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16. Abstract
The purpose of this study was to investigate the effects of curing time and air void content on asphalt paving mixtures containing Chemkrete. One goal of this study was to determine whether the rapid aging of this product in the early stages is temporary to insure that continued hardening of the binder does not eventually produce excessively brittle mixtures. Different dosages of Chemkrete, aging periods and air void contents were evaluated using different asphalt aggregate mixtures.

Laboratory tests and literature reviews indicated that the Chemkrete slows after about 20 days but does not appear to cease even at 90 days. Using a softer grade of asphalt with Chemkrete, laboratory mixtures attained equal or greater strength, stability and stiffness as compared to control mixtures containing an untreated harder grade of asphalt cement. Based on laboratory tests, Chemkrete mixtures containing higher air voids and allowed to cure at temperatures above 77°F for 30 days or more, the mixtures attained a significantly greater stiffness than the control mixtures.

Two field test pavements were constructed. Samples were subjected to long-term conditioning at high temperatures similar to summer pavement temperatures. Tensile strength, stiffness, stability and water susceptibility of roadway cores and laboratory molded samples were quantified. Extracted asphalt cements were tested for viscosity, penetration and softening point. The Chemkrete sections of both test roads are experiencing extensive cracking.

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Another Look at CHEMKRETE

by

Cindy Adams

and

Joe Button

Research Study Number 2-985-471

Report No. 471-1

Sponsored by the

State Department of

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United States Department of Transportation

Federal Highway Administration

Texas Transportation Institute

Texas A&M University

College Station, Texas 77843

June, 1987

METRIC CONVERSION FACTORS

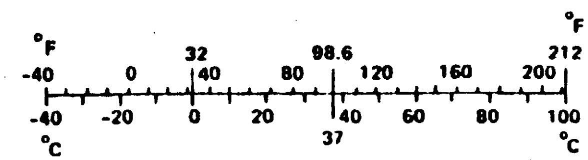
Approximate Conversions to Metric Measures

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

*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.

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



IMPLEMENTATION STATEMENT

The asphalt additive called CHEMKRETE® at the outset of this research study and in this report is believed to be the same as the product now called CTI-101 and marketed by LBD Asphalt Products Company. Design of paving mixtures and use of Chemkrete asphalt modifier in paving applications should include departure from certain standard procedures.

Chemkrete is normally used with asphalts at least one grade softer than the usual paving grade. Since Chemkrete itself has a relatively low viscosity, the initial viscosity of the modified binder is quite low. Mixture design procedures should, therefore, include an aging period prior to compaction to allow time for the oxidation reaction to occur. The manufacturer has suggested modifying the mix design procedure to include aging the uncompacted mixture for 4 hours at 275^{o}F. In the field, this low initial viscosity may manifest itself in the form of a tender mixture when marginal aggregate is used.

When Chemkrete is used, low air voids and thus low permeability of the pavement can be detrimental to the chemical reaction which depends upon availability of oxygen. Without the chemical reaction, there is no increase in viscosity of the "soft" asphalt and no decrease in binder temperature susceptibility. Plastic deformation, as manifested by rutting, shoving and/or corrugations could occur.

Presently, it appears that specifications for the Chemkrete additive will need to be specific since the properties of the material are unique. New specifications regarding an asphalt-Chemkrete blend should address additive/asphalt ratio and viscosity temperature susceptibility after a specified method to effect the reaction. Acceptance criteria based on modified mixture properties should consider minimum increases in tensile strength (indirect tension), stiffness (resilient modulus at temperatures above 70^{o}F), resistance to creep and permanent deformation, and compliance at low temperatures.

Chemkrete mixtures should not be expected to prevent reflection cracking or to perform well in thin lifts over high deflection substructures. Recent research has indicated that the principal application areas of Chemkrete include thick sections of asphalt concrete pavements. A thick test section of Chemkrete is planned for construction in District 19 in the summer of 1987. This will be monitored under Study 187.

No further research of Chemkrete asphalt additive appears justified at this time.

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.

ABSTRACT

The purpose of this study was to investigate the effects of curing time and air void content on asphalt paving mixtures containing Chemkrete. One goal of this study was to determine whether the rapid aging of this product in the early stages is temporary to insure that continued hardening of the binder does not eventually produce excessively brittle mixtures. Different dosages of Chemkrete, aging periods and air void contents were evaluated using different asphalt aggregate mixtures.

Laboratory tests and literature reviews indicated that the Chemkrete slows after about 20 days but does not appear to cease even at 90 days. Using a softer grade of asphalt with Chemkrete, laboratory mixtures attained equal or greater strength, stability and stiffness as compared to control mixtures containing an untreated harder grade of asphalt cement. Based on laboratory tests, Chemkrete mixtures containing higher air voids and allowed to cure at temperatures above 77°F for 30 days or more, the mixtures attained a significantly greater stiffness than the control mixtures.

Two field test pavements were constructed. Samples were subjected to long-term conditioning at high temperatures similar to summer pavement temperatures. Tensile strength, stiffness, stability and water susceptibility of roadway cores and laboratory molded samples were quantified. Extracted asphalt cements were tested for viscosity, penetration and softening point. The Chemkrete sections of both test roads are experiencing extensive cracking.

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CHAPTER I. INTRODUCTION

History

"CHEMKRETE®" asphalt modifier has been used in recent years as an additive in hot mixed asphalt concrete (HMAC) pavement construction. It is manufactured by Chemkrete Technologies, a division of the Lubrizol Corporation. Chemkrete is purported to reduce the temperature susceptibility of the asphalt cement. Chemkrete also increases the viscosity of the asphalt; therefore, it should be used with a softer-than-usual grade of asphalt cement making it possible to produce a mixture with strengths and stiffnesses equivalent to normal HMAC at high temperatures and with more flexibility at low temperatures (1). The mixtures made with Chemkrete generally require a "curing" period before the maximum benefits are realized (2).

Chemkrete has been used in several documented field trials (3,4). In 1980, projects were constructed in Oklahoma, Nevada, Wyoming, New Hampshire, Illinois, Arizona, Nebraska, Iowa, Virginia and South Carolina (3). In each of these projects, with the exception of South Carolina, the sections placed using the Chemkrete modifier achieved higher strength and stabilities. However, the Chemkrete sections of these pavements exhibited poor low temperature properties as manifested by excessive cracking. Raveling was also noted in the Chemkrete sections of the pavements in Oklahoma and Virginia. In 1981, projects were constructed in Ohio, Pennsylvania, California, New Hampshire, Maine, Oregon, Georgia, Colorada and Mississippi (4). In each of these projects, with the exception of Mississippi, the Chemkrete sections achieved higher strength and stabilities. Chemkrete Technologies, Inc. (CTI) attributed the cracking problems that developed in the 1981 projects to production, mixing and construction irregularities. Application of a new product or procedure can often cause departure from normal paving practices. After reviewing the performance of 1981 projects, CTI recommended reducing the concentration of Chemkrete to one part in 15 parts asphalt.

In 1982, projects were constructed in Idaho, California, Oklahoma, West Virginia, Hawaii, Washington, D.C. and Alaska (4). At the time of the report (May 1983), construction of the 1982 projects had been completed for 8 to 16 months and each project was performing very well except the project in Enid, Oklahoma, where spot failures developed on the Chemkrete section and required patching immediately after construction. Subsequently, the entire Chemkrete section had to be overlayed. Recent research indicates that the principal application areas include thick sections of asphalt concrete in new construction and thick overlays (1). This study (1) also concluded that the Chemkrete mixtures should not be expected to prevent reflection cracking or to perform in thin lifts over high deflection bases. The manufacturer has adopted the philosophy that the product should be prescribed to solve specific problems and that care must be taken in all aspects of design and construction.

Scope

The purpose of this study was to examine the effects of curing time and air void content on asphalt paving mixtures containing Chemkrete. Chemkrete is used with a softer than usual grade of asphalt cement since it catalyzes the oxidation process in asphalt making it possible to produce a mixture with strengths and stiffnesses equivalent to that containing asphalt of the usual paving grade. One goal of this study was to determine whether this rapid aging process is temporary or continues for prolonged periods thereby producing excessively brittle mixtures. Different dosages of Chemkrete, aging periods and air void contents were evaluated.

The second goal was to evaluate field performance of Chemkrete. Two field test pavements composed of Chemkrete modified asphalt concrete were constructed. One test pavement was constructed in the east and westbound lanes on State Highway 71 near LaGrange, Texas. This pavement will be referred to as the "LaGrange Test Road". A second test pavement was constructed in the north and southbound lanes of U.S. Highway 287 near Bowie, Texas. This pavement will be referred to as the "Bowie Test Road". Pavement surveys were conducted prior to construction to establish initial pavement condition. Laboratory tests were performed on the field mixes as well as on roadway cores. These data form the basis for correlation to field performance and to judge the effect of Chemkrete on asphalt mixtures.

CHAPTER II. CURING STUDY

When this research program began the material evaluated was called simply Chemkrete. It is the same as the product, CTI-101, which is now marketed by LBD Asphalt Products Company. It is described as a manganese metal complex which acts as an oxidation promoting catalyst when mixed with asphalt and exposed to air (as in thin films on aggregate surfaces). Heat will increase the rate of chemical reaction. On the contrary, lack of exposure to air (oxygen) will retard the chemical reaction. A laboratory study was conducted to judge the effects of concentration of Chemkrete, curing time and temperature and mixture air void content on the resilient modulus and tensile properties of laboratory molded specimens.

Preliminary Experiment

Mixtures were prepared using a subrounded, silicious river gravel aggregate and an AC-10 from American Petrofina. Properties of these materials are given in Appendix A. Specimens were prepared using the Marshall compactor which provides good control of compaction energy and thus air void content. A preliminary experiment (Figure 1) was conducted to determine desired compactive effort and target material properties. The results of this experiment are presented graphically in Figure 2. For a given compactive effort, the specimens containing Chemkrete exhibited less air voids and greater flow than the control mixture indicating the Chemkrete significantly reduced the viscosity of the asphalt. These specimens were tested soon after preparation, it was, therefore, assumed that no curing occurred.

Curing Study

Based on the results of the previous experiment, an experiment was designed (Figure 3) to measure the effects of air voids, concentration of Chemkrete and curing time.

		Percent Chemkrete by Weight of Asphalt		
		0	1	3
Marshall Blows per side	25	- *	-	-
	50	-	-	-
	75	-	-	-

Figure 1. Preliminary Experiment Design.

* "-" indicates one sample molded.

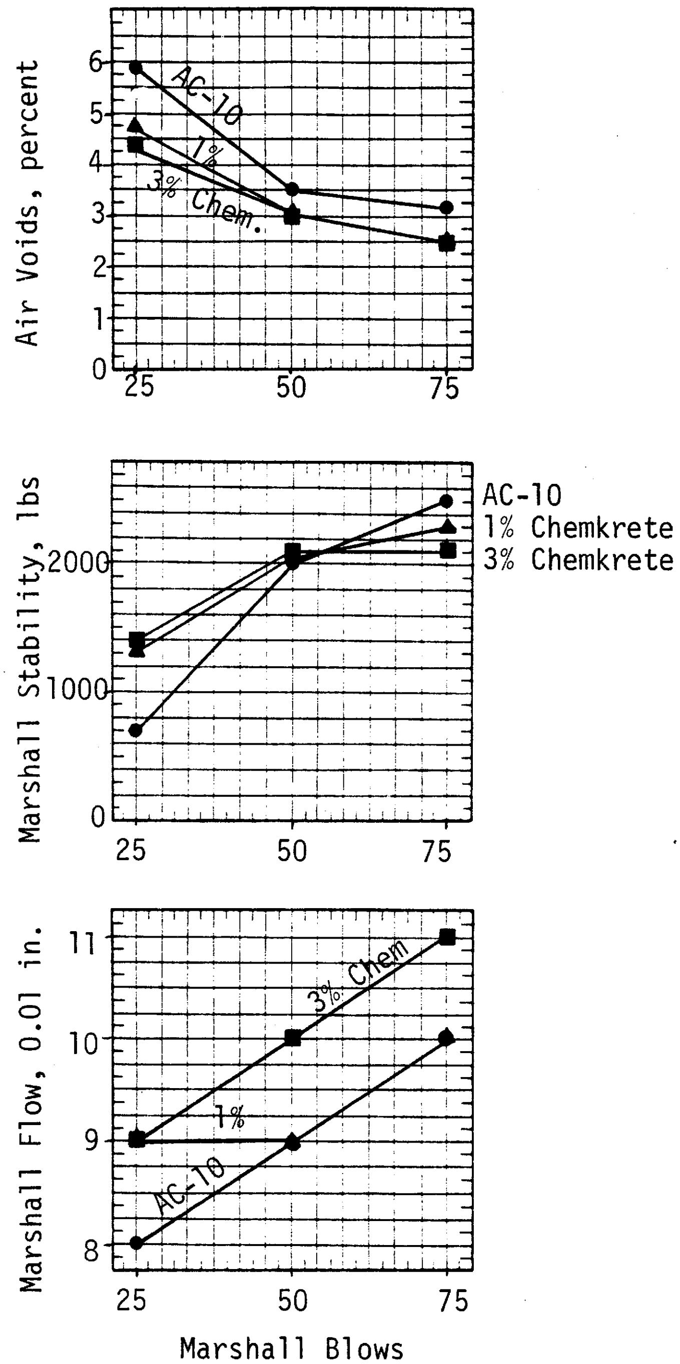

Figure 2. Laboratory Test Results of Preliminary Experiment.

% Chemkrete	0		1		3	
Marshall Blows	25	50	25	50	25	50
Curing Time, Days						
0	-* -	- -	- -	- -	- -	- -
40	- -	- -	- -	- -	- -	- -
80	- -	- -	- -	- -	- -	- -

* "-" indicates one sample molded.

Figure 3. Experiment Design for Curing Study.

Chemkrete was added to the mixtures in quantities of 0, 1, and 3 percent by weight of the binder. Samples were molded using two compactive efforts in an attempt to produce different air void contents. Samples were then cured at 140°F before testing for a time of 0, 40, and 88 days. Indirect tension and resilient modulus tests were performed on each type of sample in accordance with the test plan in Figure 4.

Laboratory Test Results

Laboratory test results are recorded in Appendix B, Tables B1 and B2. Results are presented graphically in Figures 5 and 6. The samples molded using 25 Marshall blows per side contained approximately 5 percent air voids, and the samples molded at 50 Marshall blows contained approximately 4 percent air voids. Based on the preliminary experiment (Figure 1), greater differences in air voids were expected from the two compactive efforts. The close proximity of the two void contents made it difficult to discern differences in mixture properties due to air void content.

