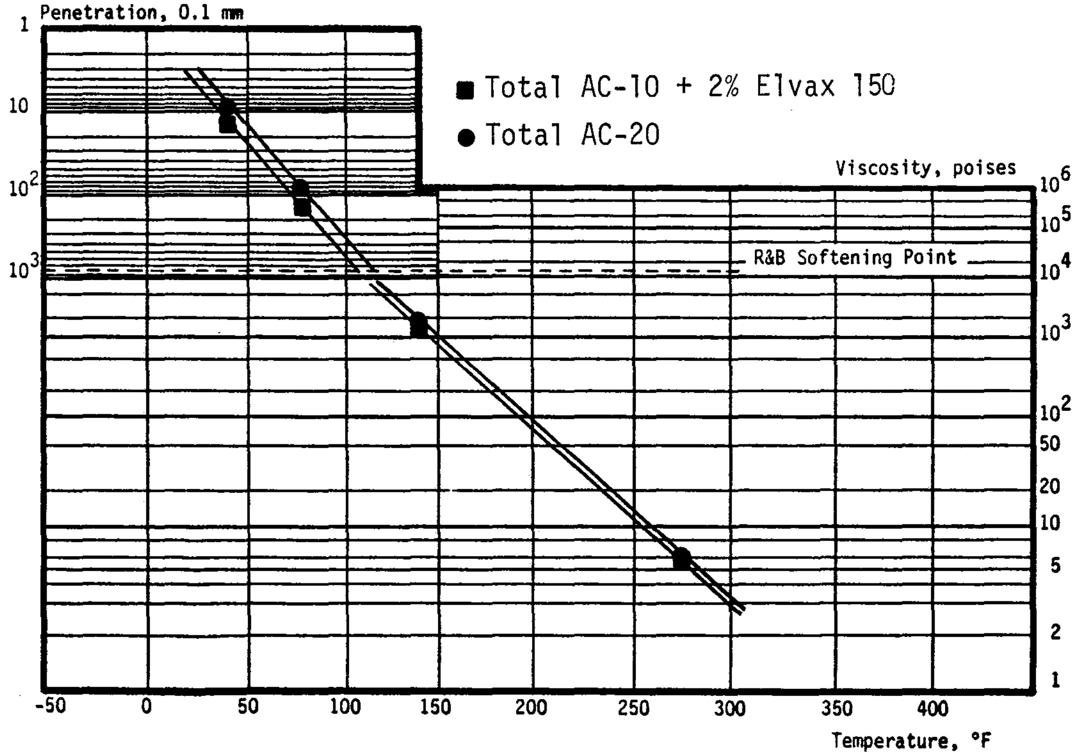

Figure 4. Rheological Properties of EVA Modified AC-10 Compared With Unmodified AC-20.

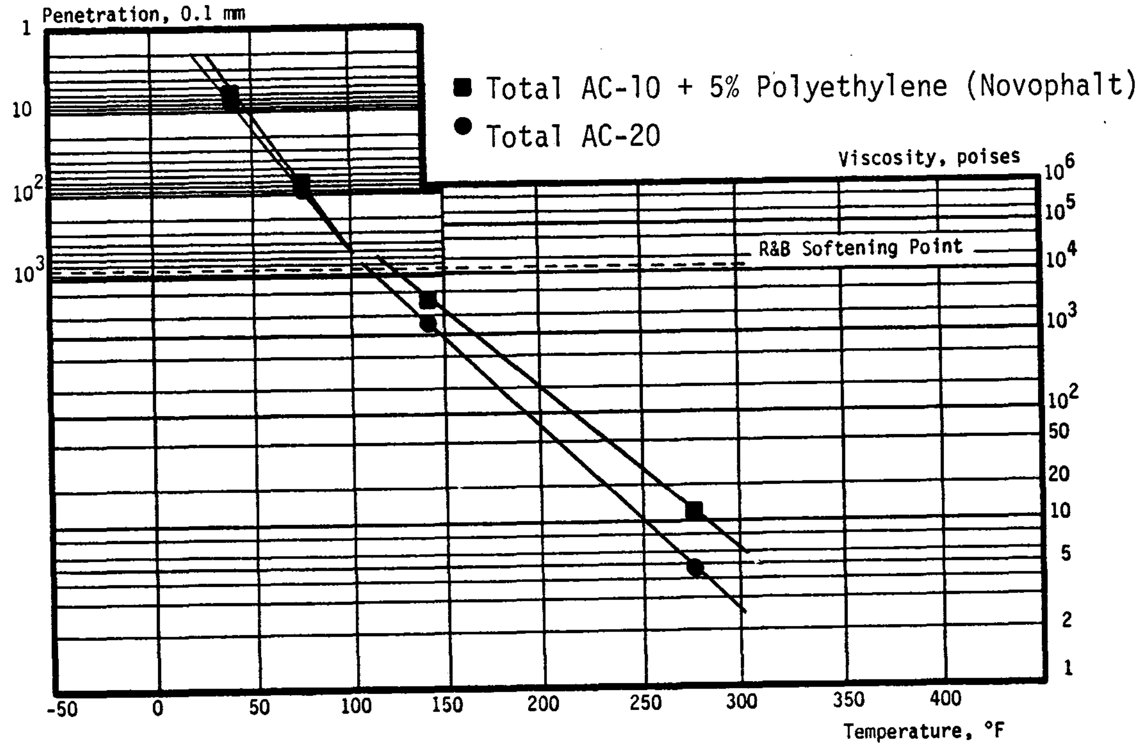

Figure 5. Rheological Properties of Polyethylene Modified AC-10 With AC-20.

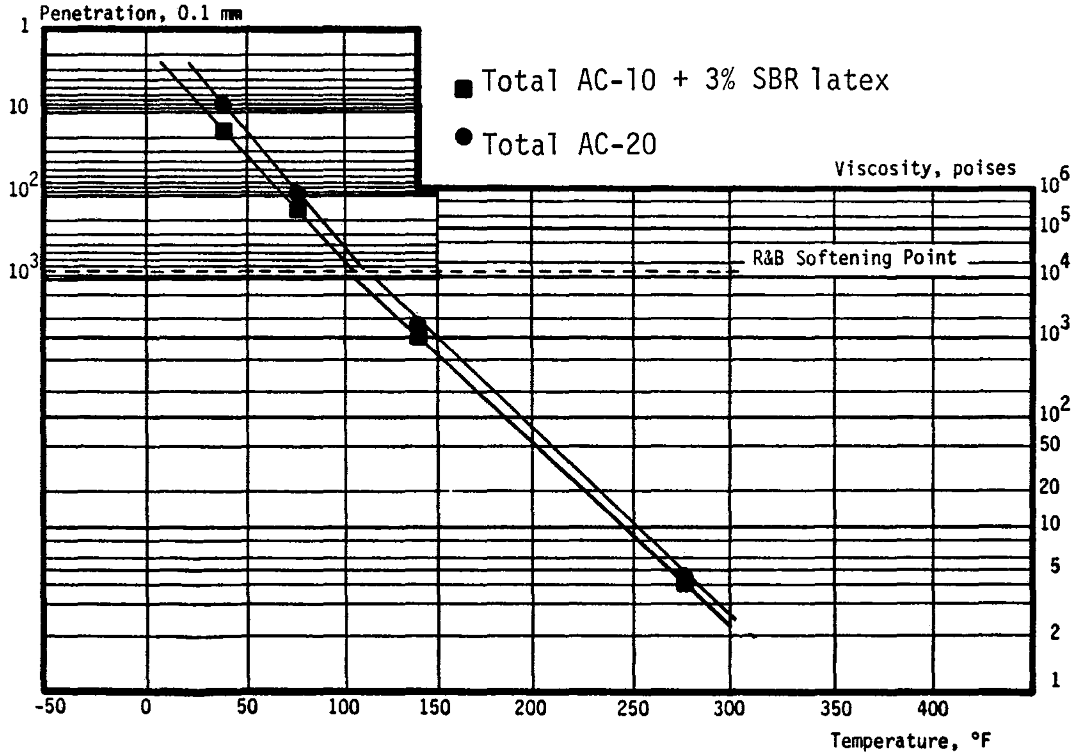

Figure 6. Rheological Properties of Latex (SBR) Modified AC-10 Compared With AC-20.

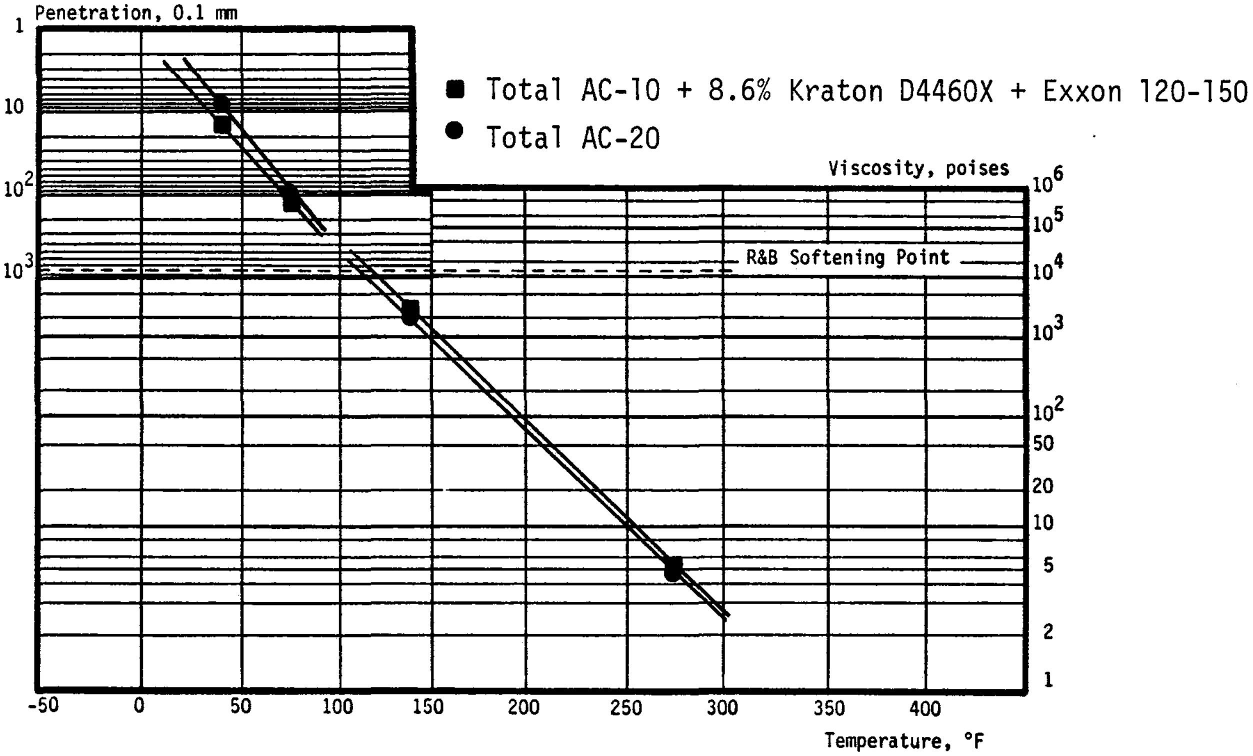

Figure 7. Rheological Properties of SBS/Extender Oil Modified AC-10 Compared With AC-20.

solely on the high stiffness of this binder at the lower temperatures, one might predict low-temperature cracking. Figure 4 shows that the addition of 2 percent Elvax 150 to AC-10 has no effect at the lower pavement service temperatures and causes only a slight increase in viscosity at the higher service temperatures. Softening point, as measured by the ring and ball method, is practically unaffected by Elvax 150. Better results may have been obtained by increasing the dosage. Figure 5 shows that 5 percent polyethylene lowers the penetration by a small amount but markedly increases the viscosity and softening point. Based on these data alone, this product offers no advantage at the lower pavement service temperatures but offers a significant advantage at the higher service temperatures. Figure 6 shows that 3 percent SBR (latex) in Total AC-10 has almost no effect at the higher service temperatures and somewhat of a softening effect at the lower service temperatures. Based on findings from previous studies (1), these consistency data suggest that the styrene butadiene rubber (SBR) may have experienced some decomposition due to heat exposure during mixing and storage. Or, a higher concentration of latex in this particular asphalt may have been required to achieve the desired results. Figure 7 and data from Table B2 indicate that, purely from a rheological standpoint, ideal results were obtained upon addition of 8.6 percent SBS/Oil (Kraton D4460X) to Total AC-10. That is, the penetration values of the AC-10 are essentially unchanged thus providing a relatively soft material at lower pavement service temperatures and the viscosity is increased two-fold which should provide resistance to permanent deformation at the higher service temperatures.

Generally, all of the additives used on this project produced a decrease in the temperature susceptibility of the Total AC-10 (Table 4). The SBS and latex increased resistance to aging by the thin film oven test; whereas, the other additives had no appreciable effects on aging (Table 4).

Ductility tests (ASTM D113) performed at 77°F and 5 cm/min revealed that only the carbon black had seriously adverse effects on ductility of the modified binders (Table B2, Appendix B). Similar revelations were obtained from force ductility tests at 39°F and 1 cm/min (Table B3). The Microfil-8 modified asphalt was prepared in the laboratory using a mechanical mixer which did not completely disintegrate all the carbon

Table 4. Calculated Values of Temperature Susceptibility and Aging Resistance from Rheological Measurements on Binders from District 1.

Calculated Value	AC-20	AC-10	AC-10 + 12.5% Microfil-8	AC-10 + 2% Elvax 150	AC-10 + 5% Polyethylene	AC-10 + 3% Latex	AC-10 + 8.6% Kraton D4460X
Temperature Susceptibility							
Penetration Index[1]	-1.5	-1.0	-0.91	-1.3	-2.0	-0.51	-0.78
Penetration Index[2]	-0.1	0.62	-0.23	-.17	1.5	0.32	1.3
Vis-Temperature Susceptibility[3]	3.52	3.53	3.06	3.39	3.23	3.37	3.54
Pen-Vis Number[4]	-0.32	-0.56	--	-0.14	0.59	-0.23	0.45
Aging Resistance (TFOT)							
Retained Pen[5]	67	70	84	67	62	79	84
Aging Index-Vis[6]	2.2	2.0	--	2.1	1.7	1.6	1.1

[1] P. I. $= (20-500A)/(1 + 50A)$, where $A = \left[\log(\text{pen}_1) - \log(\text{pen}_2)\right] / (T_1 - T_2)$, where T = C°.

[2] P. I. $= \left[30/(1 + 90\ \text{PTS})\right] - 10$, where $\text{PTS} = \left[\log 800 - \log(\text{pen } 77°\text{F})\right] / (T_{sp} - 77)$, where T_{sp} = °F.

[3] $\text{VTS} = (\log\log\eta_1 - \log\log\eta_2)/(\log T_2 - \log T_1)$, where η = viscosity in cP, T = temperature °K.

[4] $\text{PVN} = \left[(6.489 - 1.59\log P - \log\eta)/(1.050 - 0.2234\log P)\right](-1.5)$ where P = pen @ 77, η=vis @ 140° Poise.

[5] Retained Penetration = (Pen after TFOT/Original Pen) 100%.

[6] Aging Index = Viscosity at 140°F after TFOT/Original Viscosity @ 140°F.

black pellets. Polyethylene also produced a significant decrease in elongation at failure of the AC-10 but resulted in much greater tensile stress at failure in the force ductility test. Both of these products exist in asphalt as discrete particles. Overall, Kraton D4460X gave the best results from the force ductility test. Although the Ultrapave and Elvax significantly enhanced elongation at failure in the force ductility test, the energy required to produce failure test was significantly greater for the Kraton-modified material. These three products are dispersed in asphalt as a continuous matrix (supposedly).

Previous research (1,2,3,4) has shown that the effects of additives on asphalt properties are dependent on the bitumen's chemical composition and the equilibrium of its colloidal structure. Therefore, one should always test the proposed additives with the asphalt(s) selected for use on a given project. Test results should be used to select the optimum additive dosage and evaluate the economic benefits of the additive in the particular environment (climate, traffic and substrate).

Laboratory Tests on Aggregate. Crushed limestone and field sand were combined to produce the paving mixture. The sand was silicious, subangular in shape with smooth particle surfaces and nonporous. Aggregate and mixture design data are shown on Table B1. The gradation measured from pavement cores is given in Figure B2.

Laboratory Tests on Mixtures. Samples of each test mixture were obtained from a selected haul unit. Eighteen 4-inch diameter and 2-inch high cylindrical specimens of each mixture were molded using the Texas gyratory compactor and the specified procedures (5). Molding temperature was controlled at approximately 250°F. The viscosities of the different binders at this temperature had a significant effect upon the air voids of the molded specimens (Figure 8). Microfil-8 and polyethylene modified binders exhibited the highest viscosities at 250°F and also produced the highest air voids. The relatively high void content of the Control-A specimens may have resulted from inadequate temperature control as these were the first set molded and the laboratory routine had not been well established.

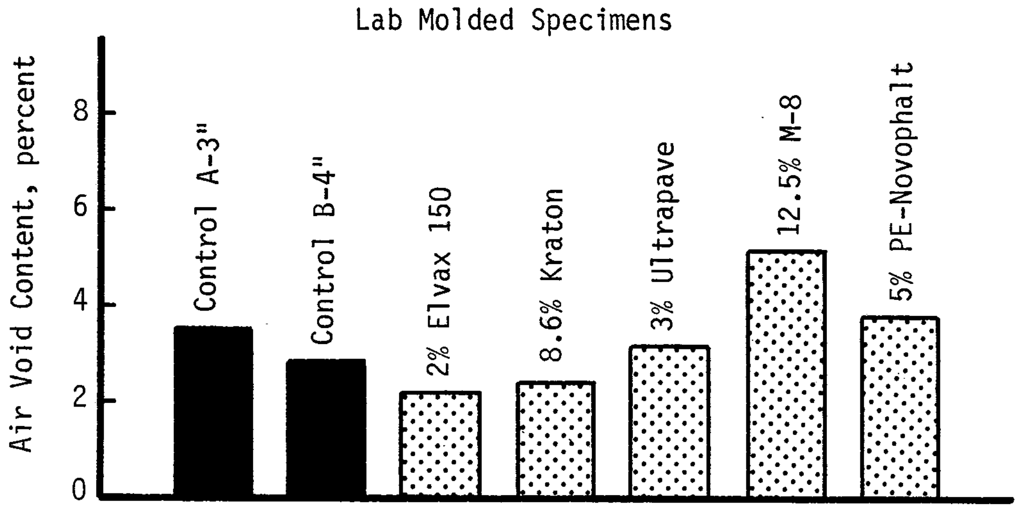

Figure 8. Average Air Void Content of 4-inch Diameter, 2-inch High Laboratory Molded Specimens from District 1.

