Report No. CDOT-DTD-R-93-23

DETERMINING OPTIMUM ASPHALT CONTENT WITH THE TEXAS GYRATORY COMPACTOR

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Final Report
December 1993

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

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Technical Report Documentation Page

1. Report No. CDOT-DTD-R-93-23	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Determining Optimum Asphalt Content with the Texas Gyratory Compactor		5. Report Date December 1993
		6. Performing Organization Code
7. Author(s) Timothy Aschenbrener		8. Performing Organization Rpt.No. CDOT-DTD-R-93-23
9. Performing Organization Name and Address Colorado Department of Transportation 4201 E. Arkansas Avenue Denver, Colorado 80222		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222		13. Type of Rpt. and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes Prepared in Cooperation with the U.S. Department of Transportation Federal Highway Administration		

16. Abstract

A recent change from the California kneading compactor to the Texas gyratory compactor has resulted in significantly lower optimum asphalt contents. Additionally, only one laboratory compactive effort has been used in Colorado regardless of traffic or high temperature environment. Adjustments are being made to the Colorado's hot mix asphalt design procedure to address these concerns.

It was decided to use results from the recently acquired European equipment to assist with the adjustments. Additionally, results were used from three other sources: 1) the previously used California kneading compactor, 2) samples from older pavements that were recompacted in the Texas gyratory, and 3) experimental field projects that used the recommended end-point stresses.

Optimum asphalt contents need to be determined using varying laboratory compactive efforts that correspond to the various traffic and environmental conditions in Colorado. The recommendations presented in this report include the variable end-point stresses for the Texas gyratory to obtain the optimum asphalt content along with the traffic and environmental categories to assist designers on the appropriate selection of the specified end-point stress. Additionally, minimum Hveem stability values, minimum voids in the mineral aggregate, and an acceptable range for voids filled with asphalt are included.

17. Key Words Texas Gyratory Compactor; Optimum Asphalt Content		18. Distribution Statement No Restrictions: This report is available to the public through the National Technical Info. Service. Springfield, VA 22161	
19.Security Classif. (report) Unclassified	20.Security Classif. (page) Unclassified	21. No. of Pages 78	22. Price

Acknowledgements

The author would like to express his gratitude to the 19 asphalt paving contractors that participated in this study by providing the aggregates for testing and their experiences with the mixes they submitted. The laboratory testing was performed by Kim Gilbert, Cindi Moya, Larry Lamar, Dave Gallegos, and Brad Black (CDOT-Staff Materials), Dave Price (CDOT-Research), and J.D. Stevenson (FHWA-Colorado Division). Throughout the study, valuable input was appreciated from Scott Shuler (CAPA), Jim Fife (Western Colorado Testing) and all of the CDOT Region Materials Engineers.

The CDOT Research Panel provided many excellent comments and suggestions for the study; it included Byron Lord and Kevin Stuart (FHWA-Turner Fairbank Highway Research Center), Doyt Bolling (FHWA-Region 8), Jerry Cloud (FHWA-Colorado Division), Denis Donnelly, Steve Horton, and Bob LaForce (CDOT-Staff Materials), Ken Wood (CDOT-Region 4 Materials), and Donna Harmelink (CDOT-Research).

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Tim Aschenbrener

1.0 INTRODUCTION

In September 1990, a group of individuals representing AASHTO, FHWA, NAPA, SHRP, AI, and TRB participated in a 2-week tour of six European countries. Information on this tour has been published in a "Report on the 1990 European Asphalt Study Tour" (1). Several areas for potential improvement of hot mix asphalt (HMA) pavements were identified, including the use of performance-related testing equipment used in several European countries. The Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center (TFHRC) were selected to demonstrate this equipment.

A recent change from the California kneading compactor to the Texas gyratory compactor has resulted in significantly lower optimum asphalt contents. Additionally, only one laboratory compactive effort has been used in Colorado regardless of traffic or high temperature environment. Adjustments are being made to the CDOT HMA design procedure to address these concerns. It was decided to use results from the new European equipment to assist with the adjustments. Additionally, results were used from three other sources: 1) the previously used California kneading compactor, 2) samples from older pavements that were recompacted in the Texas gyratory, and 3) experimental field projects that used the recommended end point stresses.

Optimum asphalt contents need to be determined using varying laboratory compactive efforts that correspond to the various traffic and environmental conditions in Colorado. The purpose of this study will be to develop and document the recommended end point stresses for the Texas gyratory to obtain the optimum asphalt content.

2.0 ENGINEERING REGIONS

2.1 Traffic

Traffic is defined by the number of equivalent 18-kip single axle loads (ESALs) applied to the pavement for its design life. The design ESALs for a project should be used to select a traffic category. A design life of 20 years and zero growth rate was used to develop the percent of the 14,800 center-line kms (9200 miles) on the CDOT network for each traffic category. The percent of CDOT network in each category includes adjustments for the number of lanes. The five traffic categories used for this analysis are shown in Table 1.

Table 1. Traffic Categories for Designing HMA Pavements.

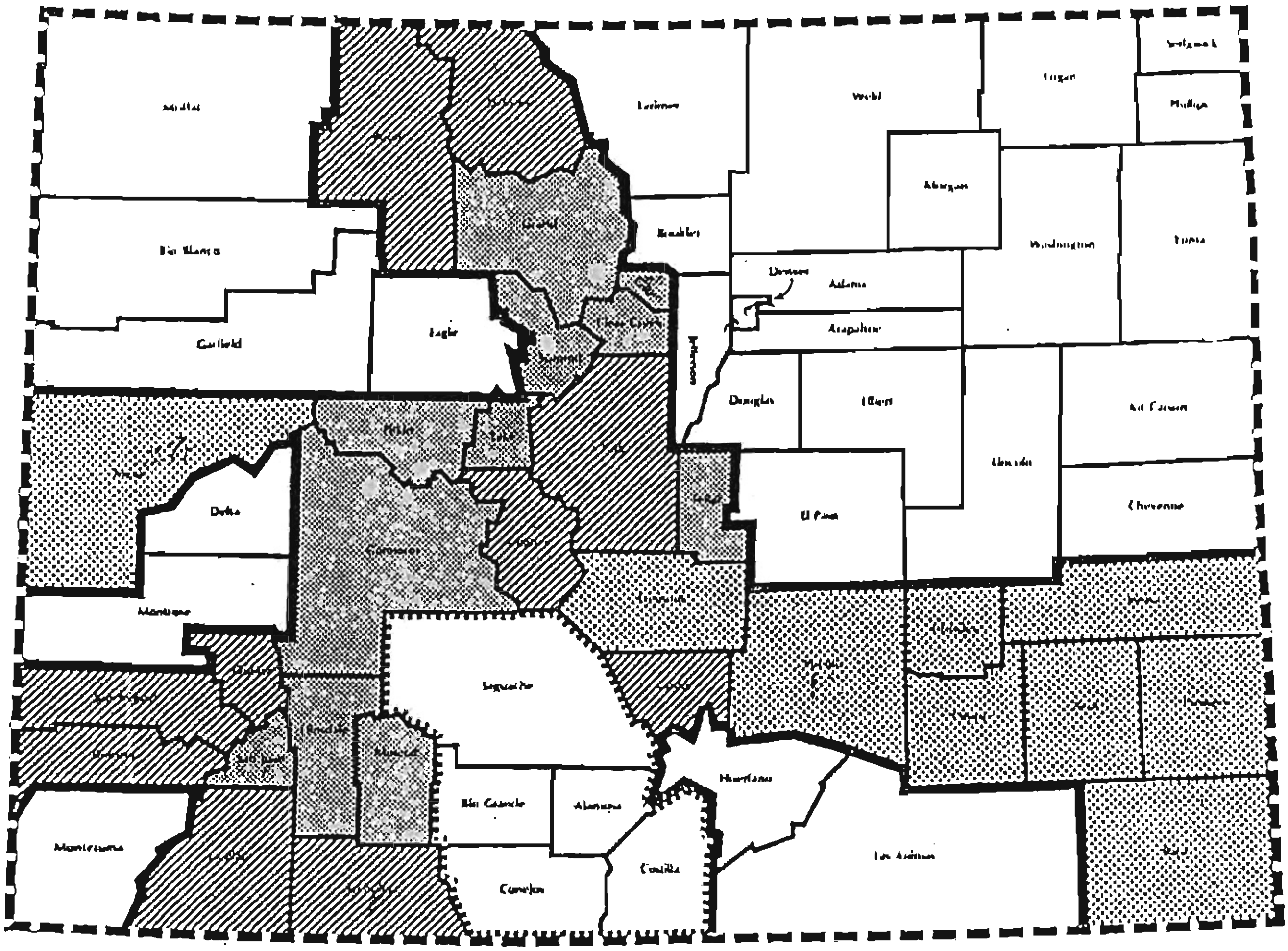
Traffic Category	Design ESALs	CDOT Network (%)
Low	$< 3 \times 10^5$	21.8
Medium	3×10^5 to 10^6	34.4
High	10^6 to 3×10^6	16.1
Very High	3×10^6 to 10^7	21.3
Very Very High	$>10^7$	6.4

2.2 Environment

Because of the wide variation in elevation in Colorado, there are four distinct high temperature environments. The four high temperature areas are shown in Fig. 1. The weather data base assembled by SHRP was used to identify the high air temperature environment for each category. The highest temperature is calculated as the average of the highest air temperature for the hottest seven consecutive days. A summary of the average highest 7-day air temperatures taken in each county are in Appendix A and a copy of the SHRP data base with 153 weather stations in Colorado are in Appendix B.

Zone ENVIRONMENTAL ZONES

1: Elevation over 8500', Cool, Wet, High Frost Penetration
2: Elevation 6500 to 8500', Cool, Wet, High Frost Penetration
3: Elevation 6500 to 8500', Cool, Very Dry, High Frost Penetration
4: Elevation less than 8500', Warm, Dry, Low Frost Penetration
5: Elevation less than 6500', Very Warm, Very Dry, Very Low Frost Penetratic



Note: This map does not reflect changes made to a small number of highway segments at the direction of the Engineering District offices.

Fig. 1. High Temperature Environmental Zones by County.

The high elevation zones have very cool high temperatures and should receive special design considerations. The counties with elevations over 2600 meters (8500 ft.) with a cold, wet, and high frost penetration environment are: Clear Creek, Gilpin, Grand, Gunnison, Hinsdale, Lake, Mineral, Pitkin, San Juan, Summit, and Teller.

Special design consideration should be given to areas with elevation between 2000 and 2900 meters (6500 and 8500 ft.). These counties are: Alamosa, Archuleta, Chaffee, Conejos, Costilla, Custer, Dolores, Jackson, La Plata, Ouray, Park, Rio Grande, Routt, San Miguel, and Saguache.

The majority of the state is in the moderate temperature region. This includes: Adams, Arapahoe, Boulder, Cheyenne, Delta, Denver, Douglas, Eagle, Elbert, El Paso, Garfield, Huerfano, Jefferson, Kit Carson, Larimer, Las Animas, Lincoln, Logan, Moffat, Montezuma, Montrose, Morgan, Phillips, Rio Blanco, Sedgwick, Washington, Weld, and Yuma.

The hottest areas of the state are on the western slope or along the Arkansas River in southeastern Colorado. These counties include: Baca, Bent, Crowley, Fremont, Kiowa, Mesa, Otero, Prowers, and Pueblo.

Table 2. Four High Temperature Environmental Zones in Colorado.

High Temperature Region	Highest 7-Day Avg. Max. Air Temperature	CDOT Network (%)
Hot (SE and West)	> 36°C (> 97°F)	14.7
Moderate (Denver, Plains and West)	32 to 36°C (90 to 97°F)	57.2
Cool (Mountains)	27 to 31°C (81 to 88°F)	13.9
Very Cool (High Mountains)	< 27°C (< 81°F)	14.2

2.3 Summary of Traffic and Temperature

The percent of the network for the various traffic and temperature categories are shown in Table 3.

Table 3. Percent of Network for Various Traffic and Temperature Categories.

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	6.6	4.3	9.4	3.3
Medium	4.7	5.0	13.6	4.1
High	1.9	4.1	14.1	3.1
Very High	1.0	0.6	13.7	4.2
Very Very High			6.4	

3.0 TESTING DEVICES

3.1 Texas Gyratory

The Texas gyratory procedure is defined in ASTM D 4013, and the device is shown in Fig. 2. A sample is compacted with a pre-gyration stress of 350 kPa (50 psi). At the end of three gyrations, the end point stress is checked. If the end point stress is less than 1030 kPa (150 psi), then three more gyrations at 350 kPa (50 psi) are performed. If the end point stress is greater than 1030 kPa (150 psi), then the compaction is completed. The end point stress is checked by applying a 0.5 mm (0.020 in.) deformation into the sample. The deformation creates a stress defined as the end point stress. A leveling load of 17,240 kPa (2500 psi) is applied after the end point stress is reached.

In order to vary compactive efforts with the Texas gyratory, the end point stress should be varied. Lower end point stresses result in lower compactive efforts.

3.2 California Kneading Compactor

AASHTO T 247 is the procedure to compact samples using the California kneading compactor. Colorado has used a modified procedure from 1973 to 1991. A comparison of the Colorado and AASHTO procedures is shown in Table 4. The Colorado procedure uses a lower compactive effort by reducing the compaction blows from 150 to 90 and the compaction pressure from 3450 kPa (500 psi) to 3100 kPa (450 psi). The Colorado procedure was used for this study since the procedure provided many excellent performing pavements during its time.

Table 4. Comparison of the Colorado and AASHTO Procedures for the California Kneading Compactor.

	AASHTO T 247	Colorado
Semi-compaction	20 blows @ 1.7 MPa	20 blows @ 1.7 MPa
Compaction	150 blows @ 3.4 MPa	90 blows @ 3.1 MPa
Leveling	6.9 MPa	6.9 MPa

3.3 French Rutting Tester

The French rutting tester is used to measure the resistance of an HMA to permanent deformation. The device is shown in Fig. 3. A slab is 50 by 18 cm (19.7 by 7.1 in.) and is typically 100 mm (4 in.) thick. Two slabs are tested simultaneously.

The slabs are loaded with 5000 N (1124 lbs.) by a pneumatic tire inflated to 600 kPa (87 psi). The tire loads the slab at 1 cycle per second. The chamber is heated to 60°C (140°F) but can be set to any temperature between 35° and 60°C (95° and 140°F).

When a test is performed on a laboratory compacted sample, it is aged at room temperature for as long as 7 days. It is then placed in the French rutting tester and loaded with 1000 cycles at room temperature. The deformations recorded at the end are the "zero" readings. It is then heated to the test temperature for 12 hours before the test begins. Rut depths are measured after 100, 300, 1000, 3000, 10000, 30000, and possibly 100,000 cycles. The rut depth after a given number of cycles is calculated as the average of 15 measurements: 5 locations along the length and 3 along the width.

A successful test will have a rut depth that is less than 10% of the slab thickness after 30,000 cycles. A pair of slabs can be tested in about 9 hours.

Fig. 2. The Texas Gyratory Compactor.

Fig. 3. The French Rutting Tester.

4.0 TESTING METHODOLOGY

4.1 Summary of Hot Mix Asphalt Designs

Contractors in Colorado were asked to submit an HMA design that would be used on a typical CDOT project. Each contractor was allowed to submit one design. Although a maximum of 20 designs were targeted for the study, 19 were submitted. All mixes contained lime. As expected, there was a wide variety of mixtures submitted. The aggregate properties are summarized in Table 5.

4.2 Experimental Grid

Each HMA used in this experiment was tested using the standard CDOT procedures as outlined below:

1) Texas gyratory, 170 kPa (25 psi) end point stress,
2) Texas gyratory, 520 kPa (75 psi) end point stress,
3) Texas gyratory, 860 kPa (125 psi) end point stress,
4) French rutting tester, and
5) California kneading compactor.

Designs performed on the Texas gyratory used 4 different asphalt contents at 0.5% increments. The pre-gyration stress was also adjusted somewhat proportionately with the end point stress. The pre-gyration, end point and consolidation stresses used were:

1) 70-170-17240 kPa (10-25-2500 psi),
2) 140-520-17240 kPa (20-75-2500 psi), and
3) 210-860-17240 kPa (30-125-2500 psi).

Designs on the California kneading compactor used 3 different asphalt contents at 0.5% increments. Samples were tested on the French rutting tester to determine the maximum asphalt content of the HMA before rutting on a high trafficked pavement.

Table 5. Summary of Aggregate Properties Used In This Study.

Mix	Grading	Nominal Maximum Size mm (In.)	Aggregate Source			
			Natural Sand (%)	RAP (%)	Crushed (%)	
					Pit	Quarry
1	C	12.5 (1/2)	0	0	100	0
2	C	19.0 (3/4)	10	10	60	20
3	C	12.5 (1/2)	20	0	0	80
4	C	19.0 (3/4)	0	0	0	100
5	C	19.0 (3/4)	20	15	0	65
6	C	19.0 (3/4)	35	0	0	65
7	C	12.5 (1/2)	10	0	90	0
8	CX	9.5 (3/8)	20	0	80	0
9	CX	12.5 (1/2)	20	20	0	60
10	CX	9.5 (3/8)	0	0	100	0
11	CX	12.5 (1/2)	20	20	0	60
12	CX	12.5 (1/2)	20	0	80	0
13	CX	12.5 (1/2)	0	0	100	0
14	C	19.0 (3/4)	10	0	90	0
15	CX	9.5 (3/8)	20	0	80	0
16	C	19.0 (3/4)	20	0	80	0
17	CX	12.5 (1/2)	0	0	100	0
18	CX	12.5 (1/2)	10	0	90	0
19	C	19.0 (3/4)	0	0	100	0

RAP - Recycled Asphalt Pavement

5.0 LABORATORY RESULTS AND DISCUSSION

5.1 Texas Gyratory Results

Each HMA submitted was compacted at 3 different end point stresses with the Texas gyratory. It was desired to determine the appropriate end point stress for the various traffic and environmental conditions in Colorado. Additionally, the Hveem stability, Voids in the Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA) were measured. Specifications relating the Hveem stability, VMA, and VFA might also need adjusting. A summary of the optimum asphalt content, Hveem stability, and VMA of each HMA compacted in the Texas gyratory is shown in Table 6. Plots of the optimum asphalt content versus the various end point stresses are shown in Appendix C.