Based on previous work, AC-10 plus Chemkrete after curing should produce a mixture with characteristics comparable to a mixture containing AC-20. This was not the case in this experiment. As shown in Figures 5 and 6, tensile strengths and stiffnesses for the AC-10 with no Chemkrete and the AC-10 plus 1 or 3 percent Chemkrete were about the same. It is, therefore, concluded that in this experiment, the Chemkrete had no effect on the mixture properties which were measured in the laboratory. This could be due to a lack of reactivity between this particular asphalt cement and the Chemkrete. It also may be that there was not sufficient Chemkrete in this particular mixture to produce any measurable differences in mixture properties. There was concern that if Chemkrete did lower the temperature susceptibility (slope of viscosity-temperature curve) of this asphalt mixture and if the pivot point was near 77°F then this improvement in mixture properties might not be detected by measuring resilient modulus and tensile strength at 77°F. However, in a study

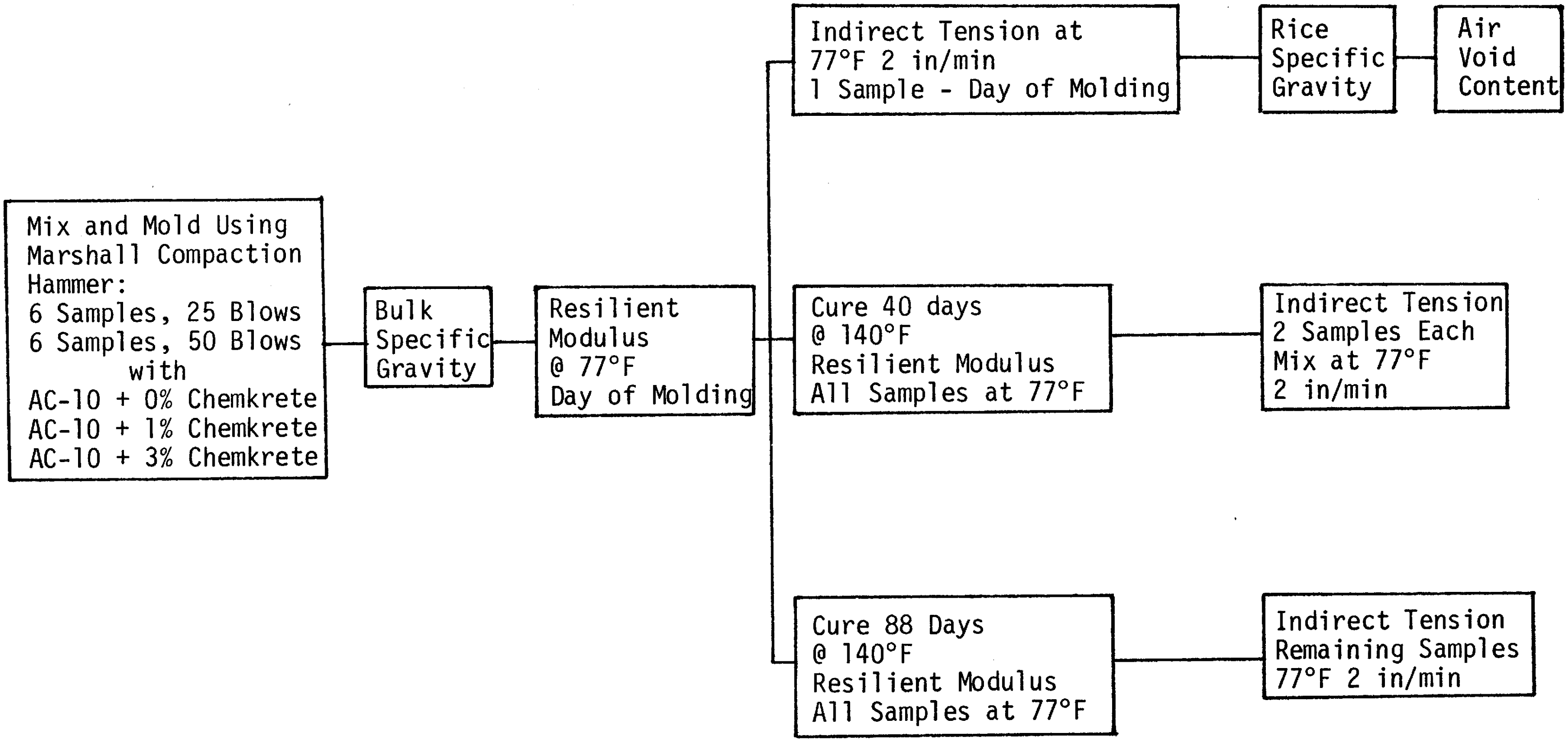

Figure 4. Testing Plan for Curing Study Using TTI Aggregate and AC-10.

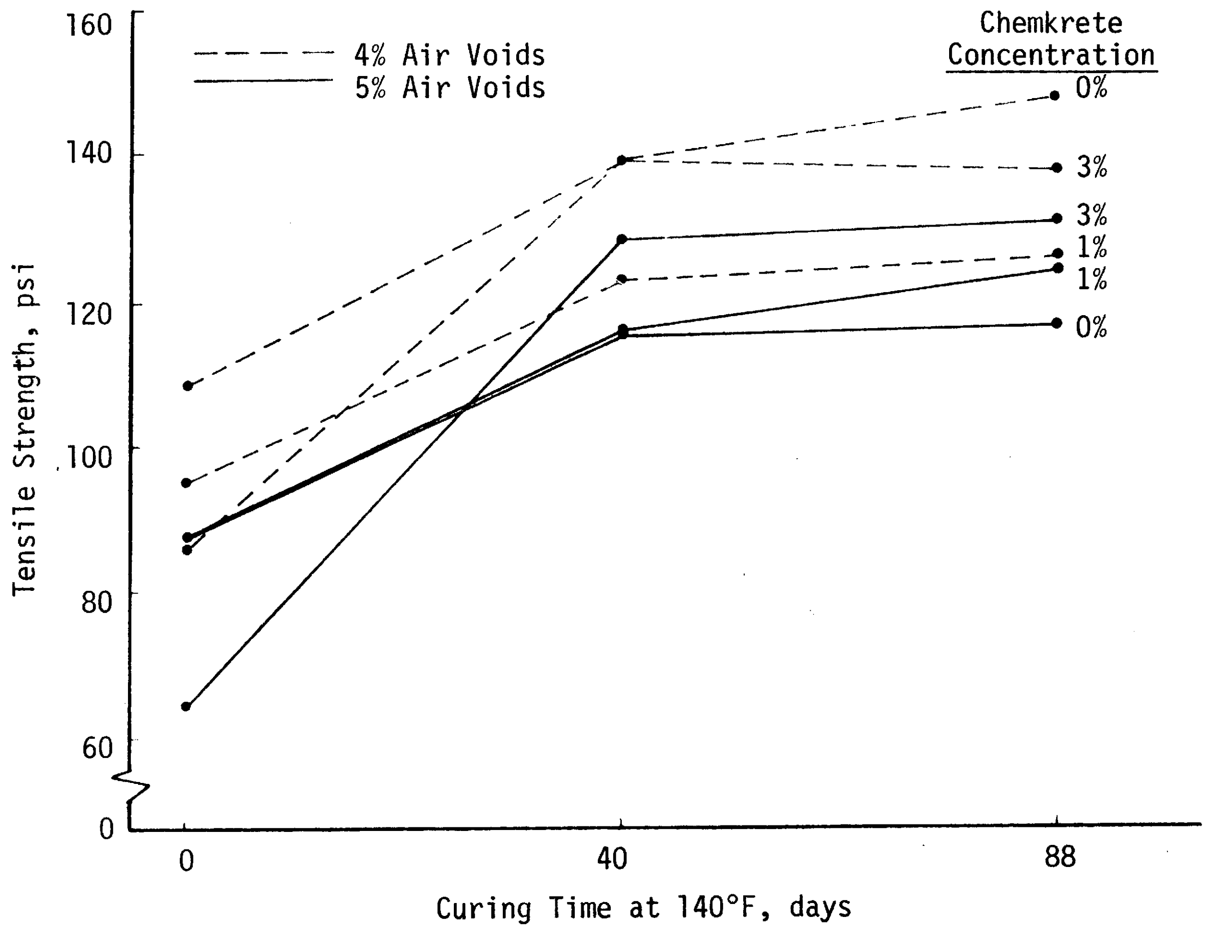

Figure 5. Tensile Strength versus Curing Time for Samples Molded with AC-10 and TTI Aggregate.

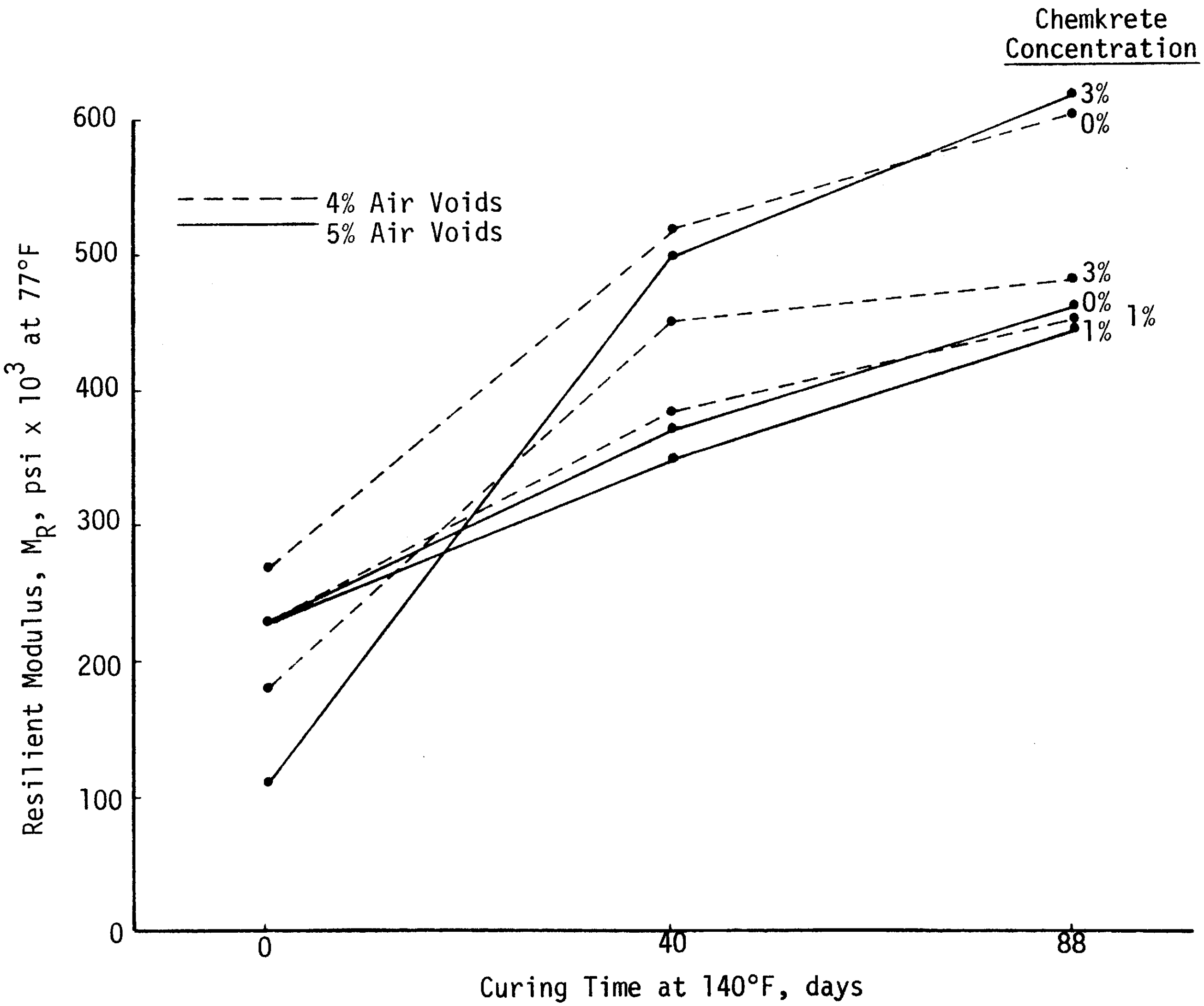

Figure 6. Resilient Modulus versus Curing Time for Samples Molded with AC-10 and TTI Aggregate.

reported by Epps, et. al. (1), Chemkrete modified asphalt cements and paving mixtures that exhibited a decrease in temperature susceptibility also exhibited an increase in resilient moduli and tensile strengths at 77°F.

As in the case with most chemical modifiers, it is suspected that Chemkrete is not equally compatible with all asphalt cements, that is, it does not catalyze the oxidation reaction to the same degree in all asphalts. This may be a result of the petroleum source, refinery process, or both.

CHAPTER III. LAGRANGE TEST ROAD

Chemkrete test pavements were built in Fayette County near LaGrange on State Highway 71. The condition of the road prior to construction was relatively good. The section to be overlaid with Chemkrete had a Pavement Rating Score (PRS) (5) of 88 and the control had a PRS of 90. The original pavement consisted of 1 1/4-inches of hot mix asphaltic concrete over flexible base.

Materials

A limestone-field sand aggregate blend was used in the construction of the asphalt concrete overlay. The aggregate gradation is shown in Figure 7 which was obtained from extraction of the field mix.

The control sections were constructed with an AC-20 and the Chemkrete sections were constructed with an AC-10 plus 4 percent Chemkrete by weight of the asphalt.

Construction

The LaGrange Test Road was constructed in May of 1984. It consisted of an overlay approximately 1 1/4-inches thick. The control sections were constructed with 5.3 percent asphalt which was the design asphalt content. During placement of the Chemkrete sections, construction problems were encountered due to periodic rainshowers. These rainshowers caused a variation in moisture content of the aggregate stockpile making it necessary to periodically adjust the plant. Therefore, in the Chemkrete sections, the binder content varied from 5.1 to 5.5 percent as shown in Figure 8. The sections with different binder contents are designated by signposts alongside the roadway. Approximately 3.5 lane miles of Chemkrete was placed and the remainder of the job (approximately 5 miles) was placed with the control material.

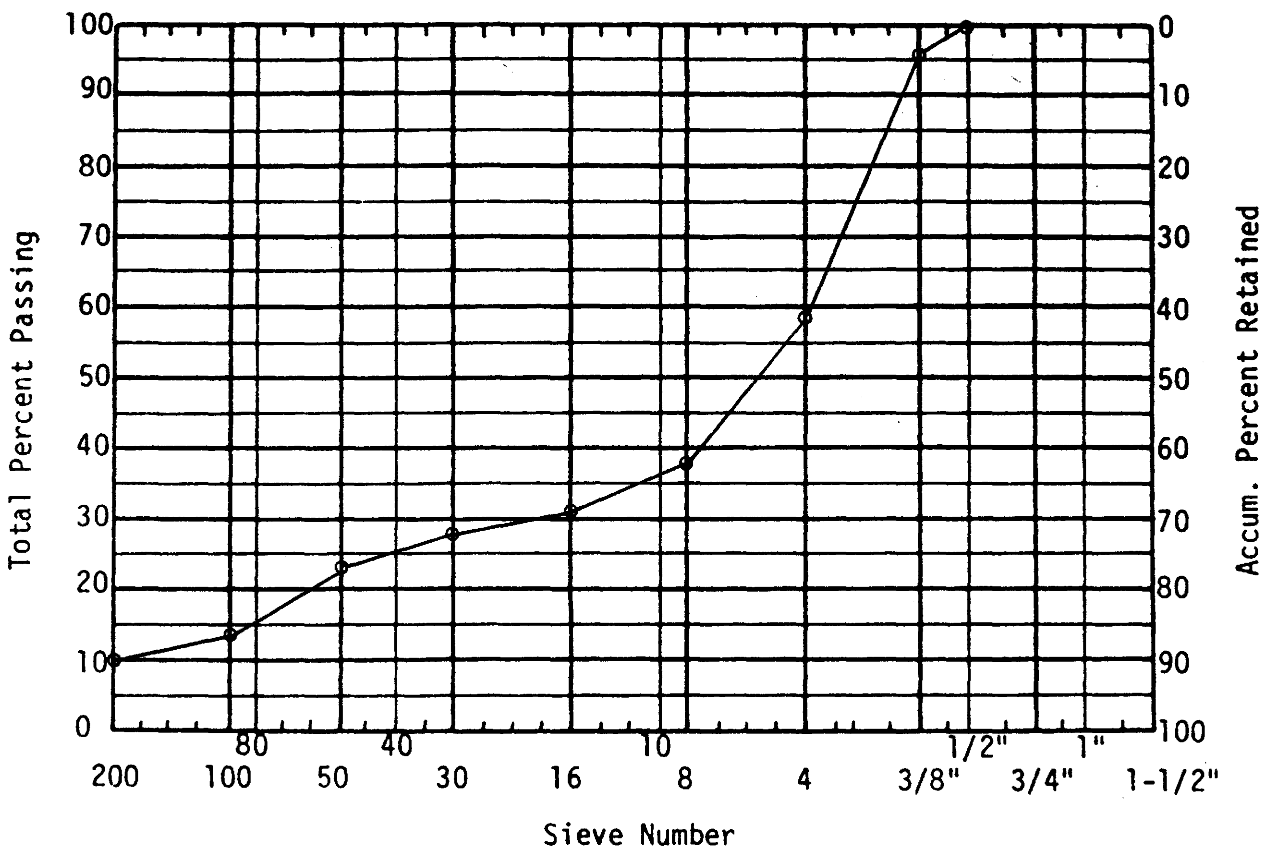

Figure 7. Aggregate Gradation for the La Grange Test Road.

