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16. Abstract

This report describes a preliminary study which was undertaken to evaluate the effects of moisture on the engineering properties of asphalt mixtures. The static indirect tensile test was used to measure the tensile strength and modulus of elasticity of dry and moisture conditioned specimens of asphalt mixtures using the procedures recommended in NCHRP Report No. 192 and the Texas State Department of Highways and Public Transportation standard mix design procedures.

Two aggregates, a rounded gravel and a crushed caliche, each with various soil binder contents, were mixed using a range of asphalt contents to produce test specimens. The engineering properties were determined and comparisons made between values for the dry and moisture conditioned specimens. Results of these comparisons indicated that the severity of the damage caused by the conditioning increased as the air void content increased and as the amount of water absorbed increased. Also, more damage was observed for the caliche mixtures than for the gravel mixtures and, generally, for both aggregate mixtures at lower asphalt contents.

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EVALUATION OF THE EFFECT OF MOISTURE CONDITIONING ON BLACKBASE MIXTURES

by

James N. Anagnos
Freddy L. Roberts
Thomas W. Kennedy

Research Report Number 183-13

Tensile Characterization of Highway Pavement Materials
Research Project 3-9-72-183

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

March 1982

PREFACE

This is the thirteenth in a series of reports dealing with the findings of a research project concerned with tensile and elastic characteristics of highway pavement materials. This report summarizes the results of a preliminary investigation to evaluate the effects of moisture on asphalt mixtures. Using the static indirect tensile test, estimates of tensile strength and static modulus of elasticity were obtained for dry and moisture conditioned specimens of asphalt mixtures using the procedures recommended in NCHRP Report No. 192 and the Texas State Department of Highways and Public Transportation standard mix design procedure. The relationships between the extent of moisture damage and various factors were investigated.

This report was completed with the help and assistance of many people. Special appreciation is due Mr. Pat S. Hardeman for his assistance in the testing program, and Messrs. Gerald Peck and Robert E. Long of the Texas State Department of Highways and Public Transportation who provided technical liaison and support for the project. Appreciation is also extended to the Center for Transportation Research staff who assisted in the preparation of the manuscript. The support of the Federal Highway Administration, Department of Transportation, is gratefully acknowledged.

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Thomas W. Kennedy
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LIST OF REPORTS

Report No. 183-1, "Tensile and Elastic Characteristics of Pavement Materials," by Bryant P. Marshall and Thomas W. Kennedy, summarizes the results of a study on the magnitude of the tensile and elastic properties of highway pavement materials and the variations associated with these properties which might be expected in an actual roadway.

Report No. 183-2, "Fatigue and Repeated-Load Elastic Characteristics of Inservice Asphalt-Treated Materials," by Domingo Navarro and Thomas W. Kennedy, summarizes the results of a study on the fatigue response of highway pavement materials and the variation in fatigue life that might be expected in an actual roadway.

Report No. 183-3, "Cumulative Damage of Asphalt Materials Under Repeated-Load Indirect Tension," by Calvin E. Cowher and Thomas W. Kennedy, summarizes the results of a study on the applicability of a linear damage rule, Miner's Hypothesis, to fatigue data obtained utilizing the repeated-load indirect tensile test.

Report No. 183-4, "Comparison of Fatigue Test Methods for Asphalt Materials," by Bryon W. Porter and Thomas W. Kennedy, summarizes the results of a study comparing fatigue results of the repeated-load indirect tensile test with the results from other commonly used tests and a study comparing creep and fatigue deformations.

Report No. 183-5, "Fatigue and Resilient Characteristics of Asphalt Mixtures by Repeated-Load Indirect Tensile Test," by Adedare S. Adedimila and Thomas W. Kennedy, summarizes the results of a study on the fatigue behavior and the effects of repeated tensile stresses on the resilient characteristics of asphalt mixtures utilizing the repeated-load indirect tensile test.

Report No. 183-6, "Evaluation of the Resilient Elastic Characteristics of Asphalt Mixtures Using the Indirect Tensile Test," by Guillermo Gonzalez, Thomas W. Kennedy, and James N. Anagnos, summarizes the results of a study to evaluate possible test methods for obtaining elastic properties of pavement materials, to recommend a test method and preliminary procedure, and to evaluate properties in terms of mixture design.

Report No. 183-7, "Permanent Deformation Characteristics of Asphalt Mixtures by Repeated-Load Indirect Tensile Test," by Joaquin Vallejo, Thomas W. Kennedy, and Ralph Haas, summarizes the results of a preliminary study which compared and evaluated permanent strain characteristics of asphalt mixtures using the repeated-load indirect tensile test.

Report No. 183-8, "Resilient and Fatigue Characteristics of Asphalt Mixtures Processed by the Dryer-Drum Mixer," by Manuel Rodriguez and Thomas W. Kennedy, summarizes the results of a study to evaluate the engineering properties of asphalt mixtures produced using a dryer-drum plant.

Report No. 183-9, "Fatigue and Repeated-Load Elastic Characteristics of Inservice Portland Cement Concrete," by John A. Crumley and Thomas W. Kennedy, summarizes the results of an investigation of the resilient elastic and fatigue behavior of inservice concrete from pavements in Texas.

Report No. 183-10, "Development of a Mixture Design Procedure for Recycled Asphalt Mixtures," by Ignacio Perez, Thomas W. Kennedy, and Adedare S. Adedimila, summarizes the results of a study to evaluate the fatigue and elastic characteristics of recycled asphalt materials and to develop a preliminary mixture design procedure.

Report No. 183-11, "An Evaluation of the Texas Blackbase Mix Design Procedure Using the Indirect Tensile Test," by David B. Peters and Thomas W. Kennedy, summarizes the results of a study evaluating the elastic and repeated-load properties of blackbase mixes determined from current blackbase design procedures using the indirect tensile test.

Report No. 183-12, "The Effects of Soil Binder and Moisture on Blackbase Mixtures," by Wei-Chou V. Ping and Thomas W. Kennedy, summarizes the results of a study to evaluate the effect of soil binder content on the engineering properties of blackbase paving mixtures.

Report No. 183-13, "Evaluation of the Effect of Moisture Conditioning on Blackbase Mixtures," by James N. Anagnos, Thomas W. Kennedy, and Freddy L. Roberts, summarizes the results of a study to evaluate the effects of moisture content on the engineering properties of blackbase paving mixtures.

ABSTRACT

This report describes a preliminary study which was undertaken to evaluate the effects of moisture on the engineering properties of asphalt mixtures. The static indirect tensile test was used to measure the tensile strength and modulus of elasticity of dry and moisture conditioned specimens of asphalt mixtures using the procedures recommended in NCHRP report No. 192 and the Texas State Department of Highways and Public Transportation standard mix design procedures.

Two aggregates, a rounded gravel and a crushed caliche, each with various soil binder contents, were mixed using a range of asphalt contents to produce test specimens. The engineering properties were determined and comparisons made between values for the dry and moisture conditioned specimens. Results of these comparisons indicated that the severity of the damage caused by the conditioning increased as the air void content increased and as the amount of water absorbed increased. Also, more damage was observed for the caliche mixtures than for the gravel mixtures and, generally, for both aggregate mixtures at lower asphalt contents.

KEY WORDS: asphalt mixtures, indirect tensile test, modulus of elasticity, moisture, moisture damage, moisture conditioning, tensile strength, tensile strength ratio, air void content.

SUMMARY

This report summarizes the findings of a preliminary study to evaluate the effect of moisture on asphalt mixtures.

Mixtures of gravel and caliche aggregates, each with a range of soil binder contents and asphalt contents, were evaluated. The primary method of evaluating engineering properties was the static indirect tensile test. Estimates of tensile strength and modulus of elasticity were obtained for dry and moisture conditioned specimens, using procedures recommended in NCHRP Report No. 192 and the Texas State Department of Highways and Public Transportation (DHT) standard mix design procedures.

Estimates of the damage caused by moisture were made by calculating the tensile strength ratio, TSR (ratio of the tensile strength of the moisture conditioned specimen to the tensile strength of the dry specimen), and the modulus of elasticity ratio, MER (ratio of the modulus of elasticity of the moisture conditioned specimen to the modulus of elasticity of the dry specimen).

Preliminary findings indicated that more damage occured as the air voids and water contents increased and as the asphalt content decreased. More damage occurred in the caliche mixtures than in the gravel mixtures. Results from both the DHT procedure and the procedure recommended in NCHRP Report No. 192 were found to be comparable in evaluating the effects of moisture on asphalt mixtures. Finally, the laboratory data were used to develop preliminary relationships between the following pairs of properties: (1) TSR and air void content, (2) TSR and water content, (3) MER and air void content, and (4) MER and water content.

IMPLEMENTATION STATEMENT

Based on the findings of this study it is apparent that the two aggregates used for testing behaved in a very different fashion when subjected to moisture conditioning. This moisture conditioning produced a very large increase in the void content of the caliche mixtures but had no effect on void content for the gravel mixtures. The void contents after standard compaction for the gravel mixtures were so low that water could not penetrate the specimen and essentially no strength loss occurred. However, the caliche specimens swelled, with the void contents almost doubling and significant strength losses occurring.

Since only one moisture conditioning procedure was used in this study, it would be desirable to investigate other conditioning techniques. In addition it seems advisable to use field gradations and field air void contents. The field air void contents could be achieved in the laboratory by varying the compaction effort. In using such a scheme, the effect of several different moisture conditioning methods on strength loss for mixtures of several aggregates with air void contents between 6 and 8 percent could be evaluated. The results from such a study should provide a basis for recommending a moisture conditioning procedure that produces results indicative of field observations.

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CHAPTER 1. INTRODUCTION

A previous study was conducted by the Center for Transportation Research (CTR) to evaluate the effects of soil binder content on the behavior of blackbase mixtures used in Texas (Ref 1). Generally, the results indicated that the various engineering properties were maximized at relatively low soil binder contents and at correspondingly lower asphalt contents. These results showed that optimum soil binder contents ranged from 5 to 10 percent, with the lowest optimum asphalt content occurring in the same soil binder content interval. Since the previous study included a very minimal look at possible moisture effects at these low asphalt contents and since many asphalt paving mixtures in Texas are exhibiting adverse moisture effects, it was felt that a more detailed investigation should be undertaken to investigate the interactions between soil binder content, asphalt content, and moisture effects.

Thus, the objectives of this investigation were to evaluate the effects of moisture on strength and the interaction of moisture and low soil binder and asphalt contents. The experimental program is described in Chapter 2. Test results are presented and discussed in Chapter 3, and the conclusions and recommendations are contained in Chapter 4.

CHAPTER 2. EXPERIMENTAL PROGRAM

This chapter describes the materials, gradations, equipment, and procedures used to evaluate the effects of moisture on the properties of asphalt mixtures with varying soil binder and asphalt contents.

MATERIALS

The same two aggregates used in a previous study (Ref 1) were selected for use in this investigation. These aggregates were obtained from actual construction sites near Eagle Lake and Lubbock, Texas, and consisted of a siliceous river gravel and a crushed limestone (caliche), respectively.

Eagle Lake Material

The aggregate particles that make up the mixture can generally be described as smooth-surfaced, angular, non-porous, crushed river gravel. This material was a mixture composed of four aggregates: Lone Star coarse aggregate, Lone Star Gem sand, Stiles coarse field sand, and Tanner Walker fine field sand. The Lone Star aggregates are siliceous river gravels with crushed faces and the Stiles and Tanner Walker sands are pit-run field sands. This mixture was used for a blackbase construction project on SH 71 south of Columbus, Texas.

Lubbock Material

This material is a rough, sub-angular, porous, crushed limestone (caliche) obtained from the Long Pit, which is located approximately 10 miles southeast of Lubbock, Texas, and was used for the blackbase construction of I-27 between the North Loop at Lubbock and New Deal, Texas.

Asphalt Cement

An AC-20 from the Exxon refinery in Baytown, Texas, was used with both mixtures. Properties of the asphalt as determined by D-9 of the Texas State Department of Highways and Public Transportation (DHT) are summarized in Table 1.

AGGREGATE GRADATIONS

The gradations used for the construction of SH 71 and I-27 blackbases were selected for specimen preparation and evaluation using the Eagle Lake and Lubbock materials.

In order to use the same gradation as in the previous study (Ref 1) but reduce the specimen size from a 204-mm (8.0-inch) and 153-mm (6.0-inch) diameter to a 51-mm (2.0-inch) and 102-mm (4.0-inch) diameter, the aggregate retained on the 22.2-mm (0.875 - inch) sieve was scalped. To evaluate the effect of soil binder content, the gradations were varied from the field gradations by adding or removing aggregates finer than the No. 40 sieve while maintaining constant the amount of material retained on the No. 40 sieve.

The Eagle Lake construction gradation consisted of four aggregates combined in the following proportions:

Lone Star coarse aggregate - 43%
Lone Star Gem sand - 12%
Styles coarse sand - 10%
Tanner Walker fine sand - 35%

For the above mixture, the selected soil binder contents, i.e., the percent passing the No. 40 sieve, were 0, 10, 20, and 30 percent. The field gradation used on SH 71 contained 30 percent soil binder. Gradations for each of the Eagle Lake gravel mixtures evaluated are shown in Fig 1 and tabulated in Table 2.