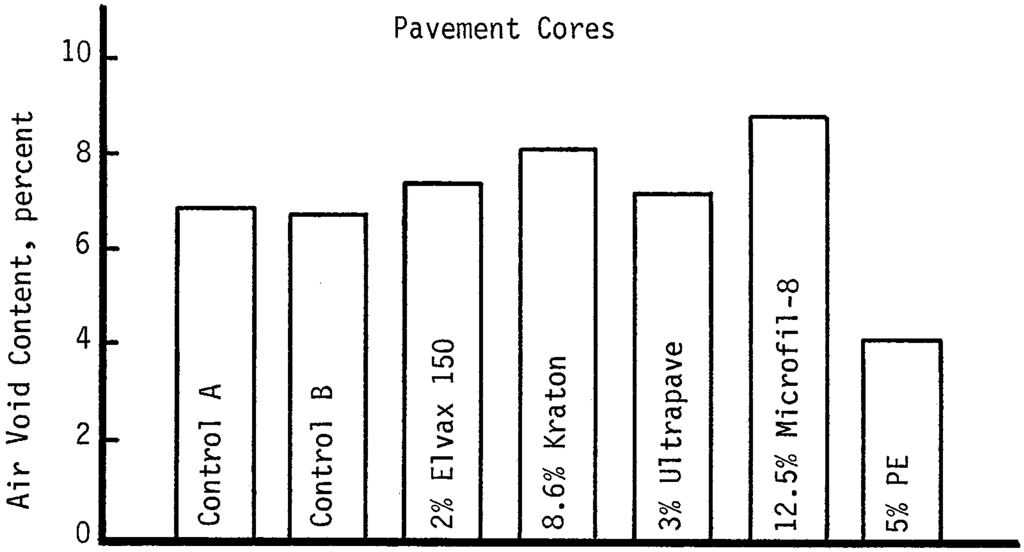

Figure 9. Average Air Void Content of 4-inch Diameter Pavement Cores from District 1.

Pavement cores were obtained by the Department within two weeks after construction and before exposure to significant traffic. Air void contents of the cores (Figure 9) are approximately twice those of the laboratory-molded specimens and exhibit significantly less variation. Microfil-8 again produced the highest void content. The comparatively low air voids in the polyethylene modified cores is due to the fact that plant temperature for this mix was increased to 350°F. For all others, the plant temperature was approximately 320°F.

These field-mixed/laboratory molded specimens were characterized using the test program described in Figure 2. Pavement cores were also tested in accordance with Figure 2, except the mixture aging portion of the study was not performed. Detailed test results are presented in Appendix B. Selected test results are discussed in the following paragraphs.

Resilient modulus (ASTM D4123-82) of laboratory-molded mixtures and pavement cores was measured over a range of temperatures from -13 to 104°F using the Mark III Device developed by Schmidt (Tables B4 and B7, respectively). Figure 10 shows that there is little difference in resilient modulus of the mixtures below 50°F and, further, that the latex and SBS/oil-modified mixtures exhibited the lowest values at all temperatures. Air void content, which varied substantially, doubtless influenced the results of these tests.

Hveem stability of the field-mixed/laboratory-molded specimens shows an unusually large degree of variation (Figure 11). Previous controlled laboratory tests using these additives and other studies have shown that variations in binder properties alone do not greatly affect Hveem stability (1). This is because Hveem stability is largely dependent upon interparticle friction of the aggregate and not particularly sensitive to changes in rheological properties of the binder. Hveem stability is, however, quite sensitive to binder content. These field (plant) mixtures exhibited some variation in aggregate properties and gradation as well as binder content. Binder content is difficult to accurately measure by standard extraction methods when these types of additives are used (1,2). Hveem stabilities of the pavement cores are significantly lower than the laboratory-molded specimens and exhibit much less variation (Table B7). This is likely related to the higher air void content of the pavement

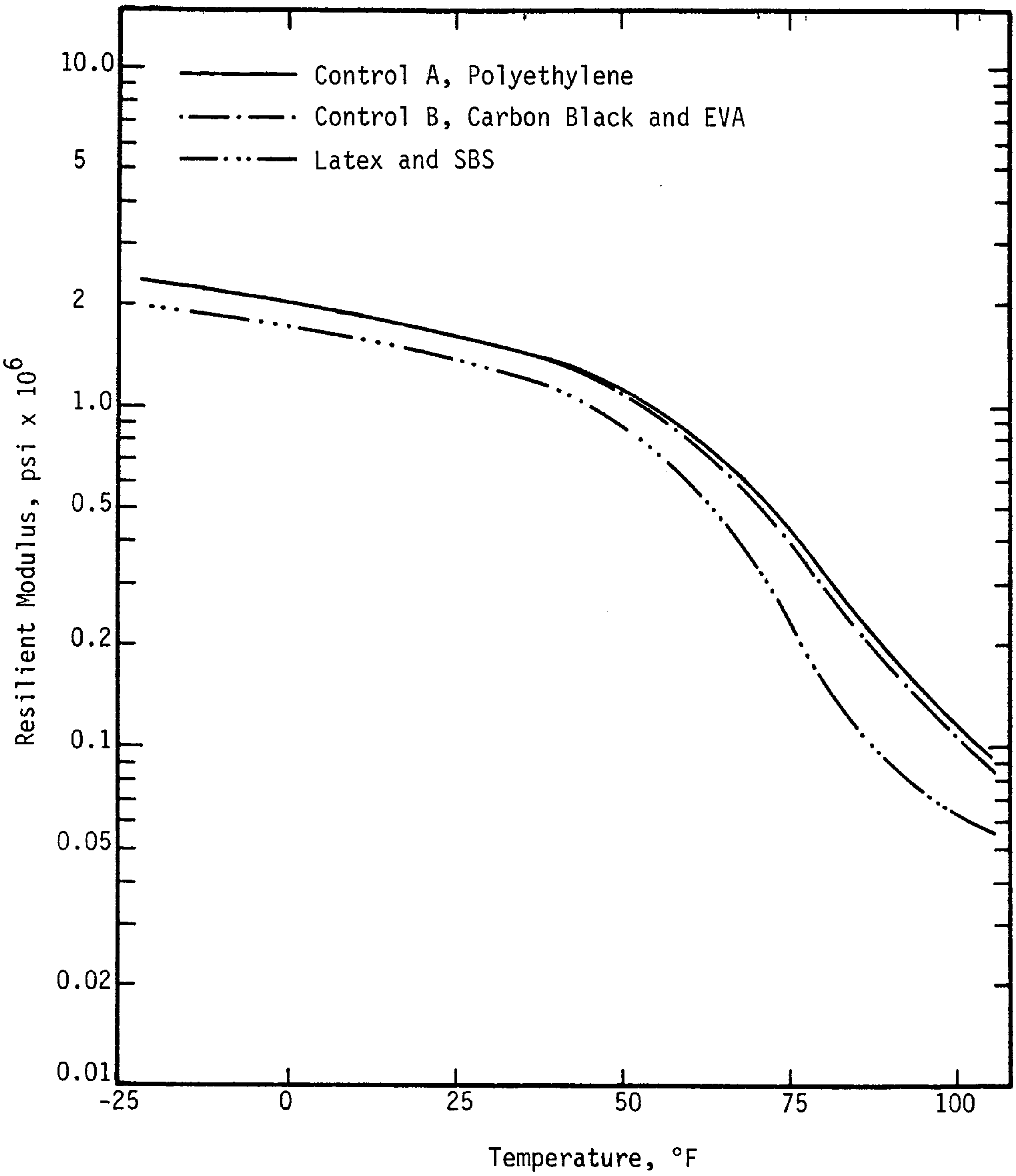

Figure 10. Resilient Modulus as a Function of Temperature for Field Mixed-Lab Molded Specimens from District 1.

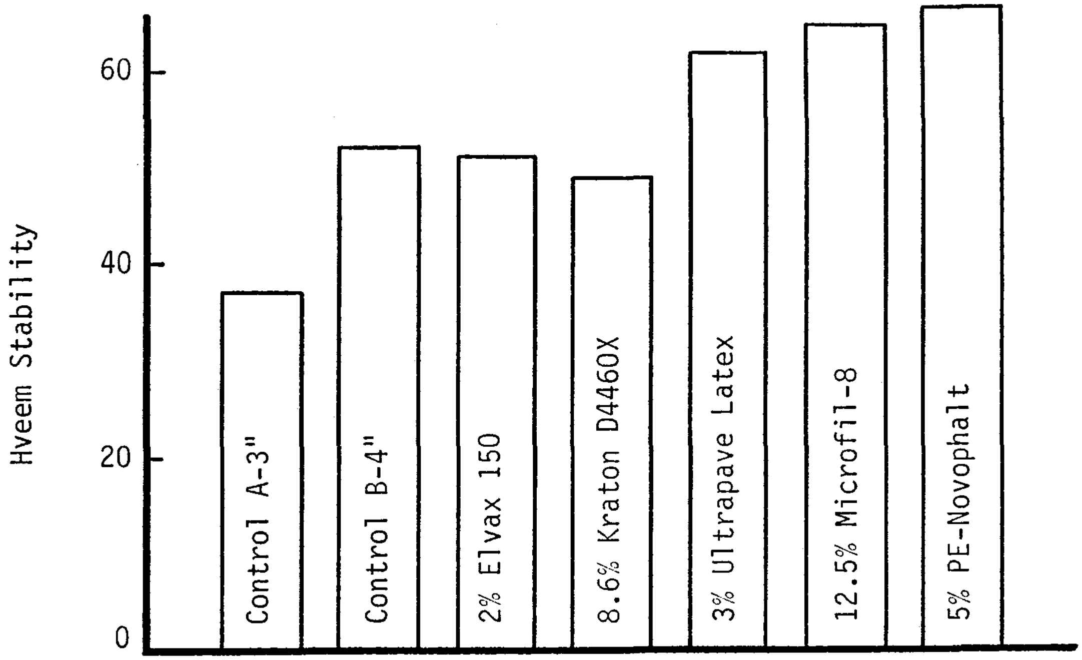

Figure 11. Hveem Stability of Field Mixed-Laboratory Molded Test Specimens from District 1.

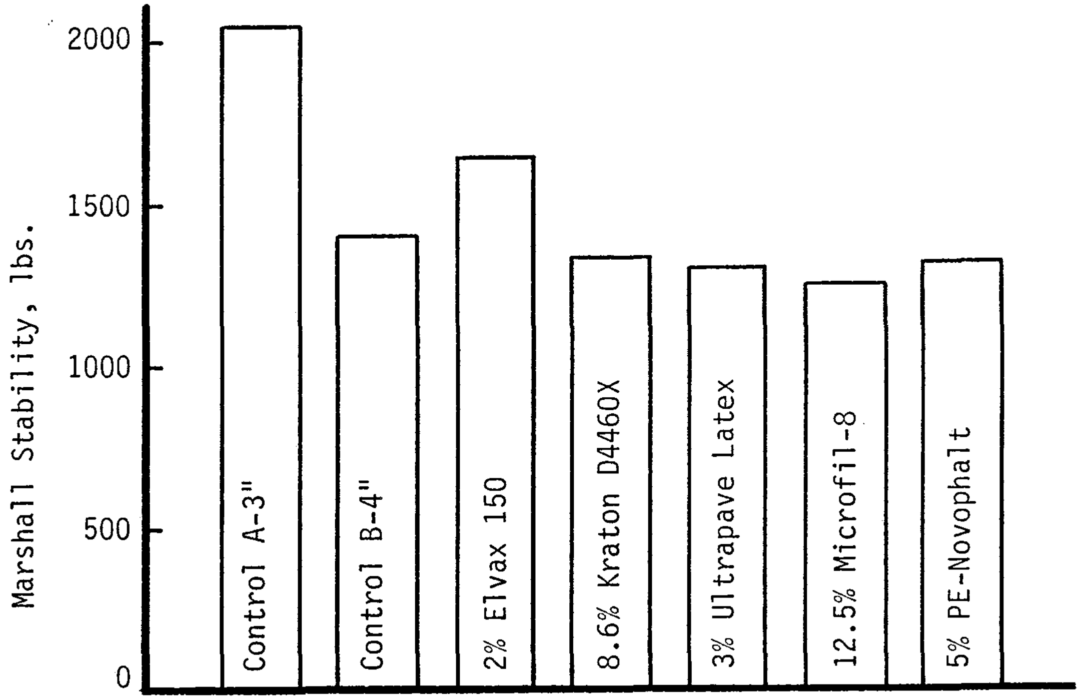

Figure 12. Marshall Stability of Field Mixed-Laboratory Molded Test Specimens from District 1. (Specimens molded using Texas gyratory method not Marshall method).

cores. The polyethylene-modified (Novophalt) mixture gave the highest Hveem stability in both types of samples.

Marshall stability was affected more by air void content than by the additives used in this test program. Marshall stability of the Control-A mixture for the field-mixed/laboratory-compacted specimens seems to be an outlier (Figure 12). There are no significant differences in the other six mixture types. Table B7, illustrates the close relationship between Marshall stability and air void content of the pavement cores. Generally, Marshall flow in this mixture was affected little by the additives.

Indirect tension tests were conducted at 77°F and 2 inches/minute on field-mixed-laboratory-molded specimens (Table 5). When compared to the control mixtures, the results showed a decrease in tensile strength (Figure 13) for the Elvax, Kraton and Ultrapave modified mixtures and no change in the Microfil and Novophalt modified mixtures. Specimen elongation at failure (Figure 14), however, exhibited a notable increase for the Kraton and Ultrapave modified mixtures. It should be borne in mind that the additive modified mixtures contained AC-10 and the control mixtures contained AC-20 and further that the tensile properties of asphalt concrete is quite sensitive to consistency of the binder. Similar results were obtained from the pavement core samples except the Microfil specimens exhibited lower tensile strength and greater strain and failure (Table B8). Presently, the significance of these data is difficult to interpret. The final analysis will depend upon performance of the field test pavements.

Indirect tension tests were performed on a second set of specimens after exposure to moisture. The modified accelerated Lottman (6) moisture treatment consisted of vacuum-saturating the specimens using a vacuum of 4-inches of mercury below atmospheric pressure at room temperature, wrapping them in cellophane to retain the moisture and freezing them at 0°F for 15 hours followed by a 24-hour period at 140°F. The specimens were then brought to 77°F and tested in accordance with the program depicted in Figure 2. Test results are given in Table B5 (laboratory molded) and Table B8 (pavement cores). Data from laboratory molded specimens is plotted in Figure 15. Normally, samples used in moisture testing are compacted to approximately 7 percent air voids; however, in this case, time did not permit development of specialized compaction

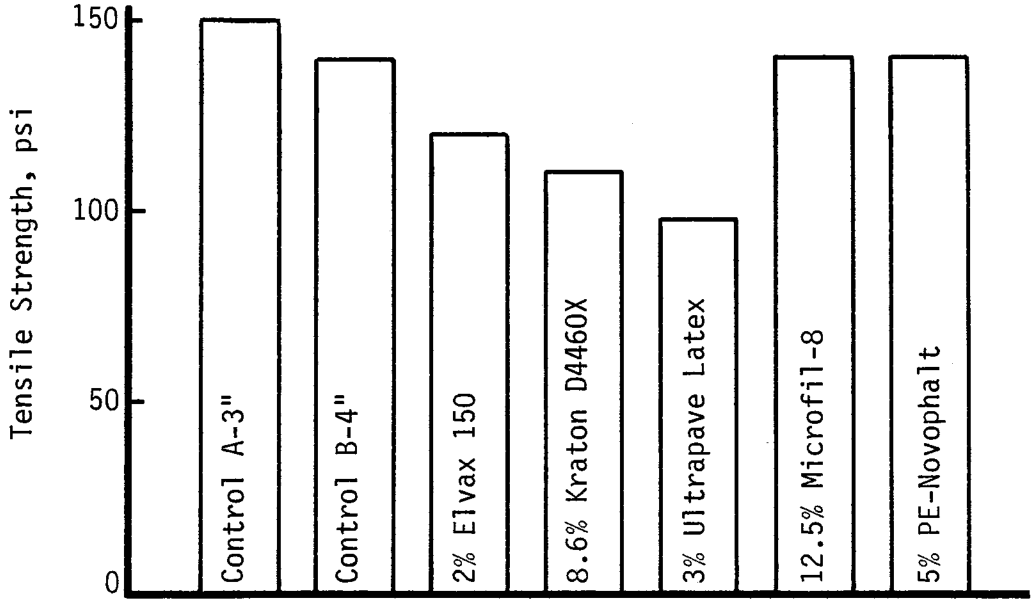

Figure 13. Tensile Strength of Field Mixed-Lab Compacted Mixtures from Indirect Tension Tests at 77°F and 2 in/min.

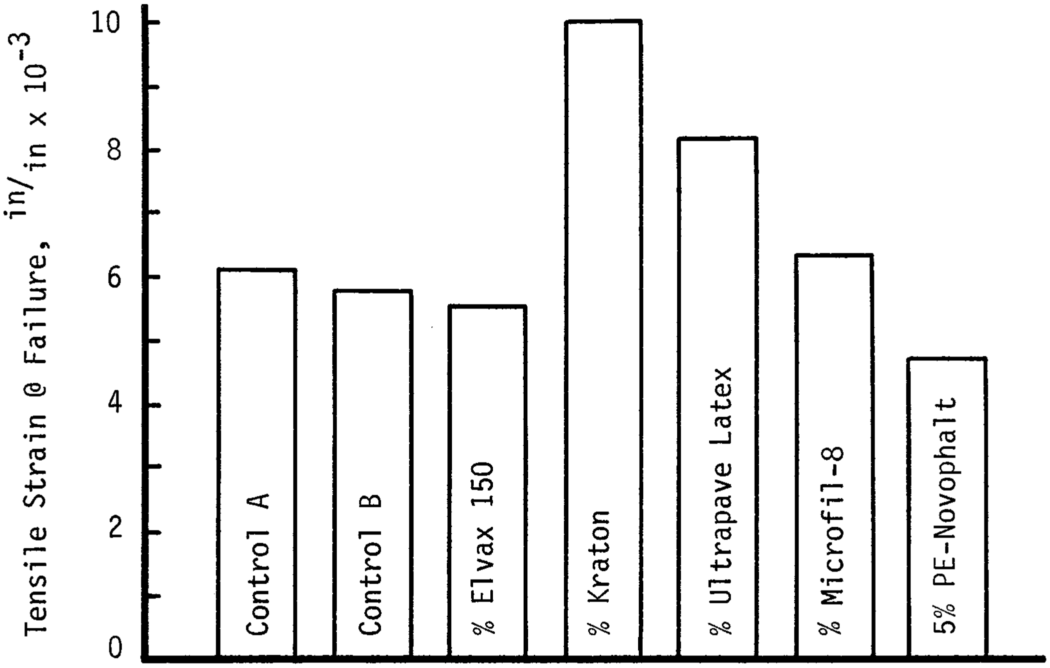

Figure 14. Elongation at Failure for Field Mixed-Laboratory Molded Specimens from District 1 during Indirect Tension Test at 77°F and 2in/min.