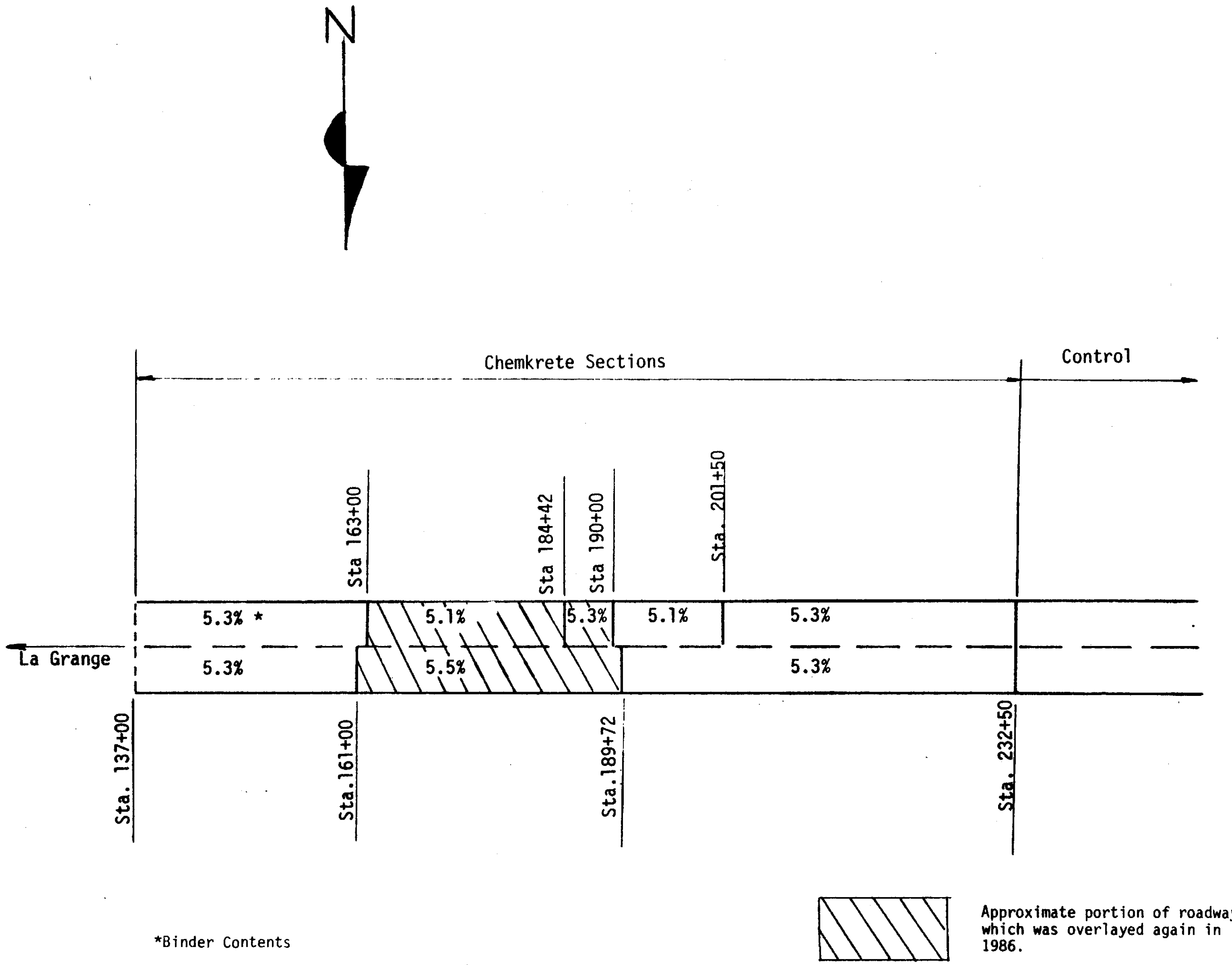

Figure 8. La Grange Test Road - Test Section Layout.

The temperature of the plant was about 300°F throughout the job. Chemkrete sections were constructed exactly as the control sections with no attempt to account for reduced viscosity of the Chemkrete mixture by changing plant temperature or rolling pattern. To prevent the pavement from being too dense, it is usually recommended that the Chemkrete be rolled at a lower temperature than a standard asphalt concrete mix because the Chemkrete initially reduces the viscosity of the binder. There must also be sufficient air voids in the overlay to allow the reaction between the Chemkrete and the asphalt cement to occur.

Laboratory Tests

Sampling. Loose samples of the Chemkrete and control mixes were obtained from haul units at the plant site and transported in insulated containers to the TTI laboratory. Samples of the Chemkrete and control mixtures were immediately molded using standard Texas gyratory compaction procedures. Another set of samples was molded using modified gyratory compaction procedures to produce a higher level of air voids.

Testing Program. A total of 36 each of Chemkrete and control samples were molded with 12 of each set containing high air voids. The air void contents were as follows:

Chemkrete: High Air Voids = 4.7 percent
Low Air Voids = 2.7 percent

Control: High Air Voids = 5.7 percent
Low Air Voids = 3.5 percent

Resilient Modulus Test Results. Four sets of samples were cured at 0, 32, 77 and 104°F for 57 days. Another set of samples was cured at 140°F for 28 days. The resilient modulus test was performed on all of the samples periodically throughout the curing period. Results of these tests are tabulated in Tables B3 and B4 and are presented graphically in Figures 9 through 13. Figures 9 and 10 show the results for the samples cured at 0°F and 32°F, respectively. At both temperatures the control samples had a higher resilient modulus than the Chemkrete samples by a factor of 2. There was no significant difference in the resilient modulus of the samples cured at 0°F and the samples cured at 32°F.

Figures 11 and 12 show the results of the samples cured at 77°F and 104°F, respectively. It is evident from these figures that a definite reaction has occurred between the Chemkrete and the asphalt cement for the samples containing the higher air void content. The Chemkrete samples containing the lower air void contents behaved in much the same way as the Chemkrete samples cured at 0°F and 32°F. The low void Chemkrete specimens cured at 104°F did exhibit a slight increase in resilient modulus over similar specimens cured at 0 and 32°F.

Figure 13 shows the results of the samples cured at 140°F. All of these samples were molded at standard compaction (low air voids). These data again prove the importance of air void content on the Chemkrete mixture. The control samples exhibited a resilient modulus value twice as high as the Chemkrete samples. It appears that, due to insufficient air voids, no reaction occurred between the Chemkrete and the asphalt cement even though the curing temperature was 140°F.

Figure 14 shows that Chemkrete is effective in decreasing mixture temperture susceptibility during the 28 day cure at 140°F even for the low air void specimens. Resilient moduli of field cores show similar results. Mixture flexibility at temperatures less than 85°F of the Chemkrete treated specimens is retained as a result of the softer AC-10. Mixture stiffness of the treated specimens is greater than the control specimens at temperatures above 85°F. These laboratory results indicate an almost ideal situation. Field performance, however, did not correspond with results that might be predicted from these laboratory tests.

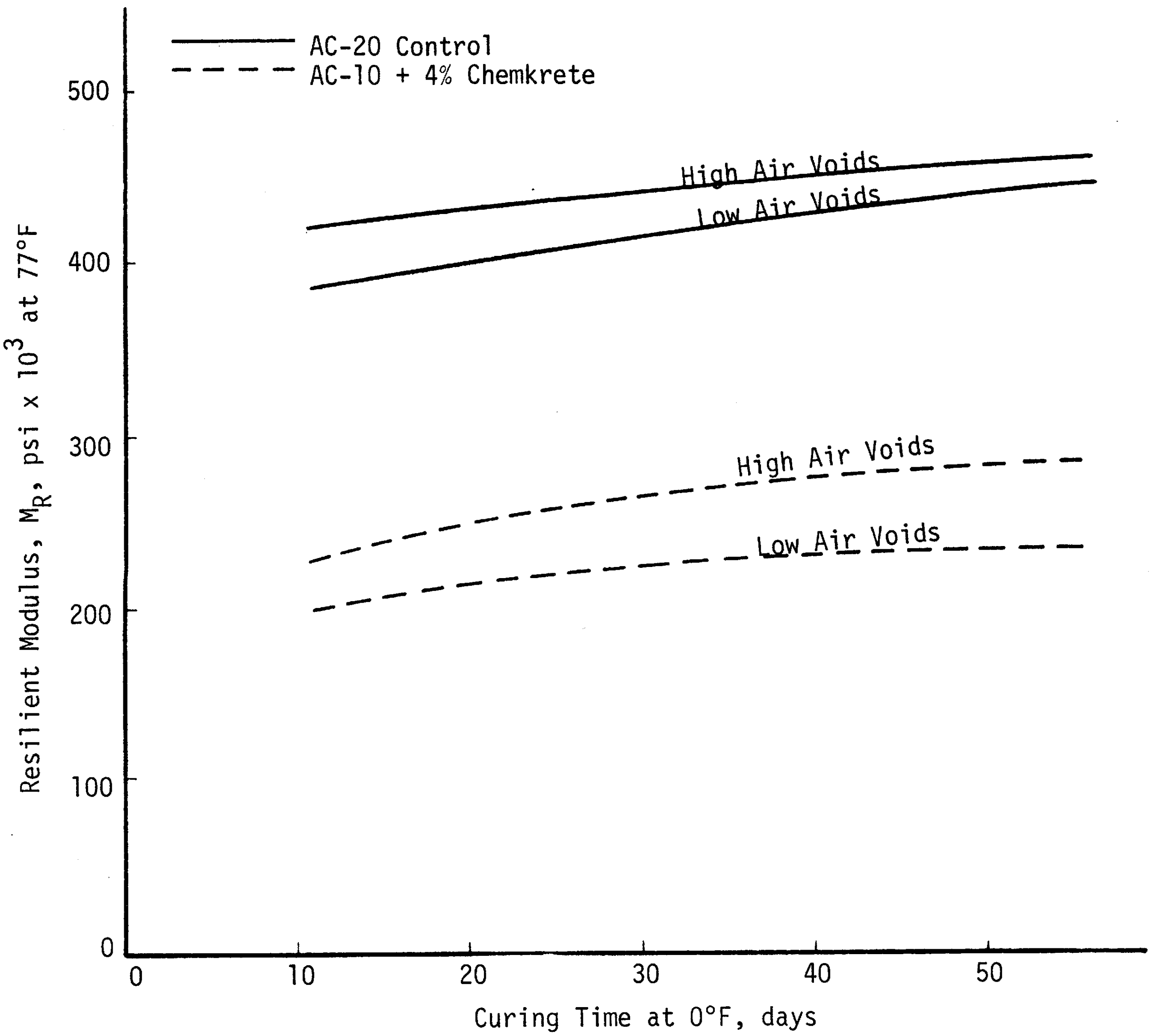

Figure 9. La Grange Test Road Laboratory Molded Samples Cured at 0°F, Resilient Moduli.

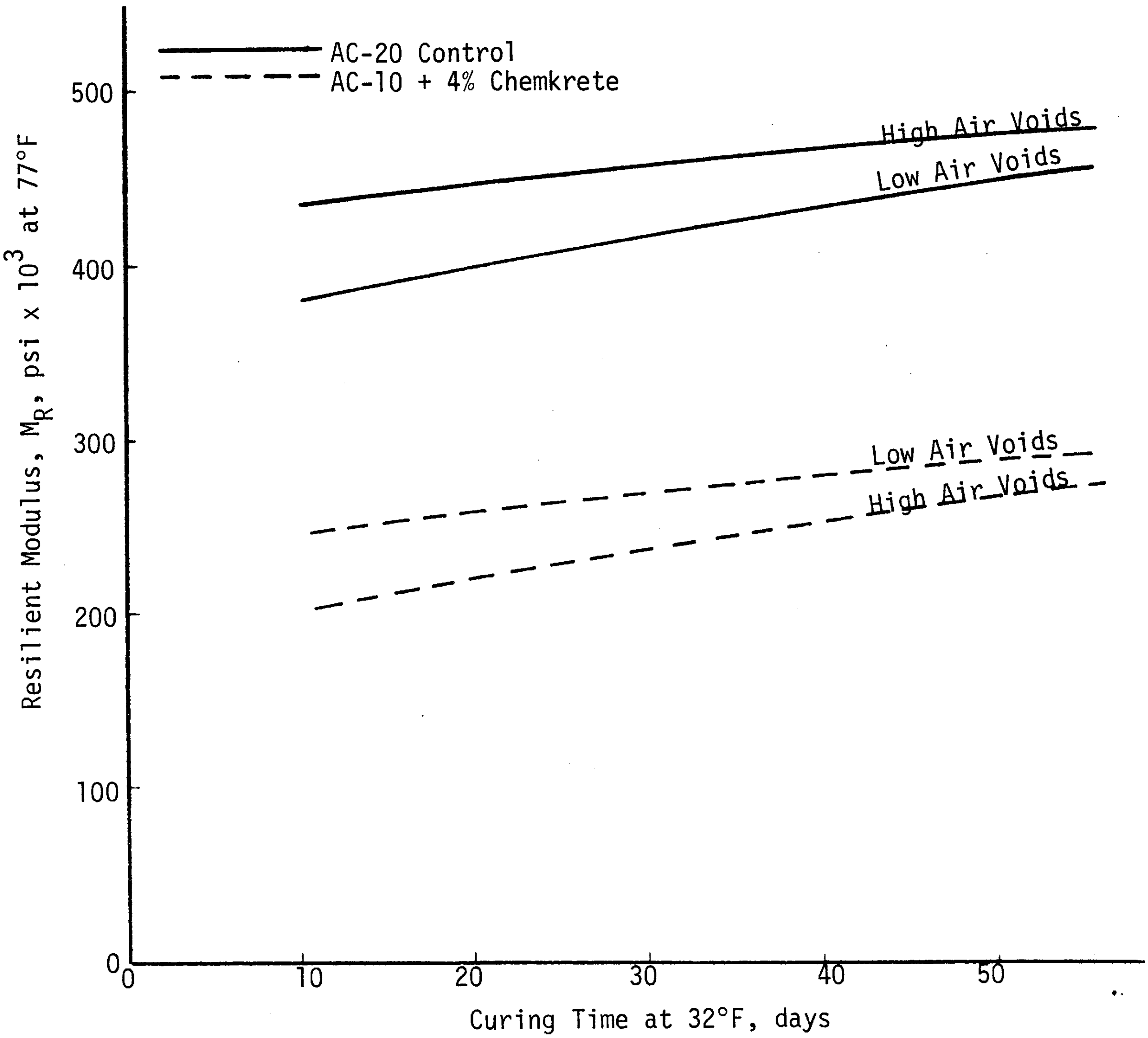

Figure 10. La Grange Test Road Laboratory Molded Samples Cured at 32°F, Resilient Moduli.

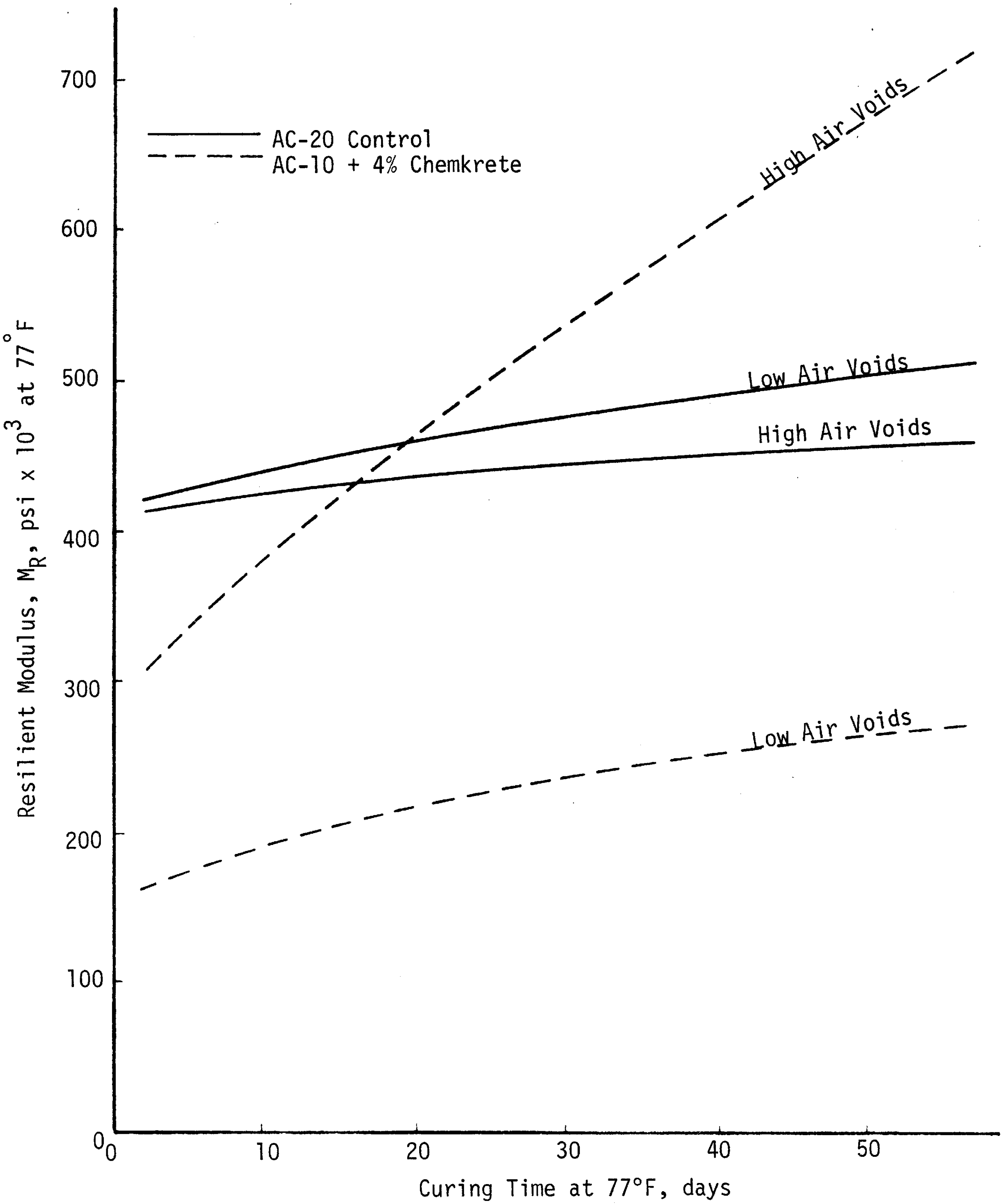

Figure 11. La Grange Test Road Laboratory Molded Samples Cured at 77°F, Resilient Moduli.

