TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWATX78-18310		

4. Title and Subtitle	5. Report Date
"Development of a Mixture Design Procedure for Recycled Asphalt Mixtures"	November 1978
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Ignacio Perez, Thomas W. Kennedy, and Adedare S. Adedimila	Research Report 183-10
9. Performing Organization Name and Address	10. Work Unit No.
Center for Highway Research, ECJ 2.5, The University of Texas at Austin, Austin, Texas 78712	11. Contract or Grant No. Research Study 3-9-72-183
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Interim
Texas State Department of Highways and Public Transportation, Transportation Planning Division, P.O. Box 5051 Austin, Texas 78763	14. Sponsoring Agency Code

15. Supplementary Notes

Work done in cooperation with the U. S. Department of Transportation, Federal Highway Administration. Research Study Title: "Tensile Characterization of Highway Pavement Materials".

16. Abstract

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Mixtures with different types and amounts of additives were evaluated in terms of their engineering properties. The primary methods of evaluation were the static and repeated-load indirect tensile tests. Estimates of tensile strength, static elastic characteristics, resilient elastic characteristics, and fatigue characteristics were obtained.

Preliminary findings indicate that recycled asphalt mixtures can be treated through the addition of asphalt and/or reclaiming agents to produce a material which exhibits satisfactory engineering properties as measured by laboratory tests on both laboratory-prepared specimens and field cores. Based on these results, a preliminary mixture design procedure was formulated which will allow engineers to begin to routinely design mixtures involving recycled asphalt mixtures. Future work may lead to modifications of this procedure.

17. Key Words	18. Distribution Statement
recycled asphalt, mixture design, blackbase, asphalt concrete, fatigue life, resilient modulus, repeated load indirect tensile test.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-69)

DEVELOPMENT OF A MIXTURE DESIGN PROCEDURE FOR RECYCLED ASPHALT MIXTURES

by

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Thomas W. Kennedy
Adedare S. Adedimila

Research Report Number 183-10

Tensile Characterization of Highway Pavement Materials

Research Project 3-9-72-183

conducted for

Texas
State Department of Highways and Public Transportation

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

by the

CENTER FOR HIGHWAY RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

November 1978

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This is the tenth in a series of reports dealing with the findings of a research project concerned with tensile and elastic characteristics of highway pavement materials. This report summarizes the results of a preliminary investigation to determine the fatigue and elastic characteristics of recycled asphalt pavement materials. Utilizing the static and repeated-load indirect tensile tests, estimates of tensile strength, static and resilient elastic characteristics, and fatigue characteristics were obtained for recycled asphalt mixtures from current construction projects in Texas. In addition, a preliminary mixture design procedure was formulated for routine design of recycled asphalt mixtures.

This report was completed with the help of many people. Special appreciation is due Messrs. James N. Anagnos and Pat S. Hardeman for their assistance in the testing program, and Messrs. Avery Smith, Gerald Pack, James L. Brown, Charles Hughes and Arthur Hill, of the Texas State Department of Highways and Public Transportation, who provided technical liason and support for the project. Appreciation is also extended to personnel from Districts 8 and 21 who worked closely with the project and to the Center for Highway Research staff who assisted in the preparation of the manuscript. The support of the Federal Highway Administration, Department of Transportation, is gratefully acknowledged.

LIST OF REPORTS

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

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

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

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

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

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

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

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

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

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

ABSTRACT

This report summarizes the findings of a study to evaluate the fatigue and elastic characteristics of recycled asphalt pavement materials and to develop a preliminary mixture design procedure.

Mixtures with different types and amounts of additives were evaluated in terms of their engineering properties. The primary methods of evaluation were the static and repeated-load indirect tensile tests. Estimates of tensile strength, static elastic characteristics, resilient elastic characteristics, and fatigue characteristics were obtained.

Preliminary findings indicate that recycled asphalt mixtures can be treated through the addition of asphalt and/or reclaiming agents to produce a material which exhibits satisfactory engineering properties as measured by laboratory tests on both laboratory-prepared specimens and field cores. Based on these results, a preliminary mixture design procedure was formulated which will allow engineers to begin to routinely design mixtures involving recycled asphalt mixtures. Future work may lead to modifications of this procedure.

KEY WORDS: recycled asphalt, mixture design, blackbase, asphalt concrete, fatigue life, resilient modulus, repeated load indirect tensile test.

SUMMARY

This report summarizes the findings of a study to evaluate the fatigue and elastic characteristics of recycled asphalt pavement materials and to develop a preliminary mixture design procedure.

Mixtures with different types and amounts of additives for three recycling projects in Texas were evaluated. The primary method of evaluation was the indirect tensile test. This basic test was conducted using a single load to failure and repeated loads. Estimates of tensile strength, resilient elastic characteristics, and fatigue characteristics were obtained. Based on these results, the results from other standard tests on the mixture and extracted asphalt, and a review of pertinent literature and past experience, a preliminary mixture design procedure was formulated which will allow engineers to begin to routinely design mixtures involving recycled, deteriorated asphalt cements.

Preliminary findings indicate that recycled asphalt mixtures can be treated through the addition of asphalt and/or reclaiming agents to produce a material which exhibits satisfactory engineering properties as measured by laboratory tests on both laboratory-prepared specimens and in field cores.

A step-by-step procedure which can be used to design recycled mixtures is presented. Future work may lead to modifications of this procedure. However, at present it is felt that the procedure is practical and capable of being used routinely.

IMPLEMENTATION STATEMENT

Based on the findings of this and other studies, the use of recycled asphalt mixtures for blackbases and surface layers is recommended. The engineering properties of the recycled mixtures were found to have slightly higher values than those of previously tested conventional mixtures. A design procedure does not exist at this time; however, with the results obtained in this study, a preliminary mixture design procedure is proposed. This procedure should be utilized for future studies and for the design of recycled asphalt mixtures. Based on these uses the procedure can be modified and improved as needed.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

The ability to characterize pavement materials in terms of fundamental properties is becoming more important, partially because many agencies are beginning to use pavement design procedures based on elastic or viscoelastic theory. In addition, previously developed empirical tests do not provide the information required to evaluate new materials such as recycled pavement mixtures.

Although the properties of the recycled mixtures have been studied, information concerning the more fundamental properties of tensile strengths, elastic properties, resilient elastic properties, and fatigue properties are limited and not readily available. Thus, the Texas State Department of Highways and Public Transportation requested that a preliminary investigation be conducted to evaluate the engineering properties of recycled asphalt mixtures and to determine whether these mixtures are satisfactory.

The primary objectives of this study were to begin the process of evaluating the engineering properties of recycled mixtures from projects currently being constructed in Texas and, based on this evaluation, to develop a preliminary mixture design procedure. This evaluation, basically, involved a comparison of the properties of recycled mixtures with the properties of conventional mixtures. The values of the elastic and fatigue properties reported in this study can be used for the preliminary mixture design procedure or in structural design procedures which involve elastic layer systems and consider fatigue cracking.

Chapter 2 briefly summarizes the findings of previous investigations of recycled mixtures and their properties. The experimental program and test procedures used in this study are described in Chapter 3. The evaluation of the engineering properties is summarized and discussed in Chapter 4. Chapter 5 presents a preliminary mixture design procedure and Chapter 6 contains the conclusions and recommendations.

CHAPTER 2. CURRENT STATUS OF KNOWLEDGE

The use of asphalt rejuvenators in the early stages of pavement distress is well established, and successful experiences with them are recorded in technical literature (Refs 1, 3, 4, 5, and 6).

Discarded asphalt concrete has often been reused. Most often it was used to replace aggregate base, but in some cases it was processed through a mixer and placed as a cold-mix cold-laid asphalt base or surface mix. In addition, during the past few years asphalt concrete and asphalt bases have been recycled through a central plant (Refs 3, 4, 5, 8, 13, 21, 22, 26, 27, and 28). The following is a brief summary of previous recycling experience.

OPERATIONS

The major portion of the published literature describes work performed employing existing equipment and demonstrates that recycling is economically feasible and desirable. Two basically different systems have been reported, an off-grade procedure and an on-grade procedure. The details of two projects, each utilizing a different procedure, are summarized in Refs 7 and 12.

The off-grade procedure involves removal of the pavement with the recycling done in a central plant. The existing pavement is broken apart; a crawler tractor with ripping teeth can be used to break up and loosen the old material before it is loaded and hauled to the central plant. At the central plant the material is crushed and screened to the desired sizes in order to obtain the proper gradation. The heating and drying of the bituminous aggregates has been a primary problem in the recycling operation. In order to eliminate pollution problems and the possibility of burning the bitumen, the flame should not touch the material, a condition which occurs in the RMI heat exchanger (Ref 26).

The on-grade procedure involves crushing and mixing in-place. Again a crawler tractor with ripping teeth can be used to break up the old pavement. Water and a softening agent are sprayed on the material before crushing to reduce dust and to begin mixing the softening agent with the material. The crushing operation is done by a traveling hammermill. When the crushing operation for one windrow is completed, the material is bladed to one side of the road and the next windrow of broken pavement is prepared for crushing. Before mixing, the crushed material is cured to permit the softening agent to soften the aged asphalt. After an entire lane is prepared conventional in-place mixing and processing can be used (Ref 13).

ASPHALT AND MIXTURE CHARACTERISTICS

A literature review indicates that few studies have been conducted to evaluate the recycling process and that there is essentially no available information on the elastic and fatigue characteristics of recycled materials.

One source (Table 1) has compared the properties of a recycled asphalt with those of various virgin asphalts (Ref 7). The recycled asphalt with different percentages of Paxole had properties in the same range as the virgin asphalts; the penetration and viscosity were controlled by the amount of softening agent used in the mixture.

In California (Ref 7) a laboratory investigation was carried out to demonstrate the use of reclaiming agents for converting deteriorated pavements into a pavement equivalent to conventional pavements. Viscosities of six asphalt cements of different durability characteristics and representative of all currently available asphalts in California, one asphalt extracted from an old pavement, and twelve different softening agents are summarized in Tables 2 and 3.

Table 4 and Figs 1 and 2 summarize measurements made from various compositions of softening agents and asphalt extracted from a severely deteriorated pavement. Table 5 shows the Marshall stability and other characteristics of the different mixtures.

One of the major objectives of the pavement engineer is to produce a high quality pavement material with acceptable stability, durability, and strength characteristics. Test results have been presented (Ref 21) which describe acceptable levels of these characteristics to meet that objective.

Standards for Marshall and Hveem stabilities for specified usage are included in various pavement specifications, but standards for resilient modulus, direct tensile strengths, and indirect tensile strengths are not readily available. To obtain an estimate of both the resilient modulus and the fracture strength required for recycled mixtures, these properties for recycled mixtures

TABLE 1. COMPARISON OF PROPERTIES OF RECYCLED ASPHALT WITH VARIOUS VIRGIN ASPHALTS TYPICAL DATA (Ref 7)

	Coastal		L. A. Basin		S. J. Valley	Recycled Asphalt*		
AR Grade	16,000	8000	8000	4000	8000	—	—	—
Percent Paxole**	—	—	—	—	—	8	13.5	16.8
Penetration, 25°C (77°F) dmm	70	103	44	66	37	42	61	78
Viscosity, Original								
60°C (140°F), poises	3320	1680	2800	1520	3870	3840	1500	1000
135°C (275°F), cs	524	381	325	250	344	351	238	190
Viscosity, RFTC								
60°C (140°F), poises	16,000	7550	6640	3400	6730	—	—	—
Ductility, 25°C (77°F), cm	150+	150+	150+	150+	150+	150+	150+	150+

*Some data interpolated

**Softening agent

TABLE 2. ASPHALT CEMENTS TESTED (Ref 6)

Crude Source	Penetration, 25°C (77°F), dmm	Viscosity, 60°C (140°F), p
San Joaquin Valley, Poso - California	60	1,847
Boscan - Venezuela	62	4,275
Smackover, Arkansas	63	4,823
Redwater - Alberta, Canada	64	1,042
San Joaquin Valley, Poso - California	50	2,180
San Joaquin Valley, Poso - California	31	4,631
Unknown (extracted from an old asphalt pavement)	7	254,000

TABLE 3. VISCOSITIES OF RECLAIMING AGENTS (Ref 6)

Reclaiming Agent Number	Viscosity, 60°C (140°F), cp	Approximate Viscosity, 135°C (275°F), cp
1	120	10
2	110	10
3	540	13
4	4,800	44
5	8,600	60
6	19,700	90
7	2,800	30
8	10,800	80
9	16,500	90
10	50,000	160
11	131,000	270
12	97,000	250

TABLE 4. EFFECT OF RECLAIMING AGENTS ON ASPHALT EXTRACTED FROM OLD PAVEMENT (Ref 6)

	Reclaiming Agent									
	None	No. 8			No. 4			No. 2		
Reclaiming agent, percent weight in blend	0	10	25	50	5	25	50	10.3	30.7	50.9
Penetration at 25°C (77°F), dmm	7	12	26	80	10	24	90	19	144	>350
Penetration at 4°C (39°F), dmm	3	5	11	31	5	11	32	9	56	>350
Penetration ratio*	42.9	41.7	42.3	38.8	50	45.8	35.6	47.4	38.9	—
Viscosity at 60°C (140°F), poises	254,000	79,200	18,100	2,516	144,000	16,900	1,187	30,500	696	47
Viscosity at 135°C (275°F), cs	3,125	1,805	916	373	2,081	767	229	1,161	139	46
Softening point, °C (°F)	73 (163)	68 (156)	61 (141)	48 (118)	70 (158)	58 (136)	41 (106)	59 (138)	40 (104)	21 (70)
Pellet abrasion, 10°C (50°F), mg/revolution										
Mixed	278	—	—	6.2	—	—	3.9	—	2.5	—
Aged 7 days at 60°C (140°F)	**	—	—	14.3	—	—	6.4	—	6.0	—
Average	—	—	—	10.2	—	—	5.2	—	4.2	—

$$\text{*Penetration ratio} = \frac{\text{Penetration at 4°C (39°F)}}{\text{Penetration at 25°C (77°F)}} \times 100$$

**Could not be pressed into pellets because of low cohesion

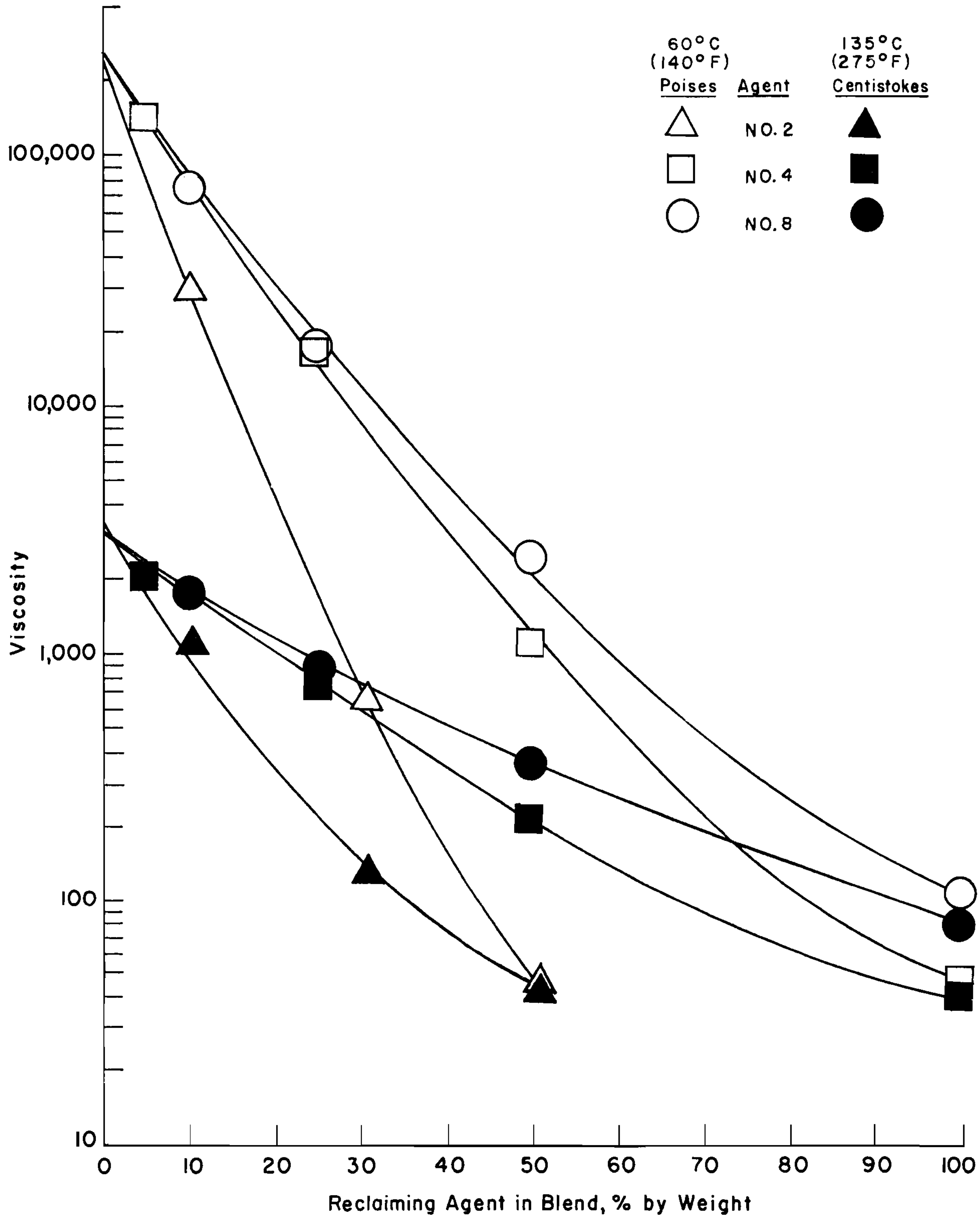


Fig 1. Effect of reclaiming agents on viscosity of asphalt extracted from old pavement (Ref 6).

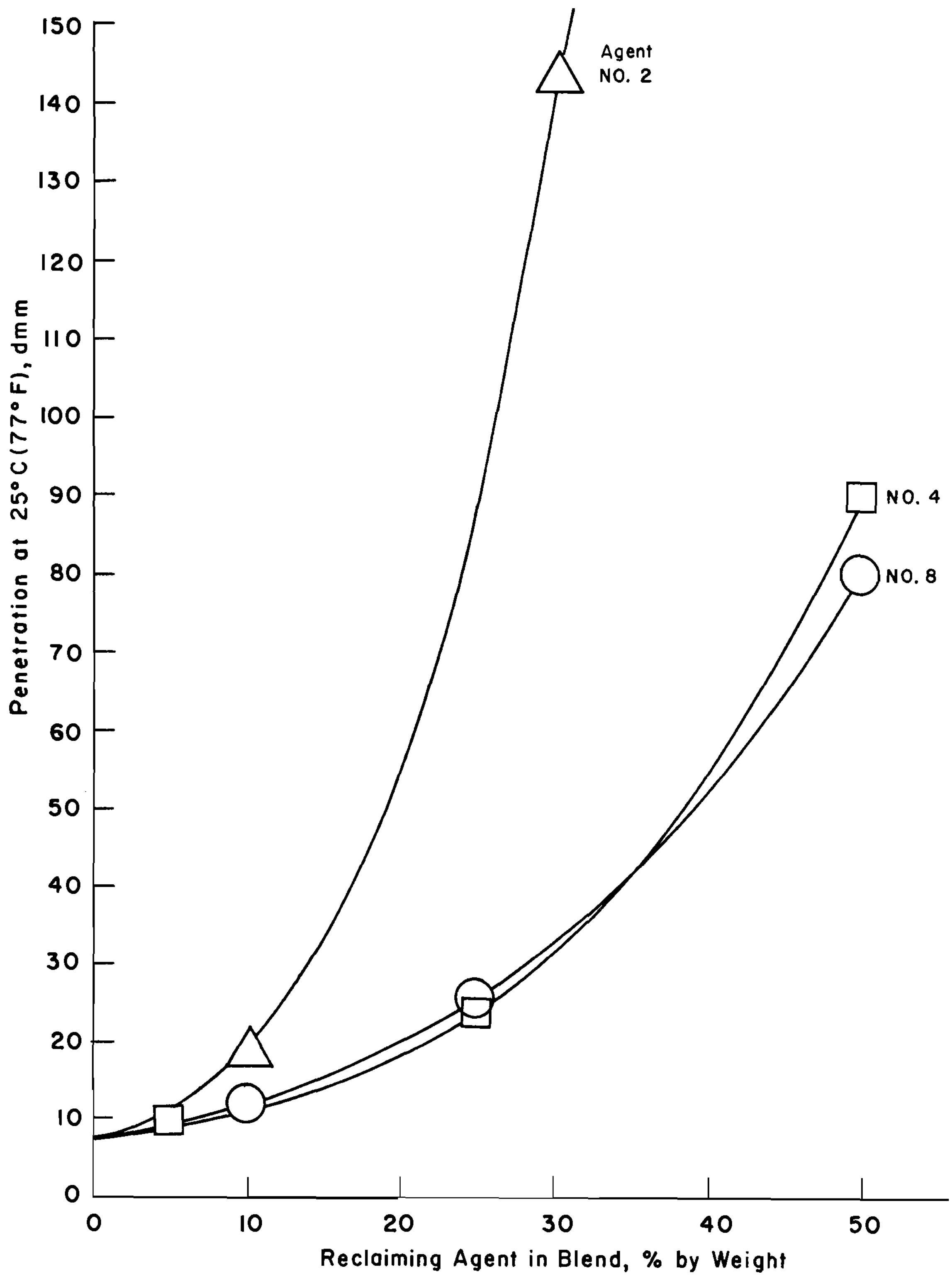


Fig 2. Effect of reclaiming agents on penetration of asphalt extracted from old pavement (Ref 6).

