

EVALUATION OF ACCOREX -
AN ASPHALT MIXTURE ADDITIVE

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by

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OF
ACCOREX - AN ASPHALT MIXTURE ADDITIVE

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	iii
LIST OF FIGURES	iv
DISCLAIMER	v
ABSTRACT	vi
INTRODUCTION	1
ASPHALT CEMENT PROPERTIES	2
General	2
Laboratory Test and Results	2
AGGREGATE PROPERTIES	4
DETERMINATION OF OPTIMUM ASPHALT CONTENT	8
General	8
Mixing of Asphalt with Aggregate	8
Gyratory Compaction and Testing	11
MIXTURE PROPERTIES	13
General	13
Resilient Modulus	13
Hveem Stability	16
Tensile Properties	16
Marshall Stability and Flow	18
Discussion of Air Void Content	19
Flexural Fatigue	19
Water Susceptibility	21

	<u>Page</u>
CONCLUSIONS	28
REFERENCES	29
APPENDIX A - Test Results for Optimum Mixture Design	30
APPENDIX B - Resilient Modulus of Individual Specimens at Optimum Asphalt Content	33
APPENDIX C - Stability of Individual Specimens at Optimum Asphalt Content	35
APPENDIX D - Splitting Tensile Test Data at Optimum Asphalt Content	38
APPENDIX E - Flexural Fatigue Results of Individual Specimens	40
APPENDIX F - Freeze-Thaw Pedestal Results of Individual Specimens	45

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Physical Properties of Cosden AC-20 Asphalt	3
2	Physical Properties of Rounded Gravel	5
3	Individual Components of the Design Gradation	6
4	Optimum Mixture Properties of Gyratory Compacted Specimens	12
5	Physical Properties of Paving Mixtures With and Without Accorex	15
6	Flexural Fatigue Results of Control and Accorex Modified Specimens	22
7	Results of Moisture Tests	26

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Project Design Gradation and Specification Limits	7
2	Test Program for Determining Optimum Asphalt Content	9
3	Test Program for Accorex and Control Mixtures Tested at Optimum Asphalt Content	14
4	Resilient Modulus as a Function of Temperature	17
5	Stress versus Load Application to Failure for Control, Accorex Modified and Standard Accorex Specimens	23
6	Strain versus Load Application to Failure for Control, Accorex Modified, and Standard Accorex Specimens	24

DISCLAIMER

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ABSTRACT

Accorex, an additive for asphalt paving mixtures, was evaluated by routine and special laboratory tests to measure its beneficial effects on mixture properties. Standard tests were performed on a control mixture and a similar mixture containing Accorex. Selected tests were performed on mixtures containing equal volumes of binder. Laboratory specimens were prepared using a common aggregate and these paving mixtures were tested to identify characteristics such as optimum asphalt content, stiffness, tensile properties, stability, flexural fatigue resistance, and water susceptibility. In general, a comparison of test results indicated improved performance for those specimens containing Accorex.

INTRODUCTION

S.P.C., Incorporated is considering the feasibility of marketing an additive for asphalt paving mixtures known as Accorex. Accorex is a high quality polymeric resin with the potential for increasing stability, tensile strength, and crack resistance of asphalt paving mixtures.

The objective of this research study is to compare physical properties of asphalt paving mixtures containing Accorex with similar mixtures containing no Accorex. Asphalt-aggregate mixtures were prepared using a blended aggregate composed of a siliceous sub-rounded river gravel, field sand, and limestone crusher fines. This report describes properties of the asphalt, aggregates and paving mixtures tested. Mixture tests included Hveem and Marshall stability, resilient modulus, indirect tension and flexural fatigue test. Test results yielded moderately higher values of tensile strength, resilient modulus (at temperatures greater than 50⁰F), Marshall stability, and fatigue resistance for those mixtures containing Accorex. This is indicative of improved resistance to pavement rutting and cracking when Accorex is used in the prescribed manner.

ASPHALT CEMENT PROPERTIES

General

An AC-20 paving grade asphalt cement was selected for use in the asphalt-aggregate mixtures tested in this study. This asphalt was produced by the American Petrofina refinery located near Big Springs, Texas. It is normally considered to be highly temperature susceptible. It also exhibits above average hardening after heating as compared to other paving grade asphalts. This asphalt is produced from domestic crudes and, therefore, exhibits very uniform physical and chemical properties. It is successfully used in the western portion of the state of Texas.

Laboratory Test and Results

Standard laboratory tests (1, 2, 3) were performed on the asphalt and the results are presented in Table 1. The purpose of the laboratory tests was to determine the basic physical characteristics of the asphalt.

Table 1. Physical Properties of American Petrofina AC-20 Asphalt.

Properties	Test Results
Viscosity, 77°F, Poises	2.25 x 10 ⁶
Viscosity, 140°F, Poises	1,910
Viscosity, 275°F, Poises	3.10
Penetration, 39.2°F, (200gm/60sec)	13
Penetration, 77°F, (100gm/5sec)	45
Softening Point, Ring and Ball, °F	119
Specific Gravity, 60°F	1.041
Thin Film Oven Test, Viscosity, 140°F, Poises	4,290
Penetration, 77°F, dmm	32
Percent Penetration Retained	71
Rolling Thin Film Oven Test, Viscosity, 140°F, Poises	5,350
Penetration, 77°F, dmm	29
Percent Penetration Retained	64

AGGREGATE PROPERTIES

Basic physical characteristics of the aggregates used in this research study are presented in Table 2. These values represent the averaged results from standard laboratory tests performed on the three different aggregates that were blended together to produce design gradation. This design was in compliance with the Texas State Department of Highways and Public Transportation (SDHPT) Type "D" (Fine Graded Surface Course) specifications of mineral aggregates for paving mixtures (4). A sub-rounded, siliceous gravel, was mixed with field sand and limestone crusher fines to obtain the desired design. The gradation of each individual aggregate is presented in Table 3 along with the percentages used in the blend. Table 3 also contains the sieve analysis of the combined aggregates used to produce the project design gradation. A graphical presentation of the Type "D" specification limits and the project design gradation is presented in Figure 1.

Table 2. Physical Properties of Rounded Gravel.

Test Designation	Aggregate Grading	Physical Property			
		Bulk Specific Gravity	Bulk Specific Gravity (SSD)	Apparent Specific Gravity	Absorption, percent
ASTM C 127 AASHTO T 85	+ No. 4 Pea Gravel	2.632	2.654	2.683	0.72
ASTM C 128 AASHTO T 84	- No. 4 Pea Gravel	2.625	2.650	2.692	0.95
ASTM C 128 AASHTO T 84	Field Sand	2.584	2.647	2.757	2.44
ASTM C 128 AASHTO T 84	Limestone Crusher Fines	2.663	2.683	2.719	0.77
ASTM C 127 & 128 AASHTO T 84 & T 85	Project Design Gradation	2.631	2.658	2.700	0.97

Table 3. Individual Components of the Project Design Gradation.