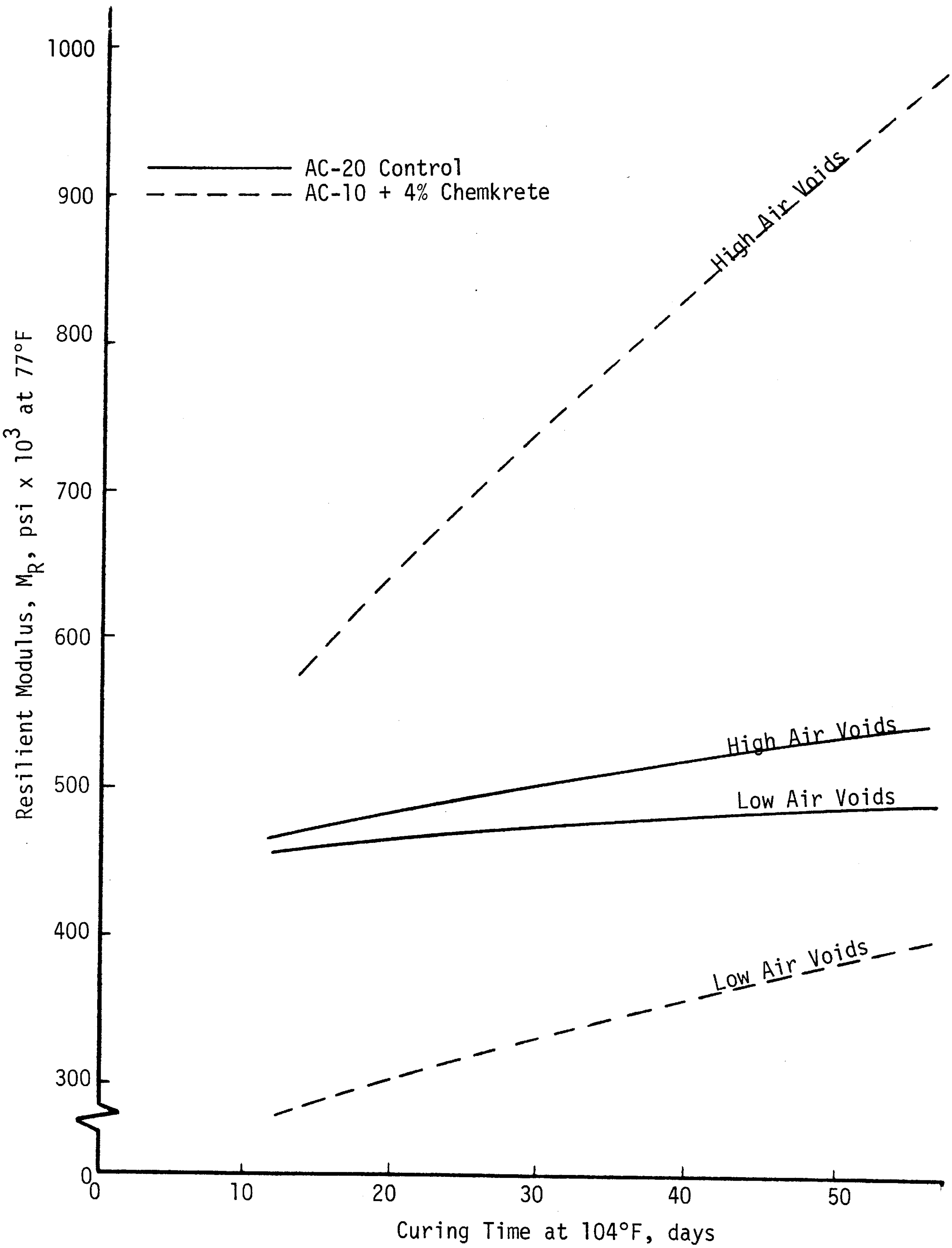

Figure 12. La Grange Test Road Laboratory Molded Samples Cured at 104°F, Resilient Moduli.

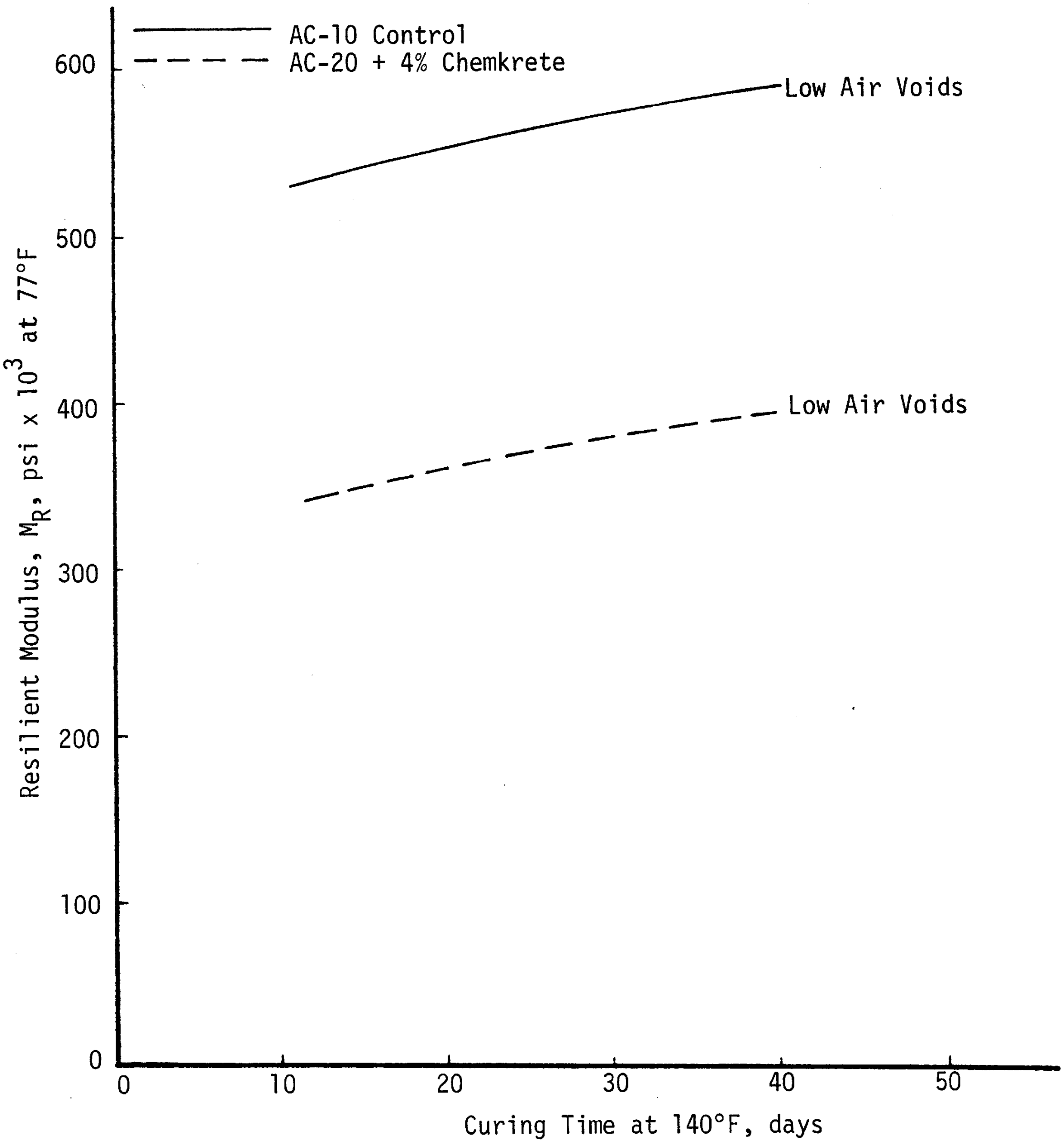

Figure 13. La Grange Test Road Laboratory Molded Samples Cured at 140°F, Resilient Moduli.

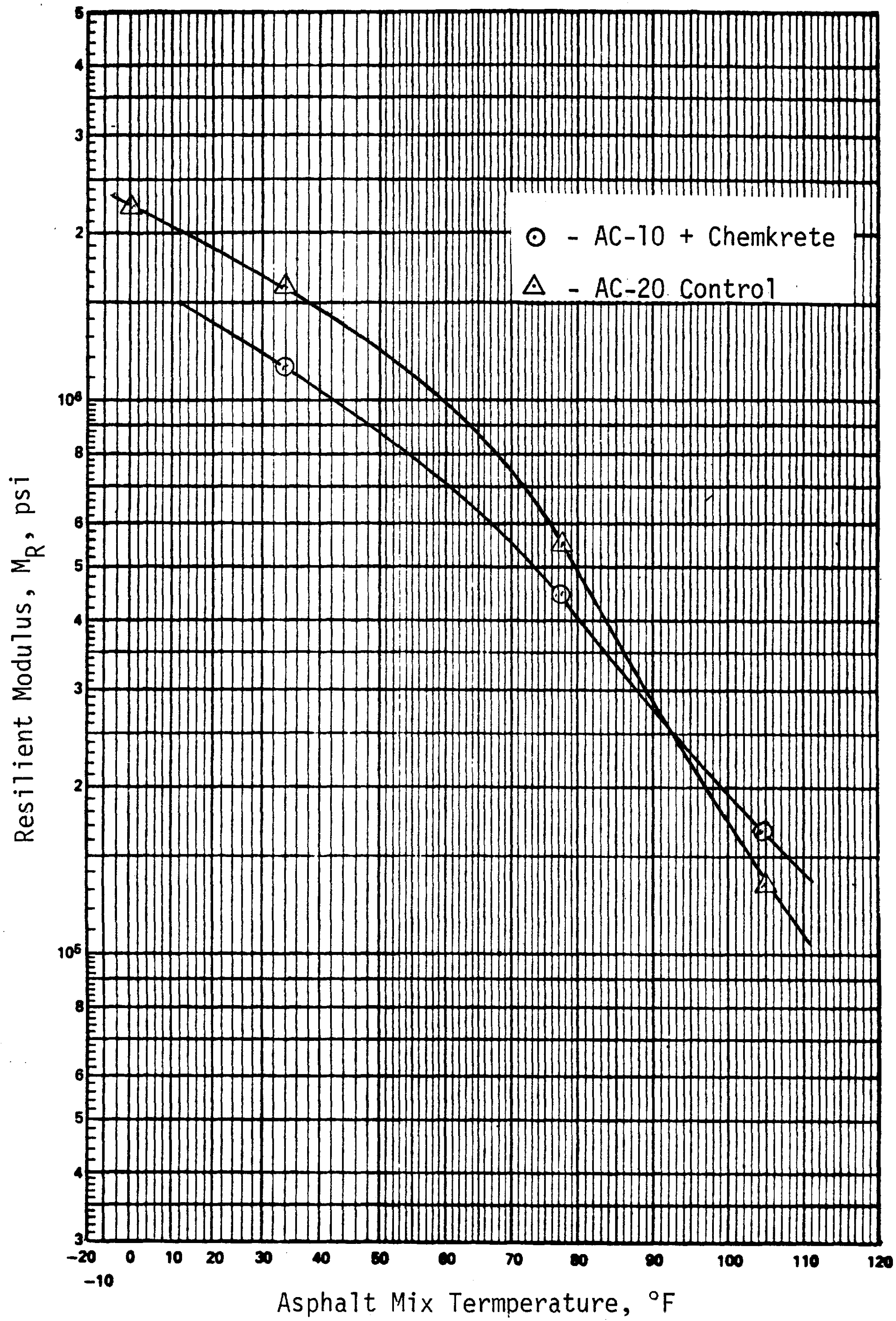

Figure 14. Resilient Modulus as a Function of Temperature for Field Mixed, Laboratory Compacted Mixtures from La Grange, (Mixtures aged for 28 days at 140°F).

In summary, the control mixtures behaved as expected showing a slight increase in resilient modulus with time and curing temperature. These values ranged from approximately 400,000 to 600,000 psi. All of the Chemkrete samples with low air void contents possessed a lower resilient modulus than the control, regardless of curing temperature or time. These values ranged from 200,000 to 400,000 psi. In the Chemkrete samples with high air void contents cured at 77^{o}F and 104^{o}F, the samples showed a very significant increase in resilient modulus with curing time. The maximum value recorded was 1,000,000 psi.

Standard Test Results. The samples which were cured at 140^{o}F were removed from the oven after 28 days and tested according to the testing program in Figure 15. It should again be noted that all of these samples were molded in accordance with standard compaction methods and, therefore, contain the "low" air voids.

These data are presented in Table 1. In the previous discussion of the resilient moduli data, it appeared that no reaction occurred between the Chemkrete and asphalt in the samples containing low voids. However, as shown in Table 1, the Chemkrete samples exhibited higher Hveem and Marshall stabilities than the control samples.

Tensile properties before and after Lottman (6) freeze-thaw treatment indicate Chemkrete has little effect on the mixture's resistance to damage by moisture.

One Year Cores. Pavement cores were obtained from the Chemkrete and control sections after the pavements were in service about one year. The laboratory test results from the cores are shown in Table 2. The samples were too short to obtain Hveem stability values. The Chemkrete mixture (AC-10 + 4%) did, however, exhibit higher Marshall stability, higher tensile strength and lower mixture temperature susceptibility (based on resilient modulus as a function of temperature). Chemkrete appeared to

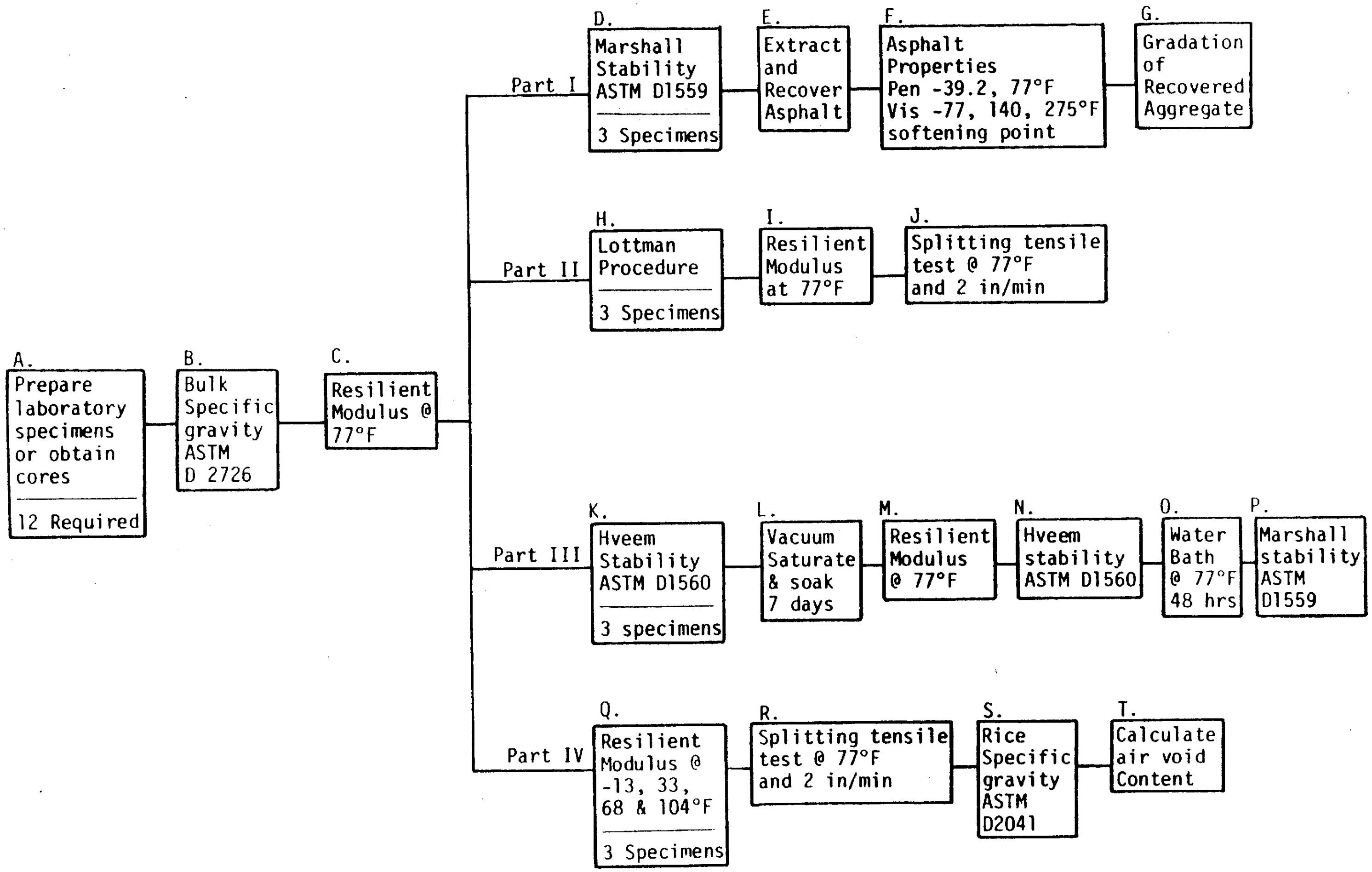

Figure 15. Standard Laboratory Test Sequence.