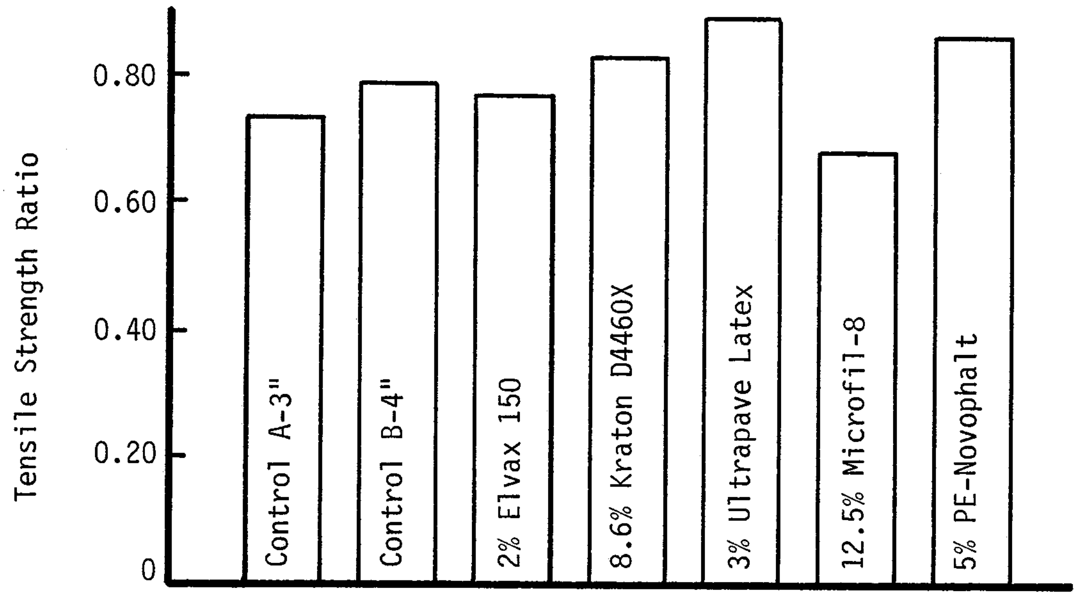

Figure 15. Tensile Strength Ratios for Field Mixed Lab Compacted Specimens after Lottman Freeze-Thaw Moisture Treatment, District 1.

procedures; therefore, these samples were compacted using standard procedures and the resulting void contents were approximately 3 percent.

The pavement core samples, on the other hand, contained, on the average, about 7 percent voids. An equipment malfunction delayed their testing. The cores were, therefore, left in a 77°F water bath for 4 days after the Lottman procedure prior to the indirect tension test which resulted in an apparent "healing" of the specimens. Tensile strength ratios were calculated by dividing measurements after moisture exposure by those obtained on unexposed specimens. All mixtures including the control contained 0.5 percent Pave Bond LP by weight of binder as an antistrip additive. Test results on both laboratory-molded specimens and pavement cores indicated the polymer additives and carbon black had little effect on moisture resistance. Ultrapave and Novophalt in AC-10 consistently exhibited a slight increase in resistance to moisture damage in comparison to the AC-20 control specimens. It should be pointed out, however, that the softer asphalt will sometimes contribute to improved resistance to moisture damage particularly when mixed at a higher temperature (1,2) as in the case for Novophalt.

Indirect tension tests were performed on a third set of specimens after exposure to heat aging (Table B6). Laboratory-molded specimens only were subjected to 140°F in air for a period of four weeks prior to the indirect tension test. Ratios obtained by dividing tensile strengths after aging by those before aging are compared in Figure 16. Retained flexibility, obtained by dividing average tensile strain at failure after aging by that before aging, is depicted in Figure 17. Generally, the additives appeared to have little effect on mixture aging by this procedure. The latex-modified mixture exhibited the least resistance to aging as manifested by the largest increase in tensile strength and the smallest retained flexibility. Kraton, Novophalt and Elvax resisted aging better than the control mixtures in that they exhibited modest increase in tensile strength but retained more flexibility. Results from resilient modulus tests after aging (Table B6) showed considerable scatter for unexplainable reasons.

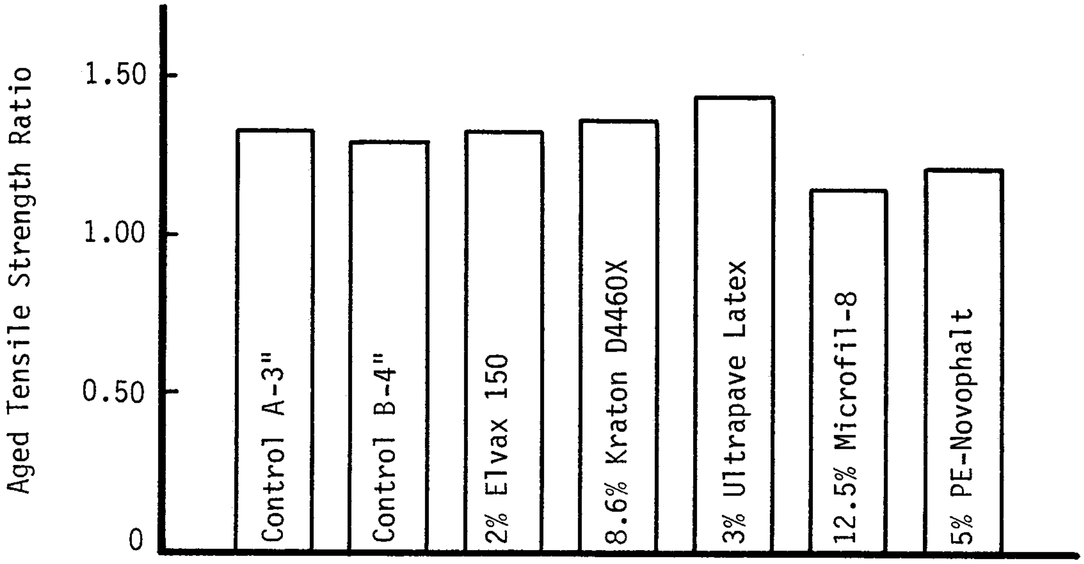

Figure 16. Ratio of Tensile Strength for Field Mixed-Lab Molded Specimens from District 1 after Aging for 4 Weeks at 140°F (from Indirect Tension Tests at 77°F and 2^{in}/min).

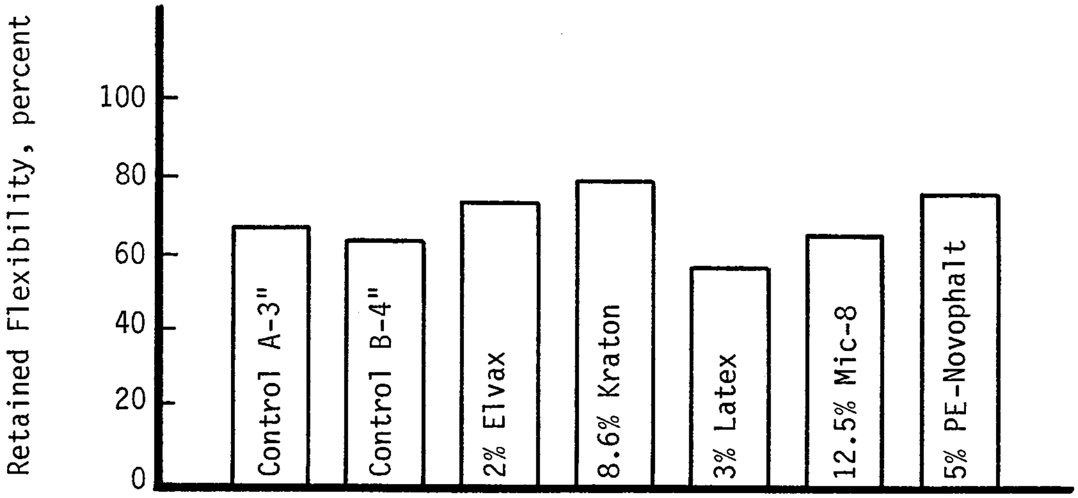

Figure 17. Retained Flexibility* of Field Mixed-Lab Molded Specimens from District 1 after Aging 4 Weeks at 140°F (from Indirect Tension Tests).

*Tensile strain at failure after aging ÷ tensile strain at failure before aging

Post-Construction Performance Evaluation

Visual inspection of the test pavements in August 1987 indicated equivalent performance by all the test pavements after 10 months in service. All pavements are in excellent condition. There were no visible signs of distress in any of the test sections.

DISTRICT 21

General

In August 1986, during construction of Project MA-F-93(40) on US 87/77 in Cameron County, a 2.6 mile segment of the project was used to evaluate four asphalt additives. The additives included ethylene vinyl acetate (EVA), styrene butadiene rubber (SBR) latex and styrene butadiene block copolymer (SBS) and carbon black. The work consisted of new construction. Two 1/4-mile test pavements 3-inches thick containing each additive and a control section with no additive were built. In addition, one 1/4-mile control section 4-inches thick was installed. All test pavements and control sections were installed in the southbound travel lane of the 4-lane divided facility. A map showing the exact location of each test pavement is provided in Figure C1, Appendix C.

Incorporation of Asphalt Additives

All additives were preblended with AC-10 from Texas Fuel and Asphalt (TFA) prior to arrival at the plant site. EVA, SBR and SBS were blended with the asphalt at the TFA plant in Corpus Christi and shipped to San Benito. Blending of 6000 gallons of each material was accomplished in a 50,000 gallon tank equipped with both an air "spinning" system for agitation and a large gear pump for recirculation and mixing. Heating was accomplished by a combination of hot-oil coils and direct-flame flue heaters. Sixty 44 pound bags of Polybilt 102 (EVA) were added to 49,938 pounds of AC-10 on August 15, 1986, and blended 4 hours per day at 330°F for the next three days, then used at San Benito on the fourth day. Polybilt 102 was added at 5 percent by weight of AC-10. Fifty pound bags of Kraton D4460X rubber were added to the asphalt at 340°F and agitated for about 6.5 hours on August 18, 1986, then maintained at 350°F until used on August 19. The blend was strained through a screen to check for non-dispersed material. Kraton D4460X, a 50-50 mixture of SBS rubber and extender oil, was added at 12 weight percent. Goodyear Ultrapave Latex was injected into TFA AC-10 at 385°F and blended for an unspecified period. Ultrapave Latex was added at 3 weight percent.

Cabot Microfil-8 (carbon black/oil) was blended at 10 weight percent with TFA AC-10 by Mono-Chem in Atlanta, Texas. Six thousand gallons of asphalt arrived at Mono-Chem at 365°F. A total of 1314 gallons was pumped into a Cowles mixer. Six hundred seventy-three pounds of surfactant were added and mixed with the asphalt. Then 3,362 pounds of Microfil-8 was added which filled the mixer to capacity. After mixing for 4 hours, the mixture was pumped back into the tanker trailer and the entire load was circulated for about 30 minutes. A second 1314 gallons of material was transferred into the mixer. Two hundred twenty-five pounds of surfactant were added and mixed for about 2 hours. This batch was pumped back into the trailer and circulated for about 30 minutes to effectively blend with the entire truckload. The blend appeared to be very smooth and homogeneous with no evidence of undispersed carbon black pellets. The load of modified asphalt left Mono-Chem at 355°F.

In addition to the additives discussed above, all mixtures including the control mixtures, contained one percent hydrated lime added to decrease moisture susceptibility of the mixture. Lime slurry was added to the aggregate on the cold feed belt at the plant.

Construction of Test Pavements

A summary of the construction procedures is given in Table 5. The work consisted of new construction involving upgrading US 77/83 from SH100 to FM511 to a 4-lane divided expressway. The structure consisted of twelve inches of subgrade treated with 3 percent lime, 12-inches of flexible base, 4-inches of black base and 3-inches of Item 340, Type D surface course. The additives were incorporated into the surface course only which was placed in one lift. This field trial is located on a tangent section fairly level alluvial plain. A summary of the test pavements is given in Table 1. Mixture design data is presented in Table C1 and C2, Appendix C.

Plant and paving operations were conducted by Ballenger Construction Company. Two different drum mix plants at the same location near San Benito, Texas, were used to produce the paving mixtures. Both plants were made by Barber-Greene. One was a Model DM 60 with 165 tons per hour capacity; the other was a Model DM55 with 115 tons per hour capacity. Control mixtures were typically produced at 280°F; whereas, the additive-modified mixtures were typically produced at about 315°F. The higher

Table 5. Construction Notes from District 21 Test Pavements.

Additive	Additive Dosage, wt. percent	Source and Grade of Asphalt	Date Pavement Placed	Plant Used, Capacity	Method of Incorporating Asphalt Additive*	Comments
Control-1 3-inch	None	TFA AC-20	8/18/86	115 tph	N.A.	Placed in one lift as all additive tests. Mix temperature ∿280°F.
EVA Polybilt-102	5%	TFA AC-10	8/18/86	165 tph	Preblended by Texas Fuel & Asphalt (TFA) in Corpus Christi, Tx. Mixed for about 12 hrs at 330°F.	Mix temperature ∿315°F.
SBR Ultrapave Latex	3%	TFA AC-10	8/18/86	115 tph	Preblended by TFA. Latex mixed with asphalt at 385°F.	Sticky mix. Clung to haul units, increased drag on paving machine. Mix temperature ∿315°F.
Carbon Black Microfil-8	10%	TFA AC-10	8/19/86	165 tph	Preblended by Mono-Chem in Atlanta, Tx. Mixed with asphalt to form a concentrate which was then blended with remaining asphalt. Used surfactant to keep carbon black in suspension.	Mix color very black. Mix temperature ∿315°F. Weight percent of binder increased to accommodate higher specific gravity.
SBS/Oil Kraton D 4460X	12%	TFA AC-10	8/19/86	115 tph	Preblended by TFA. Mixed for 6.5 hrs at 340°F. Extender oil improves "solubility" of SBS in asphalt.	Mix color brown. Mix temperature ∿315°F.
Control-2 4-inch	None	TFA AC-20	8/14/86		N.A.	Placed in 2 lifts. Mix temperature ∿280°F.

*All mixtures contained 1 percent hydrated lime added as a slurry on the cold feed belt.

temperatures were used to aid coating of the aggregate in the plant and compacting the paving mixture as the modified asphalts have comparatively high viscosities at normal mixing/compaction temperatures. All 3-inch test pavements were placed in a single lift using a Barber-Greene Model B6260 paving machine. Breakdown rolling was accomplished by a 13.2 ton vibratory steel-wheel roller. Additional compaction was achieved using a 10 ton steel-wheel tandem roller and a 25 ton pneumatic roller.

The binder content of all mixtures except the carbon black modified mixture was 5.2 percent by total weight of mixture. When carbon black was used, the binder content was increased to 5.4 weight percent to account for the higher specific gravity (1.7) of the carbon black. This yielded equivalent volume percentages for all binders.

During placement, there were no additive-associated problems. In order to enhance statistical analysis of anticipated field performance data, two 1/4-mile test pavements containing each additive were placed instead of one 1/2-mile pavement. This procedure will allow researchers to determine whether differences between additive test pavements are greater than differences between similar test pavements. No significant delays were caused by this procedure since two asphalt plants were available which were alternately operated during construction.

Latex-modified asphalt is, by comparison to unmodified asphalt, very sticky. As a result, about 500 to 1000 pounds of latex-modified mixture clung to the dump truck beds when they attempted to unload into the hopper of the paving machine. To remove the mixture, the haul units pulled forward about 50 feet and jarred it loose. The mix was picked up using a front-end loader and transported to the paving machine. Furthermore, comments by the paving machine operator indicated that the latex-modified mixture caused significantly more drag than the other mixtures.

Construction Evaluations

Samples of asphalt binders, aggregates, and paving mixtures, including gyratory compacted specimens as well as pavement cores, were obtained and tested in the laboratory. Paving mixtures were tested in accordance with Figure 2. Results from these tests are tabulated in Appendix C. Test pavement performance was evaluated after 12 months of service.

Laboratory Tests on Binders. Results from the binder tests are summarized in Table C3. Figures 18 through 21 compare rheological properties of the modified TFA asphalt with the unmodified material. Figure 18 shows that the latex-modified AC-10 has rheological properties quite similar to the unmodified AC-20 except at 275°F where the modified material exhibits a somewhat higher viscosity. The SBS modified AC-10 and the carbon black-modified AC-10 exhibited penetration values similar to the unmodified AC-10 but gave viscosity values substantially higher than those of the AC-20 (Figures 19 and 20). The EVA did not appreciably affect the properties of the AC-10 at the lower temperatures but significantly increased the ring and ball softening point and the viscosity at temperatures above 170°F.

Each of these additives demonstrates the ability to lower the temperature susceptibility of the modified binders (Table 6). This is desirable in that the softer material should resist cracking at lower temperatures and the higher viscosity at higher temperatures should resist plastic deformation. In addition, SBS, latex and EVA exhibited a slight improvement in resistance to heat aging in the thin film oven test. Carbon black showed no effect on aging.

All of the additives increased the softening point of the AC-10 but EVA (Polybilt) and SBS (Kraton) caused substantial increases.

Ductility values measured after the thin film oven test showed that the carbon black (Microfil) had none of the adverse effects shown by results from District 1 and previous data (1). These favorable results may be due to the uniform dispersion produced by preblending the carbon black and use of a surfactant to keep the carbon black in suspension. EVA (Polybilt 102) produced a substantial reduction in ductility at 77°F (Table C3).

Force ductility test results at 39.2°F (4°C) show that EVA, SBS/Oil and SBR improve the quality of the asphalt (Table C4). These products produced a marked increase in strain at failure and, in turn, an increase in area under the stress-strain curve (which is analogous to energy required to cause failure). This should be indicative of improved flexibility or resistance to low temperature cracking. Initial slope of the stress-strain curve is analogous to initial tangent modulus (i.e., stiffness at low strain levels). The decrease in initial slope of the

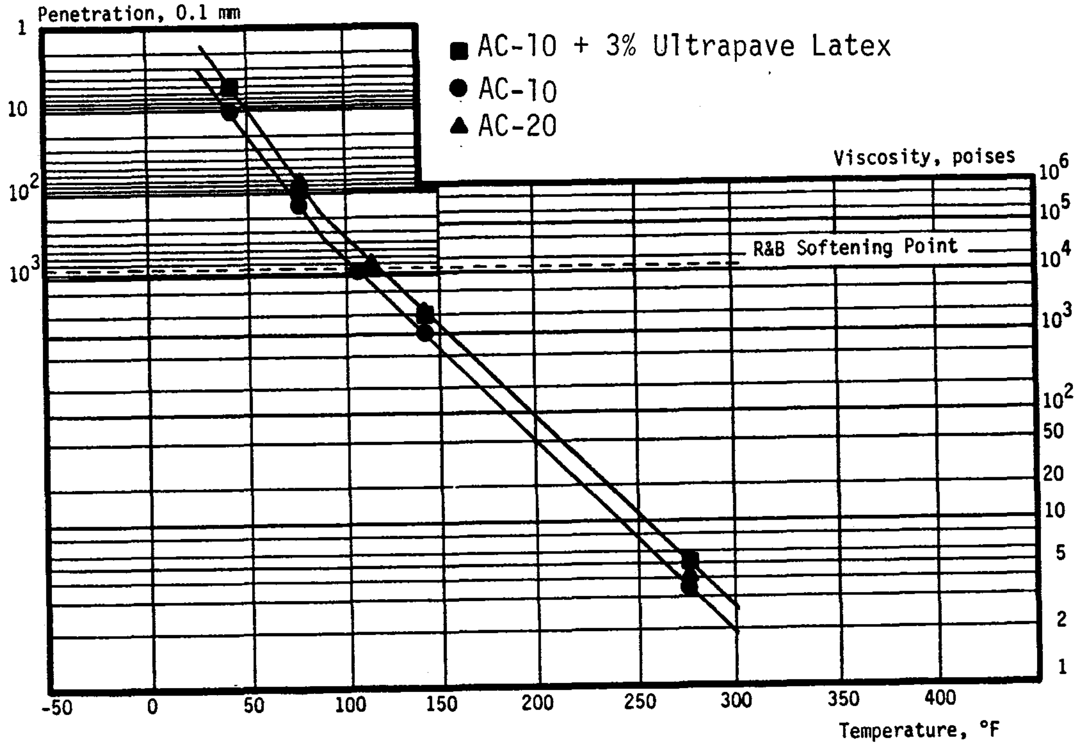

Figure 18. Rheological Properties of TFA AC-10 + 3% Latex Compared With Unmodified AC-10 and AC-20 from District 21.