TABLE 5. MARSHALL DATA FOR OLD PAVEMENT MATERIAL WITH ADDED MODIFER (Ref 6)

	Reclaiming Agent											
	No. 4			No. 4			No. 2			No. 2		
Reclaiming agent, percent wt. in blend*	35	39.3	43.2	35.2	39.7	42.9	35.2	39.3	43.2	25.0	23.3	21.8
Additional asphalt, percent wt. in blend*	0	0	0	0	0	0	0	0	0	8.9	15.1	20.6
Asphalt content, percent wt.	5.6	6.0	6.3	5.8	5.8	6.6	5.4	5.7	6.0	5.6	6.0	6.1
Marshall data**												
Load, pounds	2,396	2,197	1,932	2,463	1,936	2,010	2,104	1,504	1,045	2,609	2,304	2,045
Flow rate, 1/100 inch	19	20	24	18	17	22	17	20	23	20	25	22
Properties of asphalt extracted from Marshall specimen												
Viscosity at 60°C (140°F), poises	10,572	9,775	3,203	4,586	3,080	2,788	269	255	136	1,740	1,267	1,548
Viscosity at 135°C (275°F), cs	712	682	427	449	360	348	119	111	79	308	238	270
Penetration at 25°C (77°F), dmm	36	39	74	45	56	53	>300	>300	>300	76	90	78
Penetration at 4°C (39°F), dmm	16	18	32	19	22	23	123	108	205	32	34	33
Penetration ratio***	44.4	46.2	43.2	42.2	39.3	43.4	—	—	—	42.1	37.8	42.3
Softening points, °C, (°F)	57 (134)	56 (133)	49 (121)	51 (124)	49 (121)	51 (124)	34 (93)	33 (92)	29 (85)	47 (117)	46 (114)	46 (115)
Pellet abrasion, 10°C (50°F), mg/revolution												
Mixed	—	—	10.9	—	—	—	—	—	—	—	—	—
Aged 7 days at 60°C (140°F)	—	—	16.8	—	—	—	—	—	—	—	—	—
Average	—	—	13.8	—	—	—	—	—	—	—	—	—

*Added as 60-percent-residue cationic emulsion.

**Temperature was 121°C (250°F) for mixing and 104°C (220°F) for compaction.

$$\text{***Penetration ratio} = \frac{\text{Penetration at 4°C (39°F)}}{\text{Penetration at 25°C (77°F)}} \times 100$$

are compared with acceptable values obtained for conventional pavement mixtures and are summarized in Figs 3 through 7 and Table 6.

Figures 3, 4, and 5 illustrate resilient modulus and fracture strengths for typical recycled pavements as determined by the direct and indirect tensile tests (Ref 22). Included are values obtained from tests performed on samples from two typical pavements which were contructed with new materials.

Figure 3 indicates that the recycled mixtures possess resilient modulus values which vary over a small range. This variation is greater than that of the two typical pavement mixtures. However, all of the recycled mixtures possess resilient moduli which are comparable to those of the pavement constructed with all new materials.

Figure 4 presents the ultimate strength of the recycled and conventional mixtures as determined by the direct tension tests. Pavements containing crushed portland cement concrete had higher strengths than did the recycled and conventional asphalt concrete mixtures. The recycled and conventional asphalt concrete mixtures had similar values, indicating that the recycled mixture possesses adequate strength. Values of all the mixtures are similar to those reported by another investigator (Ref 9).

Values of tensile strength determined by the indirect tensile test for conventional and recycled mixtures are given in Fig 5. All of the recycled mixtures had tensile strengths similar to values obtained for conventional mixtures.

Cracking of asphalt pavements is a major concern. This cracking can be predicted in terms of the magnitude of the strain at the failure as obtained from the results of tension tests. Small failure strains indicate brittle behavior, which is characteristic of cracked pavements. Values of strain for recycled and conventional mixes as determined by the direct tension test are shown in Fig 6. The failure strain of the recycled mixtures were smaller than those of the conventional mixes. This is probably related to the higher viscosity of the hardened asphalts used in the recycling process.

In contrast, the failure strains, as determined by the indirect tensile test, were larger for the recycled mixtures than for the conventional mixtures (Ref 22). This observed behavior would not be expected; however, it cannot be explained but probably is due to the method of calculating the strains for the testing technique.

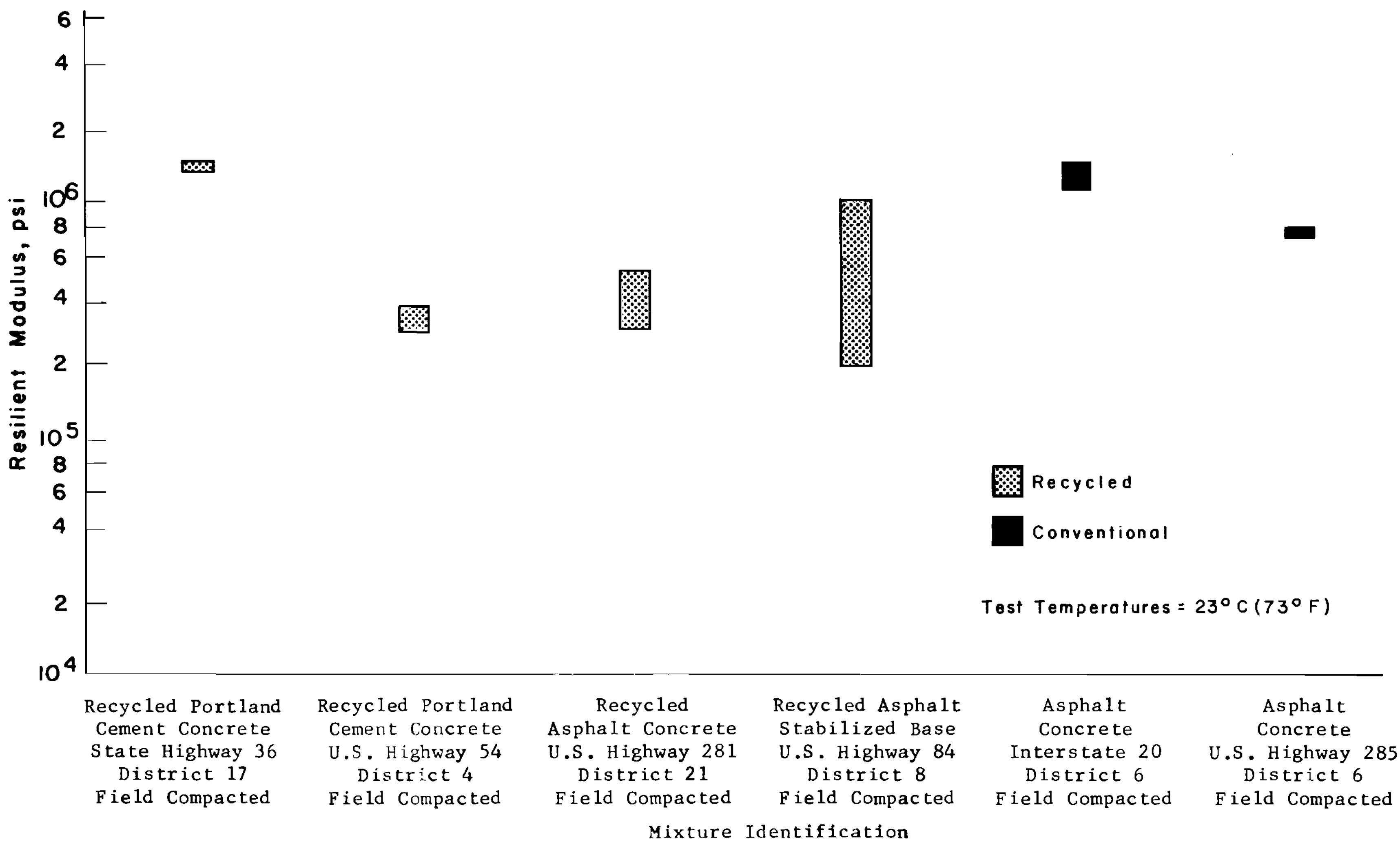


Fig 3. Resilient moduli for typical recycled and conventional pavement mixtures (Ref 22).

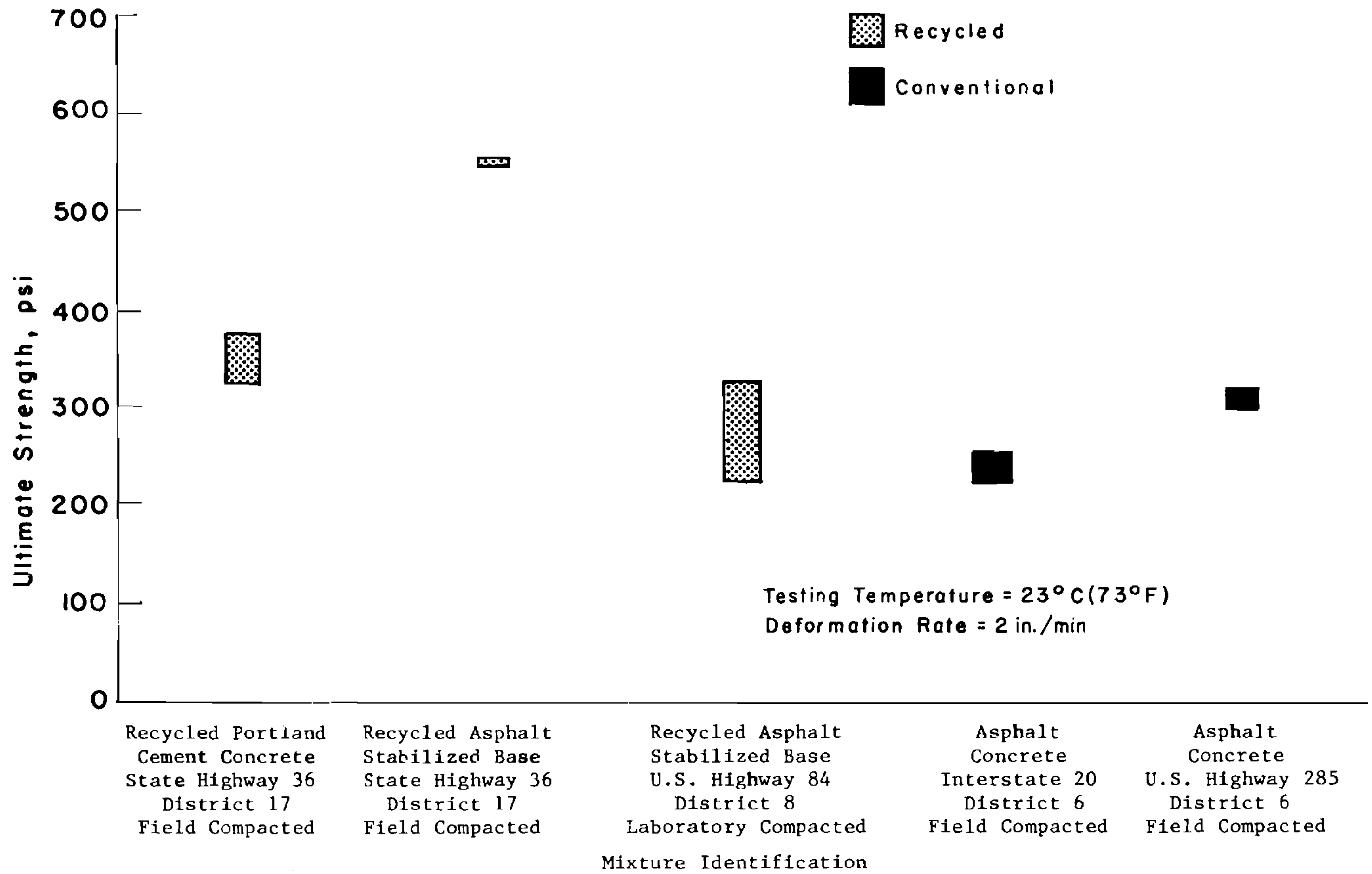


Fig 4. Ultimate strength of typical recycled and conventional pavement mixtures as determined by the direct tension test (Ref 22).

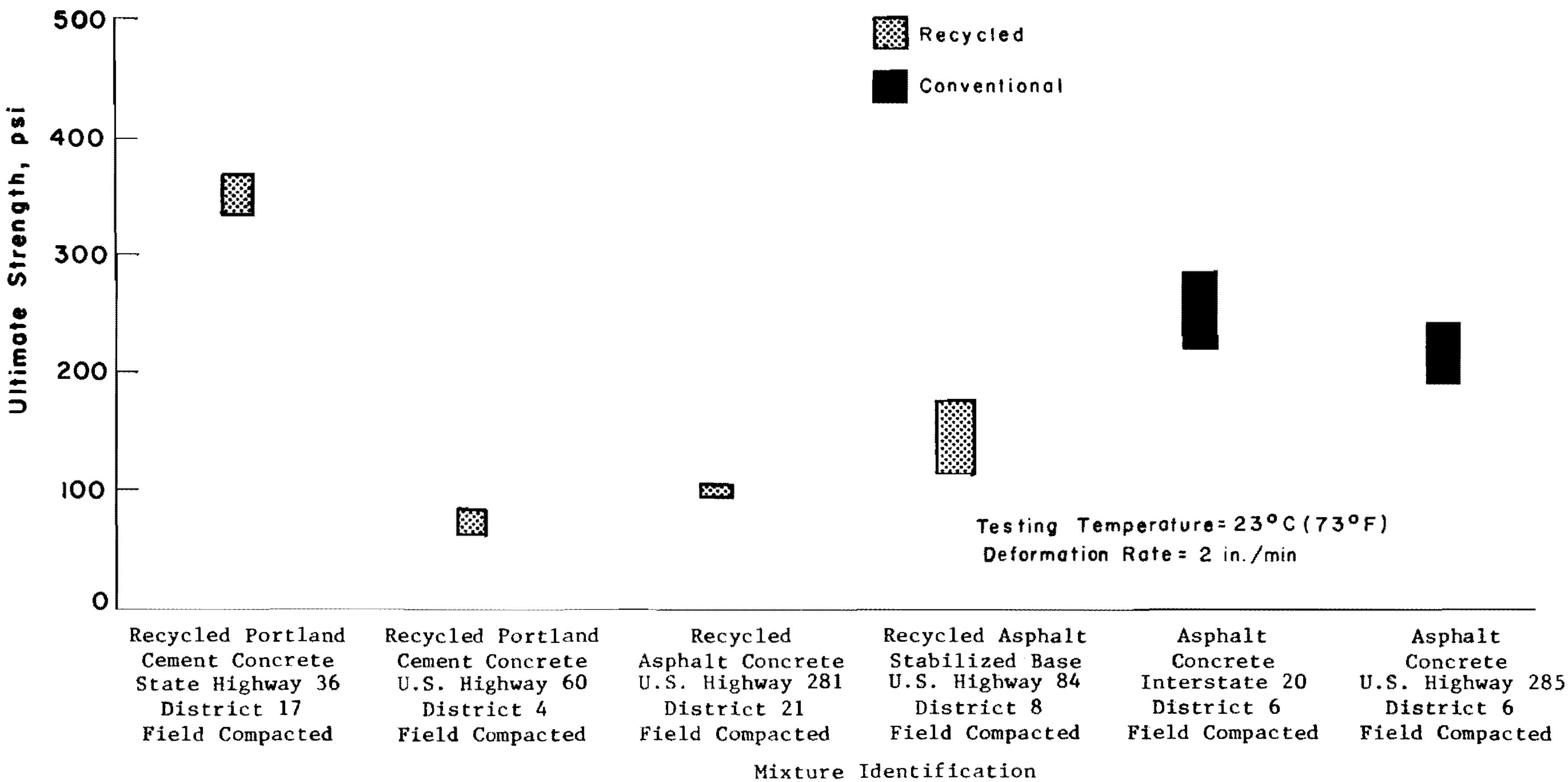


Fig 5. Ultimate strength of typical recycled and conventional pavement mixtures as determined by the splitting (indirect) tensile test (Ref 22).

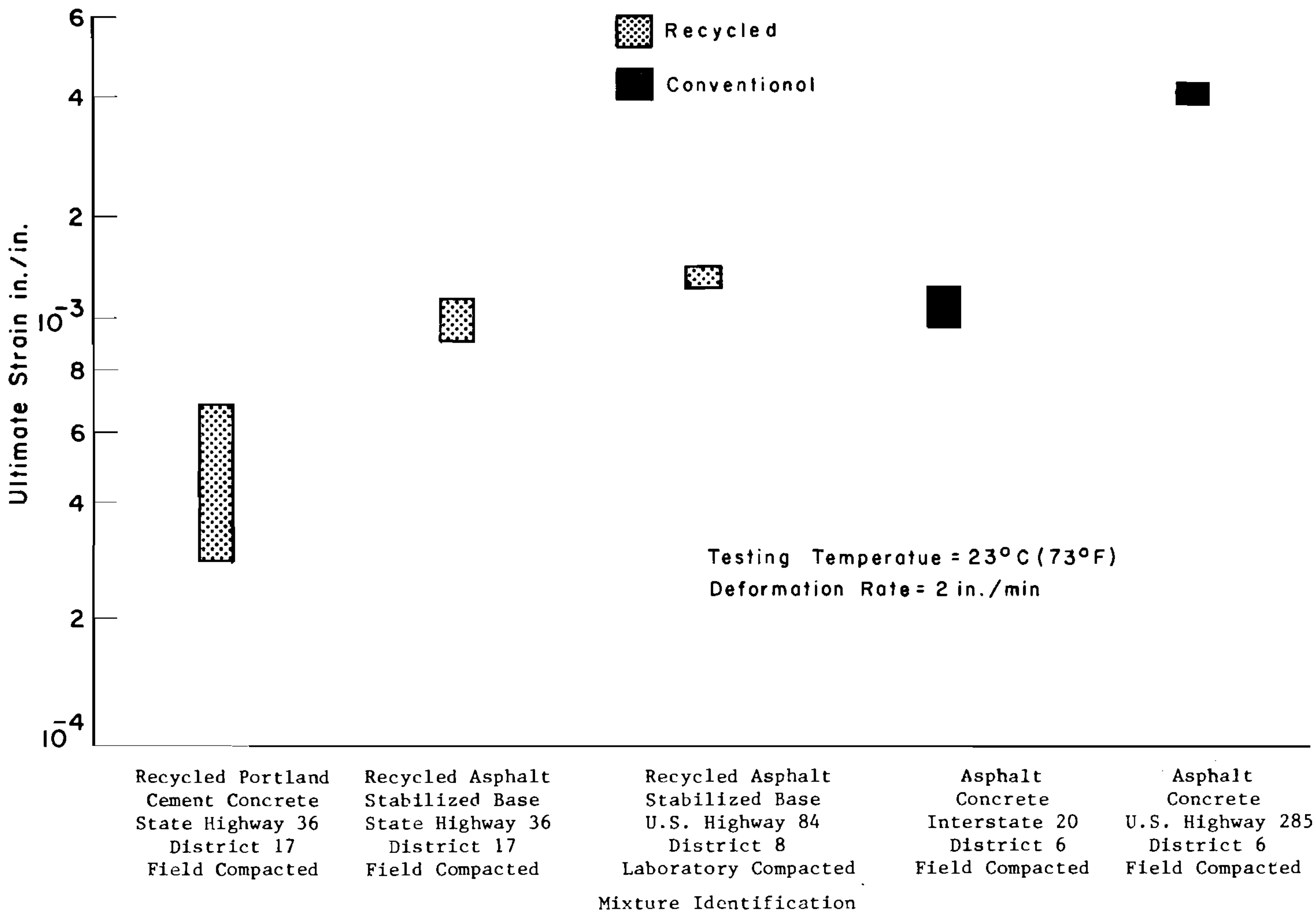


Fig 6. Ultimate strain of typical recycled and conventional pavement mixtures as determined by the direct tension test (Ref 22).

