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16. Abstract

This report summarizes information related to the engineering properties of hot mixed recycled asphalt mixtures for highways in Texas and an evaluation of the effects of softening agents on these properties.

For hot mixed asphalt mixtures the engineering properties of tensile strength, static and resilient modulus of elasticity, static and resilient Poisson's ratio, fatigue life, and Hveem stability were found to be equal to or slightly larger than those of previously evaluated conventional mixtures. Based on the findings of this study and previously reported findings it was concluded that satisfactory hot mixed asphalt mixtures can be obtained with salvaged and recycled asphalt mixtures from existing roadways.

17. Key Words

recycling, asphalt, asphalt mixtures, tensile strength, elastic properties, resilient modulus, fatigue life, Hveem stability, softening agents

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by

Thomas W. Kennedy
James N. Anagnos

Research Report Number 252-4F

Design and Characterization of Recycled Pavement Mixtures

Research Project 3-9-79-252

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

December 1983

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.

PREFACE

This is the fourth and final in a series of reports dealing with the design and characterization of recycled pavement materials. This report includes information related to the engineering properties of hot mixed recycled asphalt mixtures for proposed or actually constructed highways in Texas. Included are actual test results for a variety of mixtures and an evaluation of the effect of various softening agents on the engineering properties. Properties considered are the tensile and elastic characteristics and the fatigue properties as determined by the static and repeated-load indirect tensile tests and Hveem stabilities. Information related to cold recycled asphalt mixtures using foamed asphalt is contained in Research Report 252-3.

This report was completed with the assistance of many people. Special appreciation is due to Messrs. Pat Hardeman and Eugene Betts for the extensive field and laboratory evaluations that provided the background for this report. Appreciation is expressed to Billy R. Neeley, Robert E. Long, C. Weldon Chaffin, Harold Albers, and District personnel of the Texas State Department of Highways and Public Transportation for their assistance, both in the field and in securing specimens and material samples. Appreciation is extended to Center for Transportation Research staff for their assistance in the preparation of manuscript materials. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

Thomas W. Kennedy
James N. Anagnos

December 1983

LIST OF REPORTS

Report No. 252-1, "Mixture Design Procedure for Recycled Asphalt Pavements," by Thomas W. Kennedy, Freddy L. Roberts, and James N. Anagnos, provides an evaluation and mixture design procedure that includes the use of salvaged materials from a road that is to be recycled. May 1982.

Report No. 252-2, "Design of Recycled Asphalt Mixtures: A Step-by-Step Laboratory Manual," by Thomas W. Kennedy, Freddy L. Roberts, and James N. Anagnos, includes a laboratory procedure that can be used to design a recycled mixture. December 1983.

Report No. 252-3, "Use of Foamed Asphalt in Cold, Recycled Mixtures," by Freddy L. Roberts, Johann C. Engelbrecht, and Thomas W. Kennedy, provides a preliminary evaluation of the foamed process by comparing test results from laboratory specimens prepared with foamed recycled materials with those from conventional cold mixed materials using two emulsions and a cutback asphalt. December 1983.

Report No. 252-4F, "Engineering Properties of Recycled Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos, provides information related to the engineering properties of hot mixed recycled asphalt mixtures for proposed or actually constructed highways in Texas. December 1983.

ABSTRACT

This report summarizes information related to the engineering properties of hot mixed recycled asphalt mixtures for highways in Texas and an evaluation of the effects of softening agents on these properties.

For hot mixed asphalt mixtures the engineering properties of tensile strength, static and resilient modulus of elasticity, static and resilient Poisson's ratio, fatigue life, and Hveem stability were found to be equal to or slightly larger than those of previously evaluated conventional mixtures. Based on the findings of this study and previously reported findings it was concluded that satisfactory hot mixed asphalt mixtures can be obtained with salvaged and recycled asphalt mixtures from existing roadways.

Key Words: Recycling, asphalt, asphalt mixtures, tensile strength, elastic properties, resilient modulus, fatigue life, Hveem stability, softening agents

SUMMARY

The acceptability of recycled asphalt materials should be based on an evaluation of their engineering properties and performance. This report summarizes the engineering properties of a variety of asphalt mixtures for various proposed and actually constructed projects in Texas and provides an evaluation of the effect of various softening agents, including soft asphalts, on these properties. Emphasis was placed on fundamental properties such as tensile strength, elastic properties, resilient elastic properties, fatigue life, and Hveem stability which at the initiation of the study were not readily available.

Based on the results of this study and previous studies it was concluded that the engineering properties of hot mixed recycled asphalt mixtures are comparable to those of conventional mixtures although there is a tendency for the recycled mixtures to be more brittle. Thus the amount of added recycling agent, commercially available softening agents, or soft asphalts, should theoretically be sufficient to soften the reclaimed asphalt to a level equal to that of normally used virgin asphalt. The importance of this is emphasized by the fact that there is still a question as to whether the softening agent blends satisfactorily with the old asphalt during plant mixing.

It is also evident from this study and previous studies that the cause of distress in the old pavement must be corrected in order to achieve a satisfactory performance with recycled mixtures. This normally involves providing an adequate structural section, resistance to moisture, and softening of aged and hardened asphalt.

IMPLEMENTATION STATEMENT

The evaluation of a variety of hot mixed recycled asphalt mixtures indicates that mixtures with satisfactory engineering properties can be produced using reclaimed and recycled asphalt mixtures. Because of the nature of the recycled asphalt, which is normally hardened to some degree, there is a tendency for the recycled mixture to be more brittle, requiring that close attention be given to the amount of softening agent or new soft asphalt added. This is especially important since there is still some question as to how well the old asphalt and new additive blend during actual construction mixing. In addition, the cause of the distress in the recycled material must be corrected if the recycled mixture is to perform satisfactorily. This involves not only restoring the viscosity characteristics of the reclaimed asphalt, but also providing adequate protection against moisture and providing a structurally adequate pavement section.

It is felt that the use of hot mix recycling techniques is a viable alternative to the use of new material. The decision to recycle, however, should be based not only on the technical considerations but also on the economics of the situation. Thus, recycling does provide a potential cost effective alternative which should be allowed and encouraged.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

The acceptability of recycled materials in engineering construction should be based largely on an evaluation of their engineering properties and performance. At the time this study was initiated there was no commonly accepted method for the design of recycled asphalt mixtures nor was there information concerning the engineering and behavioral properties of these recycled mixtures. Thus, the Texas State Department of Highways and Public Transportation requested that a study of recycled asphalt mixtures be conducted. The principal objectives of this study were (1) to evaluate the engineering properties of recycled asphalt mixtures, (2) to compare such engineering properties with those obtained for conventional mixtures, and (3) to develop a mixture design procedure for recycling asphalt mixtures.

The portion of the study summarized in this report involved the evaluation of engineering properties of hot mixed recycled asphalt mixtures and the comparison of these properties with those of conventional mixtures. Emphasis was placed on fundamental properties, such as tensile strengths, elastic properties, resilient elastic properties, fatigue properties, and Hveem stabilities, which at the initiation of the study were not readily available. A limited study of recycled asphalt mixtures using foamed asphalt was also conducted and is summarized in Research Report 252-3.

A variety of mixtures with different types and amounts of additives were evaluated and designed for highway projects, ranging from low volume highways to heavily trafficked freeways. Conventional tests as well as the static and repeated-load indirect tensile tests were used to obtain estimates of tensile strengths, static and resilient moduli of elasticity, fatigue characteristics, and stability values. It had been anticipated that estimates of permanent deformation would be analyzed; however, because of the limited amount of time and material supplied, it was not possible to adequately monitor permanent strains and thus was not considered. In addition, the effects of softening agents and antistripping additives were evaluated.

Chapter 2 contains a description of the testing program including the projects and characteristics of the recycled materials. Chapter 3 summarizes the engineering properties of the recycled asphalt mixtures and the effects of softening agents, antistripping agents, and new aggregate, and Chapter 4 provides discussion and recommendations related to important considerations for recycling asphalt mixtures. Chapter 5 provides a summary of conclusions and recommendations.

CHAPTER 2. TESTING PROGRAM

To achieve the above objectives, laboratory prepared specimens of recycled asphalt mixtures from eighteen different projects in eight districts and a limited number of cores were tested using the static and repeated-load indirect tensile test and were evaluated by comparing the properties of recycled mixtures with the properties of conventional mixes. In some cases Hveem stabilities were measured and utilized. Additional tests and evaluations were also conducted by the Texas State Department of Highways and Public Transportation. In addition, information from a previous study was included for comparison purposes.

PROJECTS AND SPECIMENS TESTED

Specimens of mixtures from eight districts in Texas (Fig 1) were obtained by project staff of The Center for Transportation Research. Summary information related to the projects is contained in Table 1. The specimens from the eight projects can be divided into three groups:

(1) Laboratory--materials mixed and compacted in the laboratory;

(2) Plant--materials mixed in the field but compacted in the laboratory; and

(3) Cores--specimens obtained from in-service pavements of recycled asphalt.

Laboratory specimens were prepared by the Texas State Department of Highways and Public Transportation and the University of Texas Center for Transportation Research, according to Test Method TEX-126-E for blackbase materials and Test Method TEX-206-F for surface materials (Ref 1). Aggregates were batched by dry weight to meet the specified gradation. Both the aggregate and the additive were heated and then mixed for about three minutes. Plant specimens were made of materials taken from the plant in the field. The mixtures were placed in preheated ovens and brought to the compaction temperature and compacted using the Texas gyratory shear compactor.

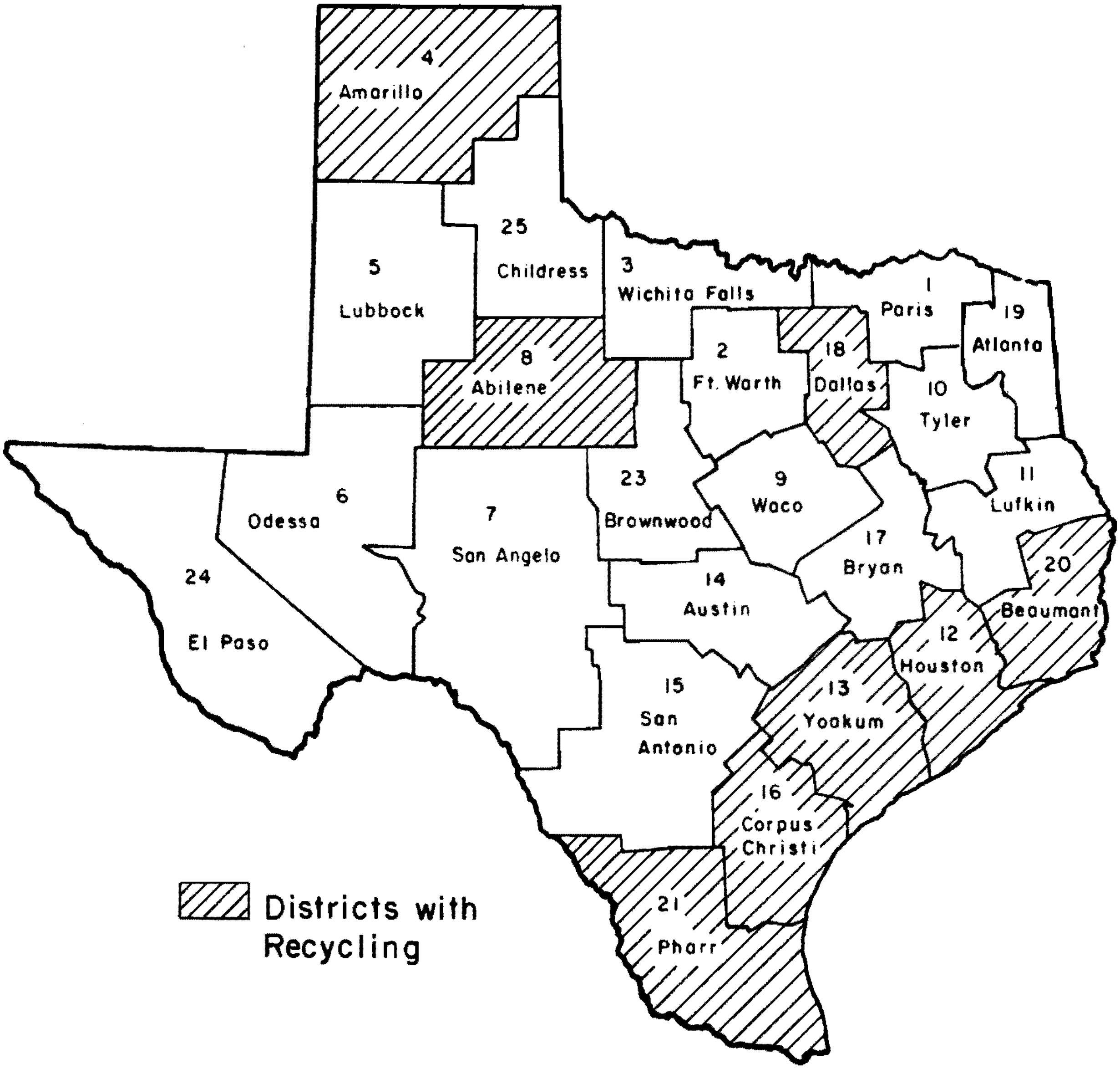

Fig 1. Districts from which recycled mixtures and specimens were obtained.

TABLE 1. MIXTURE DESIGNS AND SELECTED PROPERTIES OF THE PROPOSED PROJECTS INVOLVED

District/ Project	Properties of Residual Asphalt			Mixture Design					
				Recycling Additive		Antistrip		New Aggregate	
	%	PEN	VIS	%	Type	%	Type	%	Type[a]
Amarillo									
IH40	5.70	20	42.6	2.75	AC-3	-	-	50	S/G/C
Abilene	-	-	-	2.70	AC-3	-	-	31	LS
IH20				2.80	AC-3	-	-	35	LS
Houston	6.75	26	24.4	1.40	AC-3	-	-	15	LS
FM1640				1.40	0.6%AC-3+0.8%RBO	-	-	15	LS
Yoakum									
US 90A	5.65	37	5.6	1.0	AC-3	0.06	82S	15	LS
Corpus				0.83	Coastal Residuum	0.04	M200	30	SS
Christi				0.83	AES-300-R	M200	30	SS	
US77	5.90	42	3.6	0.62	Coastal Residuum	0.04	M200	30	GV
				0.62	AES-300-R	0.04	M200	30	GV
				1.20	AC-10	1.0	LIME	40	S/G
				1.20	AC-10	-	-	40	S/G/L
Dallas	6.15	17	NA	1.0	AC-3	-	-	-	-
IH20	4.40	11	-	3.0	AC-3	-	-	b	CC
Beaumont	4.64	9	NA	1.25	0.5%AC-3+0.75%RBO	0.05	82S	0	-
IH10				1.85	AES-300-R		M200	13	LS
Pharr	7.20	9	-	2.50	AC-3			0	-
Loop 374				3.0	AC-3			0	-
				1.60	RBO *			0	-
				2.0	FO **			0	-

a - S/G/C = Sand-Gravel-Caliche Mixture; LS = Limestone; SS = Sandstone; GV = Gravel; G/L = Gravel-Limestone Mixture; G/LD = Gravel-Limestone-Limestone Dust (1%) Mixture.

b - Unknown amount of concrete chips (CC).

* - Reclamite Base Oil

** - Flux Oil

PEN = Penetration @ 25°C; VIS = Viscosity @ 60°C in 1000 Poises.

Specimens were prepared for each set of conditions. A portion of the specimens were tested by the Center for Transportation Research and the Texas State Department of Highways and Public Transportation to obtain estimates of Hveem stabilities. The remainder of the specimens were tested at the Center for Transportation Research utilizing the static and repeated-load indirect tensile tests.

Specimens of surface mixtures and field cores had a nominal diameter of 102 mm (4 in.) and a nominal height of 51 mm (2 in.). Specimens obtained from base mixtures had a nominal diameter of 152 mm (6 in.) and a height of 76 mm (3 in.).

A portion of the indirect tensile test specimens were tested statically, and a portion were tested under repeated loads to obtain estimates of repeated-load resilient properties. Previous studies (Refs 2 and 3) included an evaluation of fatigue life which indicated that the relationship between fatigue life and tensile stress is essentially linear. The results of this study are included and involved only two stress levels.

MATERIALS

Materials consisted of the salvaged asphalt mixture, new aggregates, softening agents, and/or new asphalt.

Salvaged Asphalt Mixtures

Representative samples of crushed salvaged asphalt mixtures were obtained from each project. The properties of such materials as determined by the Texas State Department of Highways and Public Transportation are given in Appendix A. Such properties include gradation of the crushed salvaged asphalt mixtures, gradation of recovered aggregates, asphalt content, and asphalt viscosity.

New Aggregates

The mixture designs for most of the projects involved the addition of new untreated aggregates. Some of these new aggregates were salvaged base or subbase materials while others were new aggregates. Figure 2 depicts the combined aggregate gradations as computed from the new and salvaged aggregates. It should be noted that many of the gradations were not ideal.

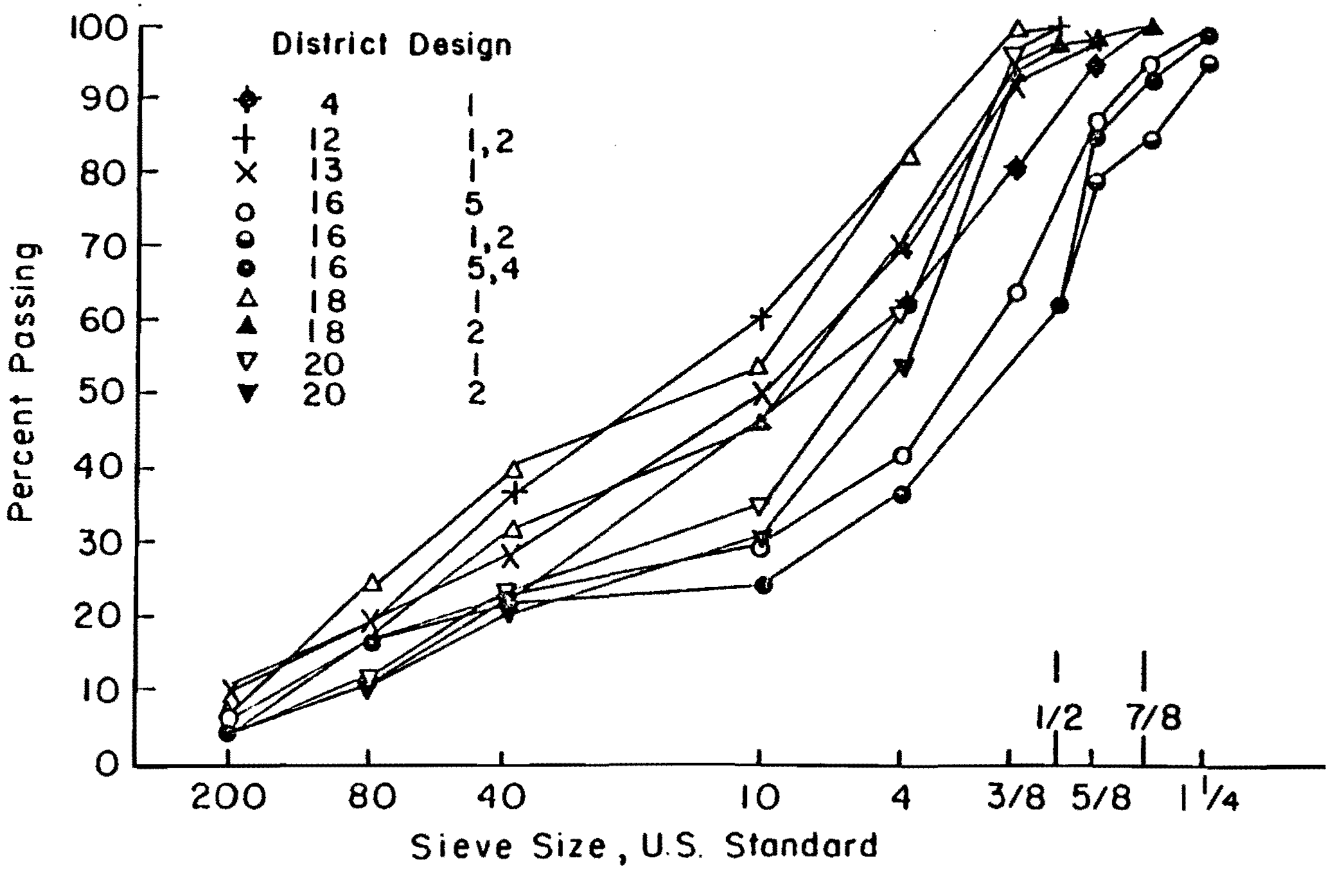

Fig 2. Combined aggregate gradations.

Recycling Agents

A variety of recycling agents were used on the projects varying from asphalt cement, flux oils, emulsions, and rejuvenating agents to some combinations of the above. Table 2 summarizes the basic recycling agents used.

Antistripping Agents

Some of the salvaged asphalt mixtures exhibited stripping tendencies, and consequently antistripping agents were included in the mixture designs. The antistripping agents used were hydrated lime, Redicote 82S, and Texas Emulsions M200.

SPECIMEN FABRICATION

The specimens were prepared according to TEX-126-E for blackbase materials and Test Method TEX-206-F for surface course materials (Ref 1). Salvaged asphalt mixtures and additive aggregates were batched by dry weight to meet project specifications. The salvaged mixtures, new aggregates, and additives were heated and then mixed for about three minutes. The mixtures were compacted using the Texas gyratory-shear compactor and allowed to cure for two days at room temperature.