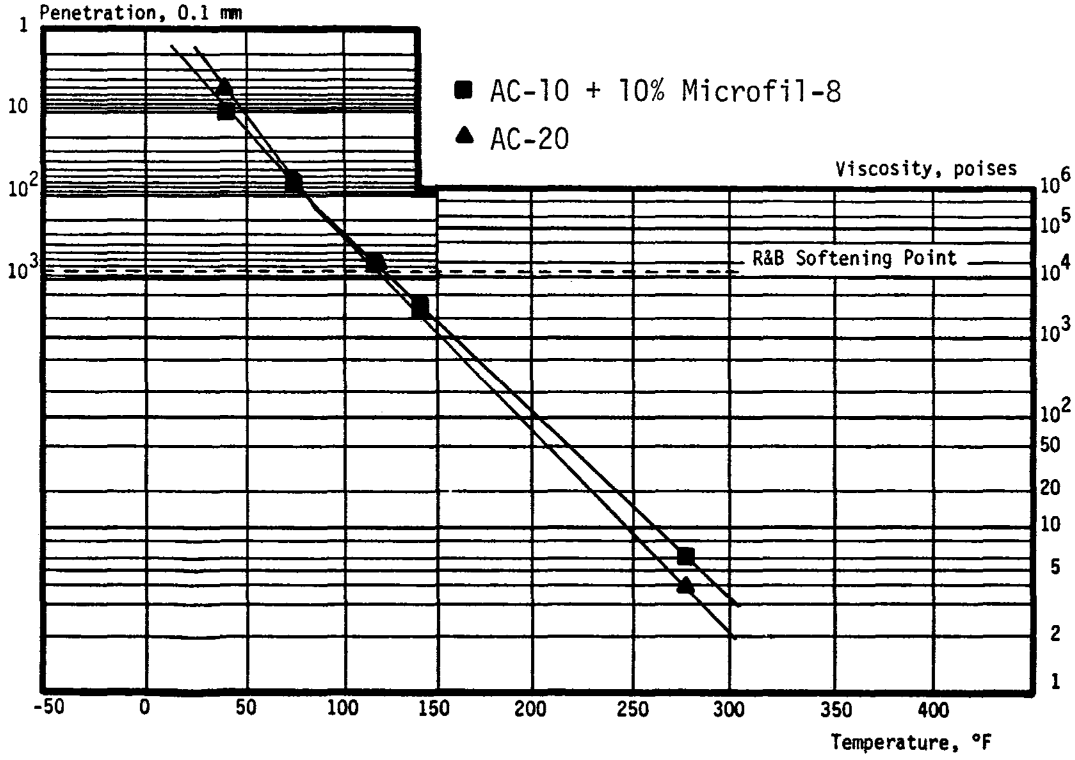

Figure 19. Rheological Properties of TFA AC-10 + Microfil-8 Compared With Unomodified TFA AC-20 from District 21.

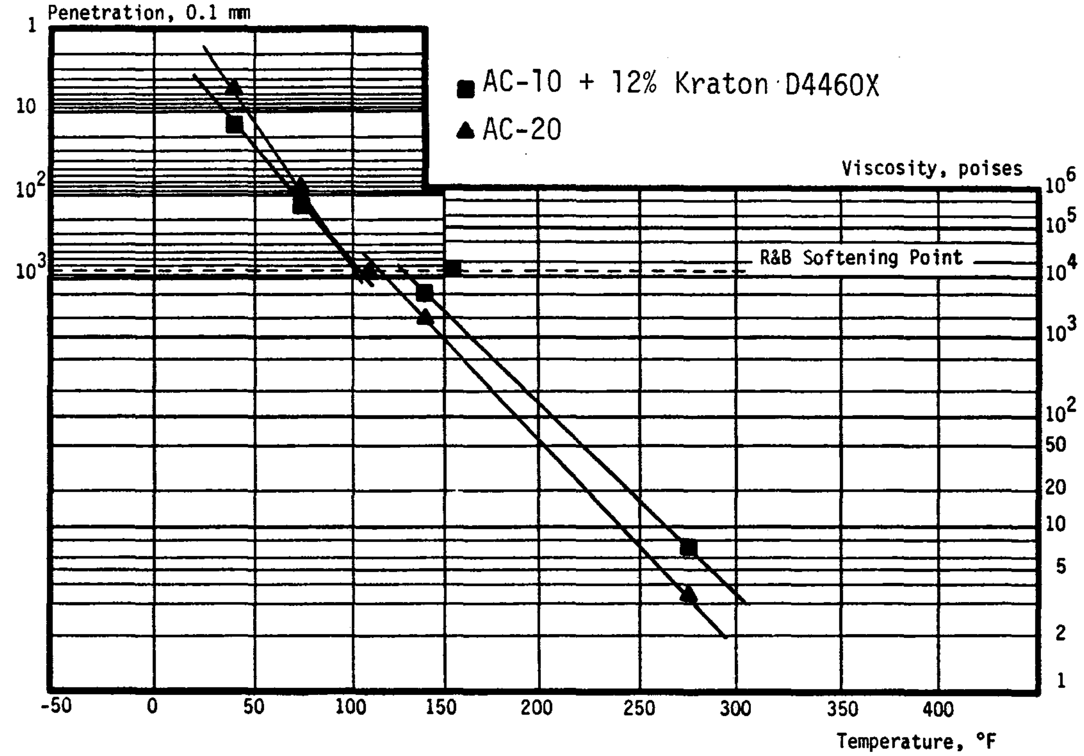

Figure 20. Rheological Properties of TFA AC-10 + Kraton Compared with Unmodified TFA AC-20 from District 21.

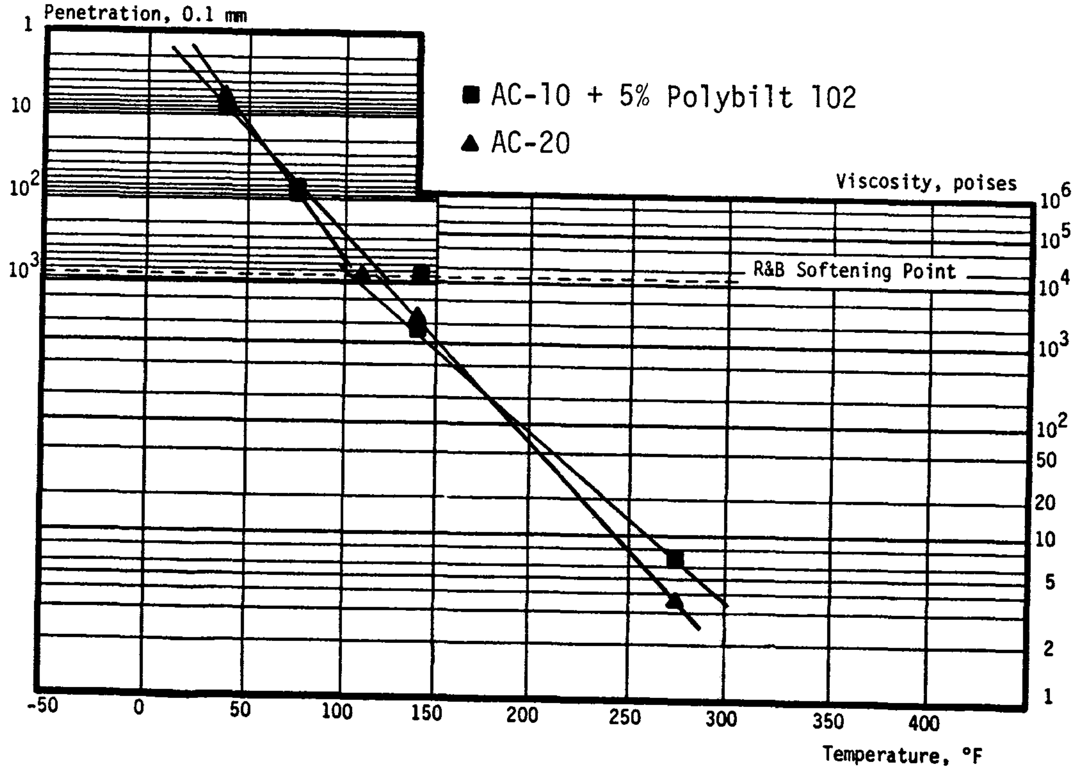

Figure 21. Rheological Properties of TFA AC-10 + Polybilt 102 Compared With Unmodified TFA AC-20 from District 21.

Table 6. Calculated Values of Temperature Susceptibility and Aging Resistance from Rheological Measurements on Binders from District 21.

Calculated Value	AC-20	AC-10	AC-10 + Latex	AC-10 + Carbon Black	AC-10 + Kraton	AC-10 + Polybilt
Temperature Susceptibility						
Penetration Index[1]	-2.0	-1.6	-2.4	-0.83	-0.07	-1.7
Penetration Index[2]	-0.51	-0.45	-0.42	-0.11	4.6	2.1
Vis-Temp. Susceptibility[3]	3.73	3.58	3.57	3.47	3.55	3.15
Pen-Vis Number[4]	-0.48	-0.16	-0.14	-0.08	1.13	-0.85
Aging Resistance (TFOT)						
Retained Pen[5]	66	62	72	62	79	79
Aging Index-Vis[6]	2.2	2.1	1.7	2.1	1.5	1.8

[1] P. I. = $(20-500A)/(1 + 50A)$, where $A = \left[\log(\text{pen}_1) - \log(\text{pen}_2)\right] / (T_1 - T_2)$, where T = C°.

[2] P. I. = $\left[30/(1 + 90\ \text{PTS})\right] - 10$, where $\text{PTS} = \left[\log 800 - \log(\text{pen } 77°\text{F})\right] / (T_{sp} - 77)$, where TSP = °F.

[3] VTS = $(\log\log \eta_1 - \log\log \eta_2)/(\log T_2 - \log T_1)$, where η = viscosity in cP, T = temperature°K.

[4] PVN = $\left[(6.489 - 1.59 \log P - \log \eta)/(1.050 - 0.2234 \log P)\right] (-1.5)$, where P = pen @ 77, η = vis @ 140° in poise.

[5] Retained Penetration = (Pen after TFOT/Original Pen) 100%.

[6] Aging Index = Viscosity at 140°F after TFOT/Original Pen 100%.

stress-strain curve imparted by EVA, SBS/Oil and SBR also indicates increased binder flexibility at low service temperatures.

Laboratory Tests on Aggregate. A blend of 55 percent crushed gravel, 25 percent crusher fines (from gravel) and 20 percent field sand were used to produce the surface mixtures. Crushing the gravel yielded both subrounded and angular-shaped particles with both rough and smooth surfaces. Most of the material was nonporous but some porous material was present in the minus number 4 sieve sizes. The resulting gradation of the fine-graded surface course, as measured from core samples, is given in Figure C2.

Laboratory Tests on Mixtures. Samples of each test mixture were obtained from selected haul units and used to prepare eighteen 4-inch diameter and 2-inch high cylindrical test specimens. Specimens were compacted in a field laboratory using the Texas gyratory shear device (5). The higher viscosity of the modified binders is reflected in the higher air void content of both the laboratory-compacted specimens and the pavement cores containing those materials (Figures 22 and 23). It should be pointed out that the void content will affect the engineering properties of these mixtures. Ideally, all mixtures should be compacted to the same void content to provide valid comparisons of mechanical properties but this was not practical here; instead, the controlling factor was the compaction procedure.

Resilient modulus tests (ASTM D4123-82) were performed at a range of temperatures from -17 to 105°F (Tables C5 and C8). As previously shown by the District 1 mixture data, there is little difference in resilient modulus of the mixtures below 35°F, and the latex and SBS/Oil mixtures exhibited the lowest values at temperatures above 60°F (Figure 24).

Hveem stability (Figure 25) was hardly affected by the additives in this mixture. Tables C5 and C8 show the laboratory-molded specimens had considerably higher Hveem stabilities than the pavement cores. This is likely due to the lower air void content of the molded specimens.

The Marshall test was performed on the gyratory-compacted specimens (Figure 26); Kraton and Microfil exhibited the highest stabilities. Similar tests on the pavement cores did not yield similar results (Table

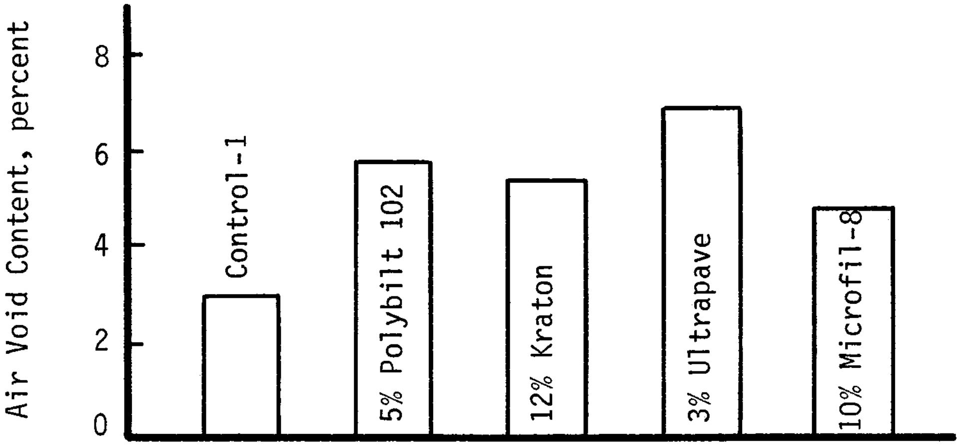

Figure 22. Average Air Void Content of 4-inch Diameter, 2-inch High Laboratory Molded Specimens from District 21.

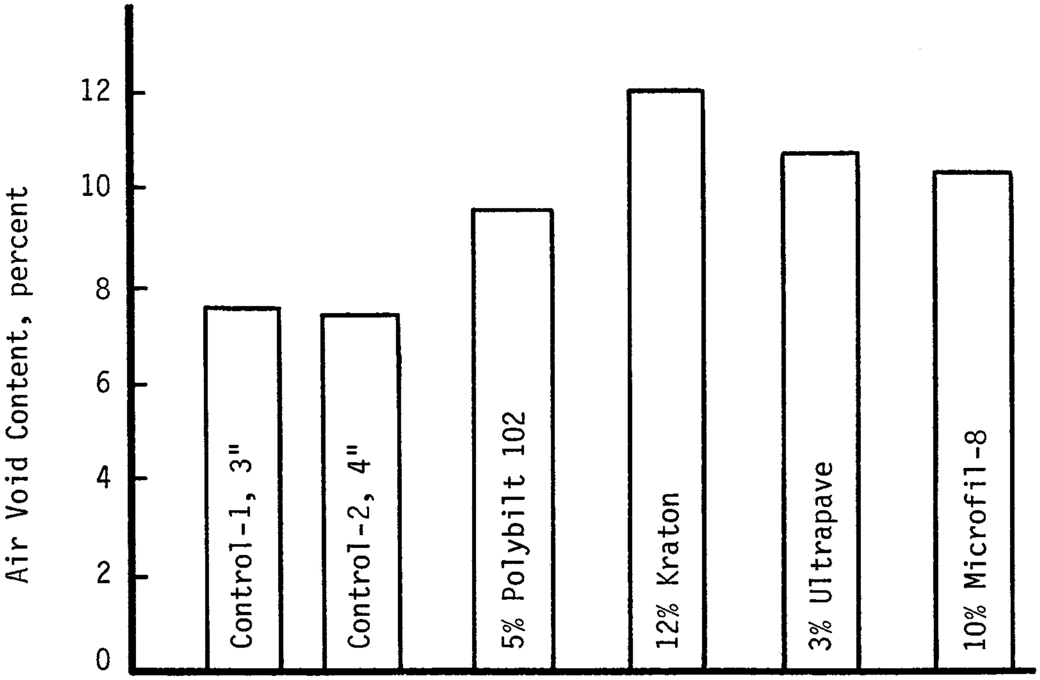

Figure 23. Average Air Void Content of 4-inch Diameter Pavement Cores from District 21.

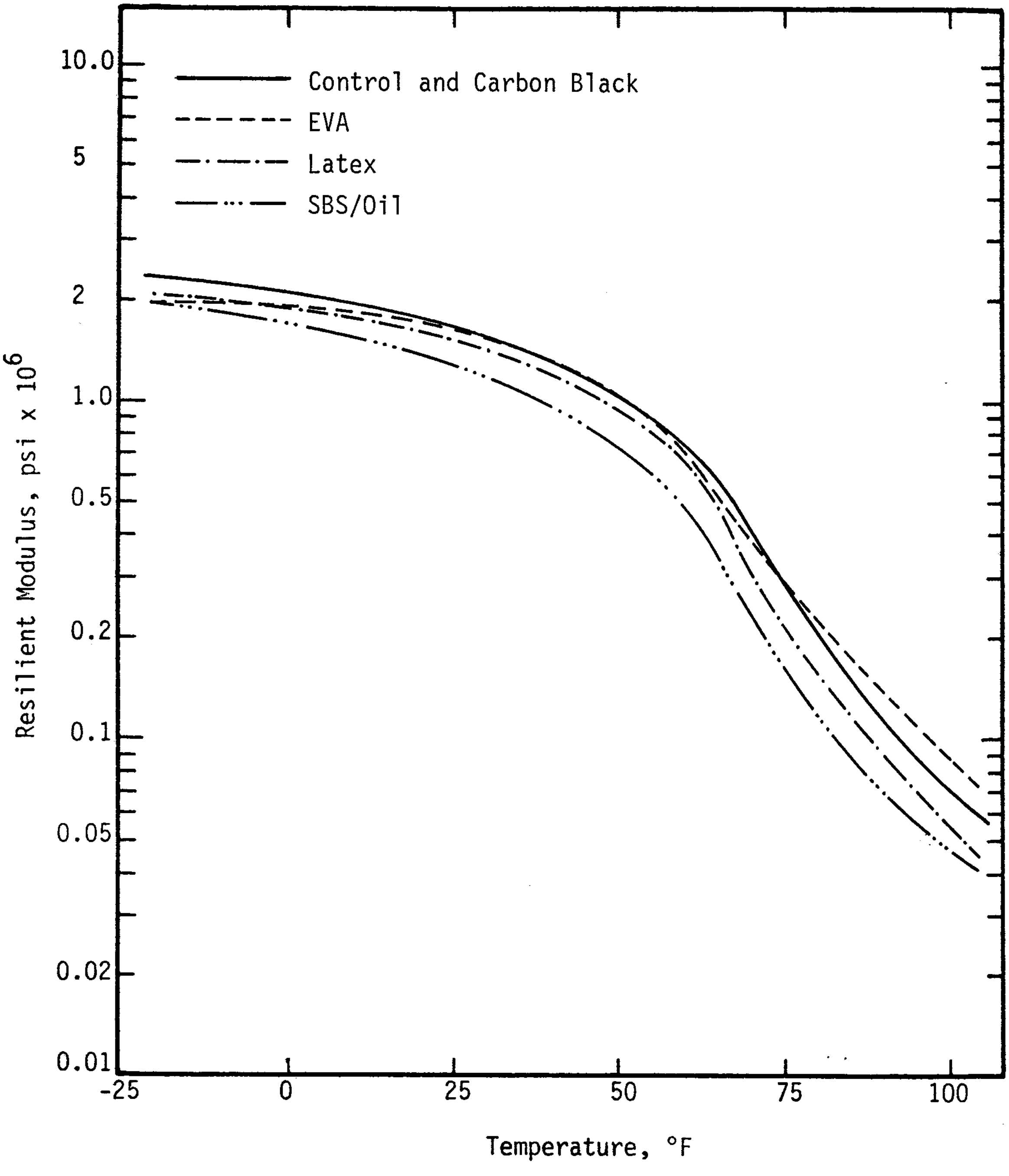

Figure 24. Resilient Modulus as a Function of Temperature for Field Mixed-Lab Molded Specimens from District 21.