Table 1. La Grange Test Road Mixture Properties for Field Mixed, Laboratory Compacted Samples Cured at 140°F for 28 Days.*

Binder Type	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Hveem Stability, Percent	Marshall at 140°F		Resilient Modulus psix10^3				Indirect Tension at 77°F, 2 in/min		
					Stability, lb	Flow, in/in	0°F	33°F	77°F	104°F	Stress, psi	Strain, in/in	Modulus, psi
AC-10 + 4% Chemkrete	2.366	2.432	2.7	40	3500	17	—	1130	451	171	143	0.0026	56,100
AC-20 Control	2.345	2.430	3.5	37	3200	17	2281	1622	547	135	201	0.0021	98,800

Binder Type	Asphalt Content, Percent	After 7-Day Soak		After Accelerated Lottman				
		Resilient Modulus @ 77°F, psix10^3	Hveem Stability, %	Resilient Modulus @ 77°F, psix10^3	Hveem Stability, %	Indirect Tension at 77°F, 2 in/min		
						Stress, psi	Strain, in/in	Modulus, psi
AC-10 + 4% Chemkrete	5.3	506	35	476	35	162	0.0021	75,300
AC-20 Control	5.5	535	32	471	23	186	0.0027	68,900

*Each value represents an average from three test specimens.

Table 2. LaGrange Test Road Mixture Properties Taken From One Year Cores.*

Sample	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Asphalt Content, Percent	Marshall at 140°F		Resilient Modulus psiX10^3			
					Stability, lb	Flow, in/in	0°F	32°F	77°F	104°F
AC-10 + 4% Chemkrete	2.256	2.433	7.3	4.9	5300	12	2221	1493	468	228
AC-20 Control	2.245	2.427	7.5	4.9	3100	12	2453	1657	454	174

Sample	Indirect Tension @ 77°F, 2 in/min			After Accelerated Lottman Indirect Tension @ 77°F, 2 in/min		
	Stress, psi	Strain, in/in	Modulus, psi	Stress, psi	Strain, in/in	Modulus, psi
AC-10 + 4% Chemkrete	192	0.0010	204,400	142	0.0019	77,800
AC-20 Control	174	0.0016	108,500	150	0.0022	70,600

*Each value represents an average from three test specimens.

have no significant effect on moisture susceptibility as measured by the accelerated Lottman (6) freeze-thaw procedure. Selected data are presented graphically in Figures 16 and 17 to facilitate comparison with the samples cured in the laboratory. In the cores sampled at one year, the Chemkrete mixture exhibited higher tensile strength and Marshall stability than the control.

Asphalt Cement Properties. Asphalt was extracted from the laboratory compacted samples cured for 28 days and from the one-year cores. These results are presented in Table 3. The viscosity of the AC-10 plus Chemkrete is generally higher than the viscosity of the AC-20 for both the laboratory compacted samples and the cores (Figure 18). Based on penetration data in the core samples, the AC-10 plus Chemkrete appears to be slightly harder than the AC-20. In the laboratory cured samples, the Chemkrete modified binder is harder than the control at 39.2^{o}F but softer at 77^{o}F, indicating greater temperature susceptibility for the Chemkrete treated material. Data on extracted asphalts, particularly when additives are involved, should be viewed with caution.

Field Performance

The Chemkrete LaGrange Test Road was built in May of 1984. A condition survey was performed in October of 1984 at which time the Chemkrete sections exhibited measurable rutting (~ 1/4") and slight flushing in the sections with the higher binder contents (5.5%). The control sections exhibited equivalent rutting (~ 1/4") but no flushing. By the summer of 1986, the Chemkrete section with the higher binder contents (5.5%) exhibited rutting and shoving. This section was overlayed at that time primarily to accomodate a by-pass tie-in; however, SDHPT personnel commented that this particular portion of the Chemkrete section would have required repair if the section had not been overlayed due to the bypass construction.

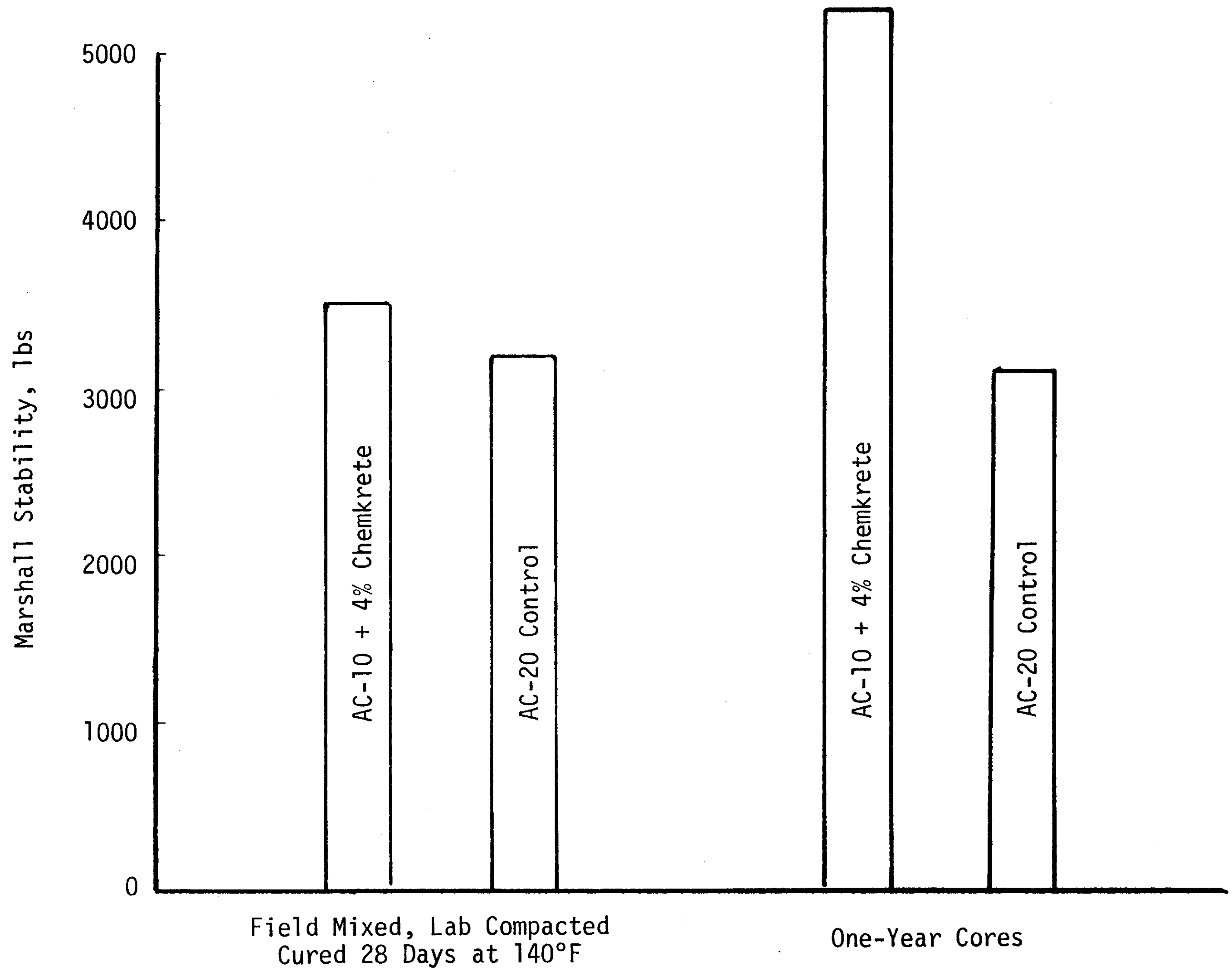

Figure 16. La Grange Test Road - Marshall Stability Results.

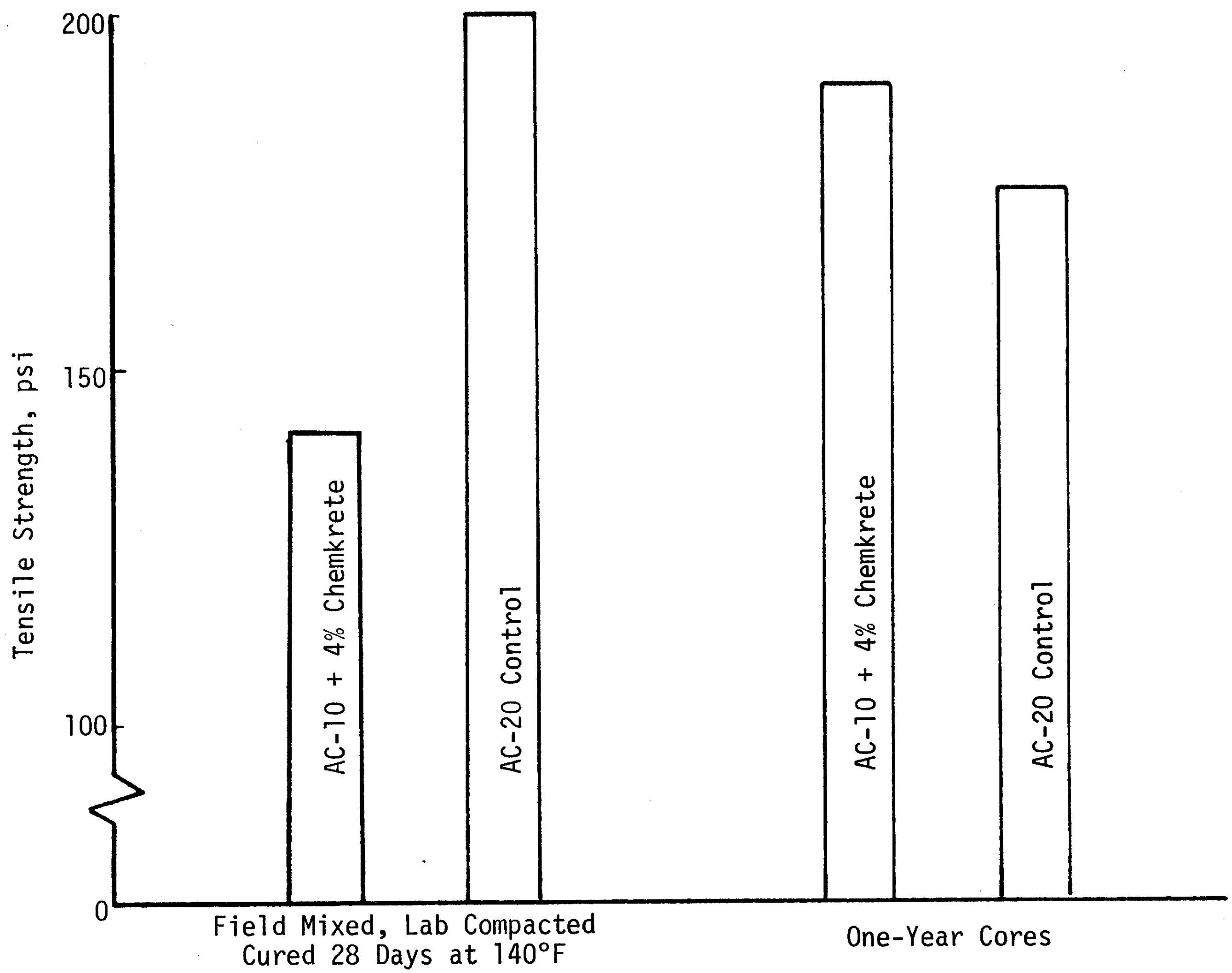

Figure 17. LaGrange Test Road - Tensile Strength Results.

Table 3. LaGrange Test Road Extracted Asphalt Cement Properties.*

Source of Specimen	Binder Type	Asphalt Content, percent	Viscosity, poises			Penetration, dmm		Softening Point, °F
			77°F poisesx10[6]	140°F	275°F	39.2°F 200g, 60 sec	77°F 100g, 5 sec	
Field Mixed, Cured 28 days @ 140°F	AC-10+4% Chemkrete	5.3	5.2	7300	7.0	25	37	131
	AC-20	5.5	11.5	5200	5.2	15	50	133
Cores	AC-10+4% Chemkrete	4.9	22.5	26,200	9.2	10	17	146
	AC-20	4.9	21.5	12,000	7.5	11	23	140

*Each value represents an average from three test specimens.

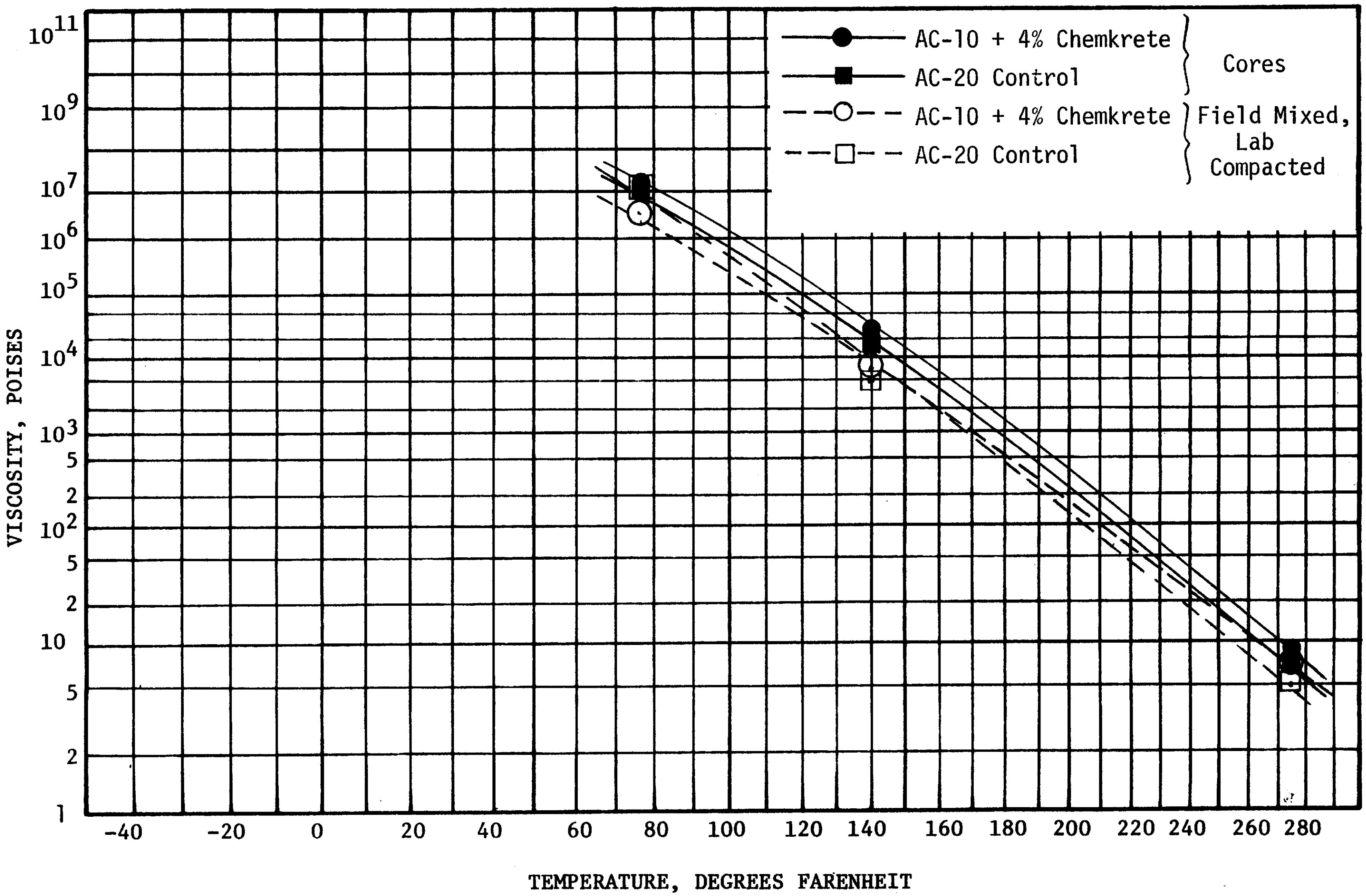

Figure 18. La Grange Test Road Viscosity Data for Extracted Asphalt Cement.