For the Lubbock caliche, the field gradation used on I-27 contained approximately 25 percent soil binder. The soil binder contents selected for evaluation were 0, 5, 10, and 25 percent. Gradations for each of the

TABLE 1. SUMMARY OF ASPHALT CEMENT PROPERTIES

Asphalt type	AC-20
Producer	Exxon
Water, percent	nil
Viscosity at 135°C (275°F), stokes	3.3
Viscosity at 60°C (140°F), stokes	2,093
Solubility in CCl_4, percent	>99.7
Flash point, C.O.C., °C, (°F)	>315 (600)
Ductility at 25°C (77°F), 5cm/min, cm	____
Penetration at 25°C (77°F), 100 g, 5 sec	56
Specific gravity at 25°C (77°F)	1,020
Tests on residues from thin film oven test:	
Visocity at 60°C (140°F), stokes	3,574
Ductility at 25°C (77°F), 5 cm/min, cm	>141
Spot test	neg

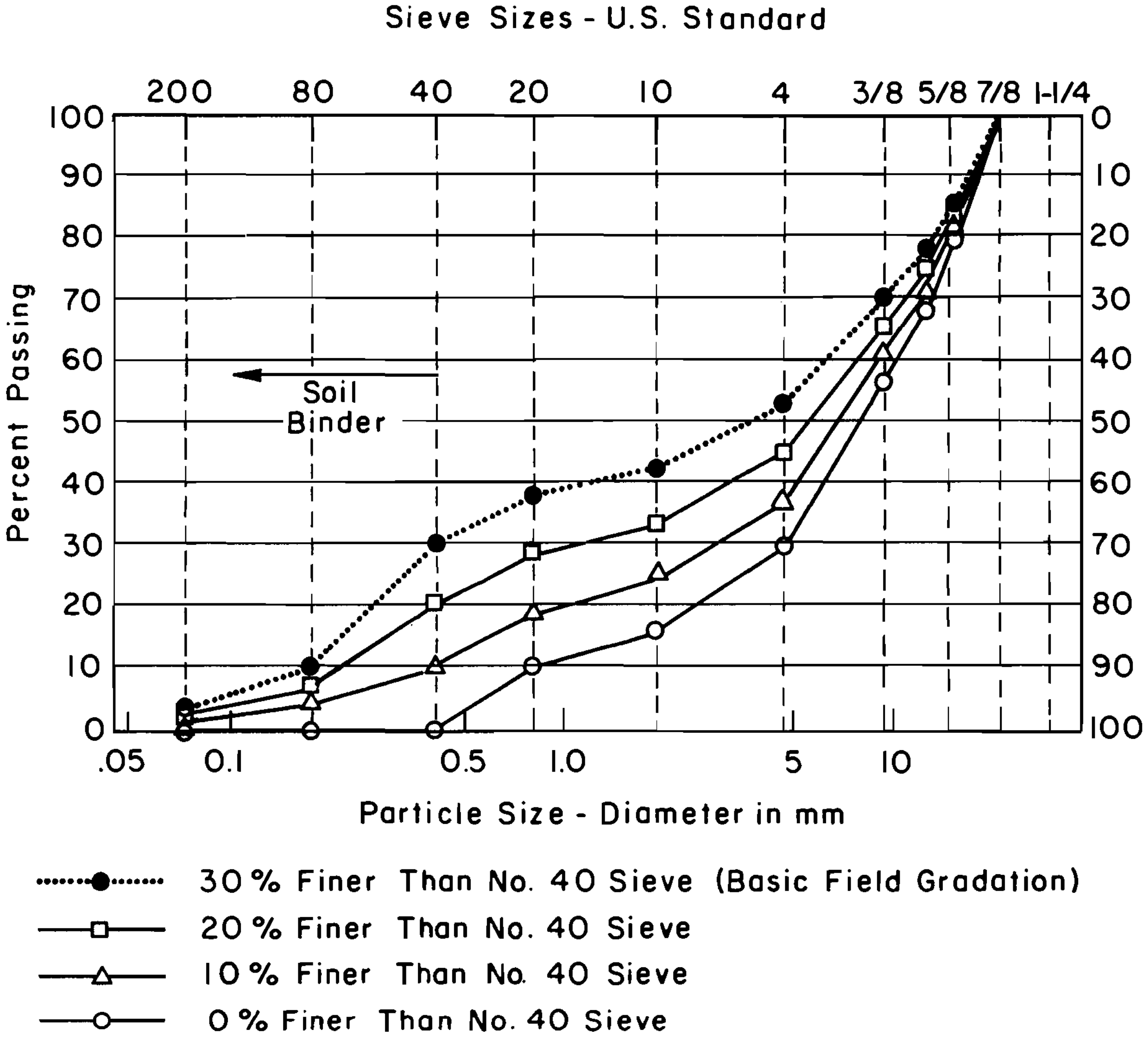


Fig 1. Gradations of Eagle Lake gravel mixtures.

TABLE 2. GRADATIONS OF MIXTURES

		U.S. Standard Sieve Size, Cumulative % Retained											
Material Description	% of Soil Binder	1-1/4"	1"	7/8"	5.8"	1/2"	3/8"	#4	#10	#20	#40	#80	#200
Eagle Lake Gravel	30	3.4	15.0	19.2	27.3	32.4	37.1	51.4	58.9	63.0	69.6	91.1	99.2
	20	3.9	17.2	22.1	31.4	37.2	42.6	59.1	67.7	72.4	69.9	94.1	99.4
	10	4.4	19.4	24.8	35.2	41.8	47.8	66.4	76.2	81.5	90.0	97.1	99.8
	5	4.6	20.5	26.3	37.3	44.2	50.6	70.2	80.4	86.0	95.0	98.5	99.9
	0	4.9	21.6	27.6	39.2	46.6	53.3	73.9	84.6	90.5	100.0	100.0	100.0
Lubbock Caliche	25			12.6	27.0	35.3	45.9	60.0	68.4		75.4		95.9
	10			15.0	32.2	42.1	54.8	71.6	81.6		90.0		98.3
	5			15.8	34.0	44.4	57.8	75.6	86.1		95.0		99.2
	0			16.7	35.8	46.8	60.9	79.6	90.7		100.0		100.0

resulting caliche mixtures are shown in Fig 2 and tabulated in Table 2.

SPECIMEN PREPARATION

All aggregate combinations were batched by dry weight and compacted at 121°C (250°F) using the Texas-Gyratory Shear compactor. However, two different mixing methods were used and they are referred to as Test Method A and Test Method B.

Test Method A preparation complied with the standard Texas DHT mixture design procedure. The aggregates and asphalt were heated to 135°C (275°F), mixed at 135°C (275°F), and compacted at 121°C (250°F).

The Test Method B procedure included heating the aggregate at 160°C (320°F) for 15 hours; then, the aggregates and asphalt were placed in an oven at 149°C (300°F) for 2 hours and then mixed at 149°C (300°F). The resulting mixture was cooled at room temperature for 2 1/2 hours and placed in a 60°C (140°F) oven for 15 hours. Prior to compaction, the mixture was reheated to 121°C (250°F) for 2 hours; then it was compacted at 121°C (250°F).

SPECIMEN CONDITIONING

In order to evaluate the interaction of moisture and soil binder content, the specimens were tested in either a dry or a wet condition. The dry condition testing consisted of curing the specimen at 24°C (75°F) for 4 days prior to testing. The wet condition testing consisted of immersing the specimen in distilled water at room temperature, 24°C (75°F), applying a 4-inch vacuum for 30 minutes, and then subjecting the specimen to a freeze-thaw cycle. The cycle consisted of freezing the saturated specimen at -18°C (0°F) for 15 hours and then heating it to 60°C (140°F) for 24 hours. The specimen was tested immediately after the freeze-thaw cycle was completed. This conditioning is referred to as the vacuum-saturated-freeze-thaw or, simply, "wet". This specimen conditioning is similar to that used in a study conducted at the University of Idaho by Lottman (Ref 2), except that the vacuum level was less.

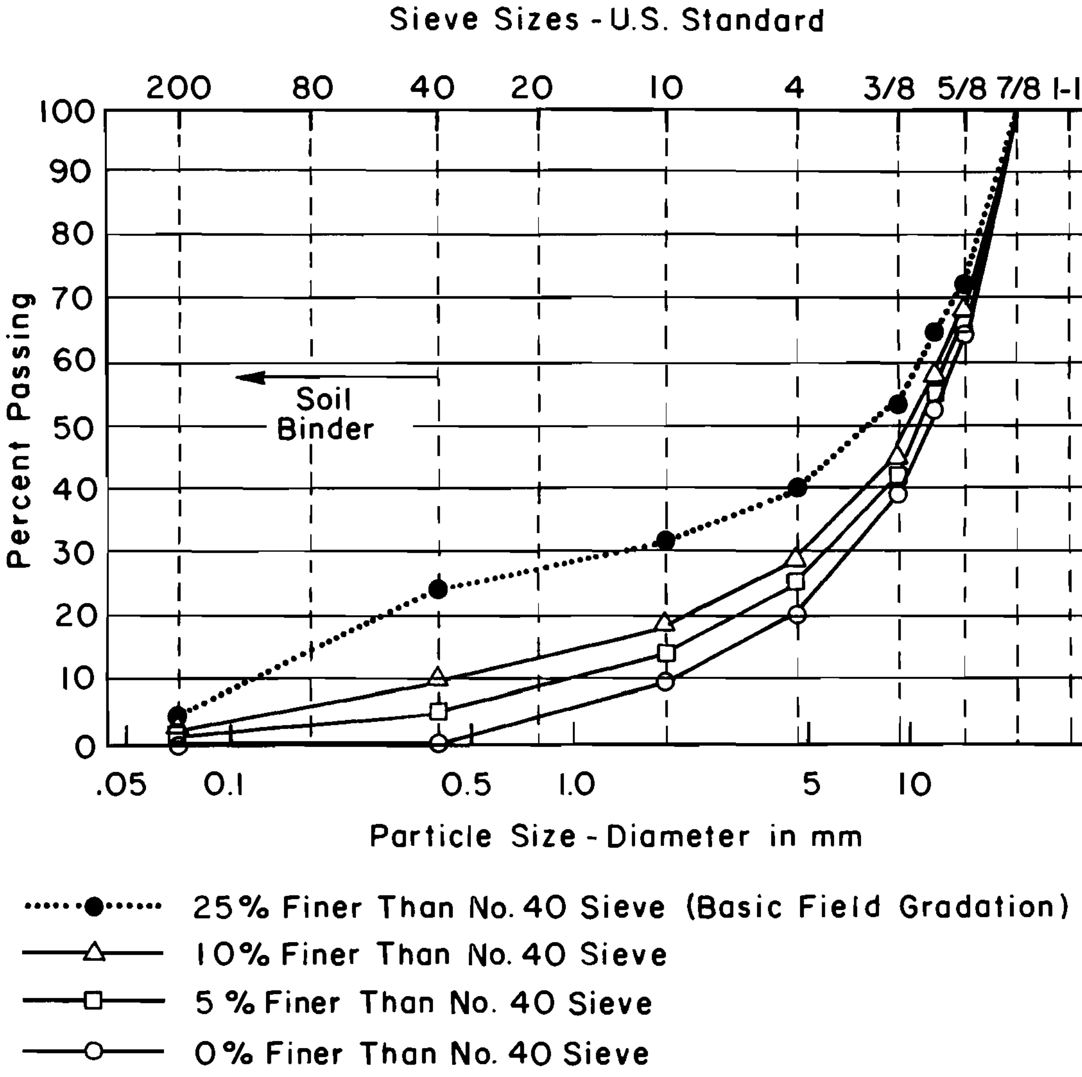


Fig 2. Gradations of Lubbock limestone mixtures.

The detailed procedure for preparing and conditioning specimens is described in Appendix A.