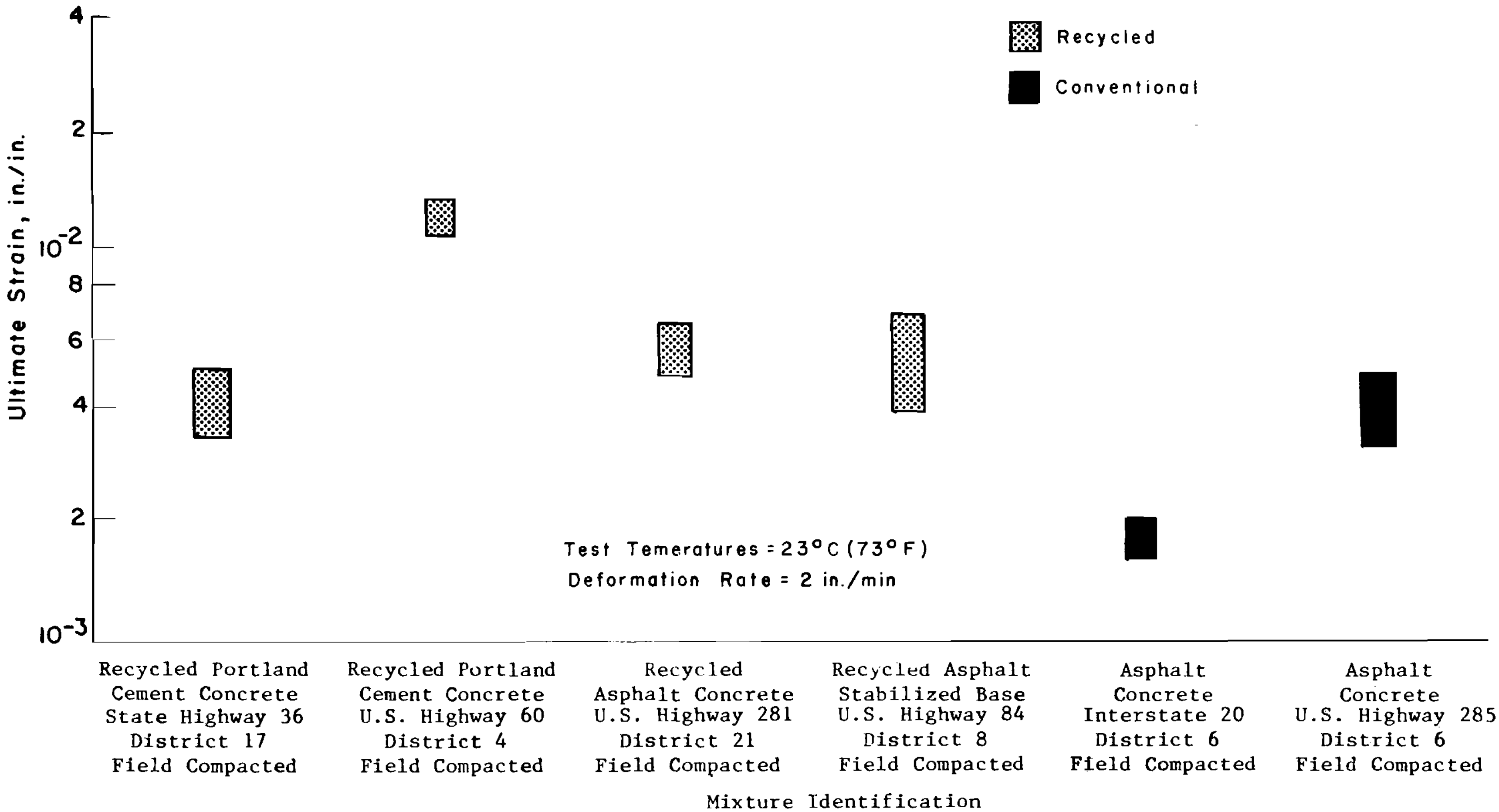


Fig 7. Ultimate strain of typical recycled and conventional pavement mixtures as determined by the splitting (indirect) tensile test (Ref 22).

TABLE 6. SUMMARY OF MARSHALL STABILITY TEST RESULTS FOR RECYCLED MIXTURES (Ref 22)

Pavement Designation	Pavement Composition	Type of Compaction	Number of Samples	Percent Air Voids	Marshall Stability, lb	Marshall Flow, 0.01 in.
Asphalt concrete State Highway 36	80 percent recycled portland cement concrete 20 percent sand 5.9 percent asphalt	Field	3	3.6	3,470	18
Asphalt stabilized base State Highway 36	85 percent recycled portland cement concrete 15 percent sand 8.7 percent asphalt	Field	3	4.9	2,000	16
Asphalt concrete U.S. Highway 60	86 percent recycled portland cement concrete 14 percent screenings 7.6 percent asphalt	Field	3	4.2	1,550	12
Asphalt concrete U.S. Highway 54	100 percent recycled portland cement concrete 6.5 percent asphalt	Field	3	10.2	1,490	11

(continued)

TABLE 6. (Continued)

Pavement Designation	Pavement Composition	Type of Compaction	Number of Samples	Percent Air Voids	Marshall Stability, lb	Marshall Flow, 0.01 in.
Asphalt concrete U.S. Highway 281	100 percent recycled asphalt concrete 7.5 percent asphalt	Field	3	9.3	840	20
	90 percent recycled asphalt concrete 10 percent sand 6.7 percent asphalt	Laboratory	5	3.6	3,990	15
Asphalt stabilized base U.S. Highway 84	80 percent recycled asphalt concrete 20 percent new base material 8.0 percent asphalt	Field	3	2.8	1,140	19
	100 percent recycled asphalt concrete 6.6 percent asphalt	Field	3	5.4	2,060	20
	100 percent recycled asphalt concrete 6.4 percent asphalt*	Field	3	6.8	4,070	26

*This mixture from U.S. Highway 84 was recycled through a pugmill plant.

Table 6 contains a summary of the Marshall stability test results showing average values of air voids, stability, and flow obtained by O'Neal (Ref 22). All the pavements investigated exhibited stabilities in excess of the suggested design values for conventional mixtures as shown in Table 7. Generally, the recycled mixtures possessed flow values which were larger than for conventional mixtures but acceptable in terms of the values shown in Table 7.

SUMMARY

Based on the results of conventional tests, the recycled pavement mixtures have been shown to possess properties generally equivalent to conventional asphalt concrete mixtures. It has been shown, also, that reclaiming agents can be used as the sole additive for converting deteriorated asphalt pavements into new paving mixtures.

The literature review showed that only a small amount of information is available on the elastic characteristics of recycled materials and no information is available on fatigue characteristics. Thus, there is a definite need for information concerning the fatigue and elastic characteristics for use in design procedures. In addition, there is a need for a mixture design procedure which will produce acceptable products and is readily available and useable by various agencies involved in recycling.

TABLE 7. ASPHALT INSTITUTE SUGGESTED MARSHALL DESIGN CRITERIA FOR VARIOUS TRAFFIC LOADINGS (Ref 33)

Test Property	Heavy Traffic	Medium Traffic	Light Traffic
Marshall stability, lb	750 minimum	500 minimum	500 minimum
Marshall flow, 0.01-in.	8-16	8-18	8-20
Percent air voids			
Surface	3-5	3-5	3-5
Base	3-8	3-8	3-8

CHAPTER 3. EXPERIMENTAL PROGRAM

The principal objectives of this study were (1) to evaluate the engineering properties of recycled asphalt mixtures and (2) to develop a preliminary mixture design procedure for recycled asphalt mixtures. To achieve these objectives laboratory prepared specimens and cores of recycled asphalt mixtures from three different projects were supplied to the project. These specimens were then tested and evaluated using the static and repeated-load indirect tensile tests. Additional corroborative tests and evaluations were also conducted by the Department of Highways and Transportation.

DESCRIPTION OF PROJECTS TESTED

Specimens composed of mixtures from three different projects located in Districts 8 and 21 in Texas were supplied by the Department of Highways and Transportation. Summary information related to the projects and the test program is contained in Table 8. Figure 8 shows the geographical distribution of the districts from which the mixtures were obtained. The actual test program was limited by the number of specimens available or the number which could be readily supplied.

DESCRIPTION OF SPECIMENS

The specimens from the three projects can be divided into three groups: laboratory prepared specimens, plant mixed specimens, and cores.

All laboratory specimens were prepared by the Department of Highways and Transportation, according to TEX-126-E for blackbase materials and TEX-206-F for surface materials (Ref 14). 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.

Field mixed specimens were sampled in the field and reheated before compaction in the laboratory. The mixtures were then placed in preheated ovens and brought to the compaction temperature and compacted using the Texas gyratory-shear compactor (TEX-206-F and TEX-126-E, Part II).

TABLE 8. DESCRIPTION OF RECYCLED PROJECTS

District, County Project	Preparation	Number of Specimens Fatigue	Number of Specimens Static	Additive Type	Additive, % Wt.*	Aggregate
8 Nolan IH-20	Laboratory	5	2	AC-3	3.0	Gradation 1 16% Old Base, 15% New Agg., 69% Salv. Surface
		5	2	AC-3	2.4	
		4	2	AC-3	2.0	
		5	2	AC-3	1.6	
		4	2	AC-20 Reclamite	3.16 0.34	
		5	2	AC-20 Reclamite	2.76 0.34	
		4	4	AC-20 Reclamite	2.36 0.34	
		4	4	AC-20 Reclamite	1.96 0.34	
		4	2	AC-20 Reclamite	2.30 0.20	
		4	2	AC-20	3.5	
		4	2	AC-20	2.3	
		4	3	None**	—	
	Plant Mixed	7	3	AC-3	2.25	Gradation 1 16% Old Base, 15% New Agg., 69% Salv. Surface
		6	3	AC-3	2.8	
		5	3	AC-3	2.8	Gradation 2 20% Old Base, 15% New Agg., 65% Salv. Surface
		5	3	AC-3 Paxole	1.87 0.93	
	Cores	-	3	AC-3	2.0	Gradation 1 16% Old Base, 15% New Agg., 69% Salv. Surface
		5	3	AC-3	2.25	
		-	4	AC-5	2.25	
		4	2	AC-3	2.5	
		4	2	AC-3	2.8	
				AC-3	3.0	
		6	5	AC-3	2.8	Gradation 2 20% Old Base, 15% New Agg., 65% Salv. Surface
		-	3	AC-3 Paxole	1.87 0.93	
21 Hidalgo Loop 374	Laboratory	5	3	None**	—	Crushed limestone from old asphalt concrete
		6	3	AC-3	2.5	
		5	3	Reclamite	1.0	
		6	3	Reclamite	1.6	
		6	3	Flux oil	1.0	
		6	3	Flux oil	1.6	
	Plant Mixed	12	6	Flux oil	2.0	
		6	6	Flux oil	1.6	
		12	6	AC-3	3.0	
		6	3	AC-3	2.5	
		12	6	Reclamite	1.6	
21 Hidalgo US 281	Cores	12	7	AC-20	1.5	Crushed limestone

*Percentage based on total weight of mixture

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

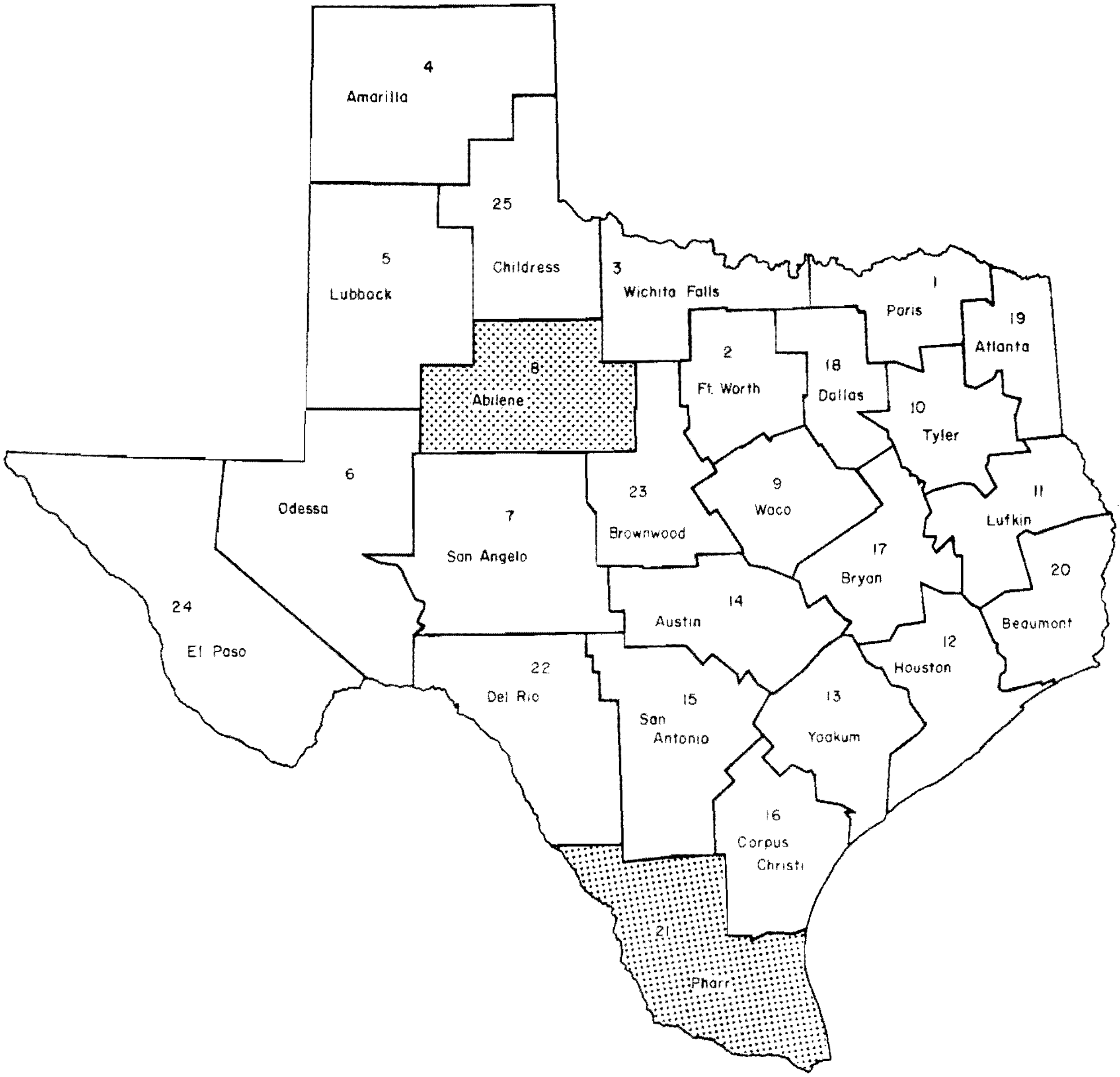


Fig 8. Districts from which recycled mixtures and specimens were obtained.

Duplicate specimens were prepared for each set of conditions. A portion of the specimens were tested by the Department of Highways and Public Transportation using TEX-126-E, Part III testing procedure. The remainder of the specimens were tested in the laboratories of the Center for Highway Research utilizing the static and repeated-load indirect tensile tests.

Specimens of two different sizes were tested. Specimens of surface mixtures had a nominal diameter of 102 mm (4 in.) and a nominal height of 51 mm (2 in.). Specimens of base mixtures had a nominal diameter of 152 mm (6 in.) and height of 76 mm (3 in.). Prior to testing, the specimens were carefully measured.

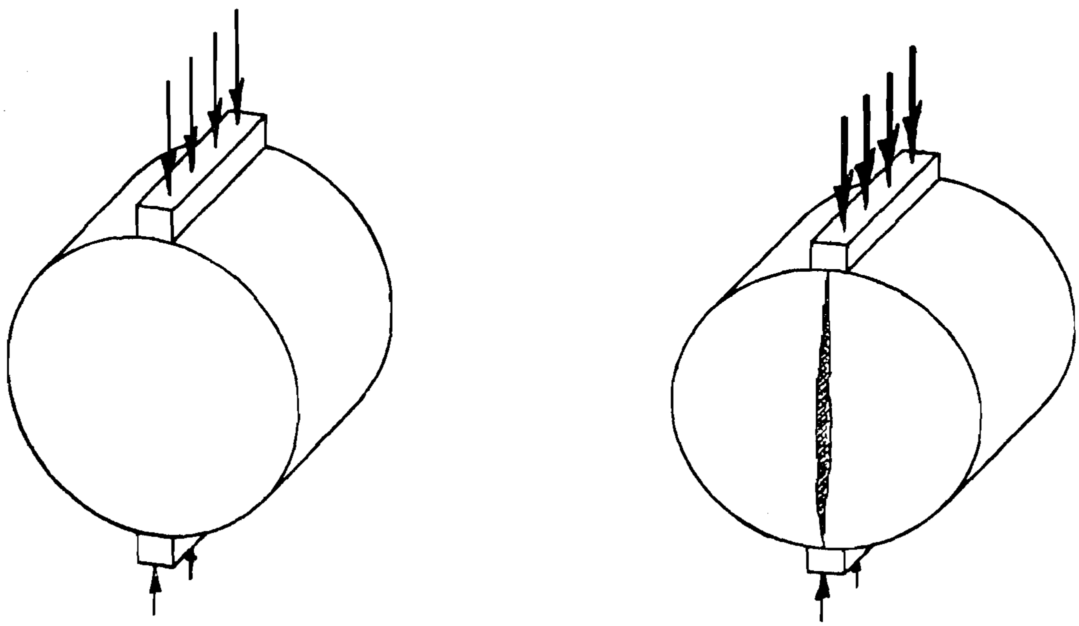
One third of the indirect tensile test specimens were tested statically. The other two thirds were tested under repeated loads to obtain estimates of fatigue and resilient properties. Previous studies (Refs 1 and 20) have shown that the relationship between fatigue life and tensile stress is linear; thus, only two stress levels were used in the repeated load portion of this study.

INDIRECT TENSILE TEST

The indirect tensile test involves loading a cylindrical specimen with static or repeated compressive loads acting parallel to and along the vertical diametral plane, as shown in Fig 9a. The compressive load is distributed through 13-mm (0.5-in.)-wide steel loading strips which are curved at the interface to fit the specimen. This method of loading produces a fairly uniform tensile stress perpendicular to the plane of the applied load and along the vertical diametral plane which ultimately causes the specimen to fail by splitting along the vertical diameter (Fig 9b). Estimates of the tensile strength, modulus of elasticity, and Poisson's ratio can be made knowing the applied load and corresponding vertical and horizontal deformations.

Test Equipment

The test equipment was the same as that used in previous studies at the Center for Highway Research and included a loading frame, a loading head, and a MTS closed-loop electrohydraulic system to apply load and to control deformation rate. The loading head was a modified commercially available die set with the lower platen fixed and the upper platen constrained, so that



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

Fig 9. Indirect tensile test loading and failure.

the platens remained parallel. The curved stainless steel loading strips were attached to both the upper and lower platens. The dimensions and configuration of the curved loading strip are contained in Ref 2.

To estimate the modulus of elasticity and Poisson's ratio required the measurement of both vertical and horizontal deformations of the specimens. For repeated load tests the deformations were measured by DC linear variable differential transducers (LVDT's). In order to obtain the individual vertical deformations, an LVDT was positioned on the upper platen (Fig 10). A horizontal deformation transducer consisting of two LVDT's was used to monitor the horizontal deformation of the specimen for selected load applications. Typical relationships between time and horizontal and vertical deformations are shown in Fig 11 along with the corresponding load-time pulse. In addition, Fig 12 illustrates typical permanent deformation relationships although permanent deformations were not measured in this study. For the static tests the vertical deformations were monitored by the LVDT positioned on the upper platen. Horizontal deformations, however, were measured using a device consisting of two cantilevered arms with strain gages attached.

Static Test Procedure

In order to prevent impact loading and to minimize the effect of seating the loading strip, a preload of 89 N (20 lb) was applied to the specimen. Then, the specimen was loaded at a rate of 51 mm (2 in.) per minute at a test temperature of 24° C (75° F). The loads and deformations were recorded on two X-Y plotters, one recording load and horizontal deformation and the other recording load and vertical deformation.

From these recordings, corresponding loads, vertical deformations, and horizontal deformations were obtained and, along with the dimensions of each specimen, were used as input for the computer program MODLAS 9 to calculate the tensile and static elastic properties of the materials tested.