	Siliceous Gravel	Field Sand	Limestone Crusher Fines	Combined Gradation	Specification
Gradation percent passing					
1/2-inch	100	100	100	100	100
3/8-inch	100	100	100	100	85-100
No. 4	51	100	100	65	32-79
No. 10	5	100	94	31	26-46
No. 40	2	99	52	20	8-62
No. 80	1	50	35	11	4-35
No. 200	1	8	19	4	1-8
Percent Combined	70	+ 10	+ 20	= 100	

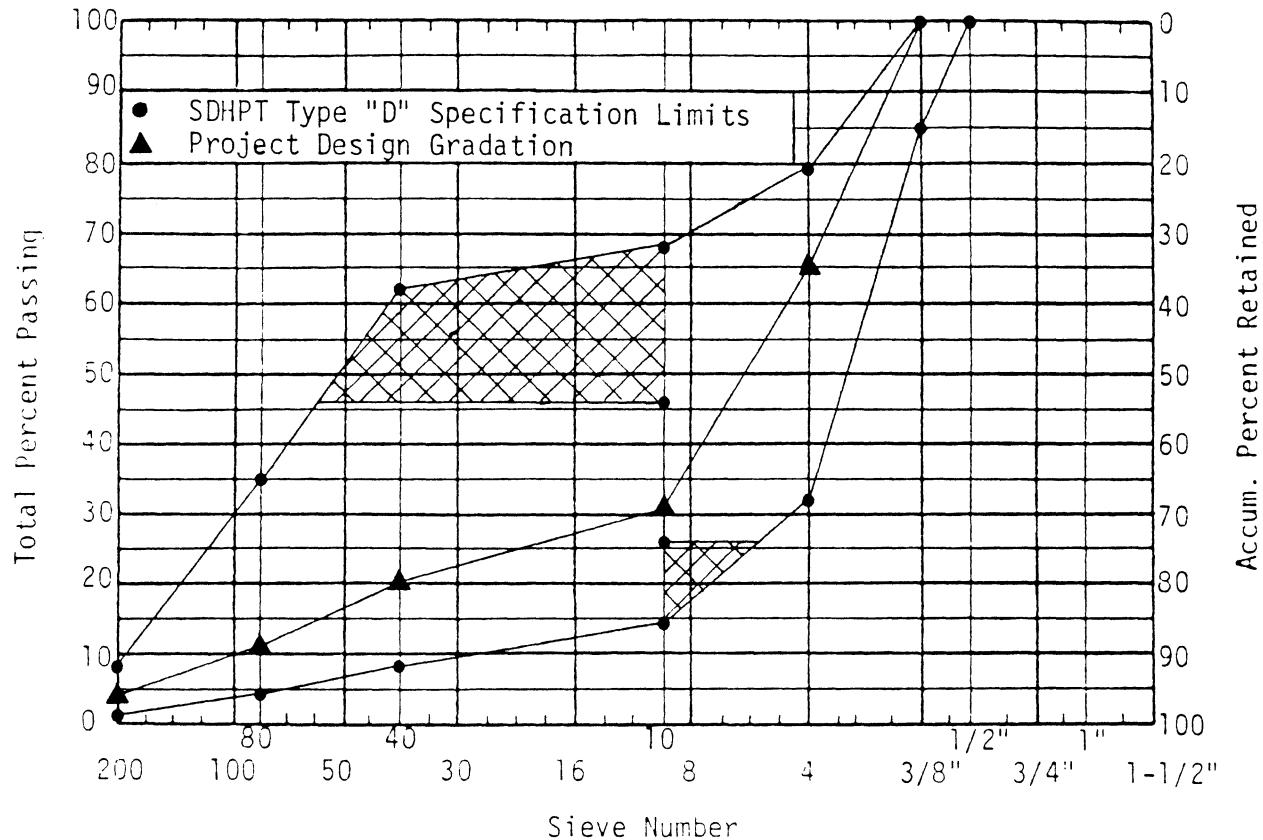


Figure 1. Project Design Gradation Specification Limits.

DETERMINATION OF OPTIMUM ASPHALT CONTENT

General

A flow chart showing the order in which tests were performed to arrive at an optimum asphalt content is presented in Figure 2. The method used to determine the optimum asphalt content was based on Construction Bulletin C-14 (5) of the Texas SDHPT. In this method, the percent density of the compacted asphalt-aggregate mixtures is plotted versus the corresponding asphalt content used. A best-fit-line is drawn through the plotted points. From past observations of pavement performance, a density of 97 percent was used to establish the optimum asphalt content. Data generated in this phase of work are given in Table A1.

Mixing of Asphalt with Aggregate

As mentioned earlier the three different aggregates were blended to form the project design gradation. Prior to mixing with asphalt, the aggregates were placed in a $300 \pm 5^{\circ}\text{F}$ oven for a minimum of four hours. The asphalt cement was heated to the same temperature. The appropriate quantity of asphalt was added to the heated aggregate and blended with a mechanical mixer. During this time, heat was applied using a Bunsen burner to maintain the specified mix temperature in the mixing bowl. When all aggregate particles were coated with asphalt cement, the mixture was carefully divided into three aliquots of predetermined weight and placed in an oven of appropriate compaction

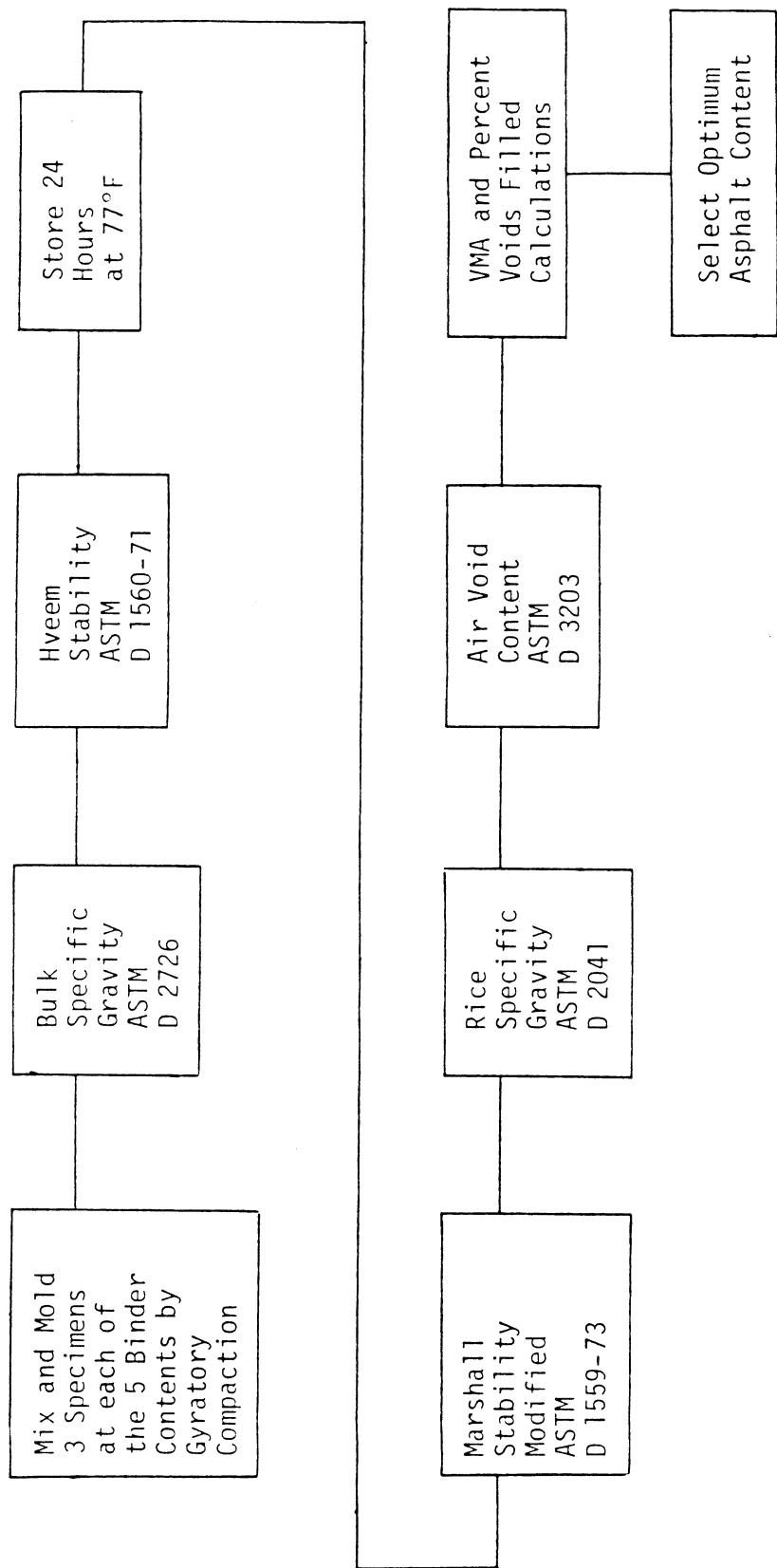


Figure 2. Test Program for Determining Optimum Asphalt Content.

temperature. The batching and mixing operation was completed in approximately four minutes.