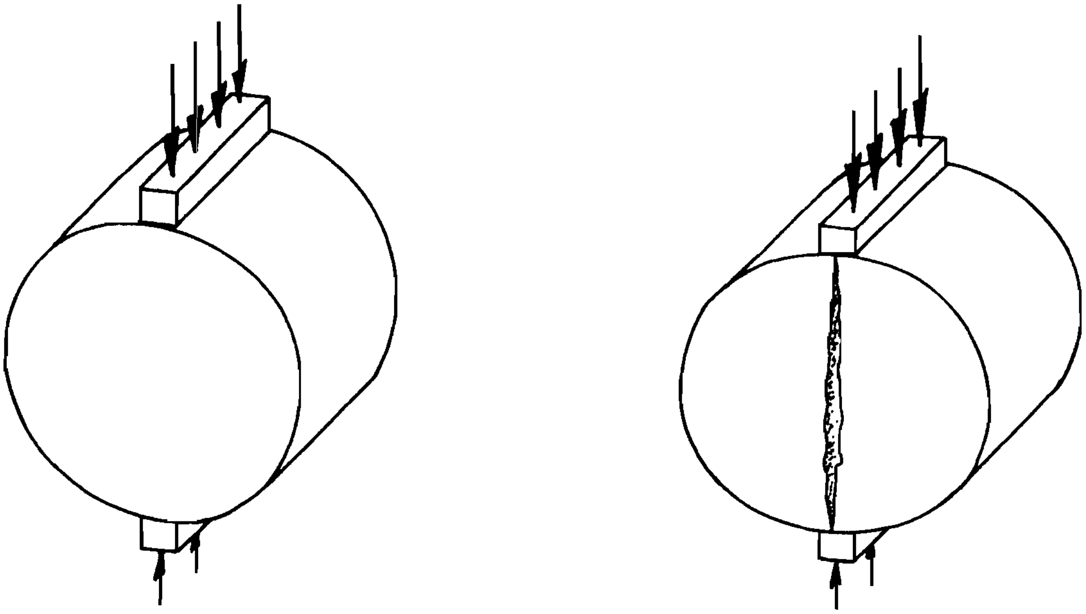
INDIRECT TENSILE TEST

The indirect tensile test involves loading a cylindrical specimen with static or repeated compressive loads acting parallel to and along the vertical diametrical plane, as shown in Fig 3a. The compressive load is distributed through 13-mm (0.5-inch) - wide steel loading strips which are curved at the interface to fit the specimen. This method of loading produces a fairly uniform tensile stress perpendicular to the plane of the applied load and along the vertical diametrical plane which ultimately causes the specimen to fail by splitting along the vertical diameter (Fig 3b). Estimates of the tensile strength, modulus of elasticity, and Poisson's ratio can be calculated from the applied load and corresponding vertical and horizontal deformations.

Test Equipment

The test equipment was the same as that used in previous studies at the Center for Transportation Research and included a loading frame, loading head, and MTS closed-loop electrohydraulic system to apply load and to control deformation rate. The loading head was a modified commercially available die set with the lower platen fixed and the upper platen constrained so that both platens remained parallel. The curved stainless steel loading strips were attached to both the upper and lower platens. Dimensions and configuration of the curved loading strips are the same as used in the previous study (Ref 1).

In order to estimate modulus of elasticity and Poisson's ratio, measurement of both vertical and horizontal deformations of the specimens was necessary. For the static test conducted in this study the vertical deformations were monitored by an LVDT positioned on the upper platen. However, horizontal deformations were measured using a device consisting of two cantilevered arms with strain gages attached (Ref 3).



(a) Compressive load being applied. (b) Specimen failing in tension.

Fig 3. Indirect tensile test loading and failure.

Test Procedure

In order to prevent impact loading and to minimize the seating effect the upper loading strip was lightly brought into contact with the specimen. A loading rate of 51 mm (2 inches) per minute (Test Method A) or 4 mm (0.15 inch) per minute (Test Method B) was applied at a test temperature of 24°C (75°F). The loads and deformations were recorded on two X-Y plotters, one recording load and horizontal deformation and the other recording load and vertical deformation.

From the strip-chart recordings vertical and horizontal deformations at corresponding loads were obtained and, with the dimensions of each specimen known, were used to calculate the tensile and elastic properties of the materials tested.

ENGINEERING PROPERTIES ANALYZED

The properties analyzed were tensile strength, static modulus of elasticity and static Poisson's ratio.

Tensile Strength

Tensile strength is the maximum tensile stress which the specimen can withstand and is related to thermal or shrinkage cracking resistance. For 102-mm (4-inch) - diameter specimens and the load-deformation information obtained from the static test, the following relationship can be used to calculate tensile strength:

$$S_T = \frac{0.156P}{t}$$

where

S_T = tensile strength, psi,

P = the maximum load carried by the specimen, lb, and

t = thickness or height of the specimen, in.

Tensile stresses produced by loads less than the maximum load P can also be calculated using the above equations.

Static Poisson's Ratio

Static Poisson's ratio is determined from an analysis of the load-deformation relationships obtained from the static indirect tensile tests. A regression analysis is performed using the data points for horizontal and vertical deformation up to the sharp inflection point in the load-deformation curves, which generally occurs between 60 and 90 percent of the ultimate load. If a sharp break in the curve does not occur, data points up to about midway between the ultimate load and the deviation from linearity are included (Ref 3). The equation for calculating static Poisson's ratio is

$$\nu = \frac{3.59}{DR} - 0.27$$

where

ν = static Poisson's ratio, and

DR = deformation ratio (the slope of the linear regression relationship between vertical and horizontal deformation), inches of vertical deformation per inch of horizontal deformation.

Static Modulus of Elasticity

Static modulus of elasticity E_S is calculated from the relationship between the vertical and horizontal deformations up to the same point in the load-deformation relationship used for calculating the static Poisson's ratio.

The equation used to calculate the static modulus is

$$E_S = \frac{S_h}{t} (0.27 + \nu)$$

where

E_S = static modulus of elasticity, psi,

S_h = the slope of the relationship between load and horizontal deformation, lb/in.,

t = thickness or height of the specimen, in., and

ν = static Poisson's ratio.

In order to evaluate the effects of moisture conditioning on the gravel and caliche mixtures two additional parameters were defined in terms of the tensile strength and the modulus of elasticity of the mixtures. These parameters were tensile strength ratio TSR and static modulus of elasticity ratio MER, which are defined as follows:

$$TSR = \frac{S_{T_{wet}}}{S_{T_{dry}}}$$

where

$S_{T_{wet}}$ = tensile strength of the wet specimen, psi, and

$S_{T_{dry}}$ = tensile strength of the dry specimen, psi;

and

$$MER = \frac{E_{S_{wet}}}{E_{S_{dry}}}$$

where

$E_{S_{wet}}$ = modulus of elasticity of the wet specimen, psi, and

$E_{S_{dry}}$ = modulus of elasticity of the dry specimen, psi.

TESTING PROGRAM

The variables included in this study were aggregate type, soil binder content, asphalt content, specimen conditioning before testing (dry and wet), and test methods. Specimens were prepared according to the testing program outlined in Table 3. All specimens were tested at room temperature, 24°C (75°F).

TABLE 3. OUTLINE OF TESTING PROGRAM

Soil Binder Content, %	Asphalt (AC-20) Content, %	Test Method A				Test Method B			
		Eagle Lake Gravel Mixtures		Lubbock Caliche Mixtures		Eagle Lake Gravel Mixtures		Lubbock Caliche Mixtures	
		Unconditioned	Conditioned	Unconditioned	Conditioned	Unconditioned	Conditioned	Unconditioned	Conditioned
0	3.0	2				2			
	4.0	2				2	2		
	4.5	2	2			2	2		
	5.0	2	2			2	2		
	5.5	2	2			2	2		
	6.0	2	2	2	2	2		2	2
	6.5			2	2			2	2
	7.0	2		2	2			2	2
	7.5			2	2			2	2
5	5.5			2	2			2	2
	6.0			-	-			2	2
	6.5			2	2			-	-
	7.0			2	2			2	2
	8.0			2	2			2	2
10	3.0	2				2			
	4.0					2	2		
	4.5	2	2			2	2		
	5.0	2	2			2	2		
	5.5	2	2	2	4	2	2	2	2
	6.0	2	2	2	4	2	2	2	2
	6.5			2	4			2	2
	7.0			2	4			2	2
	7.5	2							
20	3.0	2				2			
	4.5	2	2			2	2		
	5.0	2	4			2	2		
	5.5	2	4			2	2		
	6.0	2	4			2	2		
	6.5		2			2	2		
	7.5	2				2			
25	6.0			2	2			2	2
	6.5			2	2			2	2
	7.0			2	2			2	2
	8.0			2	2			2	2
30	3.0	2				2			
	5.0	2							
	5.5	2	4			2	2		
	6.0	2	4			2	2		
	6.5	2	4			2	2		
	7.0	2	4			2	2		
	7.5	2				2			

Testing Temperature = 24°C (75°F)

Numbers in table represent specimens tested for each set of conditions.

CHAPTER 3. DISCUSSION OF TEST RESULTS

The tensile strength ratio TSR and modulus of elasticity ratio MER reflect the change caused by moisture and relate to the moisture susceptibility of the mixture. Relationships between TSR, MER, soil binder content, asphalt content, air void content, and moisture content were examined using results from each test method. A summary of the individual test results for each method is presented in Table 4 and the range of values obtained using both test methods are included in Table 5.

VALUES OF TSR AND MER

Values of TSR ranged from 0.59 to 1.5 for the gravel mixtures and 0.19 to 0.56 for the caliche mixtures (Table 5). These ranges are slightly wider than the range (0.14 to 1.04) reported by Lottman (Ref 2) for mixtures in South Dakota. Maupin (Ref 4) reported values ranging from 0.26 to 1.17 for specimens subjected to similar freeze-thaw conditioning. This difference could be a result of the wider range of air voids included in this study. Figure 4 illustrates the relationship between TSR results from the two test methods. In general, Test Method A appears to be slightly more severe than Method B.

Values of MER ranged from 0.37 to 1.52 for the gravel mixtures and from 0.05 to 0.22 for the caliche mixtures (Table 5). These values of MER are in the same general range as the values of TSR. Figure 5 shows the relationship between TSR and MER for similar specimens and illustrates that there was no well-defined relationship between TSR and MER.

TABLE 4. SUMMARY OF TEST RESULTS

a. USING TEST METHOD A PROCEDURE

			Unconditioned					Conditioned								
				Tensile Strength S_T		Static Modulus of Elasticity E_S		Air Void Content, %			Tensile Strength S_T		Static Modulus of Elasticity E_S		Wet/Dry Ratio	
Aggregate	Soil Binder Content, %	Asphalt Content, %	Air Void Content, %	kPa	psi	10^3 kPa	10^3 psi	Prior to Cond.	After Cond.	Moisture Content, %	kPa	psi	10^3 kPa	10^3 psi	Tensile Strength Ratio TSR	Modulus of Elasticity Ratio MER
Gravel	0	4.0	11.6	516	75	569	83									
		4.5	10.4	602	87	611	89	9.5	9.5	1.9	353	51	397	58	0.59	0.65
		5.0	10.8	582	84	569	83	8.4	8.4	1.6	439	64	486	71	0.75	0.85
		5.5	8.7	694	101	772	112	7.7	7.7	1.1	594	86	335	49	0.86	0.43
		6.0	5.8	666	97	565	82	7.1	7.1	1.2	534	77	559	81	0.80	0.99
	10	4.5	5.7	957	139	945	137	4.2	4.2	0.8	1046	152	990	144	1.09	1.05
		5.0	3.8	1033	150	1193	173	3.5	3.5	0.5	1102	160	831	121	1.07	0.70
		5.5	3.2	912	132	1103	160	2.2	2.2	0.3	1185	172	859	125	1.30	0.78
		6.0	1.9	987	143	1090	158	1.5	1.5	0.2	908	132	407	59	0.92	0.37
	20	4.5	4.6	1035	150	1093	159	4.4	4.4	0.8	1084	157	1269	184	1.05	1.16
		5.0	3.7	1043	151	959	150	3.3	3.3	0.4	1248	181	1260	183	1.20	1.22
		5.5	3.0	984	143	1017	148	2.2	2.2	0.3	1202	174	969	141	1.22	0.95
		6.0	2.4	908	132	880	128	1.5	1.5	0.2	1053	153	838	122	1.16	0.95
	30	5.5	5.0	938	136	1120	163	5.0	5.0	0.8	897	130	500	41	0.96	0.45
		6.0	3.8	903	131	1024	149	4.3	4.3	0.5	1053	153	722	56	1.17	0.71
		6.5	2.6	868	126	607	88	3.0	3.0	0.2	987	143	716	67	1.14	1.18
		7.0	2.3	800	116	576	84	2.5	2.5	0.2	948	138	533	46	1.19	0.93
Caliche	0	6.0	4.7	1274	185	1307	190	5.0	10.0	6.5	312	45	114	12	0.24	0.09
		6.5	4.5	1117	162	1593	231	4.6	8.7	5.3	421	61	121	18	0.38	0.08
		7.0	4.0	1076	156	945	137	3.6	8.0	5.4	462	67	131	19	0.43	0.14
		7.5	3.6	1123	163	1079	157	4.1	9.0	5.5	391	57	183	27	0.35	0.17
	5	5.5	6.5	1069	155	1772	257	6.3	11.9	7.4	236	34	80	12	0.22	0.05
		6.5	4.9	1181	171	1459	212	4.6	8.6	6.3	374	54	97	14	0.32	0.07
		7.0	3.7	1236	179	1883	273	4.5	9.2	6.2	433	63	135	20	0.35	0.07
		8.0	2.5	1049	152	1486	216	3.6	9.2	5.8	467	68	114	17	0.45	0.08
	10	5.5	5.9	1285	186	1442	209	5.3	10.6	6.7	365	53	105	15	0.27	0.06
		6.0	4.9	1414	205	1641	238	5.2	11.4	7.0	323	47	107	16	0.23	0.07
		6.5	3.9	1287	187	1693	246	3.8	10.4	6.2	445	65	173	25	0.35	0.10
		7.0	3.0	1356	197	1734	252	2.7	8.8	5.2	562	82	167	24	0.41	0.10
	25	6.0	6.2	1466	213	2213	321	6.5	11.0	6.6	365	53	111	16	0.25	0.05
		6.5	5.5	1493	217	2196	319	5.1	9.6	6.3	387	56	124	18	0.26	0.06
		7.0	4.2	1552	225	2331	338	4.4	8.2	5.2	608	88	217	31	0.39	0.09
		8.0	3.3	1379	200	1610	234	3.5	7.2	4.7	677	98	214	31	0.49	0.13