5.2 Optimum Asphalt Content

The optimum asphalt content was selected at 4% air voids in all cases.

5.2.1 High Traffic

5.2.1.1 Hot Environment. The French rutting tester was used at 60°C (140°F) to define the threshold asphalt content of each HMA for high traffic pavements in the hot environment. The threshold asphalt content for each mix was defined as the highest asphalt content that would pass the French rutting tester. Results from the French rutting tester are shown in Appendix D.

Each mix was also designed using three different end point stresses with the Texas gyratory. When the threshold asphalt content corresponded to the asphalt content at 3% air voids for a certain end point stress, a mix designed with the same end point stress at 4% air voids would be 1% air voids away from rutting. Take Mix 2 for example, using a 450 kPa (65 psi) end point stress at 4% air voids, the optimum asphalt content is 5.8%. The asphalt content at 3% air voids is 6.2%, the rutting threshold asphalt content. Therefore, if Mix 2 were designed at 4% air voids using a 450 kPa (65 psi) end point stress, the mix would be 1% air voids from the rutting threshold.

Table 6. Optimum Asphalt Content, Hveem Stability, and VMA for Samples Compacted in the Texas Gyratory.

Mix	Optimum AC (%) @ 4% Air Voids			Stability @ Optimum			VMA (%) @ Optimum		
	25	75	125	25	75	125	25	75	125
1	5.6	5.4	5.1	45	46	48	14.4	14.3	13.7
2	6.3	5.7	5.1	40	42	46	16.9	16.1	15.2
3	5.7	5.0	4.9	42	50	48	16.0	14.5	14.1
4	5.5	5.1	5.0	40	43	42	15.2	14.0	14.3
5	5.3	4.7	4.5	40	44	43	14.0	12.8	12.4
6	5.7	5.5	5.2	43	47	49	15.8	15.4	14.7
7	6.3	5.9	5.6	--	42	41	---	16.0	15.4
8	6.1	5.7	5.3	35	38	40	15.8	15.1	14.3
9	6.6	6.1	5.7	---	40	43	---	16.3	15.4
10	6.0	5.3	5.0	36	43	44	15.9	14.0	13.9
11	6.3	5.8	5.5	40	44	47	18.5	17.4	17.1
12	6.1	5.7	5.3	37	40	42	15.7	14.7	13.6
13	5.8	5.6	4.8	37	39	46	16.0	15.7	13.5
14	>6.0	5.6	4.7	--	35	41	--	15.5	13.8
15	6.3	5.8	5.5	37	42	42	17.0	15.9	15.2
16	5.7	5.3	5.0	40	44	42	15.5	14.2	14.0
17	>6.0	5.7	5.4	--	41	43	--	15.8	14.9
18	5.6	5.2	5.1	39	42	43	14.4	13.2	13.4
19	4.9	4.6	4.4	41	45	46	13.2	13.0	12.5

25 = 170 kPa (25 psi) end point stress on the Texas gyratory
75 = 520 kPa (75 psi) end point stress on the Texas gyratory
125 = 860 kPa (125 psi) end point stress on the Texas gyratory

The threshold asphalt content and the asphalt contents at 1% and 2% air voids away from the threshold asphalt contents are shown in Table 7. Additionally, the end point stress required by the Texas gyratory to match the 1% and 2% air voids factor of safety are shown in Table 7. For high trafficked pavements, an optimum asphalt content selected at 4% air voids using a 860 kPa (125 psi) end point stress is recommended.

There is considerable scatter in the recommended end point stresses shown in Table 7. The scatter appears to be related to two variables: 1) the angularity of the aggregates used, and 2) the maximum aggregate size in the mix.

The first variable appears to be aggregate angularity. The mixes using primarily quarried material, always highly angular, meet the rutting threshold with a 1% air void factor of safety at an end point stress that is less than 690 kPa (100 psi) (Mix 9) and mostly less than 340 kPa (50 psi) (Mix 3, 4, 5, and 11). Although Mix 6 is primarily from a quarried source, it contains 35% rounded sands and meets the rutting threshold at 860 kPa (125 psi).

When aggregates are from sand and gravel pits, a higher end point stress is required to meet the rutting threshold with a 1% air void factor safety than with quarried materials. The aggregates from sand and gravel pits with <u>generally</u> marginal angularity (Mix 8, 10, 13) require an end point stress greater than 900 kPa (130 psi). Aggregates from pits with noticeably higher angularity (Mix 2, 7) have an end point stress of less than 690 kPa (100 psi) to avoid the rutting threshold by 1% air voids.

The second variable appears to be maximum aggregate size. The larger the maximum aggregate size, the stronger the mix. The 7 mixes with a 19.0 mm (3/4 in.) nominal maximum aggregate size meet the rutting threshold with a 1% air void factor of safety at an end point stress of 510 kPa (74 psi). Mixes with a nominal maximum aggregate size less than 19.0 mm meet the same factor of safety at 670 kPa (97 psi).

Varying the end point stress alone will be insufficient to resist rutting. Minimum Hveem stability and VMA values will be required to ensure that sufficiently angular materials are produced for the high and very high traffic categories. Larger nominal maximum aggregate size will be needed.

Table 7. Optimum Asphalt Contents (AC) from the French Rutting Tester and the Texas Gyratory Compactor.

Mix	AC @ Rutting Threshold (%)	AC @ 1% Higher Air Voids (%)	T.G. End Point Stress kPa (psi)	AC @ 2% Higher Air Voids (%)	T.G. End Point Stress kPa (psi)
1*	6.2	5.8	170 (25)	5.5	340 (50)
2A*	6.9	6.3	170 (25)	5.8	450 (65)
2	6.2	5.8	450 (65)	5.4	690 (100)
3	5.7	5.3	340 (50)	4.9	860 (125)
4	5.8	5.5	170 (25)	5.0	690 (100)
5	5.7	5.4	170 (25)	4.8	480 (70)
6	5.6	5.2	860 (125)	4.8	1030 (150)
7	6.6	6.2	280 (40)	5.9	520 (75)
8	5.0	4.7	1030 (150)	4.4	>1030 (>150)
9	6.2	5.9	690 (100)	5.6	930 (135)
10	5.0	4.7	1030 (150)	4.4	> 1030 (>150)
11	6.3	6.0	340 (50)	5.7	620 (90)
12	5.4	5.1	930 (135)	4.8	1030 (150)
13	5.0	4.6	900 (130)	4.2	1030 (150)
14	5.3	5.0	860 (125)	4.7	970 (140)
15	5.6	5.2	1030 (150)	4.8	>1030 (150)
16	5.3	4.9	860 (125)	4.5	>1030 (150)
17	5.8	5.5	340 (50)	5.1	1030 (150)
18	5.6	5.3	410 (60)	5.0	1030 (150)
19	5.5	5.2	<170 (25)	4.9	170 (25)
Avg.	5.62	5.31	610 (88)	4.93	850 (123)
S.D.	0.53	0.50	330 (48)	0.51	250 (37)

* High Elevation Data (not included in averages)

5.2.1.2 Cool Environment. Two of the HMAs (Mix 1 and Mix 2A) were examined for placement at high elevations. The asphalt content for the threshold of rutting was determined from the French rutting tester. The French rutting tester was performed at 50°C (122°F) to model the cool or very cool high temperature categories. For the very high traffic category in a cool environment, an end point stress of 520 kPa (75 psi) is appropriate.

5.2.2 Medium Traffic

The California kneading compactor was used successfully in Colorado from 1973 to 1991. It was particularly successful on the low and medium trafficked roads, and there were even successes on high and very high trafficked roads. It was desired to compare the asphalt contents obtained with the successful experience of the California kneading compactor with the various end point stresses used on the Texas gyratory. The results are shown in Table 8.

Results indicate the Colorado version of the California kneading compactor is comparable to a 340 kPa (50 psi) end point stress with the Texas gyratory. Once again there is scatter in the data, that can be attributed to the wide variety of aggregate angularity and maximum aggregate size. Using a 340 kPa (50 psi) end point stress for the moderate environmental and medium traffic category appears reasonable.

5.2.3 Low Traffic

For low trafficked roads there was not a significant data base or test that could be used to develop recommended end point stresses on the Texas gyratory. Primarily, the recommendations are based on the past experience of CDOT and contractor personnel.

Table 8. Optimum Asphalt Contents from the California Kneading Compactor.

Mix	Kneading Compactor Optimum AC (%)	Gyratory End Point Stress kPa (psi)
1	6.4	<170 (<25)
2	6.2	240 (35)
3	6.1	<170 (<25)
4	5.7	<170 (<25)
5	5.4	170 (25)
6	5.5	520 (75)
7	6.5	<170 (<25)
8	5.5	690 (100)
9	6.2	450 (65)
10	5.6	380 (55)
11	6.3	170 (25)
12	5.9	340 (50)
13	5.4	590 (85)
14	5.9	340 (50)
15	6.0	380 (55)
16	5.8	170 (25)
17	6.1	170 (25)
18	5.5	280 (40)
19	4.8	280 (40)
Avg.	5.83	310 (45)
SD	0.43	160 (23)

5.2.4 Summary

The recommended end point stresses to be used on the Texas gyratory for various traffic and environmental zones are shown in Table 9. The optimum asphalt content determined from the 19 mixes studied in this experiment are shown in Table 10.

Table 9. Recommended End Point Stresses (psi) for the Texas Gyratory.

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	25	25	25	50
Medium	25	25	50	75
High	25	50	75	100
Very High	50	75	100	125
Very Very High			125	

1 psi = 6.895 kPa

Table 10. Average Asphalt Contents for Each Category.

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	6.0	6.0	6.0	5.7
Medium	6.0	6.0	5.7	5.5
High	6.0	5.7	5.5	5.3
Very High	5.7	5.5	5.3	5.1
Very Very High			5.1	

5.3 Hveem Stability

The Hveem stability values were determined according to AASHTO T 246. Results at the end point stresses tested for this study are shown in Table 6 for each of the mixes. Recommendations for the minimum stability data were developed from the actual performance of 33 pavements in Colorado, both good and bad as reported by Aschenbrener (1). These data were analyzed by consultants from Aguirre Engineers. The recommended minimum stability requirements should be related to the design end point stress. The recommended values are shown in Table 11.

Table 11. Minimum Hveem Stability Specifications.

End Point Stress kPa (psi)	Minimum Stability
860 (125)	42
690 (100)	42
520 (75)	39
340 (50)	33
170 (25)	26

5.4 Voids in the Mineral Aggregate

All of the VMA results reported in this study were calculated using the bulk specific gravity of the aggregates. A summary of the actual VMA values measured in this study are shown in Table 6. A summary of the VMA values for the compactive efforts that correspond to the various traffic categories and some recommended specifications are shown in Table 12. The recommended VMA specifications are shown in Table 13.

When the design air voids are chosen differently than 3.0, 4.0 or 5.0%, the specified VMA should be chosen by linear interpolation. For example, a 19.0 mm (3/4 in.) nominal maximum size aggregate at 4.0% air voids, the VMA specification would be 13.0. For the same mix at 4.4% air voids, the VMA specification would be 13.4.

Table 12. Summary of the Voids in the Mineral Aggregate Data.

Mix	Grading	Nominal Maximum Aggregate Size mm (in)	Specified VMA @ 4% Air Voids (%)		Actual VMA (By Traffic) (%)			
			Old AI	New AI	50	75	100	125
1	C	12.5 (1/2)	15	14	14.4	14.3	14.0	13.7
2	C	19.0 (3/4)	14	13	16.5	16.1	15.7	15.2
3	C	12.5 (1/2)	15	14	15.2	14.5	14.3	14.1
4	C	19.5 (3/4)	14	13	14.6	14.0	14.0	14.3
5	C	19.5 (3/4)	14	13	13.4	12.8	12.6	12.4
6	C	19.5 (3/4)	14	13	15.6	15.4	15.0	14.7
7	C	12.5 (1/2)	15	14	16.0	16.0	15.7	15.4
8	CX	9.5 (3/8)	16	15	15.4	15.1	14.8	14.3
9	CX	12.5 (1/2)	15	14	16.3	16.3	15.9	15.4
10	CX	9.5 (3/8)	16	15	15.0	14.0	14.0	13.9
11	CX	12.5 (1/2)	15	14	17.9	17.4	17.2	17.1
12	CX	12.5 (1/2)	15	14	15.3	14.7	14.1	13.6
13	CX	12.5 (1/2)	15	14	15.8	15.7	14.6	13.5
14	C	19.0 (3/4)	14	13	15.5	15.5	14.6	13.8
15	CX	9.5 (3/8)	16	15	16.5	15.9	15.5	15.2
16	C	19.0 (3/4)	14	13	14.8	14.2	14.1	14.0
17	CX	12.5 (1/2)	15	14	16.3	15.8	15.3	14.9
18	CX	12.5 (1/2)	15	14	13.8	13.4	13.4	13.4
19	C	19.0 (1/2)	14	13	13.1	13.0	12.8	12.5

AI = Asphalt Institute
50 = 340 kPa (50 psi)
75 = 520 kPa (75 psi)
100 = 690 kPa (100 psi)
125 = 860 kPa (125 psi)

Table 13. Minimum VMA Specifications.

Minimum VMA Specifications[2]			
Nominal Maximum Size[1] mm (In)	Design Air Voids		
	3.0%	4.0%	5.0%
37.5 (1-1/2)	10.0	11.0	12.0
25.0 (1)	11.0	12.0	13.0
19.0 (3/4)	12.0	13.0	14.0
12.5 (1/2)	13.0	14.0	15.0
9.5 (3/8)	14.0	15.0	16.0
[1] The Nominal Maximum Size is defined as one size larger than the first sieve to retain more than 10%.			
[2] Interpolate specified VMA values for design air voids between those listed.			

5.5 Voids Filled with Asphalt

The voids filled with asphalt (VFA) is an important parameter relating to pavement performance. If the VFA is too high, a mix may be susceptible to premature rutting. If the VFA is too low, a mix may be susceptible to ravelling. The recommended VFA values were obtained from the Asphalt Institute MS-2 and are shown in Table 14.

Table 14. Recommended VFA Specifications.

End Point Stress kPa (psi)	VFA (%)
860 (125)	65 - 75
690 (100)	65 - 75
520 (75)	65 - 78
340 (50)	65 - 80
170 (25)	70 - 80

5.6 Impact of New Specifications

Each of the mixes analyzed in this study were compared to the new specifications. Of the 19 mixes investigated, 12 would pass the new specifications for all traffic and environmental categories. The mixes that would fail the new specifications and the reason the mix would fail is listed in Table 15. Although 9 mixes are listed in Table 15, 2 of the mixes would pass in the 3% to 5% air void window. All but one of the mixes would be acceptable for medium and low traffic roadways. Of the 17 possible combinations or grids of traffic and environment, the number of grids that the mix would be acceptable and unacceptable is shown in Table 15.

Table 15. Mixes Failing the New Specifications.

Mix	Lowest Unacceptable Grid		Of 17 Grids:		Cause for Failure
	Traffic	Environment	Acceptable	Unaccept.	
5	High	Moderate	10	7	VMA
7*	Very High	Hot	15	2	Stability
8	Very High	Moderate	13	4	Stability, VMA
10	High	Moderate	10	7	VMA
12	Very High	Hot	15	2	VMA
13	Very High	Hot	15	2	VMA
14*	High	Moderate	10	7	Stability
18	Medium	Moderate	6	11	VMA
19	High	Moderate	13	4	VMA

* Does not pass at 4.0% air voids but does pass between 3% and 5% air voids.

6.0 CASE HISTORIES FROM 1993

During 1993, several projects were constructed using the Texas gyratory with the lower end point stresses. Summaries of these trial projects are described below.

6.1 6th Avenue

The project is located in Denver with a highest 7-day air temperature of 33 to 34°C (91 to 93°F), the moderate temperature category. The 10-year ESALs used to design the overlay were 2.5 x 10^6, a borderline high traffic category. The end point stress should be 520 kPa (75 psi). The project was designed with the 690 kPa (100 psi) end point stress and had an optimum asphalt content of 4.8% at 4.0% air voids. The mix was very stiff. If the 520 kPa (75 psi) end point stress had been used, the optimum asphalt content would have been 5.0%, considered to be reasonable by the contractor and CDOT personnel.

6.2 Arapahoe Road

The project is located in Denver with a highest 7-day air temperature of 33 to 34°C (91 to 93°F), the moderate temperature category. The 10-year ESALs used to design the overlay were 6.5 x 10^5, a medium traffic category. The end point stress should be 350 kPa (50 psi). The project was designed with the 690 kPa (100 psi) end point stress and had an optimum asphalt content of 4.8% at 4.0% air voids. The mix was very stiff. If the 350 kPa (50 psi) end point stress had been used, the optimum asphalt content would have been 5.2%, considered to be reasonable by the contractor and CDOT personnel.