TEST METHODS

The three basic methods of testing were the static and repeated-load indirect tensile tests (Refs 4, 5, 6, and 7) and the Hveem stability test (Ref 1).

Indirect Tensile Tests

The indirect tensile test involves loading a cylindrical specimen with static or repeated compressive loads which act parallel to and along the vertical diametral plane. The compressive load is distributed through a 0.5-inch wide steel loading strips which are curved at the interface to fit the specimen. A 0.5-inch wide loading strip is used with 4-inch diameter specimens and a 0.75-inch strip with 6-inch specimens. This loading configuration produces a relatively uniform stress perpendicular to the plane of the applied load and along the vertical diametral plane which ultimately causes the specimen to fail by splitting along the vertical diameter (Fig 3). The

TABLE 2. RECYCLING AGENT

Code	Commercial Name
A	Oklahoma Ref. Co. AC-3
B	Exxon AC-3
C	Reclamite Base Oil (RBO)
D	Exxon Coastal Residuum
E	Tx Emulsions AES-300-R*
F	Gulf States AC-10
G	Dorchester Ref. Co. AC-3
H	Cosden AC-3
I	Cosden AC-20
J	Paxole
K	Exxon AC-3
L	Flux Oil
M	Exxon AC-20

* An emulsion consisting of 30% water, 45.5% Exxon Nuso 95, and 24.5% Texaco AC-10.

tensile strength, modulus of elasticity*, and Poisson's* ratio can be calculated from the measured load and corresponding vertical and horizontal deformations.

The test equipment was the same as that used in previous studies at the Center for Transportation Research and included a loading frame, a loading head, and an MTS closed-loop electrohydraulic system to apply the load at a controlled deformation rate. The loading head insured that the platens remained parallel during testing. A curved stainless steel loading strip was attached to both the upper and lower platens.

Estimating the resilient modulus of elasticity and Poisson's ratio requires the measurement of both the resilient vertical and horizontal deformations, V_R and H_R, of the specimens. The horizontal and vertical deformations were measured by DC linear variable differential transducers (LVDT's). Typical relationships between time and the horizontal and vertical deformations are illustrated in Figure 4 along with the corresponding load-time pulse.

Static Test Procedure. A preload of 10 lbs, which corresponds to a stress of about 0.8 psi, was applied to the specimen to prevent impact loading and to minimize the effect of seating of the loading strip. The specimens were then loaded at a rate of 2 in. per minute. The loads and deformations were recorded by two X-Y plotters, one recording load and horizontal deformation and the other recording load and vertical deformation.

From the recordings, corresponding loads, vertical deformations, and horizontal deformations were obtained and along with the dimensions of each specimen, were used to calculate the tensile and static elastic properties of the materials tested.

Repeated-Load Test Procedures. Again, a preload of 10 lbs was applied to specimens. Then repeated loads producing total stresses ranging from 17

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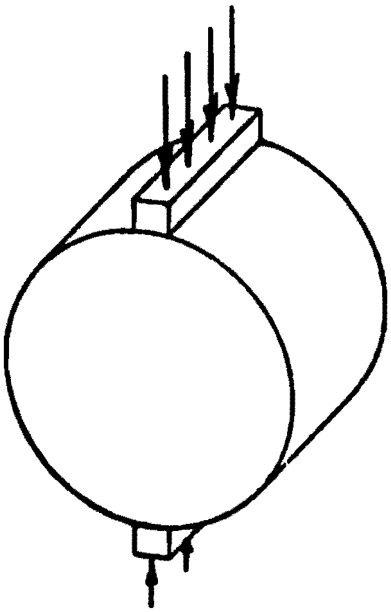
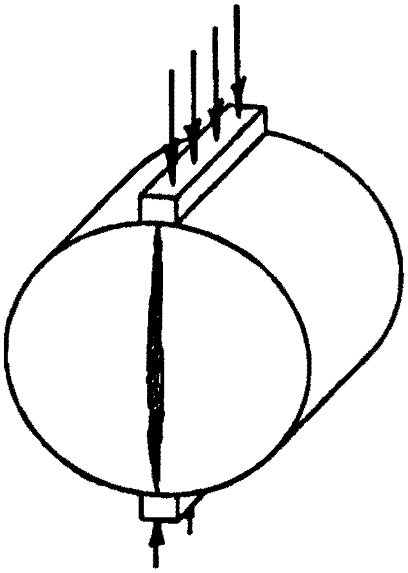
* The elastic properties are modulus of elasticity and Poisson's ratio. The modulus of elasticity is a stiffness property which relates stress and strain. Poisson's ratio, on the other hand, is the ratio of the strain perpendicular to the strain in the direction of the applied stress. Both properties can be determined for a single load to failure or for a repeated load using the recoverable or resilient strains. Both are used in analyses based on theory of elasticity and allow the calculation of stresses, strains, and deformation for the structure. In addition, the modulus is often related to other engineering properties. Poisson's ratio is relatively unimportant and can often be estimated.



(a) Compressive load being applied.



(b) Specimen failing in tension.

Fig 3. Indirect tensile test loading and failure.

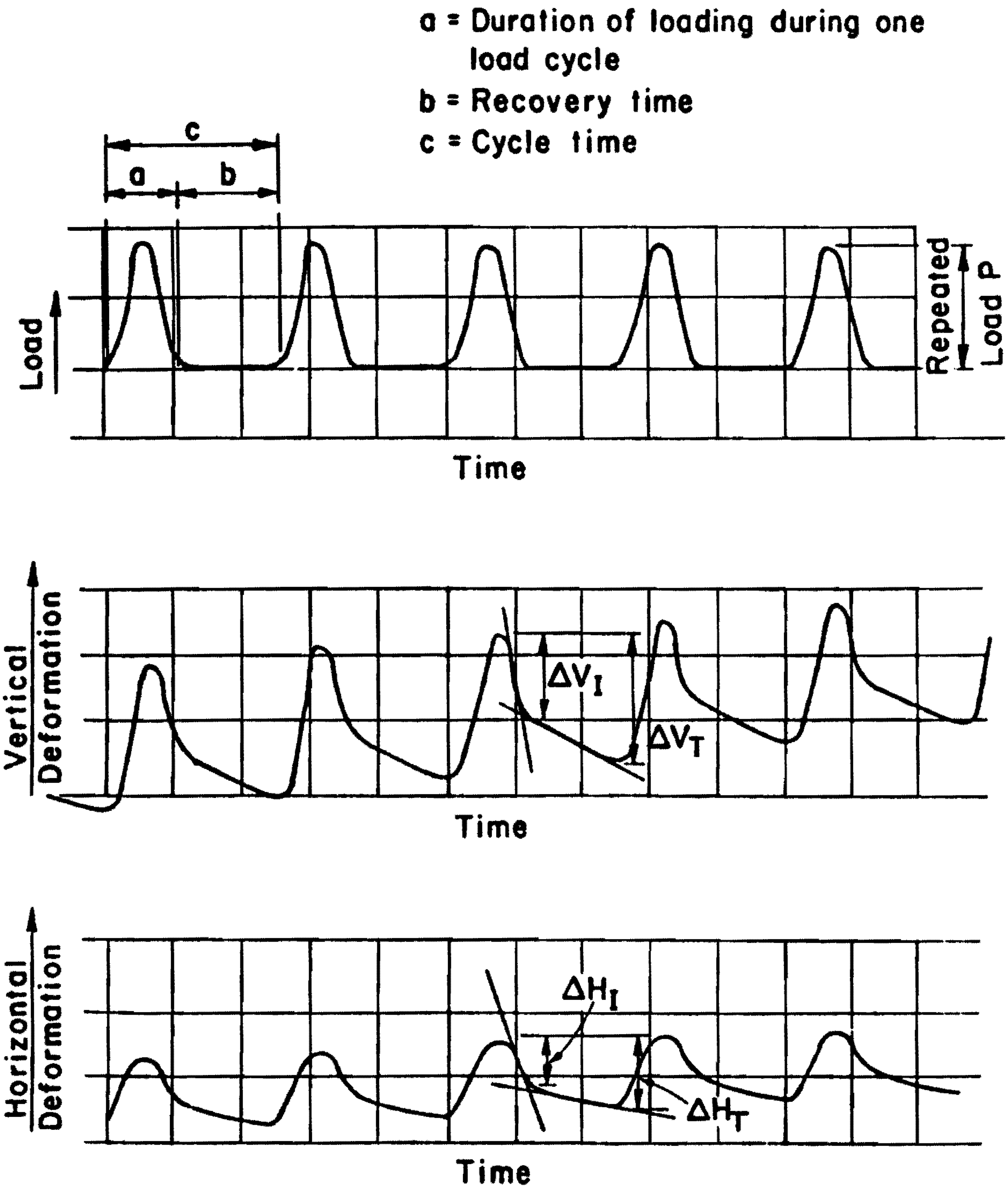


Fig 4. Load pulse and associated deformation relationships for the repeated-load indirect tensile test.

to 104 psi (10 to 30 percent of the recorded static indirect tensile strength) were applied at a frequency of one cycle per second (1 Hz) with a load duration of 0.2 sec and a rest period of 0.8 sec. All tests were conducted at 75°F.

Tests on some material were continued until failure occurred, i.e., when the specimen fractured completely. Fatigue life, N_f, was defined as the number of cycles corresponding to this failure. The individual horizontal and vertical deformations, H_R and V_R, were recorded at approximately 200 to 300 cycles.

Hveem Stability Test

The Hveem stability test was conducted according to the standard procedure used by the Texas State Department of Highways and Public Transportation. The test method is summarized in Reference 1.

EXPERIMENTAL PROGRAM

The overall program was controlled by the time available and the amount of material available since the individual evaluation programs were conducted just prior to or during the early stages of actual construction of proposed projects. Softening agents and/or new asphalt grade were specified by district personnel of the State Department of Highways and Public Transportation.

CHAPTER 3. EVALUATION OF ENGINEERING PROPERTIES

The analysis of the engineering properties has been subdivided into (1) fatigue properties, (2) tensile strength and elastic properties, (3) Hveem stability, and (4) the effect of additives on these properties.

FATIGUE LIFE

Fatigue life properties were not evaluated in this study; however, a previous study (Ref 9) did consider the fatigue properties of recycled mixtures in Texas and is included. Previous studies (Refs 2 and 8) have indicated a linear relationship between fatigue life and stress which can be expressed as

$$N_f = K_2 \left.\frac{1}{\sigma_T}\right.^{n_2} = K_2' \left.\frac{1}{\Delta\sigma}\right.^{n_2}$$

where

N_f = fatigue life, cycles,

σ_T = applied tensile stress, kPa (psi),

$\Delta\sigma$ = stress difference $\cong 4\sigma_T$, kPa (psi),

K_2 = material constant, the antilog of the intercept value of the logarithmic relationship between fatigue life and tensile stress,

K_2' = material constant, the antilog of the intercept value of the logarithmic relationship between fatigue life and stress difference, and

n_2 = material constant, the absolute value of the slope of the logarithmic relationship between fatigue life and tensile stress or stress difference.

In addition, it was shown that results expressed in terms of stress difference are more useful and comparable with results from other test methods. For the indirect tensile test, stress difference is approximately equal to $4\sigma_T$ at or near the center of the specimen.

Typical relationships between fatigue life and stress difference for laboratory and plant mixed specimens and for field cores for two projects are illustrated in Figures 5 through 8. The actual stress conditions, mean values of fatigue life, and the values of K_2, K_2', and n_2 are summarized in Table 3.

It should be noted that the slopes, n_2, were essentially the same for both projects and for all mixtures. Values of n_2 for the laboratory prepared recycled mixtures and the cores ranged from 2.15 to 8.07 and from 2.75 to 5.58, respectively. These values were in the same range, although slightly higher than those previously reported for conventional pavement materials (Table 4). Since $1/\sigma$ is always less than 1.0, high values of n_2 generally would indicate lower values of fatigue life.

Values of K_2' for recycled specimens ranged from 6.26×10^{10} to 1.30×10^{31}. These values were also higher than those previously reported for mixtures produced using conventional methods and materials (Table 4). Thus, the fatigue lives for constant stress loading conditions generally were longer for the recycled mixtures than for conventional mixtures. However, a small increase in the stress level substantially decreased the fatigue life, as indicated by the large n_2 values.

The coefficients of variation of fatigue life for recycled mixtures ranged from 3 to 92 percent; these values are in general agreement with those previously reported for cores (Ref 3) and plant mixed dryer-drum specimens (Ref 10). These values, although calculated only on the basis of three observations, were similar to those obtained from field mixed specimens and cores, indicating that a greater amount of variation may occur in recycled mixtures. Because of the time involved and the fact that experience to date did not indicate a need for such testing, additional fatigue testing was not conducted for other mixtures during design and evaluation.

STRENGTH AND STATIC ELASTIC PROPERTIES

Estimates of tensile strength, modulus of elasticity, Poisson's ratio, and strains at failure were determined using the static indirect tensile test. The mean values of strength and elastic properties along with the coefficient of variation for all data are shown in Table 5. Table 6 contains a comparison of static strengths and elastic properties obtained for recycled

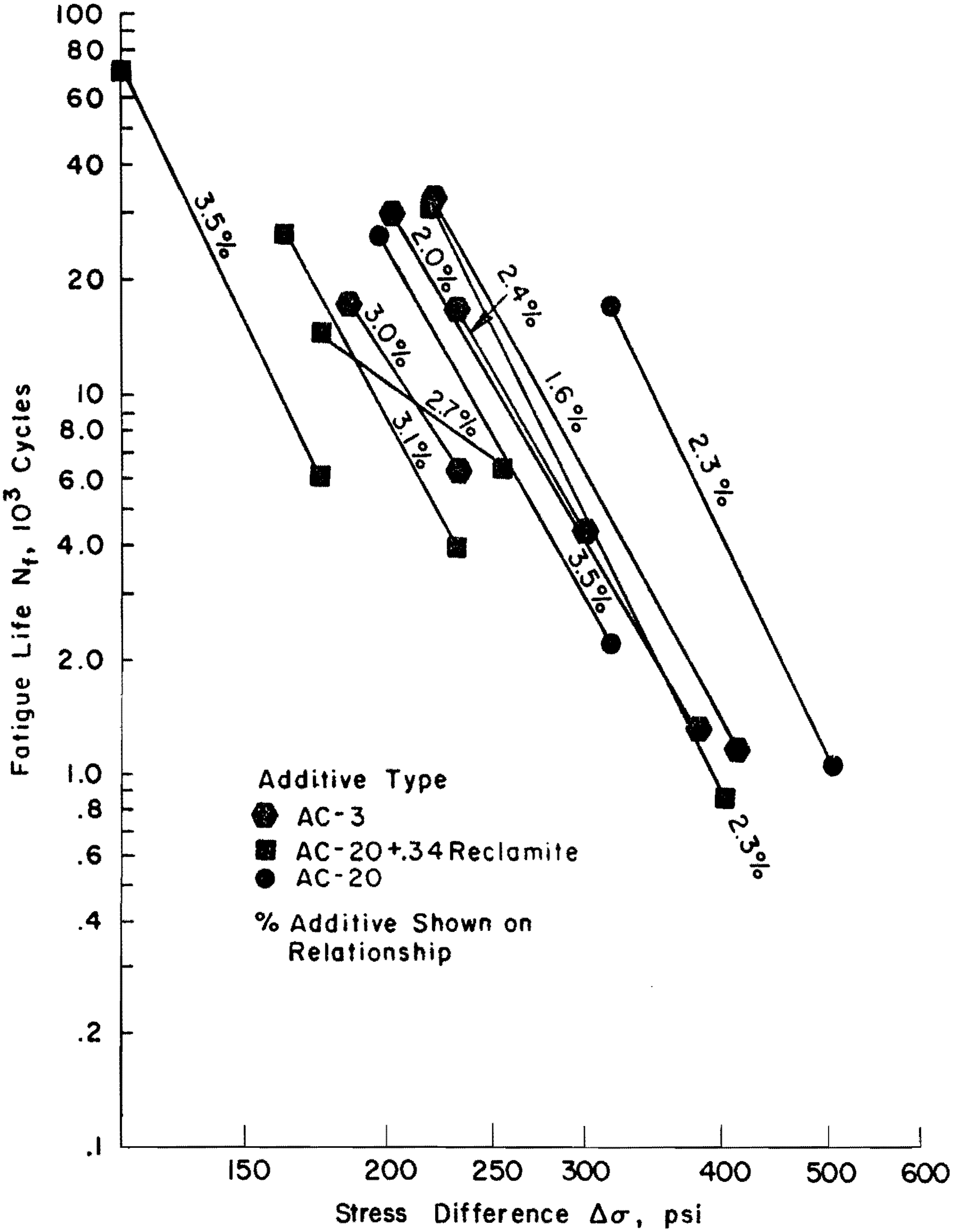


Fig 5. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from IH 20 - District 8 (laboratory specimens) (Ref 9).

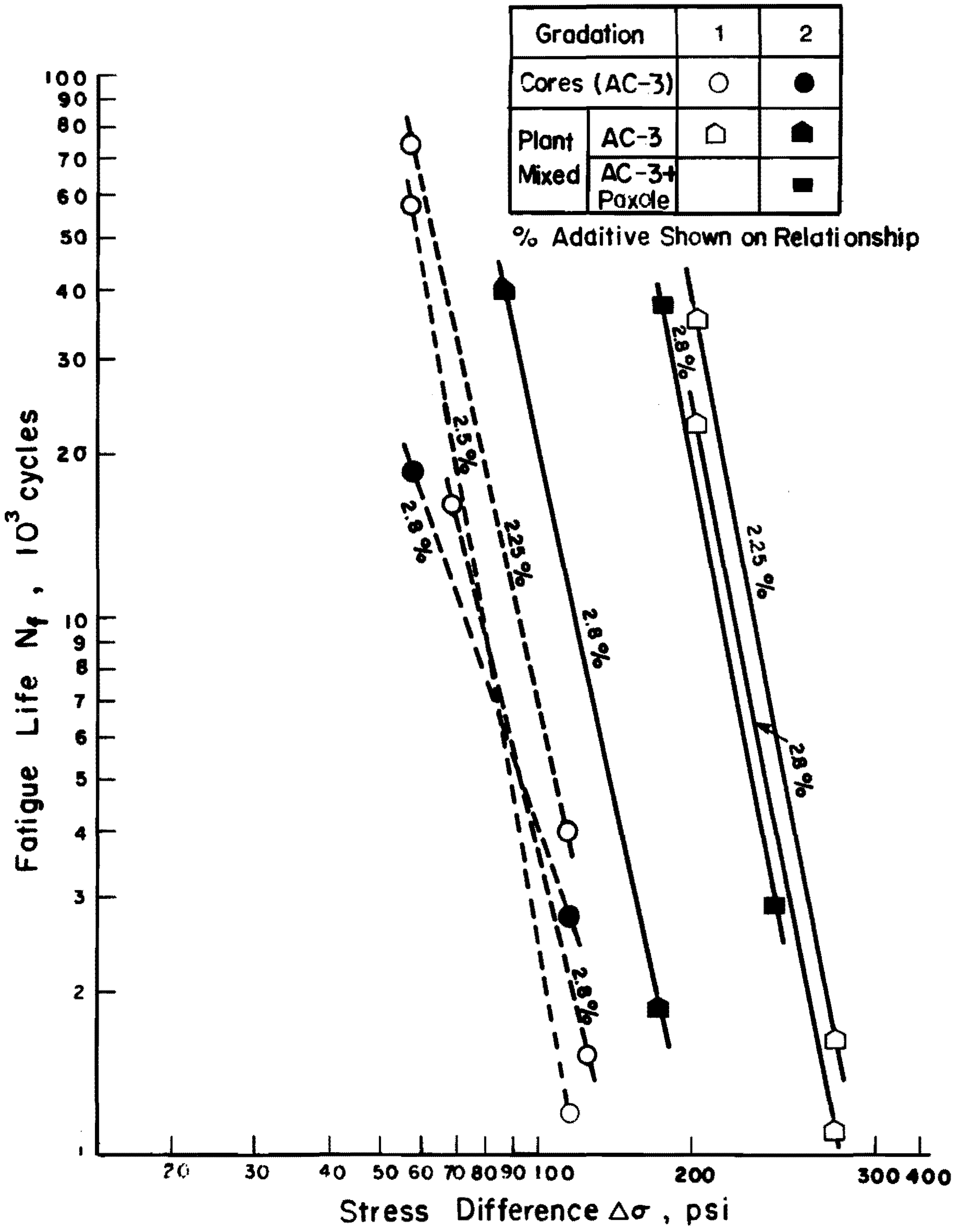


Fig 6. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from IH 20 - District 8 (cores and plant mixed specimens) (Ref 9).