Repeated Load Test Procedure

A seating load of 89 N (20 lb), which corresponds to a stress of about 1.1 N/cm^2 (1.5 psi), was also applied to specimens used in this test. Then repeated loads producing total stresses ranging from 12 to 72 N/cm^2 (17 to 104 psi) were applied at a frequency of one cycle per second (1 Hz) with a 0.4-second load duration and a 0.6-second rest period. All tests were conducted at 24° C (75° F) and were continued until failure occurred, i.e., when

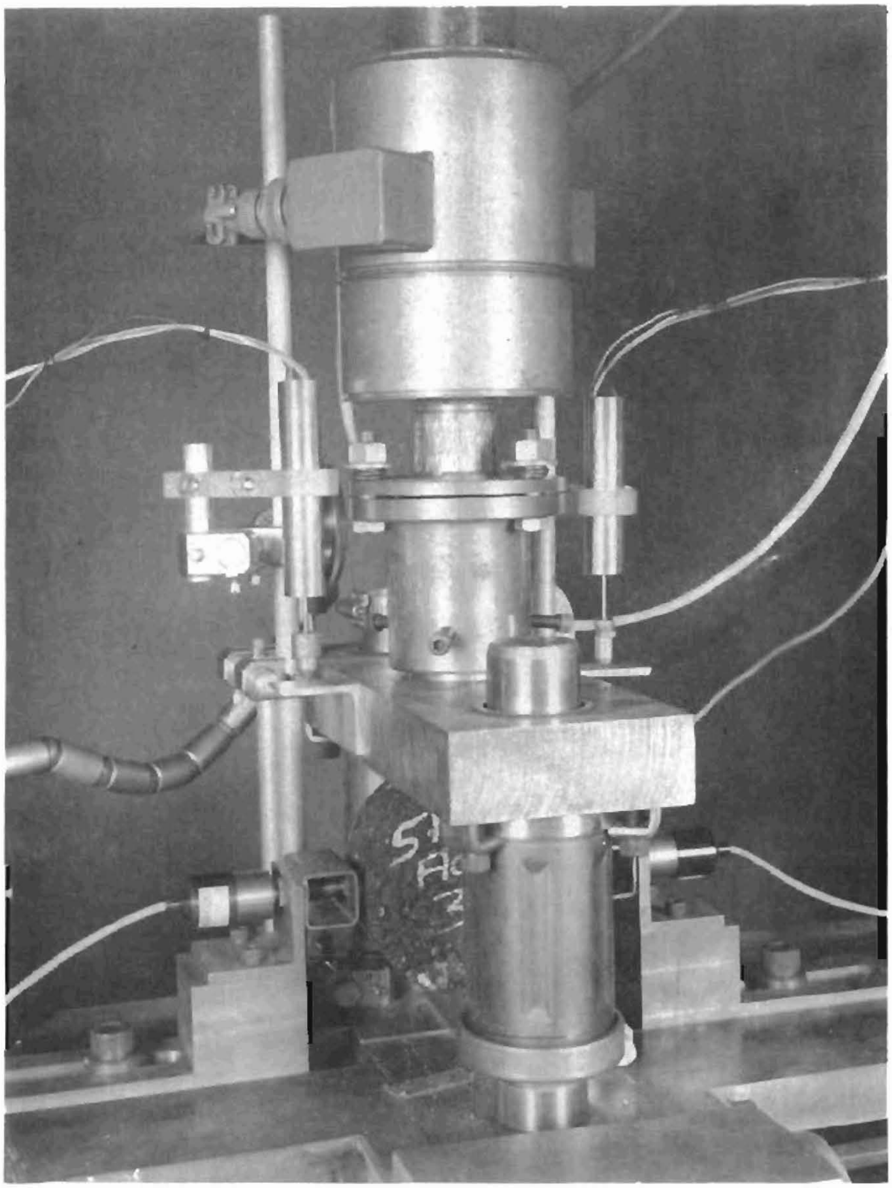


Fig 10. Repeated-load indirect tensile test.

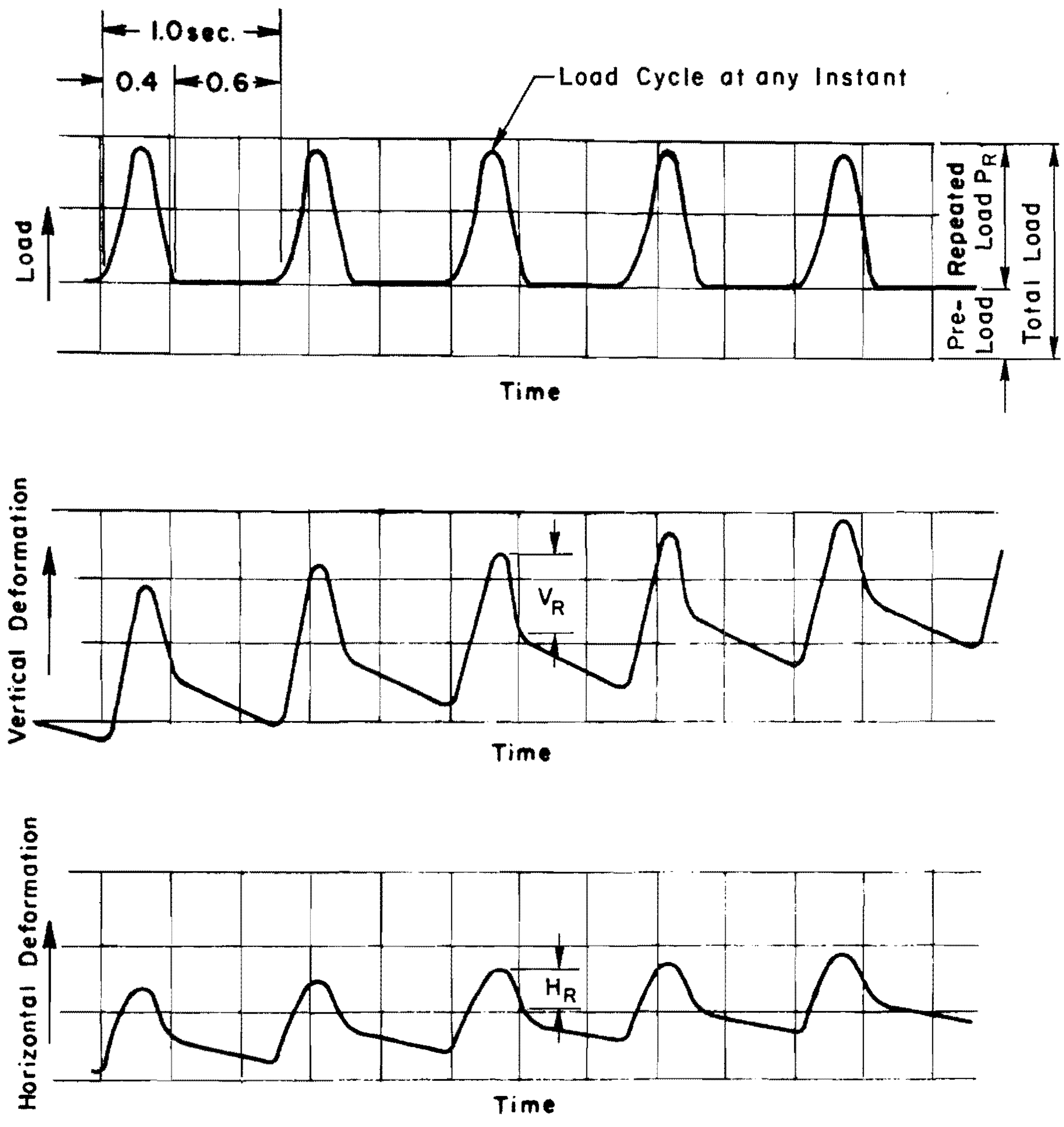
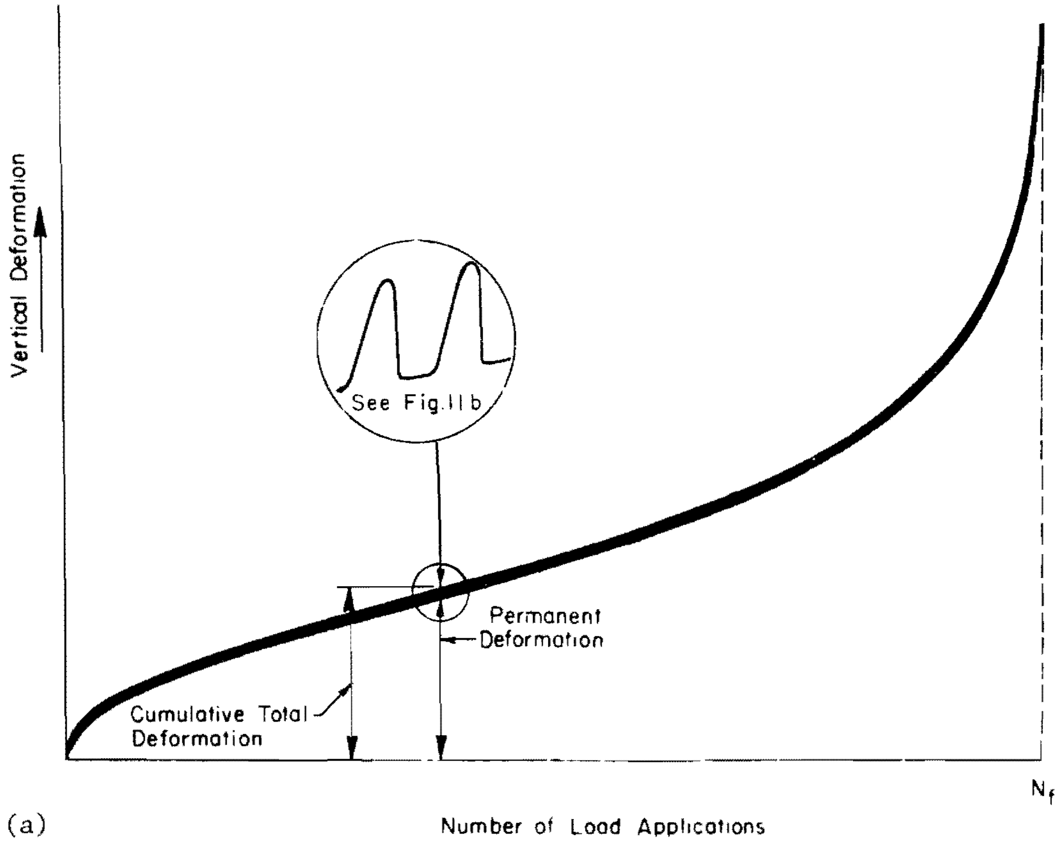
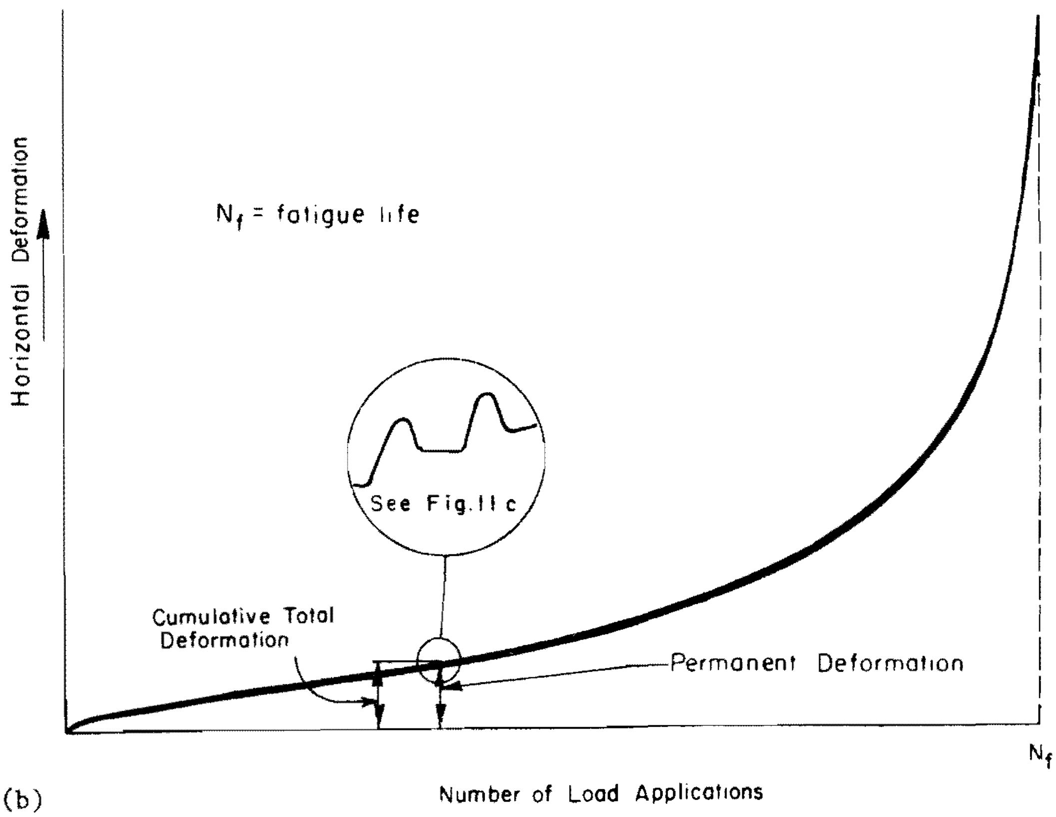


Fig 11. Load pulse and associated deformation data for the repeated-load indirect tensile test.



(a)



(b)

Fig 12. Typical relationships between number of load applications and vertical and horizontal deformations for the repeated-load indirect tensile test.

the specimen fractured completely (Fig. 12). Fatigue life N_f is the number of cycles corresponding to this failure.

The individual horizontal and vertical deformations were recorded for the 25th and 50th cycle and for cycles corresponding to approximately 30, 50, and 70 percent of the fatigue life, which represents the portion of the deformation relationship which is linear. Both the vertical and horizontal deformations were recorded on a pair of X-Y plotters which recorded deformation versus time.

PROPERTIES ANALYZED

The properties analyzed were tensile strength, static Poisson's ratio, static modulus of elasticity, fatigue life, resilient Poisson's ratio, and resilient modulus of elasticity. Several of these properties are directly or indirectly related to the relevant pavement distress modes previously discussed.

Tensile Strength

The ultimate tensile strength is a measure of the maximum stress which the mixture can withstand and is related to thermal or shrinkage cracking resistance.

The ultimate tensile strength was calculated using the following relationships for 102-mm (4-in.)-diameter and 152-mm (6-in.)-diameter specimens and the load-deformation information obtained from the static test:

$$S_T = \frac{0.156\, P_{ult}}{t} \qquad \text{102-mm (4-in.)-diameter}$$

$$S_T = \frac{0.105\, P_{ult}}{t} \qquad \text{152-mm (6-in.)-diameter}$$

where

S_T = ultimate tensile strength, psi,
P_{ult} = the maximum load carried by the specimen, lb, and
t = thickness, or height, of the specimen, in.

Tensile stresses produced by loads less than the maximum load P_{ult} can also be calculated using the above equations.

Static Poisson's Ratio

The static Poisson's ratio was calculated from the relationship between the vertical and horizontal deformations up to a sharp inflection point in the load-deformation relationships, which generally occurred between 60 and 90 percent of the ultimate load. If a sharp break in the curve was not present, data points were included up to a point about midway between the ultimate load and the deviation from linearity. The relationships are

$$\nu = \frac{3.59}{DR} - 0.27 \quad \text{for the 102-mm (4-in)-diameter}$$

and $$\nu = \frac{4.09}{DR} - 0.27 \quad \text{for the 152-mm (6-in.)-diameter}$$

where

ν = static Poisson's ratio, and

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

Static Modulus of Elasticity

The static modulus of elasticity was determined by analyzing the load-deformation relationships for static tensile tests. A regression analysis was conducted on data points up to the sharp inflection point in the load-deformation curves or to about the midpoint if a sharp inflection point was not present. This is basically the same procedure as that suggested by Anagnos and Kennedy (Ref 2).

The equation used to calculate the static modulus was

$$E_S = \frac{S_h}{t} (0.27 + \nu) \quad \text{for 102 and 152-mm (4 and 6-in.)-diameters}$$

where

E_S = static modulus of elasticity, psi, and

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

Fatigue Life

Fatigue life is defined as the number of load applications at which the specimen will no longer carry load or where deformation is so excessive that loading conditions are no longer uniform (Fig 12).

Resilient Poisson's Ratio

The resilient Poisson's ratio ν_R was determined from the repeated-load tests and calculated using the resilient vertical and horizontal deformations V_R and H_R for the loading cycle corresponding to 30, 50, and 70 percent of fatigue life. The equation is the same as those used for the static Poisson's ratio; however, since the relationships between load and deformation are essentially linear, the equation has been modified and expressed as follows:

$$\nu_R = 3.59 \frac{H_R}{V_R} - 0.27 \quad \text{for the 102-mm (4-in.)-diameter}$$

and $$\nu_R = 4.09 \frac{H_R}{V_R} - 0.27 \quad \text{for the 152-mm (6-in.)-diameter}$$

where

H_R and V_R are the resilient horizontal and vertical deformations, as shown in Fig 11.

Resilient Modulus of Elasticity

The resilient modulus of elasticity was calculated by using the resilient, or recoverable, horizontal and vertical deformations, which occurred for a loading cycle and correspond to the elastic deformations produced by rapidly applied, repeated loads. The equation used to calculate the resilient modulus is as follows:

$$E_R = \frac{P_R}{tH_R} (0.27 + \nu_R) \quad \text{for 102 and 152-mm (4 and 6-in.)-diameters}$$

where

E_R = resilient modulus of elasticity, psi, and
P_R = applied repeated load, lb (Fig 11).

CHAPTER 4. EVALUATION OF ENGINEERING PROPERTIES

A primary objective of this study was to evaluate the fatigue and elastic properties of recycled asphalt mixtures. For purposes of discussion the analysis of the data for the three projects has been subdivided into the following categories:

(1) fatigue properties,
(2) strength and elastic properties,
(3) effect of the addition of additives in the properties, and
(4) correlations.

FATIGUE PROPERTIES

Fatigue life was defined as the number of load applications required to completely fracture a specimen, which is illustrated in Fig 12.

The fatigue properties for the three projects are summarized in Table 9.

Fatigue Life - Stress Relationships

Based on the results of previous studies (Refs 1 and 20) which showed that a linear relationship exists between the logarithm of applied stress and the logarithm of fatigue life, two stress levels were selected for use in this study.