Initially, it was believed that the Chemkrete sections had insufficient air voids to produce the chemical reaction. Further, since the Chemkrete sections were constructed with an AC-10 versus an AC-20 in the control, one would suspect the Chemkrete sections to be softer and more likely to rut in the case of no chemical reaction. However, based on the test results from the roadway cores, it appears that the reaction did occur in the Chemkrete sections. Chemkrete sections showed higher values of strength and stiffness than the control.

Observation of the rheological properties of the two pavement sections revealed no apparent reason why portions of the Chemkrete sections were rutting. Probably the higher binder content, as previously noted, was a contributing factor; however, the binder content was only 0.2 percent higher than the design value. From the aggregate gradation curve in Figure 7, it appears that there may have been excessive fines and sand-size particles in the mixture which can sometimes inhibit aggregate interlock of the coarser particles, thereby causing rutting. However, the control sections were constructed with the same aggregate and exhibited significantly less rutting.

The pavement was surveyed again in May of 1987. No increases in rutting were observed in either the Chemkrete or the control sections. However, the Chemkrete sections exhibited significant amount of transverse and longitudinal cracking primarily in the east bound lane. The control sections contained no cracks.

CHAPTER IV. BOWIE TEST ROAD

Field tests of Chemkrete were performed near Bowie, Texas in Montague County on US 287 from 1.2 miles west of FM 174 to US 81. The original pavement consisted of an asphalt rubber seal with Grade 3 stone over 1 1/2-inches Type D hot mix over a Grade 3 seal on 11-inches of Item 240 flexible base. The asphalt-rubber seal was in good condition with very few cracks evident.

Materials

Crushed limestone with field sand aggregates was used in the construction of the asphalt concrete overlay. The aggregate gradation is shown in Figure 19 which was obtained from extraction of the field mix.

The control sections were constructed using an AC-10 and the Chemkrete sections were constructed with an AC-5 plus 4 percent Chemkrete by weight of the binder. Both mixtures contained an antistripping agent known as PERMA-TAC (1 1/4 percent by weight of the binder).

Construction

The Bowie Test Road was constructed in July of 1985 and the overlay thickness was approximately 2-inches. The design asphalt content was 5.3 percent but actual measurements from field extractions averaged about 5.1 percent. Plant temperatures ranged from 255-280^{o}F. Approximately 1.8 lane miles of Chemkrete was placed as shown in Figure 20. Since Chemkrete causes a reduction in binder viscosity, compaction equipment was delayed slightly before rolling the Chemkrete-modified mat to insure sufficient air voids to effect the chemical reaction.

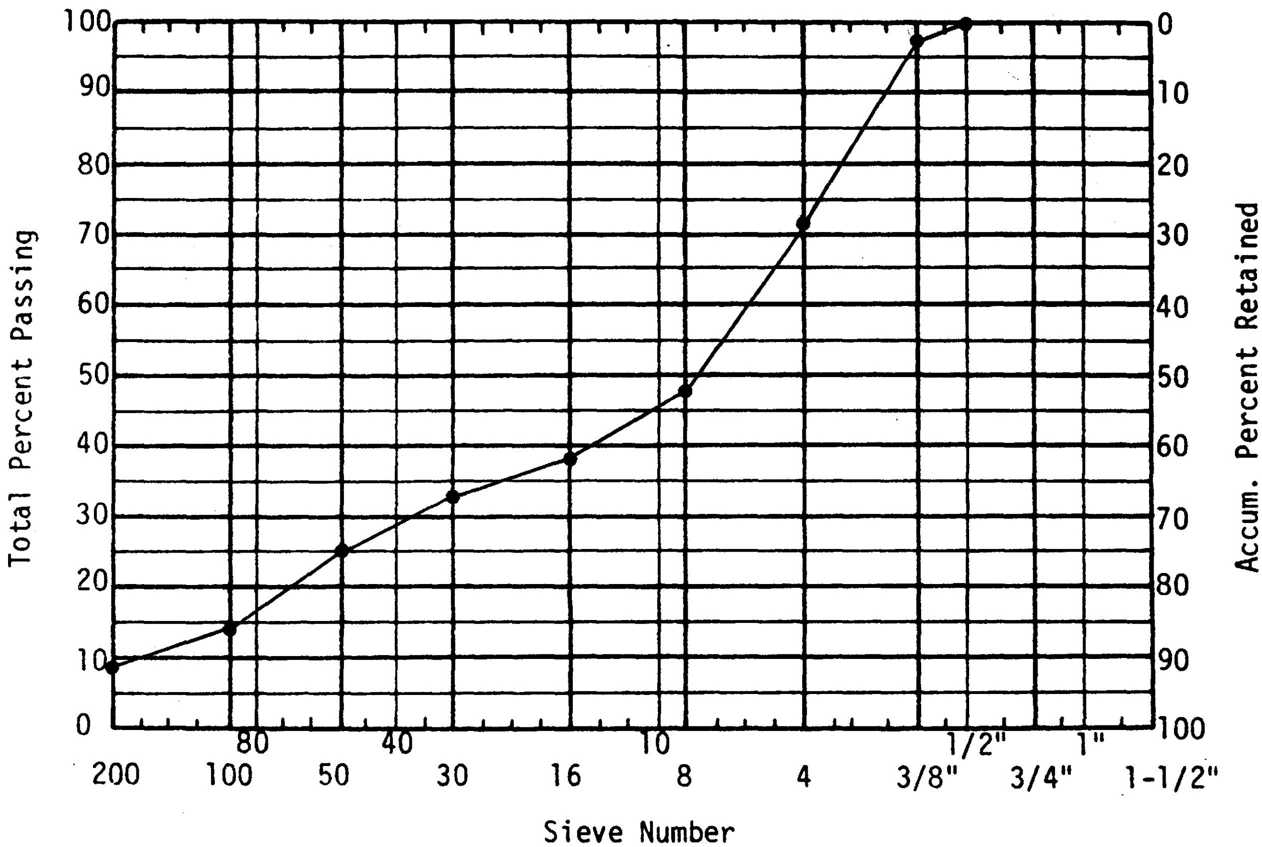

Figure 19. Aggregate Gradation for the Bowie Test Road.

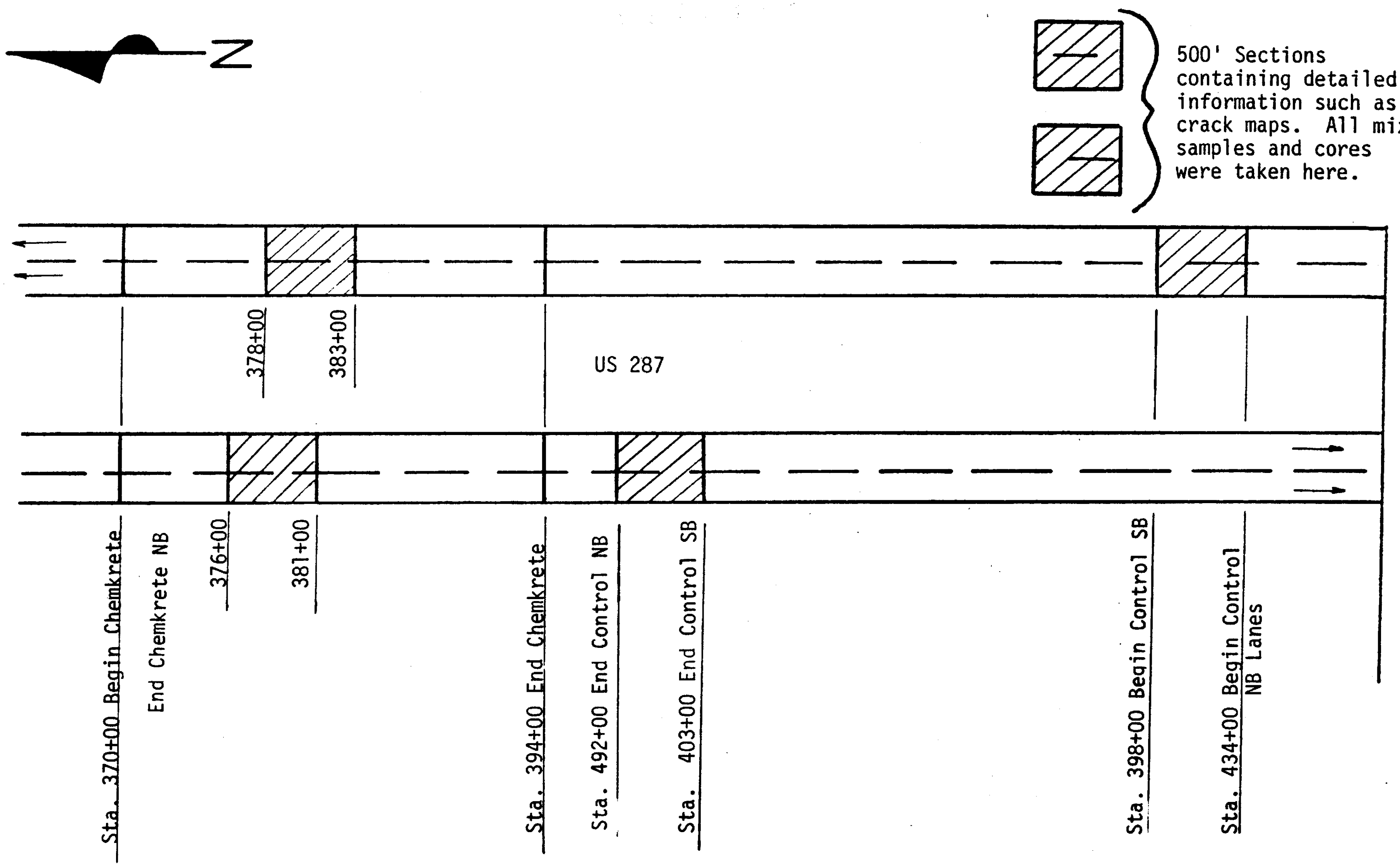

Figure 20. Bowie Test Road - Test Section Layout.

Laboratory Tests

Mixture Properties. Uncompacted samples of Chemkrete and control mixture were obtained from haul units at the plant and specimens were molded in the SDHPT field laboratory at the plant site. Specimens were prepared using standard and modified gyratory compaction procedures for control and Chemkrete mixtures, respectively. Due to inadequate temperature control, air void contents of the molded specimens were higher than desired. The control specimens contained about 8 percent voids while the Chemkrete specimens contained almost 11 percent. The molded specimens were cured for 28 days at 140°F before testing in accordance with the testing program in Figure 15.

Roadway cores were obtained approximately one month and 17 months after construction and were also tested in accordance with the program in Figure 15.

Laboratory test results are presented in Tables 4, 5 and 6 and are presented graphically in Figures 21 through 24. In both the laboratory molded samples and roadway cores, stabilities and tensile strengths were significantly higher for the Chemkrete mixtures (AC-5 + Chemkrete) than the control (AC-10). In the core samples, resilient moduli were higher than the control at all test temperatures. Based on these data, it appears that the Chemkrete produced a stiffening effect on the AC-5. Resilient modulus values of laboratory compacted specimens show a much greater stiffening effect for the Chemkrete at the higher temperatures than at the lower temperatures (Figure 24). Data on field cores support this trend (Tables 5 and 6). Although no performance relationships have been established using resilient modulus, it would appear that a significantly higher resilient modulus at 104°F may be indicative of improved resistance to rutting as would significant increases in Hveem and Marshall stability. On the other hand, at low temperatures, there appears to be no benefit from the standpoint of mixture flexibility when the AC-5 plus Chemkrete is used.

Table 4. Bowie Test Road mixture properties of field mixed, lab compacted specimens cured 28 days at 140°F.

Sample	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Hveem Stability Percent	Marshall at 140°F		Resilient Modulus psix10^3			
					Stability, lb	Flow, in/in	0°F	32°F	77°F	104°F
AC-5 + 4% Chemkrete	2.160	2.425	10.9	45	1800	15	3154	1842	188	187
AC-10	2.211	2.409	8.2	37	1000	14	3602	1804	117	69

Sample	Asphalt Content, Percent	Indirect Tension at 77°F, 2in/min			After Accelerated Lottman			
					Resilient Modulus psix10^3	Indirect Tension at 77°F, 2 in/min		
		Stress, psi	Strain, in/in	Modulus, psi		Stress, psi	Strain, in/in	Modulus, psi
AC-5 + 4% Chemkrete	4.7	90	0.0019	47400	177	49	0.0040	12200
AC-10	5.1	77	0.0030	26000	138	79	0.0059	13400

Table 5 . Bowie Test Road Mixture Properties Taken From One Month Cores.*

Binder Type	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Hveem Stability	Marshall at 140°F		Resilient Modulus psiX10^3				Indirect Tension at 77°F, 2 in/min		
					Stability, lb	Flow, in/in	0°F	32°F	77°F	104°F	Stress, psi	Strain, in/in	Modulus, psi
AC-5 + 4% Chemkrete	2.260	2.435	7.2	62	3800	9	1859	1442	716	349	154	0.0011	140,600
AC-10 Control	2.301	2.400	4.2	38	2100	11	1757	1177	330	99	126	0.0032	39,700

Binder Type	Asphalt Content, Percent	After 7-Day Soak				After Accelerated Lottman			
		Resilient Modulus @ 77°F, psix10^3	Hveem Stability	Marshall at 140°F		Resilient Modulus psix10^3	Indirect Tension at 77°F, 2 in/min		
				Stability, lb	Flow, in/in		Stress, psi	Strain, in/in	Modulus, psi
AC-5 + 4% Chemkrete	5.5	517	48	2900	13	490	114	0.0018	64,800
AC-10 Control	4.7	325	37	1800	14	325	125	0.0045	28,200

*Each value represents an average from three test specimens.

Table 6. Bowie Test Road Mixture Properties Taken From 17 Month Cores.

Binder Type	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Hveem Stability	Marshall at 140°F		Resilient Modulus psi X 10^3			
					Stability, lb	Flow, in/in	-13F	32°F	77°F	104°F
AC-5 + 4% Chemkrete	2.292	2.436	6.1	58	8100	13	2157	1463	976	404
AC-10 Control	2.310	2.396	3.9	40	2700	15	1889	1310	528	127

Binder Type	Asphalt Content, Percent	Indirect Tension @ 77°F, 2 in/min			After Accelerated Lottman			
					Resilient Modulus	Indirect Tension @ 77°F, 2 in/min		
		Stress, psi	Strain, in/in	Modulus, psi	psi X 10^3	Stress, psi	Strain, in/in	Modulus, psi
AC-5 + 4% Chemkrete	4.5	215	0.00077	337,300	865	185	0.00047	722,400
AC-10 Control	5.5	181	0.0023	79,500	478	167	0.0027	64,100

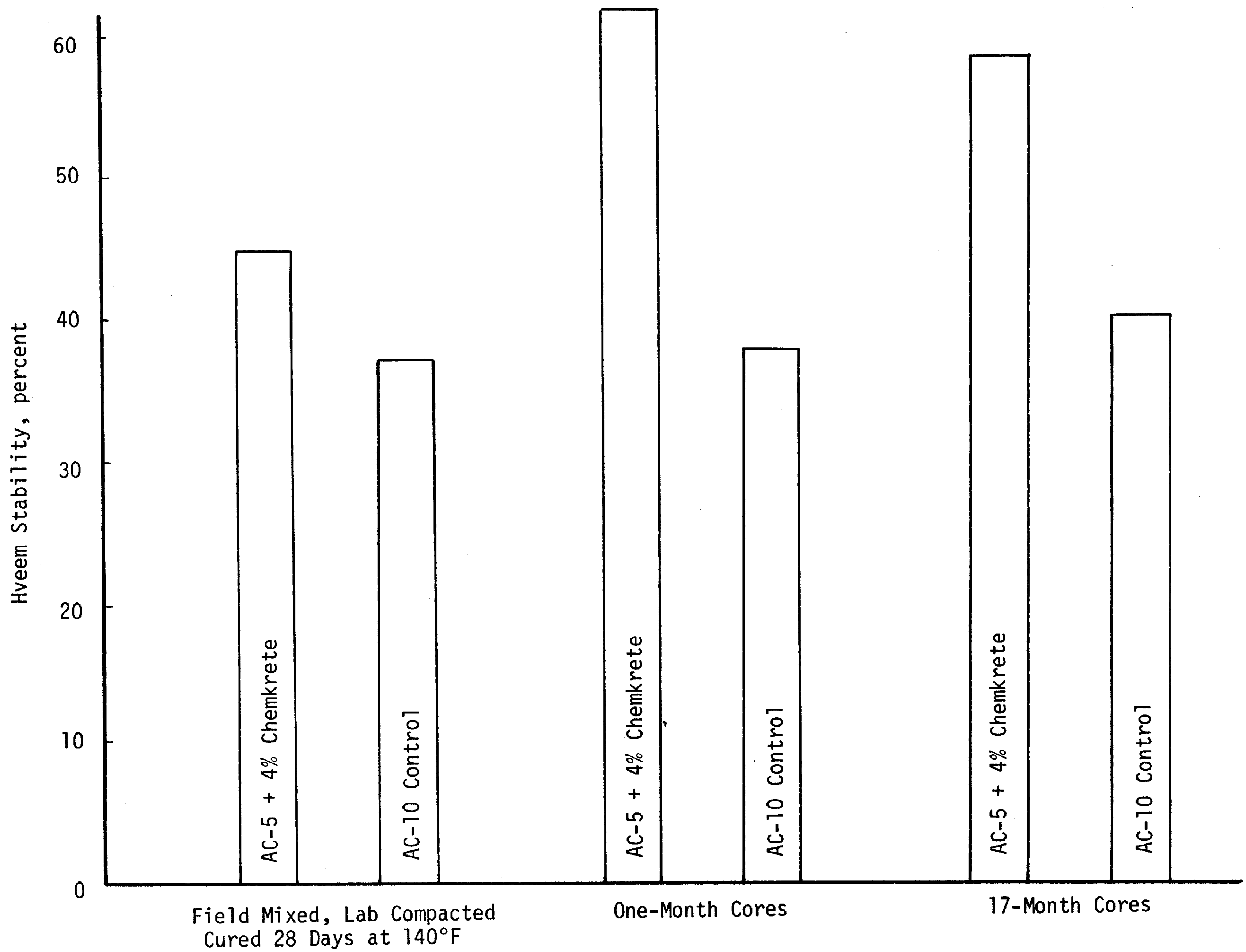

Figure 21. Bowie Test Road - Hveem Stability Results.