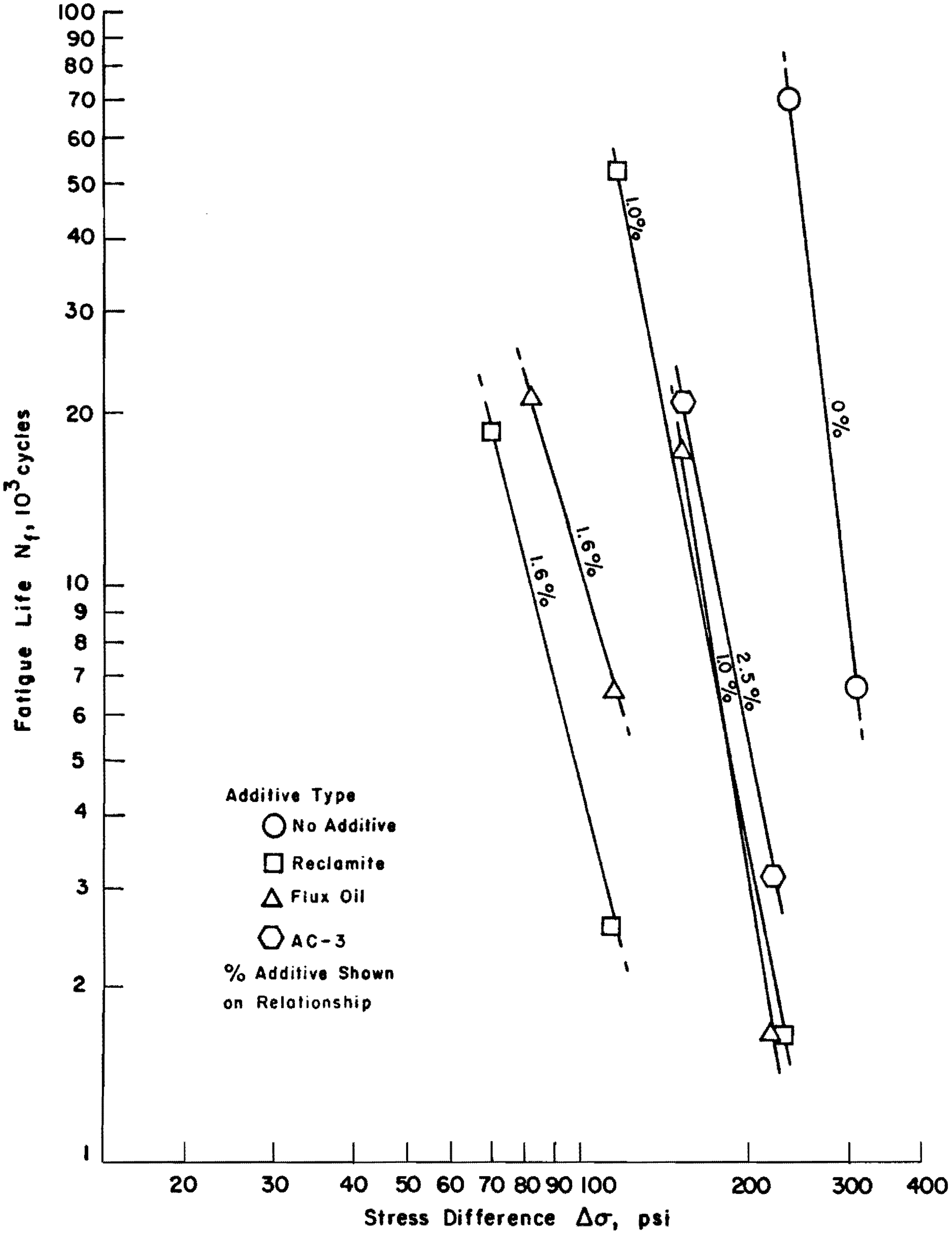


Fig 7. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from Loop 374 - District 21 (laboratory specimens) (Ref 9).

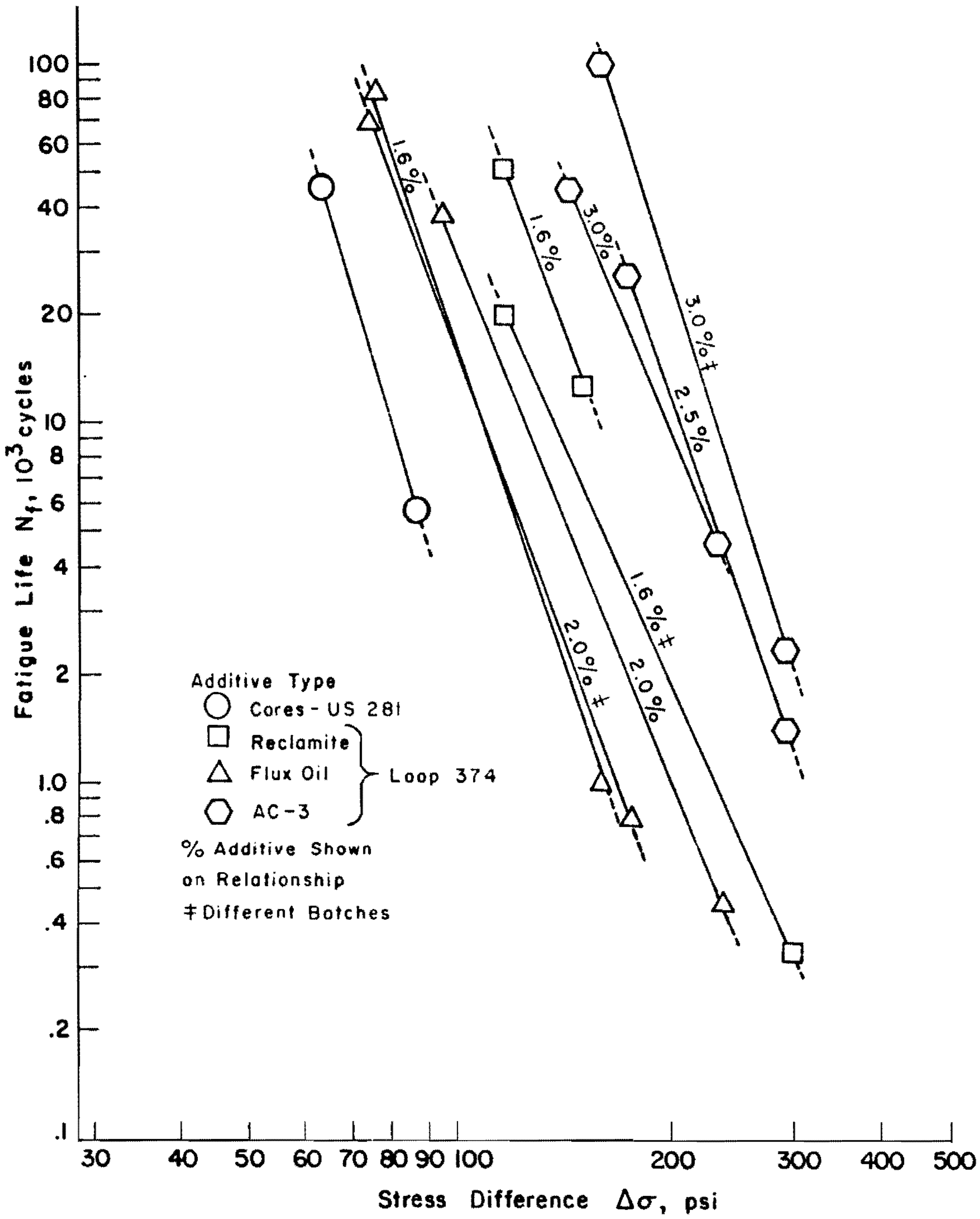


Fig 8. Relationships between the logarithms of fatigue life and stress difference for recycled asphalt mixtures (plant mixed specimens from Loop 374 and cores from US 281 - District 21) (Ref 9).

TABLE 3. SUMMARY OF FATIGUE RESULTS

District Project	Preparation, Aggregate	Treatment	Stress Level, psi	Number of Speci-mens	Fatigue Life		$N_f = K_2\left(\frac{1}{\sigma}\right)^{n_2} = K_2'\left(\frac{1}{\Delta\sigma}\right)^{n_2}$ Fatigue Constants			
					Mean	CV, %	K_2	K_2'	n_2	R^2
8 IH 20	Laboratory Gradation 1	3.0% AC-3	58	2	6,394	—	9.67×10^{11}	2.57×10^{15}	5.68	0.79
			46	3	17,546	18				
		2.4% AC-3	75	2	4,385	—	3.33×10^{11}	3.74×10^{14}	5.06	0.94
			58	3	16,867	23				
		2.0% AC-3	96	2	1,312	—	2.59×10^{11}	2.68×10^{14}	5.00	0.98
			51	2	30,890	—				
		1.6% AC-3	104	2	1,160	—	7.25×10^{11}	9.66×10^{14}	5.18	0.98
			55	3	33,000	31				
		3.5% AC-20	43	2	5,961	—	7.18×10^{11}	3.59×10^{15}	6.14	0.98
		0.34% R	29	2	71,571	—				
		3.1% AC-20	58	2	3,909	—	9.21×10^{10}	1.11×10^{14}	5.11	0.88
		0.34% R	41	3	26,528	52				
		2.7% AC-20	65	2	6,014	—	9.99×10^{6}	1.99×10^{8}	2.15	0.94
		0.34% R	43	2	14,550	—				
		2.3% AC-20	101	2	856	—	6.67×10^{12}	2.29×10^{16}	5.87	0.98
		0.34% R	55	2	31,560	—				
		3.5% AC-20	80	2	2,173	—	2.81×10^{11}	3.49×10^{14}	5.14	0.96
			49	2	26,464	—				
		2.3% AC-20	126	2	1,060	—	7.22×10^{13}	3.40×10^{17}	6.09	0.98
			80	2	17,140	—				

(continued)

TABLE 3. (Continued)

District Project	Preparation, Aggregate	Treatment	Stress Level, psi	Number of Speci- mens	Fatigue Life		$N_f = K_2\left(\frac{1}{\sigma}\right)^{n_2} = K_2\left(\frac{1}{\Delta\sigma}\right)^{n_2}$			
							Fatigue Constants			
					Mean	CV, %	K_2	K_2'	n_2	R^2
8 IH 20	Laboratory Gradation 1	2.5% AC-20	104	2	2,197	—	1.16×10^{13}	3.41×10^{16}	5.76	0.86
		0.2% R	59	2	67,698	—				
		None*	104	2	1,652	—	7.68×10^{16}	5.53×10^{21}	8.07	0.98
			65	2	70,967	—				
	Plant Gradation 1	2.25% AC-3	94	3	1,625	11	1.33×10^{11}	1.03×10^{14}	4.79	0.94
			51	4	35,200	57				
		2.8% AC-3	94	3	1,097	35	1.22×10^{11}	1.06×10^{14}	4.88	0.96
			51	3	22,575	36				
	Plant Gradation 2	2.8% AC-3	44	3	1,854	25	1.35×10^{9}	6.52×10^{11}	4.46	0.99
			22	2	40,056	—				
		2.8% AC-3+	73	3	2,938	21	1.29×10^{11}	1.28×10^{14}	4.97	0.98
		Paxole	44	2	37,285	—				
	Cores Gradation 1	2.25% AC-3	29	3	3,972	92	7.26×10^{8}	5.42×10^{11}	4.77	0.81
		Design 2	15	2	74,411	—				
		2.5% AC-3	29	2	1,177	—	2.65×10^{9}	6.09×10^{12}	5.58	0.99
		Design 3	15	2	57,180	—				
		2.8% AC-3	32	2	1,522	—	6.62×10^{7}	1.55×10^{10}	3.94	0.98
		Design 4	17	2	16,070	—				

(continued)

TABLE 3. (Continued)

					Fatigue Life		$N_f = K_2 \left(\frac{1}{\sigma}\right)^{n_2} = K_2' \left(\frac{1}{\Delta\sigma}\right)^{n_2}$			
							Fatigue Constants			
District Project	Preparation, Aggregate	Treatment	Stress Level, psi	Number of Speci-mens	Mean	CV, %	K_2	K_2'	n_2	R^2
8 IH 20	Cores Gradation 2	2.8% AC-3 Design 6	29	3	2,811	20	3.74×10^6	1.68×10^8	2.75	0.99
			15	3	18,585	4				
21 Loop 374	Laboratory	None*	83	2	6,617	—	3.52×10^{14}	3.98×10^{18}	6.73	0.98
			58	2	71,634	—				
		2.5% AC-3	55	3	3,147	14	2.89×10^{10}	1.19×10^{13}	4.74	0.86
			38	3	21,065	34				
		1.0% R	58	3	1,624	23	6.65×10^9	3.89×10^{12}	4.59	0.88
			29	2	52,945	—				
		1.6% R	29	3	2,577	51	7.62×10^7	1.88×10^{10}	3.97	0.81
			17	3	18,765	43				
		1.0% FO	55	3	1,651	7	1.01×10^{12}	6.64×10^{15}	6.24	0.98
			38	2	17,473	—				
		1.6% FO	29	3	6,706	44	1.42×10^9	4.12×10^9	3.07	0.57
			20	3	21,780	67				
21 Loop 374	Plant	1.6% FO	41	3	1,052	10	2.17×10^{10}	6.30×10^{13}	5.71	0.98
			19	3	84,561	19				
		2.0% FO	58	3	451	13	4.47×10^9	3.76×10^{12}	4.85	0.98
			23	3	40,005	35				

(continued)

TABLE 3. (Continued)

					Fatigue Life		$N_f = K_2 \left(\frac{1}{\sigma}\right)^{n_2} = K_2 \left(\frac{1}{\Delta\sigma}\right)^{n_2}$			
							Fatigue Constants			
District Project	Preparation, Aggregate	Treatment	Stress Level, psi	Number of Specimens	Mean	CV, %	K_2	K_2'	n_2	R^2
21 Loop 374	Plant	2.0% FO**	43 19	3 3	768 72,432	3 16	1.01×10^{10}	1.96×10^{13}	5.42	0.98
		1.6% R	38 29	3 3	12,150 50,140	18 27	7.07×10^{10}	1.02×10^{14}	5.35	0.94
		1.6% R**	74 29	2 2	312 19,808	— —	2.27×10^{9}	1.07×10^{12}	4.43	0.98
		2.5% AC-3	72 43	3 3	1,383 25,565	20 12	9.47×10^{11}	2.42×10^{15}	5.72	0.98
		3.0% AC-3	58 36	3 3	4,459 44,680	31 11	5.62×10^{10}	6.00×10^{13}	4.96	0.96
		3.0% AC-3**	72 41	3 3	2,307 102,144	35 6	3.44×10^{13}	2.99×10^{17}	6.60	0.98
21 US 281	Cores	1.5% AC-20	22 16	5 6	15,550 46,054	34 67	4.96×10^{6}	1.57×10^{8}	2.49	0.20

*Recycled material was heated and compacted without additives or new aggregate

**Duplicate treatment sampled from different plant batches

R = Reclamite Base Oil

FO = Flux Oil

TABLE 4. SUMMARY OF FATIGUE CONSTANTS

(a)

Material	Exponent n_2	Source
Specimens of recycled asphalt mixtures	2.15 - 8.07	--
Cores of recycled asphalt mixtures	2.49 - 6.73	Perez et al (Ref 9)
Asphalt-concrete specimens	1.85 - 6.06	Monismith et al (Ref 10)
Inservice blackbase cores	1.58 - 5.08	Navarro and Kennedy (Ref 3)
Asphalt-concrete specimens*	1.71 - 5.19	Adedimila and Kennedy (Ref 2)
Specimens of dryer-drum mixtures	1.24 - 2.65	Rodriguez and Kennedy (Ref 11)

(b)

Material	Coefficient K_2'	Source
Specimens of recycled asphalt mixtures	$6.26 \times 10^{10} - 1.30 \times 10^{31}$	--
Cores of recycled asphalt mixtures	$1.57 \times 10^{8} - 3.98 \times 10^{18}$	Perez et al (Ref 9)
Asphalt-concrete specimens	$8.00 \times 10^{7} - 4.10 \times 10^{18}$	Monismith et al (Ref 10)
Inservice blackbase cores	$2.49 \times 10^{6} - 8.18 \times 10^{15}$	Navarro and Kennedy (Ref 3)
Asphalt-concrete specimens*	$2.94 \times 10^{6} - 2.53 \times 10^{16}$	Adedimila and Kennedy (Ref 2)
Specimens of dryer-drum mixtures	$1.89 \times 10^{5} - 1.08 \times 10^{8}$	Rodriguez and Kennedy (Ref 11)

* Test Temperature Range: 50°F - 100°F.

TABLE 5. SUMMARY OF STATIC INDIRECT TENSILE PROPERTIES

Recycling Agent		Speci-men	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent	No.	Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
LABORATORY SPECIMENS								
DISTRICT 4 AMARILLO - I 40 (AC-3 and 50% New Aggregate)								
A	0.00	3	58	15	101	15	0.48	24
	0.75	3	74	45	88	30	0.39	63
	1.50	3	120	17	149	14	0.36	5
	2.25	3	123	18	138	19	0.85	88
	3.00	3	122	8	123	12	0.56	10
	3.75	3	110	2	78	2	0.50	8
	4.50	3	76	5	55	7	0.52	3
A	3.50	2	88	5	65	18	0.16	87
	3.00	2	122	8	106	0	0.13	28
	2.50	2	158	2	178	7	0.54	60
DISTRICT 8 ABILENE - I 20 (100% Surface)								
NONE	0.00	3	277	14	290	37	-	-
DISTRICT 8 ABILENE - I 20 (AC-3 or AC-20, and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)								
H	3.0	2	150	-	89	-	0.09	-
	2.4	2	225	-	206	-	0.04	-
	2.0	2	254	-	270	-	0.17	-
	1.6	2	227	-	319	-	0.11	-
H	2.25	3*	235	5	342	7	0.23	16
	2.8	2*	261	12	376	21	0.27	12
I	3.5	2	198	-	142	-	0.14	-
	2.3	2	315	-	341	-	0.12	-
DISTRICT 8 ABILENE - I 20 (AC-20 + 0.34% RBO and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)								
I + C	3.5	3	122	12	125	10	-	-
	3.1	2	197	-	191	-	-	-
	2.7	4	212	4	213	34	-	-
	2.3	4	251	11	275	27	-	-

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[1] See Table 2

CV = Coefficient of Variation

* Plant Mixed

TABLE 5. (Continued)

Recycling Agent		Speci-men	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent	No.	Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 8 ABILENE - I 20 (AC-20 + 0.20% RBO and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)								
I + C	2.5	2	262	-	239	-	0.12	-
DISTRICT 8 ABILENE - I 20 (AC-3 or AC-3 + Paxole and 20% Old Base, 15% New Aggregate, and 65% Recycled Surface)								
H	2.8	3*	123	3	90	8	0.28	86
H + J	2.8	3*	184	1	194	20	0.16	23
DISTRICT 12 HOUSTON - FM 1640 (AC-3 and 15% New Aggregate)								
B	0.00	3	201	3	163	6	0.46	15
	0.70	3	237	3	119	5	0.42	17
	1.00	3	204	1	186	4	0.45	22
	1.40	3	165	3	139	7	0.37	19
	2.00	3	141	2	102	5	0.38	9
DISTRICT 12 HOUSTON (AC-3 + 0.80 % RBO, 15% New Aggregate)								
B + C	0.80	3	126	3	81	12	0.54	-
	1.20	3	172	3	135	7	0.45	11
	1.40	3	164	5	122	3	0.48	8
	1.60	9	154	6	102	11	0.41	19
	2.00	3	130	1	75	3	0.39	16
	2.50	3	115	1	58	17	0.49	22
DISTRICT 12 HOUSTON (100% Recycled)								
NONE	0.00	3	226	4	177	31	0.40	22
DISTRICT 13 YOAKUM - US 90A (AC-3 + Redicote 82-S and 15% New Aggregate)								
B	0.00	3	171	11	150	20	0.37	18
	0.50	9	219	7	164	9	0.32	30
	1.00	3	187	2	147	5	0.16	59
	1.50	3	174	4	139	10	0.39	3
DISTRICT 13 YOAKUM (100% Recycled)								
NONE	0.00	3	228	4	158	11	0.35	37

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[1] See Table 2

CV = Coefficient of Variation

* Plant Mixed

TABLE 5. (Continued)

Recycling Agent		Specimen No.	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent		Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 16 CORPUS CHRISTI - US 77 (Coastal Residuum and 30% Sandstone)								
D	0.00	2	227	8	247	17	0.42	26
	0.41	2	192	7	187	23	0.39	29
	0.62	2	146	16	139	21	0.36	15
	0.83	2	140	15	135	27	0.32	13
	1.03	2	116	2	100	16	0.31	14
	1.24	2	113	9	67	16	0.23	-
DISTRICT 16 CORPUS CHRISTI (AES-300-R and 30% Sandstone)								
E	0.62	2	166	1	153	8	0.41	7
	0.83	2	181	4	210	1	0.44	24
	1.03	2	170	11	153	29	0.31	35
DISTRICT 16 CORPUS CHRISTI (Coastal Residuum and 30% Gravel)								
D	0.00	2	200	2	218	1	0.22	35
	0.41	2	141	13	126	12	0.22	16
	0.63	2	112	3	118	5	0.52	3
	0.83	2	116	5	83	15	0.21	65
	1.03	2	46	2	35	15	0.42	15
	1.24	2	42	2	21	4	0.23	22
DISTRICT 16 CORPUS CHRISTI (AES-300-R and 30% Gravel)								
E	0.41	2	134	0	99	1	0.27	3
	0.62	2	118	9	82	17	0.24	29
	0.83	2	111	6	77	9	0.20	40
DISTRICT 16 CORPUS CHRISTI (AC-10, and 40% Sand and Gravel + 1.0 Lime)								
F	0.50	3	131	4	101	15	0.13	-
	1.00	3	165	19	162	51	0.19	23
	1.50	3	178	1	146	13	0.35	18
	2.00	3	157	6	142	14	0.31	33
	2.50	3	140	7	135	18	0.47	21
	3.00	3	113	11	84	33	0.42	35
	3.50	3	102	12	60	36	0.35	49

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[1] See Table 2

CV = Coefficient of Variation

TABLE 5. (Continued)