6.3 Copper Mountain

The project is located near Dillon with a highest 7-day air temperature of 26°C (79°F), the very cool temperature category. The 10-year ESALs used to design the overlay were 3.5 x 10^6, a very high traffic category. The end point stress should be 350 kPa (50 psi). The project was designed with the 350 kPa (50 psi) end point stress and had an optimum asphalt content of 5.7% at 4.0% air voids. The mix was considered reasonable by the contractor and CDOT personnel.

6.4 Idaho Springs

The project is located on I-70 at Idaho Springs with a highest 7-day air temperature of 29°C (84°F), the cool temperature category. The 10-year ESALs used to design the overlay were 3.5 x 10^6, a very high traffic category. The end point stress should be 520 kPa (75 psi). The project was designed with the 520 kPa (75 psi) end point stress and had an optimum asphalt content of 5.7% at 4.0% air voids. The mix was considered reasonable by the contractor and CDOT personnel.

6.5 Cherry Creek State Park

The project is located in Denver with a highest 7-day air temperature of 33 to 34°C (91 to 93°F), the moderate temperature category. The design ESALs were unknown. The low traffic category was used since the road serves only recreational vehicles. The end point stress should be 170 kPa (25 psi). The project was designed with low air voids at the 170 kPa (25 psi) end point stress and had an optimum asphalt content of 5.6% at 4.0% air voids. The mix appeared to have too low an asphalt content for the application.

6.6 Berthoud Pass

The project is located on Berthoud Pass with a highest 7-day air temperature of 19°C (66°F), the very cool temperature category. The 10-year ESALs used to design the overlay were 4.1 x 10^5, a medium traffic category. The end point stress should be 170 kPa (25 psi). The project was constructed with the 170 kPa (25 psi) end point stress and had an optimum asphalt content of 5.8% at 4.0% air voids. The mix was considered reasonable by the CDOT maintenance and engineering personnel.

6.7 Muddy Pass

The project is located from Muddy Pass to the east with a highest 7-day air temperature of 30°C (86°F), the cool temperature category. The 10-year ESALs used to design the overlay were 3.3 x 10^5, a medium traffic category. The end point stress should be 170 kPa (25 psi). The project was constructed with the 170 kPa (25 psi) end point stress and had an optimum asphalt content of 5.7% at 4.0% air voids. The mix was considered reasonable by the CDOT and contractor personnel.

6.8 Walden

The project is located from Walden to the south with a highest 7-day air temperature of 28°C (82°F), the cool temperature category. The 10-year ESALs used to design the overlay were in the medium traffic category. The end point stress should be 170 kPa (25 psi). The project was constructed with the 170 kPa (25 psi) end point stress and had an optimum asphalt content of 6.0% at 4.0% air voids. The mix was considered reasonable by the CDOT and contractor personnel.

6.9 Basalt

The project is located around Basalt with a highest 7-day air temperature of 34°C (93°F), the moderate temperature category. The 20-year ESALs used to design the overlay were 1.9×10^6, a high traffic category. The end point stress should be 520 kPa (75 psi). The project was constructed with the 520 kPa (75 psi) end point stress and had an optimum asphalt content of 5.8% at 4.0% air voids. The mix was considered reasonable by the CDOT and contractor personnel.

6.10 Wilkerson Pass

The project is located on Wilkerson Pass with a highest 7-day air temperature of 27°C (81°F), the cool temperature category. The 10-year ESALs used to design the overlay were 3.2×10^5, a medium traffic category. The project was constructed with the 170 kPa (25 psi) end point stress and had an optimum asphalt content of 5.9% at 4.0% air voids. The mix was considered reasonable by the CDOT and contractor personnel.

7.0 FIELD CORRELATIONS

Ideally, in 3 to 5 years the air voids in the wheel path of the pavement should match the design air voids. A study previously performed by Aschenbrener (1) correlated the laboratory compacted air voids with the air voids in the wheel path. The correlation of the air voids in the wheel path with the laboratory compacted air voids is shown in Table 16. For the high trafficked pavements, the correlation of air voids in the wheel path with laboratory compacted voids is shown in Fig. 4. The variables used in Table 16 are defined as:

Y = air voids (%) from the sample recompacted in the Texas gyratory,
X = air voids (%) in the wheel path, and
r^2 = coefficient of determination.

Table 16. Correlation of Air Voids in the Wheel Path with Recompacted Samples for Different Traffic Categories and Laboratory Compactive Efforts.

Traffic Category	T.G. End Point Stress, kPa (psi)	Regression Equation	r^2
Medium	620 (90)	Y = 1.2X + 0.6	0.68
Medium	1030 (150)	Y = 1.4X + 1.3	0.63
High	620 (90)	Y = 1.1X - 0.1	0.78
High	1030 (150)	Y = 0.9X + 1.2	0.36

For an ideal relationship, the slope should equal 1.0 and the intercept should equal 0.0. For a perfect relationship, the coefficient of determination, r^2, should equal 1.0. For traffic in the high category, an end point stress of 620 kPa (90 psi) is close to ideal (the slope equals 1.1 and intercept is 0.1) and close to perfect (the r^2 is 0.78) as shown in Fig. 4.

For the very high traffic and moderate temperature category, it is recommended to design at a 690 kPa (100 psi) end point stress. The recommendation compares favorably with the measured air voids in the wheel path.

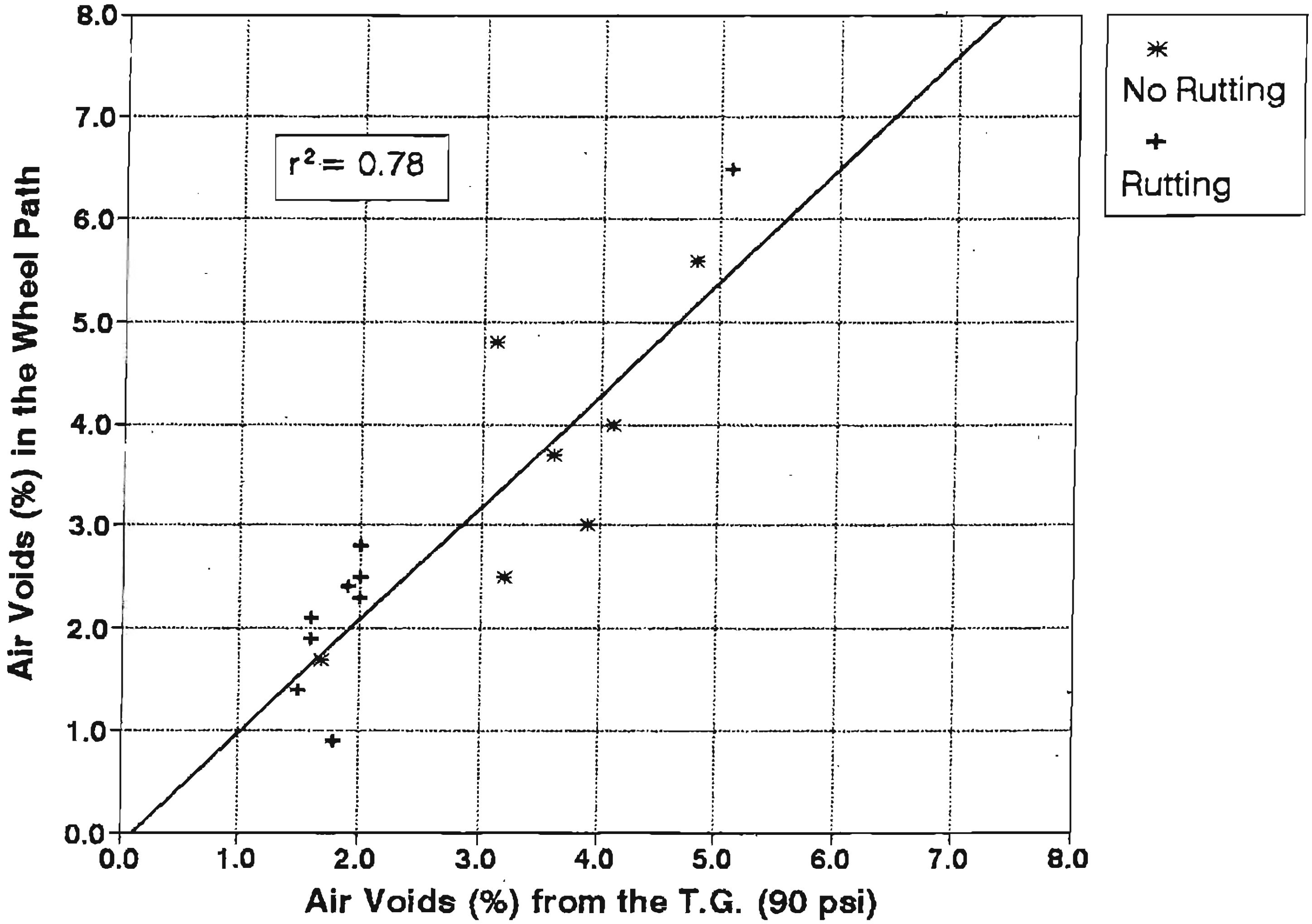


Fig. 4. Air Voids in the Wheel Path Versus Air Voids from Samples Recompacted in the Texas Gyratory with a 620 kPa (90 psi) End Point Stress for the High Traffic Category.

8.0 IMPLEMENTATION

The results of this research effort were presented to the Region Materials Engineers and a joint task force of CDOT, paving contractor, and industry representatives. The original findings of the study were modified based on the experience of all the individuals who provided feedback. The final recommendations are summarized below.

It is recommended the state be divided into four high temperature categories and five traffic categories. The traffic and high temperature environment recommendations are shown below.

Traffic Category	Design ESALs	CDOT Network (%)
Low	$< 3 \times 10^5$	21.8
Medium	3×10^5 to 10^6	34.4
High	10^6 to 3×10^6	16.1
Very High	3×10^6 to 10^7	21.3
Very Very High	$>10^7$	6.4

High Temperature Region	Highest 7-Day Avg. Max. Air Temperature	CDOT Network (%)
Hot (SE and West)	> 36°C (> 97°F)	14.7
Moderate (Denver, Plains and West)	32 to 36°C (90 to 97°F)	57.2
Cool (Mountains)	27 to 31°C (81 to 88°F)	13.9
Very Cool (High Mountains)	< 27°C (< 81°F)	14.2

The resulting 4x4 matrix (plus the very, very high traffic) will have a unique Texas gyratory design and stability. The recommended end point stresses are shown below in psi (1 psi = 6.895 kPa).

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	25	25	25	50
Medium	25	25	50	75
High	25	50	75	100
Very High	50	75	100	125
Very Very High			125	

The recommended minimum Hveem stability values and voids filled with asphalt (VFA) are shown below.

End Point Stress kPa (psi)	Minimum Stability	VFA (%)
860 (125)	42	65-75
690 (100)	42	65-75
520 (75)	39	65-78
340 (50)	33	65-80
170 (25)	26	70-80

The recommended minimum voids in the mineral aggregate (VMA) requirements are shown below.

Minimum VMA Specifications[2]			
Nominal Maximum Size[1] mm (In)	Design Air Voids		
	3.0%	4.0%	5.0%
37.5 (1-1/2)	10.0	11.0	12.0
25.0 (1)	11.0	12.0	13.0
19.0 (3/4)	12.0	13.0	14.0
12.5 (1/2)	13.0	14.0	15.0
9.5 (3/8)	14.0	15.0	16.0

[1] The Nominal Maximum Size is defined as one size larger than the first sieve to retain more than 10%.

[2] Interpolate specified VMA values for design air voids between those listed.

9.0 FUTURE RESEARCH

During the 1994 construction season, pavements should be selected for a void monitoring program. The pavements should include all traffic and environmental categories. After monitoring these pavements for 3 to 5 years, adjustments can be made to the end point stresses recommended in this study.

10.0 REFERENCES

1. Aschenbrener, T. (1992), "Investigation of the Rutting Performance of Pavements in Colorado," Colorado Department of Transportation Research Report, CDOT-DTD-R-92-12, 63 pages.

Appendix A

Summary of High Temperature Information

Counties with Mostly High Air Temperatures (> 36°C or 97°F)

County	7-Day High Air Temperatures
Baca	36, 36, 36
Bent	37,39
Crowley	
Fremont	37
Kiowa	37
Mesa	33, 36, 36, 36, 36, 36, 37
Otero	37, 38
Prowers	38, 38
Pueblo	31, 37, 37

Counties with Mostly Medium Air Temperatures (32 to 36°C or 90 to 97°F)

County	7-Day High Air Temperatures
Adams	35
Arapahoe	34
Boulder	27, 34, 34
Cheyenne	36, 37
Delta	33, 33, 33, 36
Denver	33, 33, 34
Douglas	33
Eagle	33
Elbert	33, 34
El Paso	25, 29, 33, 33
Garfield	34, 34, 34
Huerfano	33
Jefferson	30, 32, 33, 34
Kit Carson	36, 36, 36
Larimer	27, 28, 32, 33
Las Animas	27, 33, 33, 34, 37
Lincoln	33, 34, 36
Logan	36
Moffat	32, 32, 34, 36
Montezuma	33, 33, 33
Montrose	32, 34, 36, 37
Morgan	36
Phillips	36
Rio Blanco	32, 32, 36
Sedgwick	36, 37
Washington	35, 36
Weld	34, 35, 35, 36
Yuma	35, 36, 37

Counties with Mostly Low Air Temperatures (27 to 31°C or 81 to 88°F)

County	7-Day High Air Temperatures
Alamosa	29, 30
Archuleta	31
Chaffee	30, 31
Conejos	29
Costilla	31
Custer	30
Dolores	27, 33
Jackson	27, 28
La Plata	29, 30, 32, 33
Ouray	29
Park	27, 27, 27, 29
Rio Grande	28, 29, 29
Routt	27, 30, 32
San Miguel	27, 31
Saguache	29

Counties with Mostly Very Low Air Temperatures (<27°C or <81°F)

County	7-Day High Air Temperatures
Clear Creek	23, 27, 29
Gilpin	
Grand	19, 26, 26, 27, 29, 29
Gunnison	24, 25, 27, 29, 29
Hinsdale	28
Lake	21, 23, 24, 24
Mineral	21, 27, 27
Pitkin	29, 29
San Juan	25
Summit	26, 29
Teller	