The batching and mixing process for the specimens containing Accorex was essentially the same with one exception. Prior to mixing the asphalt and aggregate, Accorex was added to the hot aggregate and blended. While the hot aggregate was being stirred, 0.8 percent (by total weight of mix) of Accorex was sprinkled into the mixing bowl. This method produced a more uniform coating of the Accorex on the aggregate than stirring the aggregate by hand. When mixed by hand the mixture contained small aggregate clumps approximately 1/2 to 3/4 inch in diameter. After stirring the Accorex and aggregate for two minutes, the appropriate amount of asphalt was added and the same procedure as described earlier for the control mixture was followed.

Three observations were made while preparing the Accorex mixtures. (1) A major portion of the Accorex added appeared to coat the larger aggregate particles in the mix. (2) The addition of Accorex apparently increased the viscosity of the mixture. (3) The addition of Accorex improved the compactibility of this mixture. This gravel mixture is normally tender and subject to plastic distortion in the mold during compaction. The addition of Accorex toughened an otherwise slightly tender mix and significantly improved the compaction process.

Gyratory Compaction and Testing

Compaction of the asphalt-aggregate mixtures was conducted in accordance with Texas SDHPT test method TEX-206-F, Part II, "Motorized

"Gyratory-shear Molding Press Operating Procedure" (3). This method requires a compaction temperature of $250 \pm 5^{\circ}\text{F}$ and produces 4-inch diameter by 2-inch high specimens weighing approximately 1000 grams. After compaction, specimens were allowed to cool before height and weight measurements were determined. The bulk specific gravity of each specimen was determined in accordance with ASTM D 2726. Basic properties of this mixture are given in Table 4.

Hveem stability of the specimens was determine in accordance with the Texas SDHPT test method TEX-208-F "Test for Stabilometer Value of Bituminous Mixtures" (3). This is a modification of ASTM D 1560 (1).

Marshall stability tests were performed on the gyratory compacted specimens. Since all of the specimens prepared for the determination of optimum asphalt content were approximately 2-inches in height, the measured stabilities were corrected to the standard height of 2.5-inches as per ASTM D 1559 (1).

Some of the previously failed specimens were randomly selected and used to determine the maximum specific gravity of the mixture in accordance with ASTM D 2041 "Maximum Specific Gravity of Bituminous Paving Mixtures" (1).

Table 4. Optimum Mixture Properties of Gyratory Compacted Specimens.

Property	Accorex	Control
Design Asphalt Content, Percent by wt. of total Mix	4.6	4.6
Bulk Specific Gravity of Compacted Mixture	2.39	2.39
Maximum Specific Gravity of Mixture	2.43	2.47
Effective Specific Gravity of Aggregate	2.64	2.64
Asphalt Absorption, Percent by wt. of Aggregate	0.18	0.16
Effective Asphalt Content, Percent by wt. of total Mix	4.4	4.4
Voids in Mineral Aggregate, Percent Bulk Volume	14.0	13.2
VMA Filled with Asphalt, Percent VMA	87	77
Air Void content, Percent total Volume	1.8	3.1

MIXTURE PROPERTIES

General

Asphalt concrete specimens were prepared at the optimum asphalt content using gyratory compaction. Three were prepared containing Accorex and three containing no Accorex. Additional specimens with and without Accorex were prepared using the Marshall Compaction Method as specified in ASTM D 1559 (1). Specimens were tested in accordance with the program presented in Figure 3. A summary of mixture properties of the gyratory compacted specimens is presented in Table 5.

Resilient Modulus

Resilient Modulus (a measure of mixture stiffness) was determined for each specimen at the specified temperatures listed in Table 5. These values were obtained after a minimum time of 24 hours after molding, using the Mark IV Resilient Modulus Device developed by Schmidt (6). A diametral load of approximately 75 lbs was applied for a duration of 0.1 seconds while monitoring the lateral deformation in accordance with Schmidt (7).

Results on individual specimens are presented in Table B1 in Appendix B. The values displayed in Table 5 are the averages of the three specimens tested. The specimens containing Accorex exhibited higher stiffness values at temperatures higher than 50°F. Test results further indicated that the addition of Accorex decreased the temperature susceptibility of the mixture. To illustrate this,

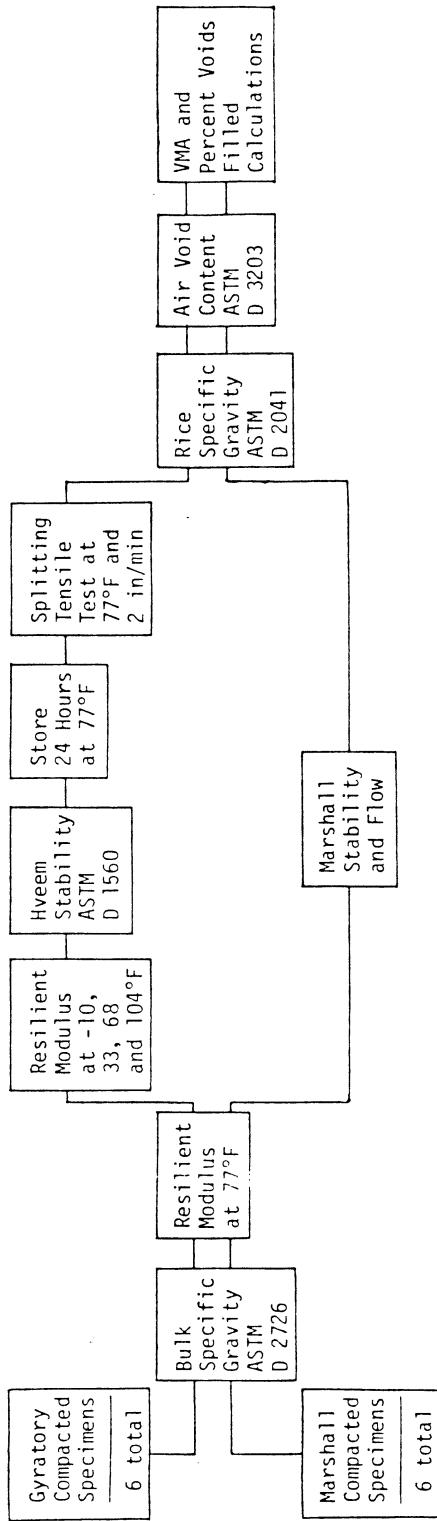


Figure 3. Test Program for Accorex and Control Mixtures Tested at Optimum Asphalt Content.

Table 5. Physical Properties of Paving Mixtures With and Without Accorex*.