Recycling Agent		Specimen No.	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent		Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 16 CORPUS CHRISTI (AC-10 and 40% Sand and Gravel + 1% Limestone Dust)								
F	0.50	3	201	15	207	11	0.37	20
	1.00	3	206	7	173	7	0.35	17
	1.50	3	209	4	164	14	0.49	14
	2.00	3	194	5	151	8	0.51	12
	2.50	3	166	7	133	6	0.40	17
	3.00	3	149	4	111	19	0.31	54
	3.50	3	134	4	92	11	0.31	26
DISTRICT 18 DALLAS - I 20 (AC-3, No New Aggregate)								
G	0.00	4	377	10	495	11	0.18	44
	0.50	4	261	1	187	6	0.14	20
	1.00	4	215	2	133	5	0.06	27
	1.50	4	173	2	153	7	0.10	65
DISTRICT 18 DALLAS (AC-3 + Unknown Amount of Concrete Chips)								
G	0.00	4	318	6	480	17	0.04	51
	2.00	4	296	4	479	25	0.26	10
	2.50	4	223	12	347	25	0.20	36
	3.00	4	173	6	198	13	0.12	47
DISTRICT 20 BEAUMONT - I 10 (AC-3 + 0.75% RBO + 0.05% Redicote 82-S, No New Aggregate)								
B+C	0.00	3	314	14	269	28	0.21	56
	0.95	3	311	5	235	16	0.19	12
	1.25	3	258	3	212	8	0.34	5
	1.95	3	192	10	135	15	0.26	7
DISTRICT 20 BEAUMONT (AES-300-R, and 13% Limestone)								
E	1.50	3	262	14	176	13	0.42	14
	1.85	3	255	4	174	18	0.42	4
	2.00	3	179	4	158	8	0.43	28
	2.50	3	147	12	84	13	0.37	17

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[1] See Table 2

CV = Coefficient of Variation

TABLE 5. (Continued)

Recycling Agent		Speci-men No.	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent		Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 21 PHARR - Loop 374 (100% Recycled)								
-	None	3	319	4	392	6	-	-
DISTRICT 21 PHARR - Loop 374 (AC-3 and 100% Recycled)								
K	2.5	3	213	3	245	7	0.37	15
	2.5	3*	239	5	179	4	0.28	18
	3.0**	3*	277	2	213	6	0.23	4
	3.0**	3*	223	3	172	10	0.32	16
DISTRICT 21 PHARR - Loop 374 (RBO and 100% Recycled)								
C	1.0	3	180	7	222	10	0.30	3
	1.6	3	122	23	146	20	0.27	22
	1.6**	3*	188	2	64	4	0.33	18
	1.6**	3*	185	11	140	39	0.33	20
DISTRICT 21 PHARR - Loop 374 (FO and 100% Recycled)								
L	1.0	3	157	23	138	16	0.23	29
	1.6	3	118	4	120	22	0.25	71
L	1.6	3*	1250	4	111	10	0.36	10
	2.0**	3*	150	8	130	26	0.33	14
	2.0**	3*	125	3	100	10	0.28	24
CORES								
DISTRICT 8 ABILENE - I 20 (AC-3 and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)								
H	2.0	3	89	11	105	23	0.32	8
	2.25	3	87	23	93	35	0.18	62
	2.25	4	96	4	126	13	0.25	58
	2.5	2	78	-	90	-	0.24	-
	2.8	2	77	-	75	-	0.28	-

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[1] See Table 2

CV = Coefficient of Variation

* Plant Mixed

** Duplicate treatments sampled from different plant batches

TABLE 5. (Continued)

Recycling Agent		Specimen	Tensile Strength		Static Modulus of Elasticity		Static Poisson's Ratio	
Type[1]	Percent	No.	Mean, psi	CV, %	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 8 ABILENE - I 20 (AC-3 and 20% Old Base, 15% New Aggregate, and 65% Recycled Surface)								
H	2.8	5	71	9	129	14	0.16	83
DISTRICT 8 ABILENE - I 20 (AC-3 + Paxole and 20% Old Base, 15% New Aggregate, and 65% Recycled Surface)								
H + J	2.8	2	78	-	184	-	0.27	-
DISTRICT 21 PHARR - US 281 (AC-20 and 100% Recycled)								
M	1.5	7	81	39	57	55	0.03	459

[1] See Table 2

CV = Coefficient of Variation

mixtures with corresponding values for other types of mixtures for the final design mixtures.

Tensile Strength

The average values* for tensile strength ranged from 40 to 380 psi with an overall average of 170 psi, which is in agreement with the data reported by Perez and Kennedy (Ref 9).

At design additive contents, the tensile strength ranged from 123 to 260 psi, with an overall average of 177 psi and a coefficient of variation of 26 percent, which is slightly higher than the range reported for conventional mixtures at or near optimum asphalt contents (Table 6).

High tensile strength may also indicate higher fatigue resistance for controlled stress conditions which are applicable to thick asphalt layers, but could lead to cracking due to brittleness in thin layers. Thus, for thick layers, hot mixed recycled materials are comparable to conventional mixtures and should perform as well if constructed properly.

Static Modulus

The average static modulus*, all data included, ranged from 21 to 495 ksi with an overall average of 151 ksi and a coefficient of variation of 58 percent which is in agreement with previous findings (Ref 9).

At design additive contents (Table 6) the static modulus ranged from 82 to 212 ksi, with an average of 148 ksi and a coefficient of variation of 28 percent. The values reported for laboratory specimens (Ref 13), in-service cores (Ref 14), and drum mixing plants (Ref 11) ranged from 46 to 265 ksi. The static modulus of recycled mixtures at design additive contents are within the range reported for conventional mixtures.

Static Poisson's Ratio

Poisson's ratio for all data points ranged from 0.04 to 0.74 with an overall average of 0.34 and a coefficient of variation equal to 38 percent, which is comparable to previously reported values for both recycled and conventional mixtures.

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* All measured values regardless of additive type and content.

TABLE 6. COMPARISON OF STATIC STRENGTHS AND ELASTIC PROPERTIES OF DESIGNED MIXTURES

Type of Specimens	Tensile Strength, psi	Modulus of Elasticity, ksi	Poisson's Ratio	Source
Recycled laboratory specimens	40 - 380*	21 - 495	0.04 - 0.74	-
Recycled cores	71 - 127	57 - 184	0.03 - 0.32	Ref 9
Inservice cores (blackbase)	61 - 158**	46 - 168	0.03 - 0.35	Ref 3
Laboratory asphalt mixture specimens+	145 - 164*	116 - 197*	0.08 - 0.29	Ref 2
Blackbase laboratory specimens	100 - 175	50 - 340	0.35 - 0.68	Ref 12
Dryer-drum	61 - 148	81 - 256	0.14 - 0.42	Ref 11

Testing Temperature - 24°C (75°F)

* Ultimate tensile strength

** Tensile strength at first inflection point

\+ At optimum asphalt content

Poisson's ratio corresponding to the design additive contents ranged from 0.10 to 0.56; the average was 0.31 and the coefficient of variation was 51 percent (Table 4).

Strain at Failure

Epps et al. (Ref 15) found that field compacted recycled mixtures have higher ultimate indirect tensile strains than field compacted conventional mixtures. Others (Refs 16, 17, 18, and 19) reported high Marshall flow values for recycled materials. Unusually high strain values under static tests may be indicative of rutting susceptibility. Thus, the tensile strains at failure were evaluated and were compared to those computed for conventional mixtures using the data reported in References 2, 14, and 20.

At design conditions, the strains at failure ranged from 1,200 to 3,300 microunits and averaged 2,400 microunits; the coefficient of variation was 25 percent. The values computed for conventional materials, at or near optimum, ranged from 900 to 4,400 microunits with an average coefficient of variation of 47 percent. The higher variability associated with conventional materials is due to the inclusion of in-service core data. Thus, for the materials tested the strain at failure for recycled and conventional materials was not different.

Summary

Strength and moduli values obtained for recycled mixtures were slightly larger than those obtained previously for conventional mixtures. Thus, based on the static elastic and strength properties, the recycled material is expected to perform as well as conventional mixtures. The higher values may be due to the fact that the softening agent did not restore the viscosity characteristics of the recycled asphalt to a value equal to the virgin asphalt. This could be due to an insufficient quantity or the fact that it does not adequately blend with the old asphalt in an actual mixture.

REPEATED-LOAD PROPERTIES

The relationship between permanent deformation and the number of load applications is linear between 10 and 80 percent of the fatigue life, and in this range, the modulus of elasticity decreases with an increase in the number of load applications (Ref 2). For this study, the elastic properties were calculated at stress levels varying from 10 to 30 percent of the static tensile strength after approximately 200 to 300 cycles. Generally estimates were made after 300 load application of a stress equal to 25 percent of the ultimate tensile strength. Table 7 summarizes the means and coefficients of variations corresponding to each additive content; the individual values are given in Appendix B. Table 8 contains a comparison with the resilient properties of conventional mixtures for the final design conditions.

Resilient Modulus of Elasticity

The resilient modulus values at 75°F ranged from 450 to 1,500 ksi. The mean resilient modulus values, at design conditions, ranged from 580 to 1,250 ksi, and averaged 880 ksi; the coefficient of variation was 28 percent. The range for conventional materials at or near optimum asphalt contents was 186 to 615 ksi (Table 8).

The design modulus values were higher for recycled materials than for conventional materials (Table 3), but were essentially the same as reported by Epps et al. (Ref 15). This suggests possible brittleness and premature fatigue cracking under constant strain loading conditions such as exist in thin layers, but under constant stress conditions (thick layers) longer fatigue lives and better performance would be expected.

Resilient Poisson's Ratio

Resilient Poisson's values for all conditions ranged from .01 to .42 (Table 7). At design additive contents, Poisson's ratio ranged from 0.01 to 0.24 (Table 8) and averaged 0.15; the coefficient of variation was 45 percent. In contrast to the static Poisson's ratio, the resilient Poisson's ratio did not exceed 0.50, probably due to the fact that the lower stress values did not produce failure. Values were similar to those previously obtained for conventional mixtures (Table 8).

Hveem Stabilities

The mean values of Hveem stability ranged from 20 to 58 for laboratory compacted recycled mixtures. Coefficients of variation ranged from 20 to 62 percent.

TABLE 7. SUMMARY OF RESILIENT PROPERTIES FOR MATERIAL CHARACTERIZATION

Recycling Agent			Resilient Modulus of Elasticity		Resilient Poisson's Ratio	
Type[1]	Percent	Specimen No.	Mean, ksi	CV, %	Mean	CV, %
LABORATORY SPECIMENS						
DISTRICT 4	AMARILLO - I 40 (AC-3 and 50% New Aggregate)					
A	0.00	3	450	13	0.15	64
	0.75	3	525	26	0.06	76
	1.50	3	654	14	0.10	16
	2.25	3	977	3	0.06	-
	3.00	3	953	9	0.13	15
	3.75	3	842	2	0.22	19
	4.50	3	735	3	0.36	29
A	3.50	2	835	4	0.20	69
	3.00	2	924	1	0.09	8
	2.50	2	1327	12	0.27	26
DISTRICT 8	ABILENE - I 20 (100% Recycled Surface)					
-	None	4	826	-	0.29	-
DISTRICT 8	ABILENE - I 20 (AC-3 or AC-20, and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)					
H	3.0	4	462	-	0.11	-
	2.4	5	563	10	0.11	20
	2.0	4	596	-	0.10	-
	1.6	5	605	3	0.17	60
H	2.25	7*	750	-	0.25	46
	2.8	6*	724	4	0.32	38
I	3.5	4	758	-	0.16	-
	2.3	4	786	-	0.17	-
DISTRICT 8	ABILENE - I 20 (AC-20 + 0.34% RBO and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)					
I + C	3.5	4	614	-	0.27	-
	3.1	5	630	19	0.18	52
	2.7	4	652	-	0.13	-
	2.3	4	676	-	0.30	-

---

[1] See Table 2

CV - Coefficient of variation

* Plant mixed

TABLE 7. (Continued)

Recycling Agent			Resilient Modulus of Elasticity		Resilient Poisson's Ratio	
Type[1]	Percent	Specimen No.	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 8	ABILENE - I 20 (AC-20 + 0.20% RBO and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)					
I + C	2.5	4	600	-	0.17	-
DISTRICT 8	ABILENE - I 20 (AC-3 or AC-3 + Paxole and 20% Old Base, 15% New Aggregate, and 65% Recycled Surface)					
H	2.8	5*	635	27	0.30	19
H + J	2.8	5*	934	11	0.30	46
DISTRICT 12	HOUSTON - FM 1640 (AC-3 and 15% New Aggregate)					
B	0.00	3	559	2	0.16	21
	0.70	3	1076	8	0.41	13
	1.00	3	749	3	0.21	0
	1.40	3	783	8	0.24	23
	2.00	3	655	2	0.30	14
DISTRICT 12	HOUSTON (AC-3 + 0.80% RBO and 15% New Aggregate)					
B + C	0.80	3	1006	6	0.33	14
	1.20	3	558	2	0.20	21
	1.40	3	574	4	0.18	20
	1.60	3	708	2	0.31	25
	2.00	3	655	4	0.42	35
	2.50	3	569	5	0.30	21
DISTRICT 12	HOUSTON (100% Recycled)					
NONE	0.00	3	671	3	0.12	22
DISTRICT 13	YOAKUM - US 90A (AC-3 + Redicote 82-S and 15% New Aggregate)					
B	0.00	3	565	5	0.16	47
	0.50	9	885	4	0.15	22
	1.00	3	764	2	0.11	9
	1.50		686	9	0.08	27
DISTRICT 13	YOAKUM (100% Recycled)					
NONE	0.00	3	969	6	0.19	18

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[1] See Table 2

CV - Coefficient of variation

* Plant mixed

TABLE 7. (Continued)

Recycling Agent			Resilient Modulus of Elasticity		Resilient Poisson's Ratio	
Type[1]	Percent	Specimen No.	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 16	CORPUS CHRISTI - US 77 (Coastal Residuum and 30% Sandstone)					
D	0.00	2	1482	10	0.05	-
	0.62	2	1194	6	0.20	99
	0.83	2	1249	2	0.24	15
	1.03	2	1119	1	0.14	0
DISTRICT 16	CORPUS CHRISTI (AES-300-R and 30% Sandstone)					
E	0.62	2	1234	25	0.09	44
	0.83	2	1207	10	0.22	3
	1.03	2	1242	16	0.12	6
DISTRICT 16	CORPUS CHRISTI (Coastal Residuum and 30% Gravel)					
D	0.00	2	1319	3	0.09	0
	0.41	2	1023	1	0.03	28
	0.63	2	1153	5	0.28	44
	0.83	2	1163	2	0.16	78
DISTRICT 16	CORPUS CHRISTI (AES-300-R and 30% Gravel)					
E	0.41	2	1240	4	0.07	-
	0.62	2	1108	6	0.01	47
	0.83	2	1012	6	0.03	20
DISTRICT 18	DALLAS - I 20 (AC-3 + 0% New Aggregate)					
G	0.00	3	801	15	0.09	90
	0.50	4	609	12	0.09	61
	1.00		818	9	0.06	44
	1.50		655	12	0.20	35
DISTRICT 18	DALLAS (AC-3 and Unknown Amount of Concrete Chips)					
G	0.00	4	705	10	-	-
	2.00	4	598	1	0.09	29
	2.50	4	688	11	0.14	40
	3.00	4	641	8	0.14	63

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[1] See Table 2

CV - Coefficient of variation

TABLE 7. (Continued)

Recycling Agent			Resilient Modulus of Elasticity		Resilient Poisson's Ratio	
Type[1]	Percent	Specimen No.	Mean, ksi	CV, %	Mean	CV, %
DISTRICT 20	BEAUMONT - I 10 (AC-3 + 0.75% RBO + 0.05% Redicote 82-S, and 0.0% New Aggregate)					
B+C	0.00	3	681	6	0.03	58
	0.95	3	727	1	0.08	-
	1.25	3	773	5	0.18	30
	1.95	3	783	3	0.18	20
DISTRICT 20	BEAUMONT (AES-300-R and 13% New Aggregate)					
E	1.50	3	742	19	0.13	30
	1.85	3	688	10	0.16	33
	2.00	3	1341	13	0.25	33
	2.50	3	916	7	0.09	6
DISTRICT 21	PHARR - Loop 374 (100% Recycled)					
-	None	4	838	-	-	-
DISTRICT 21	PHARR - Loop 374 (AC-3 and 100% Recycled)					
K	2.5	6	452	5	0.36	30
	2.5	6*	428	8	0.24	27
	3.0**	6*	485	8	0.18	15
	3.0**	6*	482	5	0.32	12
DISTRICT 21	PHARR - Loop 374 (RBO and 100% Recycled)					
C	1.0	5	470	8	0.41	17
	1.6	6	344	15	0.60	20
	1.6**	6	381	6	0.34	18
	1.6**	4	372	-	0.34	-
DISTRICT 21	PHARR - Loop 374 (FO and 100% Recycled)					
L	1.0	5	444	5	0.39	30
	1.6	6	286	8	0.44	18
L	1.6**	6*	282	5	0.41	9
	2.0**	6*	281	6	0.27	28
	2.0**	6*	276	6	0.29	24

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[1] See Table 2

CV - Coefficient of variation

* Plant mixed

** Duplicate treatments sampled from different plant batches

TABLE 7. (Continued)

Recycling Agent			Resilient Modulus of Elasticity		Resilient Poisson's Ratio	
Type[1]	Percent	Specimen No.	Mean, ksi	CV, %	Mean	CV, %
<u>CORES</u>						
DISTRICT 8	ABILENE - I 20 (AC-3 and 16% Old Base, 15% New Aggregate, and 69% Recycled Surface)					
	2.25	5	540	18	0.44	22
H	2.5	4	465	-	0.51	-
	2.8	4	400	-	0.28	-
DISTRICT 8	ABILENE - I 20 (AC-3 and 20% Old Base, 15% New Aggregate, and 65% Recycled Surface)					
H	2.8	6	458	9	0.37	10
DISTRICT 21	PHARR - US 281 (AC-20 and 100% Recycled)					
M	1.5	11	353	7	0.34	19

[1] See Table 2

CV - Coefficient of variation

TABLE 8. COMPARISON OF RESILIENT PROPERTIES

Type of Specimens	Resilient Modulus, ksi	Resilient Poisson's Ratio	Source
Recycled laboratory specimens	580 - 1250	0.01 - 0.24	-
Recycled cores	325 - 584	0.25 - 0.59	Ref 9
Inservice cores (blackbase)	220 - 615	0.06 - 0.58	Ref 3
Laboratory specimens (blackbase)	200 - 500	-	Ref 20
Laboratory specimens*	352 - 339	0 - 0.29	Ref 2
Dryer-drum	186 - 506	0.05 - 0.38	Ref 11

Testing Temperature - 24°C (75°F)

* At optimum asphalt content

EFFECT OF SOFTENING AGENTS

A primary feature in the design of recycled mixtures often involves determining the type and amount of softening agent required to restore the asphalt to an acceptable viscosity level. For construction the viscosity of the additive must be low enough and the volume sufficient to wet and penetrate uniformly the crushed asphalt material being recycled (Ref 16).

The effects of the amount and type of softening agent on the tensile strength, static modulus of elasticity, resilient modulus of elasticity, and fatigue life of laboratory and plant prepared specimens are illustrated in Figures 9 through 15. Generally, all four properties tended to decrease with an increase in the amount of additive. It should be noted that in a previous study (Refs 21 and 22) it appeared that for recycled mixtures which were not brittle, i.e., did not have low penetrations for the recovered asphalt, the effects of the additive were less for strength and modulus.

The recycling agent can affect the engineering properties of the mixture by

(a) increasing the asphalt content of the mix and
(b) reducing the viscosity of the asphaltic binder and hence decreasing the strength.

These two effects may reinforce or offset each other depending on the amount of residual asphalt with respect to optimum. If the residual asphalt is below optimum, the two effects will tend to offset each other; if it is near or above optimum, the two effects will tend to be additive.

An evaluation of the data (Figs 9 to 14) suggested that the different relations between strength properties and mixture properties can be grouped according to

(a) the amount of residual asphalt in the final mix,
(b) the hardness of the residual asphalt, and
(c) the type of recycling agent used.

The strength and static modulus of mixtures containing less than 4.0 percent residual asphalt, projects 4 and 16, tended to increase gradually as the amount of recycling agent was increased up to an optimum and then decreased (relation A, Fig 16).