(continued)

TABLE 4. SUMMARY OF TEST RESULTS (Continued)

b. USING TEST METHOD B PROCEDURE

			Unconditioned					Conditioned								
				Tensile Strength S_T		Static Modulus of Elasticity E_S		Air Void Content, %			Tensile Strength S_T		Static Modulus of Elasticity E_S		Wet/Dry Ratio	
Aggregate	Soil Binder Content, %	Asphalt Content, %	Air Void Content, %	kPa	psi	10^3 kPa	10^3 psi	Prior to Cond.	After Cond.	Moisutre Content, %	kPa	psi	10^3 kPa	10^3 psi	Tensile Strength Ratio TSR	Modulus of Elasticity Ratio MER
Gravel	0	4.0	11.8	178	26	107	16	11.3	11.3	2.0	173	25	83	12	0.97	0.76
		4.5	11.1	192	28	148	22	10.1	10.1	1.7	180	26	125	18	0.94	0.84
		5.0	8.4	233	34	190	28	10.0	10.0	1.5	205	30	83	12	0.88	0.44
		5.5	8.1	242	35	149	22	8.3	8.3	1.2	283	41	162	24	1.17	1.09
		6.0	8.5	200	29	93	14									
	10	4.0	6.6	402	58	383	56	6.8	6.8	1.1	481	70	248	36	1.20	0.65
		4.5	5.1	381	55	483	70	4.8	4.8	0.7	517	75	297	43	1.36	0.61
		5.0	3.8	390	57	490	71	3.6	3.6	0.4	415	60	248	36	1.06	0.51
		5.5	3.5	383	56	369	54	3.6	3.6	0.4	426	62	207	30	1.11	0.56
		6.0	3.4	350	51	269	39	2.4	2.4	0.3	337	49	142	21	0.96	0.53
	20	4.5	4.8	406	59	352	51	4.9	4.9	0.9	494	72	331	48	1.22	0.94
		5.0	3.5	449	65	486	71	3.8	3.8	0.3	513	74	259	38	1.14	0.53
		5.5	2.3	418	61	372	54	2.5	2.5	0.2	524	76	307	45	1.25	0.83
		6.0	1.9	297	43	159	23	1.8	1.8	0.1	445	65	241	35	1.50	1.52
		6.5	1.7	290	42	159	23	1.6	1.6	0.1	338	49	117	17	1.16	0.75
	30	5.5	4.8	416	60	321	47	5.1	5.1	0.6	403	58	176	26	0.97	0.55
		6.0	3.6	429	62	290	42	4.2	4.2	0.4	416	60	228	33	0.97	0.79
		6.5	2.7	388	56	225	33	3.2	3.2	0.1	466	68	242	35	1.20	1.08
		7.0	2.5	346	50	125	18	2.8	2.8	0.1	345	50	131	19	1.00	1.05
Caliche	0	6.0	8.0	493	72	428	62	8.2	12.5	7.9	131	19	28	4	0.27	0.07
		6.5	7.3	533	77	483	70	6.7	11.7	7.5	160	23	73	11	0.30	0.15
		7.0	4.5	587	85	714	104	5.2	11.3	6.4	206	30	66	10	0.35	0.09
		7.5	4.1	572	83	514	75	4.6	11.9	7.0	216	31	59	9	0.38	0.11
	5	5.5	5.9	671	97	566	82	6.5	12.1	7.4	184	27	59	9	0.27	0.10
		6.0	5.5	704	102	569	83	5.3	10.0	7.1	156	23	62	9	0.22	0.11
		7.0	4.8	679	99	600	87	5.4	9.8	6.1	274	40	80	12	0.40	0.13
		8.0	3.0	555	81	511	74	3.1	8.0	5.1	303	44	83	12	0.55	0.16
	10	5.5	6.0	732	106	673	98	5.0	11.0	7.2	133	20	35	5	0.19	0.05
		6.0	3.7	823	119	728	106	3.8	9.5	5.8	239	35	69	10	0.29	0.09
		6.5	3.0	785	114	934	136	2.7	7.8	5.3	296	43	73	11	0.38	0.08
		7.0	2.0	693	100	642	93	3.0	7.8	5.1	312	45	90	13	0.45	0.14
	25	6.0	5.8	771	112	1059	154	5.9	10.0	6.6	242	35	90	13	0.31	0.08
		6.5	3.9	982	142	1041	151	4.6	9.0	6.0	275	40	117	17	0.28	0.11
		7.0	3.2	939	136	1148	167	3.2	7.8	4.6	424	62	166	24	0.45	0.14
		8.0	1.6	876	127	828	120	1.7	5.6	3.9	488	71	183	27	0.56	0.22

TABLE 5. RANGE OF TEST VALUES

Aggregate Type	Test Method	Soil Binder Content, %	Asphalt Content, %	Air Void Content, %	Moisture Content, %	Tensile Strength S_T		Static Modulus of Elasticity E_S		Tensile Strength Ratio TSR	Modulus of Elasticity Ratio MER
						Unconditioned kPa (psi)	Conditioned kPa (psi)	Unconditioned 10^3 kPa (10^3 psi)	Conditioned 10^3 kPa (10^3 psi)		
Eagle Lake Gravel	A	0 - 30	4.5 - 7.0	1.5 - 11.6	0.2 - 1.9	516 - 1043 (75 - 181)	353 - 1248 (51 - 173)	565 - 1193 (82 - 184)	335 - 1269 (49 - 184)	.59 - 1.3	.37 - 1.22
	B	0 - 30	4.0 - 7.0	1.6 - 11.8	0.1 - 2.0	178 - 449 (26 - 65)	173 - 524 (25 - 76)	93 - 490 (14 - 71)	83 - 331 (12 - 48)	.94 - 1.5	.44 - 1.52
Lubbock Caliche	A	0 - 25	5.5 - 8.0	1.4 - 6.7	4.7 - 7.4	1049 - 1552 (152 - 225)	236 - 677 (34 - 98)	945 - 2331 (137 - 338)	80 - 217 (12 - 31)	.22 - .49	.05 - .17
	B	0 - 25	5.5 - 8.0	0.4 - 8.2	3.9 - 7.9	493 - 982 (72 - 142)	131 - 488 (19 - 71)	428 - 1148 (62 - 167)	28 - 183 (4 - 27)	.19 - .56	.05 - .22

Test Temperature - 24°C (75°F)
Loading Rate - A - 51 mm (2 in) per minute
B - 4 mm (0.15 in) per minute

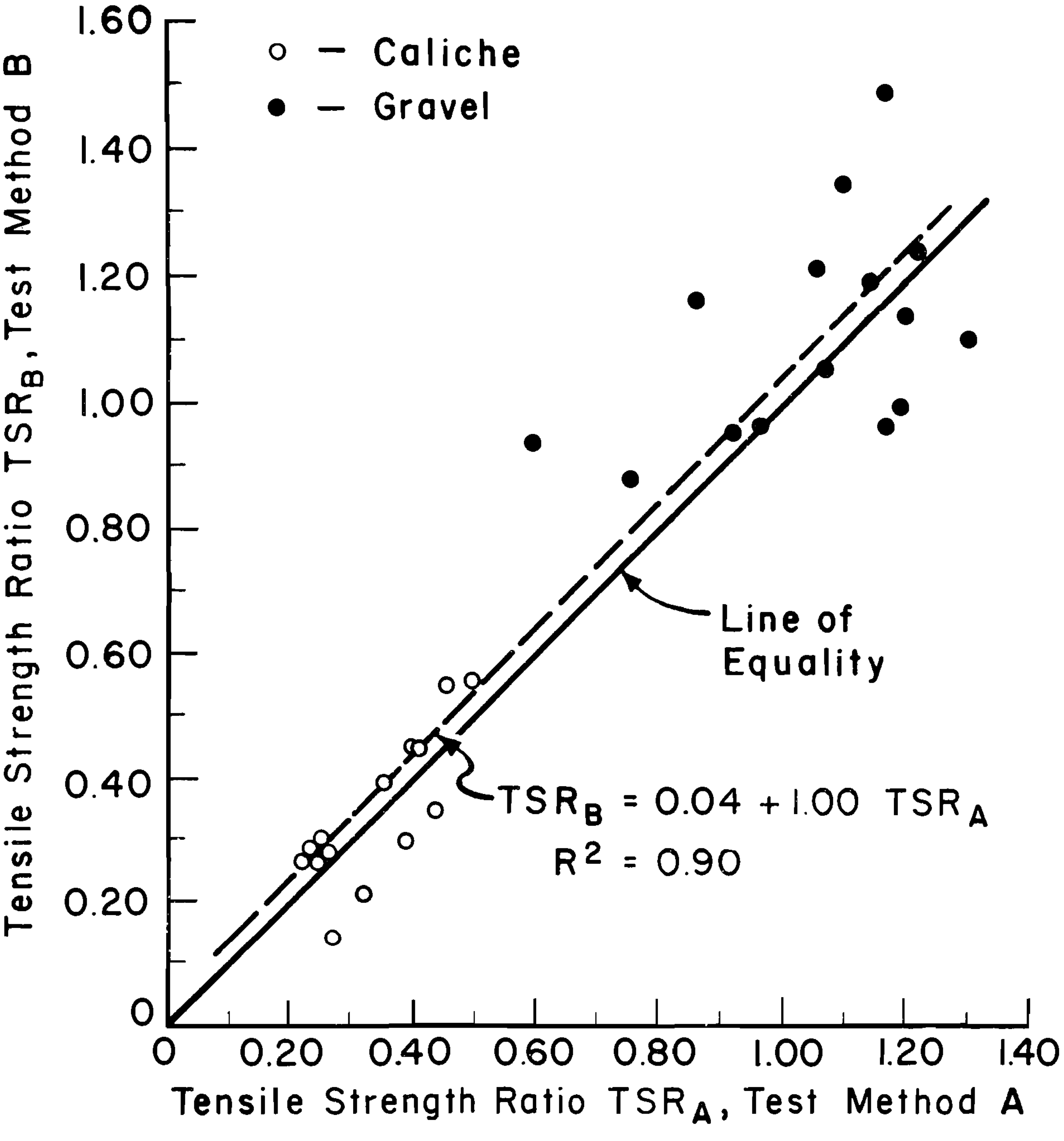


Fig 4. Comparison of tensile strength ratios obtained for Test Methods A and B.

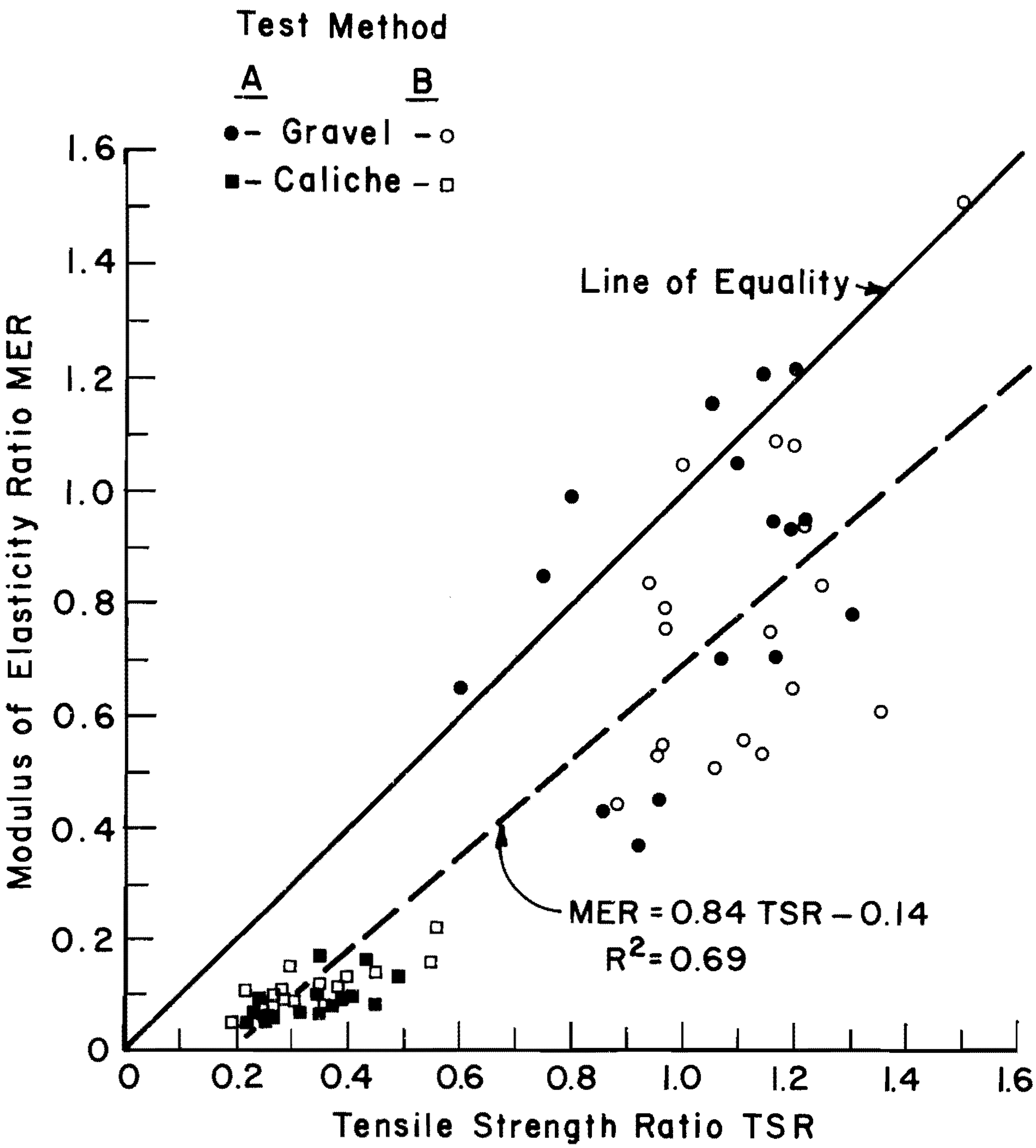


Fig 5. Relationship between tensile strength ratio and modulus of elasticity ratio.