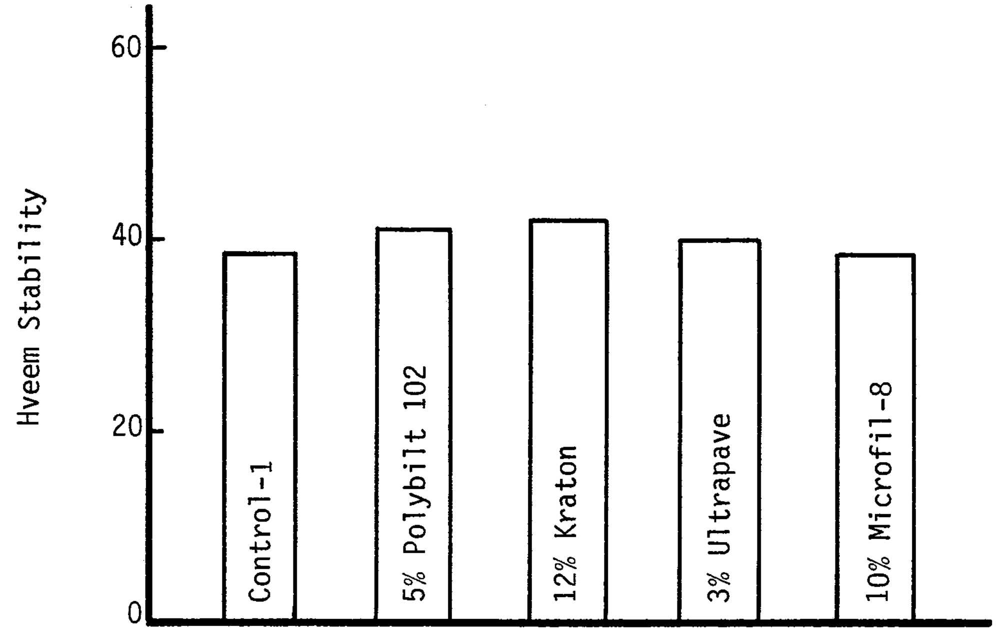

Figure 25. Hveem Stability of Field Mixed-Laboratory Molded Test Specimens from District 21.

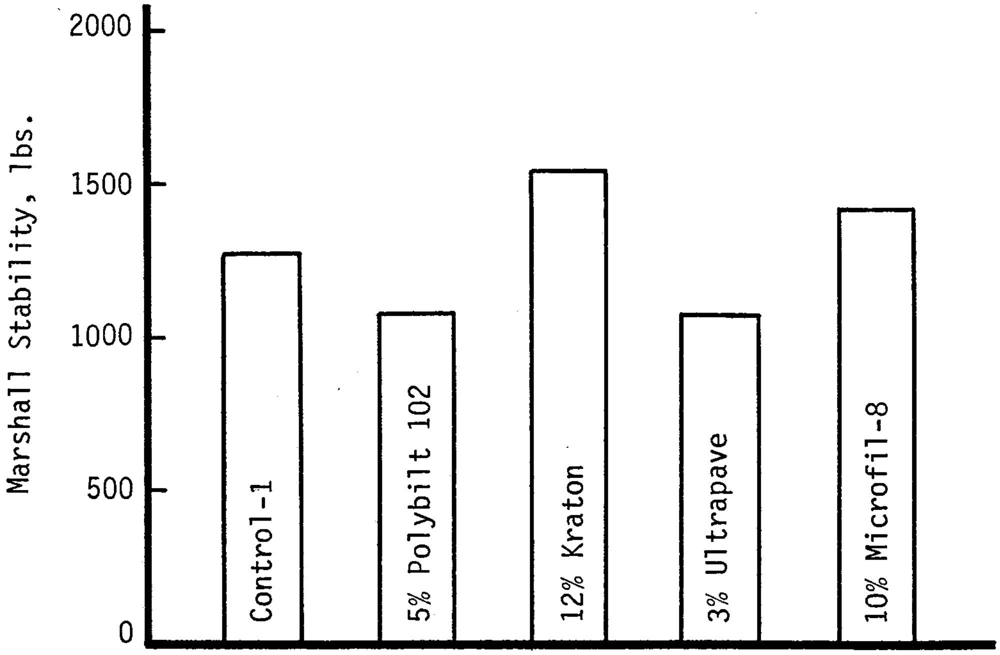

Figure 26. Marshall Stability of Field Mixed-Laboratory Molded Test Specimens from District 21. (specimens molded using Texas gyratory method not Marshall method).

C8). Air void content of the mixtures had more effect on Marshall stability than the additives. It is concluded, therefore, that the additives have little effect on Marshall stability.

Indirect tension tests performed at 77°F and 2 inches per minute showed that all the additives produced a decrease in tensile strength (Figure 27) while only the SBS/Oil and SBR latex produced an increase in strain at failure (Figure 28). Decreased tensile strength in the additive-modified mixtures was probably due in part to their relatively higher void contents when compared to the control mixture. These test results, however, are generally consistent with results on materials from District 1, as discussed earlier.

Moisture susceptibility of the laboratory-molded mixtures (Table C6) and pavement cores (Table C9) was estimated using the Lottman (6) freeze-thaw procedure (described earlier). Comparison of tensile strength ratios (Figure 29) indicates that the additive-modified mixtures exhibited slightly more resistance to moisture damage. The reader is reminded that the additive-modified mixtures were prepared using a plant temperature of about 315°F; whereas, the control mixture was prepared at about 280°F. This difference in mixing temperature alone could account for the resulting difference in moisture sensitivity. Conversely, the control mixture contained significantly lower air voids than the additive-modified mixtures which should have provided, by comparison to the other mixtures, improved resistance to moisture damage.

Resistance to aging of the mixtures was evaluated by performing indirect tension tests before and after continual exposure to 140°F for 4 weeks (Table C7). Test results were similar to those obtained on the mixtures from District 1 (Figures 30 and 31). That is, the mixture containing Microfil-8 exhibited the least increase in tensile strength and the mixture containing Ultrapave exhibited the largest increase in tensile strength. The differences in tensile strength ratio, however, were quite small. The Ultrapave modified mixture had the lowest retained flexibility; whereas, the Polybilt-modified mixture had the greatest retained flexibility. Based on this test, the Polybilt and Kraton modified mixtures appear to resist aging a little better than the other mixtures. The Ultrapave-modified mixture was least resistant to aging.

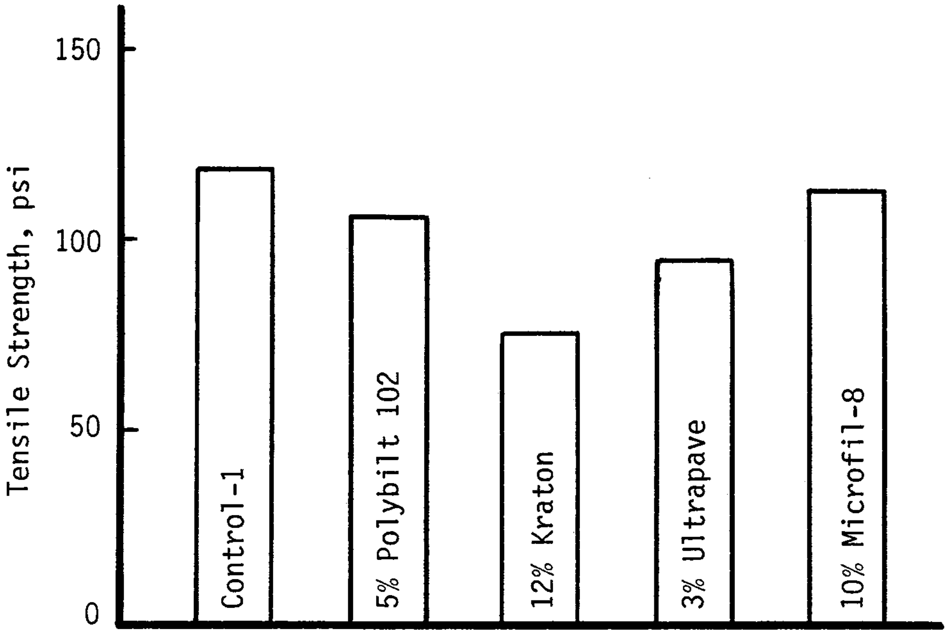

Figure 27. Tensile Strength of Field Mixed-Lab Compacted Mixtures from Indirect Tension Tests at 77°F and 2 in/min - District 21.

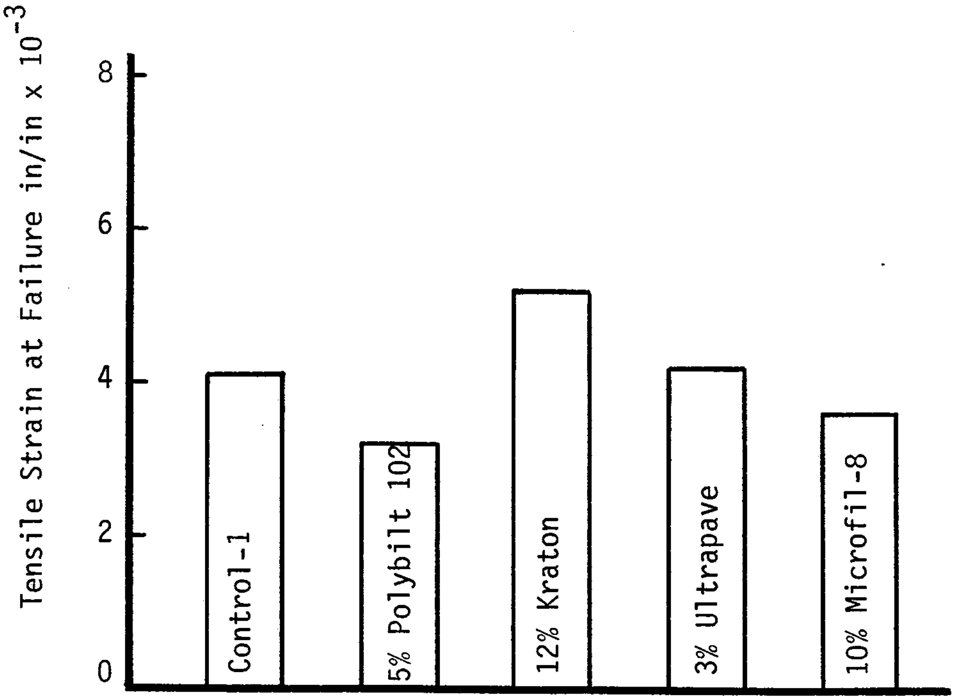

Figure 28. Elongation at Failure for Field Mixed-Laboratory Molded Specimens from Indirect Tension Tests at 77°F and 2 in/min - District 21.

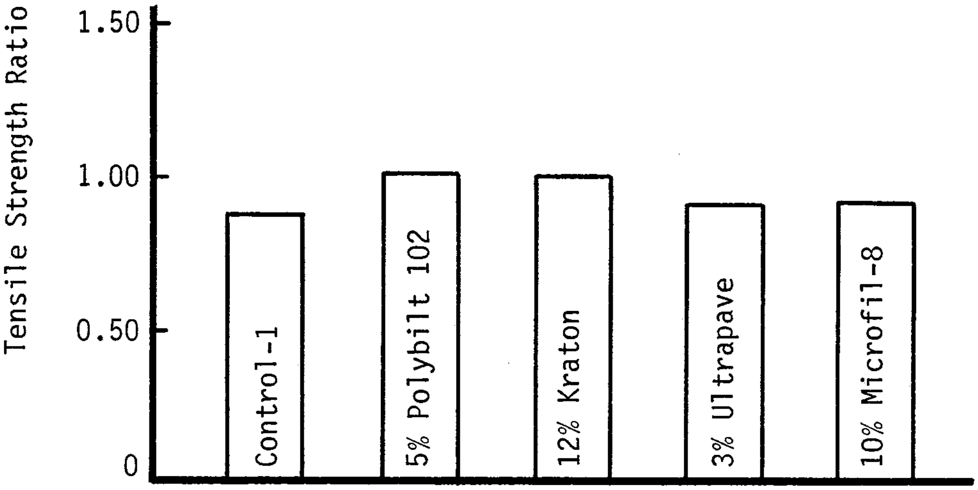

Figure 29. Tensile Strength Ratios for Field Mixed-Lab Compacted Specimens after Lottman Freeze-Thaw Moisture Treatment, District 21.

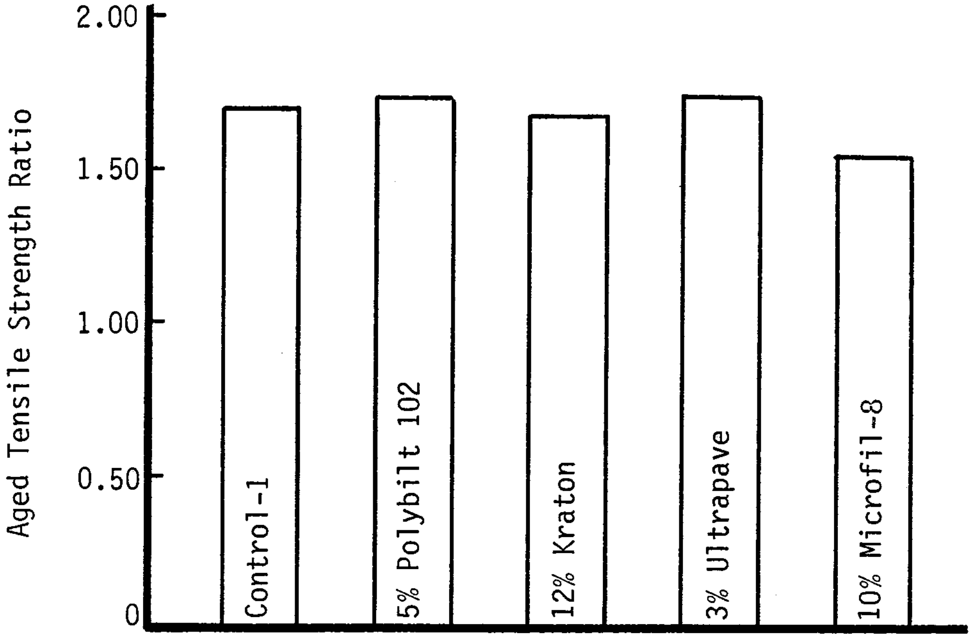

Figure 30. Ratio of Tensile Strength for Field Mixed-Lab Molded Specimens for District 21 Before and After Aging for 4 weeks at 140°F (from indirect tension tests at 77°F and 2 in/min).

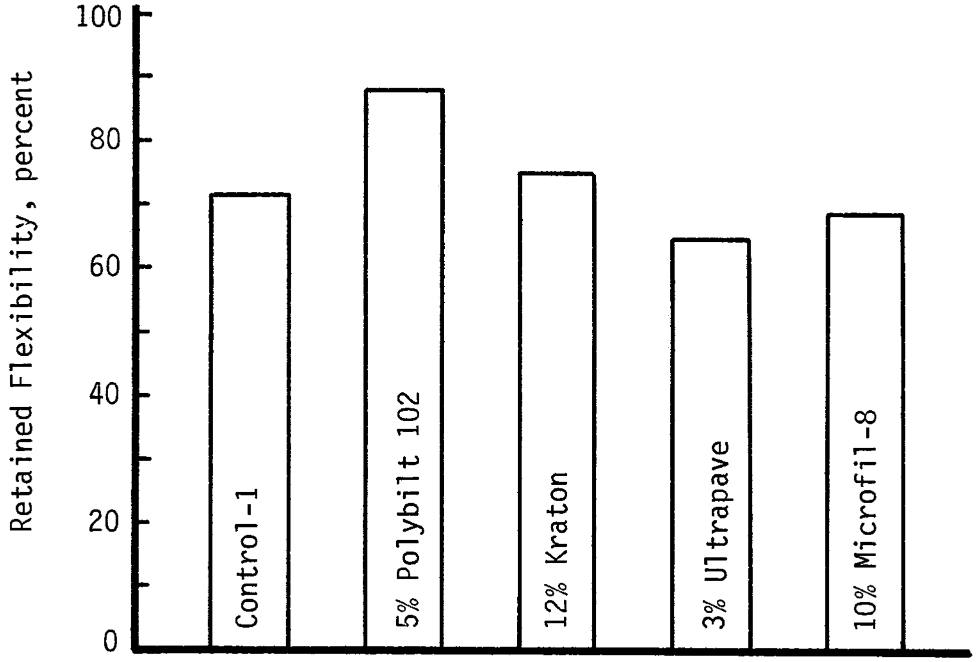

Figure 31. Retained Flexibility* of Field Mixed-Lab Molded Specimens from District 21 after Aging 4 Weeks at 140°F (from Indirect Tension Tests).

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*Tensile strain at failure after aging ÷ Tensile strain at failure before aging x 100.

Post-Construction Performance Evaluation

All test pavements in District 21 were visually examined in August 1987. There were no signs of rutting, surface cracking or any other modes of pavement distress. After one year in service the pavements are performing equally well.

ECONOMIC CONSIDERATIONS

The effective cost of additive-modified paving mixtures involves not only the unit cost of the additive but also the dosage requirements for the additive. Unit cost of the additives and additive-modified binders and mixtures are presented in Table 7. In order for these products to be cost-effective, the percentage increase in cost must be matched (approximately) by an equivalent percentage increase in pavement service life and/or offset by appropriate reductions in pavement maintenance costs.

An in-place cost of 30 dollars per ton of unmodified hot mix asphalt concrete was used as a basis for computing the percentage cost increases in Table 7. Based on these figures and an average pavement service life of 1 year (Elvax) to 6 years (preblended microfil) to be cost effective. This is a very simplified approach and is given for general comparisons only.

Table 7. Cost Data for Modified Binders and Paving Mixtures.

Type Additive	Additive Dosage, wt. percent	Additive Cost[1], dollars/lb	Approximate Binder Cost, dollars/ton	Approximate Increase in In-Place Cost of Paving Mixture, dollars/ton	percent[5]
None	-	-	100	0	0
Polybilt 102	5	0.87	187[2]	4[2]	13[2]
Elvax 150	2	0.82	133[2]	2[2]	7[2]
Ultrapave	3	0.88	153[2]	3[2]	10[2]
Kraton	12	0.89	302[2]	10[2]	33[2]
Novophalt	5	0.40	200[4]	5[3]	17[3]
Microfil	12.5	0.33	183[4]	4[4]	13[4]
Microfil (preblended)	10	0.33	340[3]	12[3]	40[3]

[1] Cost does not include freight.