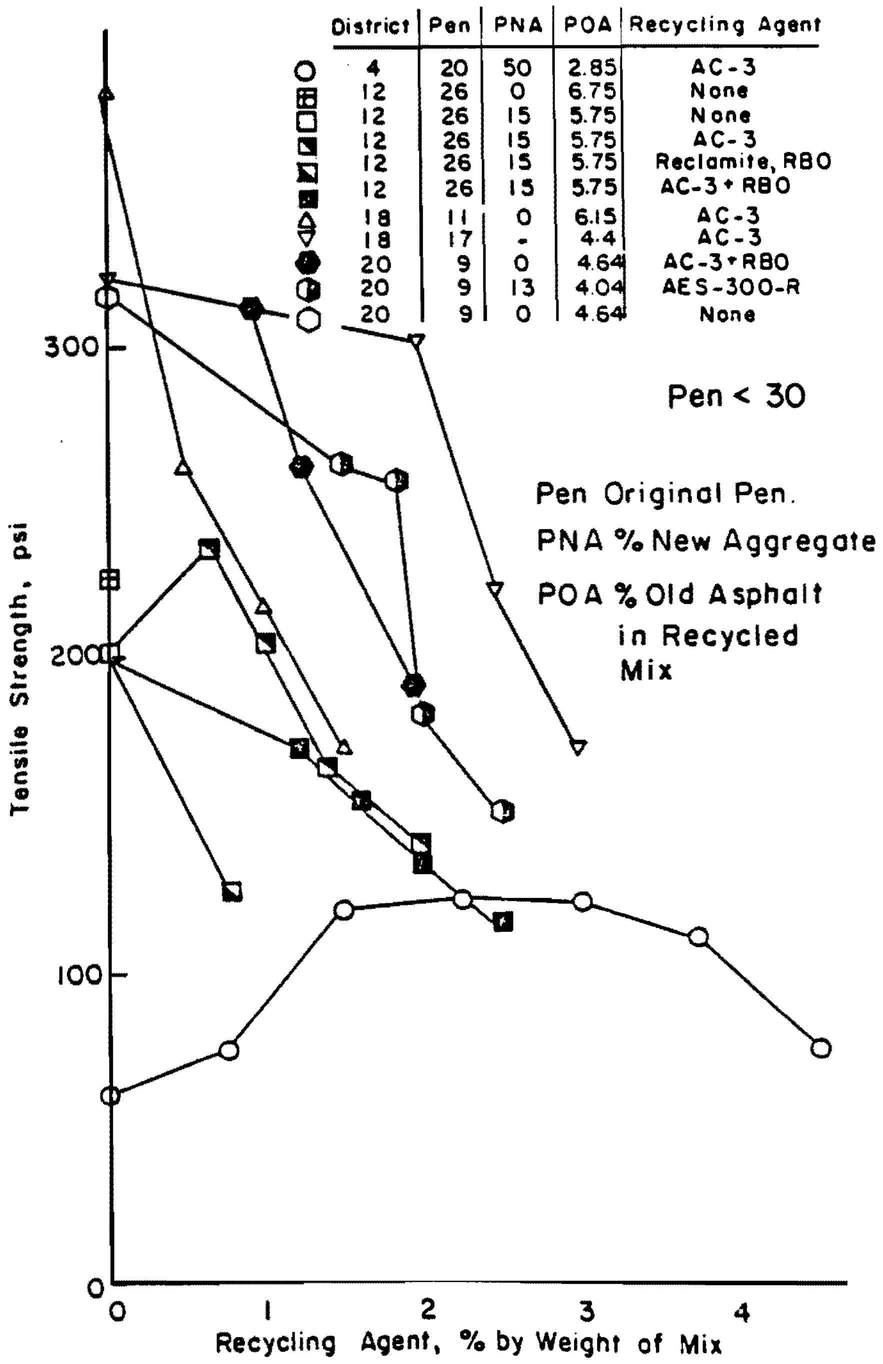


Fig 9. Indirect tensile strength vs. recycling agent for brittle mixtures.

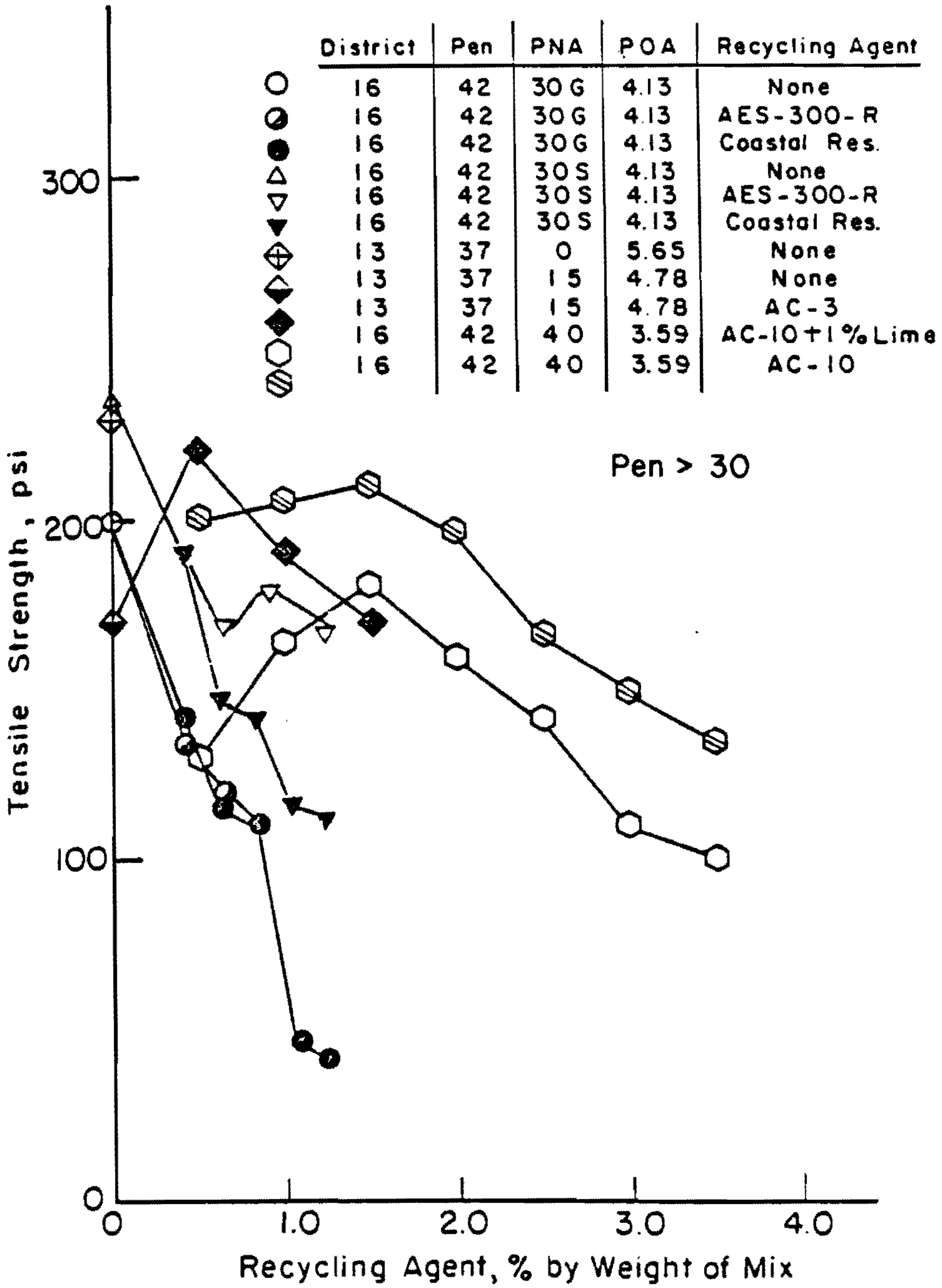


Fig 10. Indirect tensile strength vs. recycling agent for nonbrittle mixtures.

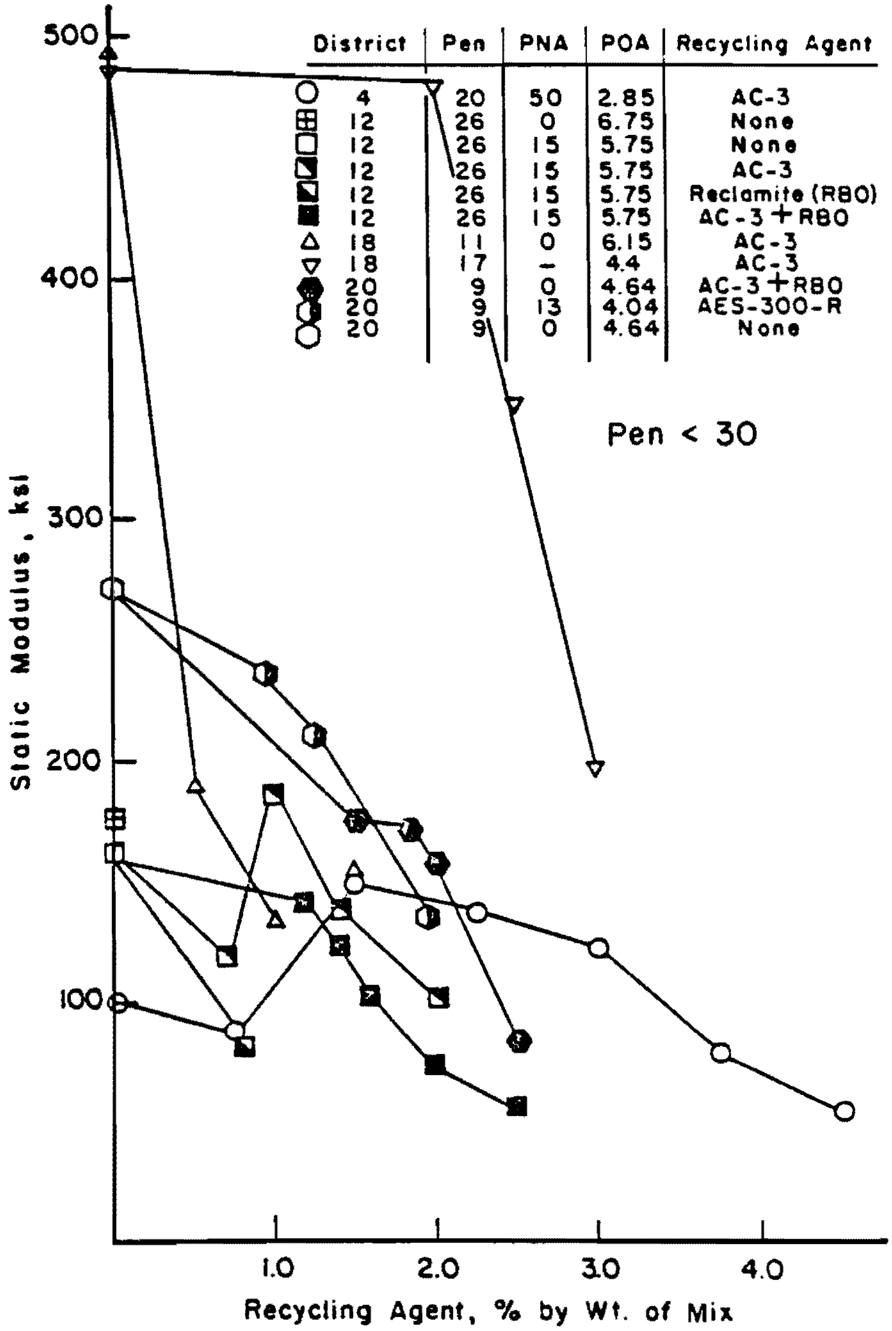


Fig 11. Static modulus vs. recycling agent for brittle mixtures.

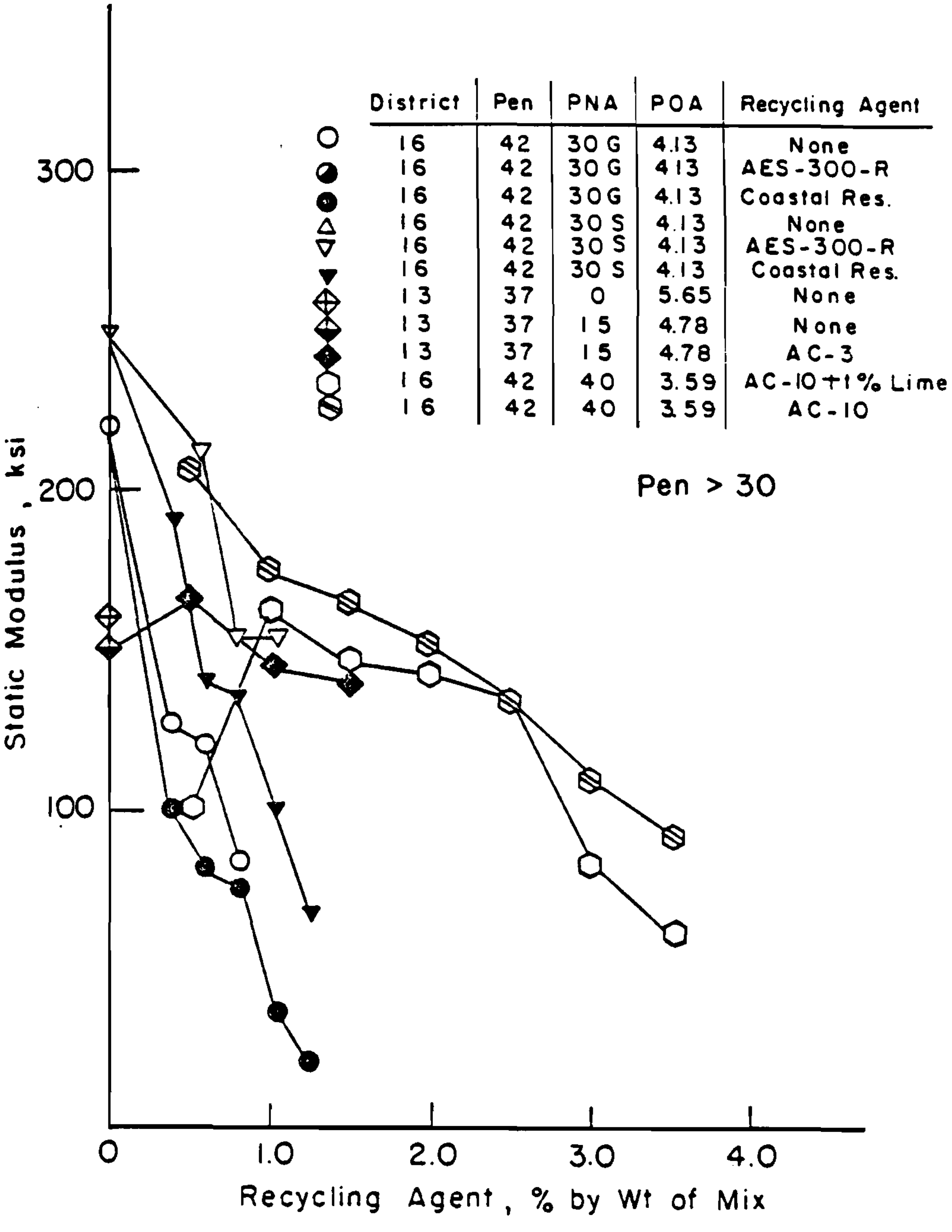
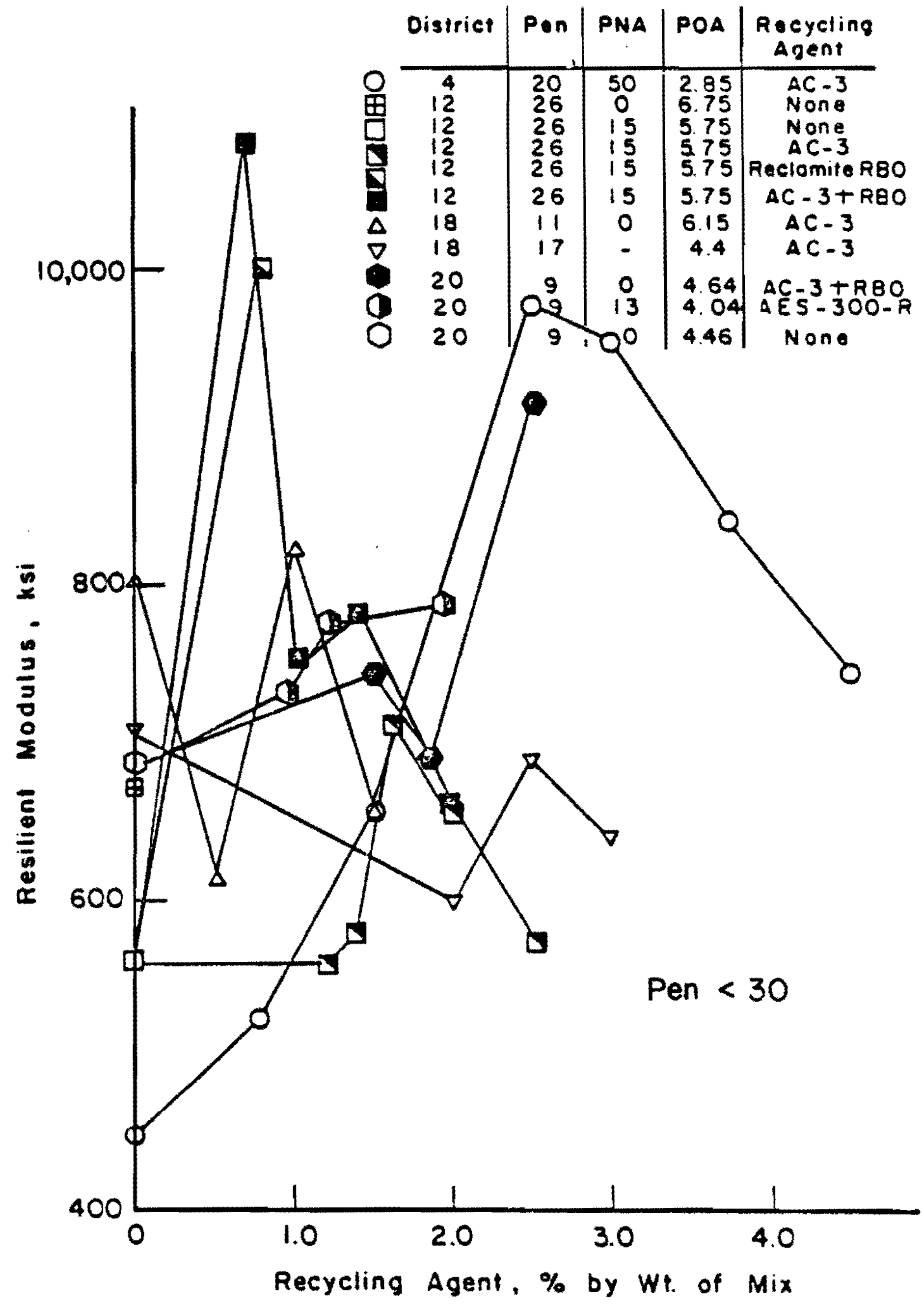
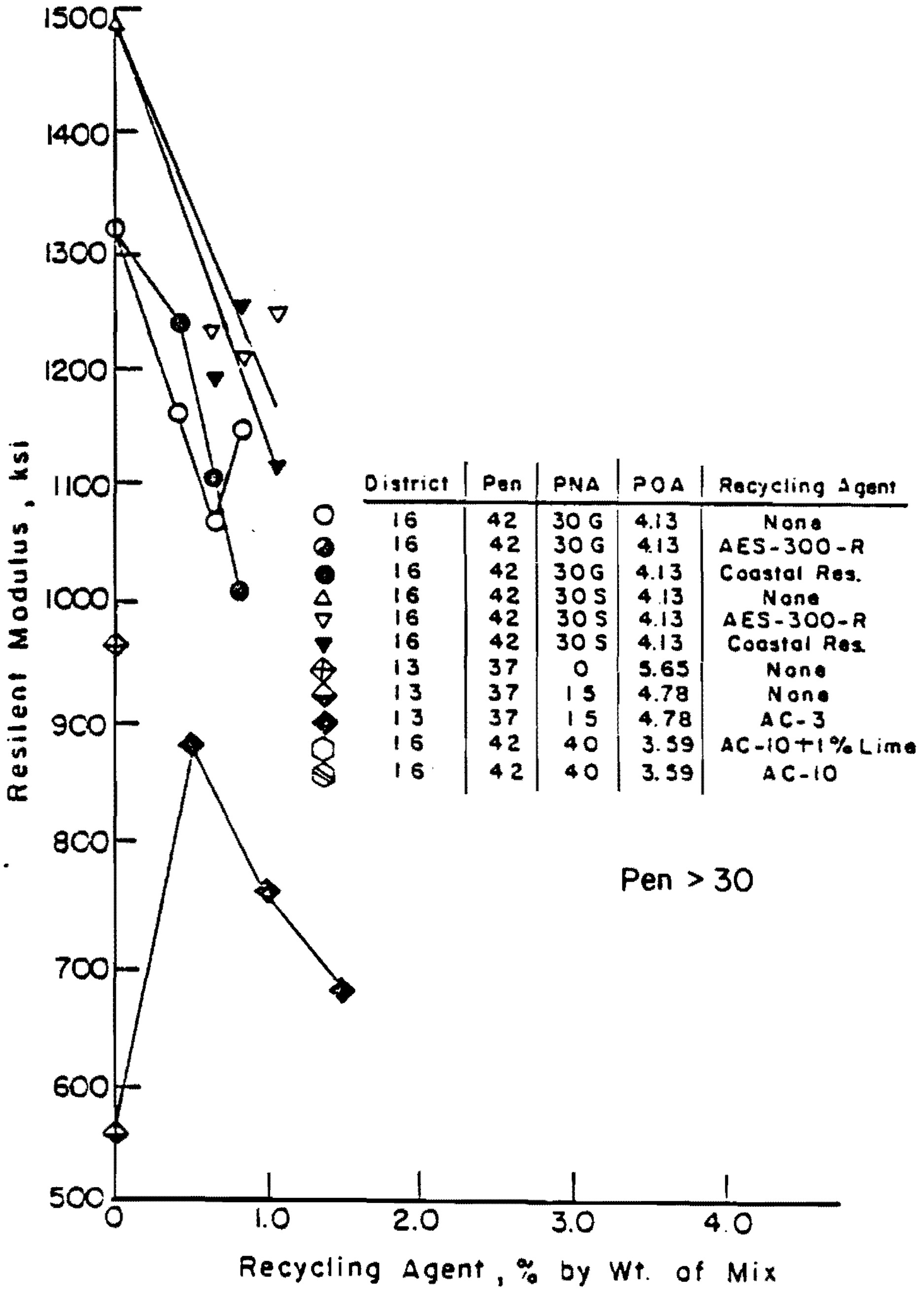


Fig 12. Static modulus vs. recycling agent for nonbrittle mixtures.