FACTORS AFFECTING TSR

The test results from this study were used to investigate the changes in TSR as a result of changes in binder content, asphalt content, air void content, and moisture content for both aggregate types and test methods.

Soil Binder Content

The effects of changing the soil binder content on TSR for both aggregate mixtures and test methods are shown in Fig 6. The gravel mixtures exhibited little loss of strength due to moisture except at 0 percent soil binder. The TSR generally stayed near 1.0, with the highest ratios occurring between 10 and 20 percent soil binder content.

The caliche mixtures, on the other hand, exhibited large losses of the tensile strength ratio at all soil binder contents as a result of moisture conditioning. However, the loss was somewhat mitigated with higher asphalt contents since the higher asphalt contents always decreased the loss of the TSR, especially for Test Method B (Fig 6).

Asphalt Content

Figure 7 illustrates the relationship between TSR and asphalt content. It would appear that for the gravel mixtures there was an optimum TSR-asphalt-content, depending on the soil binder content. However, for the caliche mixtures there was an apparent increase in TSR with an increase in asphalt content. Both test methods A and B produced the same results.

Air Void Content

Previous studies indicated that moisture damage is dependent on the relative density or the air void content of the mixtures (Refs 1 and 2). Generally, mixtures having high air void contents are more adversely affected by moisture than mixtures with low air void contents. For this study the relationships between TSR and air void content, shown in Fig 8, indicate that as the air void content increased for both types of mixtures the TSR decreased. These figures also show that the effects of the moisture were

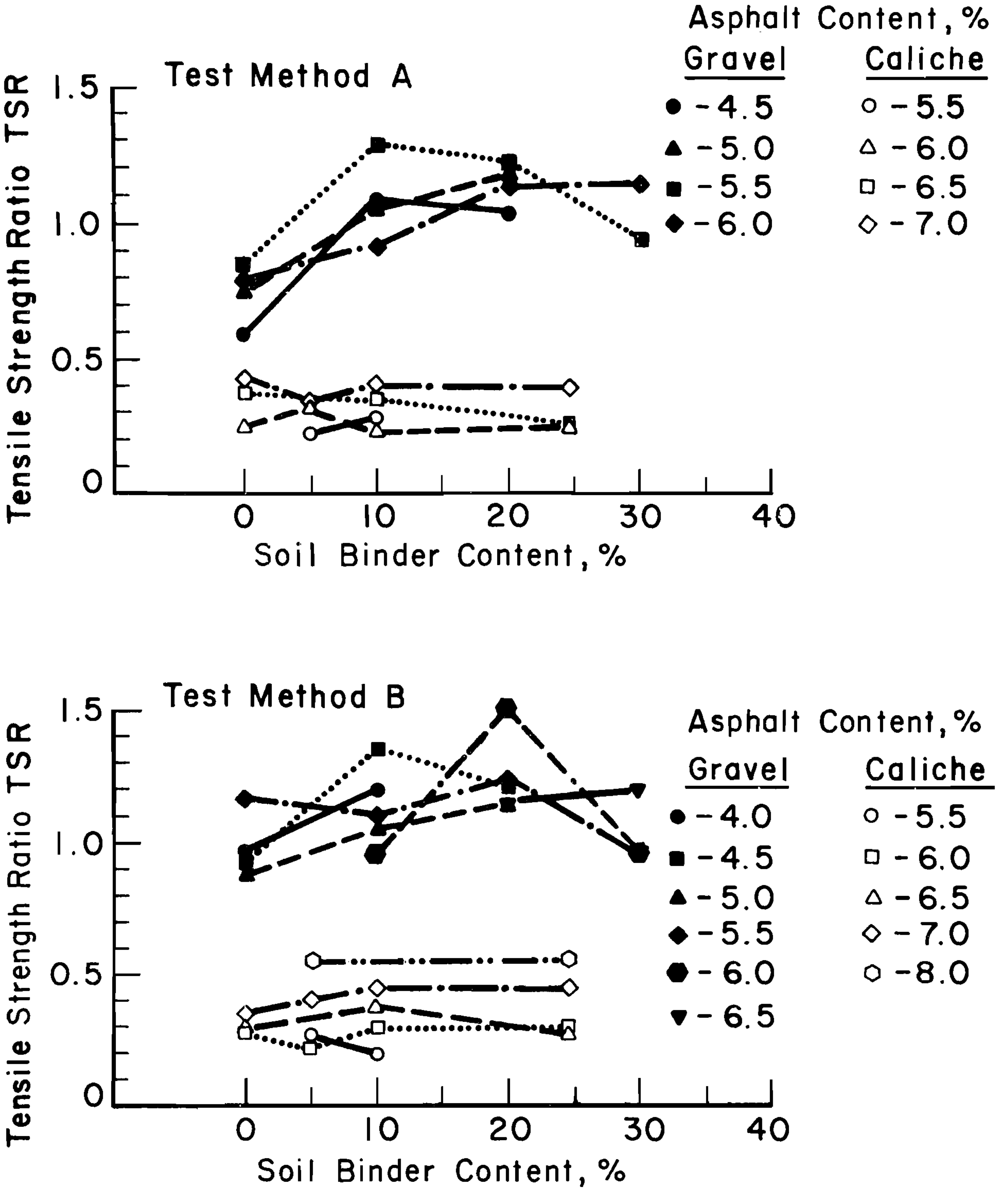


Fig 6. Relationship between soil binder content and tensile strength ratio.

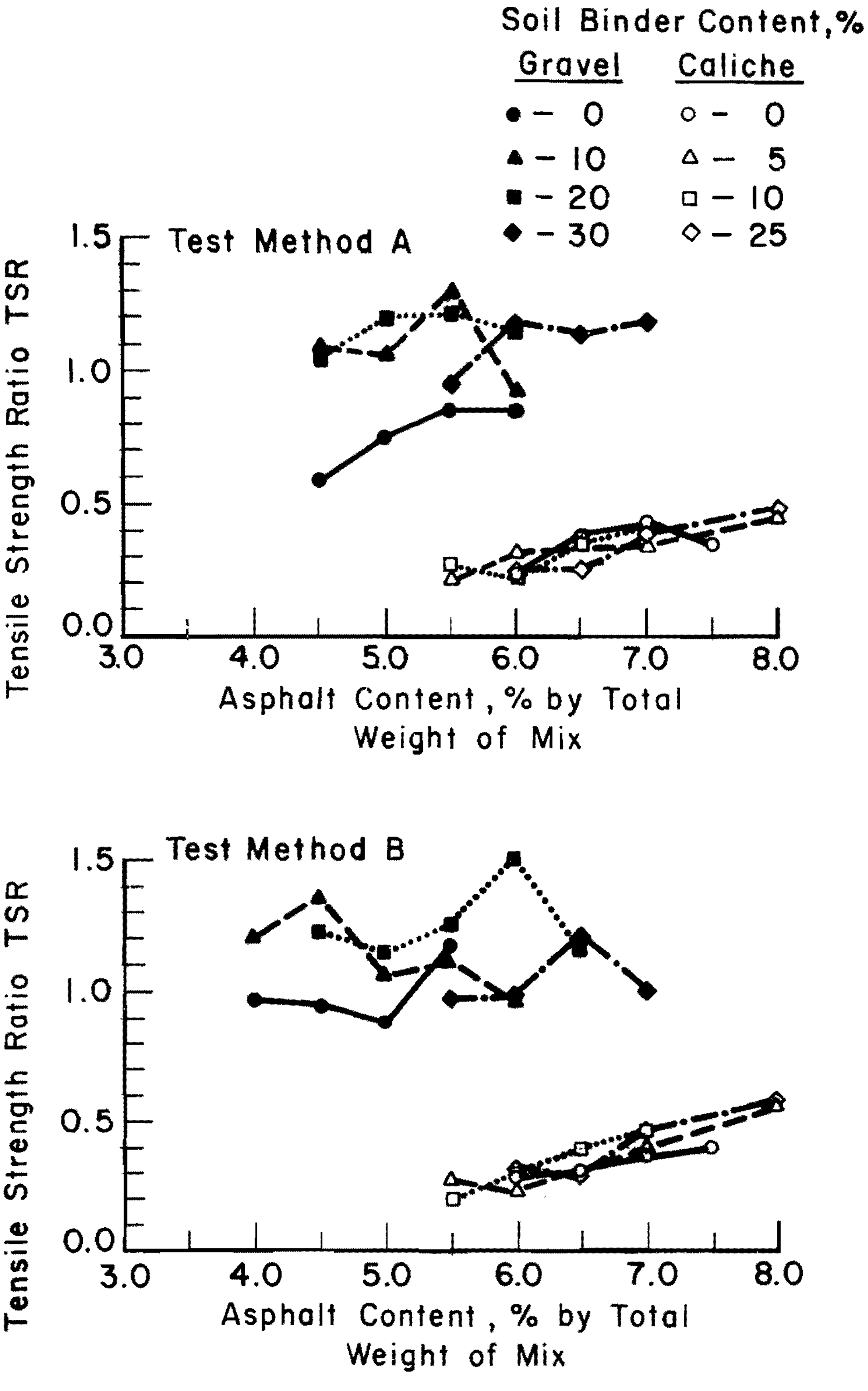


Fig 7. Relationship between asphalt content and tensile strength ratio.

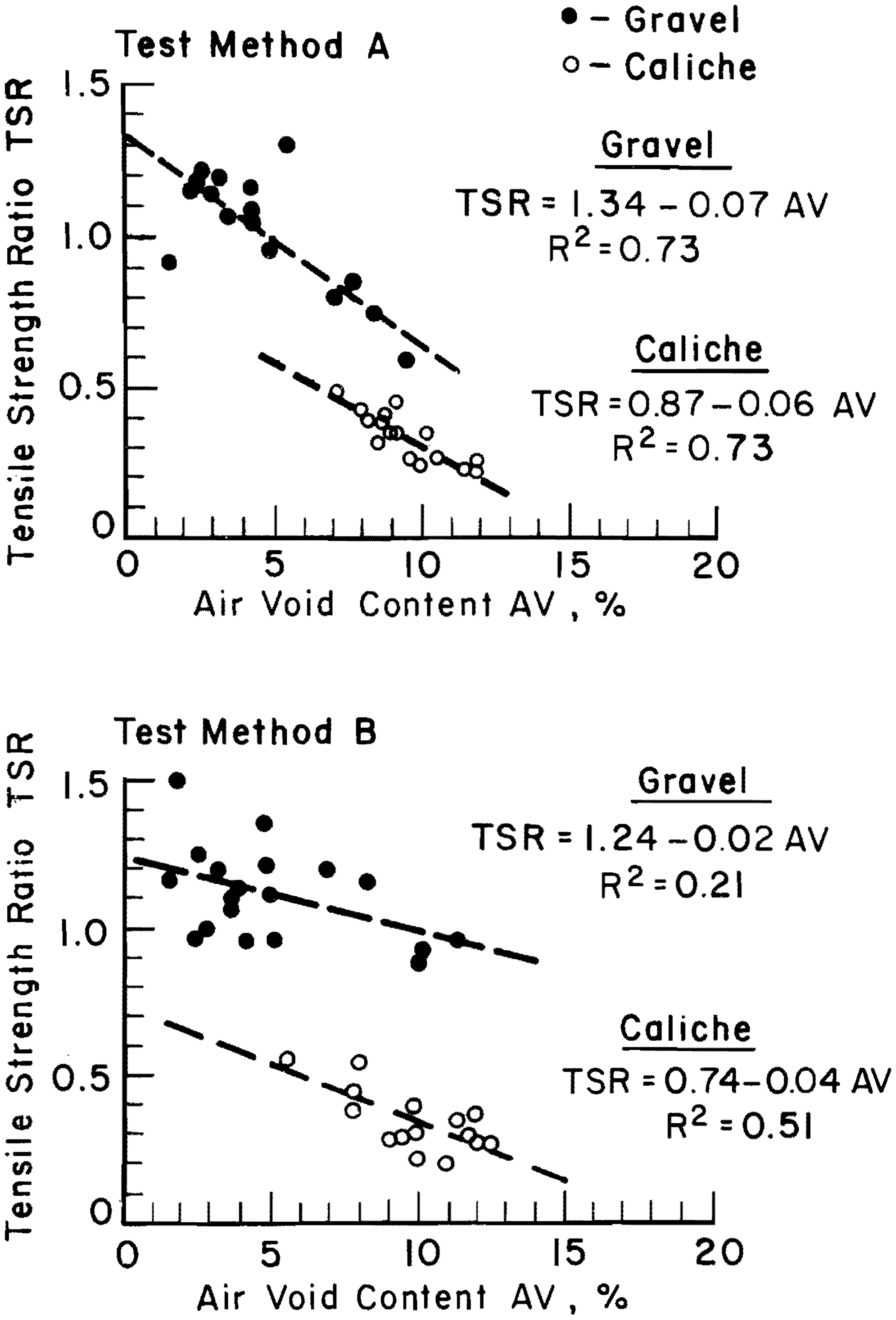


Fig 8. Relationship between air void content and tensile strength ratio.

more pronounced for Method A than for Method B. In fact, both the slopes and the intercepts of the relationships in Fig 8 are greater for Method A than for Method B, indicating a greater severity for Method A. It can also be seen that the caliche mixtures had higher air void contents (5.6 to 12.5 percent) than the gravel mixtures (1.5 to 11.3 percent).