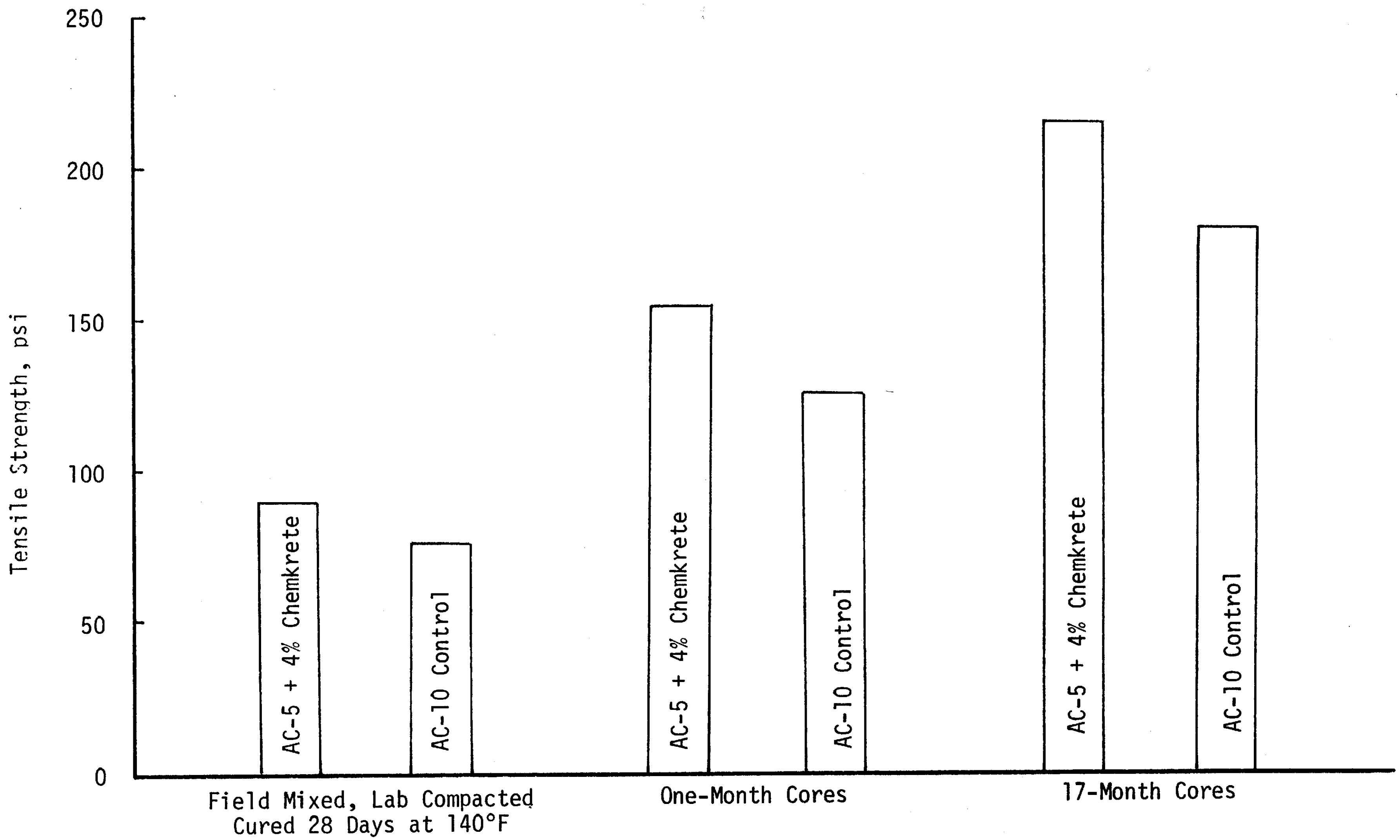

Figure 22. Bowie Test Road - Tensile Strength Results.

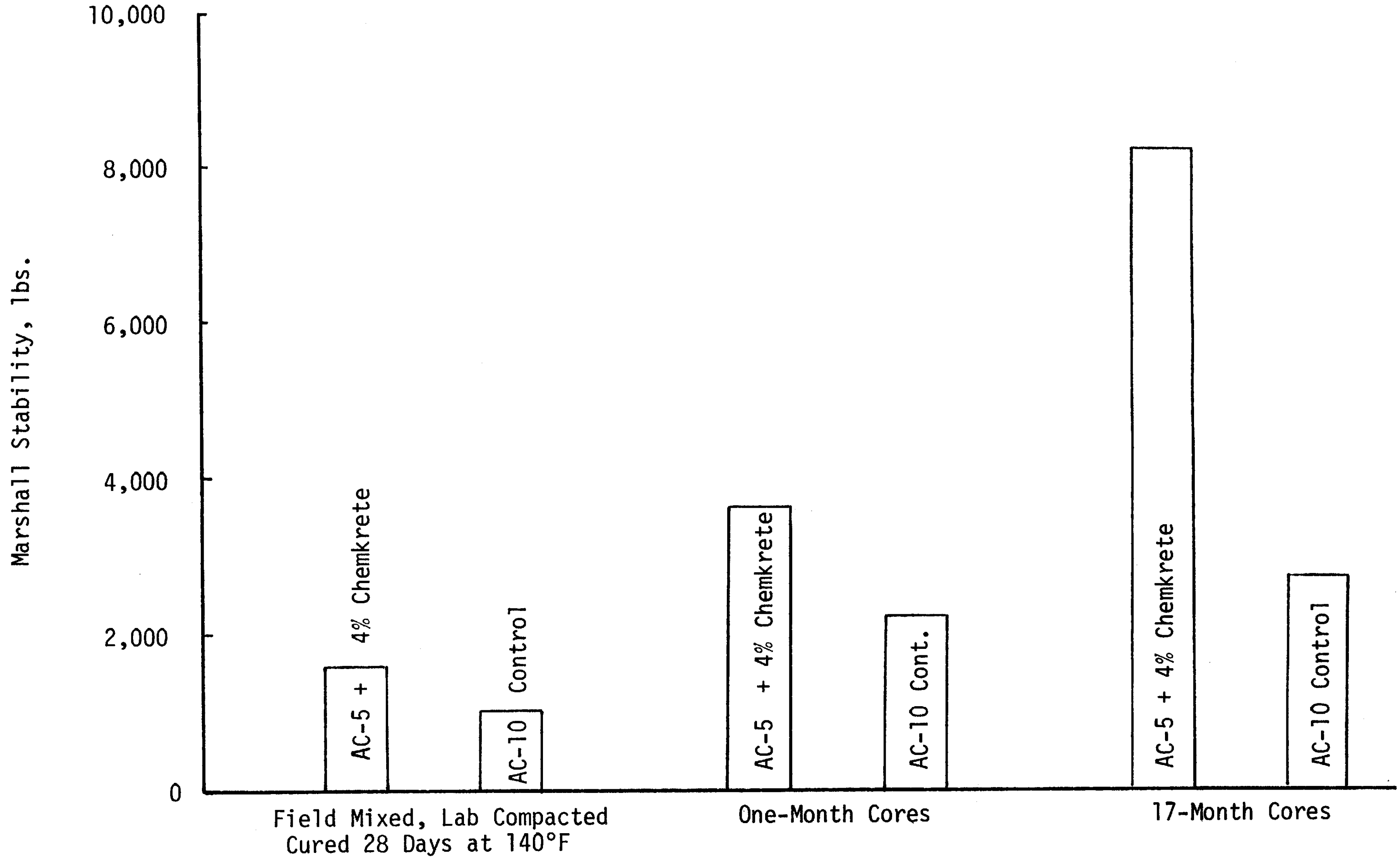

Figure 23. Bowie Test Road - Marshall Stability Results.

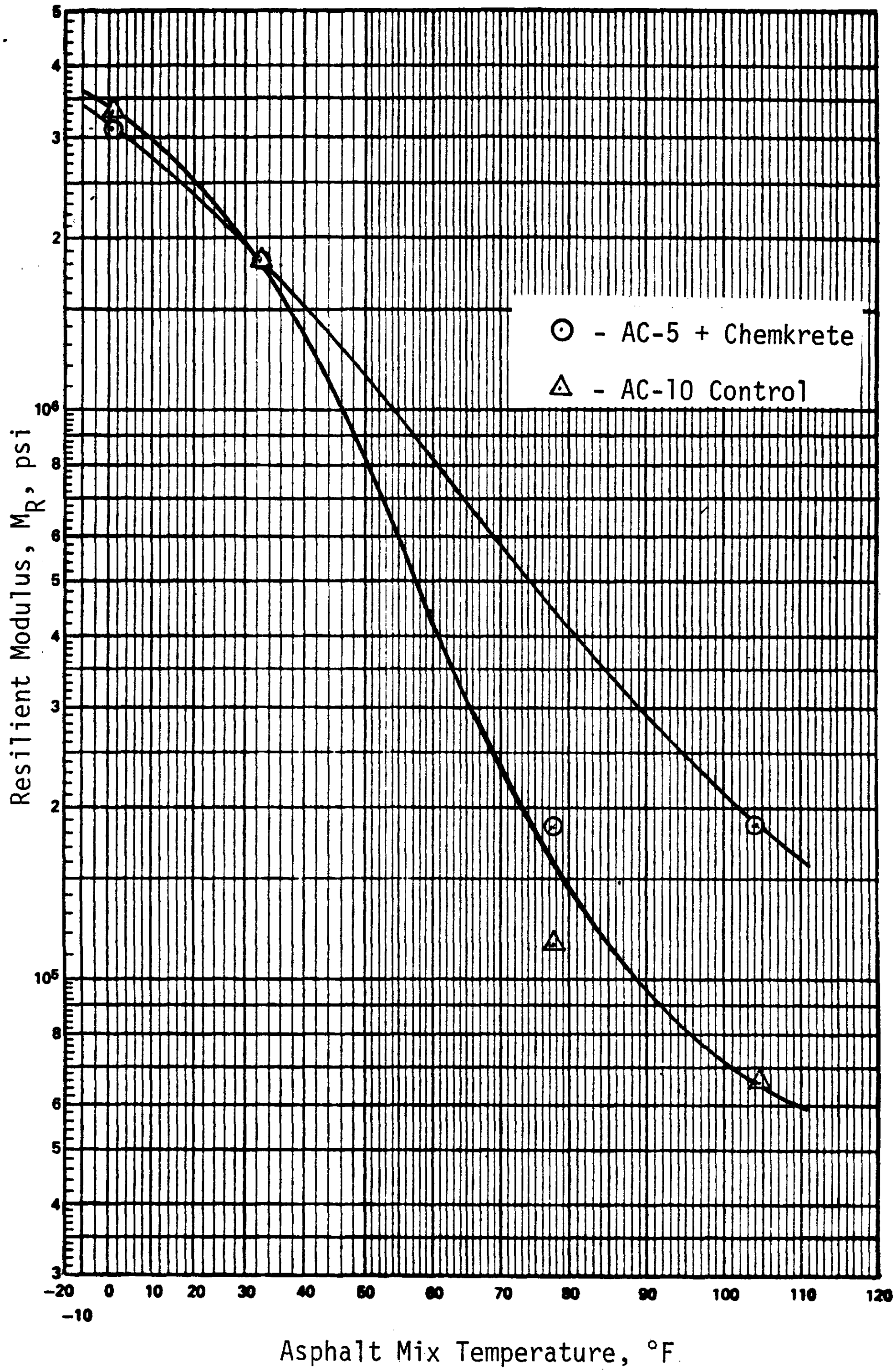

Figure 24. Resilient Modulus as a Function of Temperature for Field Mixed, Laboratory Compacted Mixtures from Bowie, Texas (Mixtures aged for 28 days at 140°F).

Indirect tension test before and after the accelerated Lottman (6) freeze-thaw treatment indicates the Chemkrete had little effect on resistance to moisture damage.

Asphalt Cement Properties. Asphalt cement was extracted from the laboratory molded samples and from the roadway cores. Test results on these materials are presented in Table 7. Viscosity values are plotted in Figure 25.

Viscosity and penetration data indicate that the consistencies of the treated and untreated binders are generally about equivalent for the lab compacted samples as well as for the cores taken at one month. However, in the cores taken at 17 months, the treated binder appears to be significantly harder than the control.

Note that, based on the asphalt cement properties, the asphalt for the control sections is becoming softer with age. One possible explanation is that the diluent from the underlying asphalt rubber seal coat had not completely evaporated at the time the overlay was placed. This diluent may be permeating the overlay thereby softening the asphalt cement.

Field Performance

The Bowie Test Road was constructed in July of 1985. In the summer of 1986 the pavement was surveyed and the Chemkrete sections contained a few slight cracks and the control sections contained no cracks. Note that the only portions of the road surveyed were the 500-foot sections shown in Figure 20. In October of 1986, the Chemkrete sections were extensively cracked in both lanes, both directions. Cracks consisted of slight to moderate longitudinal and transverse cracks. Each 500-foot section contained approximately 1200 linear feet of longitudinal cracking and 500 feet of transverse cracking per lane. The control sections contained no cracks.

Table 7. Bowie Test Road Extracted Asphalt Cement Properties.*

Source	Binder Type	Asphalt Content, Percent	Viscosity, Poises			Penetration, dmm		Softening Point °F
			77°F Poises x 10^6	140°F	275°F	39.2°F 200g, 60sec	77°F 100g, 5sec	
Field Mixed Cured 28 days at 140°F	AC-5 + 4% Chemkrete	4.7	3.7	3700	4.0	20	48	130
	AC-10 Control	5.1	3.0	2300	4.0	19	56	124
One-Month Cores	AC-5 + 4% Chemkrete	5.5	3.4	2000	3.9	23	60	123
	AC-10 Control	4.7	3.7	2600	3.6	23	56	122
17-Month Cores	AC-5 + 4% Chemkrete	4.5	2.9	33000	7.6	12	26	150
	AC-10 Control	5.5	1.6	1900	3.6	34	72	115

*Each value represents an average from three test specimes.