Appendix B

Summary of SHRP's Weather Data Base for Colorado

SUPERPAVE DETERMINATION OF ASPHALT BINDER GRADE

Weather Database Used in SUPERPAVE Software

					AIR TEMP				50% RELIABILITY							98% RELIABILITY						
					LOW TEMP		HIGH TEMP		TEMPERATURES				BINDER GRADE			TEMPERATURES				BINDER GRADE		
COUNTY ID	STATION	LONG	LAT	ELEV	AVG	STD	AVG	STD	MAX AIR	MAX PVT	MIN AIR	MIN PVT	PG	HT	LT	MAX AIR	MAX PVT	MIN AIR	MIN PVT	PG	HT	LT
WASHINGTON	AKRON 4 E	103.15	40.15	1385	-27	3	36	2	36	56	-27	-27	PG	58	-28	40	60	-33	-33	PG	64	-34
WASHINGTON	AKRON FAA AP	103.22	40.17	1421	-26	3	35	1	35	55	-26	-26	PG	58	-28	37	57	-32	-32	PG	58	-34
ALAMOSA	ALAMOSA WSO AP	105.87	37.45	2300	-33	4	30	1	30	51	-33	-33	PG	52	-34	32	53	-41	-41	PG	58	-46
BOULDER	ALLENSPARK	105.53	40.53	2538	-28	5	27	2	27	47	-28	-28	PG	52	-28	31	51	-38	-38	PG	52	-40
GARFIELD	ALTENBERN	108.38	39.50	1736	-26	4	34	2	34	54	-26	-26	PG	58	-28	38	58	-34	-34	PG	64	-34
PARK	ANTERO RESERVOIR	105.88	39.00	2721	-39	4	27	1	27	48	-39	-39	PG	52	-40	29	50	-47	-47	PG	52	-52
LINCOLN	ARRIBA	103.27	39.28	1598	-24	4	34	2	34	54	-24	-24	PG	58	-28	38	58	-32	-32	PG	64	-34
PITKIN	ASPEN	106.83	39.18	2419	-27	3	29	1	29	50	-27	-27	PG	52	-28	31	52	-33	-33	PG	52	-34
GRAND	BERTHOUD PASS	105.78	39.80	3450	-31	4	19	2	19	40	-31	-31	PG	40	-34	23	44	-39	-39	PG	46	-40
COSTILLA	BLANCA	105.52	37.43	2364	-30	4	31	1	31	52	-30	-30	PG	52	-34	33	54	-38	-38	PG	58	-40
YUMA	BONNY LAKE	102.18	39.63	1144	-24	4	36	1	36	56	-24	-24	PG	58	-28	38	58	-32	-32	PG	64	-34
BOULDER	BOULDER	105.28	40.03	1653	-22	4	34	1	34	54	-22	-22	PG	58	-22	36	56	-30	-30	PG	58	-34
LAS ANIMAS	BRANSON	103.88	37.02	1918	-21	4	33	1	33	54	-21	-21	PG	58	-22	35	56	-29	-29	PG	58	-34
WELD	BRIGGSDALE	104.32	40.63	1473	-27	7	36	2	36	56	-27	-27	PG	58	-28	40	60	-41	-41	PG	64	-46
MOFFAT	BROWNS PARK REFUGE	108.92	40.80	1632	-29	4	34	2	34	54	-29	-29	PG	58	-34	38	58	-37	-37	PG	58	-40
CHAFFEE	BUENA VISTA	106.13	38.85	2419	-27	3	30	1	30	51	-27	-27	PG	52	-28	32	53	-33	-33	PG	58	-34
KIT CARSON	BURLINGTON	102.27	39.32	1272	-24	4	36	2	36	56	-24	-24	PG	58	-28	40	60	-32	-32	PG	64	-34
ADAMS	BYERS 5 ENE	104.13	39.75	1556	-28	4	35	1	35	55	-28	-28	PG	58	-28	37	57	-36	-36	PG	58	-40
CLEAR CREEK	CABIN CREEK	105.70	39.65	3056	-27	3	23	1	23	44	-27	-27	PG	46	-28	25	46	-33	-33	PG	46	-34
FREMONT	CANON CITY	105.22	38.42	1635	-22	4	34	1	34	55	-22	-22	PG	58	-22	36	57	-30	-30	PG	58	-34
DOUGLAS	CASTLE ROCK	104.87	38.38	1915	-27	4	33	1	33	53	-27	-27	PG	58	-28	35	55	-35	-35	PG	58	-40
DELTA	CEDAREDGE	107.93	38.90	1903	-21	4	33	1	33	54	-21	-21	PG	58	-22	35	55	-29	-29	PG	58	-34
RIO GRANDE	CENTER 4 SSW	106.13	37.70	2339	-32	4	29	2	29	50	-32	-32	PG	52	-34	33	54	-40	-40	PG	58	-40
JEFFERSON	CHEESMAN	105.28	39.22	2098	-29	4	32	1	32	53	-29	-29	PG	58	-34	34	54	-37	-37	PG	58	-40
ARAPAHOE	CHERRY CREEK DAM	104.85	39.65	1723	-26	4	34	2	34	54	-26	-26	PG	58	-28	38	58	-34	-34	PG	64	-34
CHEYENNE	CHEYENNE WELLS	102.35	38.82	1296	-24	4	36	2	36	56	-24	-24	PG	58	-28	40	60	-32	-32	PG	64	-34
MONTROSE	CIMARRON	107.45	38.55	2104	-33	4	32	2	32	53	-33	-33	PG	58	-34	36	56	-41	-41	PG	58	-46
LAKE	CLIMAX	106.18	39.37	3462	-29	6	21	2	32	42	-29	-29	PG	46	-34	25	46	-41	-41	PG	46	-46
GUNNISON	COCHETOPA CREEK	106.77	38.43	2440	-34	3	29	1	29	50	-34	-34	PG	52	-34	31	52	-40	-40	PG	52	-40
MESA	COLLBRAN	107.97	39.25	1824	-26	5	33	2	33	53	-26	-26	PG	58	-28	37	57	-36	-36	PG	58	-40
EL PASO	COLORADO SPGS WSO AP	104.72	38.82	1858	-23	4	33	1	33	54	-23	-23	PG	58	-28	35	55	-31	-31	PG	58	-34
MONTEZUMA	CORTEZ	108.55	37.37	1894	-24	4	33	1	33	54	-24	-24	PG	58	-28	35	56	-32	-32	PG	58	-34
MOFFAT	CRAIG	101.55	40.53	1909	-32	6	32	2	32	52	-32	-32	PG	58	-34	36	56	-44	-44	PG	58	-46
GUNNISON	CRESTED BUTTE	106.97	38.87	2702	-35	4	27	2	27	48	-35	-35	PG	52	-40	31	52	-43	-43	PG	52	-46
LAS ANIMAS	DELHI	104.02	37.63	1552	-27	4	37	1	37	58	-27	-27	PG	58	-28	39	60	-35	-35	PG	64	-40
DELTA	DELTA	108.07	38.75	1504	-23	5	36	1	36	56	-23	-23	PG	58	-28	38	58	-33	-33	PG	64	-34
DENVER	DENVER CITY UR	104.98	39.75	1623	-24	4	33	1	33	53	-24	-24	PG	58	-28	35	55	-32	-32	PG	58	-34
DENVER	DENVER WSFO AP	104.87	39.77	1610	-24	4	34	1	34	54	-24	-24	PG	58	-28	36	56	-32	-32	PG	58	-34
DENVER	DENVER CITY	104.98	39.75	1623	-21	4	33	1	33	53	-21	-21	PG	58	-22	35	55	-29	-29	PG	58	-34
SUMMIT	DILLON 1E	106.03	39.63	2766	-35	4	26	1	26	47	-35	-35	PG	52	-40	28	49	-43	-43	PG	52	-46
MOFFAT	DINOSAUR NATL MONUMENT	108.97	40.23	1806	-26	4	35	2	35	55	-26	-26	PG	58	-28	39	59	-34	-34	PG	64	-34
LA PLATA	DURANGO	107.88	37.28	2013	-24	4	32	2	32	53	-24	-24	PG	58	-28	36	57	-32	-32	PG	58	-34
KIOWA	EADS	102.78	38.48	1284	-24	5	37	2	37	57	-24	-24	PG	58	-28	41	61	-34	-34	PG	64	-34
LARIMER	ESTES PARK	105.52	40.38	2297	-29	4	28	1	28	48	-29	-29	PG	52	-34	30	50	-37	-37	PG	52	-40
JEFFERSON	EVERGREEN	105.32	39.63	2135	-28	4	30	1	30	50	-28	-28	PG	52	-28	32	52	-36	-36	PG	58	-40
KIT CARSON	FLAGLER 2 NW	103.08	39.32	1519	-27	4	36	1	36	56	-27	-27	PG	58	-28	38	58	-35	-35	PG	64	-40
LINCOLN	FORDER 8 S	103.68	38.55	1458	-26	5	36	3	36	56	-26	-26	PG	58	-28	42	62	-36	-36	PG	64	-40
LARIMER	FORT COLLINS	105.08	40.58	1525	-28	5	32	1	32	52	-28	-28	PG	58	-28	34	54	-38	-38	PG	58	-40

SUPERPAVE DETERMINATION OF ASPHALT BINDER GRADE

Weather Database Used in SUPERPAVE Software

COUNTY	STATION	LONG	LAT	ELEV	AIR TEMP: LOW TEMP AVG	LOW TEMP STD	HIGH TEMP AVG	HIGH TEMP STD	50% RELIABILITY TEMPERATURES: MAX AIR	MAX PVT	MIN AIR	MIN PVT	BINDER GRADE: PG	HT	LT	98% RELIABILITY TEMPERATURES: MAX AIR	MAX PVT	MIN AIR	MIN PVT	BINDER GRADE: PG	HT	LT
LA PLATA	FORT LEWIS	108.05	37.23	2318	-26	6	29	1	29	50	-26	-26	PG	52	-28	31	52	-38	-38	PG	58	-40
WELD	FORT LUPTON 2 SE	104.78	40.07	1531	-27	4	35	2	35	55	-27	-27	PG	58	-28	39	59	-35	-35	PG	64	-40
GRAND	FRASER	105.83	39.95	2611	-38	4	26	2	26	47	-38	-38	PG	52	-40	30	50	-46	-46	PG	52	-46
MESA	FRUITA 1 W	108.75	39.17	1366	-24	6	36	2	36	56	-24	-24	PG	58	-28	40	60	-36	-36	PG	64	-40
CLEAR CREEK	GEORGETOWN	105.70	39.70	2596	-22	8	27	2	27	48	-22	-22	PG	52	-22	31	51	-38	-38	PG	52	-40
MESA	GRAND JUNCTION WSO AP	108.55	39.10	1479	-20	5	36	1	36	56	-20	-20	PG	58	-22	38	58	-30	-30	PG	64	-34
MESA	GRAND JUNCTION 6 ESE	108.45	39.05	1452	-19	5	36	1	36	56	-19	-19	PG	58	-22	38	58	-29	-29	PG	64	-34
GRAND	GRAND LAKE 1 NW	105.83	40.27	2660	-34	3	27	1	27	47	-34	-34	PG	52	-34	29	49	-40	-40	PG	52	-40
GRAND	GRAND LAKE 6 SSW	105.87	40.18	2528	-34	4	26	1	26	47	-34	-34	PG	52	-34	28	48	-42	-42	PG	52	-46
PARK	GRANT	105.68	39.47	2644	-28	3	27	1	27	48	-28	-28	PG	52	-28	29	50	-34	-34	PG	52	-34
ALAMOSA	GREAT SAND DUNES N M	105.53	37.72	2477	-25	3	29	2	29	50	-25	-25	PG	52	-28	33	54	-31	-31	PG	58	-34
WELD	GREELEY UNC	104.70	40.42	1440	-26	3	35	1	35	55	-26	-26	PG	58	-28	37	57	-32	-32	PG	58	-34
SUMMIT	GREEN MOUNTAIN DAM	106.33	39.88	2361	-31	4	29	1	29	49	-31	-31	PG	52	-34	31	51	-39	-39	PG	52	-40
WELD	GROVER 10 W	104.42	40.87	1549	-24	4	34	2	34	54	-24	-24	PG	58	-28	36	58	-32	-32	PG	58	-34
GUNNISON	GUNNISON	106.93	38.53	2336	-36	4	29	2	29	50	-36	-36	PG	52	-40	33	54	-44	-44	PG	58	-46
ROUTT	HAYDEN	107.25	40.48	1946	-33	5	32	1	32	52	-33	-33	PG	58	-34	34	54	-43	-43	PG	58	-46
MINERAL	HERMIT 7 ESE	107.13	37.77	2745	-36	3	27	1	27	48	-36	-36	PG	52	-40	29	50	-42	-42	PG	52	-46
PROWERS	HOLLY	102.12	38.05	1034	-24	4	38	2	38	59	-24	-24	PG	64	-28	42	62	-32	-32	PG	64	-34
PHILLIPS	HOLYOKE	102.30	40.58	1138	-26	4	36	2	36	56	-26	-26	PG	58	-28	40	60	-34	-34	PG	64	-34
GRAND	HOT SULPHUR SP 2 SW	106.13	40.05	2318	-33	4	29	2	29	49	-33	-33	PG	52	-34	33	53	-41	-41	PG	58	-46
CLEAR CREEK	IDAHO SPRINGS	105.52	39.75	2306	-26	4	29	1	29	50	-26	-26	PG	52	-28	31	51	-34	-34	PG	52	-34
LA PLATA	IGNACIO 1 N	107.63	37.13	1970	-26	4	33	1	33	54	-26	-26	PG	58	-28	35	56	-34	-34	PG	58	-34
BENT	JOHN MARTIN DAM	102.92	38.07	1162	-24	4	37	3	37	58	-24	-24	PG	58	-28	43	63	-32	-32	PG	64	-34
SEDGWICK	JULESBURG	102.25	41.00	1058	-27	4	37	2	37	57	-27	-27	PG	58	-28	41	61	-35	-35	PG	64	-40
JEFFERSON	KASSLER	105.10	39.50	1678	-27	3	34	1	34	54	-27	-27	PG	58	-28	36	56	-33	-33	PG	58	-34
WELD	KAUFFMAN 4 SSE	103.93	40.85	1601	-27	3	34	1	34	54	-27	-27	PG	58	-28	36	56	-33	-33	PG	58	-34
CHEYENNE	KIT CARSON 6 S	102.77	38.70	1290	-26	4	37	1	37	57	-26	-26	PG	58	-28	39	59	-34	-34	PG	64	-34
GRAND	KREMMLING	106.38	40.07	2248	-36	4	29	2	29	49	-36	-36	PG	52	-40	33	53	-44	-44	PG	58	-46
OTERO	LA JUNTA FAA AP	103.52	38.05	1281	-24	4	38	1	38	59	-24	-24	PG	64	-28	40	60	-32	-32	PG	64	-34
HINSDALE	LAKE CITY	107.32	38.03	2644	-32	3	28	1	28	49	-32	-32	PG	52	-34	30	51	-38	-38	PG	52	-40
PARK	LAKE GEORGE 8 SW	105.48	38.92	2599	-34	5	27	2	27	48	-34	-34	PG	52	-34	31	52	-44	-44	PG	52	-46
JEFFERSON	LAKEWOOD	105.13	39.75	1720	-24	3	33	1	33	53	-24	-24	PG	58	-28	35	55	-30	-30	PG	58	-34
PROWERS	LAMAR	102.62	38.08	1104	-24	4	38	2	38	58	-24	-24	PG	64	-28	42	62	-32	-32	PG	64	-34
BENT	LAS ANIMAS	103.22	38.07	1186	-25	4	39	1	39	59	-25	-25	PG	64	-28	41	61	-33	-33	PG	64	-34
LAKE	LEADVILLE	106.30	39.25	3078	-29	3	24	1	24	45	-29	-29	PG	46	-34	26	47	-35	-35	PG	52	-40
ELBERT	LIMON 10 SSW	103.77	39.15	1696	-26	4	34	2	34	54	-26	-26	PG	58	-28	38	58	-34	-34	PG	64	-34
LINCOLN	LIMON	103.70	39.27	1635	-26	3	33	1	33	53	-26	-26	PG	58	-28	35	55	-32	-32	PG	58	-34
RIO BLANCO	LITTLE HILLS	108.20	40.00	1873	-33	4	32	1	32	52	-33	-33	PG	58	-34	34	54	-41	-41	PG	58	-46
BOULDER	LONGMONT	105.10	40.18	1522	-27	4	34	1	34	54	-27	-27	PG	58	-28	36	56	-35	-35	PG	58	-40
CONEJOS	MANASSA	105.93	37.17	2346	-30	4	29	2	29	50	-30	-30	PG	52	-34	33	54	-38	-38	PG	58	-40
MOFFAT	MAYBELL	108.08	40.52	1803	-37	7	32	3	32	52	-37	-37	PG	58	-40	38	58	-51	-51	PG	58	-52
RIO BLANCO	MEEKER	107.90	40.03	1903	-31	5	32	2	32	52	-31	-31	PG	58	-34	36	56	-41	-41	PG	58	-46
PITKIN	MEREDITH	106.75	39.37	2388	-30	3	29	2	29	50	-30	-30	PG	52	-34	33	53	-36	-36	PG	58	-40
RIO GRANDE	MONTE VISTA 1 E	106.08	37.57	2330	-30	3	29	1	29	50	-30	-30	PG	52	-34	31	52	-36	-36	PG	52	-40
MONTROSE	MONTROSE 2	107.88	38.48	1778	-22	4	34	2	34	55	-22	-22	PG	58	-22	38	58	-30	-30	PG	64	-34
WELD	NEW RAYMER	103.85	40.60	1458	-27	4	36	1	36	56	-27	-27	PG	58	-28	38	58	-35	-35	PG	58	-40
DOLORES	NORTHDALE	109.02	37.82	2037	-28	4	33	1	33	54	-28	-28	PG	58	-28	35	56	-36	-36	PG	58	-40

SUPERPAVE DETERMINATION OF ASPHALT BINDER GRADE

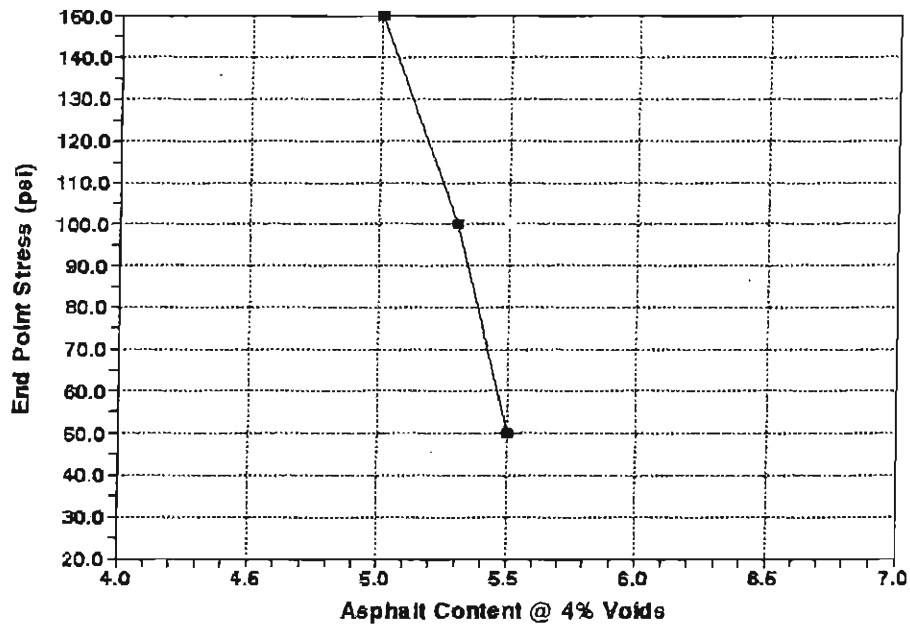
Weather Database Used in SUPERPAVE Software