	District	Pen	PNA	POA	Recycling Agent
○	4	20	50	2.85	AC-3
⊞	12	26	0	6.75	None
□	12	26	15	5.75	None
◪	12	26	15	5.75	AC-3
◩	12	26	15	5.75	Reclamite RBO
■	12	26	15	5.75	AC-3+RBO
△	18	11	0	6.15	AC-3
▽	18	17	-	4.4	AC-3
⬢	20	9	0	4.64	AC-3+RBO
⬣	20	9	13	4.04	AES-300-R
⬡	20	9	0	4.46	None

Fig 13. Resilient modulus vs. recycling agent for brittle mixtures.



	District	Pen	PNA	POA	Recycling Agent
○	16	42	30 G	4.13	None
⊘	16	42	30 G	4.13	AES-300-R
●	16	42	30 G	4.13	Coastal Res.
△	16	42	30 S	4.13	None
▽	16	42	30 S	4.13	AES-300-R
▼	16	42	30 S	4.13	Coastal Res.
◇	13	37	0	5.65	None
⬘	13	37	15	4.78	None
◆	13	37	15	4.78	AC-3
⬡	16	42	40	3.59	AC-10+1% Lime
▨	16	42	40	3.59	AC-10

Fig 14. Resilient modulus vs. recycling agent for nonbrittle mixtures.

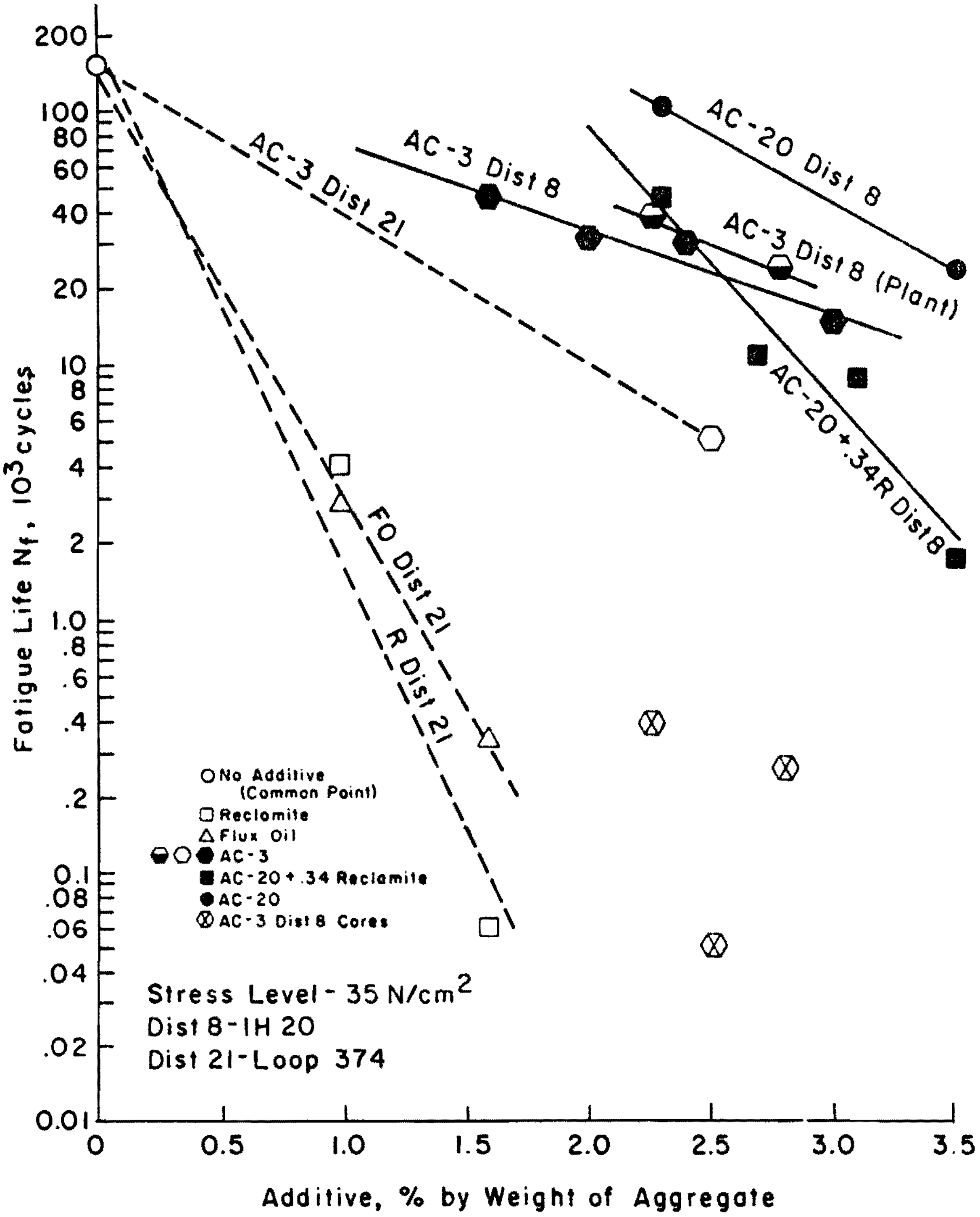


Fig 15. Effects of the amount of additive on fatigue life of laboratory and field mixtures (Ref 9).

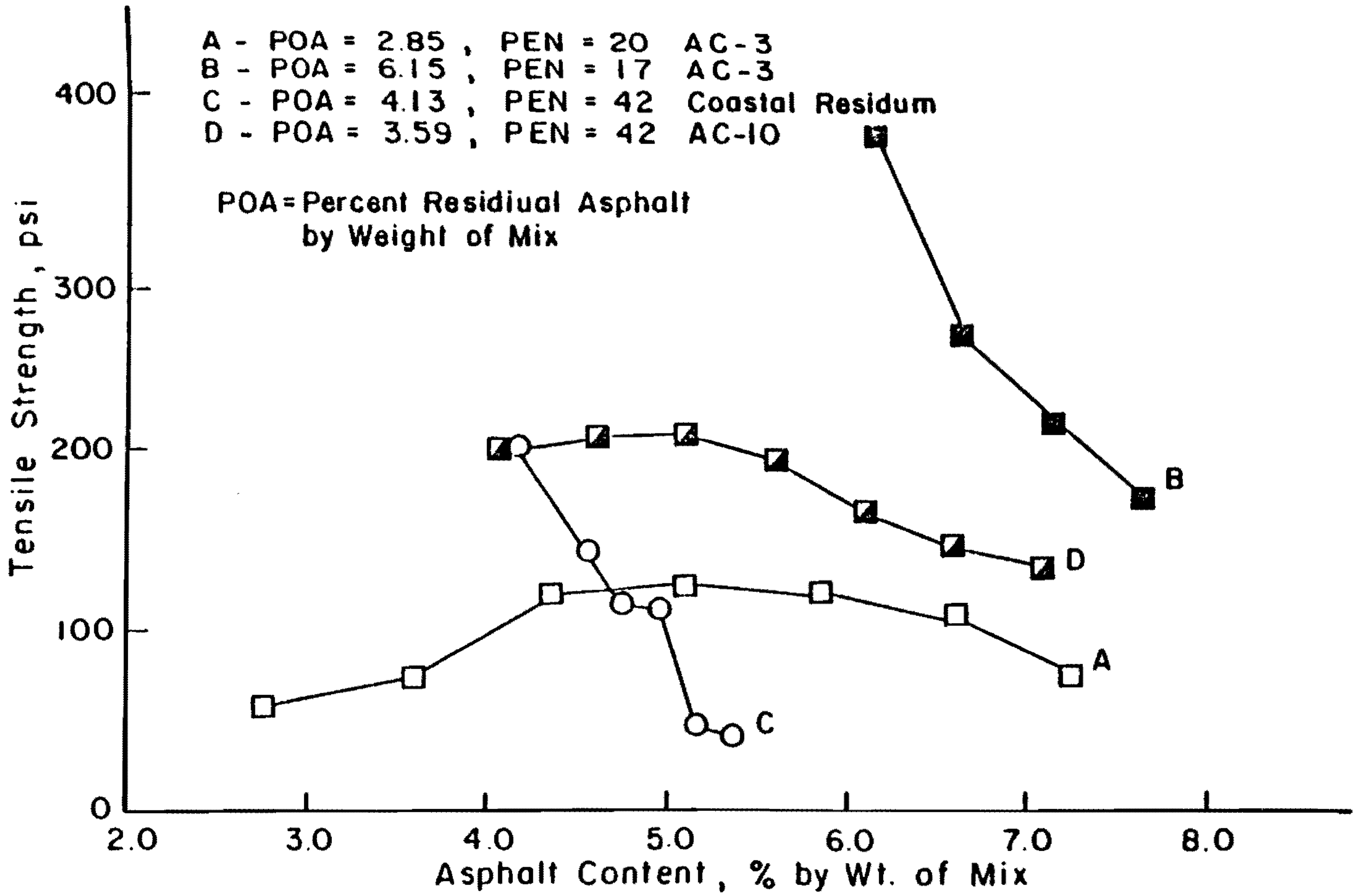


Fig 16. Influence of the amount of residual asphalt on the shape of strength-asphalt content relations.

The strength and modulus of mixtures containing more residual asphalt, e.g., more than 6 percent, tended to decrease rapidly with the addition of recycling agents (relation B, Fig. 16).

The strength of mixtures containing an intermediate level of residual asphalt either increased or decreased as the amount of recycling agent was increased, depending on the hardness of the residual asphalt and the viscosity of the recycling agent. High viscosity recycling agents produced an effect similar to group I above (relations C and D, Fig 16).

The findings of this study are in agreement with what has been reported by Kennedy et al. (Refs 9 and 21) in the sense that brittle mixtures are more sensitive to additives than nonbrittle mixtures and that the resilient modulus is more sensitive to additives than either tensile strength or static modulus. However, as can be seen in Figure 17, brittle mixtures are less sensitive to recycling agent type than nonbrittle mixtures. For example, the difference between the slopes of relations A and B of Figure 17 (Pen = 9,11) is negligible despite the fact that A represents high viscosity recycling agent ($\eta_R \cong 343$ stokes) and B represents low viscosity recycling agent ($\eta_R \cong 8$ stokes). On the other hand, the difference between the slopes of relations C ($\eta_R \cong 823$ stokes) and D ($\eta_R \cong 8$ stokes) is substantial, even though relations C and D describe the response of one nonbrittle mixture ($Pen_0 = 42$ dmm).

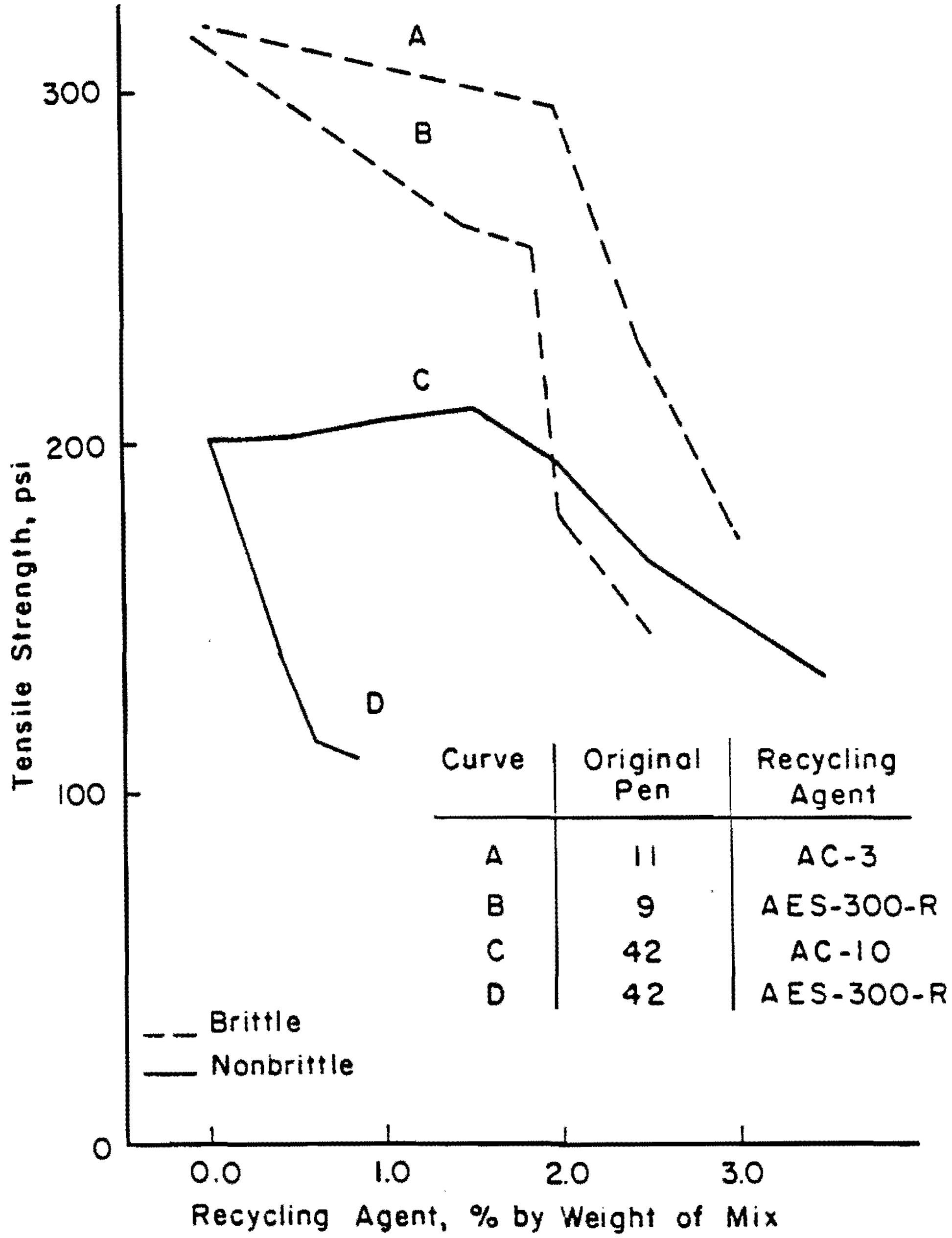
Antistripping Agents

Both dry hydrated lime, which served as a mineral filler, and M200 reduced the dry tensile strength and static modulus of the recycled mixtures tested. The resilient modulus was not affected by the use of the M200 antistripping agent. Figure 18 depicts the effects of using 1.0 percent hydrated lime instead of 1.0 percent limestone dust passing number 200 mesh. As can be seen from the figure, both tensile strength and static modulus were reduced by the use of lime.

The above observation agrees with the finding, reported in References 23 and 24, that lime reduced the dry tensile strength and resilient modulus of conventional materials containing certain types of aggregate.

New Aggregate

The immediate impact of introducing new untreated aggregates into recycled mixtures is the reduction of the residual asphalt which influences



Curve	Original Pen	Recycling Agent
A	11	AC-3
B	9	AES-300-R
C	42	AC-10
D	42	AES-300-R

Fig 17. Effects of recycling agent type on the strength of brittle and nonbrittle mixtures.

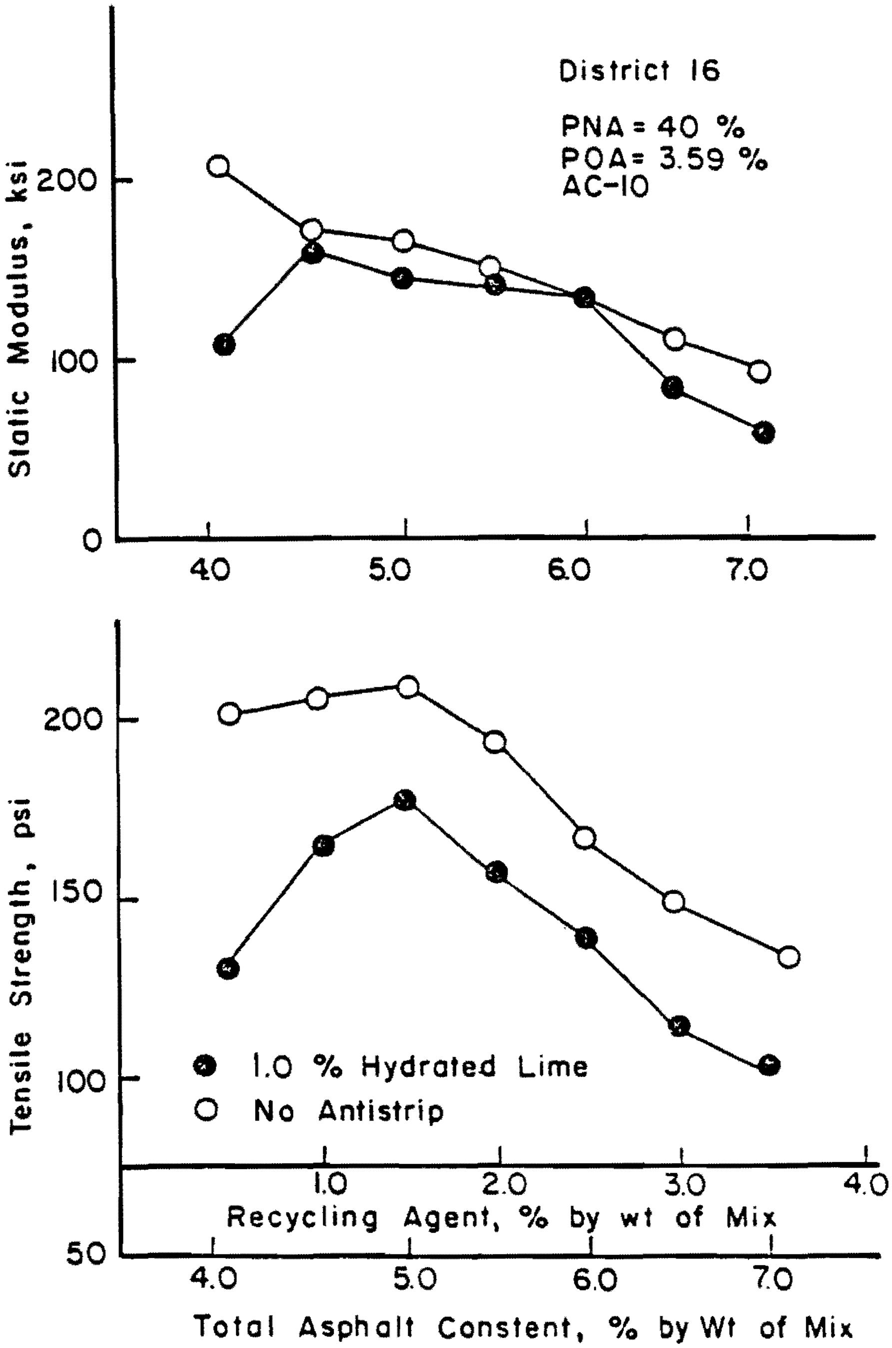


Fig 18. Effect of hydrated lime on indirect tensile properties.

the type and amount of recycling agent to be used. Other effects include (1) changes in aggregate gradation, (2) changes in voids in mineral aggregates (VMA), (3) changes in asphalt demand of the aggregate, and (4) changes in angularity.

Although a comprehensive evaluation could not be conducted, an example of the type of additional aggregate is shown in Figure 19. The use of rounded gravel instead of crushed sandstone reduced the tensile strength, static modulus, and resilient modulus. The resilient modulus was less sensitive to aggregate type than strength and static modulus.

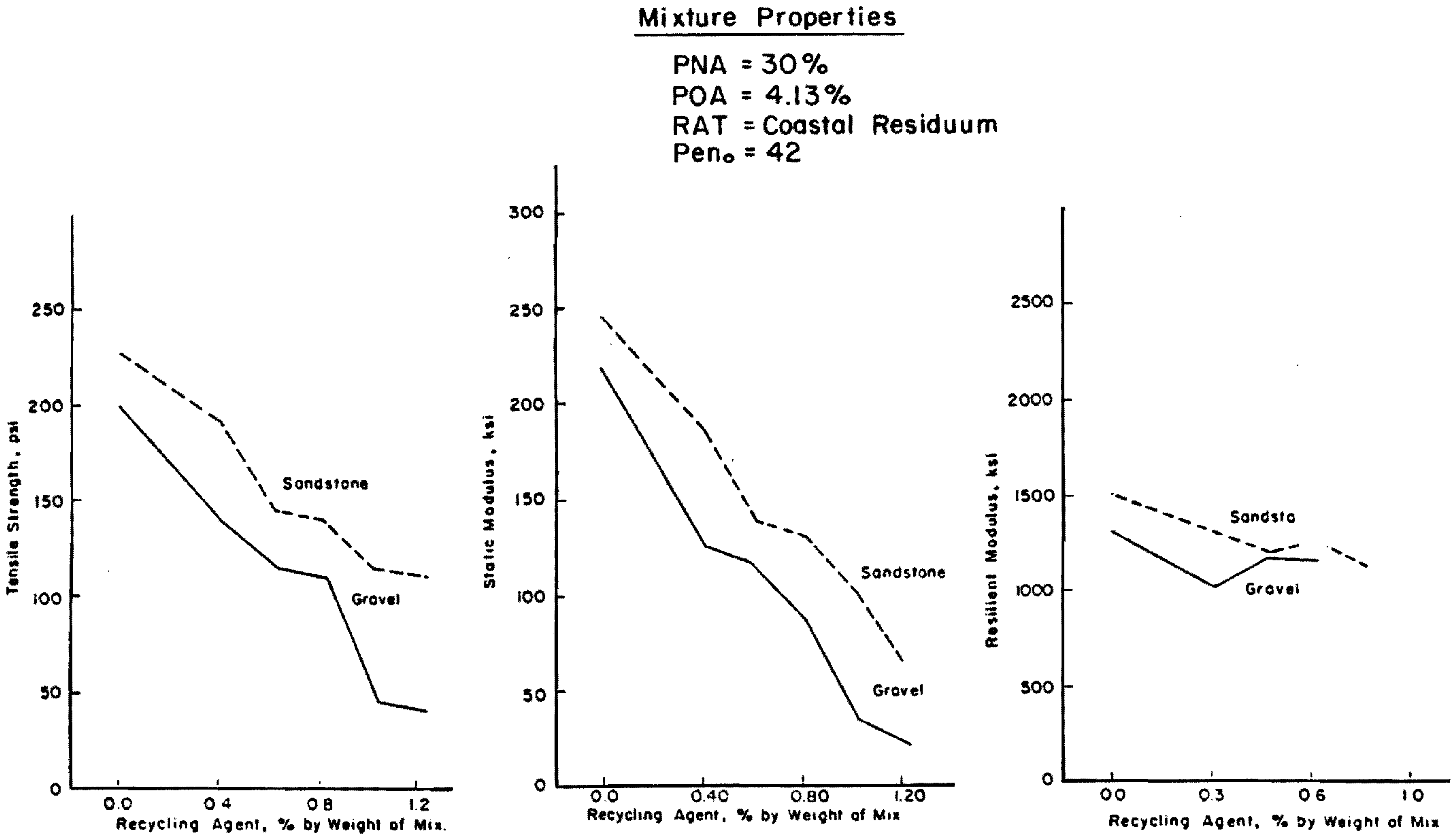


Fig 19. Effect of type of new aggregate.