[2] Cost does not include preblending of additive with asphalt but does include freight.

[3] Cost includes preblending labor, equipment usage and freight.

[4] Cost does not include handling of carbon black at plant site but does include freight.

[5] Basis used for in-place cost of hot mix asphalt concrete was $30/ton.

ADDITIONAL ADDITIVE FIELD TRAILS

GENERAL

During the conduct of this research study, several individual field trials have been installed in Districts 2, 10, 16, 17 and 19 to evaluate asphalt additives. Funding and time constraints prevented detailed testing of materials from these test pavements; however, long-term performance evaluations of these field tests will be most helpful in determining cost effectiveness. A brief description of these additive field tests is given in the following paragraphs.

DISTRICT 2

Test pavements 2500 feet in length were installed to evaluate latex on SH 121 in Ft. Worth in June of 1985. The lane in which these pavements were installed carries about 11,500 vehicles per day. A 2-inch overlay was placed over 8-inch continuously reinforced concrete pavement (CRCP). Fabric (5 ounce per square yard Trevira) was installed directly on the CRCP prior to the overlay in both the latex and control sections. Liquid latex was added in the drum plant just downstream from the asphalt inlet. This procedure is always specified in District 2 to minimize degradation of the styrene butadiene rubber that may occur upon prolonged exposure to heat during storage. The latex dosage was 3 percent solids by weight of asphalt cement. Silicone was added to all mixtures to improve workability. The paving mixture was a Texas Item 340, Type D containing lightweight coarse aggregate, limestone screenings and field sand with approximately 7.5 percent Kerr-McGee AC-10. Mix design was performed without latex, then latex was added without altering the design.

After two years in service, there are only minor differences between the latex section and the control section. On the average, there appears to be slightly more rutting (1/16-inch) in the control section. No other signs of distress are visible in either of the sections. Both sections have a present serviceability index of 4.0.

DISTRICT 10

Polysar latex was used on SH31/US69 in Tyler in September 1986. Three percent latex and 0.5 percent Perma Tac (antistrip additive) were incorporated in two different mixtures. One was a Type D mixture composed of synthetic lightweight aggregate, Richland screenings and local field sand with a design asphalt content of 7.8 percent. The other was a Type C mixture comprised of crushed limestone, Richland screenings and local field sand with a design asphalt content of 4.6 percent.

The test pavements consisted of 3-inch overlays on an asphalt concrete pavement. A drum mix plant operating at 340 to 350°F was employed to produce the paving mixture. The normal mixing temperature of 300°F was unacceptable when the latex-modified asphalt was used. Although not a particular problem, the mixture was notably tackier than usual and tended to tear at times under the screen of the paver. No control section was installed to facilitate comparative performance; however, after one year in service the pavements are in excellent condition with only minor rutting at certain intersections.

DISTRICT 16

In April 1985, Styrelf-13 modified asphalt was used in a paving mixture on IH37 in Live Oak County (Project IP37-1(87)041). Styrelf was preblended at 3 percent by weight with Exxon AC-10 at the Texas Emulsion plant in Baytown. Control sections containing Exxon AC-20 with no Styrelf were also constructed. Part of the study was to evaluate the effects of Styrelf in reducing moisture damage; therefore, control mixtures were prepared with and without hydrated lime added to the aggregate as a slurry. The aggregate consisted of 55 percent crushed limestone, 25 percent limestone screenings and 20 percent field sand. The test pavement consisted of an overlay 1 1/2-inches thick placed over a full-depth asphalt pavement. A batch plant was used to produce the mixes. The Styrelf-modified mixture was produced at about 320°F; the other mixtures were produced at less than 300°F.

There are no signs of distress in any of these pavements after 2 1/2 years in service. All pavements are performing equally well.

DISTRICT 17

In the spring of 1985, Kraton G1650 was evaluated in construction project HES-000S(163) on FM 2818 in Brazos County at College Station. Kraton G is a block copolymer comprised of styrene-ethylene/butylene-styrene (SEBS). A 1 1/2-inch overlay was placed on the northbound outside lane from station 180+00 to 232+00. The inside lane which contained Exxon AC-20 was considered to be the control section. Three percent Kraton G1650 was preblended with Exxon 120-150 pen asphalt in Brownwood by Riffe Petroleum in September 1984. They used a Siefer mixer (high shear) to blend the materials. As a result of an unplanned sequence of events, the binder was stored hot for 7 months prior to being used in District 17. Force ductility tests before and after the storage period showed little change in asphalt properties. The Type D paving mixture contained 58 percent crushed limestone, 15 percent limestone screenings, 15 percent washed sand and 12 percent field sand. The washed sand was treated with 1 1/2 percent hydrated lime added as a slurry and mixed in a plug mill. Design asphalt content was 5.5 percent by weight of mix. Plant temperatures were the same for both modified and control mixtures. No noticeable differences in mixture properties were evident during construction. After almost two and one half years in service, control and Kraton-modified pavements are performing similarly. Both pavements contain intermittent longitudinal cracks in the outer wheel path. There are no other signs of distress.

In the fall of 1985, a Styrelf-13 modified mixture was used in a 1-inch surface course in reconstruction of a portion of SH6 in Robertson county from Hearne to 1 mile northwest of Benchley, Project F401(8) (7). A 2-lane road was widened and upgraded to a 4-lane divided facility. After widening and repairs were completed, two courses of Type B hot mix were applied to level up the existing pavement. Type D hot mix was used for the riding surface wherein the field trials were conducted. The experiment is described in Table 8. The aggregate in all mixes consisted of 56 percent limestone (Texas Crushed Stone), 14 percent screenings, 12 percent washed sand and 18 percent field sand. Styrelf was blended by Texas Emulsions with Exxon AC-10; the control pavement contained Exxon AC-20. The 1 percent Styrelf binder was prepared at the hot mix plant by adding one part asphalt containing 3 percent Styrelf to two parts AC-20.

Table 8. Description of Asphalt Additive Experiment in District 17.

Test Section	Lane	Location STA Limits	Percent Asphalt	Percent Styrelf In Asphalt	Treatment of Washed Sand
Control	Southbound	401+90	5.3	None	1 1/2% Lime
	Outside	541+50			
A	Southbound	431+00	5.3	1.0	1 1/2% Lime
	Inside	509+00			
B	Southbound	509+00	5.3	3.0	1 1/2% Lime
	Inside	527+00			
C	Southbound	527+00	5.0	3.0	1 1/2% Lime
	Inside	571+15			
D	Southbound	575+38	5.0	3.0	None
	Inside	584+40			

(After Reference 7)

All mixes were prepared at 300 to 310°F in a drum mix plant. The polymer had little effect on pavement density as air voids in cores taken one week after construction averaged 10.5 percent for the Styrelf mix and 9.3 percent for the control mix. The Styrelf mix was slightly more tender and had more tendency to stick to the tires of pneumatic rollers than the control mix. Vacuum extractors using methylene chloride solvent were unsuitable for use with the Styrelf mix, however, no problems were reported when the centrifuge extractor using trichlorethylene was employed. After two years in service all five test pavements are exhibiting excellent performance.

DISTRICT 19

A field trial containing Microfil-8 was constructed in November 1985 on IH30 in Bowie County about 35 miles west of Texarkana (Project IR-30-3(77)188). A concentration of 10 percent Microfil was blended with MacMillan AC-10 by Mono-Chem Corporation in Atlanta, Texas, using a high-shear Cowles mixer and a surfactant to keep the carbon black in suspension. Ten percent Microfil-8 increased the viscosity of the AC-10 at 140°F to approximately 2000 centistokes or that of an AC-20. Control sections contained MacMillan AC-20. The test pavement and control section were 2-inches thick, 2200 feet long and 12-feet wide and were placed over an existing continuously reinforced concrete pavement with crack spacings of one to three feet and some spalling. Crushed sandstone, sandstone screenings and field sand were blended with 4.8 percent asphalt to produce the Type D mixture. The binder content was adjusted upward to 5.1 percent when the carbon black-treated material was used to account for the differences in specific gravity. A mixing temperature of 280 to 290°F was used for both mixes in a fuel oil-heated drum mix plant. After 21 months in service, the pavements are giving excellent performance with no visible signs of distress.

DISTRICT 21

A Type D hot mix asphalt concrete overlay was placed on the westbound main lane of US83 from the second street exit to a point just south of the tenth street exit in McAllen in June, 1985. This was a portion of Project

CSR 39-17-85. Test pavements contained Styrelf-13 modified Exxon AC-10; control pavements contained Exxon AC-20. Optimum binder content was 5.8 percent. Mixes were produced using 30 percent crushed 7/16-inch silicious river gravel, 15 percent 1/4-inch river gravel, 30 percent gravel screenings and 25 percent field sand in a drum mix plant. One percent lime was added as a slurry. The Styrelf-modified mix was prepared at about 25°F hotter than the usual mixing temperature of 310°F. Workability was good. The underlying pavement was an asphalt-rubber seal coat with grade 3 stone on an asphalt concrete pavement. After two years in service the pavements are generally in good condition.

A second test pavement was placed in District 21 to evaluate Shell Kraton in hot mix. This portion of Project CSR 39-18-61 was installed in June of 1985 on US83 west of Harlingen in the eastbound lanes near the Cameron/Hidalgo county line. A 50-50 mixture of Kraton D1101 and 1118 was added at 6 percent by weight to Exxon AC-10 and preblended at the Gulf States plant in South Houston. Fifty percent crushed silicious gravel plus 25 percent screenings plus 25 percent field sand with 5.4 to 6.0 percent binder by weight of mix was used in a drum mix plant to produce the 1 1/2-inch overlay mixtures. One percent hydrated lime in a slurry was added to the aggregate on the cold feed belt. The plant temperature was about 300°F for the control mix and about 340°F for the polymer-modified mixture.

OTHER STATES

There is presently a great deal of interest worldwide in asphalt additives. Most state highway departments are testing additives in asphalt concrete pavements. Some, like Texas, have designed and installed end-to-end test pavements with the additive as the only variable that will provide valuable comparative information on long term performance of additive-modified mixtures (8,9,10 and 11).

CONCLUSIONS AND RECOMMENDATIONS

Based on observations and measurements made during preparations for construction and construction of field test pavements containing asphalt additives and subsequent laboratory testing of materials obtained from the field trials, the following conclusions and recommendations are tendered:

CONCLUSIONS

1. It presently appears that standard Texas SDHPT asphalt mix design methods are acceptable when polymeric or carbon black additives are used. Based on limited testing and literature reviews, the Hveem and Marshall mixture design methods also appear acceptable. One should pay close attention to air void content of laboratory-molded specimens, particularly when additives are used, as this may be an indicator that adjustments in compactive effort or compaction temperatures are required to optimize pavement quality.

2. Although standard mixture design methods are considered acceptable when additives are utilized, these methods will give little or no indication of changes in fundamental engineering properties of the mixtures which an additive is designed to provide. In fact, Hveem stability is primarily a measure of interparticle friction of aggregate and not sensitive to binder properties although it is quite sensitive to binder content.

3. Generally, the temperature susceptibilities of the additive-modified binders were lower than the unmodified asphalts. It presently appears best to add these types of additives to a softer than usual asphalt. The soft asphalt provides flexibility at low service temperatures; whereas, the additive stiffens the asphalt at high service temperatures.

4. Force ductility is a sensitive measure of modified asphalt properties. The more completely an additive is dispersed in asphalt the less the probability the additive will adversely affect ductility. Additives that "dissolve" in asphalt have a higher probability of enhancing ductility.

5. The additives tested had little effect on artificial oxidative aging of paving mixtures. SBS, EVA and polyethylene-modified mixtures

resisted aging slightly better than the control. The latex-modified mixtures were least resistant to aging.

6. Marshall stability was affected more by air void content of the compacted mixtures than by the presence or type of additive.

7. Indirect tension tests showed that mixtures containing AC-10 plus EVA, SBR or SBS had lower tensile strength than the control mixture containing unmodified AC-20. However, mixtures containing SBS and SBR exhibited greater strain at failure (flexibility) than the control mixture.

8. None of the additives tested in this study consistently exhibited significant effects on moisture susceptibility of the paving mixtures. The variations in moisture susceptibility were generally explainable by differences in air void content and/or mixing temperature. All field mixtures were tested with an antistrip additive.

9. After one year in service, there are no perceptible differences in performance of the control and additive-modified test pavements in Districts 1 and 21. All pavements are performing well.

10. Preblending of carbon black and asphalt using the high shear mixer and surfactant to keep the carbon black in suspension yielded a much more ductile binder than when added without surfactant using low shear mixing in the laboratory.

11. When SBS block copolymer is used as an additive, the resulting asphalt concrete will be unusually brown in color. Carbon black will produce an intensely black paving mixture.

RECOMMENDATIONS

1. Effects of additives on mixture properties are dependent on the chemical composition of the asphalt cement. One should, therefore, always test proposed additives with the materials selected for use on a given project.

2. Future research efforts on asphalt additives should address: (1) long-term aging effects on pavements; (2) development of suitable binder extraction methods; and, (3) prolonged hot storage of additive-modified asphalts.

3. Since the additives generally produced no substantial increase in mixture stiffness, i.e., load bearing capacity, it is the opinion of the author that pavement thickness should not be reduced when additives of these types are employed; therefore, use of these additives will result in no cost savings during the first year. Cost savings should be realized by extended pavement service life and reduced maintenance.

4. Significant research and construction funds have been invested by the state in the field experiments discussed above. Several years are usually required to determine the benefits and cost-effectiveness of new paving materials. It is, therefore, recommended that annual monitoring of these test pavements be continued for an unspecified period to evaluate the long-term effects of asphalt additives in paving mixtures. This will also facilitate realistic estimates of the benefits of the different types of additives and thus allow maximum achievement of the project objectives.

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APPENDIX A

Summary of Previous TTI Additive Studies

APPENDIX A

SUMMARY OF LABORATORY RESULTS FROM PREVIOUS TTI STUDIES

The overall objectives of this research (1,2) were to: (1) identify through laboratory testing, the most promising types of additives or admixtures for reducing rutting and cracking in hot-mixed asphalt pavements; (2) develop guidelines showing how the additives can be incorporated into actual pavements; and, (3) develop procedures for evaluating additives. This work was sponsored by the Federal Highway Administration and the Texas State Department of Highways and Public Transportation.

The additives selected for evaluation in the experimental program included:

1. Latex (styrene-butadiene rubber)
2. Block Copolymer Rubber (styrene-butadiene-styrene)
3. Ethylene Vinylacetate
4. Polyethylene-finely dispersed
5. Carbon Black

Based on current prices, these additives will add about 5 to 10 dollars to the cost of a ton of hot mixed asphalt concrete. The additives were combined with asphalt cements from two sources with widely differing chemical compositions and rheological properties. Preliminary testing showed that incorporation of these additives into asphalt had little effect on penetration at 39°F (4°C) but significantly increased viscosity at 140°F, (60°C) thus producing a binder with lower temperature susceptibility. Using this rheological information, asphalt cements two grades softer (AC-5 and AR-1000) than that normally used in hot-mixed asphalt concrete (HMAC) and additive dosages were selected such that, when the additive was incorporated into the asphalt cement, the resulting binder exhibited a viscosity at 140°F (60°C) near 2,000 poise and a penetration at 39°F (4°C) essentially the same as the unmodified asphalt.

Physical binder tests included penetration at two temperatures, viscosity at various temperatures and by various methods, softening point, flash point, specific gravity, rolling thin film oven test, thin film accelerated aging, ductility, heat stability, viscoelastic analysis and stress relaxation. Component analysis of the original asphalts was determined using the Rostler-Sternberg and Corbett analysis techniques.

Chemical characterization included infrared analysis before and after artificial aging and nuclear magnetic resonance. Energies of interaction between selected asphalts and additives were measured using a microcalorimeter.

Paving mixtures were tested in the laboratory using primarily a river gravel and sand aggregate with the modified binders. This material produced a relatively binder-sensitive mixture which was designed to be realistic but yet reveal subtle differences in the modified and unmodified asphalts. Limited tests were performed using mixtures made from crushed limestone to address possible differences in mixture properties associated with high stability mixtures. Mixture tests included:

Hveem Stability,
Marshall Stability,
Resilient Modulus at 5 Temperatures,
Indirect Tension at 3 Temperatures and 3 Loading Rates,
Resistance to Moisture Damage,
Extraction and Recovery of Asphalts,
Flexural Fatigue at 2 Temperatures,
Creep/Permanent Deformation at 3 Temperatures,
Fracture Resistance at 2 Temperatures and
Fracture Healing.

The mixture test results were used with the VESYS IV structural subsystem to predict the effects of the additives on pavement performance, cracking, rutting and roughness. AASHTO structural layer coefficients and pavement thickness equivalencies were estimated for the modified mixtures. Fracture mechanics theory was applied to selected mixture test data to compute resistance to crack propagation and crack healing capacity imparted by the additives.

Conclusions from the study are summarized below:

1. Traditional mixture design procedures, such as the Marshall, Hveem and Texas methods,are acceptable for determining target binder contents for asphalt mixtures.

2. Each additive studied demonstrated the ability to substantially alter the temperature susceptibility of asphalt concrete mixtures. The degree of alteration is highly dependent upon the chemical composition of the asphalt cement.

3. The ability of additives to alter the mechanical properties of asphalt concrete is reflected in the predicted performance of the pavement systems which incorporate modified asphalt concrete layers. Although each additive tested showed a potential to reduce temperature susceptibility of the base asphalt, no additive appeared to be a panacea. The task of selecting the best additive for a specific combination of climatic, pavement structure and traffic condition is formidable.

4. Although certain binder and mixture properties appeared to be sensitive to compatibility between the asphalt and the additives, overall, the mixture properties demonstrated an ability for each additive to alter temperature susceptibility in a generally favorable manner.

5. Flexural fatigue response at 68°F (20°C) of mixtures containing AC-5 plus an additive was superior to the control mixture which contained AC-20 with no additive. Accelerated aging of mixtures containing additives resulted in a significant decrease in fatigue life; the control specimens, however, exhibited better fatigue properties after aging.

6. Controlled displacement fatigue testing at 34°F (1°C) demonstrated that mixtures containing AC-5 plus an additive gave better resistance to crack propagation than control mixtures containing AC-20. The "solubilized" additives, EVA, SBR and SBS, showed evidence of improving the distribution of tensile stresses within the mixture. Practically, this could result in retarding crack propagation as manifested by resistance to cracking in asphalt concrete overlays.

7. In a limited study of crack healing, the mixtures containing the soft asphalt (AC-5) plus an additive gave better responses than those containing the control asphalt (AC-20). The practical significance of improved healing potential could be substantially improved flexural fatigue lives of asphalt concrete pavements.

8. Creep/permanent deformation testing showed that, at high temperatures, all the additives except latex produced equal or better performance than the AC-20 control mixture. (The binder content of the latex mixture was apparently in excess of the true optimum). At low temperatures, all the additives in AC-5 except polyethylene produced equal or better performance than the AC-20 control mixture.