					AIR TEMP				50% RELIABILITY							98% RELIABILITY						
					LOW TEMP		HIGH TEMP		TEMPERATURES				BINDER GRADE			TEMPERATURES				BINDER GRADE		
COUNTY ID	STATION	LONG	LAT	ELEV	AVG	STD	AVG	STD	MAX AIR	MAX PVT	MIN AIR	MIN PVT	PG	HT	LT	MAX AIR	MAX PVT	MIN AIR	MIN PVT	PG	HT	LT
LAS ANIMAS	NORTH LAKE	105.05	37.22	2684	-27	5	27	2	27	48	-27	-27	PG	52	-28	31	52	-37	-37	PG	58	40
SAN MIGUEL	NORWOOD	108.28	38:13	2141	-26	4	31	1	31	52	-26	-26	PG	52	-28	33	54	-34	-34	PG	58	34
OURAY	OURAY	107.67	38.02	2391	-22	3	29	1	29	50	-22	-22	PG	52	-22	31	52	-28	-28	PG	52	28
ARCHULETA	PAGOSA SPRINGS	107.02	37.27	2169	-32	4	31	1	31	52	-32	-32	PG	52	-34	33	54	-40	-40	PG	58	40
MESA	PALISADE	108.35	39.12	1464	-17	4	37	2	37	57	-17	-17	PG	58	-22	41	61	-25	-25	PG	64	28
EL PASO	PALMER LAKE	104.92	39.12	2202	-26	4	29	2	29	50	-26	-26	PG	52	-28	33	53	-34	-34	PG	58	34
DELTA	PAONIA 1 S	107.58	38.87	1870	-22	4	33	1	33	54	-22	-22	PG	58	-22	35	55	-30	-30	PG	58	34
MONTROSE	PARADOX 1 E	108.95	38.37	1610	-23	4	36	1	36	57	-23	-23	PG	58	-28	38	58	-31	-31	PG	64	34
ELBERT	PARKER 6 E	104.65	39.53	1925	-28	4	33	1	33	53	-28	-28	PG	58	-28	35	55	-36	-36	PG	58	40
GUNNISON	PITKIN	106.53	38.60	2806	-33	3	25	2	25	46	-33	-33	PG	46	-34	29	50	-39	-39	PG	52	40
PUEBLO	PUEBLO WSO AP	104.52	38.28	1415	-26	4	37	1	37	57	-26	-26	PG	58	-28	39	59	-34	-34	PG	64	34
LARIMER	RED FEATHER LAKES 2 SE	105.55	40.78	2492	-29	4	27	2	27	47	-29	-29	PG	52	-34	31	51	-37	-37	PG	52	40
DOLORES	RICO	108.03	37.70	2678	-29	4	27	1	27	48	-29	-29	PG	52	-34	29	50	-37	-37	PG	52	40
GARFIELD	RIFLE	107.80	39.53	1623	-26	6	34	2	34	54	-26	-26	PG	58	-28	38	58	-38	-38	PG	64	40
OTERO	ROCKY FORD 2 SE	103.70	38.03	1272	-26	4	37	1	37	58	-26	-26	PG	58	-28	39	59	-34	-34	PG	64	34
EL PASO	RUSH 4N	104.10	38.88	1864	-25	7	33	2	33	54	-25	-25	PG	58	-28	37	57	-39	-39	PG	58	40
EL PASO	RUXTON PARK	104.98	38.85	2760	-30	4	25	1	25	46	-30	-30	PG	46	-34	27	48	-38	-38	PG	52	40
PUEBLO	RYE	104.93	37.92	2074	-26	4	31	2	31	52	-26	-26	PG	52	-28	35	56	-34	-34	PG	58	34
SAGUACHE	SAGUACHE	106.13	38.08	2346	-27	4	29	1	29	50	-27	-27	PG	52	-28	31	52	-35	-35	PG	52	40
CHAFFEE	SALIDA	106.02	38.53	1879	-27	4	31	1	31	52	-27	-27	PG	52	-28	33	54	-35	-35	PG	58	40
SEDGWICK	SEDGWICK 5 S	102.52	40.85	1217	-25	6	36	1	36	56	-25	-25	PG	58	-28	38	58	-37	-37	PG	58	40
SAN JUAN	SILVERTON	107.67	37.82	2827	-32	3	25	2	25	46	-32	-32	PG	52	-34	29	50	-38	-38	PG	52	40
JACKSON	SPICER	106.45	40.47	2544	-34	5	27	1	27	47	-34	-34	PG	52	-34	27	49	-44	-44	PG	52	46
BACA	SPRINGFIELD 7 WSW	102.73	37.38	1397	-23	3	36	1	36	57	-23	-23	PG	58	-28	38	59	-29	-29	PG	64	34
ROUTT	STEAMBOAT SPRINGS	106.83	40.48	2062	-36	4	30	2	30	50	-36	-36	PG	52	-40	34	54	-44	-44	PG	58	46
LOGAN	STERLING	103.22	40.62	1202	-27	4	36	2	36	56	-27	-27	PG	58	-28	40	60	-35	-35	PG	64	40
KIT CARSON	STRATTON	102.60	39.30	1339	-23	5	36	2	36	56	-23	-23	PG	58	-28	40	60	-33	-33	PG	64	34
LAKE	SUGARLOAF RESERVOIR	106.37	39.25	2971	-34	5	23	2	23	44	-34	-34	PG	46	-34	27	48	-44	-44	PG	52	46
PUEBLO	TACONY 10 SE	104.07	38.38	1513	-26	3	37	1	37	57	-26	-26	PG	58	-28	39	59	-32	-32	PG	64	34
GUNNISON	TAYLOR PARK	106.62	38.82	2809	-42	4	24	1	24	45	-42	-42	PG	46	-46	26	47	-50	-50	PG	52	52
SAN MIGUEL	TELLURIDE	107.82	37.93	2684	-28	4	27	2	27	48	-28	-28	PG	52	-28	31	52	-36	-36	PG	52	40
LAS ANIMAS	TRINIDAD	104.48	37.17	1839	-24	4	33	1	33	54	-24	-24	PG	58	-28	35	56	-32	-32	PG	58	34
LAS ANIMAS	TRINIDAD FAA AP	104.33	37.25	1754	-24	4	34	1	34	55	-24	-24	PG	58	-28	36	57	-32	-32	PG	58	34
LAKE	TWIN LAKES RESERVOIR	106.35	39.10	2806	-33	4	24	1	24	45	-33	-33	PG	46	-34	26	47	-41	-41	PG	52	46
BACA	TWO BUTTES	102.40	37.57	1260	-21	7	36	3	36	57	-21	-21	PG	58	-22	42	62	-35	-35	PG	64	40
MONTROSE	URAVAN	108.73	38.37	1528	-21	4	37	2	37	57	-21	-21	PG	58	-22	41	61	-29	-29	PG	64	34
LA PLATA	VALLECITO DAM	107.58	37.37	2333	-28	4	30	1	30	51	-28	-28	PG	52	-28	32	53	-36	-36	PG	58	40
MINERAL	WAGON WHEEL GAP 3 N	106.83	37.80	2592	-36	3	27	1	27	48	-36	-36	PG	52	-40	29	50	-42	-42	PG	52	46
JACKSON	WALDEN	106.28	40.73	2477	-35	4	28	1	28	48	-35	-35	PG	52	-40	30	50	-43	-43	PG	52	46
BACA	WALSH 1 W	102.25	37.38	1211	-23	4	36	2	36	57	-23	-23	PG	58	-28	40	61	-31	-31	PG	64	34
LARIMER	WATERDALE	105.20	40.43	1595	-27	4	33	1	33	53	-27	-27	PG	58	-28	35	55	-35	-35	PG	58	40
CUSTER	WESTCLIFFE	105.48	38.13	2397	-33	4	30	1	30	51	-33	-33	PG	52	-34	32	53	-41	-41	PG	58	46
MINERAL	WOLF CREEK PASS 1E	106.78	37.48	3245	-28	4	21	2	21	42	-28	-28	PG	46	-28	25	46	-36	-36	PG	52	40
YUMA	WRAY 1 E	102.18	40.08	1074	-27	4	37	2	37	57	-27	-27	PG	58	-28	41	61	-35	-35	PG	64	40
ROUTT	YAMPA	106.90	40.15	2406	-31	3	27	2	27	47	-31	-31	PG	52	-34	31	51	-37	-37	PG	52	40
MONTEZUMA	YELLOW JACKET 2 W	108.75	37.52	2092	-23	4	33	2	33	54	-23	-23	PG	58	-28	37	58	-31	-31	PG	58	34
YUMA	YUMA	102.73	40.13	1263	-26	4	36	1	36	56	-26	-26	PG	58	-28	38	58	-34	-34	PG	64	34

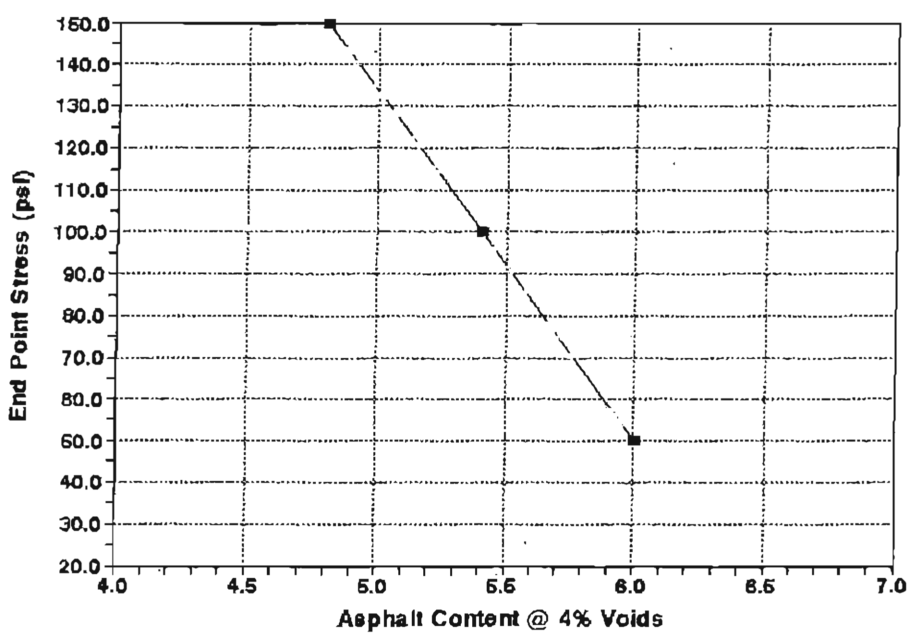
Appendix C

Summary of Optimum Asphalt Contents on the Texas Gyratory

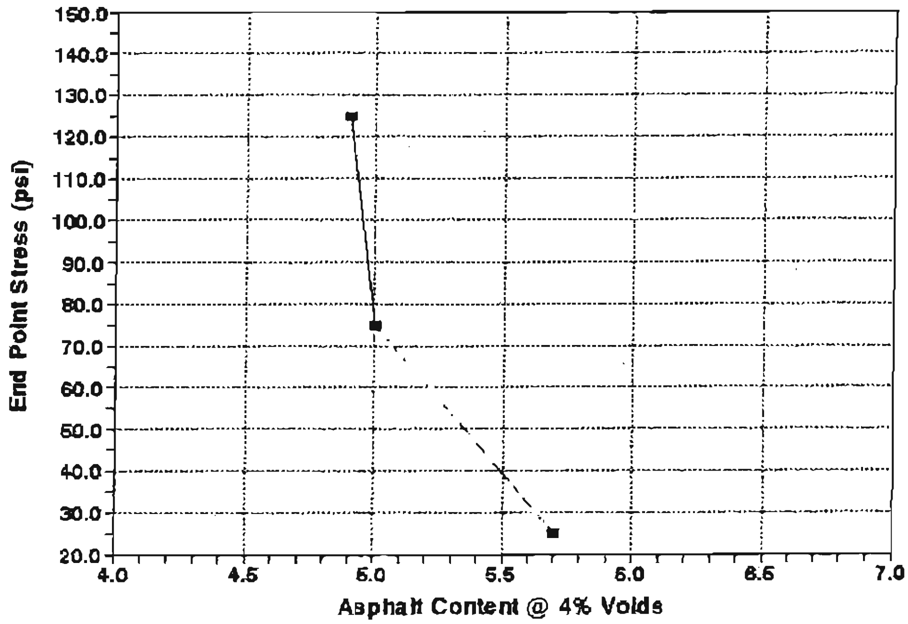
Mix 1


End Point Stress (psi)
Asphalt Content @ 4% Voids

Mix 2


End Point Stress (psi)
Asphalt Content @ 4% Voids

Mix 3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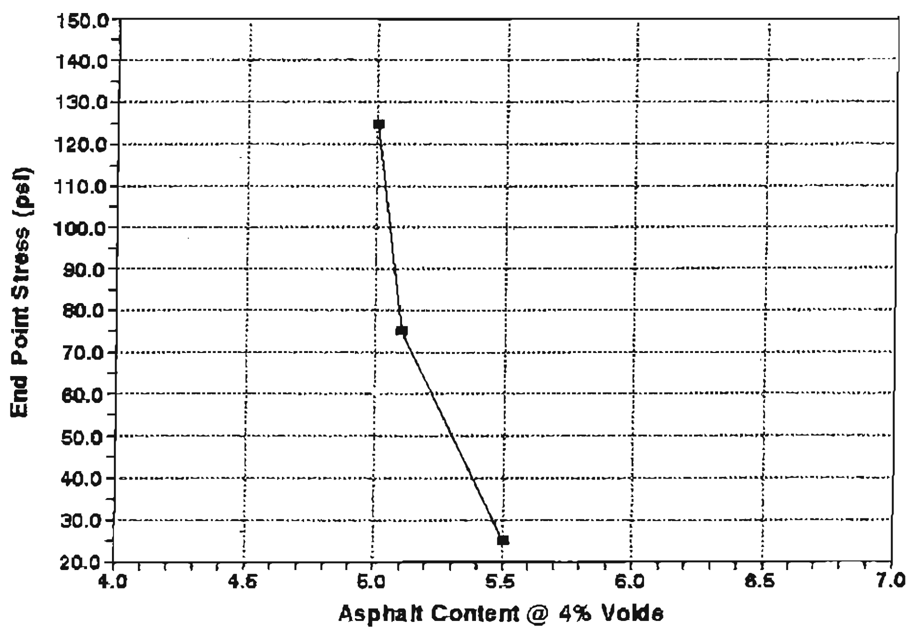
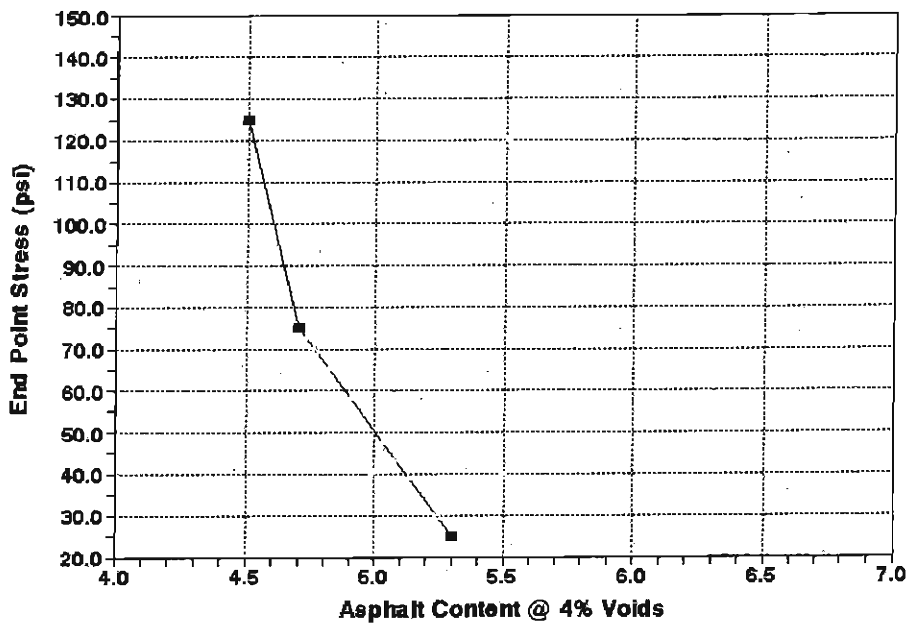
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

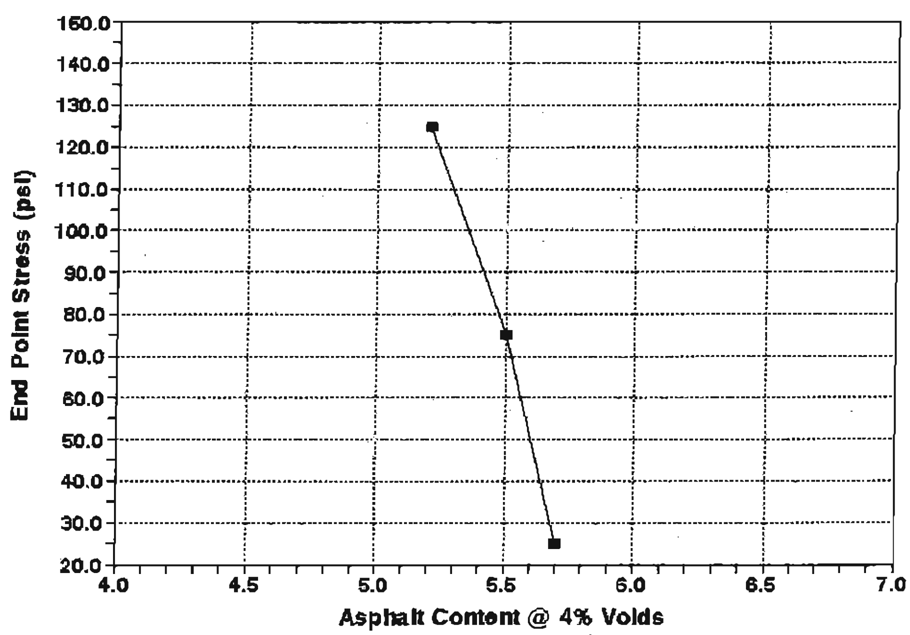
Mix 4


150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

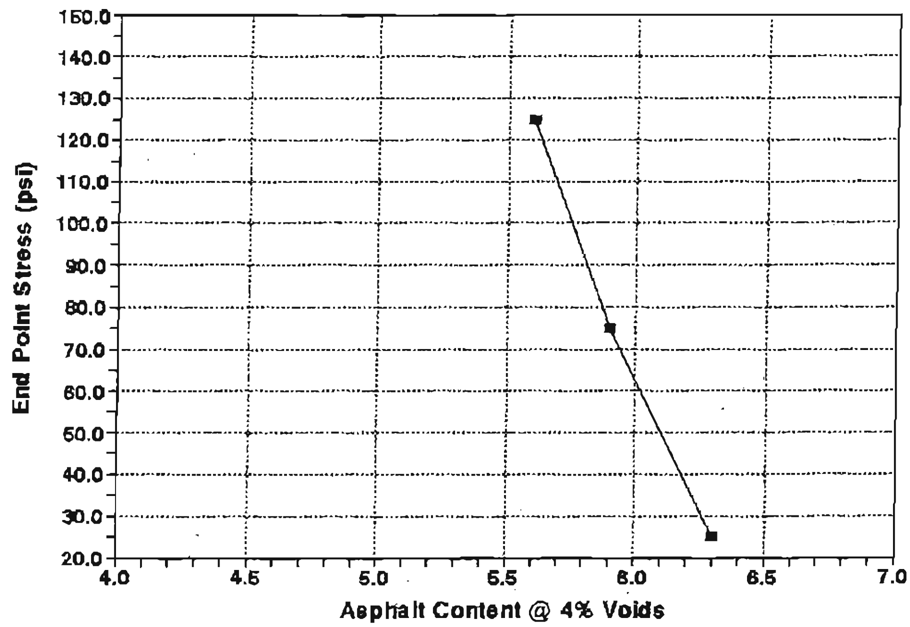
Mix 5


150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
6.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 6