A comparison of the air void contents at time of test for both test methods is shown in Fig 9. In general, the air void content was not affected by the difference in specimen preparation or testing for the two test methods. However, there was considerably more scatter in the data for the caliche than for the gravel mixtures regardless of test method.

Water Content

The amount of water absorbed by each specimen during moisture conditioning was measured before testing and expressed as a percentage of the dry weight of the specimen. Water contents ranged from 0.1 to 2.0 percent for the gravel mixtures and from 3.9 to 7.9 percent for the caliche mixtures.

The relationships between TSR and water content produced results similar to those with air void content, in that an increase in water content produced a decrease in TSR, as shown in Fig 10. Test method similarity is demonstrated in Fig 11.

Aggregate Type

Results indicated that the moisture susceptibility of the Lubbock caliche mixtures was much greater than that of the Eagle Lake gravel mixtures. Similar results were obtained in the previous study. As shown, the TSR values for the caliche mixtures were consistently much smaller than the values for the gravel mixtures (Figs 4 through 8 and 10). Figure 12, a comparison of air void contents and moisture contents for both materials, shows that the caliche mixtures had higher moisture contents and air void contents than did the gravel mixtures. After compaction both mixtures had about the same air void contents, 1.7 to 8.2 percent for the caliche and 1.5 to 11.3 percent for the gravel (Table 4). After moisture conditioning, however, the air void contents for the gravel were the same as before conditioning but for the caliche mixture the air voids had increased in range

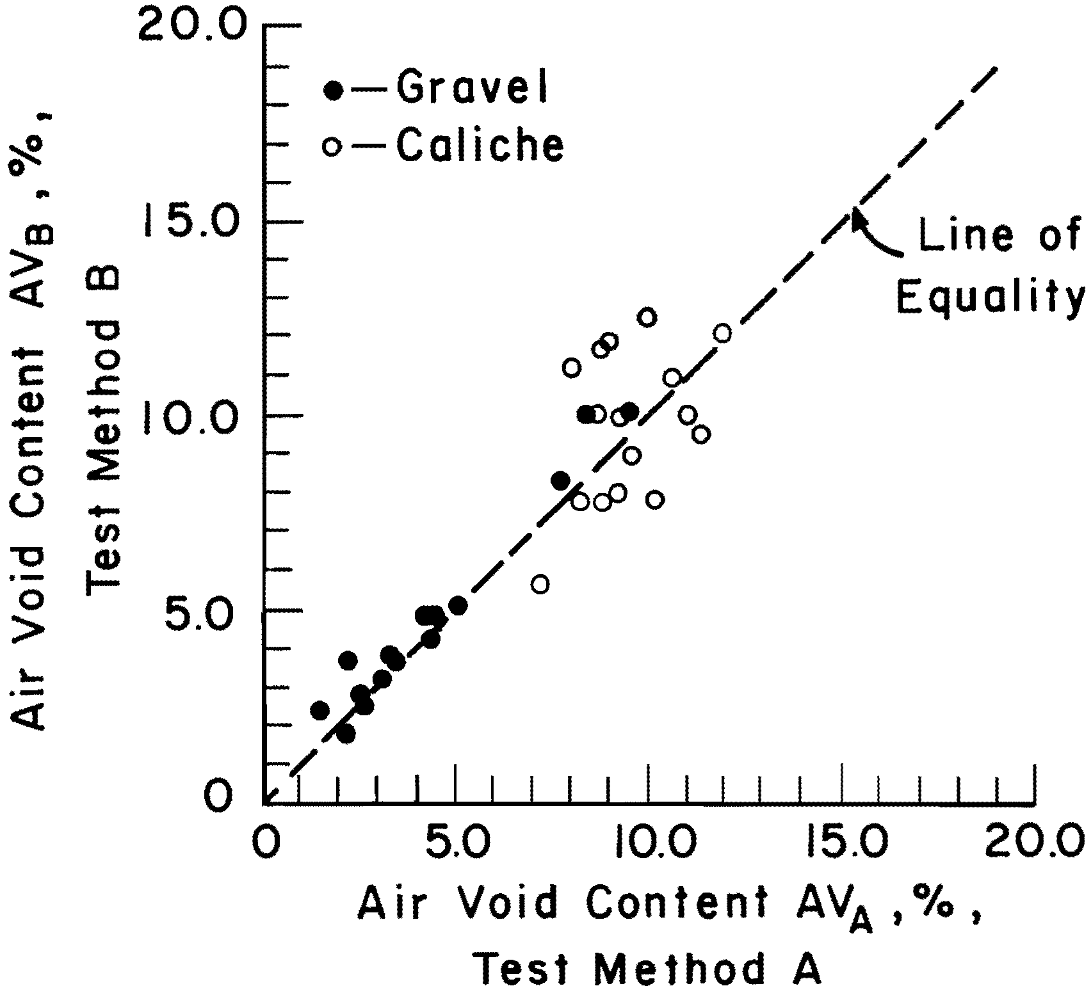


Fig 9. Comparison of air void contents obtained for Test Methods A and B.

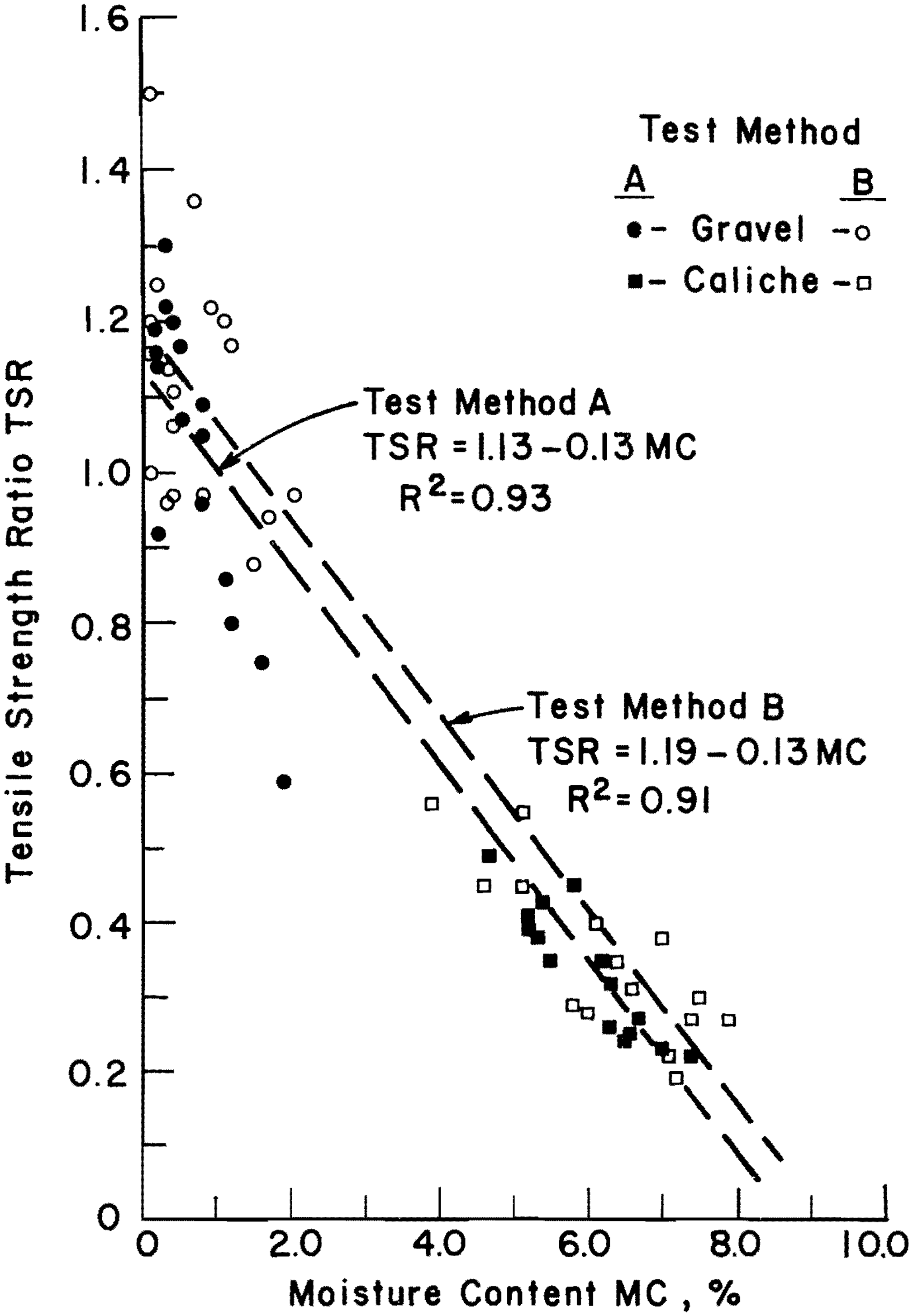


Fig 10. Relationship between moisture content and tensile strength ratio.

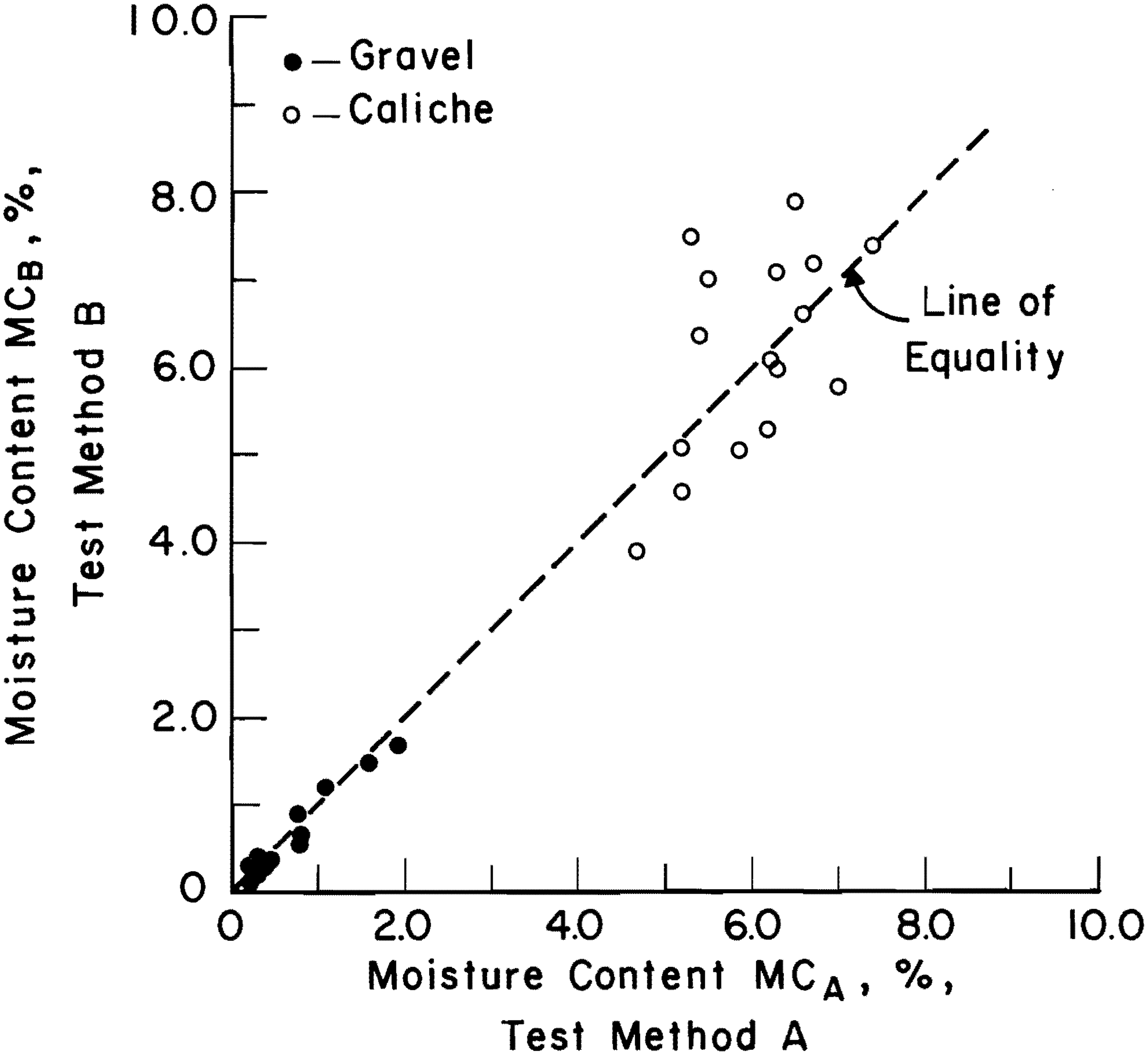


Fig 11. Comparison of moisture contents obtained for Test Methods A and B.