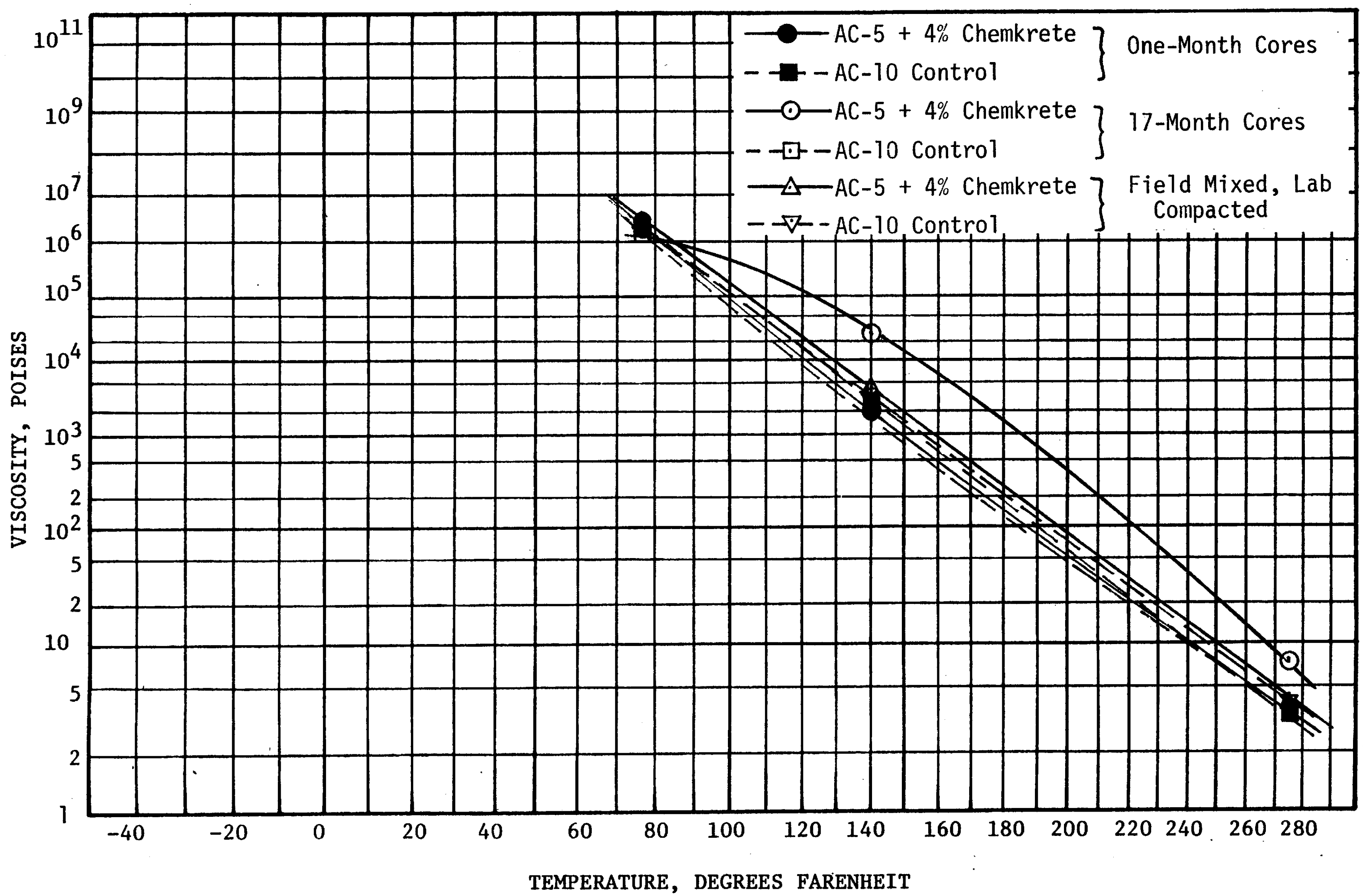

Figure 25. Bowie Test Road Viscosity Data for Extracted Asphalt Cement.

Since most of this cracking occurred between July and October, it is doubtful that it could be considered thermal cracking. A possible explanation is that the underlying pavement is more flexible than the comparatively stiff Chemkrete overlay. The action of traffic on such a pavement structure could produce longitudinal cracking in the wheelpaths (fatigue cracking).

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Two test pavements were constructed under this research study containing Chemkrete modified asphalts. Laboratory tests were performed on Chemkrete mixtures to judge the effect of curing time, air void content and asphalt grade. Field performance of the test roads was monitored in addition to testing roadway cores. This study generated the following conclusions:

1. During the early life (first 1 1/2 years) of the test pavements near LaGrange, the Chemkrete-modified mixture with the highest binder content exhibited severe rutting. Excessive binder content may have been a contributing factor. After 3 years, Chemkrete test pavements at LaGrange are exhibiting significantly more cracking than similar control pavements.

2. The Chemkrete section of the Bowie Test Road experienced extensive cracking after approximately 15 months of service. This is probably due to placing a stiff overlay over a flexible substructure. The control sections are performing well with no cracks during that same period.

3. Limited data indicate that, Chemkrete is not equally compatible with all asphalts, that is, it does not catalyze the oxidation reaction to the same degree in all asphalts. This is a result of the chemical composition of the asphalt cement.

4. Air void content plays an important role in Chemkrete pavements as measured by resilient modulus of specimens cured at various temperatures. In laboratory molded Chemkrete samples containing air voids of 2.7 percent, no measureable increase in stiffness was effected by Chemkrete; however, in samples with 4.7 percent air voids, stiffness increased with time very significantly in samples cured at or above 77°F.

5. Laboratory tests on roadway cores from both test roads indicated that the Chemkrete mixtures attained strengths and stiffnesses equivalent to or greater than the control sections within one month.

6. Properties of asphalt concrete mixtures do not always describe field performance. Based on strength and stiffness parameters measured from roadway cores, the Chemkrete sections in LaGrange with the highest binder content should not have exhibited rutting problems. This may indicate that better test methods are needed for modified binders. For example, if there are changes in the rheology of the binder, then parameters such as stiffness may not correlate well with permanent deformation.

7. Tensile properties before and after Lottman (6) freeze-thaw treatment indicate Chemkrete has little effect on a paving mixture's resistance to damage by moisture.

Recommendations

1. When using Chemkrete, reactivity of the asphalt cement and the Chemkrete should be determined in the laboratory to estimate any benefits to be realized.

2. Pavements constructed with Chemkrete should initially contain air void contents on the order of 4 to 6 percent to allow the reaction between the Chemkrete and asphalt cement to occur.

3. Chemkrete generally produces stiffer mixtures than untreated asphalt. Based on other research (1) and the performance of the Bowie Test Road, Chemkrete should not be placed in thin lifts over flexible substrates as cracking may occur.

4. Chemkrete has been recommended for use in thick asphalt concrete pavements (1).

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APPENDIX A

Properties of Materials Used in Laboratory Study

Table A1. Individual aggregate gradations for washed pea gravel, washed sand, field sand, and limestone crusher fines.

Sieve Size	Washed Pea Gravel	Washed Sand	Field Sand	Limestone Crusher Fines
	Percent retained	Percent retained	Percent retained	Percent retained
#4	65.6	0.3	1.4	0.1
#8	31.6	13.1	1.1	6.2
#16	1.6	17.7	1.0	18.4
#30	0.4	18.4	0.4	16.1
#50	0	35.4	1.1	11.7
#100	0	11.9	44.8	10.4
#200	0	0.7	28.5	7.1
-#200	0.8	2.5	21.7	30.0
Percentage of each aggregate used in blend	50%	30%	10%	10%

Table A2. Bulk specific gravity, apparent specific gravity, and percent absorption for the pea gravel and combined fines.

	Pea Gravel	Pea Gravel	Combined Fines (washed sand, field sand, limestone fines)
Bulk Specific Gravity	2.575	2.529	2.584
Apparent (maximum) specific gravity	2.658	2.640	2.642
Absorption, percent	1.22	1.68	0.86

Table A3. Summary of Asphalt Cement Properties.

Grade of Asphalt	AC-10
Viscosity @ 77°F (25°C), poise	5.8×10^5
Viscosity @ 140 °F (60°C), poise	1576
Viscosity @ 275°F (135°C), poise	3.76
Penetration @ 39.2°F (4°C), dmm	26
Penetration @ 77°F (25°C), dmm	118
Penetration Ratio, %	107 (41.7)
R & B Softening Pt, °F (°C)	1.020
Specific Gravity @ 60°F (16°C)	615 (323.9)
Flash Point (COC), °F (°C)	99.9
Solubility in $C_2H_3Cl_3$,%	Negative
Spot Test	
Thin Film Oven Test Residue Properties	
Viscosity @ 140°F (60°C), poise	3054
Penetration @ 77°F (25°C), dmm	68
Ductility @ 77°F (25°C), cm	150

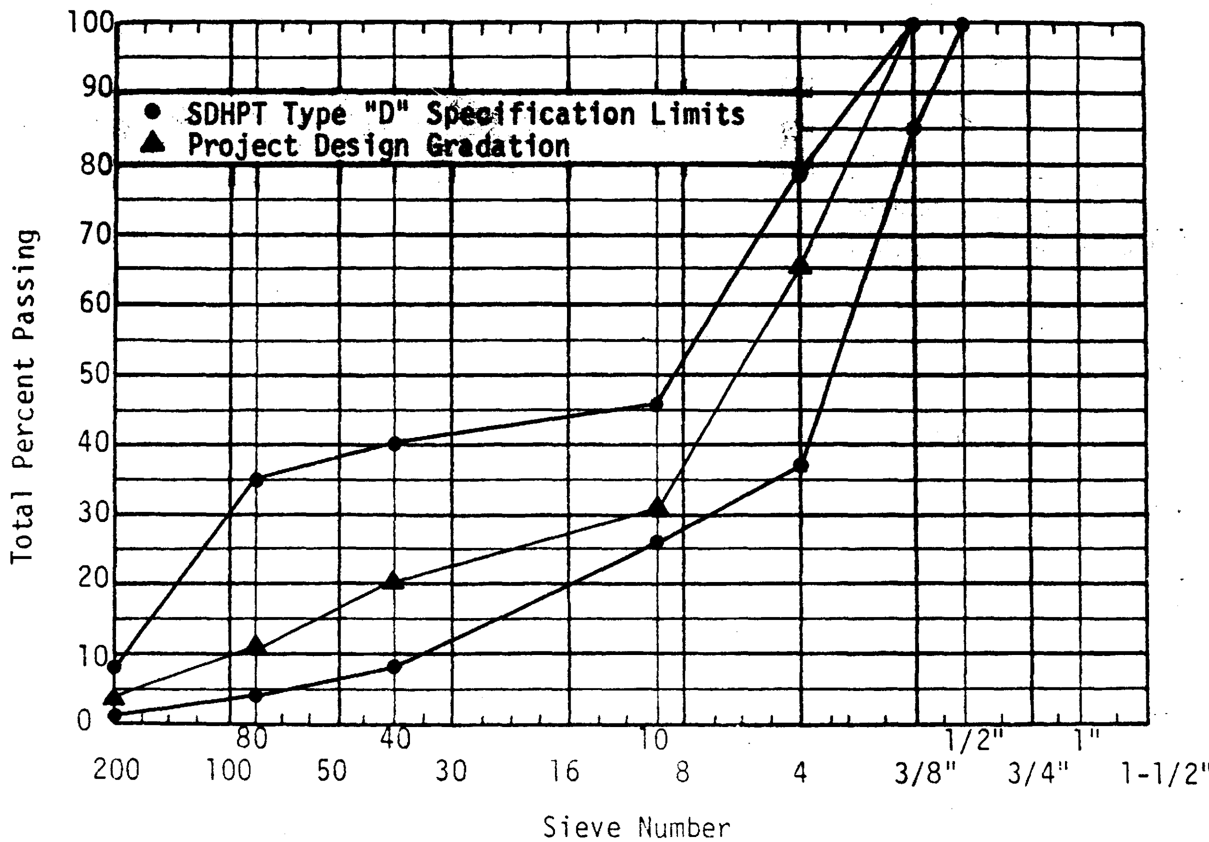

Figure A1. Design gradation specification limits for pea gravel aggregate.

APPENDIX B

Tabulated Results from Curing Study

Table B1. Laboratory Results of Samples Molded at 25 Marshall Blows Using TTI Lab Standard Aggregate and American Petrofina, AC-10.

Curing Time, Days	Chemkrete, Percent	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Resilient Modulus @ 77°F, psi x 10^6	Indirect Tension		
						Stress, psi	Strain, in/in	Modulus, psi
0	0	2.328	2.465	5.2	0.231	88	0.0037	24,100
	1	2.350	2.465	4.7	0.232	88	0.0033	26,900
	3	2.342	2.465	5.0	0.109	65	0.0044	14,800
40	0	2.328	2.465	5.2	0.380	117	0.0031	37,900
					0.358	113	0.0029	36,600
					0.369	115	0.0030	37,300
	1	2.350	2.465	4.7	0.352	117	0.0031	37,800
					0.342	115	0.0031	37,200
					0.347	116	0.0031	37,500
	3	2.342	2.465	5.0	0.502	129	0.0031	41,800
					0.505	129	0.0029	44,200
					0.504	129	0.0030	43,000
88	0	2.328	2.465	5.2	0.462	119	0.0030	39,600
					0.453	119	0.0028	42,000
					0.464	113	0.0030	38,800
					0.460	117	0.0029	40,100
	1	2.350	2.465	4.7	0.411	120	0.0031	38,600
					0.471	125	0.0027	45,500
					0.453	129	0.0031	41,900
				Avg.	0.445	125	0.0031	42,000
	3	2.342	2.465	5.0	0.642	133	0.0027	48,700
					0.651	133	0.0024	56,300
					0.576	126	0.0024	53,100
				Avg.	0.623	131	0.0025	52,700

Table B2. Laboratory Results of Samples Molded at 50 Marshall Blows Using TTI Lab Standard Aggregate and American Petrofina, AC-10.

Curing Time, Days	Chemkrete, Percent	Bulk Specific Gravity	Rice Specific Gravity	Air Voids, Percent	Resilient Modulus @ 77°F psi x 10^6	Indirect Tension		
						Stress, psi	Strain, in/in	Modulus, psi
0	0	2.365	2.465	4.1	0.273	109	0.0037	29,800
	1	2.368	2.465	3.8	0.229	95	0.0037	26,000
	3	2.366	2.465	4.0	0.182	87	0.0033	26,500
40	0	2.365	2.465	4.1	0.498	139	0.0026	54,500
					0.546	138	0.0022	63,200
					0.522	139	0.0024	58,900
	1	2.368	2.465	3.8	0.370	120	0.0033	36,500
					0.395	126	0.0029	43,100
					0.383	123	0.0031	39,800
	3	2.366	2.465	4.0	0.464	143	0.0024	60,200
					0.432	134	0.0031	43,300
					0.448	139	0.0028	51,800
88	0	2.365	2.465	4.1	0.623	147	0.0022	67,300
					0.624	144	0.0026	56,200
					0.573	152	0.0027	55,600
					0.607	148	0.0025	59,700
	1	2.368	2.465	3.8	0.468	125	0.0027	45,900
					0.451	124	0.0029	42,700
					0.441	130	0.0029	44,700
					0.453	126	0.0028	44,400
	3	2.366	2.465	4.0	0.521	136	0.0029	46,600
					0.470	136	0.0027	49,600
					0.458	141	0.0029	48,800
					0.483	138	0.0028	48,300

Table B3. Resilient Modulus Data for LaGrange Field Mixed, Laboratory Compacted Control Samples (AC-20).

Curing Time, Days	Resilient Modulus at 77°F, M_r, psix10^3 for LaGrange Control Lab Molded Specimens								
	Aged at 0°F Air Voids		Aged at 32°F Air Voids		Aged at 77°F Air Voids		Aged at 104°F Air Voids		Aged at 140°F Air Voids
	Low	High	Low	High	Low	High	Low	High	Low
1	-	-	-	-	375	408	-	-	-
4	-	-	-	-	448	466	-	-	-
5	-	-	-	-	396	401	-	-	-
7	-	-	-	-	441	492	-	-	-
12	405	435	-	-	496	492	-	-	-
13	-	-	422	442	514	435	465	440	513
14	370	432	392	491	448	423	454	425	522
19	413	451	443	535	445	468	484	519	630
27	367	401	377	439	410	415	440	491	558
34	419	465	395	443	477	472	491	510	526
39	385	414	384	453	470	440	490	534	-
47	427	438	432	462	491	448	449	518	-
57	443	459	465	492	526	472	525	561	-

Table B4. Resilient Modulus Data for LaGrange Field Mixed, Laboratory Compacted Chemkrete Samples (AC-10 + 4%).

Curing Time, Days	Resilient Modulus at 77°F, M_r, psix10^3 for LaGrange Chemkrete Lab Molded Specimens								
	Aged at 0°F		Aged at 32°F		Aged at 77°F		Aged at 104°F		Aged at 140°F
	Air Voids		Air Voids		Air Voids		Air Voids		Air Voids
	Low	High	Low	High	Low	High	Low	High	Low
1	-	-	-	-	162	288	-	-	-
4	-	-	-	-	186	333	-	-	-
6	-	-	-	-	178	337	-	-	-
8	-	-	-	-	202	369	-	-	-
11	-	-	-	-	204	403	-	-	-
13	215	247	278	234	204	384	304	658	363
15	222	254	267	210	235	464	287	598	337
18	194	195	232	189	186	426	280	603	310
21	209	222	262	212	209	483	315	688	375
25	205	225	251	213	221	529	342	704	403
33	218	272	290	264	222	560	335	691	366
36	239	284	290	261	237	683	354	876	-
42	230	265	273	249	261	632	367	765	-
50	222	284	281	264	265	686	386	885	-
57	220	275	294	272	273	729	406	1038	-