9. Indirect tension results showed that, at the lower temperatures and higher loading rates, the additives increased mixture tensile strength

over that of the control mixtures. Deformation at failure was generally increased by the additives. This is indicative of improved resistance to traffic-induced cracking at low temperatures. At the higher temperatures and lower loading rates, the additives did not appreciably affect the mixture tensile properties as measured by the indirect tension test.

10. The additives increased Marshall stability of mixtures when added to AC-5 (or AR-1000) but not up to that of mixtures containing AC-20 (or AR-4000) with no additive. This should not discourage the use of these additives with asphalts softer than the usual paving grade, particularly when low temperature cracking is a concern.

11. Hveem stability of mixtures was not significantly altered by the additives. Although Hveem stability is quite sensitive to changes in binder quantity, it is not very sensitive to changes in rheological properties of the binder.

12. At low temperatures (less than 32°F or 0°C), the additives had little effect on consistency of the asphalt cements. This was reflected in the diametral resilient moduli (stiffness) of the mixtures. Resilient moduli of AC-5 (or AR-1000) mixtures above 60°F (16°C) were generally increased by the additives but not up to that of the AC-20 (or AR-4000) mixtures without additives. Although the load spreading ability of asphalt concrete containing a soft asphalt is increased when these additives are employed, the pavement thickness should not be reduced.

13. The additives had little effect on moisture susceptibility of the mixtures made using the materials included in this study.

14. Standard asphalt extraction methods to determine binder content of paving mixtures are unsuitable when polymers or carbon black are used as these materials are insoluble or only partly soluble in standard solvents.

15. Long-term aging characteristics of modified binders are substantially different, physically but not so much chemically, from the unmodified asphalts. Short-term aging characteristics, as measured by standard tests, do not manifest appreciable differences between modified and unmodified asphalts.

16. The five additives studied were selected because of their potential to reduce rutting and cracking. Each additive proved to be successful to some degree in improving properties on at least one end of

the performance spectrum. The need for an additive selection procedure based on traffic conditions, pavement structure and climatic conditions is emphasized. To rank the additives according to relative capabilities is a difficult task as sensitivity to the base asphalt played a significant role. In general, the most effective additives in reducing rutting were EVA, polyethylene and SBS (Kraton) for the Texaco (AC-5) asphalt. For the California Valley asphalt, carbon black, polyethylene, and EVA performed most effectively and without significant difference. In terms of reduction of flexural fatigue cracking, the most successful additives were, in order, EVA, SBS (Kraton) and SBR (latex) and polyethylene which demonstrated essentially equivalent performance.

17. Force ductility offers promise as a means of estimating compatibility between an additive and asphalt. In addition, the force ductility test may be useful in predicting changes in mixture tensile strength when asphalt additives are employed.

APPENDIX B

Test Results on Materials from District 1

Table B1. Hot Mix Asphalt Concrete Design Data-District 1.

Aggregate Gradation

Sieve Size	Percent
Passing 7/8"	100
Passing 5/8"	99.1
Passing 3/8"	77.5
Passing #4	52.3
Passing #10	38.8
Retained #10	61.2
Passing #40	23.4
Passing #80	8.5
Passing #200	3.3

Optimum Asphalt Content (AC-20) = 5.3%

Percent Bitumen	Percent Density	Hveem Stability
4.0	92.9	54
5.0	96.3	50
6.0	98.8	42
7.0	100.0	25

Table B2. Properties of Binders used in Test Pavements in District 1.

Test Property	Type of Binder						
	AC-20	AC-10	Car. Blk. + AC-10[3]	EVA + AC-10	PE + AC-10	SBR + AC-10	SBS + AC-10[2]
Original Binder							
Penetration, ASTM D5							
77°(25°C) 100gm, 5s	92	114	38	127	86	137	115
39°F(4°C) 100gm, 5s	8	12	4	12	6	17	13
39°F(4°C) 200gm, 60s	28	38	28	42	28	53	50
Viscosity, ASTM D2171							
140°F(60°C), poise	1730	1000	100,000[1]	1230	4510	1010	2250
275°F(135°C), poise	4.61	3.39	21.3	4.49	10.9	4.14	5.13
R&B Soft Pt., °F(°C), ASTM D36	119 (48)	116 (47)	134 (57)	112 (44)	131 (55)	113 (45)	123 (51)
Flash Pt., °F(°C), ASTM D92	615 (324)	615 (324)	605 (318)	610 (321)	640 (338)	630 (332)	610 (321)
After Thin Film Oven Test, ASTM D1754							
Penetration, ASTM D5							
77°F(25°C) 100gm, 5s	62	80	32	85	53	108	97
Viscosity, ASTM D2171							
140°F(60°C), poise	3770	2007	-	2450	7730	1650	2580
Ductility, ASTM D113							
77°F(25°C), 5^{cm}/min	120+	120+	5	120+	115	120+	120+
Weight Loss, percent	0.17	0.07	0.47	0.22	0.10	0.21	0.22

[1] *Viscosity measured using Brookfield viscometer.

[2] Also contains some Exxon 120/150 grade asphalt. See Text.

[3] Blended in the TTI laboratory using low shear desk top mixer.

Table B3. Summary of Forced Ductility Tests at 39.2°F and 5 cm/min after Thin Film Over Tests District 1*.

Sample Type	Maximum Engineering Stress, psi	Maximum Engineering Strain, in/in	Area Under Stress-Strain Curve	Initial Slope of Ture Stress-Strain Curve	Total Deformation at Specimen Rupture, cm
AC-20	11.3	9.4	28.2	27.9	30
AC-10	7.0	5.4	14.1	32.8	40
AC-10 + 12.5%** Microfil	--	--	--	--	<1
AC-10 + 2% Elvax 150	8.0	12.3	33.5	18.3	40
AC-10 + 5% Polyethylene	13.7	4.6	23.8	31.3	14
AC-10 + 3% Latex	4.3	13.7	12.1	12.3	78
AC-10 + 8.6% Kraton D4460X	4.4	29.6	45.6	15.8	88

*Each value represents an average from two tests.

**Sample prepared in laboratory, ie, not mixed in plant in District 1.

Table B4. Resilient Modulus, Hveem and Marshall Stability of Field Mixed-Laboratory Molded Test Specimens from District 1.

Type Mixture	Air Void Content, Percent	Resilient Modulus, psi x 10^{-3}					Hveem Stability	Marshall Test	
		-13 F	35 F	70 F	77 F	103 F		Stability, lbs	Flow, 0.01"
AC-20 Control A (3-inches)	3.6	2100	1400	540	370	100	37	2060	16
AC-20 Control B (4-inches)	2.8	1900	1400	510	330	91	52	1400	15
AC-10 + EVA(2%)	2.2	2000	1500	490	310	87	51	1650	17
AC-10 + SBS/Oil (8.6%)	2.3	2000	1200	320	190	59	49	1330	18
AC-10 + Latex(3%)	3.2	1900	1200	310	190	58	62	1300	15
AC-10 + Carbon Black(12.5%)	5.1	1900	1300	510	340	89	65	1250	15
AC-10 + Polyethylene(5%)	3.8	1900	1300	540	380	110	67	1320	14

Table B5. Properties of Field Mixed-Laboratory Molded Specimens from District 1 Before and After Accelerated Lottman Freeze-Thaw Procedure.

Type Mixture	Before Moisture Treatment					After Moisture Treatment					Tensile Strength Ratio
			Tensile Properties*					Tensile Properties*			
	Air Void Content, Percent	Resilient Modulus at 77 F, psi x 10	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Saturated Air Void Content, Percent	Voids Filled w/Water Percent	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	
AC-20 Control A (3-inches)	3.5	400	150	0.0061	25,000	2.6	32	110	0.0061	30,000	0.73
AC-20 Control B (4-inches)	2.7	340	140	0.0058	25,000	2.0	21	110	0.0039	29,000	0.79
AC-10 + EVA(2%)	2.3	270	120	0.0054	23,000	1.9	16	92	0.0046	20,000	0.77
AC-10 + SBS/Oil (8.6%)	2.7	190	110	0.0100	12,000	1.8	29	91	0.0069	13,000	0.83
AC-10 + Latex(3%)	3.4	170	98	0.0082	12,000	2.1	35	87	0.0056	15,000	0.89
AC-10 + Carbon Black(12.5%)	4.6	350	140	0.0064	21,000	4.0	20	95	0.0036	27,000	0.68
AC-10 + Polyethylene(5%)	3.8	380	140	0.0047	30,000	3.3	18	120	0.0034	34,000	0.86

*Indirect tension tests were performed at 77^{o}F and 2-inches/minute before and after moisture treatment.

Table B6. Properties of Field Mixed-Laboratory Molded Specimens from District 1 Before and After Thermal Aging Treatment*.

Type Mixture	Before Aging					After Aging					Resilient Modulus Ratio (Aged)	Tensile Strength Ratio (Aged)
			Tensile Properties**					Tensile Properties**				
	Air Void Content, Percent	Resilient Modulus at 77 F, psi x 10	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Air Void Content, Percent	Resilient Modulus at 77 F, psi x 10	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi		
AC-20 Control A (3-inches)	3.5	400	150	0.0061	25,000	3.3	670	200	0.0041	50,000	1.68	1.33
AC-20 Control B (4-inches)	2.7	340	140	0.0058	25,000	2.8	640	180	0.0037	48,000	1.88	1.29
AC-10 + EVA(2%)	2.3	270	120	0.0054	23,000	2.2	480	160	0.0040	39,000	1.78	1.33
AC-10 + SBS/Oil (8.6%)	2.7	190	110	0.0100	12,000	2.2	420	150	0.0080	19,000	2.21	1.36
AC-10 + Latex(3%)	3.4	170	98	0.0082	12,000	3.6	460	140	0.0047	29,000	2.71	1.43
AC-10 + Carbon Black(12.5%)	4.6	350	140	0.0064	21,000	5.2	610	160	0.0042	40,000	1.74	1.14
AC-10 + Polyethylene(5%)	3.8	380	140	0.0047	30,000	4.1	600	170	0.0036	48,000	1.58	1.21

*Aging consisted of exposure to 140^{o}F for a period of four (4) weeks.

**Indirect tension tests were performed at 77^{o}F and 2-inches/minute before and after aging.

Table B7. Resilient Modulus, Hveem and Marshall Stability of Pavement CORES from District 1.

Type Mixture	Air Void Content, Percent	Resilient Modulus, psi x 10^{-3}					Hveem Stability	Marshall Test	
		-13°F	36°F	69°F	77°F	102°F		Stability, lbs.	Flow 0.01"
AC-20 Control A (4-inches)	6.8	1600	1100	450	370	78	36	1220	15
AC-20 Control B (3-inches)	6.8	1700	1100	390	290	62	33	1050	16
AC-10 + EVA (2%)	8.3	1500	1100	390	290	67	34	930	16
AC-10 + SBS /oil Oil (8.6%)	8.9	1500	840	220	160	42	33	900	21
AC-10 + Latex (3%)	6.2	1600	1000	290	210	50	35	1080	18
AC-10 + Carbon Black (12.5%)	9.0	1600	1100	320	260	51	32	870	17
AC-10 + Poly-ethylene (5%)	4.1	1700	1200	490	370	96	40	1800	14

Table B8. Properties of Pavement CORES from District 1 Before and After Accelerated Lottman Freeze-Thaw Procedure.

Type Mixture	Before Moisture Treatment					After Moisture Treatment**					Tensile Strength Ratio
			Tensile Properties*					Tensile Properties*			
	Air Void Content, Percent	Resilient Modulus at 77 F, psi x 10	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Saturated Air Void Content, Percent	Air Voids Filled, Percent	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	
AC-20 Control A (4-inches)	6.9	370	110	0.0029	37,000	4.5	28	120	0.0041	29,000	1.09
AC-20 Control B (3-inches)	6.8	340	97	0.0030	32,000	6.2	25	86	0.0045	20,000	0.89
AC-10 + EVA(2%)	6.6	310	93	0.0032	31,000	5.6	25	97	0.0039	25,000	1.04
AC-10 + SBS/Oil (8.6%)	7.5	190	68	0.0043	16,000	5.7	26	71	0.0069	10,000	1.04
AC-10 + Latex(3%)	8.4	190	62	0.0034	19,000	5.4	26	69	0.0053	13,000	1.11
AC-10 + Carbon Black(12.5%)	8.8	220	77	0.0047	18,000	6.1	27	73	0.0036	20,000	0.95
AC-10 + Polyethylene(5%)	4.5	330	110	0.0032	37,000	2.4	27	140	0.0046	31,000	1.27

*Indirect tension tests were performed at 77°F and 2-inches/minute before and after moisture treatment.

**Specimens were left in 77°F water bath for 4 days after 24 hour conditioning in 140°F water bath prior to testing due to temporary mechanical failure of testing machine.

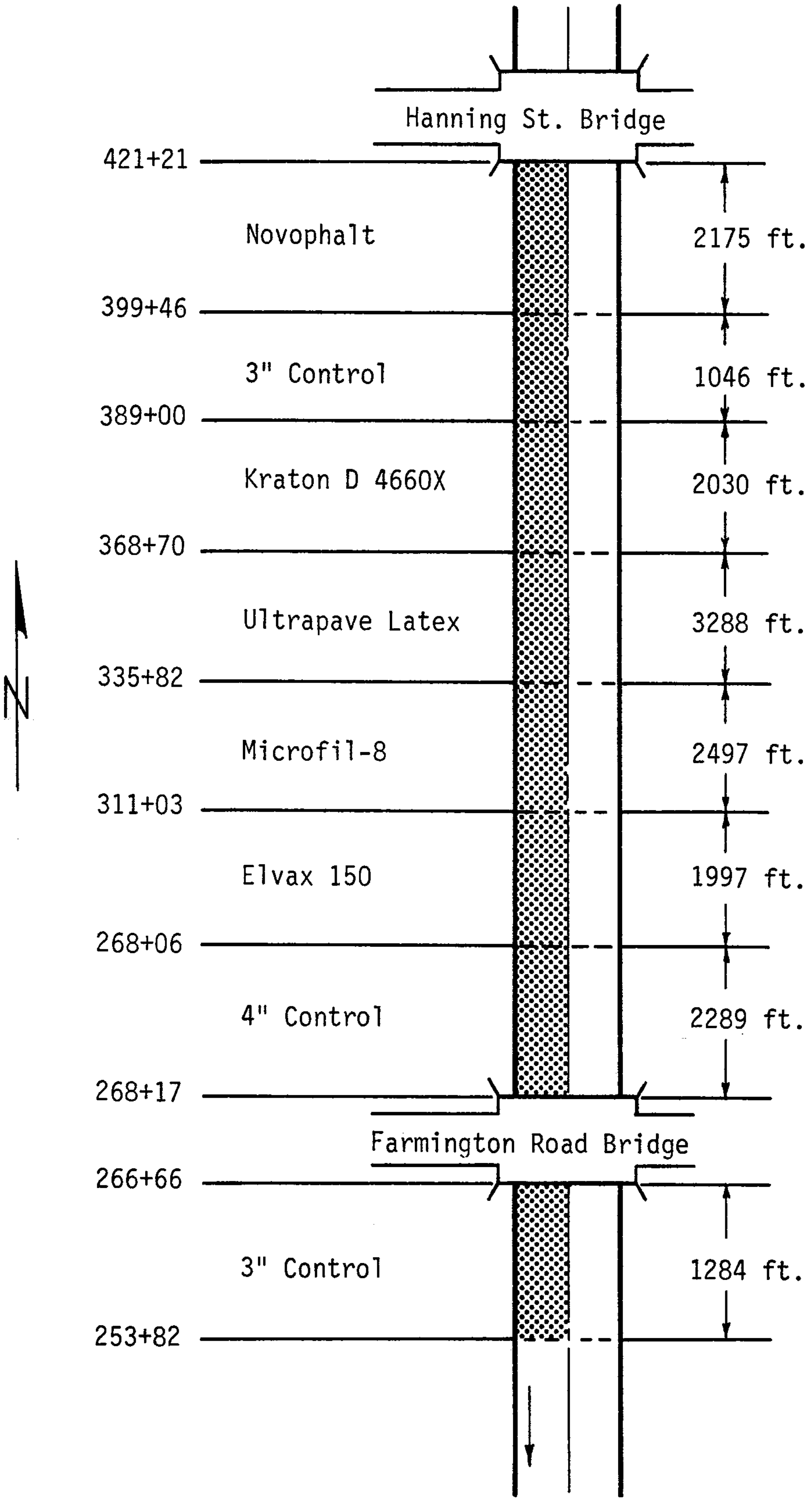

Figure B1. Limits of Additive Test Pavements in District 1.

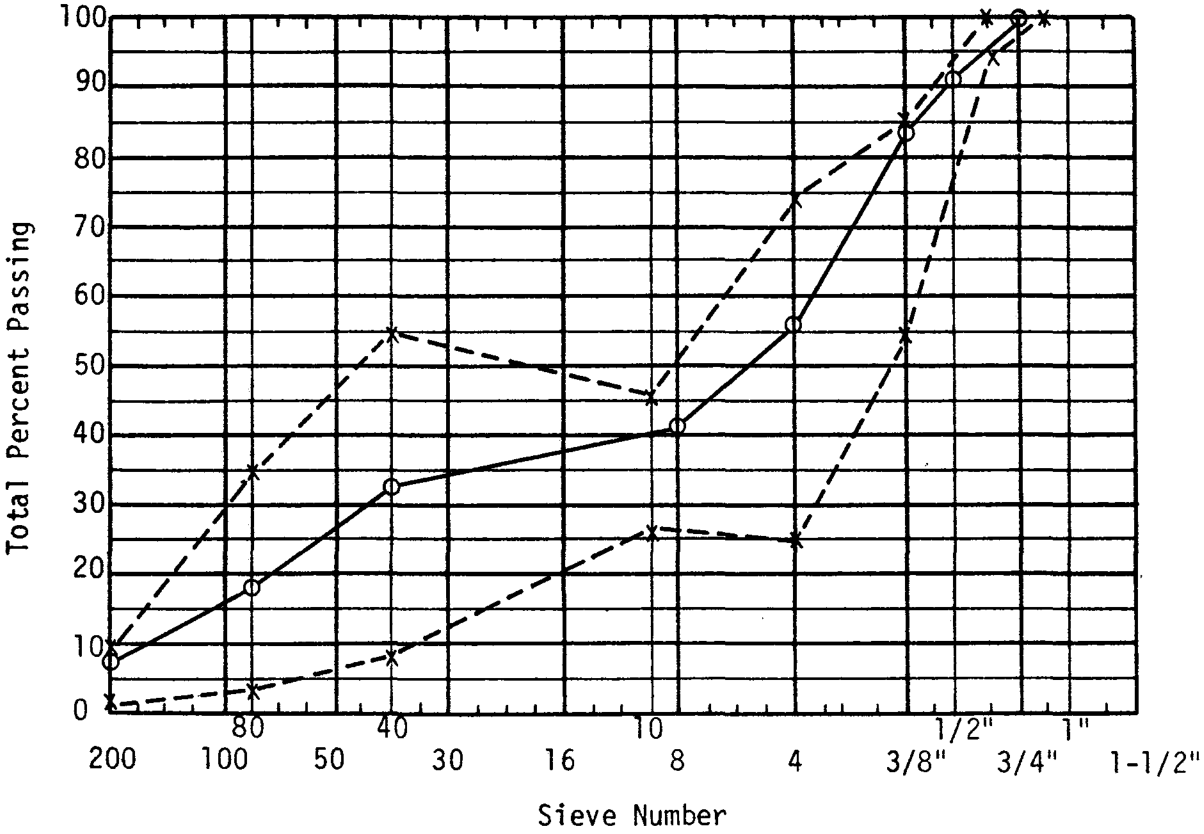

Figure B2. Aggregate Sieve Analysis from Pavement Cores from District 1 and Type G (modified course graded surface course) Gradation Specification.