Properties of Specimens Tested		Gyratory Compacted Specimens		Marshall Compacted Specimens	
		AC with ACCOREX	AC Standard	AC with ACCOREX	AC Standard
Mixture Properties	Sample Height inches	2.07	2.07	2.53	2.51
	Bulk Specific Gravity	2.39	2.39	2.37	2.39
	Rice Specific Gravity	2.43	2.47	2.43	2.47
	Air Voids, percent	1.6	3.2	2.6	3.4
Stability	Hveem Stability, percent	27	28	---	---
	Marshall Stability, lbs	---	---	2360	1980
	Marshall Flow, 0.01 in.	---	---	9	8
	Tested @ 104° F	100	40	1180	910
Resilient Modulus, $\text{psi} \times 10^3$	Tested @ 77° F	750	540	---	---
	Tested @ 68° F	1,060	860	---	---
	Tested @ 33° F	2,050	2,130	---	---
	Tested @ -10° F	2,960	3,030	---	---
	Tensile Strength, psi	190	150	---	---
Indirect Tension	Strain at Failure, in/in	0.0034	0.0040	---	---
	Secant Modulus, psi	55,700	36,800	---	---
	Toughness lb-in/in ³	0.55	0.52	---	---

* Each value represents the average of 3 specimens.

resilient modulus was plotted as a function of temperature in Figure 4. Although there are no field performance data to substantiate this statement, these data seem to indicate that the addition of Accorex to this paving mixture will improve its resistance to cracking and rutting.

Hveem Stability

The Hveem stability test was developed in the late 1930's by the California Division of Highways. The Hveem stability value is a measure of a paving mixture's ability to resist plastic flow. The value is primarily a measure of interparticle friction and, is therefore, strongly dependent on the angularity of the aggregate utilized.

The specimens containing Accorex exhibited Hveem stabilities approximately equivalent to those of the control specimens (Table 5). This result is not surprising since both mixtures used identical aggregates. Test results on individual specimens are given in Table C1 of Appendix C.

Tensile Properties

Tensile properties of the gyratory compacted specimens were examined using the indirect tensile test (8). Specimens were tested at 77°F with a loading head displacement rate of 2-inches per minute. Test results for individual specimens are presented in Table D1 in Appendix D.

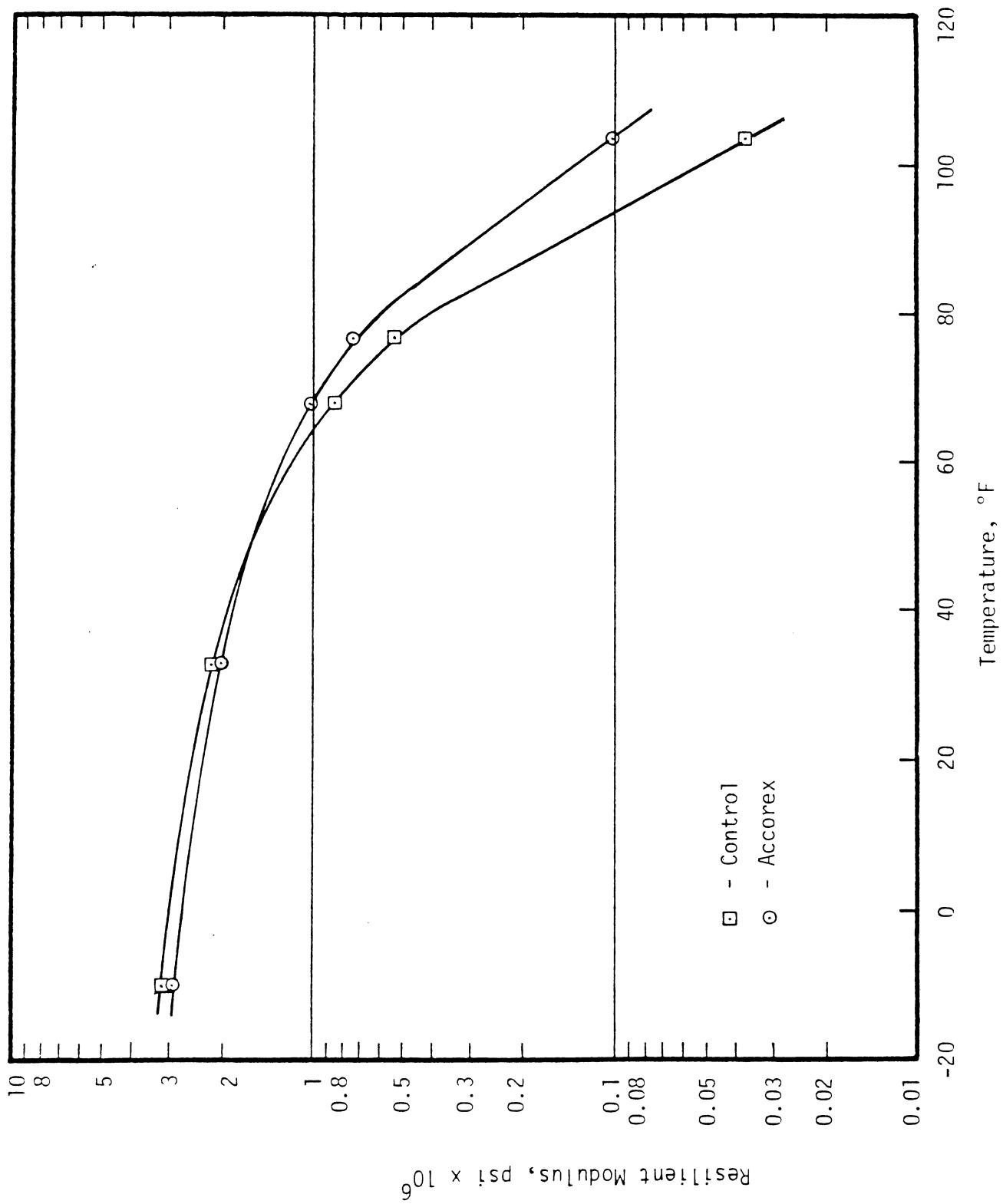


Figure 4. Resilient Modulus as a Function of Temperature.

A summary of these data (Table 5) indicates that the addition of Accorex resulted in a 27 percent increase in tensile strength. Toughness (Table 5) of the paving mixture was estimated by computing the area under the stress-strain curves to the point of specimen failure. Those specimens containing Accorex exhibited slightly higher values of toughness. The higher values of tensile strength and toughness are indicative of improved resistance to cracking when Accorex is added.

Marshall Stability and Flow

The Marshall test was developed in the late 1930's and early 1940's by the Mississippi State Highway Department and the U.S. Army Corps of Engineers. Marshall stability and flow values of an asphalt concrete material are measures of the materials ability to resist plastic flow. Unlike Hveem stability, Marshall stability is more dependent on the properties of the binder and less dependent on interparticle friction of the aggregate.

Results for each individual specimen are presented in Table C2 in Appendix C. Specimens containing Accorex exhibited approximately 20 percent higher stability values than the control with only a negligible increase in plastic flow. This indicates that the addition of Accorex to this paving mixture will reduce the probability of rutting, shoving and corrugations.

Discussion of Air Void Content

One of the most noticeable effects of Accorex on the mixture was the reduction in the air void content (Table 4). The addition of Accorex resulted in a reduction in air voids of approximately 50 percent. A change in air void content of this magnitude alone will substantially change the properties of a compacted asphalt mixture. Therefore, the decision was made to compare the Accorex and control specimens on an equivalent air void basis for the remainder of the test program. The most practical method to accomplish this was to design the mixtures using an equal volume of binder. (Binder is defined as asphalt cement or asphalt plus Accorex.) A specific gravity test was performed on the Accorex material and the value was found to be approximately 0.91. Calculations were then made to determine the required reduction in asphalt cement for those specimens containing Accorex. Essentially, the specimens containing Accorex required 0.9 percent less asphalt than the control specimens. They will be referred to as the modified mixture throughout the remainder of the report. Control and modified mixtures were prepared and tested for beam fatigue and water susceptibility.