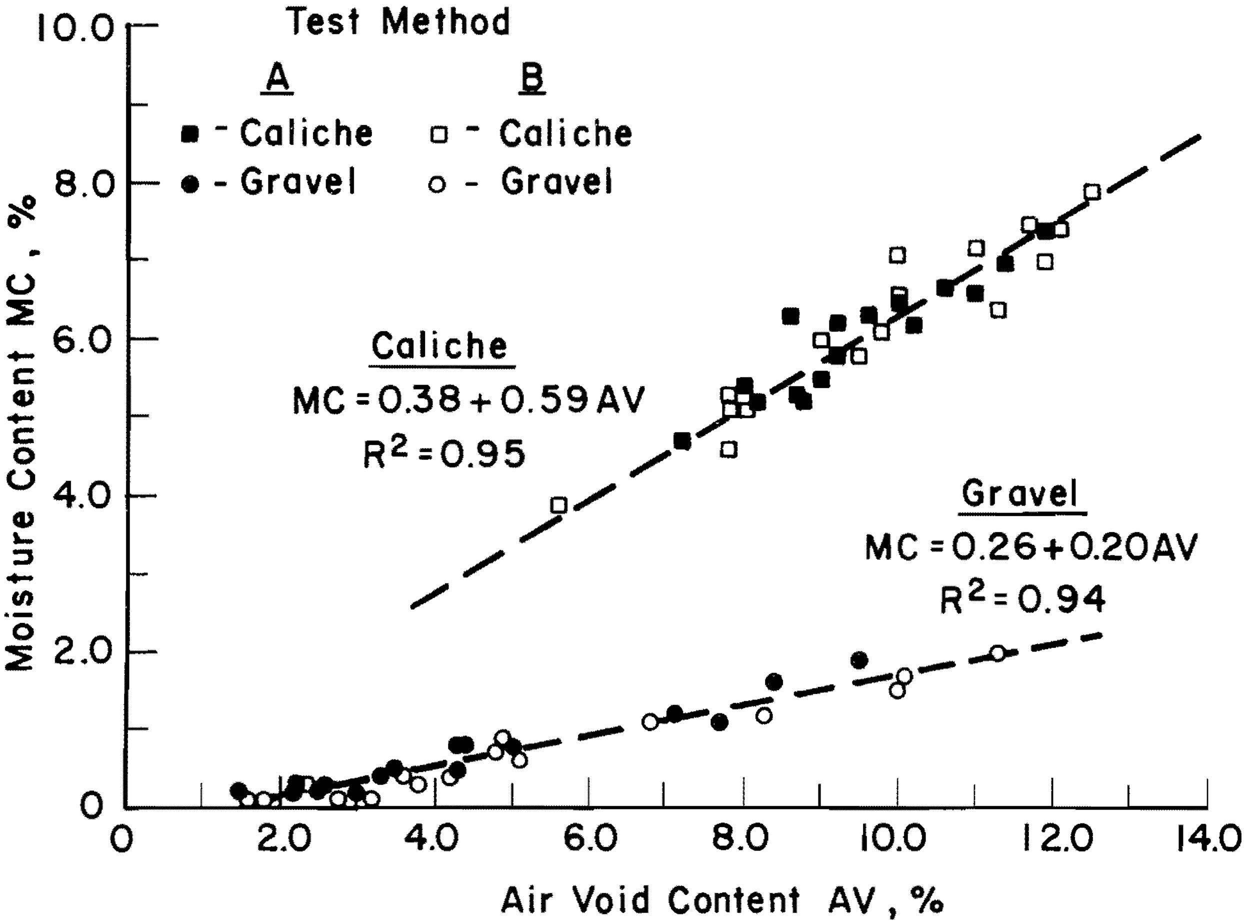


Fig 12. Relationship between air void content and moisture content.

from 5.6 to 12.5 percent. Figure 13 shows the significance of this change in air void content. Because of this large volume change after conditioning, it would appear quite reasonable to expect the caliche mixtures to exhibit a greater loss in strength, or lower TSR.

In addition, the effects of asphalt content and soil binder content on moisture content after conditioning are demonstrated in Fig 14. It would appear that for the gravel mixtures the moisture contents are lowest in the 10 to 20 percent soil binder contents. Generally, the same holds true for the caliche mixtures except that the binder content is in the range of 10 to 25 percent and the asphalt content continues to have an effect on moisture content at the highest value used in the study.

Likewise, as seen in Figs 15 and 16, the air voids at a given asphalt content are lowest for gravel mixtures containing 10 to 20 percent soil binder. For the caliche mixtures there is not the clear relationship between asphalt content and air voids that there was for the gravel. This effect is probably due to the volume change that occurred in the caliche mixtures during the moisture conditioning, which biases the results.

Test Method Variations

The main differences between the two test methods were in the rate of loading, which was 55 mm (2 in.) per minute for Method A and 4 mm (0.15 in.) per minute for Method B, and in specimen preparation procedures. All mixtures were tested at a room temperature of 24°C (75°F) after four days of curing. Comparison of the various test data from Table 4 shows that only for air void content (Fig 8) does the difference in test method have any significant effect. The conclusion is that both test methods can be used to evaluate the moisture susceptibility of asphalt mixtures; however, Method A appeared to be slightly better than Method B. In addition, Method A uses standard methods used by the Texas DHT and standard methods of indirect tensile testing (Refs 3 and 5).

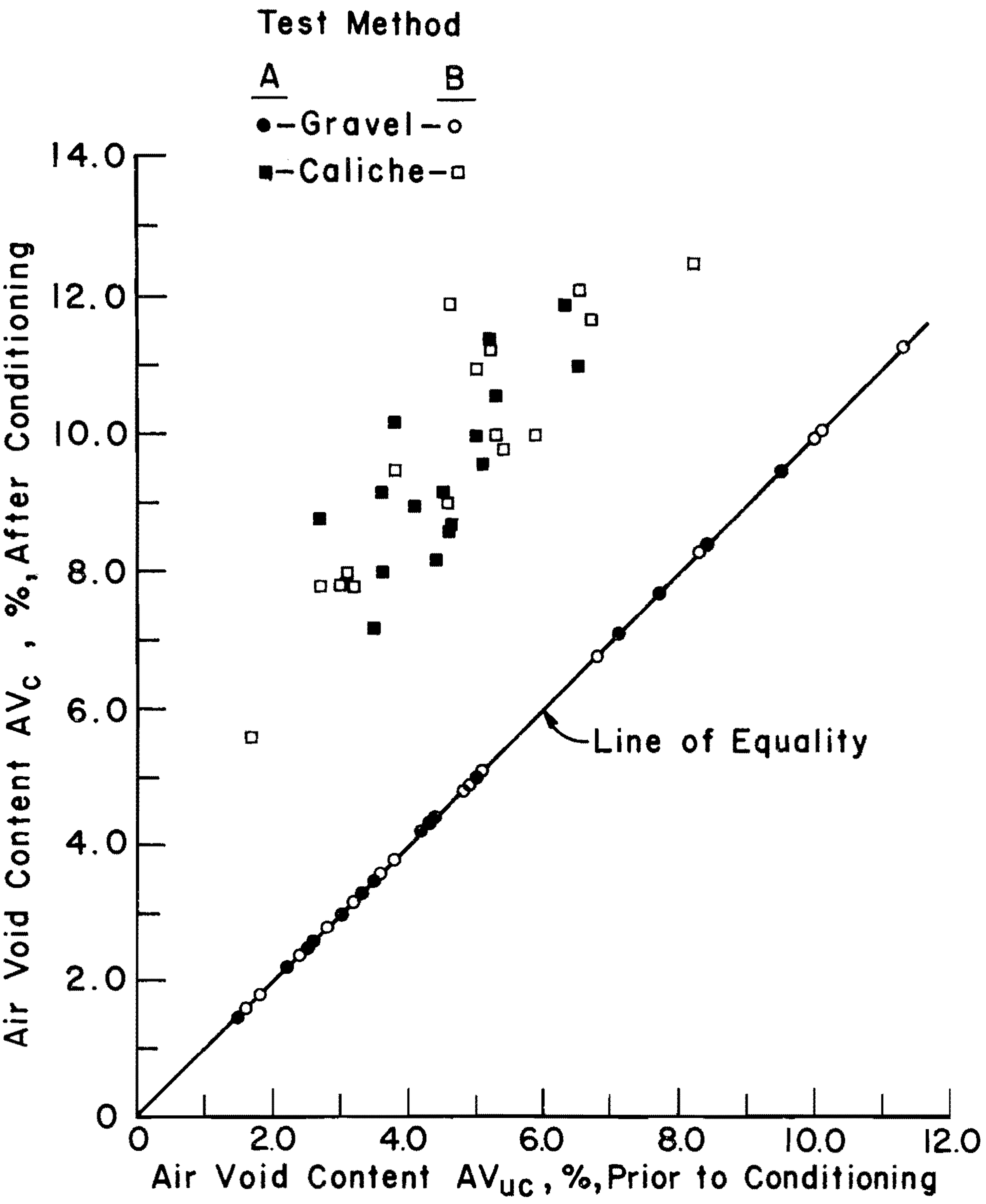


Fig 13. Comparison of air void contents obtained prior to conditioning with air void contents obtained after conditioning.

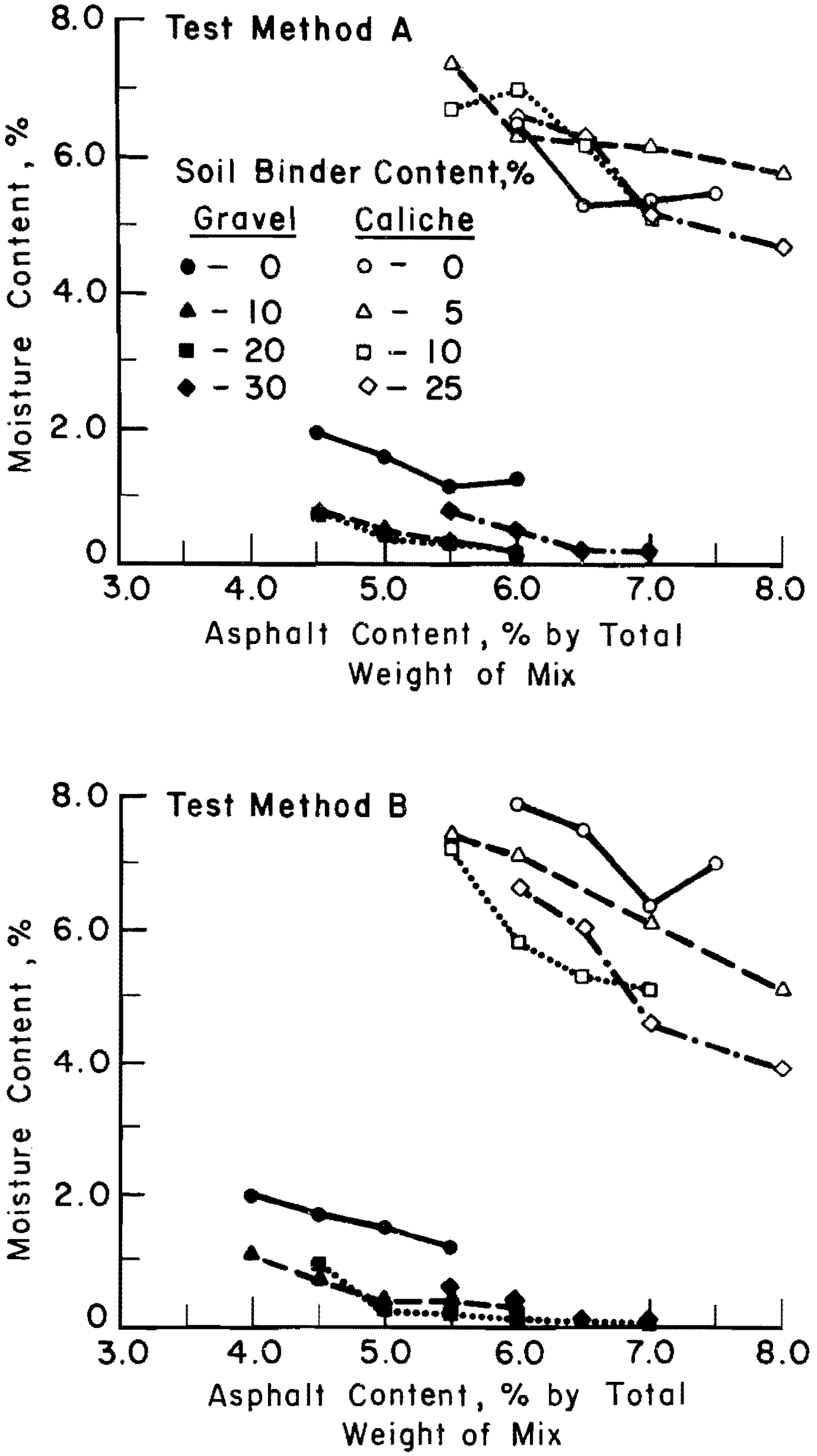


Fig 14. Relationship between asphalt content and moisture content.