APPENDIX C

Test Results on Materials from District 21

Table C1. Hot Mix Asphalt Concrete Design Data - District 21.

Aggregate Gradation		Aggregate Blend	
Sieve Size	Percent	Aggregate	Percent
Passing 1/2"	100.0	Fordyce Grade 4	40
Passing 3/8"	94.2	Fordyce Grade 6	15
Pass 3/8" Ret. #4	36.1	Crow Medium Aggregate	25
Pass #4 Ret. #10	19.9	Fordyce Fine Sand	20
Total Ret. #10	61.8	Lime Added	1
Pass #10 Ret. #40	6.2		
Pass #40 Ret. #80	24.3		
Pass #80 Ret. #200	6.2		
Passing #200	1.5		

Optimum Asphalt Content (AC-20) = 5.6%

Percent Bitumen	Percent Density	Hveem Stability
5.0	95.4	43
5.5	96.7	44
6.0	98.6	43

Table C2. Data on Aggregate used in District 21 Test Pavements.

Sieve Size	Fordyce Grade 4	Fordyce Grade 6	Crow Med. Aggr.	Fordyce Sand
1/2" - 3/8"	14.6	-	-	-
3/8" - #4	80.8	16.0	5.5	-
#4 - #10	3.7	75.8	27.2	1.1
#10 - #40	0.4	8.2	14.4	6.0
#40 - #80	0.1	-	41.9	68.8
#80 - #200	0.2	-	10.4	17.6
- #200	0.2	-	0.6	6.5
Loss by Decantation:	Nil	Nil	-	-
Plasticity Index	-	-	3.0	4.1
Specific Gravity	2.579	2.564	(+80) 2.527 (-80) 2.527	2.604 2.587

Sand Equivalent (Combine Aggregate) = 54

Table C3. Properties of Binders used in Test Pavements in District 21.

Test Property	Type of Binder					
	AC-20	AC-10	Car. Blk. + AC-10	EVA + AC-10	SBR + AC-10	SBS + AC-10
<u>Original Binder</u>						
Penetration, ASTM D5						
77°F (25°C), 100 gm, 5 sec	74	121	90	65	88	106
39°F (4°C), 100 gm, 5 sec	5	10	10	8	5	15
39°F (4°C), 200 gm, 60 sec	26	40	37	43	36	50
Viscosity, ASTM D2171						
140°F (60°C), poise	2060	1020	2600[1]	1750	2190	5230
275°F (135°C), poise	3.87	3.26	6.00[1]	7.22	4.87	7.74
R&B Soft Point, °F(°C), ASTM D36	120(49)	112(44)	119(48)	143(62)	118(48)	153(67)
Flash Point, °F(°C), ASTM D92	530(277)	425(218)	475(246)	530(277)	570(299)	495(257)
<u>After Thin Film Oven Test</u>, ASTM D1754						
Penetration, ASTM D5						
77°F (25°C), 100 gm, 5 sec	49	75	56	51	63	84
Viscosity, ASTM D2171						
140°F (60°C), poise	4510	2130	5500[1]	3170	3770	8070
Ductility, ASTM D113						
77°F (25°C), 5 cm/min	120+	120+	120+	19	120+	116
Weight Loss, percent	0.48	0.49	0.34	0.40	0.48	0.69

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[1] Viscosity measured using Brookfield viscometer.

Table C4. Summary of Forced Ductility Tests @ 39.2°F and 5 cm/min after Thin Film Oven Test District 21.*

Sample Type	Maximum Engineering Stress, psi	Maxiumum Engineering Strain, in/in	Area Under Stress-Strain Curve	Initial Slope of True Stress-Strain Curve
AC-10	8.9	4.9	17	22
AC-20	Broke with no measurable stress or strain.			
AC-10 + 5% EVA[1]	10.4	30.2	41	14
AC-10 + 12% SBS/Oil[2]	4.8	33.6	85	9
AC-10 + 2.1% SBR[3]	8.5	35.2	46	3
AC-10 + 10% CB[4]	13.4	6.8	29	20

* Each value represents an average from two tests.

Table C5. Resilient Modulus, Hveem and Marshall Stability of Field Mixed - Laboratory Molded Specimens from District 21.

Type Mixture	Air Void Content, percent	Resilient Modulus, psi x 10^3					Hveem Stability	Marshall Test	
		-17°F	35°F	67°F	77°F	105°F		Stability, lbs.	Flow, 0.01"
AC-20 Control-1	3.2	2180	1420	500	240	56	39	1310	13
AC-10+5% EVA[1]	5.9	2020	1270	460	260	70	42	1190	11
AC-10+12% SBS/Oil[2]	5.5	1940	1030	280	130	40	43	1520	14
AC-10+2.1% SBR[3]	7.0	1990	1400	380	190	43	40	1090	14
AC-10+10% CB[4]	4.8	2160	1480	430	230	57	39	1440	13

[1] EVA consisted of Exxon Polybilt 102.

[2] The SBS product, Shell Kraton D4460X, is a 50-50 blend of SBS copolymer and extender oil.

[3] SBR rubber solids (2.1%) resulted from the addition of 3% neat Goodyear Ultrapave Latex.

[4] Carbon Black (CB) consisted of Cabot Microfil-8.

Table C6. Properties of Field Mixed - Laboratory Molded Specimens from District 21 Before and After Accelerated Lottman Freeze-Thaw Moisture Treatment.

	Before Treatment					After Treatment[5]					
			Tensile Properties*					Tensile Properties[6]			
Type Mixture	Air Void Content, percent	Resilient Modulus @ 77°F, psi x 10^3	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Air Void Content, percent	Percent Voids Filed with Water	Tensile Strength, psi	Strain @ Failure, in/in	Secant Modulus, psi	Tensile Strength Ratio
AC-20 Control-1	3.2	230	117	0.0041	28,400	2.9	18	104	0.0042	25,400	0.89
AC-10 + 5% EVA[1]	6.3	260	107	0.0032	34,000	4.8	15	114	0.0037	31,500	1.07
AC-10 + 12% SBS/Oil[2]	6.1	130	75	0.0052	14,800	4.5	20	76	0.0065	12,100	1.01
AC-10 + 2.1% SBR[3]	6.8	190	96	0.0043	22,700	6.0	17	91	0.0054	16,900	0.95
AC-10 + 10% CB[4]	5.3	230	113	0.0036	33,500	4.0	18	108	0.0040	27,800	0.96

[1] EVA consisted of Exxon Polybilt 102

[2] The SBS product, Shell Kraton D4460X, is a 50-50 blend of SBS copolymer and extender oil.

[3] SBR rubber solids (2.1%) resulted from the addition of 3% neat Goodyear Ultrapave Latex.

[4] Carbon Black (CB) consisted of Cabot Microfil-8.

[5] Specimens were left in 77°F water bath for 2 days after complete Lottman procedure and prior to testing due to equipment malfunction.

[6] Tensile tests at 2 in/min and 77°F.

Table C7. Properties of Field Mixed - Laboratory Molded Specimens from District 21 Before and After Thermal Aging Treatment.

Type Mixture	Before Treatment					After Treatment[6]						
			Tensile Properties[5]					Tensile Properties[5]				
	Air Void Content, percent	Resilient Modulus @ 77°F, psi x 10^3	Stress, psi	Max Strain, in/in	Secant Modulus, psi	Air Void Content, percent	Resilient Modulus @ 77°F, psi x 10^3	Stress, psi	Max Strain, in/in	Secant Modulus, psi	Resilient Modulus Ratio	Tensile Strength Ratio
AC-20 Control 1	3.2	230	117	0.0041	28,400	3.4	470	195	0.0029	67,200	2.04	1.67
AC-10 + 5% EVA[1]	6.3	260	107	0.0032	34,000	6.4	460	181	0.0028	65,800	1.77	1.69
AC-10 + 12% SBS/Oil[2]	6.1	130	75	0.0052	14,800	5.9	350	123	0.0039	31,900	2.69	1.64
AC-10 + 2.1% SBR[3]	6.8	190	96	0.0043	22,700	6.5	450	166	0.0028	60,700	2.37	1.73
AC-10 + 10% CB[4]	5.3	230	113	0.0036	33,500	5.1	450	175	0.0025	71,100	1.96	1.55

[1] EVA consisted of Exxon Polybilt 102.

[2] The SBS product, Shell Kraton D4460X, is a 50-50 blend of SBS copolymer and extender oil.

[3] SBR rubber solids (2.1%) resulted from the addition of 3% neat Goodyear Ultrapave Latex.

[4] Carbon Black (CB) consisted of Cabot Microfil-8.

[5] Tensile tests at 2 in/min and 77°F.

[6] Samples cured at 140°F for 4 weeks.

Table C8. Resilient Modulus, Hveem and Marshall Stability of Pavement CORES from District 21.

Type Mixture	Air Void Content, percent	Resilient Modulus, psi x 10^3					Hveem Stability	Marshall Test	
		-17°F	34°F	65°F	77°F	104°F		Stability, lbs.	Flow
AC-20 Control 1	7.6	1900	1300	460	240	50	31	540	13
AC-20 Control 2	7.4	1700	1400	500	250	50	29	700	13
AC-10 + 5% EVA[1]	9.6	1800	1100	390	220	60	31	810	14
AC-10 + 12% SBS/Oil[2]	12.2	1500	700	170	80	30	27	520	15
AC-10 + 2.1% SBR[3]	11.8	1700	1100	350	220	40	29	640	14
AC-10 + 10% CB[4]	10.3	1700	1100	320	210	40	27	650	13

[1] EVA consisted of Exxon Polybilt 102.

[2] The SBS product, Shell Kraton D4460X, is a 50-50 blend of SBS copolymer and extender oil.

[3] SBR rubber solids (2.1%) resulted from the addition of 3% neat Goodyear Ultrapave Latex.

[4] Carbon Black (CB) consisted of Cabot Microfil-8.

Table C9. Properties of Pavement CORES from District 21 Before and After Accelerated Lottman Freeze-Thaw Moisture Treatment Procedure.

Type Mixture	Before Treatment					After Treatment					
	Air Void Content, percent	Resilient Modulus @ 77°F, psi x 10^3	Tensile Properties[5]			Air Void Content, percent	Air Voids Filled with Water, percent	Tensile Properties[5]			Tensile Strength Ratio
			Strength, psi	Max. Strain, in/in	Secant Modulus, psi			Strength, psi	Max. Strain, in/in	Secant Modulus, psi	
AC-20 Control 1	7.2	240	110	0.0033	35,000	4.4	36	78	0.0047	17,000	0.71
AC-20 Control 2	7.2	250	120	0.0038	32,000	4.7	36	79	0.0055	14,000	0.66
AC-10 + 5% EVA[1]	9.5	220	93	0.0032	28,000	6.5	35	63	0.0040	42,000	0.68
AC-10 + 12% SBS[2]	12.6	80	51	0.0064	8,000	9.5	22	40	0.0082	5,000	0.78
AC-10 + 2.1% SBR[3]	11.9	260	97	0.0044	23,000	9.9	23	61	0.0059	11,000	0.63
AC-10 + 10% CB[4]	9.9	210	91	0.0039	23,000	7.9	23	59	0.0049	12,000	0.65

[1] EVA consisted of Exxon Polybilt 102.

[2] The SBS product, Shell Kraton D4460X, is a 50-50 blend of SBS copolymer and extender oil.

[3] SBR rubber solids (2.1%) resulted from the addition of 3% neat Goodyear Ultrapave Latex.

[4] Carbon Black (CB) consisted of Cabot Microfil-8.

[5] Tensile tests at 2 in/min and 77°F.

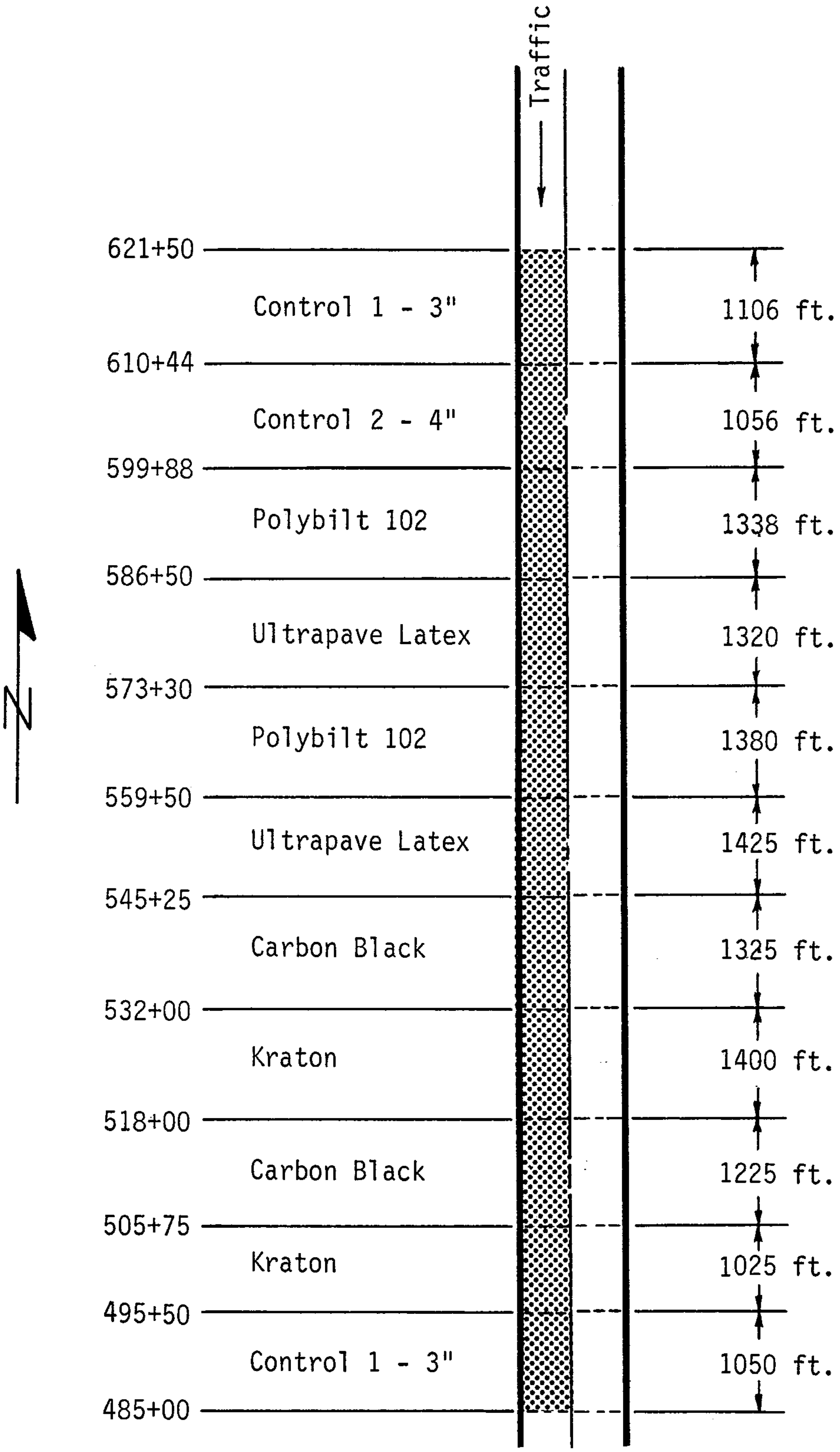

Figure C1. Limits of Additive Test Pavements in District 21.

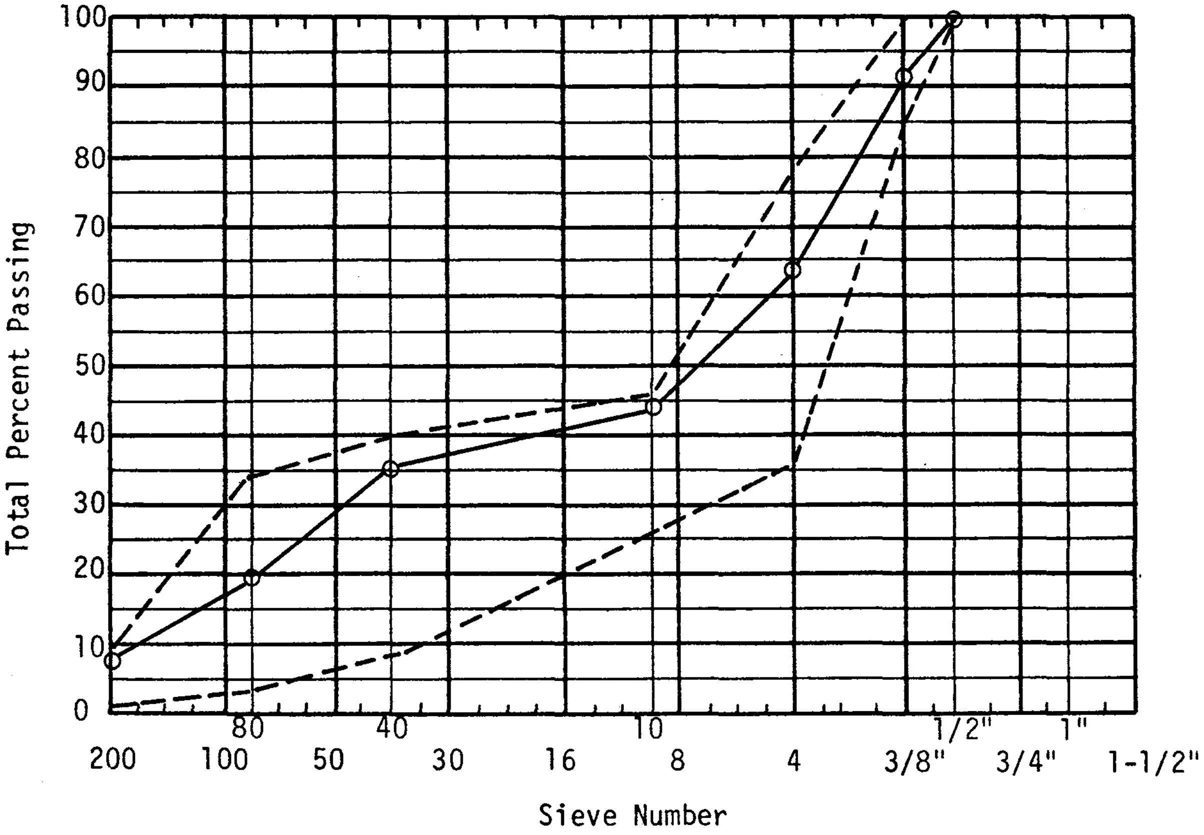

Figure C2. Aggregate Sieve Analysis from Pavement Cores from District 21 and Type G (modified fine graded surface course) Gradation Specification.