Flexural Fatigue

Beam fatigue tests were performed on the control and the modified Accorex specimens at three stress levels and on standard Accorex specimens at one stress level to provide information for the prediction of fatigue life of pavements using these mixtures. Fatigue

cracking of pavements appears in patterns similar to "chicken wire" or "alligator skins". This is the origin of the term alligator cracking. This type of cracking is due to repeated wheel loads; it normally begins in the wheel path.

The beam fatigue testing apparatus applies loads at the third points of the beam, four inches on center, through one inch wide steel blocks. The applied load is measured by a load transducer and continuously recorded on an oscillographic recorder. Linear variable differential transformers (LDVT) measure the specimen deformation at the center of the beam. This deformation is also recorded on the two channel oscillographic recorder. The machine is operated in the load control mode with half-sine wave form at a frequency of 100 cycles per minute and a load duration of 0.1 seconds. A reverse load is applied at the end of each cycle to insure that the specimen will return to its original at-rest position after each cycle. It is necessary to periodically tighten the specimen loading and holding clamps as a result of plastic flow of the asphalt concrete. Upon rupture of the specimen, limit switches shut off the testing machine, and a cycle counter indicates the number of cycles to complete rupture.

Peak stress, initial bending strain (bending strain @ the 200th cycle), initial stiffness modulus (@ the 200th cycle), and estimated total input energy were calculated for each fatigue test specimen in accordance with the formulae given in Appendix E. The total input energy is a measure of energy imparted to the specimen during testing

to failure. Table E1 and E2 give the results of the calculations for individual beams tested and Table 6 gives a statistical summary of those tests conducted at the low, medium, and high stress levels.

The Accorex modified specimens exhibited fewer total load cycles to failure, lower initial stiffness modulus, and less total energy input than the other specimens (Table 6). Fatigue test results are plotted in Figures 5 and 6. Based on these fatigue test results, Accorex modified specimens would most likely exhibit fatigue cracking earlier than the other specimens when tested at stress levels above 100 psi.

Fatigue test results of the standard Accorex specimens exhibited improved fatigue performance (Table 6). The number of load cycles to failure, initial stiffness modulus and total energy input were dramatically increased by the addition of Accorex. It should also be pointed out that the air void content of the Accorex specimens was reduced by approximately 50 percent and, further, that an increase in asphalt content of a paving mixture will also improve fatigue performance, however, mixture stability will be decreased. Nevertheless, the addition of Accorex to an asphalt mixture without reducing the asphalt content will significantly improve the resistance of an asphalt paving mixture to traffic-induced cracking.

Water Susceptibility Study

The "Texas Boiling Test" (3) was performed to evaluate the effects of Accorex on moisture susceptibility of asphalt paving mixtures. Mixtures were prepared and tested in accordance with the

Table 6. Flexural Fatigue Results of Control and Accorex Modified Specimens.

Sample Type	Stress Level	Statistic	Maximum Specific Gravity, gm/cc	Air Voids, percent	Input Stress, psi	Bending Strain at 200 Cycles, in/in $\times 10^{-4}$	Cycles to Failure	Initial Stiffness Modulus, psi	Total Energy Input, lb-in
Control Specimens	Low	Mean Std. Dev. Coef. Var.	2.473 0.002 0.8	5.5 0.34 6	98 3.2 3	1.8 0.3 17	266,800 130,700 49	566,400 94,000 17	53,700 28,800 54
	Medium	Mean Std. Dev. Coef. Var.	2.473 0.002 0.8	5.8 0.40 7	154 11.5 8	2.8 0.2 8	38,100 8,800 23	545,200 26,700 5	19,100 4,000 21
	High	Mean Std. Dev. Coef. Var.	2.473 0.002 0.8	5.5 0.20 4	182 8.1 4	3.2 0.5 15	27,300 20,100 73	597,400 105,000 18	18,600 11,800 63
Modified Accorex Specimens	Low	Mean Std. Dev. Coef. Var.	2.466 0.003 0.1	5.7 0.17 3	106 6.3 6	2.2 0.2 7	137,400 65,000 47	440,700 18,400 4	36,900 18,200 49
	Medium	Mean Std. Dev. Coef. Var.	2.466 0.003 0.1	5.7 0.31 5	155 9.0 6	3.5 0.5 15	20,200 7,500 37	473,000 72,144 15	14,000 7,000 50
	High	Mean Std. Dev. Coef. Var.	2.466 0.003 0.1	5.9 0.23 4	183 18.4 10	4.3 1.3 29	4,800 1,300 27	470,800 110,000 23	5,200 2,700 53
Standard Accorex Specimens	Medium	Mean Std. Dev. Coef. Var.	2.434 0.009 0.4	2.7 0.3 11	159 1.7 1	2.1 0.6 26	359,300 150,500 42	797,900 240,600 30	137,300 71,200 52

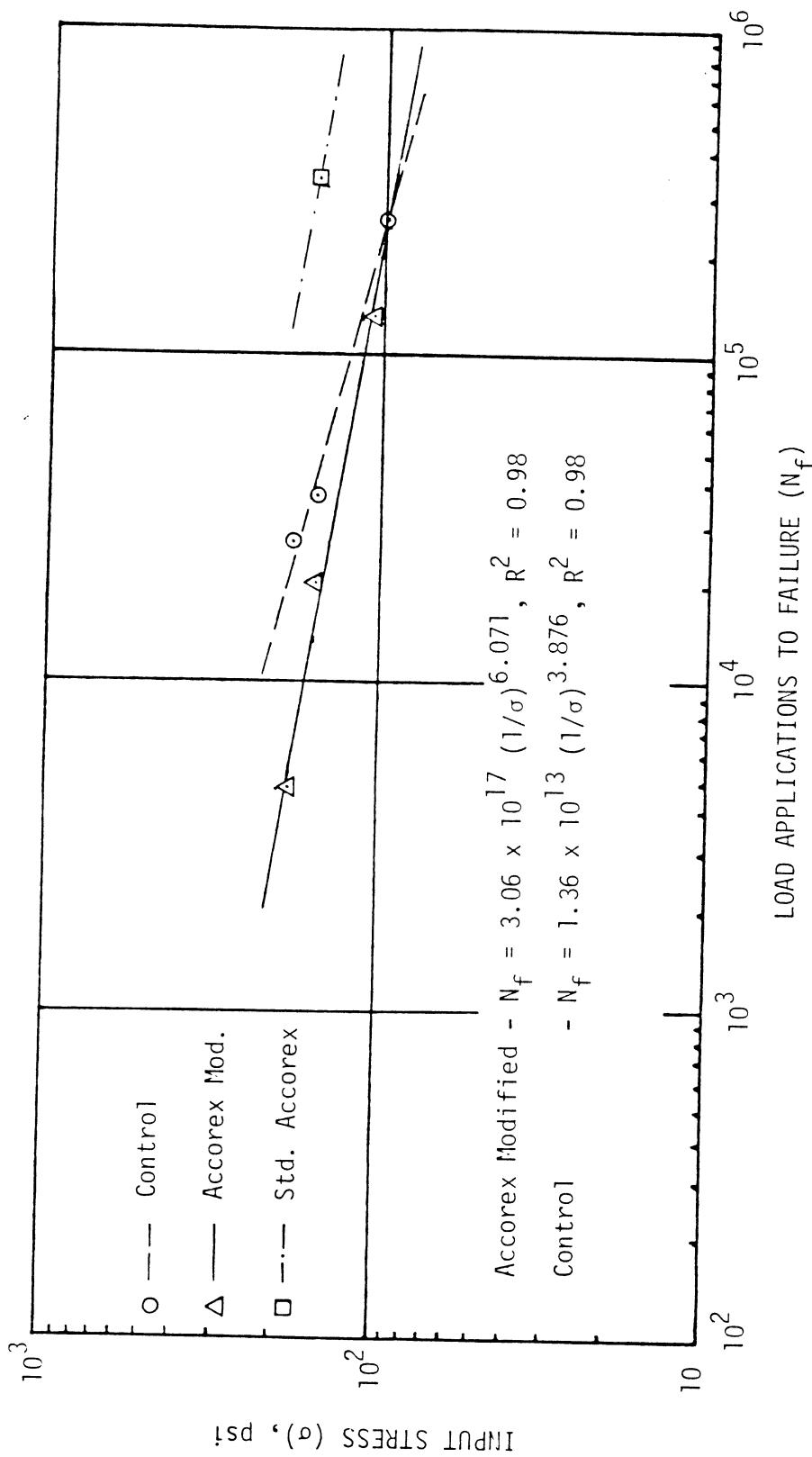


Figure 5. Stress versus Load Applications to Failure for Control, Accorex Modified, and Standard Accorex Specimens.