CHAPTER 4. IMPORTANT CONSIDERATIONS FOR ASPHALT RECYCLING

While the information contained in this report does not necessarily relate to the following design and recycling considerations, it is felt that the overall experience obtained from the project and the experience of others (Ref 27) should be summarized for use by the Texas State Department of Highways and Public Transportation.

CAUSE OF DISTRESS

It is essential that the cause of the distress which led to the need for recycling be identified and corrected. The three most common basic causes in Texas are

1. aging (brittleness) of the asphalt cement,
2. stripping of the asphalt from the aggregate, and
3. structural inadequacy.

Texas experience would suggest that one or more of these causes are involved in most failures leading to recycling. Thus, a detailed condition survey should be conducted to determine the severity and extent of the distress present on the job for which recycling is being considered.

The condition survey should be separate for each section of road that is determined to be different, based on surface thickness or mixture design, evidence of heavy maintenance discontinuously along the section, seal or friction coat difference, etc. For each section identified, the types of distress and the severity should be evaluated to determine the primary cause of the distress.

It is most important to identify whether these failures are associated with the characteristics of the mixture to be recycled or with the pavement structure.

Mixture Problems

Brittle failures occur when axle loads and thermally or shrinkage induced stresses, combined with aged brittle asphalt cements, produce cracking. Typically, when such an asphalt mixture is to be recycled, softening agents or soft asphalts must be added to restore the salvaged asphalt cement to its original viscosity.

Nonbrittle failures are often caused by stripping or softening due to the effects of moisture. The typical distresses caused by stripping are rutting, shoving, corrugations, and localized bleeding. In addition, because of the loss of adhesion in the underlying asphalt mixture, structural problems may also develop.

In the case of the stripping mixture, an appropriate treatment must be applied to the salvaged mixture to alleviate the stripping problem or the mixture must be discarded or used for other purposes. If the stripping problem can be alleviated, the salvaged mixture should be adequate for use in the recycled mixture. In addition, if the amount of salvaged material is limited to a relatively small proportion, the adverse effects of the stripping material may be minimized. Nevertheless, a detailed and comprehensive laboratory evaluation is needed to determine the adequacy of the recycled mixture.

Structural Problems

Structural deterioration may occur as the result of underdesign, increased traffic volumes and axle loads, decreased support values due to the action of water, and brittleness of asphalt due to aging, all of which can produce increased stresses and strains. If these increased stresses and strains exceed limiting values, fatigue or longitudinal cracking in the surface layer or permanent deformations can occur.

An evaluation of the strength conditions of the existing pavement structure should be conducted using nondestructive testing methods. If the existing structure is inadequate an improved pavement cross section should be provided which is capable of carrying the anticipated traffic volumes and loads.

SOFTENING AGENTS

Softening agents may involve commercially available additives or soft asphalts. To date, Texas has used only a limited number of commercially available additives on a few projects. While blending of the old reclaimed asphalt and the proposed softening agent can be accomplished in the laboratory during design and evaluation, there is a great deal of concern related to whether these agents, commercial additives or soft asphalt, blend satisfactorily during construction.

Thus additional evaluation related to the effectiveness of softening agents is warranted. A practical approach to answering this question is to sample recycled mixtures at the plant and prepare specimens for testing to determine whether the properties of the mixture are similar to those obtained using virgin asphalt and similar aggregates. The static indirect tensile test as well as the Hveem stability test and the unconfined compression test should be utilized.

PROPORTION OF SALVAGED MATERIAL

The amount of salvaged material used in a recycled mixture should be limited to less than 50 percent and generally the amount of salvaged material should be less than 30 percent. This recommendation is based on the following:

(a) Limiting the amount of salvaged material will significantly reduce problems related to air pollution.
(b) The effects of variability in the salvaged material are minimized by the addition of new material.
(c) Failure to correct the cause of distress associated with the salvaged material does not have a significant effect on the properties, behavior and performance of the recycled mixture.
(d) Gradation deficiencies in the salvaged material can be more readily corrected by the addition of new aggregates.
(e) The effects of inadequate dispersion or blending of softening agents with the salvaged asphalt are minimized.

CONTRACTOR OWNERSHIP OF SALVAGED MATERIAL

The contractor should be allowed to own the salvaged material and to use it on the same project or other projects at his discretion. This eliminates the need to use high percentages of salvaged material or the need to stockpile this material until a use can be found by the State. In addition, all or a portion of the salvaged material may be more effectively and optimally used on other projects. Nevertheless, the salvaged material represents a valuable resource and by allowing contractors to use this material to satisfy their needs and the circumstances, lower bids will be achieved.

AGGREGATE GRADATION

The combined gradation of the salvaged and new aggregates should conform to the specifications for conventional mixtures. The common practice of cold milling the old roadway, which produces the salvaged material, can result in an excessive amount of fines. Thus, samples produced or simulated by cold milling should be used in mixture design and combined aggregate gradation analysis.

VARIABILITY

Salvaged material must be stockpiled or blended to produce a uniform material since salvaged material exhibits a great deal of variability which is evident in the variation obtained in the engineering properties. The control of this variability is complicated if the contractor is allowed to own the salvaged material and use it on other projects. Nevertheless, appropriate consideration should be given to variability and its control. Possibly, the responsibility for the quality of the constructed recycled mixture should be left to the contractor with an end result specification that penalizes for poor quality and high variability.

MOISTURE DAMAGE

If the salvaged material contains stripping aggregates, these aggregates must be treated to alleviate the tendency to strip and/or the recycled mixture should be protected from the penetration of water.

Special care should be taken to obtain adequate compaction which will prevent moisture penetration. As a general guideline, most of the mixture should have less than 7 percent air voids. In addition, care must be taken not to trap water on the surface. An open graded friction course can cause problems if the water cannot be drained quickly. In cold milled sections, in which only one lane or a portion of the roadway surface is removed and replaced with a recycled mixture, water can be trapped in the resulting cold milled trench.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the findings of a study to evaluate the fatigue and elastic properties of recycled asphalt mixtures. The conclusions and recommendations are summarized below.

GENERAL

1. The engineering properties of the recycled asphalt mixtures evaluated were equal to or slightly better than those of previously evaluated conventional mixtures.
2. Based on the findings of this study and previously reported findings from this study and others, it is concluded that satisfactory mixtures can be obtained with recycled mixtures.
3. An amount of recycling agent, softening agent, or soft asphalt should be added which is sufficient to soften the reclaimed asphalt to a level equal to that of a normally used virgin asphalt. The effectiveness of softening agents for actual field use is still questionable.
4. A mixture design procedure has been suggested and is contained in References 25 and 26.

RECYCLED ASPHALT MIXTURE PROPERTIES

5. The tensile strength of recycled mixtures at design conditions is slightly higher than what has been reported for conventional mixtures at or near optimum asphalt content. Tensile strengths of the designed mixture ranged from 123 to 260 psi.
6. The static modulus and static Poisson's ratios, and the strain at failure at design conditions, are within the range reported for conventional mixtures at or near optimum asphalt content. For designed mixtures, the static moduli ranged from 82 to 212 ksi and the static Poisson's ratio ranged from 0.10 to 0.56 and averaged 0.31.

7. The resilient modulus values of recycled mixtures are higher than what has been reported for conventional mixtures in previous studies but are in agreement with the values reported in the literature for laboratory and inservice cores of conventional surface and base courses. Resilient moduli and resilient Poisson's ratios ranged from 580 to 1,250 ksi and from 0.01 to 0.24, respectively. The average values were 880 ksi and 0.15.

8. The controlled stress fatigue life of recycled mixtures is longer than that of conventional mixtures at comparable stress levels; however, recycled mixtures seem to have steeper fatigue curves. The fatigue constants, n and k, ranged from 2.15 to 8.07 and from 1.26×10^{10} to 1.30×10^{31}, respectively.

9. The response of indirect tensile properties to changes in the amount of recycling agent depended on the residual asphalt content of the recycled mixtures and the viscosity of the residual asphalt.

RECOMMENDATIONS

1. Recycling should be considered as a viable alternative for reconstruction and rehabilitation of asphalt pavements.

2. The decision to recycle should be based on the cost effectiveness compared to other conventional options.

3. The contractor should be allowed to own the salvaged material and to use the material to his best advantage.

4. Specifications and required properties of the recycled mixture should be equal to those of conventional mixtures.

5. Additional research is required relative to the following:
    a. Determine the viscosity and aging characteristics of the asphalt in the mixture after plant mixing and with time after construction.
    b. Determine the effectiveness of softening agents and new asphalt and the compatibility of these asphalt components.

REFERENCES

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APPENDIX A

Properties of Raw Materials (After DHT)

DISTRICT 4 AMARILLO

IH-40

Gradation of Raw Materials

Sieve Size	Percent Retained (Cum.)			
	Salvaged Sand and Gravel A	Salvaged Caliche B	Salvaged HMAC C	Slaked 80% A Plus 20% B
1-3/4	0	0	0	0
1-1/4	2	3	3	3
7/8	12	13	23	14
5/8	18	26	42	23
3/8	30	40	63	32
4	43	54	79	44
10	57	66	88	54

Average Specific Gravity (50% C + 40% A + 10% B) = 2.602

Extraction Results of HMAC

Gradation

Sieve Size	Cumulative Percent Retained
1-3/4	0
7/8	0
5/8	1.5
1/2	5.2
3/8	14.3
4	36.4
10	50.7
40	67.0
80	77.6
200	85.0

Residual Asphalt Properties

Asphalt Content = 5.70%

Penetration @ 77°F = 20

Viscosity @ 140°F = 42539 Poises

Dustility @ 77°F = 4.5 cm

Properties of Recycling Agent-Residual Asphalt Blends

	Recycling Agent Type							
	Shamrock AC-3			Shamrock AC-3+RBO		Cosden AC-3		ORC AC-3
% RA by Wt. of Res. Ac	100	130	150	130[a]	105[b]	130	140	136
Vis. @ 140°F Poises	3491	2033	1651	1998	947	1637	1404	2315
Pen. @ 77°F dmm	-	-	87	76	145	78	-	75
Thin Film Oven Test Residue:								
Vis. @ 140°F Poises	-	-	3076	7695	2339	3266	-	6301
Pen. @ 77°F Poises	-	-	66	44	91	44	-	50
Duct. @ 77°F cm	-	-	22	24	141	141[c]	-	53

[a] 113% AC-3 + 17% RBO

[b] 70% AC-3 + 35% RBO

[c] Limit of Test Equipment without Failure Occurring.

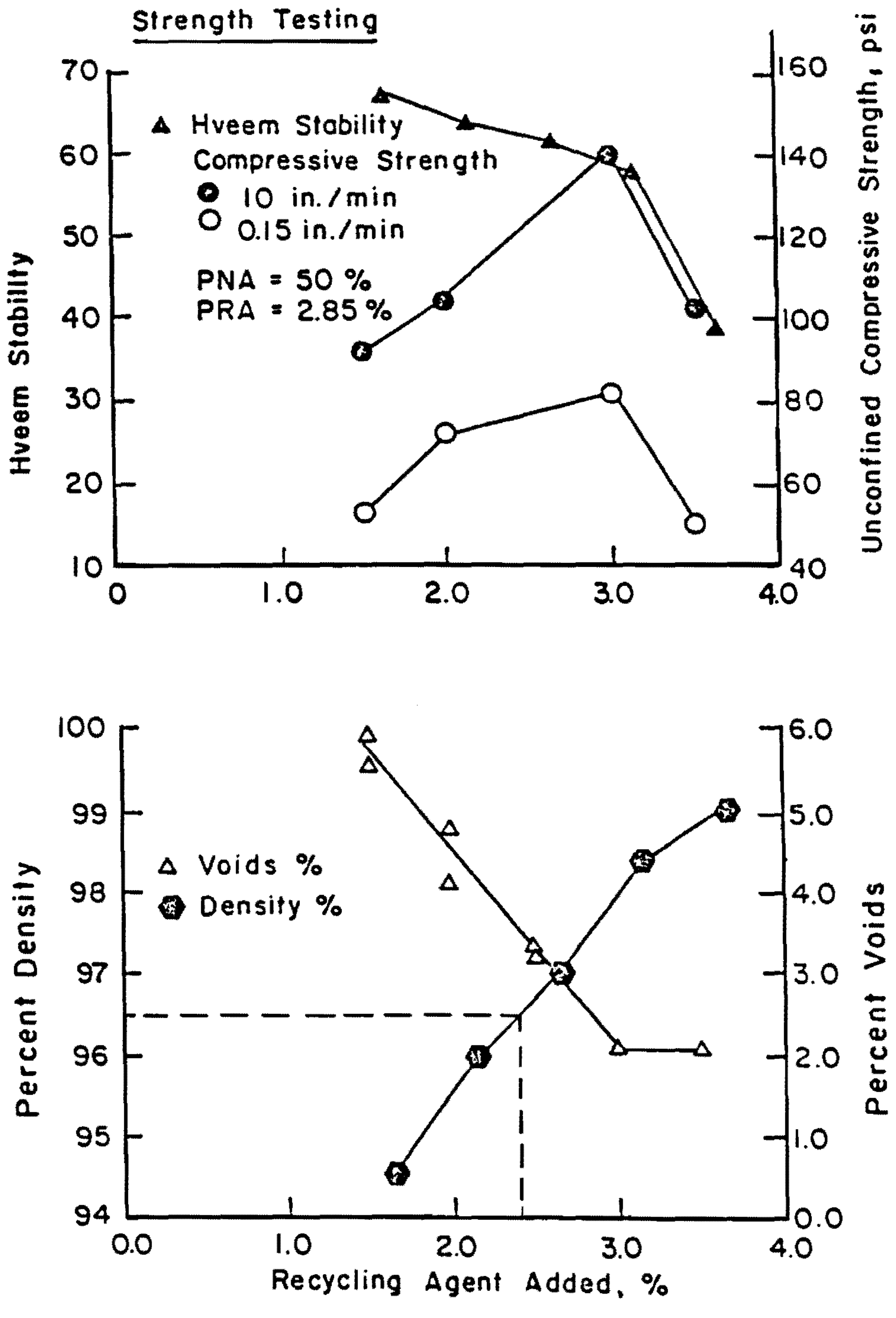

Fig A.1. Mixture Properties vs. Recycling Agent for District 4 Recycling Project.

DISTRICT 12 HOUSTON

F.M. 1640

Gradation of Raw Materials

Cumulative Retained %

Sieve Size	Salvaged Sample No 1	Asphaltic Sample No 2	Pavement Samples No 1 & 2 Combined	Limestone Concrete Sand
3/4	0.0	0.0	0.0	0.0
1/2	7.7	4.3	6.0	0.0
3/8	23.0	16.3	20.0	0.0
4	64.6	60.0	62.2	0.0
10	82.7	80.3	81.5	18.4
40	-	-	-	66.8
80	-	-	-	79.3
200	-	-	-	87.8

Extraction Results

Gradation

Cumulative Retained %

Sieve Size	Sample No. 1	Sample No. 2
1/2	0.0	0.0
3/8	0.6	1.2
4	19.7	19.0
10	42.1	39.9
40	58.6	57.3
80	76.4	75.8
200	84.6	83.4
Pass No. 200	8.8	9.3
Residual Asphalt	6.6	6.9

Residual Asphalt Properties

	Sample 1	Sample 2
Penetration @ 77°F	23	28
Viscosity @ 140°F	27348 St	21537 St
Ductility @ 77°F, cm	9.5	13.5

Tests on Recycled Mixture

Molded Specimens

New Aggregate = 15% by weight of mix.

AC-3 = 0.6% by weight of mix.

RBO = 0.8% by weight of mix.

Hveem Stability = 31

Cohesiometer Value = 271

Indirect Tensile Strength = 80 psi

Resilient Modulus = 445 ksi

Recovered Asphalt

Penetration @ 77°F = 74

Viscosity @ 140°F, St = 2069

Ductility @ 77°F, cm = 141

Specific Gravity @ 77°F = 1.049

DISTRICT 13 YOAKUM

U.S. 90A

Properties of Raw Materials

Gradation

Sieve Size	Cumulative Retained % Salvaged HMAC	Cumulative Retained % Washed Screenings Tx Crushed Stone Co.
1-1/4	0.0	0.0
1	4.5	0.0
7/8	8.6	0.0
5/8	19.8	0.0
3/8	36.2	0.0
4	69.7	0.2
10	87.5	16.3
40	-	57.3
80	-	70.9
200	-	82.6

Test Results on Model Specimens

Material Passing 7/8 in. Sieve, Heated then Recompacted without additives:

Hveem Stability = 42
Cohesiometer Value = 173
Indirect Tensile Strength = 147 psi
Resilient Modulus = 1,755 ksi

Properties of RA-Asphalt Blends

The blend is extracted from Hveem specimens recycled with 15% new aggregate, 1.0% AC-3 and 0.06% Redicote 82S. The new AC-3 is about 17% by weight of blend.

Penetration @ 77°F = 50 (dmm)
Ductility @ 77°F = 141 (cm)
Viscosity @ 140°F = 3442 (Poises)

Extraction Results

Gradation

Sieve Size	Cumulative Retained % Sample A	Sample B
1-1/4	0.0	0.0
1	1.3	1.4
7/8	3.5	2.6
5/8	6.1	6.5
3/8	12.7	10.7
4	36.9	35.7
10	55.8	54.6
40	70.3	69.6
80	78.9	78.1
200	85.7	84.8
Pass No. 200	8.8	9.4
Residual Bitumin	5.5	5.8

Residual Asphalt

	Sample A	Sample B
Penetration @ 77°F =	37	37 (dmm)
Ductility @ 77°F =	141	141 (cm)
Viscosity @ 77°F =	5592	5549 (Poises)

Tests on Recycled Mixtures

Proportions

Salvaged HMAC = 85%
Screenings = 15%
Exxon AC-3 = 1.0% by Weight
Redicote 82S = 0.06% by Weight

Strength Properties

Hveem Stability = 39
Cohesimeter Value = 270
Indirect Tensile Strength = 123 psi
REsilient Modulus = 899 ksi

DISTRICT 16 CORPUS CHRISTI

U.S. 77

Gradation of New Aggregates

Sieve Size	Cumulative Retained % Gravel	Sandstone
1-3/4	0.0	0.0
1-1/4	4.6	15.2
7/8	21.9	48.1
5/8	48.2	66.0
3/8	89.9	86.4
4	99.9	100.0

Extraction of Salvaged Mixture

Gradation

Sieve Size	Cumulative Retained % Sample A	Sample B
5/8	0.0	0.0
1/2	5.8	3.6
3/8	15.0	13.1
4	44.7	41.1
10	61.5	58.8
40	65.0	62.6
80	72.2	70.2
200	89.1	88.0
Passing No. 200	5.4	5.7
Residual Bitumen	5.5	6.3

Properties of Recovered Asphalt

Penetration @ 77°F = 42 (dmm)
Ductility @ 77°F = 141+ (cm)
Viscosity @ 140°F = 3623 (Poises)

Properties of RA-Residual Asphalt Blends

	Recycling Agent Type		
	RBO	Coastal Residuum	Exxon AC-3
Properties of RA:			
Viscosity @ 140°F, Stokes	1.11	30.36	331
Flash Point C.O.C., °F	425	590	600
Specific Gravity @ 77°F	-	0.975	1.011
Penetration @ 77°F	-	-	272
Amount of RA added, % by Wt. of Residual Asphalt	11	30	85
Properties of Blend			
Viscosity @ 140°F, Stokes	1012	1093	1121
Penetration @ 77°F	116	123	99
Properties of TFOT Residue			
Viscosity @ 140°F, Stokes	1742	1496	1982
Penetration @ 77°F	75	82	70
Ductility @ 77°F	141+	141+	141+

Properties of Recycled Mixtures

30% Sandstone + Coastal Residuum

AVR Optimum = 20.2% Coastal Residuum by Wt. of Residual Asphalt.

Total Voids = 8.8%

Compressive Strength
Slow = 92 psi
Fast = 176 psi

Properties of Recycled Mixtures (cont.)