This linear relationship between fatigue life and stress (Figs 13, 14, 15, and 16) can be expressed either as

$$N_f = K_2 \left(\frac{1}{\sigma_T} \right)^{n_2} \qquad (4.1)$$

or in the form

$$N_f = K_2' \left(\frac{1}{\Delta\sigma} \right)^{n_2} \qquad (4.2)$$

TABLE 9. SUMMARY OF FATIGUE RESULTS

District Project	Preparation, Aggregate	Treatment	Stress Level, N/cm^2	(psi)	Number of Specimens	Fatigue Life Mean	Fatigue Life CV, %	Fatigue Constants $N_f = K_2 \left(\frac{1}{\sigma}\right)^{n_2} = K_2' \left(\frac{1}{\Delta\sigma}\right)^{n_2}$ K_2	K_2'	n_2	R^2
		3.0% AC-3	40	(58)	2	6,394	—	7.98×10^{12}	2.11×10^{16}	5.68	0.79
			32	(46)	3	17,546	18				
		2.4% AC-3	52	(75)	2	4,385	—	2.18×10^{12}	2.45×10^{15}	5.06	0.94
			40	(58)	3	16,867	23				
		2.0% AC-3	66	(96)	2	1,312	—	1.66×10^{12}	1.72×10^{15}	5.00	0.98
			35	(51)	2	30,890	—				
		1.6% AC-3	72	(104)	2	1,160	—	4.97×10^{12}	6.62×10^{15}	5.18	0.98
			38	(55)	3	33,000	31				
		3.5% AC-20	30	(43)	2	5,961	—	7.03×10^{12}	3.52×10^{16}	6.14	0.98
		0.34% R	20	(29)	2	71,571	—				
	Laboratory Gradation 1	3.1% AC-20	40	(58)	2	3,909	—	6.15×10^{11}	7.41×10^{14}	5.11	0.88
		0.34% R	28	(41)	3	26,528	52				
		2.7% AC-20	45	(65)	2	6,014	—	2.22×10^{7}	4.43×10^{8}	2.15	0.94
		0.34% R	30	(43)	2	14,550	—				
		2.3% AC-20	70	(101)	2	856	—	5.91×10^{13}	2.03×10^{17}	5.87	0.98
		0.34% R	38	(55)	2	31,560	—				
		3.5% AC-20	55	(80)	2	2,173	—	1.90×10^{12}	2.36×10^{15}	5.14	0.96
			34	(49)	2	26,464	—				
		2.3% AC-20	87	(126)	2	1,060	—	6.94×10^{14}	3.27×10^{18}	6.09	0.98
			55	(80)	2	17,140	—				
8 IH 20		2.5% AC-20	72	(104)	2	2,197	—	9.87×10^{13}	2.90×10^{17}	5.76	0.86
		0.2% R	41	(59)	2	67,698	—				
		None*	72	(104)	2	1,652	—	1.54×10^{18}	1.11×10^{23}	8.07	0.98
			45	(65)	2	70,976	—				
	Plant Gradation 1	2.25% AC-3	65	(94)	3	1,625	11	7.91×10^{11}	6.08×10^{14}	4.79	0.94
			35	(51)	4	35,200	57				
		2.8% AC-3	65	(94)	3	1,097	35	7.46×10^{11}	6.50×10^{14}	4.88	0.96
			35	(51)	3	22,575	36				
	Plant Gradation 2	2.8% AC-3	30	(44)	3	1,854	25	7.06×10^{9}	3.42×10^{12}	4.46	0.99
			15	(22)	2	40,056	—				
		2.8% AC-3+	50	(73)	3	2,938	21	8.19×10^{11}	8.10×10^{14}	4.97	0.98
		Paxole	30	(44)	2	37,285	—				
		2.25% AC-3	20	(29)	3	3,972	92	4.27×10^{9}	3.19×10^{12}	4.77	0.81
		Design #2	10	(15)	2	74,411	—				
	Cores Gradation 1	2.5% AC-3	20	(29)	2	1,177	—	2.11×10^{10}	4.84×10^{13}	5.58	0.99
		Design #3	10	(15)	2	57,180	—				
		2.8% AC-3	22	(32)	2	1,522	—	2.86×10^{8}	6.72×10^{10}	3.94	0.98
		Design #4	12	(17)	2	16,070	—				
	Cores Gradation 2	2.8% AC-3	20	(29)	3	2,811	20	1.04×10^{7}	4.66×10^{8}	2.75	0.99
		Design #6	10	(15)	3	18,585	4				

*Recycled material was heated and compacted without additives or new aggregate
R = Reclamite
FO = Flux Oil

TABLE 9. (Continued)

District Project	Preparation, Aggregate	Treatment	Stress Level, N/cm^2	(psi)	Number of Specimens	Fatigue Life: Mean	Fatigue Life: CV, %	$N_f = K_2\left(\frac{1}{\sigma}\right)^{n_2} = K_2'\left(\frac{1}{\Delta\sigma}\right)^{n_2}$ — Fatigue Constants: K_2	K_2'	n_2	R^2
21 Loop 374	Laboratory	None*	57 40	(83) (58)	2 2	6,617 71,634	— —	4.29×10^{15}	4.85×10^{19}	6.73	0.98
		2.5% AC-3	38 26	(55) (38)	3 3	3,147 21,065	14 34	1.68×10^{11}	6.93×10^{13}	4.74	0.86
		1.0% R	40 20	(58) (29)	3 2	1,624 52,945	23 —	3.66×10^{10}	2.14×10^{13}	4.59	0.88
		1.6% R	20 12	(29) (17)	3 3	2,577 18,765	51 43	3.33×10^{8}	8.21×10^{10}	3.97	0.81
		1.0% FO	38 26	(55) (38)	3 2	1,651 17,473	7 —	1.02×10^{13}	6.75×10^{16}	6.24	0.98
		1.6% FO	20 14	(29) (20)	3 3	6,706 21,780	44 67	4.45×10^{9}	1.29×10^{10}	3.07	0.57
	Plant	1.6% FO	28 13	(41) (19)	3 3	1,052 84,561	10 19	1.81×10^{11}	5.26×10^{14}	5.71	0.98
		2.0% FO	40 16	(58) (23)	3 3	451 40,005	13 35	2.71×10^{10}	2.28×10^{13}	4.85	0.98
		2.0% FO**	30 13	(43) (19)	3 3	768 72,432	3 16	7.59×10^{10}	1.47×10^{14}	5.42	0.98
		1.6% R	26 20	(38) (29)	3 3	12,150 50,140	18 27	5.16×10^{11}	7.45×10^{14}	5.35	0.94
		1.6% R**	51 20	(74) (29)	2 2	312 19,808	— —	1.18×10^{10}	5.56×10^{12}	4.43	0.98
		2.5% AC-3	50 30	(72) (43)	3 3	1,383 25,565	20 12	7.93×10^{12}	2.03×10^{16}	5.72	0.98
		3.0% AC-3	40 25	(58) (36)	3 3	4,459 44,680	31 11	3.55×10^{11}	3.79×10^{14}	4.96	0.96
		3.0% AC-3**	50 28	(72) (41)	3 3	2,307 102,144	35 6	4.00×10^{14}	3.47×10^{18}	6.60	0.98
21 US 281	Cores	1.5% AC-20	15 11	(22) (16)	5 6	15,550 46,054	34 67	1.25×10^{7}	3.96×10^{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
FO = Flux Oil

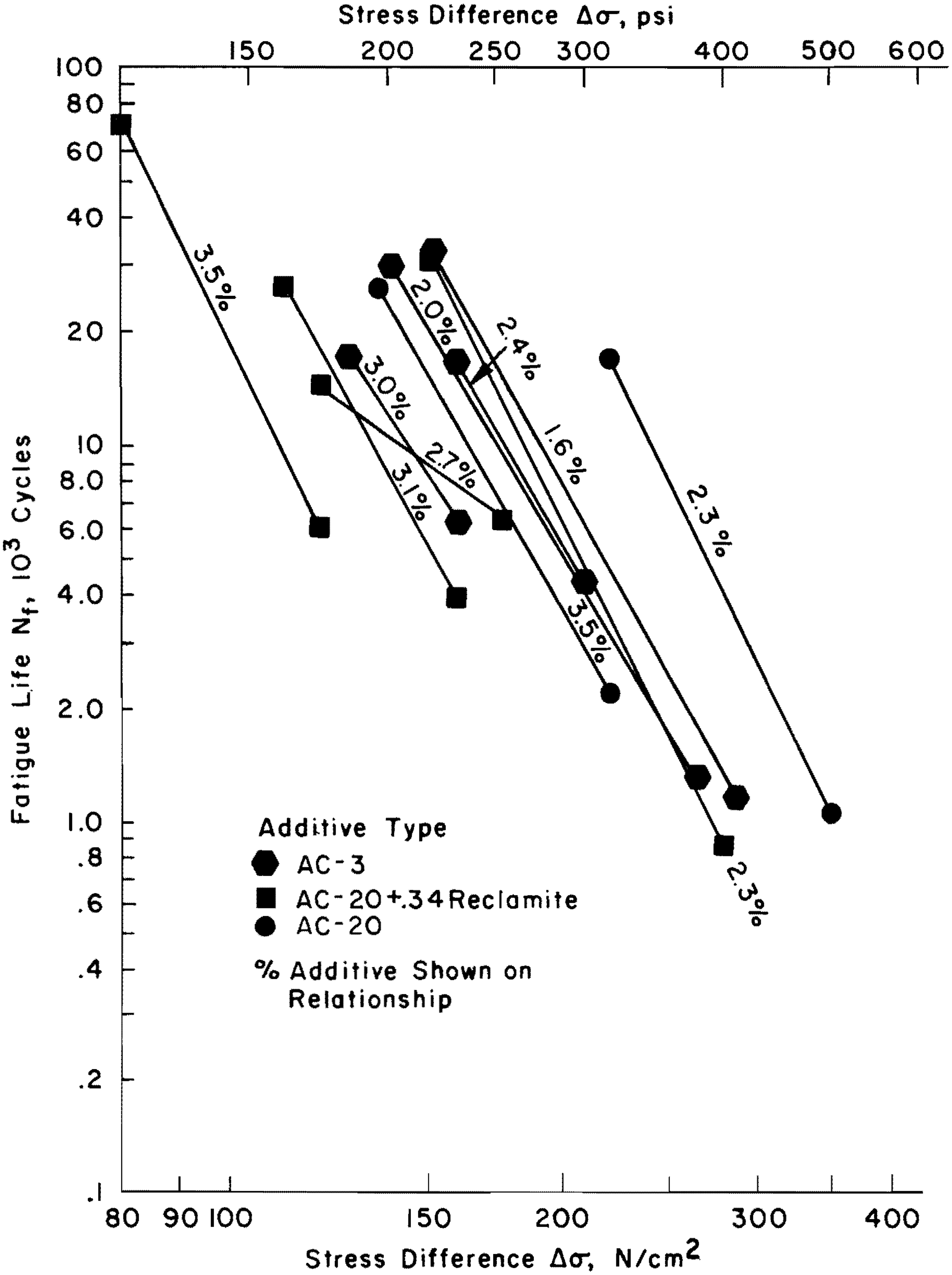


Fig 13. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from IH 20 - District 8 (laboratory specimens).

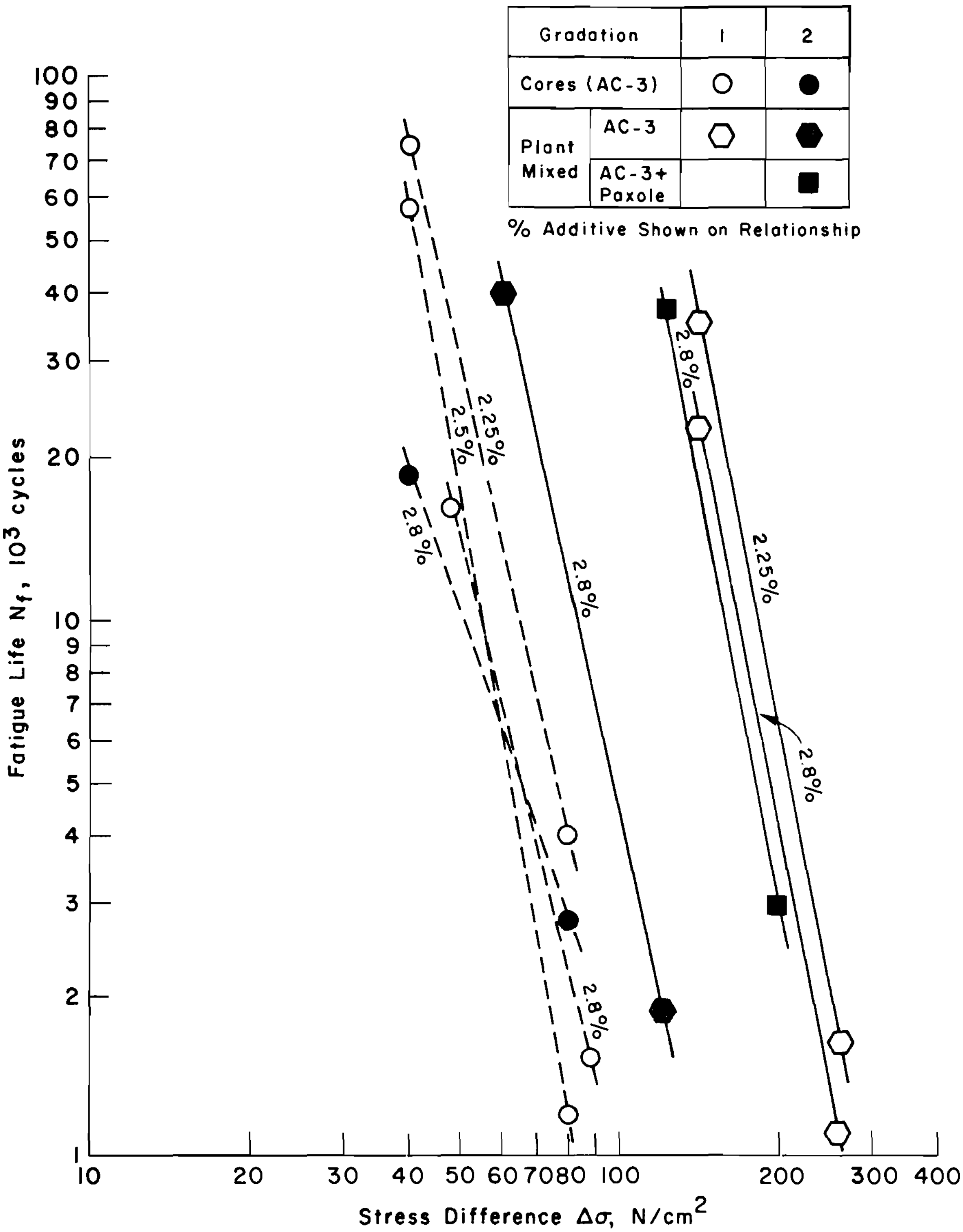


Fig 14. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from IH 20 - District 8 (cores and plant mixed specimens).

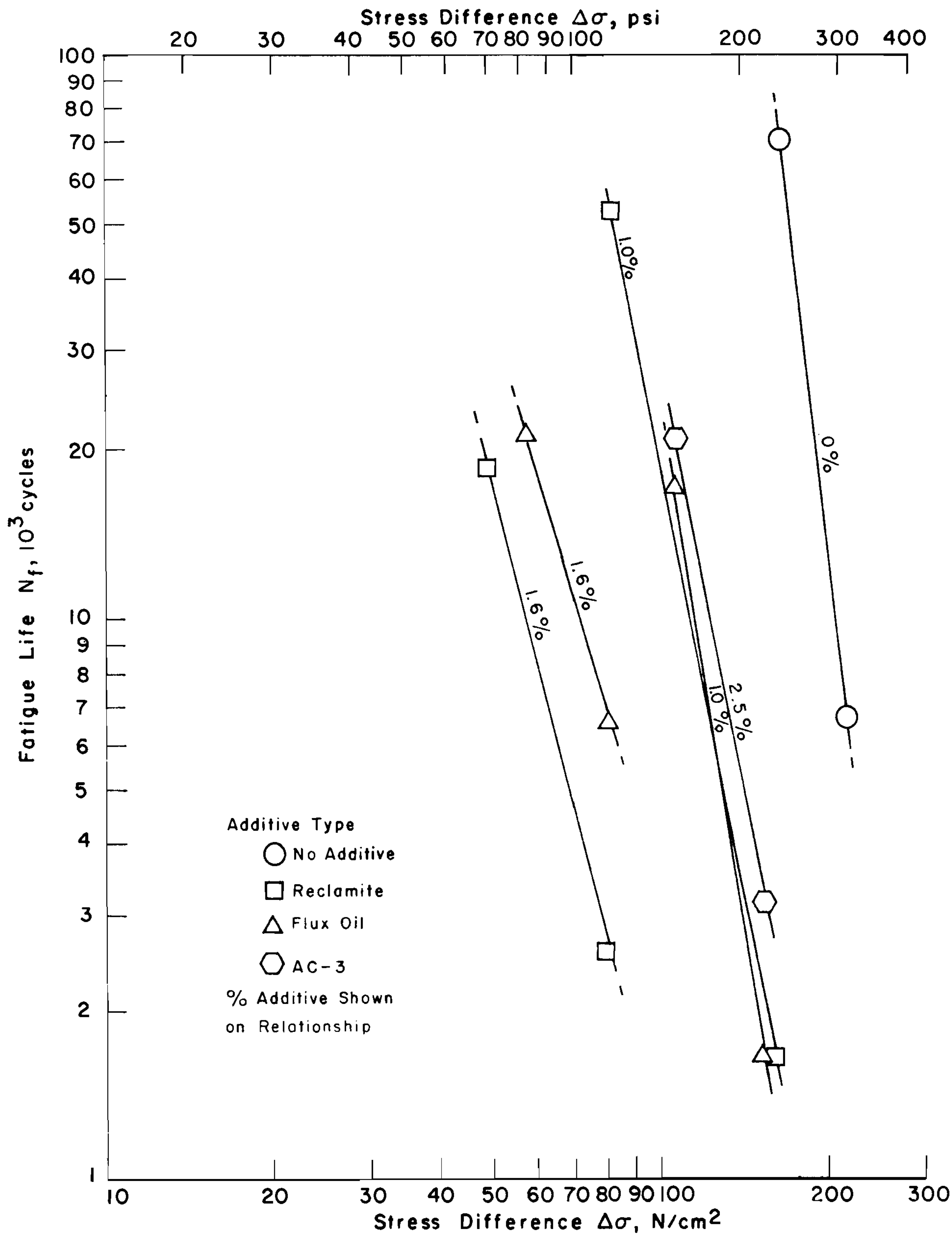


Fig 15. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures from Loop 374 - District 21 (laboratory specimens).

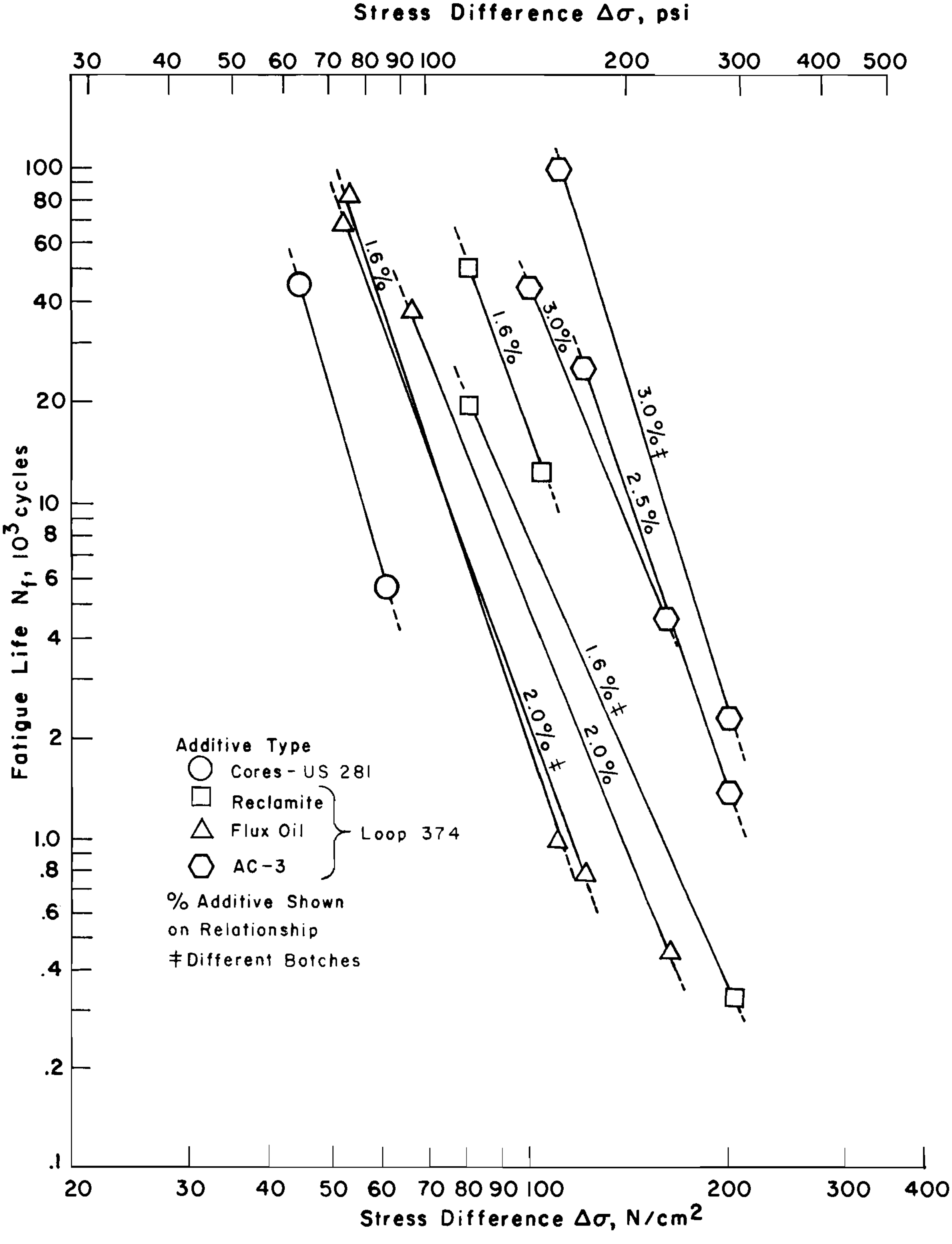


Fig 16. Relationships between the logarithms of fatigue life and stress difference for recycled mixtures (plant mixed specimens from Loop 374 and cores from US 281 - District 21).

where

N_f = fatigue life, cycles,

σ_T = applied tensile stress, N/cm^2,

$\Delta\sigma$ = stress difference $\simeq$ $4\sigma_T$, N/cm^2,

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.

Previous studies (Refs 1 and 25) have shown that results from Eq 4.2 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.