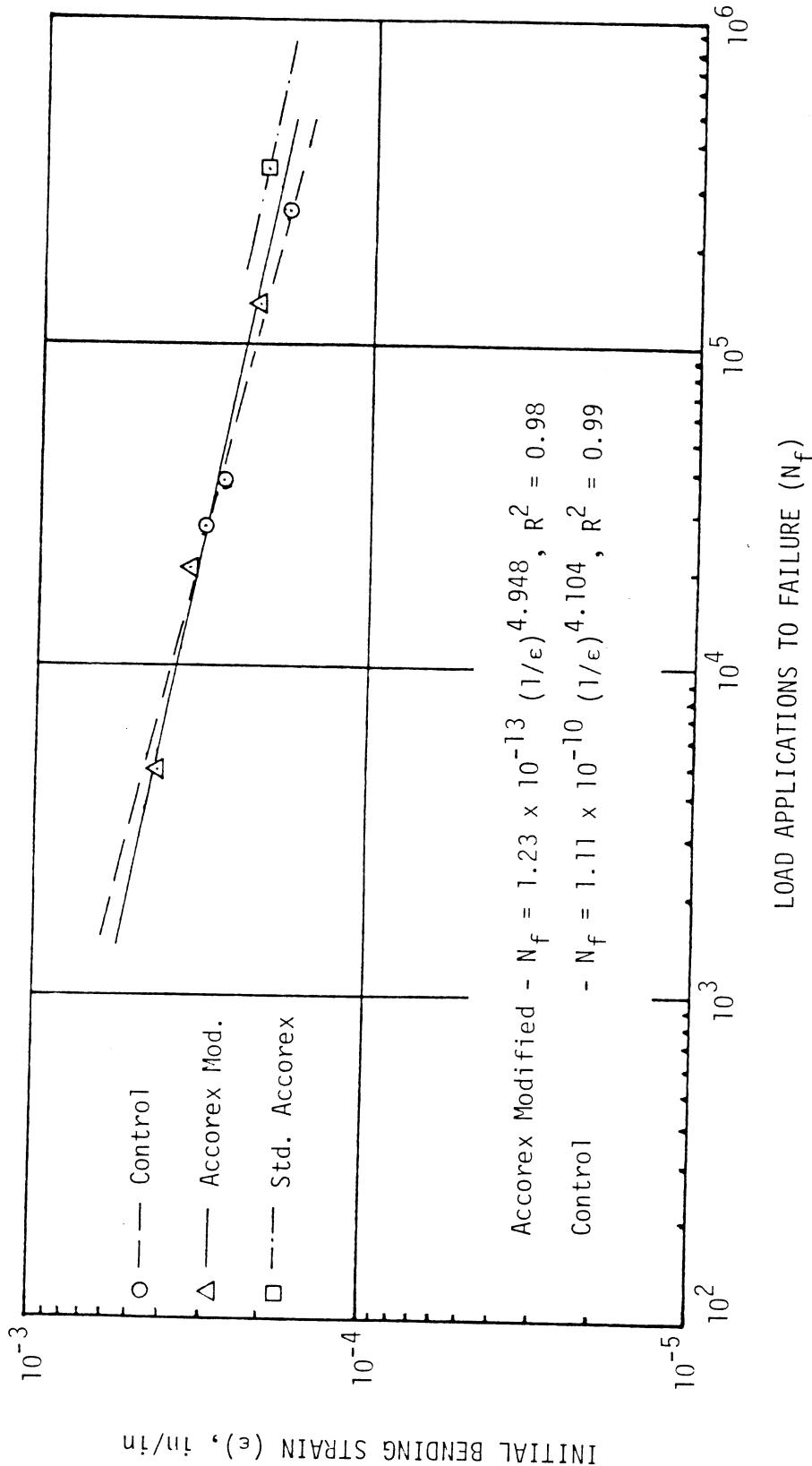


Figure 6. Strain versus Load Applications to Failure for Control, Accorex Modified, and Standard Accorex Specimens.

test method TEX-530-C of the Texas (SDHPT) (3). Test results are reported in Table 7.

The mixtures were placed in a stainless steel beaker of boiling distilled water for 10 minutes. After removal of all stripped asphalt from the surface of the water, the mixtures were poured into shallow pans and allowed to dry. Visual observation was made of the mixtures before and after boiling and the degree of stripping was estimated. Modified Accorex and control mixtures exhibited approximately 10 percent stripping. This indicates that the addition of Accorex had no effect on moisture susceptibility of this particular asphalt mixture.

A new but very sensitive test called the freeze-thaw pedestal test was also performed to determine the effects of Accorex on moisture susceptibility of asphalt concrete.

The size of the aggregate used in the freeze-thaw pedestal test was between a No. 20 and a No. 35 sieve. Use of the uniformly sized material minimized the effect of aggregate interlock while maximizing the effects of bond between the aggregate and the asphalt cement. Of course, the optimum asphalt content for this mixture was different from the previously discussed mixtures. The control specimens contained 6.6 percent asphalt by total weight of the mix and the modified Accorex specimens contained 5.6 percent. The mixtures were compacted into briquets 0.75-inches in height and 1.6-inches in diameter. The briquets were then cured for three days, placed on a beveled stress pedestal, submerged in distilled water in a small jar, and place in a controlled temperature environment at 0°F for 14

Table 7. Results of Moisture Tests for Control and Accorex Modified Specimens.

Freeze-Thaw Pedestal Test			Texas Boiling Test		
Sample Type	Statistic	Maximum Specific Gravity, gm/cc	Air Voids, percent	Number of Cycles to Failure	Degree of Stripping, percent
Control	Mean	2.440	26.7	1	10
	Std. Dev.	0.010	0.06	0	--
	Coef. Var.	0.4	0.2	0	--
Accorex	Mean	2.413	26.4	2	10
	Std. Dev.	0.010	0.35	0.6	--
	Coef. Var.	0.4	1	25	--

hours. After thawing in 77⁰F water for 45 minutes, the jars were placed in a controlled temperature environment at 120⁰F for 9 hours. Test results on individual specimens are given in Table F1 in Appendix F and a statistical summary is presented in Table 7.

The Accorex modified specimens failed after two cycles whereas the control specimens failed after only one cycle of the freeze-thaw procedure. From past research (9), it appears that those asphalt-aggregate mixtures exhibiting high stripping potential will fail in less than 10 cycles and those exhibiting low stripping potential will require more than 50 cycles to produce failure. The test results indicate, therefore, that the addition of Accorex to this mixture does not significantly affect moisture susceptibility.