30% Sandstone + AES-300-R

AVR Optimum = 15% AES-300-R by Wt. of Residual Asphalt

Total Voids = 9.2%

Compressive Strength

Slow = 66 psi

Fast = 152 psi

30% Gravel + Coastal Residuum

AVR Optimum = 15% Coastal Residuum by Wt. of Old Asphalt

Total Voids = 3.7%

Compressive Strength

Slow = 96 psi

Fast = 158 psi

30% Gravel + AES-300-R

AVR Optimum = 10% AES-300-R

Total Voids = 2.5%

Compressive Strength

Slow = 70 psi

Fast = 158 psi

DISTRICT 18 DALLAS

IH-20 and US 75

Gradation of Salvaged Materials

Sieve Size	Cumulative Retained % IH-20 Roto Milled Light Weight Aggreg.	Cumulative Retained % US-75 Roto Milled Some Concrete Chips
1-1/2	0.0	0.0
1-1/4	0.9	4.5
7/8	6.4	10.4
5/8	14.2	15.8
3/8	28.4	26.1
4	61.7	55.6
10	82.9	74.4
Passing No. 10	17.1	25.6

Extraction Results

Gradation

Sieve Size	Cumulative Retained % IH-20 A	IH-20 B	US 75 A	US 75 B
1	0	0.0	0.0	0.0
3/4	0.0	0.0	0.0	1.1
5/8	0.0	0.0	1.1	1.9
1/2	0.0	0.0	3.1	3.5
3/8	0.2	0.1	6.3	6.1
4	16.9	16.6	27.2	27.7
10	43.2	43.1	51.7	51.4
40	56.6	56.5	64.4	64.6
80	71.6	72.2	79.5	79.2
200	88.2	88.2	90.5	90.4
Passing No. 200	5.7	5.8	4.9	5.4
Residual Bitumen	6.3	6.0	4.6	4.2

Properties of RA-Residual Asphalt Blends

IH - 20 Material + 18.5 % by Wt. of Old Asphalt RBO

Penetration @ 77°F = 81 (dmm)
Viscosity @ 140°F = 1775 (Poises)

TFOT Residue:
Penetration @ 77°F = 48 (dmm)
Ductility @ 77°F = 141+ (cm)
Viscosity @ 150°F = 4465 (Poises)

US - 75 Material + 26% by Wt. of Old Asphalt RBO

Penetration @ 77°F = 76 (dmm)
Ductility @ 77°F = 141+ (cm)
Viscosity @ 140°F = 2461 (Poises)

TFOT Residue:
Penetration @ 77°F = 54 (dmm)
Ductility @ 77°F = 141+ (cm)
Viscosity @ 150°F = 4770 (Poises)

Properties of Recycled Mixtures

IH - 20 Materials

Density (pcf)	% Voids	Test Speed in/Min	% Moist. at Test	AC-3 Added %	Unconfined Compressive Strength (psi)
133.9	12.3	0.15	0.65	0.0	214
134.4	11.9	0.15	0.50	0.0	127
134.5	11.8	10.0	0.51	0.0	345
133.5	12.2	0.15	0.24	1.0	101
134.9	11.5	0.15	0.26	0.5	78
135.2	11.1	10.0	0.16	1.0	218
134.9	11.4	10.0	0.31	0.5	278

US - 75 Materials

Density (pcf)	% Voids	Test Speed in/Min	% Moist. at Test	AC-3 Added %	Unconfined Compressive Strength (psi)
130.4	14.7	10.0	4.72	0.0	162
130.0	15.0	0.15	4.60	0.0	81
131.2	13.9	0.15	3.29	1.0	111
133.3	12.4	0.15	0.92	2.0	144
131.7	13.1	0.15	0.31	3.0	79
130.1	14.3	0.15	0.82	2.5	124
130.3	14.2	10.0	0.83	2.5	271
131.1	13.5	10.0	0.45	3.0	228
132.0	13.2	10.0	1.75	2.0	382
129.5	15.0	10.0	3.66	1.0	318

Test Temperature = 140 - 143 °F

Other Strength Properties of Recycled Mixtures

IH - 20 Materials

Density (pcf)	AC-3 Added %	Hveem Stability %	Cohesiometer value	Indirect Tensile Strength (psi)	Tension Resilient Modulus (ksi)
132	0.0	55	550	222	1,884
132.3	0.5	44	493	214	2,418
131.8	1.0	35	444	203	1,462
133.2	1.5	24	382	174	626
132.8	2.0	*	304	151	625
US - 75 Materials					
132.1	2.5	52	470	146	925
129.7	3.0	45	436	140	781
125.8	3.5	37	375	131	668
128.4	4.0	36	428	116	475

* Stability too low to calculate

DISTRICT 20 BEAUMONT

IH - 10

Gradation of Raw Materials

Sieve Size	Cumulative Retained % Salvage Asphaltic Pavement Material	Limestone
1	0.0	0.0
3/4	5.6	-
1.2	14.3	1.6
3.8	23.7	17.1
4	57.0	88.2
10	81.1	97.6
49	-	98.4
80	-	98.6
200	-	98.8
Passing No. 200	-	1.2

Extraction Results

	Cumulative Retained %				
Sieve Size	Sample No 1	Sample No 2	Sample No 3	Sample No 4	Sample No 5
1/2	0.0	0.0	0.0	0.0	0.0
3/8	2.5	1.8	1.7	1.6	1.5
4	32.0	30.0	30.1	27.9	27.5
10	59.3	58.9	58.1	57.0	55.4
40	70.0	70.0	72.1	70.3	70.8
80	81.8	81.6	83.5	84.1	82.6
200	91.1	90.5	90.7	91.1	90.9
Pass 200	4.4	4.7	4.6	4.1	4.5
Residual Bitumen	4.5	4.6	4.7	4.8	4.6
Penetration @ 77°F	9	6	14	8	8

Properties of RA- Residual Asphalt Blend[a]

Penetration ° 77°F = 45 dmm
Ductility @ 77°F = 141 (cm)
Viscosity @ 140°F = 4632 Stokes
Specific Gravity @ 77°F = 1.035
Viscosity @ 275°F = 5.2 Stokes

TFOT Residue:

Penetration @ 77°F = 34 dmm
Ductility @ 77°F = 141 cm
Viscosity @ 140°F = 10250 Stokes
Viscosity @ 275°F = 7.0 Stokes

Tests on Molded Specimens

Hveem Stability = 34
Cohesiometer Value = 297
Indirect Tensile Strength = 142 psi
Resilient Modulus = 920 ksi
Actual Specific Gravity = 2.393
Maximum Specific Gravity - ASTM D-2041:

	Sp. Gr.	Percent Density
Dry	2.482	(2.393/2.482)x100+96.4
SSD	2.476	(2.393/2.476)x100+96.6

Properties of Asphalt Extracted from Hveem Specimens

Penetration @ 77°F = 24 dmm
Ductility @ 77°F = 50 cm
Viscosity @ 140°F = 10695 Stokes
Specific Gravity @ 77°F = 1.045

---

[a] The blend consists of 0.75% RBO, 0.50% AC-3, 0.05% Redicote 82S, and 4.64% by Wt. of Total Mix Residual Asphalt.

APPENDIX B

Tests Results of Individual Specimens

District 4 (Amarillo) Recycling Project, 50% HMAC, 40% Salvaged Gravel, 10% Salvaged Caliche, and Varying Amounts of AC-3.

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
0.0	68	118	0.57	432	0.18	2.220	2x4
	53	88	0.52	403	0.22	2.170	
	53	97	0.35	515	0.04	2.210	
0.75	53	58	0.23	417	0.07	2.220	
	113	101	0.27	681	0.10	2.250	
	57	105	0.68	477	0.01	2.200	
1.50	113	163	0.38	550	0.10	2.270	
	142	160	0.35	720	0.08	2.280	
	104	125	0.35	691	0.11	2.264	
2.25	107	110	1.40	945	0.04	2.332	
	147	160	0.51	1011	0.13	2.340	
	115	140	0.34	969	0.002	2.342	
3.00	112	129	0.52	959	0.13	2.349	
	130	105	0.62	861	0.11	2.334	
	125	133	0.53	1039	0.15	2.352	
3.75	108	76	0.52	852	0.21	2.344	
	111	78	0.45	826	0.19	2.346	
	111	79	0.52	848	0.27	2.349	
4.50	74	56	0.52	713	0.38	2.340	
	75	51	0.47	733	0.23	2.345	
	80	58	0.57	758	0.46	2.334	
3.5	92	57	0.06	859	0.10	2.363	6x8
	85	73	0.25	810	0.29	2.351	
3.00	179	106	0.15	932	0.09	2.389	
	115	106	0.10	917	0.08	2.394	
2.50	161	169	0.77	1210	0.22	2.390	
	155	187	0.31	1444	0.32	2.388	

S_T = Tensile Strength, E_S = Static Modulus, υ_S = Static Poisson's Ratio, E_R = Resilient Modulus, υ_R = Resilient Poisson's Ratio

District 12 (Houston) Recycling Project,

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
15% New Aggregate + Varying Amounts of AC-3							
0.0	205	162		569	0.17	2.194	2x4
	195	154		562	0.12	2.194	
	203	173		545	0.18	2.193	
0.70	242	124		1104	0.47	2.223	
	230	121		1146	0.37	2.226	
	238	113		977	0.39	2.218	
1.00	205	195		772	0.21	2.236	
	205	179		733	0.21	2.227	
	202	183		744	0.21	2.230	
1.40	166	131		839	0.29	2.232	
	169	153		791	0.18	2.223	
	160	133		720	0.24	2.221	
2.00	143	100		692	0.34	2.225	
	142	108		694	0.29	2.223	
	139	99		669	0.26	2.219	
15% New Aggregate + 0.8% RBO + Varying Amounts of AC-3							
0.40	177	143		569	0.14	2.224	
	167	126		562	0.16	2.218	
	173	136		543	0.19	2.228	
0.60	161	122		551	0.19	2.211	
	158	119		582	0.21	2.221	
	173	126		589	0.14	2.248	
0.80	188	140		553	0.19	2.239	
	174	118		563	0.20	2.236	
	169	118		551	0.07	2.234	
0.80	130	67		880	0.62	2.226	
	142	87		895	0.50	2.222	
	149	73		897	0.47	2.223	
0.80	147	112		684	0.24	2.224	
	143	105		704	0.20	2.226	
	145	96		164	0.26	2.230	

(Continued)

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
15% New Aggregate + 0.8% RBO + AC-3							
1.20	130	71		651	0.59	2.221	2x4
	131	79		628	0.34	2.217	
	129	71		686	0.34	2.225	
1.7	114	50		593	0.35	2.216	
	115	70		575	0.32	2.213	
	115	56		538	0.23	2.223	
0.00[a]	225	233		675	0.11	2.197	
	235	123		687	0.15	2.196	
	218	176		651	0.10	2.189	
0.00	129	92		1076	0.37	2.218	
	128	76		947	0.34	2.220	
	122	74		996	0.28	2.204	

District 13 (Yoakum) Recycling Project

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
15% New Aggregate + 0.60% Redicote 82S							
0.00[a]	239	174	0.29	943	0.16	2.238	2x4
	221	140	0.26	1035	0.23	2.243	
	225	161	0.50	929	0.19	2.243	
0.00	156	132	0.44	595	0.13	2.208	
	166	133	0.31	535	0.24	2.204	
	192	186	0.35	566	0.10	2.202	
0.50	208	201	0.32	814	0.11	2.257	
	221	203	0.57	790	0.09	2.254	
	214	198	0.26	808	0.08	2.267	
1.00	190	156	0.21	785	0.10	2.305	
	189	142	0.21	754	0.11	2.289	
	183	144	0.05	755	0.12	2.276	

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[a] As Received, No Additives of Any Kind.

(Continued)

R.A.%	S_T (psi)	E_S (ksi)	ν_S -	E_R (ksi)	ν_R -	S.G.	Size (in)
0.50	229	212		822	0.06	2.269	2x4
	213	148		847	0.12	2.277	
	226	154		819	0.09	2.286	
1.50	171	152	0.38	624	0.07	2.279	
	168	143	0.37	743	0.10	2.277	
	182	124	0.39	693	0.06	2.276	
0.50	229	122	0.35	1079	0.30	2.277	
	219	125	0.33	1054	0.32	2.263	
	208	114	0.32	1020	0.23	2.265	

District 16 (Corpus Christi) Recycling Project

R.A.%	S_T (psi)	E_S (ksi)	ν_S -	E_R (ksi)	ν_R -	S.G.	Size (in)
Sandstone + Coastal Residuum + M200 (30% New Aggregate).							
0[a]	240	308	0.49	1582	0.09	2.180	6x8
	214	241	0.34	1382	0.003	2.230	
15	162	160	0.32	1247	0.34	2.156	
	130	118	0.39	1141	0.06	2.219	
20	125	110	0.29	1269	0.26	2.171	
	154	161	0.35	1229	0.21	2.208	
25	114	88	0.34	1125	0.14	2.193	
	117	111	0.28	1112	0.14	2.172	
30	106	59	-	-	-	2.133	
	120	74	0.45	-	-	2.223	
10	201	218	0.42	-	-	2.196	
	182	156	0.28	-	-	2.209	
Gravel + Coastal Residuum + M200 (30% New Aggregate)							
0	202	220	0.16	1069	0.05	2.380	
	197	216	0.27	944	0.13	2.396	

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[a] Percent Recycling Agent is on the basis of Residual Asphalt in the total mix.

M200 is an antistripping agent added at a rate of 1.0% by Weight of Residual Asphalt.

(Continued)

Gravel + Coastal Residuum + M200 (30% New Aggregate)

R.A.%	S_T (psi)	E_S (ksi)	ν_S -	E_R (ksi)	ν_R -	S.G.	Size (in)
10	154	137	0.24	1032	0.02	2.374	6x8
	128	115	0.19	1015	0.03	2.353	
15	120	75	0.31	1176	0.24	2.362	
	112	82	0.12	1150	0.07	2.377	
20	114	114	0.51	1113	0.19	2.367	
	109	122	0.53	1193	0.36	2.351	
25	47	39	0.46	-	-	2.353	
	46	31	0.37	-	-	2.343	
30	42	20	0.26			2.344	
	41	22	0.19			2.379	
0	-	-	-	1322	0.01	2.394	
	-	-	-	1316	0.01	2.393	

Sandstone + AES-300-R (30% New Aggregate)

10	165	144	0.39	961	0.11	2.205
	166	161	0.43	1338	0.21	2.178
20	176	208	0.51	1293	0.22	2.187
	187	212	0.36	1120	0.21	2.223
25	157	122	0.36	1102	0.11	2.211
	183	184	0.23	1383	0.12	2.209

Gravel + AES-300-R (30% New Aggregate)

10	134	98	0.26	1202	0.02	2.383
	134	99	0.27	1279	0.12	2.382
15	111	72	0.29	1058	0.01	2.368
	126	92	0.19	1158	0.02	2.375
20	115	82	0.25	1058	0.03	2.366
	106	72	0.14	967	0.04	2.362

(Continued)

40% New Aggregate (Gravel/Limestone Screenings), 1.0% Lime, and Varying Amounts of AC-10.

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
2.00	167	162	0.44			2.302	2x4
	152	140	0.45			2.314	
	152	123	0.23			2.290	
2.5	148	156	0.57			2.312	
	129	108	0.38			2.289	
	141	142	0.45			2.286	
3.00	121	84	0.26			2.286	
	98	56	0.46			2.279	
	119	111	0.55			2.286	
3.50	114	85	0.51			2.286	
	89	48	0.35			2.274	
	102	47	0.20			2.289	
0.50	134	108	0.28			2.256	
	134	110	0.17			2.274	
	124	84	-0.06			2.248	
1.00	199	257	0.24			2.290	
	156	121	0.19			2.230	
	139	108	0.15			2.290	

40% New Aggregate (Gravel/Limestone Screenings), 1.0& Limestone Dust and Varying Amounts of AC-10.

0.50	167	183	0.45			2.299	
	210	230	0.30			2.303	
	225	208	0.37			2.312	
1.0	194	186	0.28			2.298	
	201	167	0.37			2.300	
	222	166	0.39			2.311	
1.50	213	148	0.42			2.316	
	213	153	0.56			2.317	
	200	191	0.50			2.319	
2.00	186	154	0.39			2.314	
	206	139	0.55			2.322	
	190	161	0.59			2.308	

(Continued)

40% New Aggregate (Gravel/Limestone Screenings), 1.0% Limestone Dust, and Varying Amounts of AC-10.

R.A.%	S_T (psi)	E_R (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
2.50	161	129	0.40			2.340	2x4
	178	142	0.56			2.321	
	158	128	0.51			2.325	
3.00	156	135	0.51			2.315	
	147	101	0.21			2.316	
	146	98	0.22			2.345	
3.50	129	82	0.25			2.312	
	133	102	0.28			2.314	
	139	92	0.40			2.308	

District 18 (Dallas) Recycling Project

IH - 20 Materials + AC-3

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
0.00	355	478	0.20	906	0.15	2.182	6x8
	436	386	0.08	761	0.05	2.181	
	364	485	0.17	735	0.08	2.174	
	354	488	0.27	801	0.09		
1.0	220	135	0.08	636	0.06	2.189	
	216	132	0.06	544	0.08	2.132	
	212	124	0.04	630	0.06	2.127	
	212	140	0.06	625	0.05	2.160	
0.50	262	199	0.15	886	0.12	2.156	
	260	193	0.10	717	0.06	2.160	
	263	173	0.13	833	0.05	2.153	
	257	182	0.16	839	0.13	2.162	
1.50	170	160	0.10	637	0.16	2.142	
	176	138	0.04	644	0.23	2.137	
	175	162	0.20	637	0.21	2.127	
	172	153	0.08	702	0.21	2.126	

(Continued)

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
US - 75 Materials (Unspecified Amount of Concrete Chips)							
0.00	328	592	-0.06	751	-0.06	2.074	6x8
	296	390	0.04	757	0.06	2.073	
	331	459	-0.05	708	-0.01	2.022	
2.00	296	459	0.24	600	0.11	2.086	
	297	533	0.30	595	0.06	2.073	
	283	734	0.25	600	0.10	2.103	
	309	490	0.26	-	-	2.146	
2.50	260	455	0.23	587	0.08	2.044	
	251	368	0.16	739	0.20	2.091	
	217	312	0.28	753	0.18	2.079	
	201	252	0.12	674	0.11	2.051	
3.00	175	173	0.15	638	0.11	2.054	
	172	231	0.04	677	0.20	2.076	
	160	184	0.13	572	0.03	2.079	
	184	205	0.17	678	0.22	2.079	

District 20 (Beaumont) Recycling Project

0% New Aggregate + 0.75% RBO + 0.05% Redicote (82S) + Varying Amounts of AC-3.

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
	327	254	0.42	745	0.07	2.307	2x4
	350	351	0.26	656	0.02	2.306	
	265	202	0.12	687	0.04	2.305	
	260	230	0.41	750	0.40	2.383	
	269	233	0.36	744	0.05	2.381	
	244	173	0.32	751	0.10	2.379	
	304	218	0.33	702	0.07	2.374	
	320	234	0.31	768	0.12	2.365	
	310	254	0.30	752	0.13	2.374	
	213	157	0.43	771	0.12	2.356	
	183	130	0.43	817	0.18	2.369	
	179	119	0.48	816	0.16	2.374	

[A] As Received, no additives of any kind.

District 20 Recycling Project (Continued)

13% New Aggregate and Varying Amounts of AES-300-R

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
A- Compacted at 240°F							
1.50	228	153	0.41	856	0.17	2.339	2x4
	258	177	0.48	790	0.14	2.323	
	300	199	0.36	581	0.09	2.330	
1.85	263	209	0.42	718	0.20	2.355	
	259	167	0.44	725	0.17	2.356	
	244	147	0.41	602	0.10	2.351	
2.00	188	169	0.40	1489	0.32	2.359	
	174	161	0.57	1379	0.26	2.338	
	177	145	0.33	1156	0.16	2.346	
2.50	165	97	0.40	890	0.10	2.351	
	145	80	0.42	984	0.09	2.353	
	130	76	0.30	916	0.09	2.355	
B- Compacted at 200°F (Standard Compaction)							
1.85	214	189	0.39	659	0.21	2.331	
	204	141	0.31	691	0.13	2.339	
	211	154	0.32	746	0.29	2.344	
1.50	185	176	0.27	687	0.20	2.328	
	149	155	0.48	627	0.16	2.300	
	170	173	0.42	577	0.19	2.318	
2.00	150	125	0.55	1171	0.28	2.334	
	132	96	0.67	1124	0.42	2.335	
	96	87	0.71	1232	0.16	2.334	
2.50	82	59	0.60	588	0.13	2.339	
	117	73	0.63	542	0.13	2.345	
	71	51	0.59	617	0.17	2.327	

District 20 (Continued)

R.A.%	S_T (psi)	E_S (ksi)	υ_S -	E_R (ksi)	υ_R -	S.G.	Size (in)
C- Compacted at 175°C (Standard Compaction)							
1.50	163	170	0.52	390	0.07	2.286	2x4
	169	99	0.42	393	-	2.316	
	140	135	0.61	355	0.03	2.330	
1.85	155	128	0.62	581	0.28	2.313	
	108	111	0.53	599	0.20	2.322	
	116	77	0.52	495	0.23	2.321	
2.00	74	80	0.64	987	0.25	2.319	
	100	75	0.64	858	0.17	2.319	
	49	46	0.66	963	0.15	2.313	
2.50	53	70	0.70	518	0.12	2.336	
	86	63	0.63	493	0.14	2.336	
	65	49	0.58	483	0.21	2.336	
D- 9 Compaction Cycles at 200°F							
1.85	186	148	0.38				2x4
	150	123	0.37				
	138	103	0.16				
E- 9 Compaction Cycles at 175°C							
1.85	147	71	0.46				
	110	95	0.49				
	84	93	0.53				