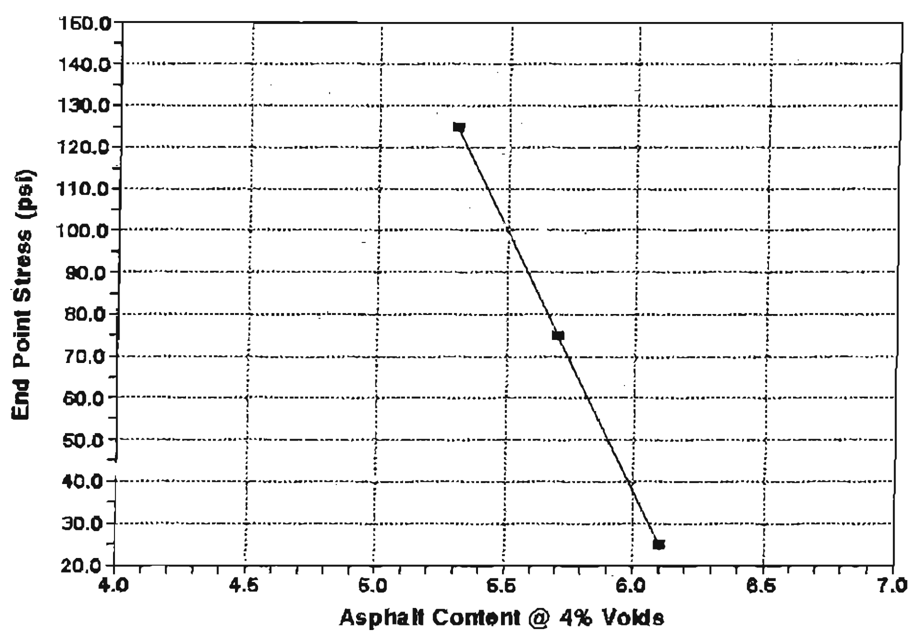

150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 7



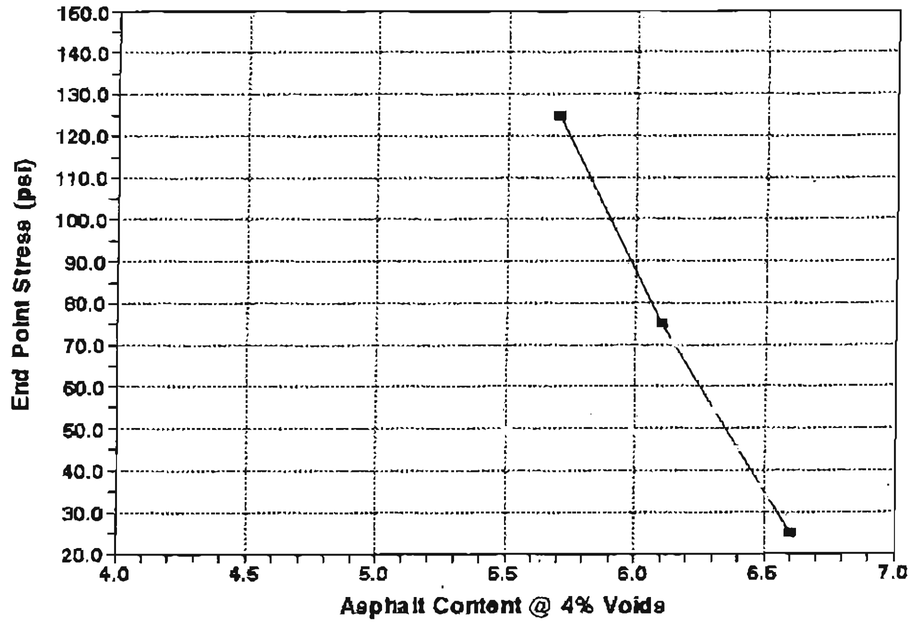
End Point Stress (psi)
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 8

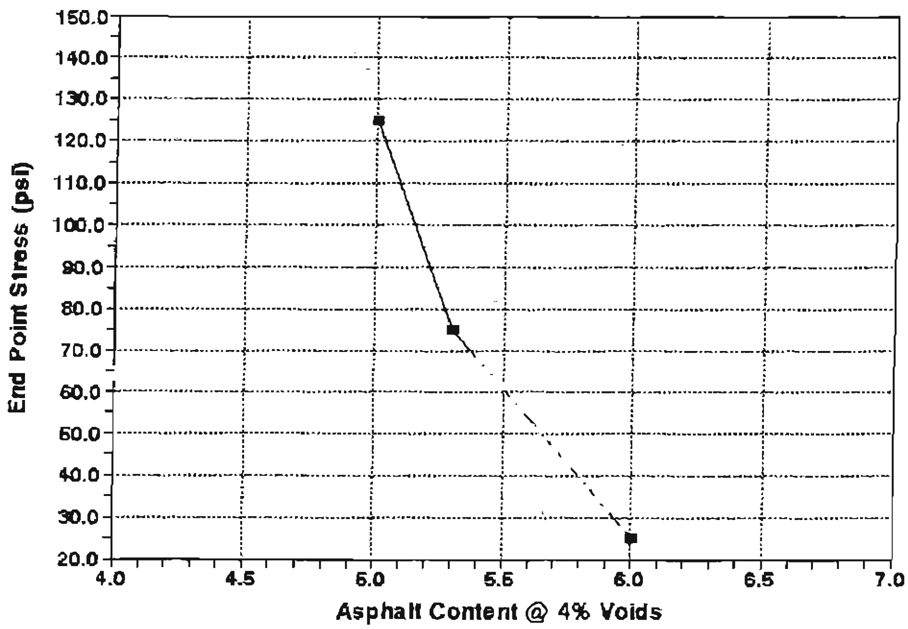


End Point Stress (psi)
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

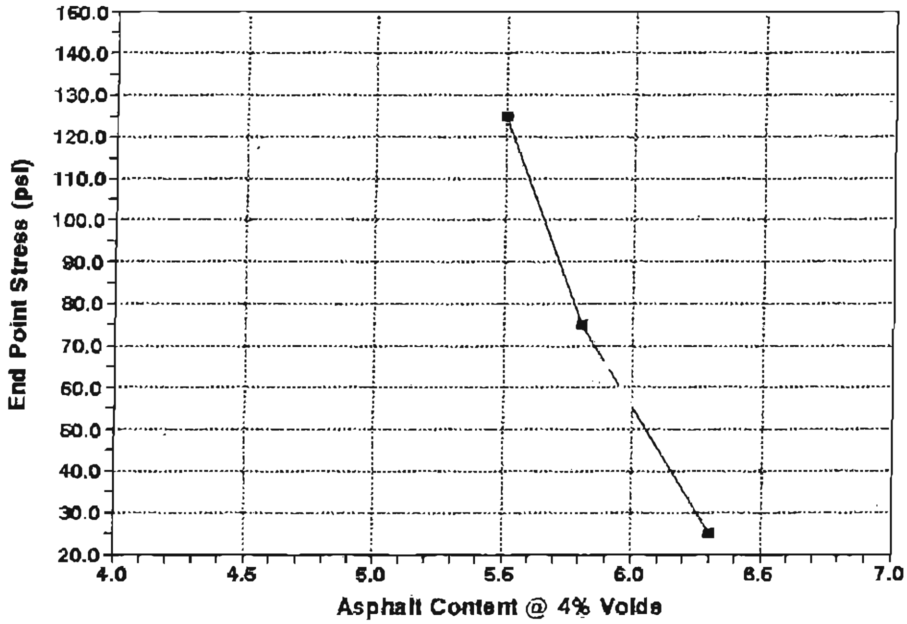
Mix 9


160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 10

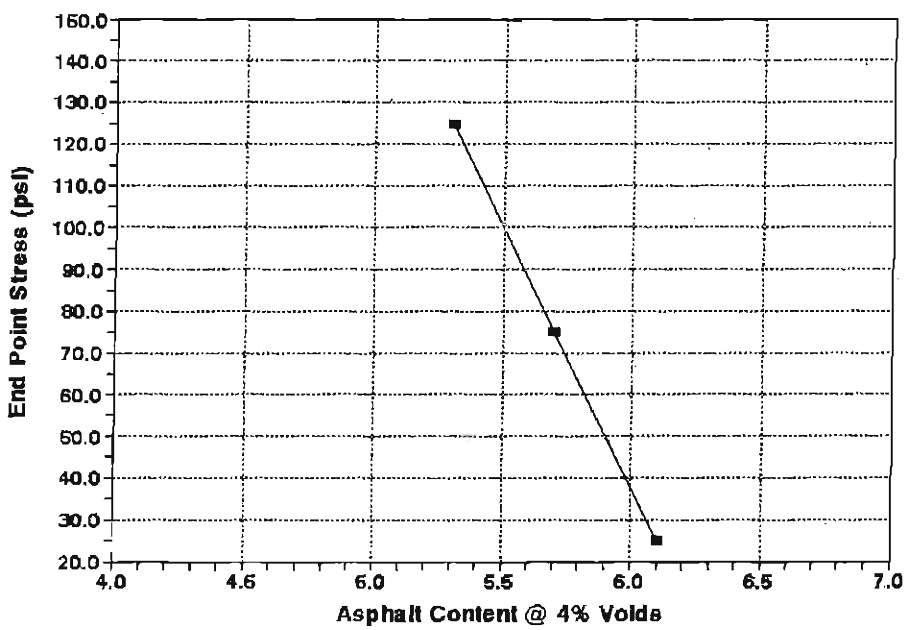

150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 11



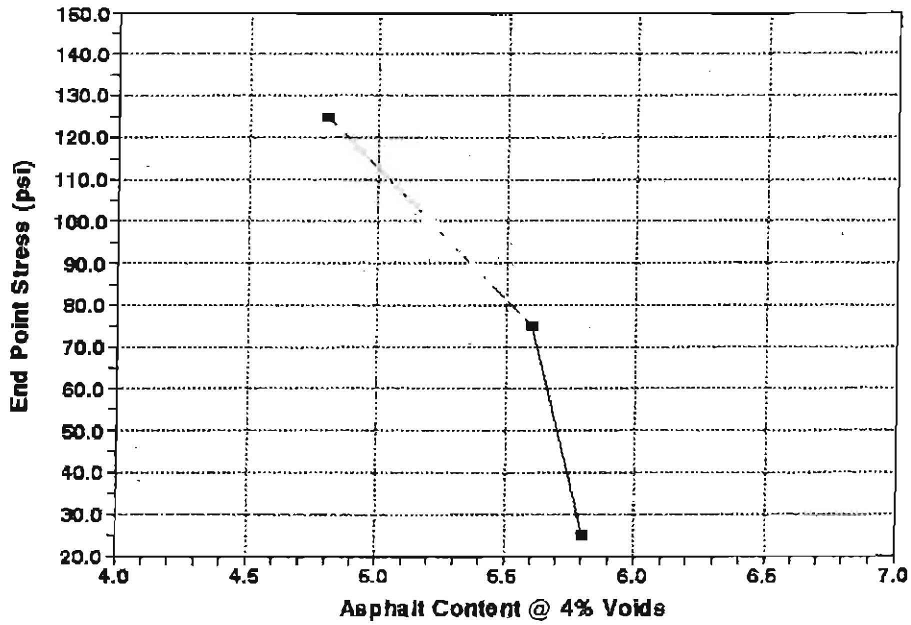
End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 12



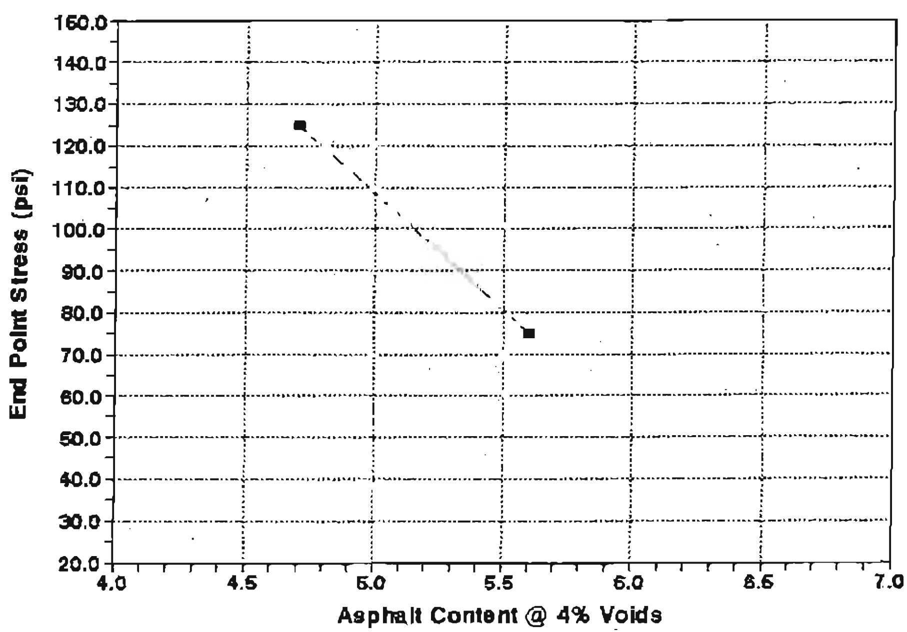
End Point Stress (psi)
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 13



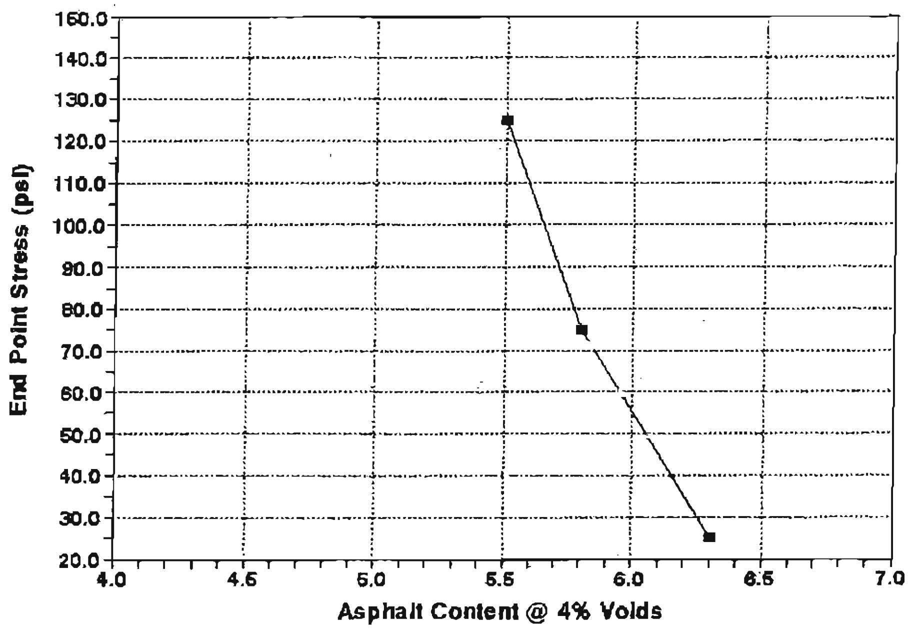
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 14



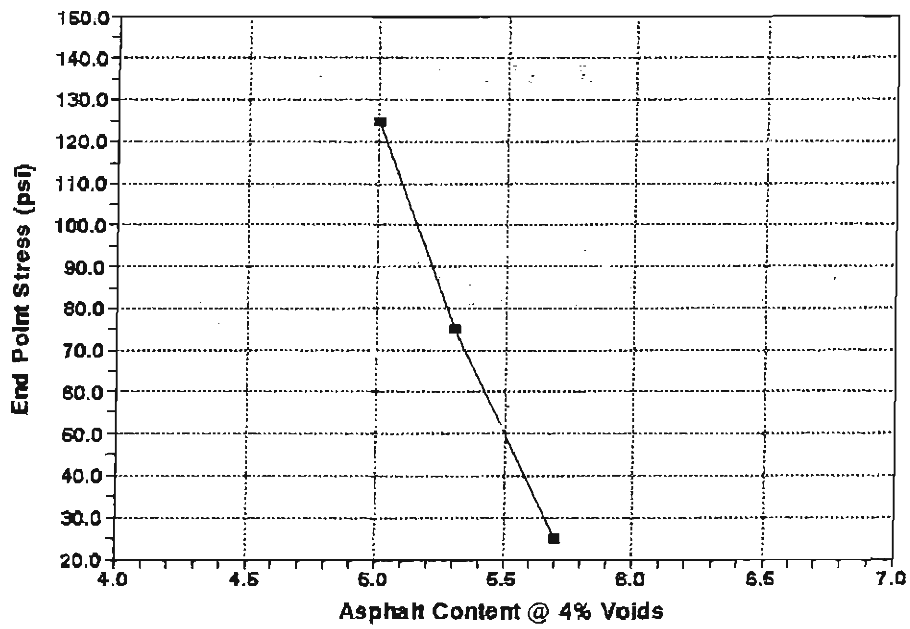
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
End Point Stress (psi)
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 15