CONCLUSIONS

Based on a laboratory investigation of Accorex, an additive for asphalt paving mixtures, the following conclusions appear warranted:

1. Marshall stability of an asphalt mixture will be increased by the addition of Accorex. This indicates improved resistance to plastic flow (that is, rutting, shoving, etc),
2. Hveem stability of an asphalt mixture is not appreciably affected by the addition of Accorex,
3. Addition of Accorex to asphalt-aggregate mixtures will substantially reduce the air void content,
4. The addition of Accorex will increase tensile strength and stiffness of asphalt concrete mixtures which may be indicative of improved resistance to cracking and rutting,
5. Addition of Accorex will decrease mixture temperature susceptibility which may also be indicative of improved resistance to cracking and rutting,
6. The addition of Accorex to an asphalt mixture will significantly improve its resistance to traffic-induced cracking and
7. Accorex will not significantly affect an asphalt mixture's resistance to moisture damage.

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APPENDIX A

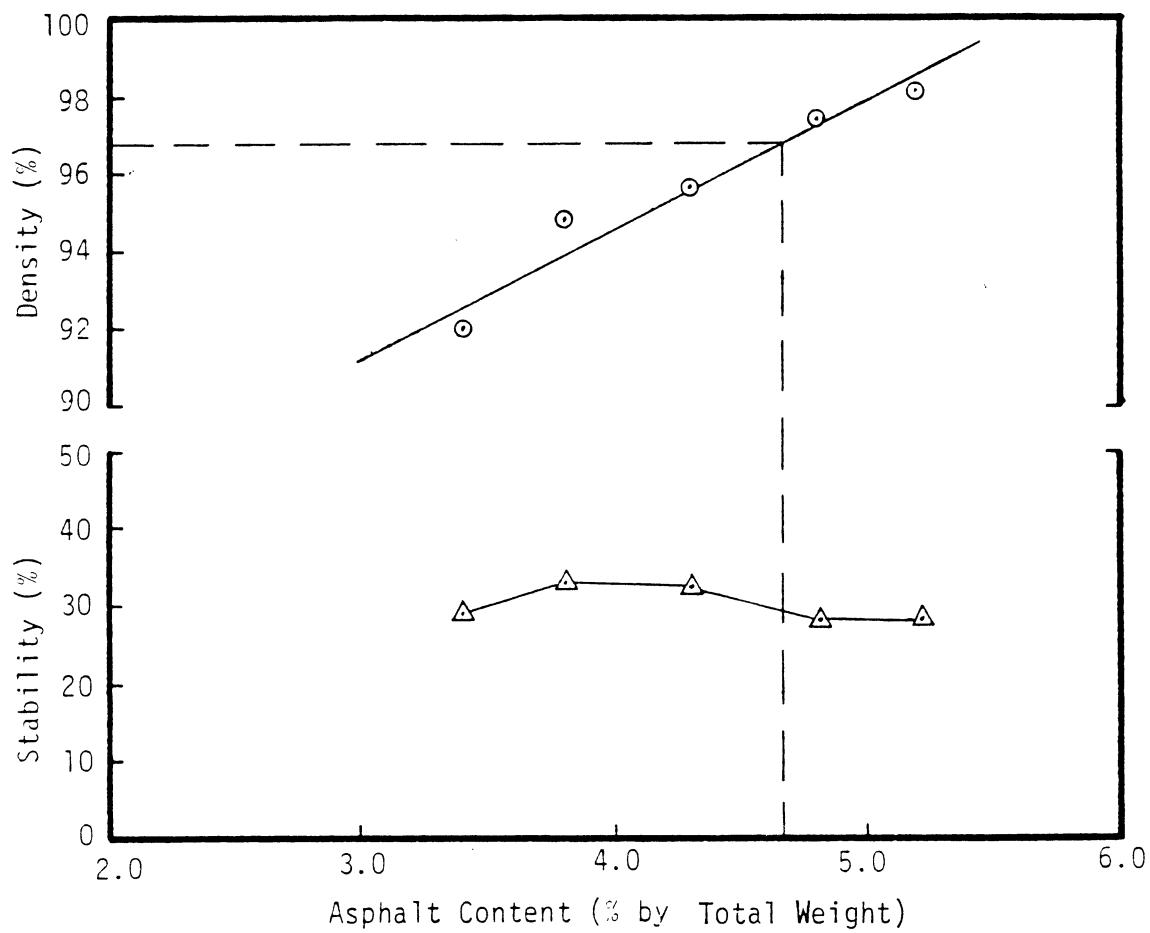
Test Results for Optimum Mixture Design

Table A1. Data Summary of Optimum Mixture Design.

Asphalt Content, percent by wt. of dry Aggregate	3.5	4.0	4.5	5.0	5.5
Bulk Specific Gravity of Compacted Mixture	2.311	2.364	2.372	2.397	2.403
Maximum Specific Gravity of Mixture	2.511	2.493	2.478	2.460	2.446
Effective Specific Gravity of Aggregate	2.642	2.642	2.642	2.642	2.642
Asphalt Absorption, percent by wt. of aggregate	0.16	0.16	0.16	0.16	0.16
Effective Asphalt Content, percent by wt. of aggregate	3.3	3.8	4.3	4.8	5.3
Voids in Mineral Aggregate, per- cent bulk volume	15.2	13.7	13.7	13.3	13.4
VMA Filled with Asphalt, percent VMA	47	62	69	80	87
Air Void Content, percent total volume	8.0	5.2	4.3	2.6	1.8
Hveem Stability	29	33	32	28	28
Marshall Stability*, lbs	790	960	940	1,080	1,030
Marshall Flow*, 0.01 inch	13	13	15	17	17

* These values were obtained from the averages of two tests. All other values listed in Table A1 are averages of three tests.

Mix. No.	Asphalt Content (%) By Total Weight	Asphalt Content (%) By Total Weight of Agg.	Bulk Sp. Gr. of Specimens (G _b)	Max. Sp. Gr. of Specimens (G _m)	Density (%) G _b G _m × 100%	Hveem Stability %
1	3.4	3.5	2.311	2.511	92.0	29
2	3.8	4.0	2.364	2.493	94.8	33
3	4.3	4.5	2.372	2.478	95.7	32
4	4.8	5.0	2.397	2.460	97.4	28
5	5.2	5.5	2.403	2.446	98.2	28



Optimum Results

Asphalt Content (%) By Total Weight	Asphalt Content (%) By Total Weight of Agg.	Density (%)	Hveem Stability (%)
4.6	4.8	97	30

Figure A1. Selection of Optimum Asphalt Content.

APPENDIX B

Resilient Modulus of Individual Specimens at
Optimum Asphalt Content

Table B1. Resilient Modulus of Gyratory Compacted Specimens.

Type	Sample Number	Resilient Modulus, psi $\times 10^3$				
		-10°F	33°F	68°F	77°F	104°F
Accorex	ACC-1	3,040	1,965	990	741	98
	ACC-2	2,674	2,153	1,011	723	103
	ACC-3	3,154	2,040	1,180	770	106
Control	LS-1	3,021	2,260	862	540	39
	LS-2	3,139	2,172	865	495	34
	LS-3	2,920	1,961	860	580	37

Table B2. Resilient Modulus of Marshall Compacted Specimens.

Type	Sample Number	Resilient Modulus, psi $\times 10^3$ 77°F
Accorex	ACC-M1	1,148
	ACC-M2	1,201
	ACC-M3	1,202
Control	LS-M1	863
	LS-M2	914
	LS-M3	941

NOTE: Values listed on both tables are average of two or more tests.

APPENDIX C

Stability Results of Individual Specimens at
Optimum Asphalt Content

Table C1. Individual Stability results of Gyratory Compacted Specimens.