Values of the constants n_2 , K_2 , and K_2' are summarized in Table 9. Values of n_2 ranged from 2.15 to 8.07. These values were in the same range, although slightly higher than those previously reported for conventional pavement materials. Monismith et al (Refs 18 and 19) reported values ranging from 1.85 to 6.06. Navarro and Kennedy (Ref 20) reported values ranging from 1.58 to 5.08, and Rodriguez and Kennedy (Ref 29) reported values ranging from 1.24 to 2.28. Since $\frac{1}{\sigma}$ is always less than 1.0, high values of n_2 generally would indicate lower values of fatigue life.

Values of K_2' ranged from 3.96×10^8 to 1.11×10^{23}. These values were also higher than those for previously reported mixtures produced using conventional methods and materials. Navarro and Kennedy (Ref 19) reported values of K_2' ranging from 1.38×10^6 to 1.24×10^{15}, and Monismith et al (Refs 18 and 19) reported values in the range of 4.02×10^7 to 4.31×10^{17}. Adedimila and Kennedy (Ref 1), for laboratory specimens at the optimum asphalt content, reported average values of K_2' of 3.68×10^9 for gravel mixtures and 1.44×10^9 for limestone mixtures. Rodriguez and Kennedy (Ref 29) reported values of K_2' in the range of 7.05×10^5 to 2.52×10^8 for dryer-drum field-prepared specimens.

Thus, the fatigue lives generally were longer for the recycled mixtures. This observation is confirmed by the logarithmic relationships shown in Figs 13, 14, 15, and 16 and as indicated by the K_2' values. However, a small increase in the stress level would substantially decrease the fatigue life as evidenced by the large n_2 values.

The coefficients of variation of fatigue life for compacted specimens (Table 9) ranged from 3 to 67 percent; these values are in general agreement with those reported by Navarro and Kennedy (Ref 20) for cores and Rodriguez and Kennedy (Ref 28) for field mixed specimens. These values, however, were based on only three observations. Thus, the variations for these laboratory specimens are similar to those obtained with conventional field mixed specimens and cores, indicating that a greater amount of variation may occur in recycled mixtures. The range for the cores of recycled mixtures was 4 to 92 percent.

STRENGTH AND STATIC ELASTIC PROPERTIES

Estimates of tensile strength, modulus of elasticity, and Poisson's ratio were determined using the static indirect tensile test. Table 10 summarizes the static test results and includes the means and coefficients of variation, which are probably not very meaningful because of the small number of specimens tested.

Values of tensile strength, modulus of elasticity, and Poisson's ratio are summarized in Table 11 along with values previously reported by Adedimila and Kennedy for laboratory specimens (Ref 1), Navarro and Kennedy for cores from inservice pavements (Ref 20), and Rodriguez and Kennedy for dryer-drum prepared specimens (Ref 29).

Strength and moduli obtained for recycled mixtures generally were slightly larger than values obtained previously for conventional mixtures. Thus, in terms of static elastic and strength properties, the recycled material should perform as well as the conventional mixtures.

REPEATED-LOAD TEST RESULTS

As reported by Adedimila and Kennedy (Ref 1), the relationship between permanent deformation and the number of load applications is linear between 10 and 80 percent of the fatigue life, and, after a conditioning period, the

TABLE 10. SUMMARY OF STATIC TEST RESULTS

District Project	Preparation, Aggregate	Treatment	Number of Specimens	Ultimate Tensile Strength Mean, N/cm^2 (psi)		Ultimate Tensile Strength CV, %	Static Modulus of Elasticity Mean, 10^3 N/cm^2 (10^3 psi)		Static Modulus of Elasticity CV, %	Static Poisson's Ratio Mean	Static Poisson's Ratio CV, %
8 IH 20	Laboratory Gradation 1	3.0% AC-3	2	104	(150)	—	61	(89)	—	0.09	—
		2.4% AC-3	2	156	(225)	—	143	(206)	—	0.04	—
		2.0% AC-3	2	176	(254)	—	186	(270)	—	0.17	—
		1.6% AC-3	2	191	(227)	—	220	(319)	—	0.11	—
		3.5% AC-20 0.34% R	3	84	(122)	12	87	(125)	10	—	—
		3.1% AC-20 0.34% R	2	136	(197)	—	132	(191)	—	—	—
		2.7% AC-20 0.34% R	4	146	(212)	4	147	(213)	34	—	—
		2.3% AC-20 0.34% R	4	174	(251)	11	190	(275)	27	—	—
		3.5% AC-20	2	137	(198)	—	98	(142)	—	0.14	—
		2.3% AC-20	2	217	(315)	—	235	(341)	—	0.12	—
		2.5% AC-20 0.20% R	2	181	(262)	—	165	(239)	—	0.12	—
		None*	3	191	(277)	14	201	(290)	37	—	—
	Plant Gradation 1	2.25% AC-3	3	174	(253)	5	236	(342)	7	0.23	16
		2.8% AC-3	3	180	(261)	12	259	(376)	21	0.27	12
	Plant Gradation 2	2.8% AC-3	3	85	(123)	3	62	(90)	8	0.28	86
		2.8% AC-3+ Paxole	3	127	(184)	1	134	(194)	20	0.16	23
	Cores Gradation 1	2.0% AC-3 Design #1	3	61	(89)	11	72	(105)	23	0.32	8
		2.25% AC-3 Design #2	3	60	(87)	23	64	(93)	35	0.18	62
		2.25% AC-5 Design #2A	4	66	(96)	4	87	(126)	13	0.25	58
		2.5% AC-3 Design #3	2	54	(78)	—	62	(90)	—	0.24	—
		2.8% AC-3 Design #4	2	53	(77)	—	52	(75)	—	0.28	—
		3.0% AC-3 Design #5	—	—	—	—	—	—	—	—	—
	Cores Gradation 2	2.8% AC-3 Design #6	5	49	(71)	9	89	(129)	14	0.16	83
		2.8% AC-3+ Paxole Design #7	2	54	(78)	—	127	(184)	—	0.27	—

*Recycled material was heated and compacted without additives or new aggregate
R = Reclamite
FO = Flux Oil

(continued)

TABLE 10. (Continued)

District Project	Preparation, Aggregate	Treatment	Number of Specimens	Ultimate Tensile Strength Mean, N/cm^2 (psi)	Ultimate Tensile Strength CV, %	Static Modulus of Elasticity Mean, 10^3 N/cm^2 (10^3 psi)	Static Modulus of Elasticity CV, %	Static Poisson's Ratio Mean	Static Poisson's Ratio CV, %
21 Loop 374	Laboratory	None*	3	220 (319)	4	270 (392)	6	—	—
		2.5% AC-3	3	147 (213)	3	169 (245)	7	0.37	15
		1.0% R	3	124 (180)	7	153 (222)	10	0.30	3
		1.6% R	3	84 (122)	23	101 (146)	20	0.27	22
		1.0% FO	3	108 (157)	23	95 (138)	16	0.23	29
		1.6% FO	3	82 (118)	4	83 (120)	22	0.25	71
	Plant	1.6% FO	3	86 (125)	4	77 (111)	10	0.36	10
		2.0% FO	3	104 (150)	8	90 (130)	26	0.33	14
		2.0% FO**	3	86 (125)	3	69 (100)	10	0.28	24
		1.6% R	3	130 (188)	2	44 (64)	4	0.33	18
		1.6% R**	3	128 (185)	11	97 (140)	39	0.33	20
		2.5% AC-3	3	165 (239)	5	124 (179)	4	0.28	18
		3.0% AC-3	3	191 (277)	2	147 (213)	6	0.23	4
		3.0% AC-3**	3	154 (223)	3	119 (172)	10	0.32	16
21 US 281	Cores	1.5% AC-20	7	56 (81)	39	40 (57)	55	0.03	459
			Range	49 - 220 (71 - 379)	1-23	40 - 270 (57 - 392)	4-55	0.03-0.37	3-86

*Recycled material was heated and compacted without additives or new aggregate
**Duplicate treatments sampled from different plant batches
R = Reclamite
FO = Flux Oil

TABLE 11. COMPARISON OF STATIC STRENGTHS AND ELASTIC PROPERTIES

Type of Specimens	Tensile Strength, N/cm^2 (psi)	Modulus of Elasticity, 10^3 N/cm^2 (10^3 psi)	Poisson's Ratio	Source
Recycled	49-220* (71-319)	40-270 (57-392)	0.03-0.37	-
Inservice cores	42-109** (61-158)	32-116 (46-168)	0.03-0.35	Ref 20
Laboratory specimens+	100-113* (145-164)	80-136 (116-197)	0.08-0.20	Ref 1
Dryer-drum	42-102* (61-148)	56-183 (81-265)	0.14-0.42	Ref 29

Testing Temperature = 24°C (75°F)

*Ultimate tensile strength

**Tensile strength at first inflection point

+At optimum asphalt content

modulus of elasticity decreases with an increase in the number of load applications. For this study, the elastic properties were determined at approximately 50 percent of fatigue life. Table 12 summarizes test values and coefficients of variation.

Resilient Modulus of Elasticity

The means and coefficients of variation of the resilient modulus of elasticity for each project, treatment, and stress are shown in Table 12. The values of the mean ranged from 172×10^3 to 692×10^3 N/cm^2 (249×10^3 to 1003×10^3 psi), with the coefficient of variation ranging from 2 to 27 percent. For dryer drum mixtures Rodriquez and Kennedy (Ref 29) reported values ranging from 128×10^3 to 349×10^3 N/cm^2 (185×10^3 to 506×10^3 psi) with coefficients of variation of 3 to 19 percent. For inservice blackbase and asphalt concrete tested at 24° C (75° F), moduli ranged from 152 to 424×10^3 N/cm^2 (221 to 615×10^3 psi) with a coefficient of variation of 4 to 28 percent (Ref 20). For laboratory prepared specimens the range was 207 to 345×10^3 N/cm^2 (300 to 500×10^3 psi) (Ref 1). Thus, the moduli for this study were higher than those reported in previous evaluations of conventional mixtures.

Resilient Poisson's Ratio

The values for resilient Poisson's ratio ranged from 0.04 to 0.68 (Table 12). Previously reported values (Ref 20) of resilient Poisson's ratio for field cores of asphalt concrete were 0.44 and 0.57. Adedimila and Kennedy (Ref 1) reported values of resilient Poisson's ratio ranging from 0.04 to 0.20 for laboratory prepared specimens tested at 24° C (75° F). Thus, the values of the resilient Poisson's ratio found in this study overlapped values previously reported for conventional mixtures.

EFFECTIVE OF ADDITIVE CONTENT

Essentially, the design of recycled mixtures involves determining the type of additive and the amount of additive.

As a construction requirement the amount of additive must be sufficient in volume, and the viscosity low enough, to wet and penetrate uniformly the crushed asphalt pavement to be recycled.

TABLE 12. SUMMARY OF REPEATED-LOAD ELASTIC PROPERTIES

District Project	Preparation, Aggregate	Treatment	Stress Level, N/cm^2 (psi)	Number of Specimens	Resilient Modulus of Elasticity: Mean, 10^3 N/cm^2 (10^3 psi)	Resilient Modulus of Elasticity: Coefficient of Variation, %	Resilient Poisson's Ratio: Mean	Resilient Poisson's Ratio: Coefficient of Variation, %
8 IH-20	Laboratory Gradation 1	3.0 % AC-3	40 (58)	2	327 (474)	—	0.17	—
			32 (46)	2	310 (450)	—	0.05	—
		2.4 % AC-3	52 (75)	2	394 (571)	—	0.09	—
			40 (58)	3	384 (557)	10	0.13	20
		2.0 % AC-3	66 (96)	2	458 (664)	—	0.16	—
			35 (51)	2	365 (529)	—	0.04	—
		1.6 % AC-3	72 (104)	2	433 (628)	—	0.13	—
			38 (55)	3	407 (590)	3	0.20	60
		3.5 % AC-20	30 (44)	2	441 (640)	—	0.20	—
		0.34% R	20 (29)	2	405 (587)	—	0.34	—
		3.1 % AC-20	40 (58)	2	419 (608)	—	0.11	—
		0.34% R	28 (41)	3	445 (645)	19	0.22	52
		2.7 % AC-20	45 (65)	2	444 (644)	—	0.12	—
		0.34% R	30 (44)	2	455 (660)	—	0.14	—
		2.3 % AC-20	70 (102)	2	518 (751)	—	0.42	—
		0.34% R	38 (55)	2	414 (600)	—	0.17	—
		3.5 % AC-20	55 (80)	2	500 (725)	—	0.19	—
			34 (49)	2	546 (792)	—	0.14	—
		2.3 % AC-20	87 (126)	2	533 (773)	—	0.13	—
			55 (80)	2	550 (798)	—	0.21	—
		2.5 % AC-20	72 (104)	2	369 (535)	—	0.19	—
		0.20% R	41 (59)	2	458 (664)	—	0.15	—
		None*	72 (104)	2	618 (896)	—	0.38	—
			45 (65)	2	521 (755)	—	0.20	—

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

R = Reclamite

(Continued)

TABLE 12. (Continued)

District Project	Preparation, Aggregate	Treatment	Stress Level, N/cm^2 (psi)	Number of Specimens	Resilient Modulus of Elasticity: Mean, 10^3 N/cm^2 (10^3 psi)	Resilient Modulus of Elasticity: Coefficient of Variation, %	Resilient Poisson's Ratio: Mean	Resilient Poisson's Ratio: Coefficient of Variation, %
8 IH-20	Plant Gradation 1	2.25% AC-3	65 (94)	3	494 (716)	3	0.19	87
			35 (51)	4	535 (775)	14	0.30	16
		2.8 % AC-3	65 (94)	3	515 (747)	2	0.36	23
			35 (51)	3	484 (702)	7	0.27	52
	Plant Gradation 2	2.8 % AC-3	30 (44)	3	509 (738)	27	0.45	19
			15 (22)	2	332 (481)	—	0.38	—
		2.8 % AC-3+ Paxole	50 (73)	3	651 (944)	11	0.26	46
			30 (44)	2	634 (920)	—	0.37	—
	Cores Gradation 1	2.25% AC-3 (Design #2)	20 (29)	3	352 (511)	18	0.44	22
			10 (15)	2	402 (584)	—	0.43	—
		2.5 % AC-3 (Design #3)	20 (29)	2	306 (444)	—	0.59	—
			10 (15)	2	335 (486)	—	0.43	—
		2.8 % AC-3 (Design #4)	22 (32)	2	267 (387)	—	0.31	—
			12 (17)	2	284 (412)	—	0.25	—
	Cores Gradation 2	2.8 % AC-3 (Design #6)	20 (29)	3	326 (473)	5	0.38	8
			10 (15)	3	306 (444)	13	0.36	13
21 Loop 374	Laboratory	None*	57 (83)	2	692 (1003)	—	—	—
			40 (58)	2	465 (674)	—	—	—
		2.5 % AC-3	38 (55)	3	310 (450)	6	0.34	19
			26 (38)	3	313 (454)	5	0.37	40
		1.0 % R	40 (58)	3	337 (489)	8	0.41	17
			20 (29)	2	305 (442)	—	—	—
		1.6 % R	20 (29)	3	246 (357)	16	0.68	17
			12 (17)	3	228 (331)	15	0.52	23

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

R = Reclamite

(Continued)

TABLE 12. (Continued)

District Project	Preparation, Aggregate	Treatment	Stress Level, N/cm^2 (psi)	Number of Specimens	Resilient Modulus of Elasticity: Mean, 10^3 N/cm^2 (10^3 psi)	Resilient Modulus of Elasticity: Coefficient of Variation, %	Resilient Poisson's Ratio: Mean	Resilient Poisson's Ratio: Coefficient of Variation, %
21 Loop 374	Laboratory	1.0 % FO	38 (55)	3	278 (403)	5	0.41	30
			26 (38)	2	245 (355)	—	0.35	—
		1.6 % FO	20 (29)	3	211 (306)	5	0.51	7
			14 (20)	3	184 (267)	12	0.36	28
	Plant	1.6 % FO	28 (41)	3	172 (249)	5	0.39	15
			13 (19)	3	217 (314)	5	0.43	3
		2.0 % FO	40 (58)	3	200 (290)	5	0.32	21
			16 (23)	3	188 (272)	6	0.22	34
		2.0 % FO	30 (44)	3	174 (252)	3	0.33	24
			13 (19)	3	207 (300)	10	0.25	25
		1.6 % R	26 (38)	3	265 (384)	2	0.32	13
			20 (29)	3	261 (378)	9	0.35	22
		1.6 % R	51 (74)	2	275 (399)	—	0.37	—
			20 (29)	2	237 (344)	—	0.30	—
		2.5 % AC-3	50 (72)	3	305 (442)	5	0.31	27
			30 (44)	3	285 (413)	12	0.17	27
		3.0 % AC-3	50 (72)	3	330 (478)	9	0.20	8
			28 (41)	3	339 (492)	6	0.15	22
		3.0 % AC-3	40 (58)	3	358 (519)	7	0.35	15
			25 (36)	3	307 (445)	3	0.30	8
21 US 281	Cores	1.5 % AC-20	15 (22)	5	224 (325)	9	0.33	4
			11 (16)	6	260 (377)	6	0.35	31
				Range	172 - 692 (249 - 1003)	2 - 27	0.04 - 0.68	3 - 87

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

R = Reclamite

FO = Flux oil

The effects of the amount and type of additive on the tensile strength, static modulus of elasticity, resilient modulus of elasticity, and fatigue life for the three projects are summarized below. Generally, all three properties decreased linearly with an increase in the amount of additive. For District 21 the no additive point was a common point for the three additives. As indicated in Tables 9, 10, and 12, for District 8, mixtures having additives comprised of AC-3 and Paxole generally had higher fatigue lives, tensile strength, and modulus of elasticity values than corresponding mixtures having additives comprised of only AC-3.

Tensile Strength

The relationships between indirect tensile strengths and amount and types of additive added to the original mix are shown in Fig 17. A linear relationship exists in the ranges used for this study, with strength decreasing linearly with increasing amounts of additive. The values of R^2 varied between 0.89 and 0.98.

Modulus of Elasticity

The effect of additive content on the modulus is illustrated in Fig 18, in which it is evident that the modulus decreased linearly with increasing amounts of additive. The values of R^2 computed from a correlation analysis varied from 0.90 to 0.98.

Resilient Modulus of Elasticity

The relationships between resilient modulus and additive content were also linear, as shown in Fig 19. The effect of additive type is more evident for resilient modulus than for static modulus and tensile strength. The mean values were different, and a large difference exists between slopes. Values of R^2 ranged from 0.90 to 0.99.

Fatigue Life

The relationships between fatigue life, at a specific stress level, and additive content are shown in Fig 20. The linear relationship is evident, and the values of R^2 ranged from 0.96 to 1.0. Here it is necessary to compare not only the actual values of fatigue life but the slopes. A steep slope indicates that fatigue life is very sensitive to a small change of additive.