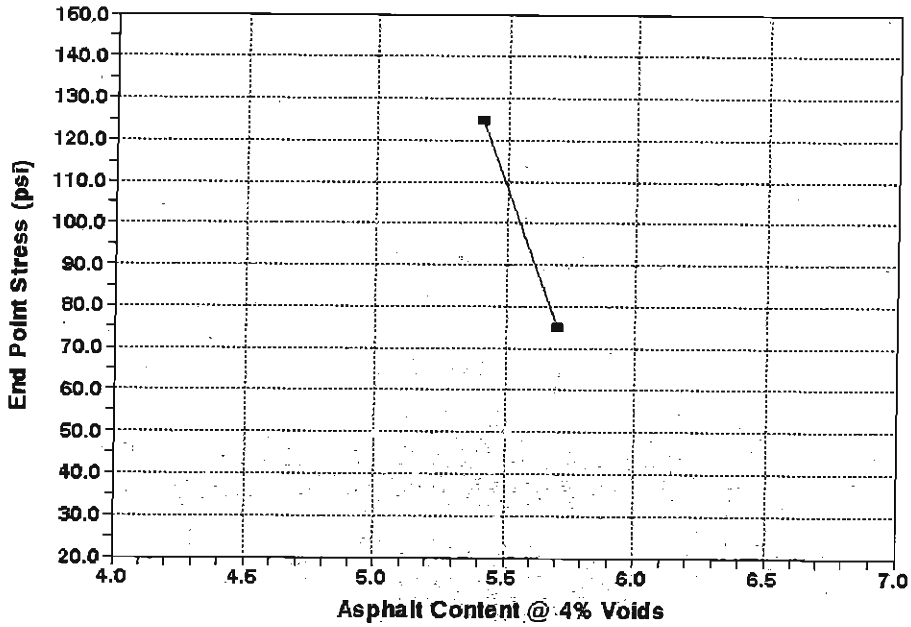
End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 16



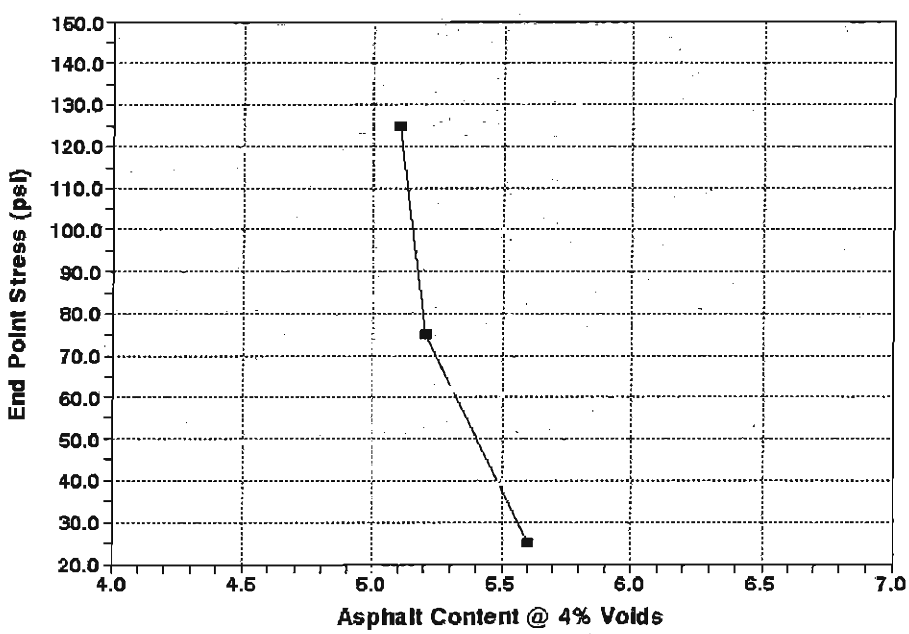
End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 17



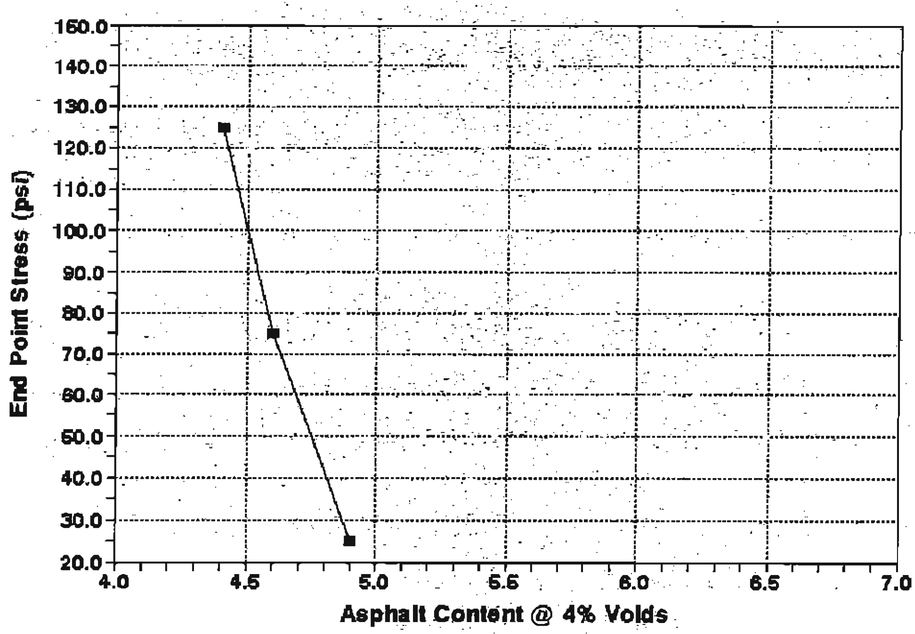
End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 18



End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
6.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Mix 19

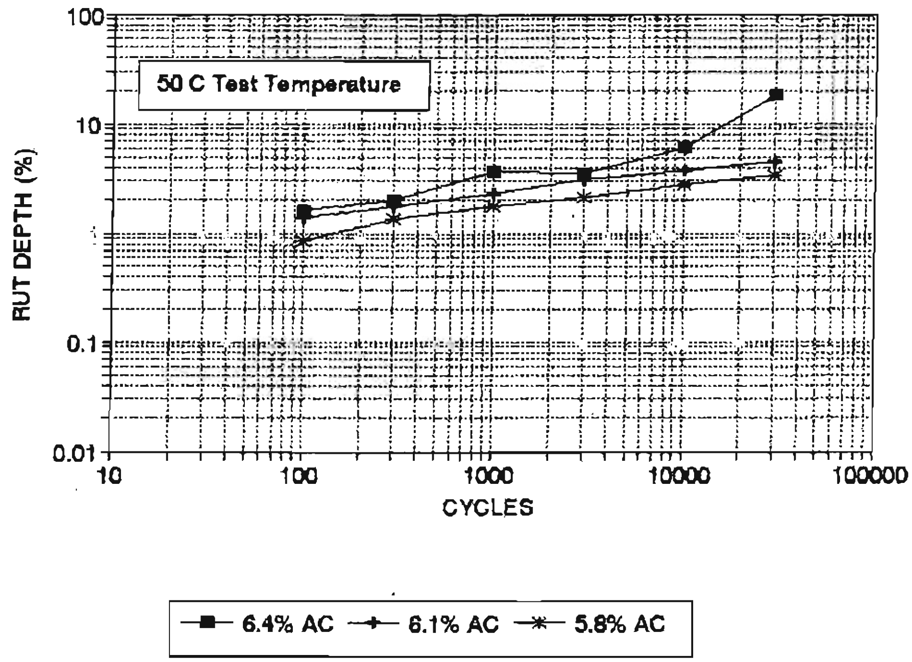


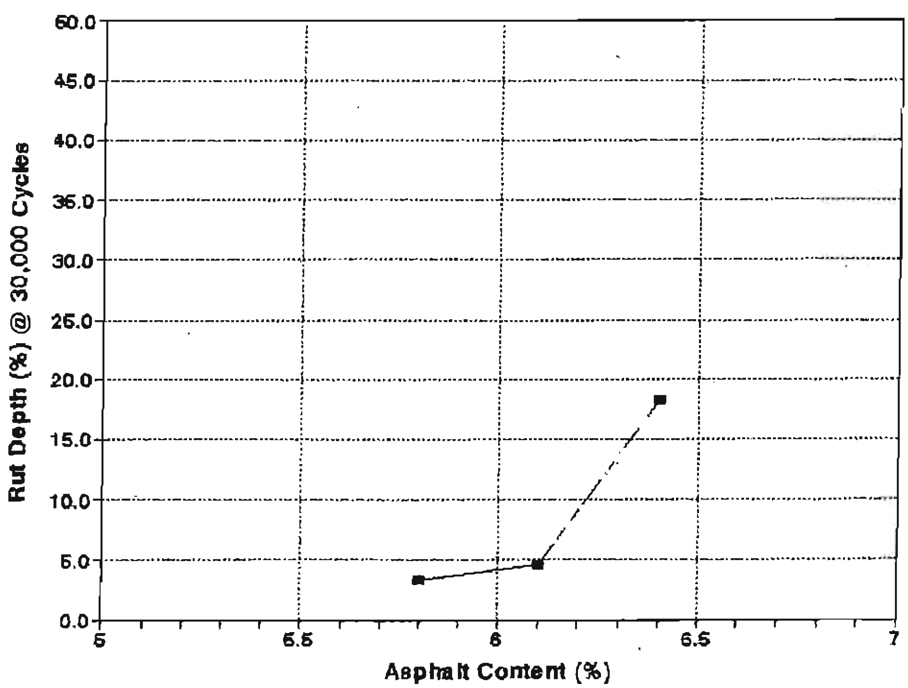
End Point Stress (psi)
160.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Asphalt Content @ 4% Voids

Appendix D

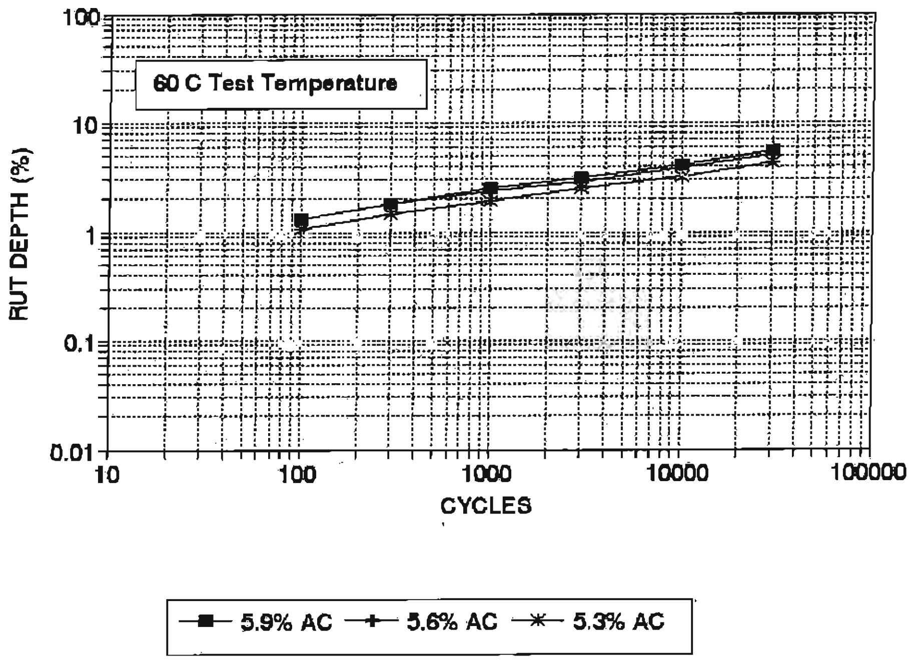
Summary of the French Rutting Tester Results