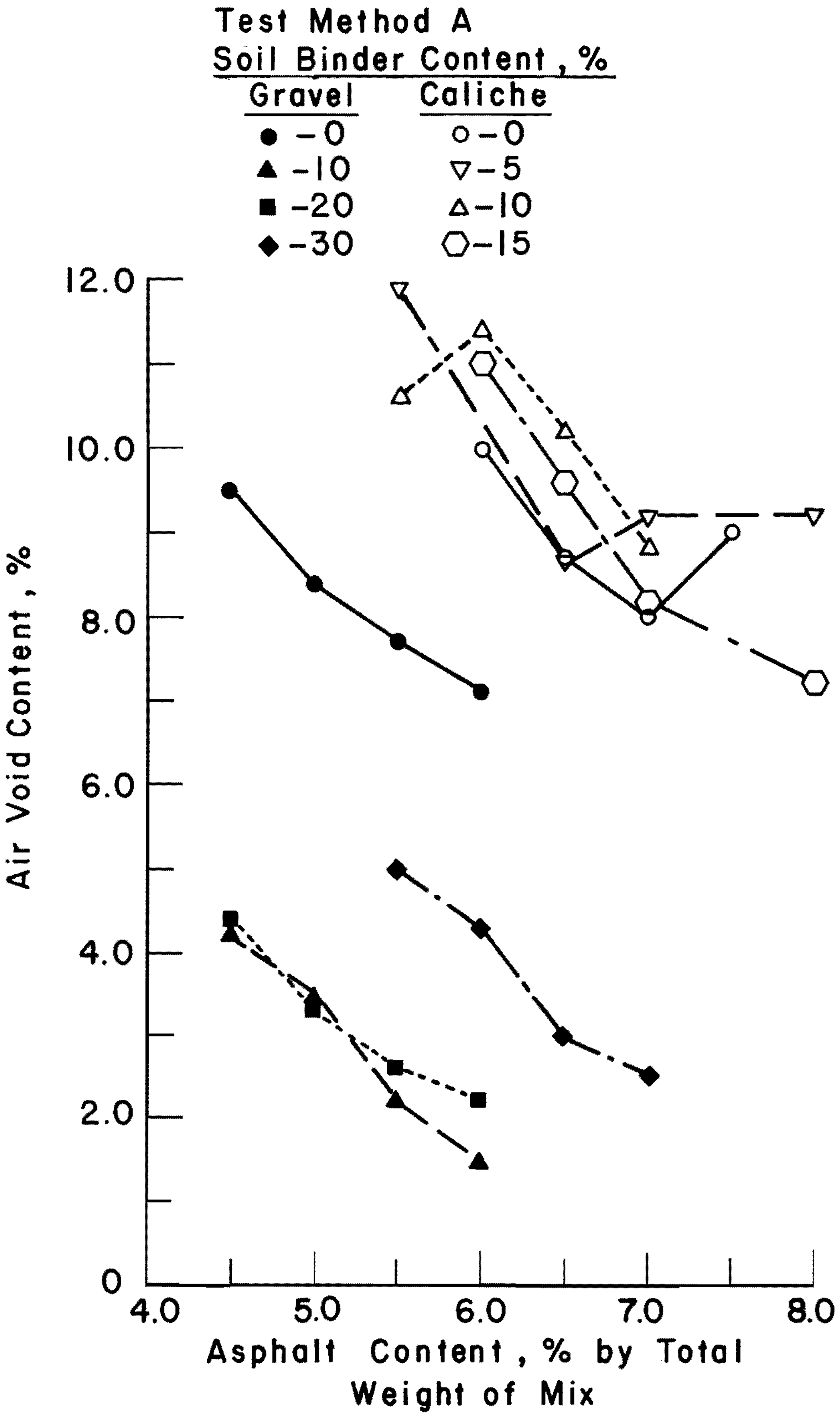


Fig 15. Relationship between asphalt content and air void content for Test Method A.

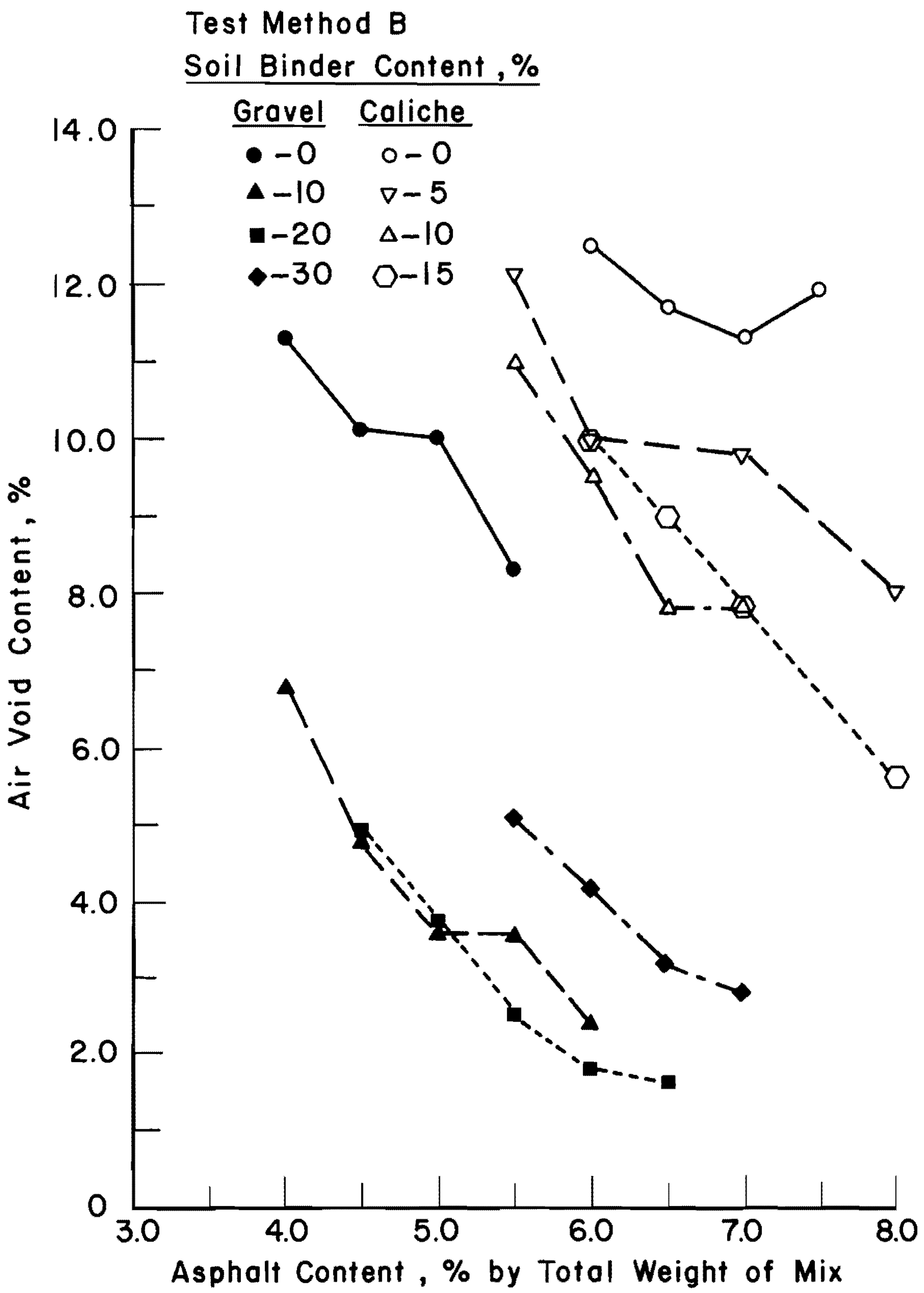


Fig 16. Relationship between asphalt content and air void content for Test Method B.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings from this study, the following conclusions and recommendations are made.

CONCLUSIONS

(1) For the same range of air void contents, values of TSR and MER obtained in this study are consistent with values previously reported for asphalt mixtures under comparable conditions.

(2) The relationship between asphalt content and TSR produces an optimum asphalt content for the gravel mixtures at each soil binder content; however, the TSR increased with increasing asphalt content regardless of the soil binder content for the caliche. This phenomenon could very well be explained by the increase in voids during moisture conditioning that occurred for the caliche specimens.

(3) While TSR did not change systematically with soil binder content for the caliche mixtures, the TSR values for the gravel mixtures peaked at soil binder contents of 10 to 20 percent.

(4) Values of TSR decreased with increased air void contents.

(5) Values of TSR decreased with increased water contents.

(6) The relationship between TSR and air void content was better defined for Method A than for Method B, with better R and steeper slopes indicating better differentiation for Method A. However, the information from the test program is not conclusive enough to select either Method A or B on the basis of test results. Either test method should perform satisfactorily.

(7) Based on TSR there was an extreme loss of strength in the moisture conditioned specimens of the caliche mixtures. This deterioration

was due to the large changes in air voids that occurred during moisture conditioning. The gravel mixtures exhibited very little loss of strength and no change in void content during moisture conditioning.

RECOMMENDATIONS

(1) Additional aggregates should be selected for use in future studies.
(2) Future tests should be conducted at optimum asphalt contents.
(3) Aggregate gradations should be comparable to those of field mixes.
(4) Specimens should be prepared with air void contents between 6 and 8 percent.
(5) Test Method A should be used in future studies since the specimen preparation procedures are identical to those used in the DHT standard mixture design procedure.
(6) Additional studies on the effects of moisture on asphalt mixtures should be conducted using a variety of moisture conditioning techniques, with the specimens tested using both the static and repeated-load indirect tensile tests.

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APPENDIX

Specimen Preparation and Conditioning Procedures

APPENDIX. SPECIMEN PREPARATION AND CONDITIONING PROCEDURES

Specimens were prepared and conditioned using the following procedures.

DRY CONDITIONING

Test Method A

1. Mix and compact specimen.
2. Cure specimen at 24°C (75°F) for 4 days.
3. Test specimen at 24°C (75°F) at a loading rate of 51 mm (2 in.) per minute.

Mixture age at testing: 4 days.

Test Method B

1. Mix specimen, cool at room temperature for about 2-1/2 hours, and then keep in oven at 60°C (140°F) for 15 hours.
2. Heat mixture to compaction temperature and compact.
3. Cure specimen at 24°C (75°F) for 3 days.
4. Test specimen at 24°C (75°F) at a loading rate of 4 mm (0.15 in.) per minute.

Mixture age at testing: 4 days.

VACUUM SATURATION PLUS FREEZE-AND-SOAK CONDITIONING

Test Method A

1. Mix and compact specimen.
2. Cure specimen at 24°C (75°F) for 2 days.
3. Vacuum saturate for 30 minutes at 4 inches of mercury in distilled water at 24°C (75°F).
4. Soak for 30 minutes (no vacuum) at 24°C (75°F).
5. Wet the surface of the specimen, place it in a plastic bag, and seal; place sealed bag in water bag with 10 ml of water and seal outer bag.
6. Freeze specimen at -18 ± 2.8°C (0 ± 5°F) for 15 hours.
7. Thaw specimen at 24°C (75°F) for 1 hour.
8. Remove specimen from both bags, place in 60°C (140°F) water bath for 24 hours.
9. Place specimen in 24°C (75°F) water bath for 3 hours.
10. Test at 24°C (75°F) at a loading rate of 51 mm (2 in.) per minute.

Mixture age at testing: 4 days, approximately.

Test Method B

1. Mix specimen, cool at 24°C (75°F) for 2-1/2 hours, put in 60°C (140°F) oven for 15 hours.
2. Heat mixture to compaction temperature and compact.
3. Cure at 24°C (75°F) for 24 hours.
4. Vacuum saturate for 30 minutes at 4 inches of mercury in distilled water at 24°C (75°F).
5. Soak for 30 minutes (no vacuum) at 24°C (75°F).
6. Wet the surface of the specimen, place it in a plastic bag, and seal; place sealed bag in water bag with 10 ml of water and seal outer bag.
7. Freeze specimen at -18 ± 2.8°C (0 ± 5°F) for 15 hours.

8. Thaw specimen at 24°C (75°F) for 1 hour.
9. Remove specimen from both bags, place in 60°C (140°F) water bath for 24 hours.
10. Test at 24°C (75°F) at a loading rate of 4 mm (0.15 in.) per minute.

Mixture age at testing: 4 days.