Type	Sample Number	Height, in.	Bulk Specific Gravity	Air Voids, percent	Hveem Stability, percent
Accorex	ACC-1	2.070	2.389	1.8	31.7
	ACC-2	2.068	2.392	1.7	23.5
	ACC-3	2.064	2.391	1.8	24.7
Control	LS-1	2.071	2.392	3.2	28.2
	LS-2	2.074	2.383	3.5	30.0
	LS-3	2.060	2.405	2.6	25.6

NOTE: Values listed above are average of three or more tests.

Table C2. Individual Marshall Stability results of Marshall Compacted Specimens.

Type	Sample Number	Height, in.	Bulk Specific Gravity	Air Voids, percent	Marshall Stability, lbs	Marshall Flow, 0.01 in.
Accorex	ACC-M1	2.547	2.350	3.5	2,259	10
	ACC-M2	2.513	2.374	2.5	2,391	9
	ACC-M3	2.517	2.372	2.5	2,424	8
Control	LS-M1	2.517	2.380	3.6	2,058	6
	LS-M2	2.502	2.387	3.4	1,858	8
	LS-M3	2.501	2.395	3.0	2,019	9

NOTE: Values listed are averages of three tests.

APPENDIX D

Splitting Tensile Test Data at Optimum Asphalt Content

Table D1. Splitting Tensile Test Data.

Type	Sample Number	Ultimate Stress,* psi	Ultimate Strain,* in/in	Secant Modulus,* psi	Toughness lb-in/in ³
Accorex	ACC-1	184	0.0036	51,700	0.544
	ACC-2	187	0.0033	57,400	0.510
	ACC-3	199	0.0034	58,100	0.605
Control	LS-1	145	0.0038	38,400	0.506
	LS-2	141	0.0044	32,100	0.542
	LS-3	156	0.0039	39,900	0.508

*All samples were tested at 77°F (25°C) at a rate of 2.0 in/min and all values were measured at point of failure and represent averages of two or more tests.

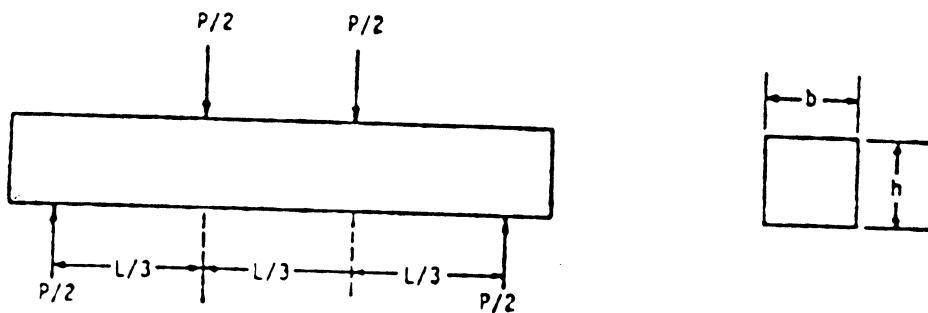
APPENDIX E

Flexural Fatigue Results of Individual Specimens

Summary of Formulae

for

Third-Point Loaded Beam (10)



Equation No.

$$\text{Peak stress in extreme fiber} = \sigma_{\max} = \frac{PL}{bh^2}, \text{ psi} \quad (\text{D1})$$

$$\begin{aligned} \text{Initial stiffness modulus} = E = & \frac{0.213 PL^3}{W_0 bh^3} + \frac{0.400 PL(1+\mu)}{W_0 bh}, \\ & \text{psi} \end{aligned} \quad (\text{D2})$$

$$\begin{aligned} \text{Initial bending strain in extreme fiber} = \epsilon = & \frac{\sigma}{E}, \text{ in./in.} \\ & \text{(Hooke's Law)} \end{aligned} \quad (\text{D3})$$

$$\text{Total input energy} = U_f = \frac{10.2 P W_0 N_f}{23}, \text{ in.-lb} \quad (\text{D4})$$

where P = applied load, lbs

L = tested length of beam, in.

b = width of beam, in.

h = depth of beam, in.

W_0 = center deflection of beam at 200th cycle, in.

μ = Poisson's ratio (assumed 0.35)

N_f = number of cycles to failure

Table E1. Individual Beam Fatigue Test Results on the Control Specimens.

Stress Level	Sample Number	Sample Ht. (in)*	Cycles to Failure	Average Input Stress, psi	Bending Strain at the 200 cycle, in/in $\times 10^{-4}$	Initial Modulus (E) at the 200 cycle, psi	Total Input Energy at the 200 cycle, in - lb
Low	C-T1	3.0	225,475	97	1.5	635,568	37,400
	C-2	3.0	169,126	97	2.2	435,253	41,000
	C-5	3.0	459,790	99	1.8	561,327	96,800
	C-8	3.0	213,116	100	1.6	633,369	39,800
Medium	C-3	3.0	46,528	152	2.9	524,071	23,600
	C-6	2.9	28,962	167	2.9	536,250	16,100
	C-9	3.1	38,919	144	2.5	575,178	17,700
High	C-4	3.0	13,599	179	3.8	476,184	11,300
	C-7	3.0	18,062	184	3.0	656,125	12,300
	C-10	3.0	50,390	185	2.9	659,941	32,200

* Width of beam specimens was 3-inches.

Table E2. Individual Beam Fatigue Test Results on Accorex Specimens Containing Approximately 1% Less Asphalt than the Control Specimens.

Stress Level	Sample Number	Sample Ht. (in)*	Cycles to Failure	Average Input Stress, psi	Bending Strain at the 200 cycle, in/in $\times 10^{-4}$	Initial Modulus (E) at the 200 cycle, psi	Total Input Energy at the 200 cycle, in - lb
Low	ACC-T1	3.1	150,223	103	2.1	455,063	37,500
	ACC-2	3.0	215,477	108	2.3	434,039	58,700
	ACC-5	3.1	125,878	103	2.4	417,595	37,200
	ACC-8	3.1	58,119	106	2.1	456,085	14,200
Medium	ACC-3	3.0	26,944	165	3.9	459,692	21,800
	ACC-6	3.1	21,650	149	2.9	550,871	12,100
	ACC-9	3.1	12,070	153	3.7	408,435	12,100
High	ACC-4	3.0	5,105	199	5.5	420,473	7,700
	ACC-7	3.1	3,327	173	3.0	596,925	2,200
	ACC-10	3.1	5,820	176	4.5	395,037	5,600

* Width of beam specimens was 3-inches.

Table E 3. Individual Beam Fatigue Test Results on Accorex Specimens Containing the Same Amount of Asphalt as the Control.

Stress Level	Sample Number	Sample Ht. (in)*	Cycles to Failure	Average Input Stress, psi	Bending Strain at the 200 cycle, in/in $\times 10^{-4}$	Initial Modulus (E) at the 200 cycle, psi	Total Input Energy at the 200 cycle, in - lb
Medium	ACC-11	2.95	406,130	157.2	1.5	1,074,699	108,800
	ACC-12	2.98	190,870	160.2	2.4	679,752	84,700
	ACC-13	2.99	480,820	157.2	2.5	639,287	218,300

*Width of beam specimens was 3-inches.

APPENDIX F

Results of Freeze-Thaw Pedestal Tests
on Individual Specimens

Table F1. Freeze-Thaw Pedestal Test Results.

Type	Sample Number	Height in.	Bulk Specific Gravity	Air Void Content, percent	Complete Cycles to Failure
Accorex	AC-1	0.747	1.776	26.4	2
	AC-2	0.746	1.766	26.8	2
	AC-3	0.748	1.784	26.1	3
Control	C-1	0.748	1.785	26.8	1
	C-2	0.746	1.788	26.7	1
	C-3	0.750	1.788	26.7	1