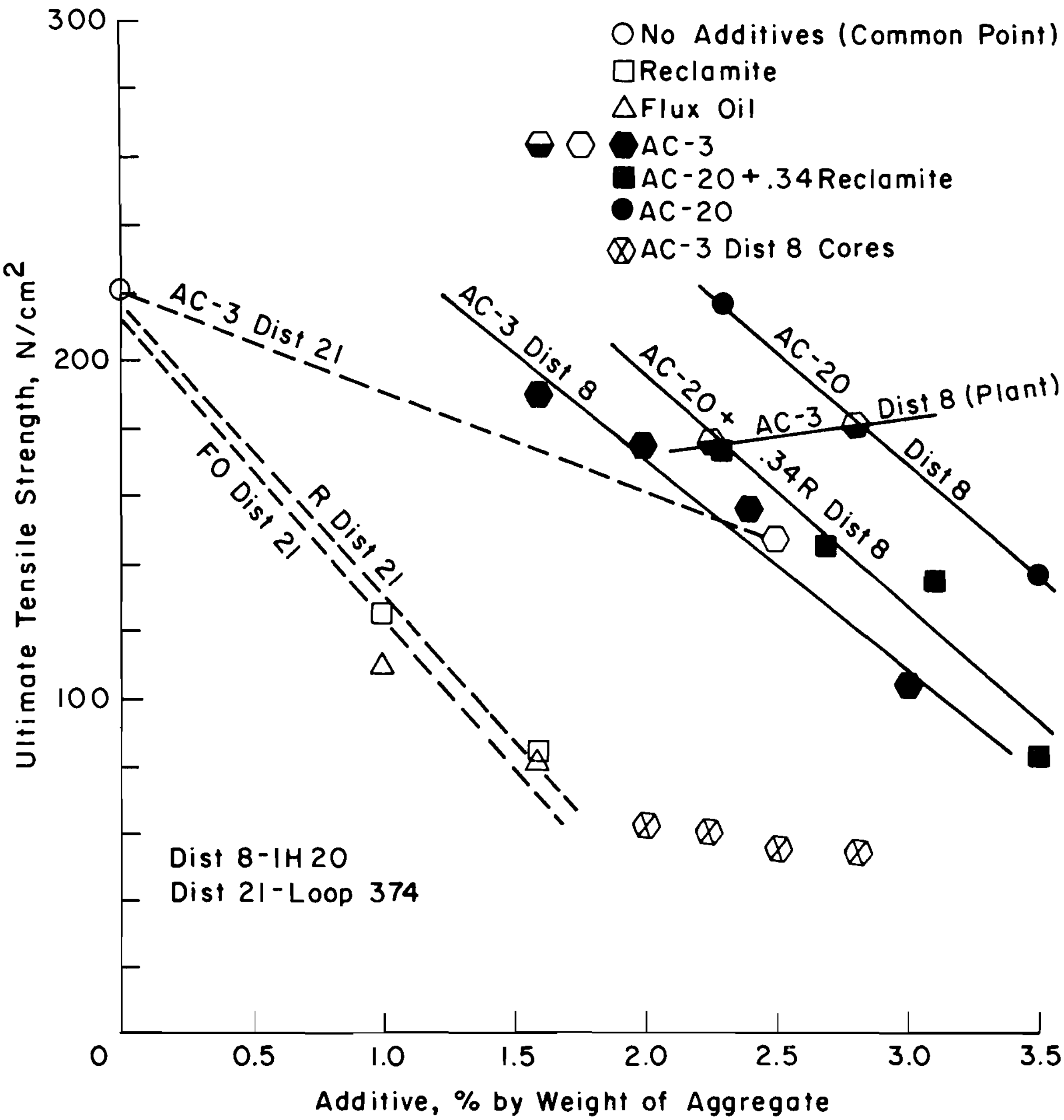


Fig 17. Effects of the amount of additive on tensile strength of laboratory and field mixtures.

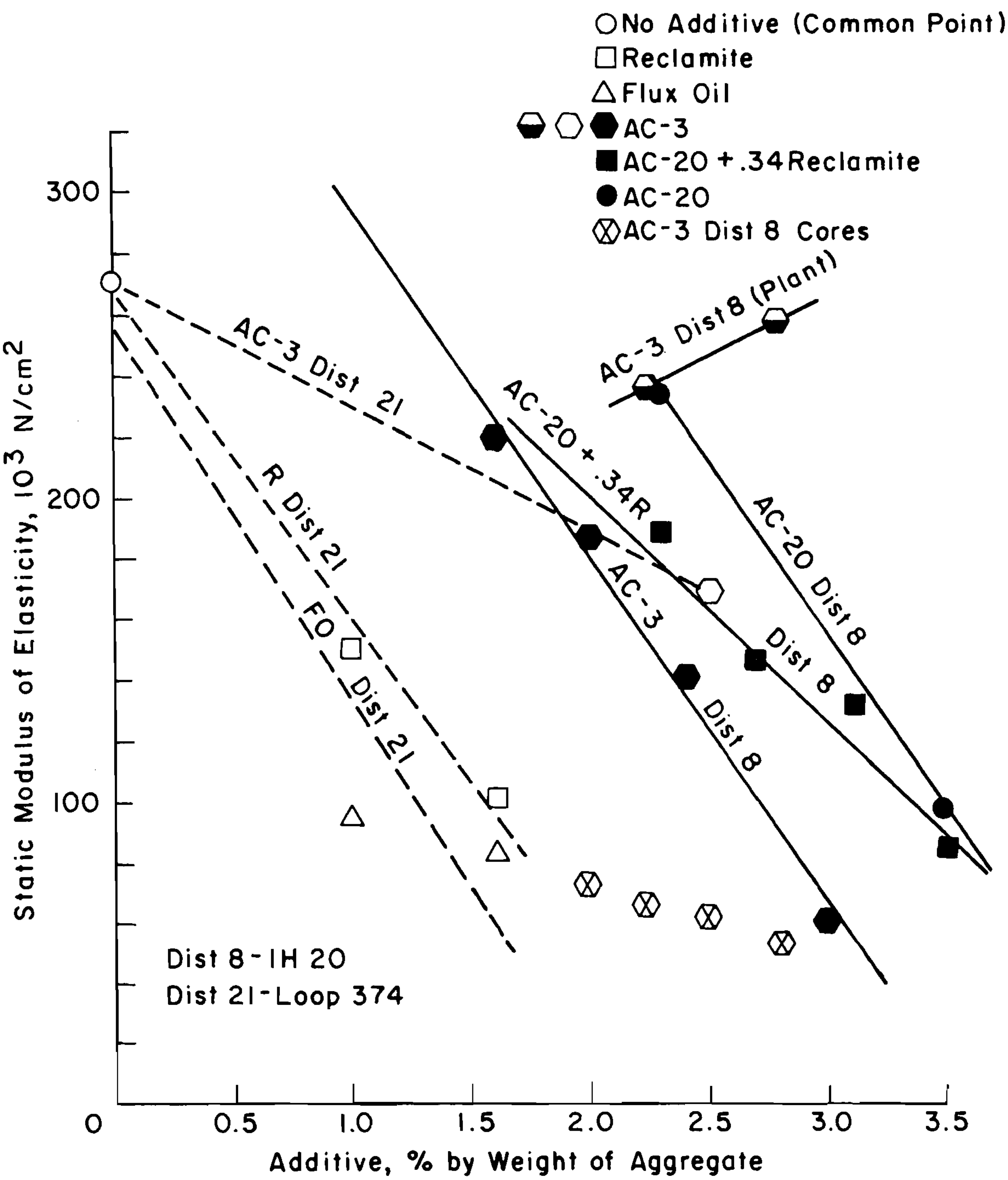


Fig 18. Effects of the amount of additive on static modulus of elasticity of laboratory and field mixtures.

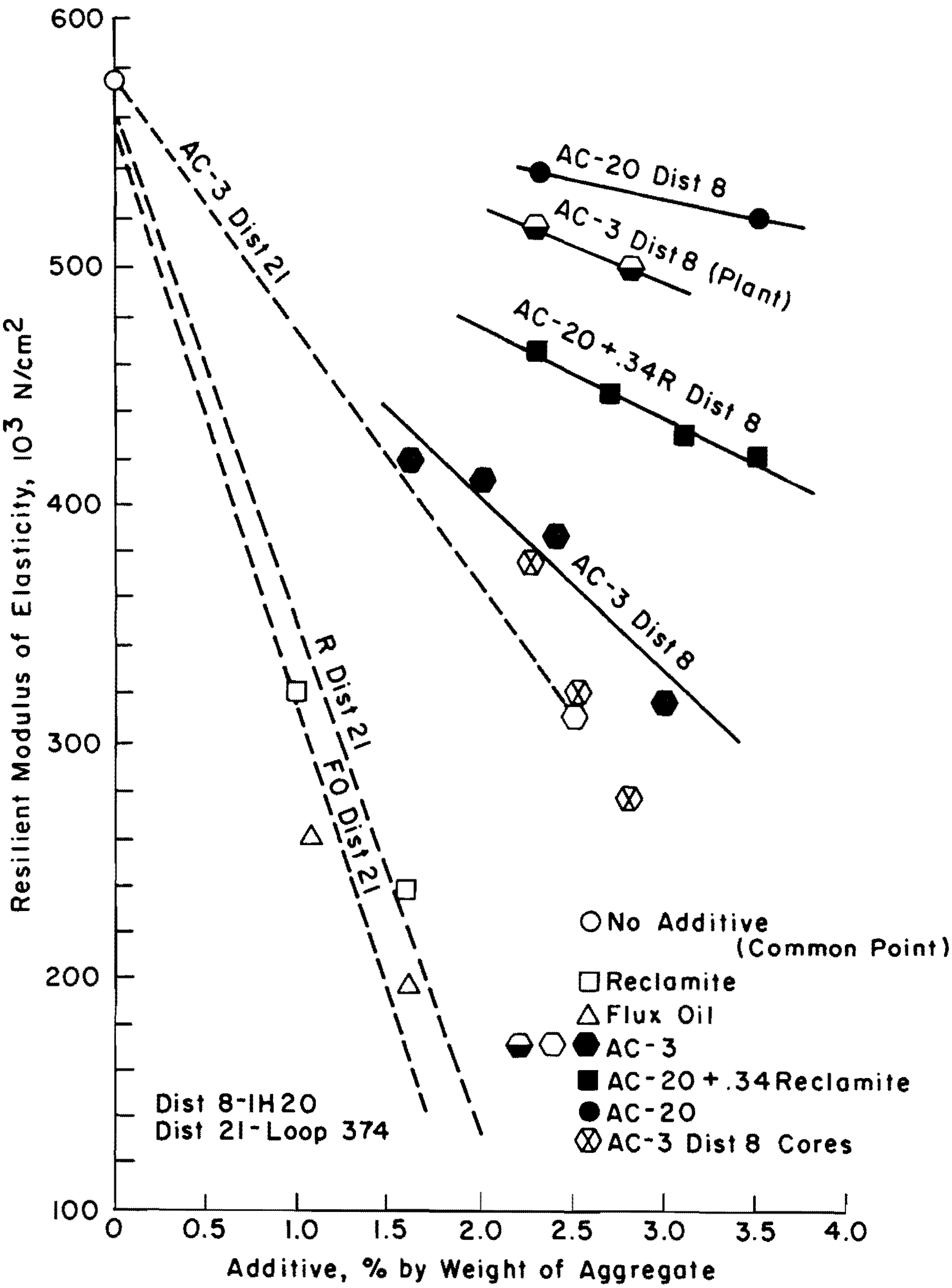


Fig 19. Effects of the amount of additive on resilient modulus of elasticity of laboratory and field mixtures.

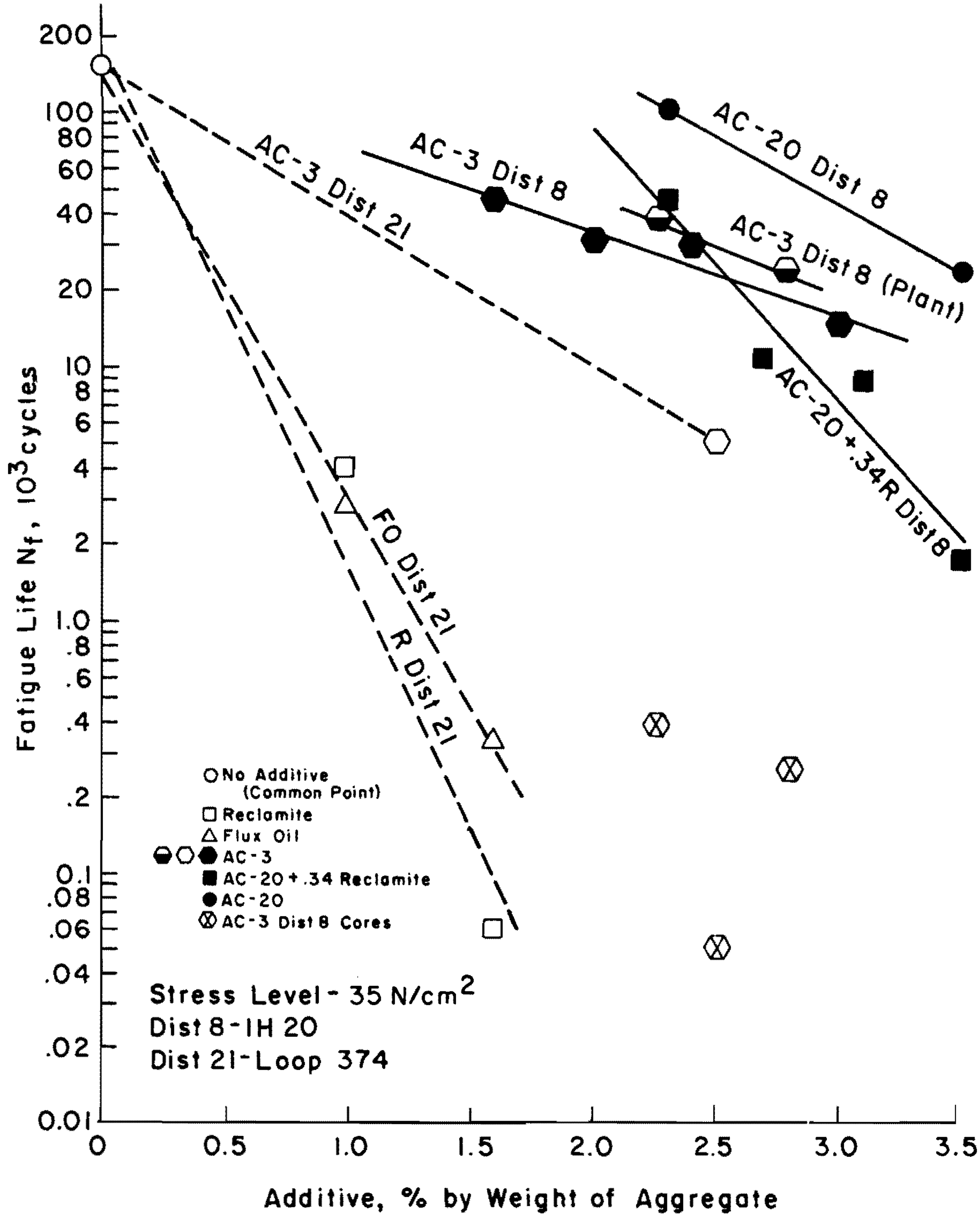


Fig 20. Effects of the amount of additive on fatigue life of laboratory and field mixtures.

This suggests the possible need for tighter control during construction to prevent variations that will affect the performance of the pavement.

CORRELATIONS

Previous studies on conventional asphalt mixtures have included correlations between

(1) fatigue life and tensile strain,
(2) fatigue life and stress/strength ratio,
(3) fatigue constants n and K ,
(4) K_2' and indirect tensile strength, and
(5) static modulus and tensile strength.

These same correlations will be evaluated to determine whether the behavior of recycled mixtures is similar to that of conventional mixtures and, if possible, whether they can be used for design.

Fatigue Life - Initial Tensile Strain Relationship

Previous investigations have shown that fatigue life is related to strain (Ref 16) and that fatigue life can be predicted in terms of initial strain (Refs 16 and 17). Saal and Pell (Ref 32) found that the relationship between the logarithm of strain and the logarithm of fatigue life was linear for constant stress loading. Navarro and Kennedy (Ref 20) evaluated the relationship between fatigue life and tensile strain for field core specimens. A relationship was established, indicating that a great deal of variation could be accounted for by the relationship, but there were substantial estimation errors, which would be expected if the relationship were used to predict fatigue life.

Adedimila and Kennedy (Ref 1) evaluated the relationship between the fatigue life and the initial strain, defined as repeated stress divided by the static modulus of elasticity. These relationships (Fig 21), which were considered relatively accurate, had a coefficient of determination of 0.70, indicating that a large error could be expected if the relationship was used to estimate fatigue life.

In this study tensile strains were estimated by dividing the tensile stress σ_T by the resilient modulus of elasticity E_R . The relationships between fatigue life and initial strain are shown in Fig 21. Coefficients

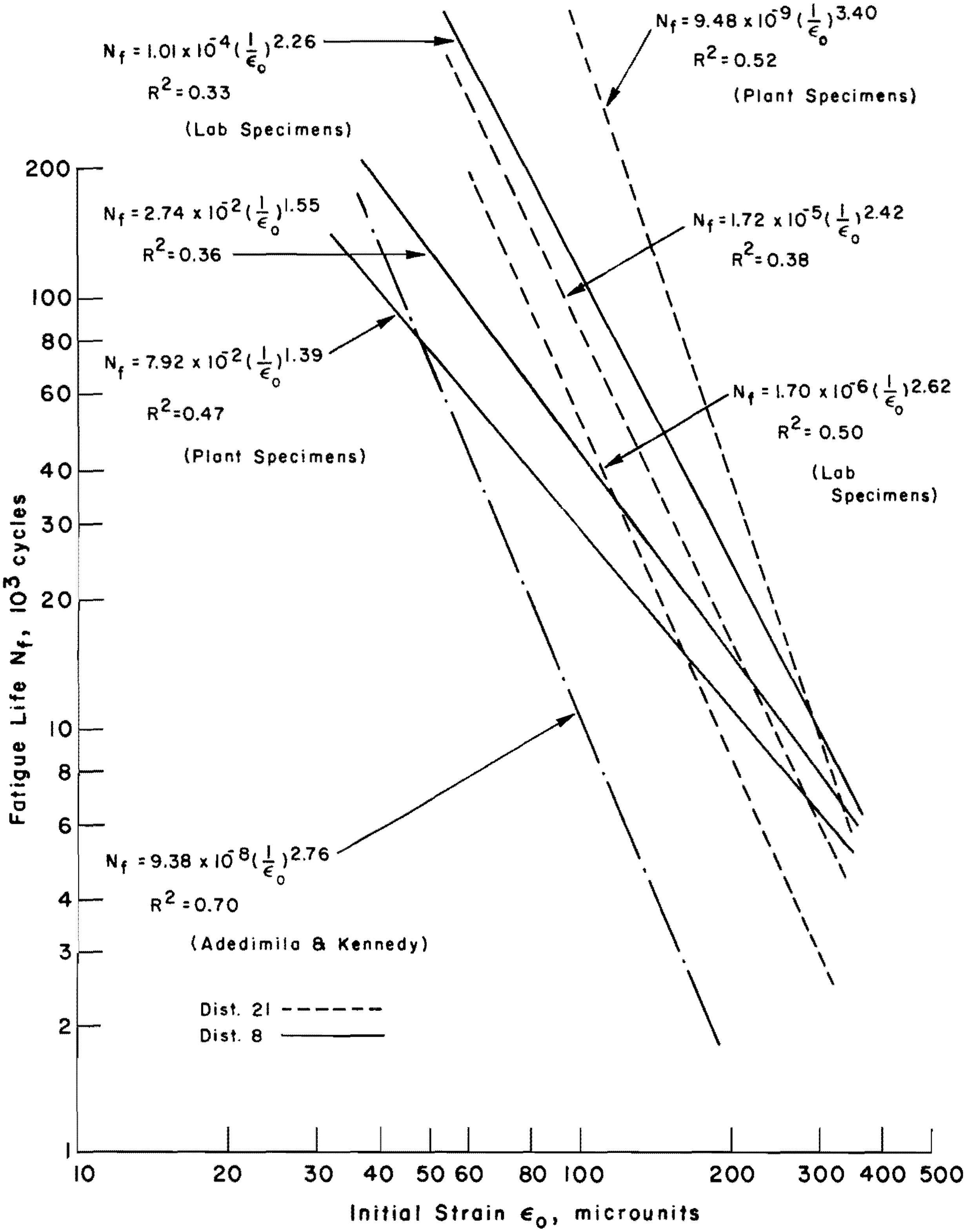


Fig 21. Relationships between fatigue life and initial strain.

of determination of 0.50 and 0.36 indicate that the correlation is weak. Also, a similarly weak correlation was obtained for the relationships between fatigue life and tensile strain. Thus, it was not possible to develop an acceptable relationship between fatigue life and tensile strain or between fatigue life and initial strain.

Stress-Strength Ratio

Previous studies have indicated that the relationship between fatigue life and the stress-strength ratio can be used to estimate fatigue life. Navarro and Kennedy (Ref 20) evaluated this relationship between fatigue life and stress-strength ratio for field core specimens and Adedimila and Kennedy (Ref 1) evaluated the relationship for laboratory processed specimens. The relationship between fatigue life and stress-strength ratio for this study is shown in Fig 22, along with the relationship reported by Adedimila and Kennedy.

The coefficients of determination R^2 for the projects in this study ranged from 0.46 to 0.85. These values are small compared with the previously reported value of 0.81 (Ref 1), indicating a weak relationship.

Relationships Between n_2 and K_2'

Adedimila and Kennedy (Ref 1) found that a linear relationship exists between n_2 and the logarithm of K_2' in the form

$$n_2 = A_2 + B_2 \log K_2'$$

treating n_2 as the dependent variable, or

$$\log K_2' = C_2 + D_2 n_2$$

treating K_2' as the dependent variable.

The relationships obtained for this study were

$$n_2 = -0.3191 + 0.3676 \log K_2'$$
$$(R^2 = 0.92,\ S_e = 0.34)$$

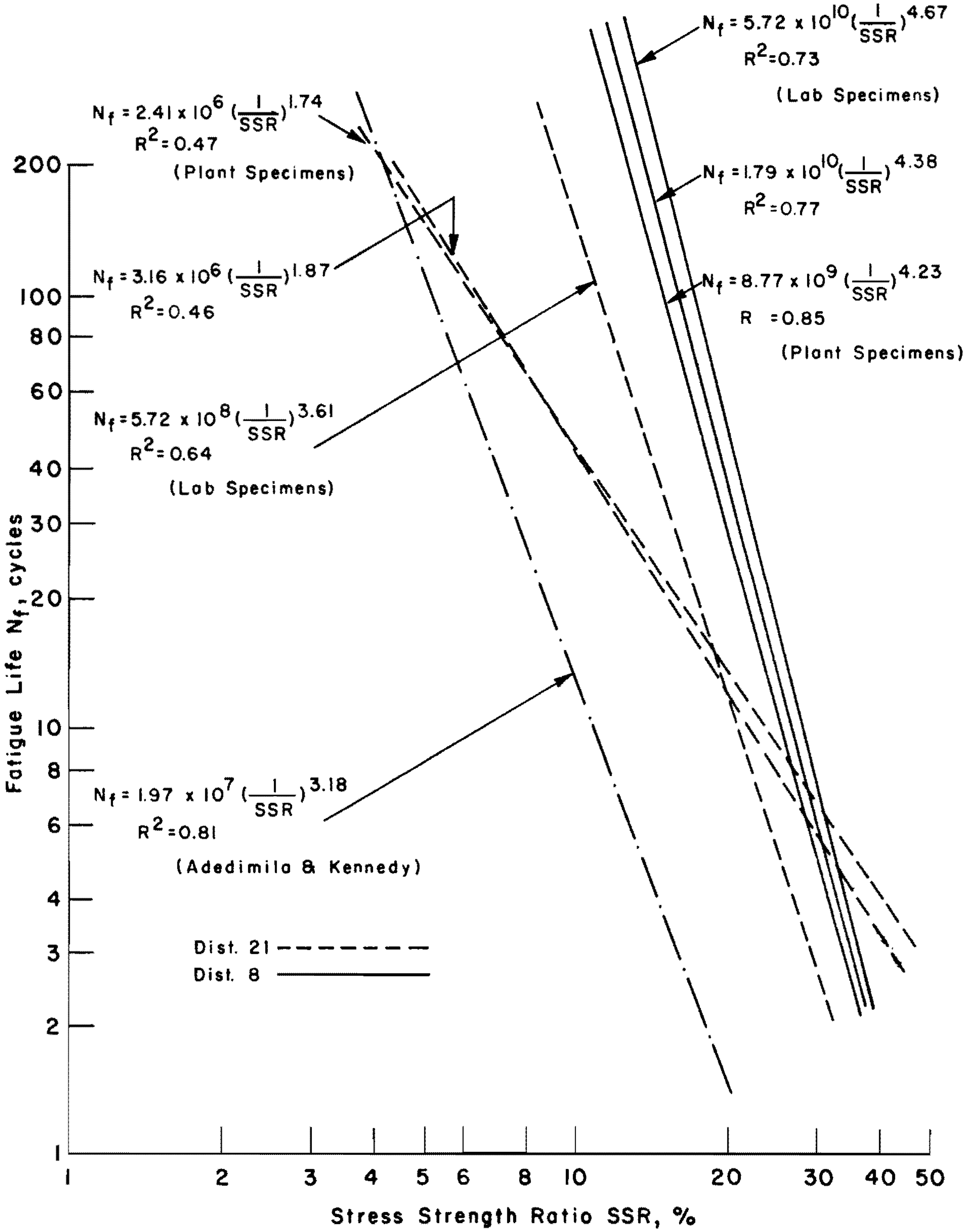


Fig 22. Relationships between fatigue life and stress-strength ratio.

and

$$\log K_2' = 1.9469 + 2.5061\ n_2$$
$$(R^2 = 0.92,\ S_e = 0.89)$$

Figure 23 illustrates the relationship between n_2 and log K_2' obtained for this study, along with those obtained by Adedimila and Kennedy (Ref 1), Navarro and Kennedy (Ref 20), and Rodriguez and Kennedy (Ref 29). The relationship obtained in this study showed a fairly high correlation, which is the same as reported in previous studies.

A correlation analysis was conducted for the values in Refs 1, 20, and 29 and in this study. The resulting relationships (Fig 24) were

$$n_2 = -0.4694 + 0.3763 \log K_2'$$
$$(R^2 = 0.96,\ S_e = 0.32)$$

and

$$\log K_2' = \log 1.6902 + 2.5458\ n_2$$
$$(R^2 = 0.96,\ S_e = 0.82)$$

Because of the high correlation coefficient obtained for the combination, it was felt that a relationship probably exists between n_2 and log K_2', which is consistent with the findings reported in Ref 1.

Relationships Between K_2' and Indirect Tensile Strength

An investigation conducted by Maupin (Ref 15) found a correlation between K_2 and indirect tensile strength for constant stress fatigue tests and it was suggested that this correlation could be used to estimate fatigue life. Thus, a similar correlation analysis was performed for K_2' and indirect tensile strength values obtained in this study.

The resulting relationship was

$$\log K_2' = 8.6418 + 0.0450\ S_T$$
$$(R^2 = 0.51,\ S_e = 2.23)$$

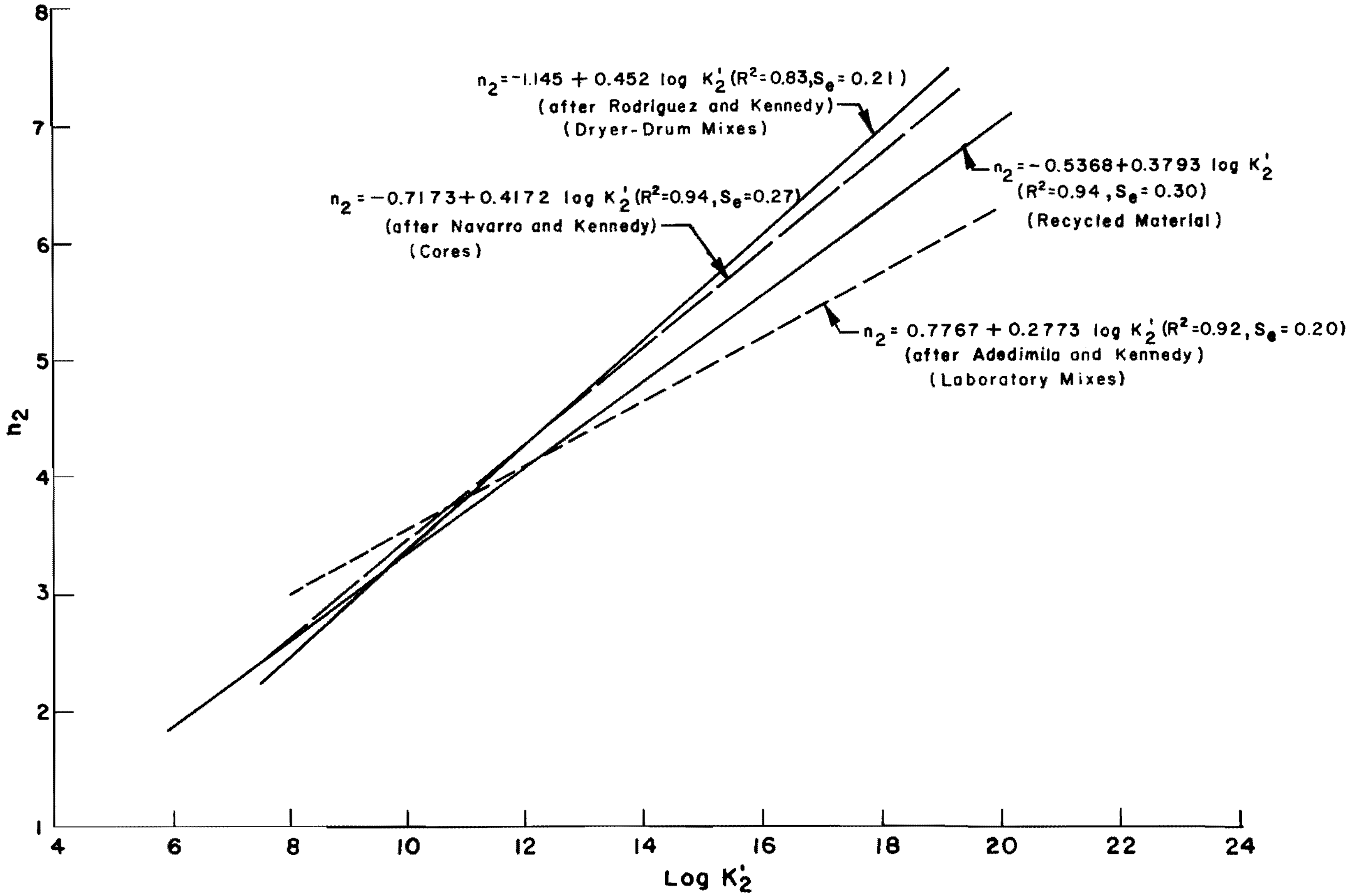


Fig 23. Relationship between n_2 and log K_2' for various studies.

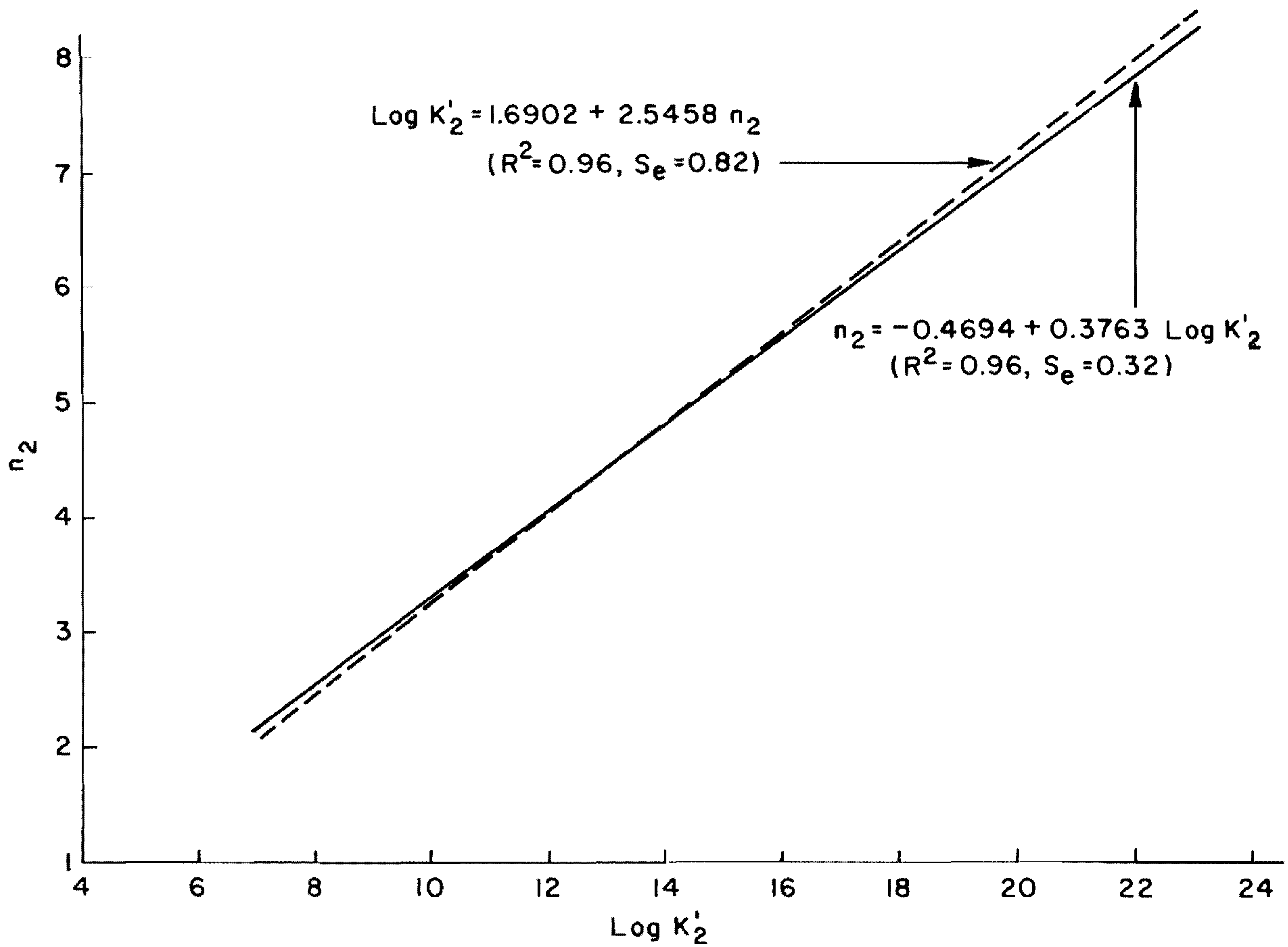


Fig 24. Combined relationships between n_2 and $\log K_2'$.

In addition, a regression analysis was conducted for the values obtained in previous studies (Refs 1 and 29) as well as this study. The resulting relationship obtained was

$$\log K_2' = 4.7278 + 0.0660\, S_T$$
$$(R^2 = 0.57,\ S_e = 2.75)$$

The relationship reported by Maupin (Ref 15) was

$$K_2 = e^{n_2 \ln (12.6\sigma_{IT} - 558)}$$
$$(R^2 = 0.28,\ S_e = 2.43)$$

where

σ_{IT} = indirect tensile strength, Pa.

Thus, it can be seen that there are significant differences between the form of the relationships and in the values of R^2 and S_e. Since the relationships could be very beneficial for estimating fatigue life, additional study is recommended.

Relationships Between Static Modulus and Tensile Strength

As previously reported by Adedimila and Kennedy (Ref 1), results from this study indicated a possible correlation between indirect tensile strength and static modulus of elasticity.

Such a relationship would be useful for those agencies which are not equipped to conduct the indirect tensile test with deformation measurements, such as the district laboratories of the State Department of Highways and Public Transportation. A regression analysis for modulus of elasticity and indirect tensile strength with modulus of elasticity as the dependent variable showed that an approximate linear relationship exists as follows:

$$E_S = 4946 + 986\, S_T$$
$$(R^2 = 0.73,\ S_e = 30907)$$

where

E_S = static modulus of elasticity, N/cm^2 , and

S_T = ultimate indirect tensile strength, N/cm^2 .

The above relationship was obtained with a coefficient of determination R^2 of 0.73. Since the correlation between E_S and S_T is good it may be possible to estimate E_S in terms of S_T .

Values from Refs 1 and 29 were combined with values from this study to develop a more general relationship; the result is

$$E_S = -10432 + 1081\ S_T$$
$$(R^2 = 0.76,\ S_e = 20668)$$

Further studies may improve this correlation, which could serve as an estimating tool for those agencies not equipped to measure deformations. However, the equation should be used only when it is not possible or practical to measure deformations and should not be used as justification for not making the necessary deformation measurements. In addition, values for a variety of conditions and projects should be included in order to improve the relationship and extend its inference space.

CHAPTER 5. PRELIMINARY MIXTURE DESIGN PROCEDURE

At present there is no established procedure for the design of recycled asphalt mixtures. The following recommendations are based on the experience of project personnel to date and are preliminary in nature. It is anticipated that modifications will be required as additional information and experience are developed.

The design problem involves (1) bringing the asphalt to its optimum composition for durability, (2) restoring the asphalt characteristics to a consistency level appropriate for the mixture, and (3) meeting the asphalt content requirement of the mixture design procedure.

MIXTURE DESIGN

The steps necessary for the design of recycled asphalt mixtures have been subdivided into three categories: general, preliminary design, and final design.

General

(1) Determine the gradation of the aggregate in the mixture to be recycled.

(2) Determine the amount of asphalt in the asphalt mixture to be recycled.

(3) Determine the final aggregate conditions, e.g., final gradation after the addition of new aggregate.

(4) Determine the maximum size of the mixture particles after pulverization.

Preliminary Design

The primary objective of this preliminary procedure is to select the types and amounts of additives which can be used to recondition the asphalt in the mixture being recycled and involves the selection of an additive which will soften the existing asphalt. A variety of materials are available, such as a soft asphalt, flux oil, commercially available softening agents, and combinations of these materials. The primary criterion is to reduce the viscosity or increase the penetration of the asphalt until it reaches an acceptable or specific range. Suggested steps for this evaluation are summarized as follows:

(1) Extract and recover asphalt from a sample of the mixture to be recycled (Tex-211-F).

(2) Mix the extracted asphalt with the selected types and amounts of additives.

(3) Measure the viscosity (Tex-513-C, Tex-528-C) and/or penetration (Tex-502-C) of each sample of the treated asphalt.

(4) Develop curves describing the relationships between the amount of additive and the viscosity and/or penetration over the range of each additive.

(5) Select those combinations which will produce a binder of the desired consistency, i.e., penetration and/or viscosity.

(6) Select those combinations which warrant further evaluation. This selection can be based on cost, availability, construction considerations, past reliability and experience, etc.

Final Design

The materials selected in the preliminary design should be evaluated further in order to select the final type and amount of additive and to determine whether the resulting engineering properties are acceptable. The following steps are suggested:

(1) Prepare duplicate specimens of mixtures containing various percentages of the selected additives in the approximate range determined in the preliminary design and compatible with variations in field application procedures.

(2) Test according to the Standard Tests used by the Texas State Department of Highways and Public Transportation:

  (a) for blackbase - Tex-126-E, unconfined compression; and

  (b) for asphalt concrete - Tex-208-F, stabilometer.

  Other agencies should test using their standard tests.

(3) Compare the results with those required in the specifications for conventional mixtures. For the Standard Tests used by the Texas State Department of Highways and Public Transportation, these values are

  (a) for blackbase - Tex-126-E: the best base material, the unconfined compressive strength should not be less than 50 psi at a slow loading rate and 100 psi at a fast loading rate;

for the poorest acceptable base material, the unconfined compressive strength should not be less than 30 psi at a slow loading rate and 100 psi at a fast loading rate

(b) for asphalt concrete - Tex-208-F: the stability value should not be less than 30 percent.

(4) Test using the static and repeated-load indirect tensile tests. Tentative test procedures for the static test are contained in Ref 2. Tentative test procedures for the repeated-load indirect tensile test are being developed.

(5) Compare the indirect tensile test results with those obtained for conventional mixtures. Properties to be considered are

(a) tensile strength,

(b) static modulus of elasticity,

(c) fatigue life, and

(d) resilient modulus of elasticity.

The relationships between the above properties and the amount of additive should be developed as shown in Figs 17 through 20. The resulting values should then be compared to desired values for which there is a limited amount of information. Most specifications specify minimum values of strength, etc. For recycled asphalt mixtures, values normally need to be reduced below some maximum since the asphalt is extremely stiff and brittle.

(6) Evaluate the workability of the mixture by visual inspection and make necessary adjustments.

RECOMMENDED INDIRECT TENSILE DESIGN VALUES

Previous studies have evaluated the tensile strength, static modulus of elasticity, resilient modulus of elasticity, and fatigue characteristics of laboratory-prepared and inservice asphalt mixtures. Since these materials are performing satisfactorily, they represent a guide to the engineering properties required for recycled mixtures.

Based on the results reported in Refs 1, 20, 23, 24, and 29 for various types of asphalt mixtures, typical values of mixture properties are obtained. Additional experimental and theoretical work is needed to define the range of values required; however, at this time it is suggested that the values shown in Table 13 can serve as a guide.

Based on experience to date mixture design probably should be based on strength and modulus values, with limited consideration given to the fatigue values.

TABLE 13. SUGGESTED DESIGN VALUES

Property	Design Value N/cm^2	(psi)
Tensile strength	50-140	(75-200)
Static modulus of elasticity	70,000-350,000	(100,000-500,000)
Resilient modulus of elasticity	170,000-650,000	(250,000-900,000)
Fatigue life:		
n_2	2-8	
K_2	10^{11}-10^{18}	

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the findings of a study to evaluate the fatigue and elastic properties of recycled asphalt mixtures and outlines a preliminary procedure for mixture design. The conclusions and recommendations from this study are summarized below.

CONCLUSIONS

(1) The engineering properties of the recycled mixtures evaluated in this study generally were slightly higher than those of conventional mixtures which have been previously evaluated.

(2) It is concluded that satisfactory mixtures can be obtained with recycled mixtures based on the findings of this study and on the experience and findings of others.

(3) A preliminary mixture design procedure has been presented which will be modified as additional experience is obtained.

RECOMMENDATIONS

(1) The design procedure should be used so that field experience and verification can be obtained and the procedure improved.

(2) A long-term study of the behavior and performance of recycled mixtures should be made.

(3) Additional testing should be conducted to obtain the tensile, elastic, and fatigue properties of field mixtures used in construction. These values are needed to improve the recommended values for design.

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