MIX 1

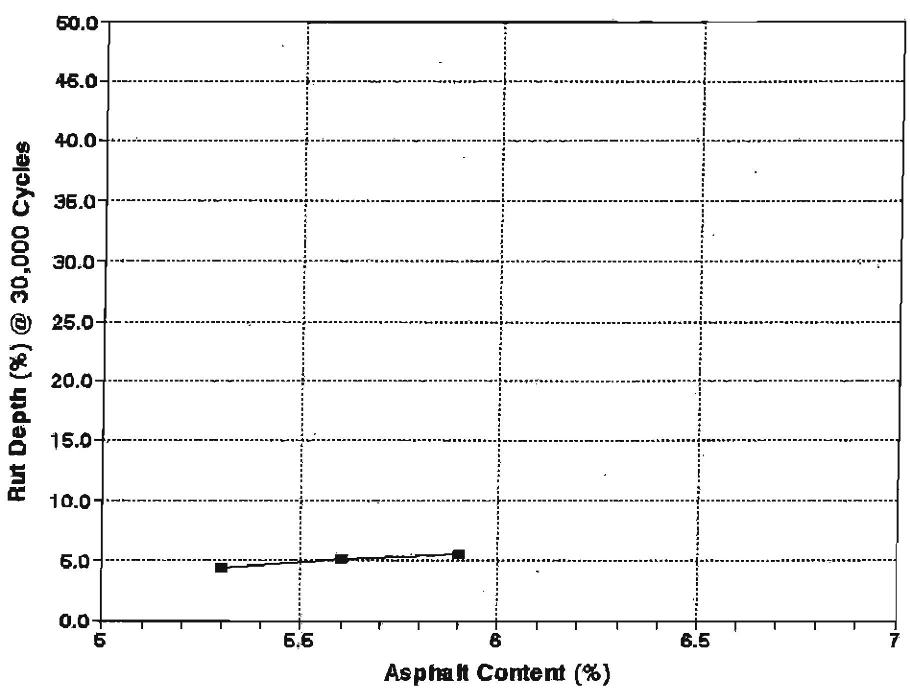

50 C Test Temperature
RUT DEPTH (%)
100
10
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.4% AC
6.1% AC
5.8% AC


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 2

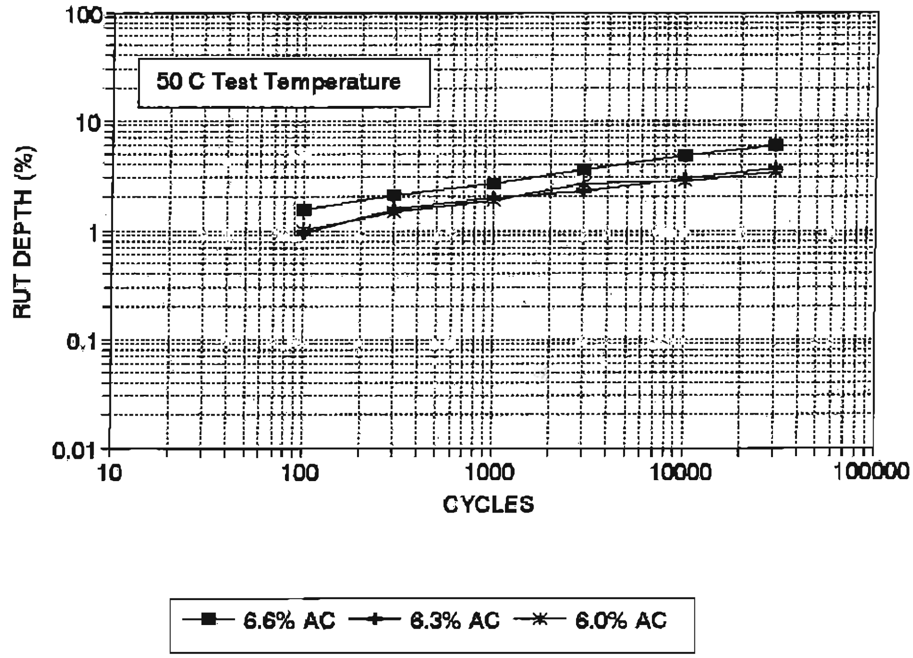


60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
5.9% AC
5.6% AC
5.3% AC

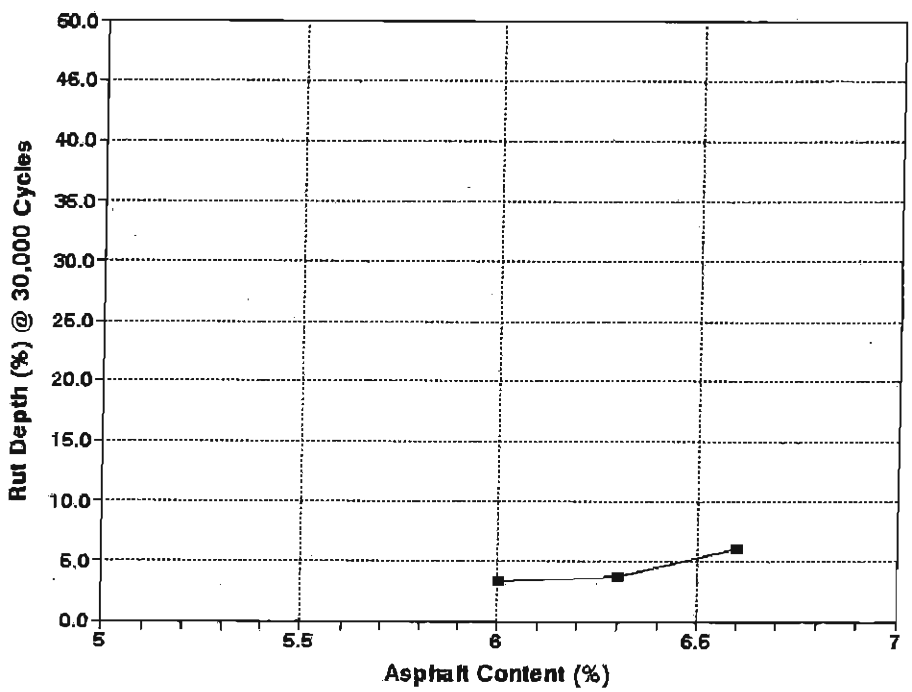


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 2

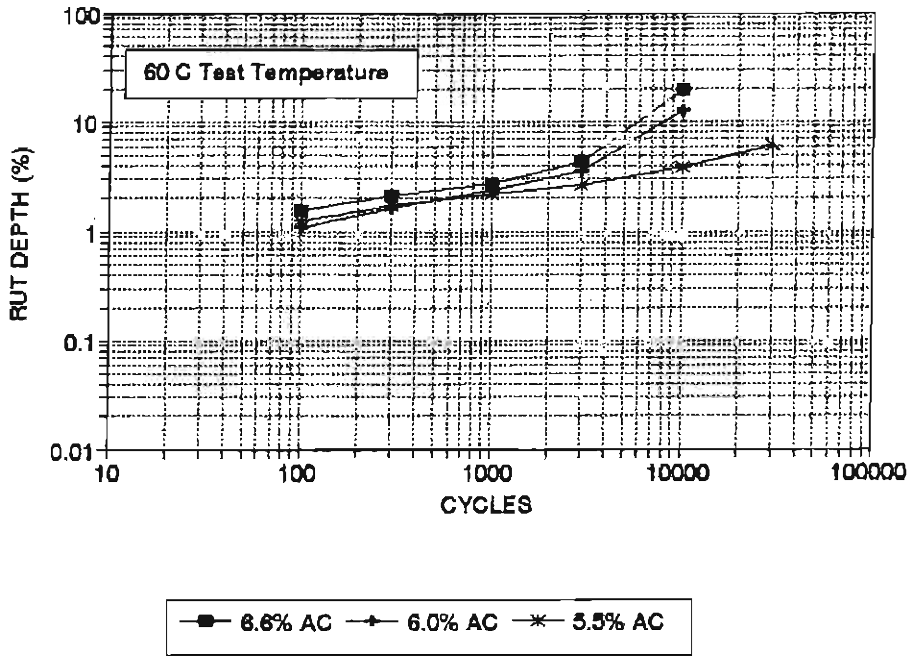


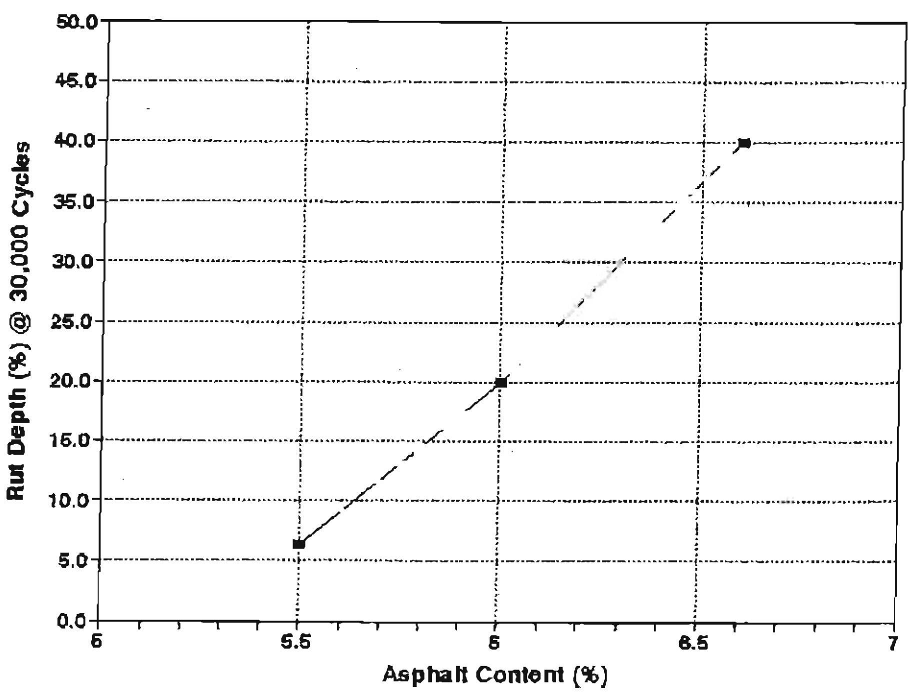
50 C Test Temperature
RUT DEPTH (%)
CYCLES
100
10
1
0.1
0.01
10
100
1000
10000
100000
6.6% AC
6.3% AC
6.0% AC



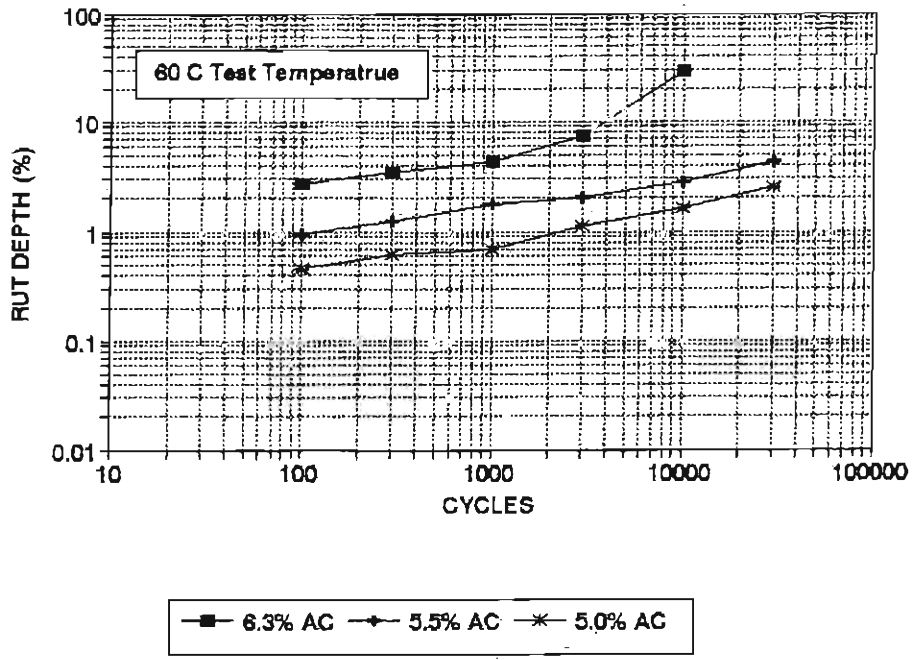
Rut Depth (%) @ 30,000 Cycles
Asphalt Content (%)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7

MIX 3

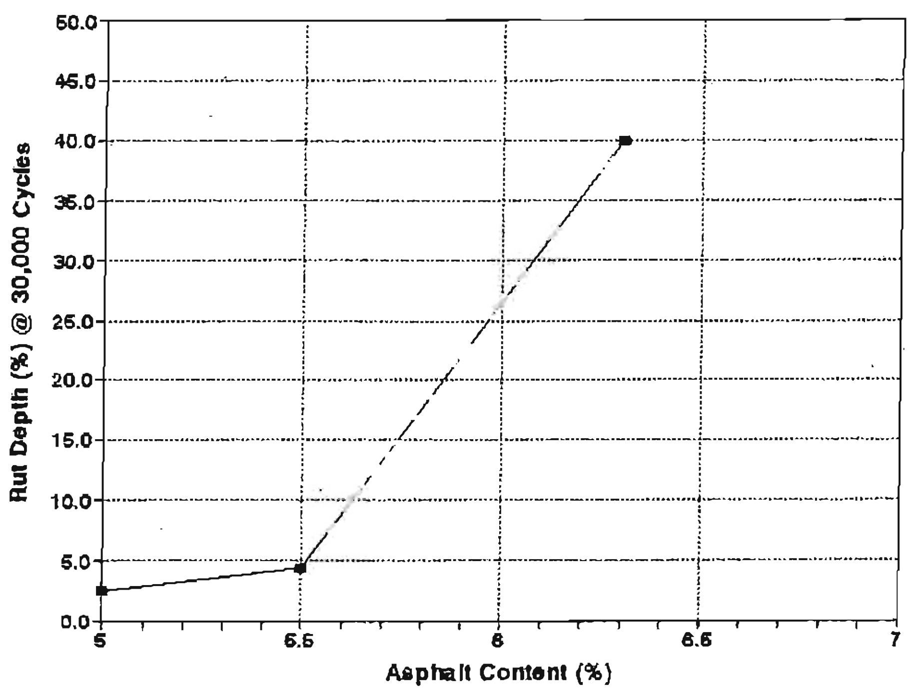

60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.6% AC
6.0% AC
5.5% AC


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 4

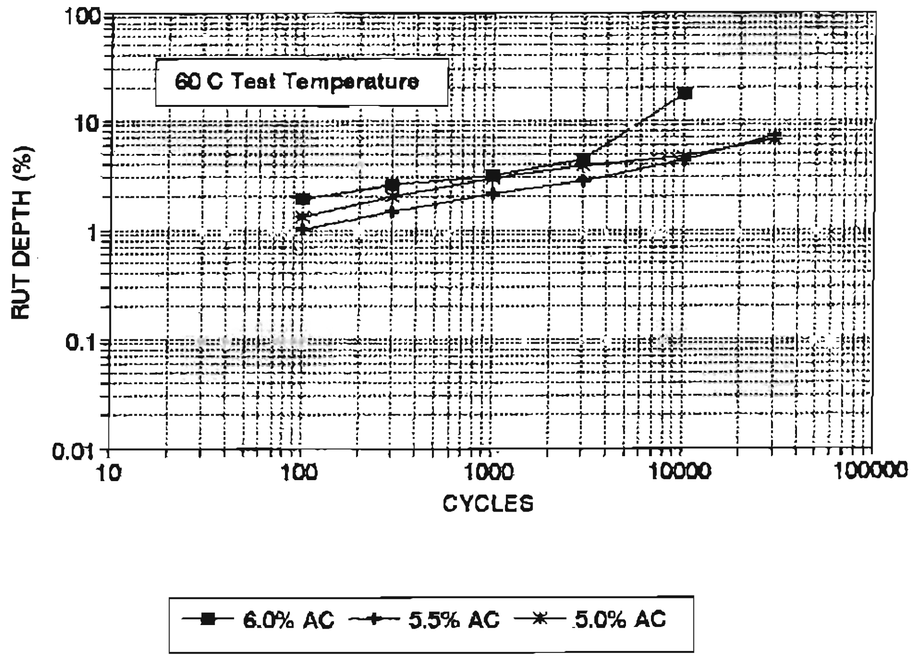


60 C Test Temperatrue
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.3% AC
5.5% AC
5.0% AC

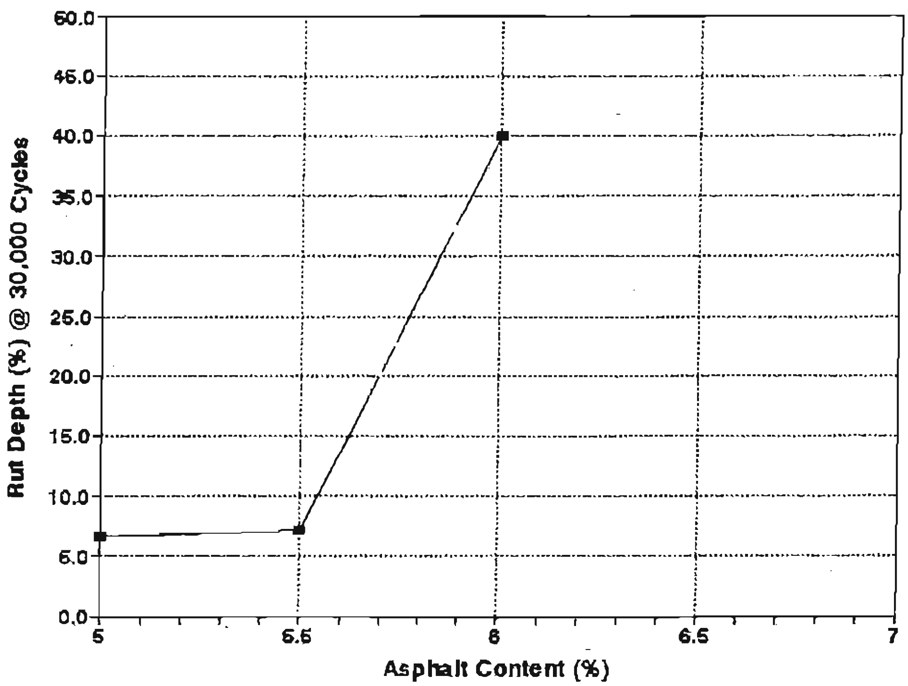


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 5

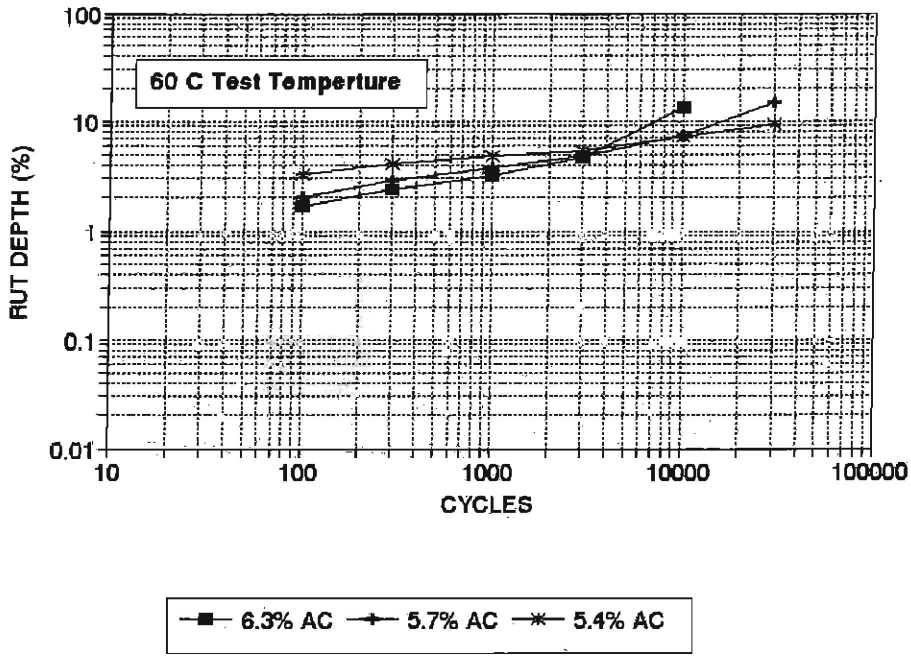


60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.0% AC
5.5% AC
5.0% AC

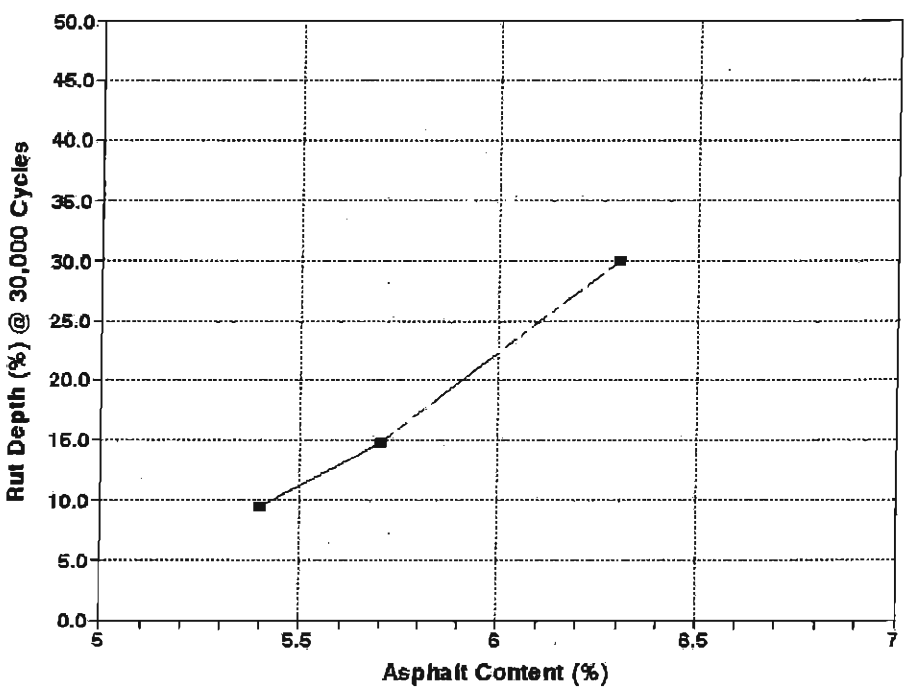


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 6

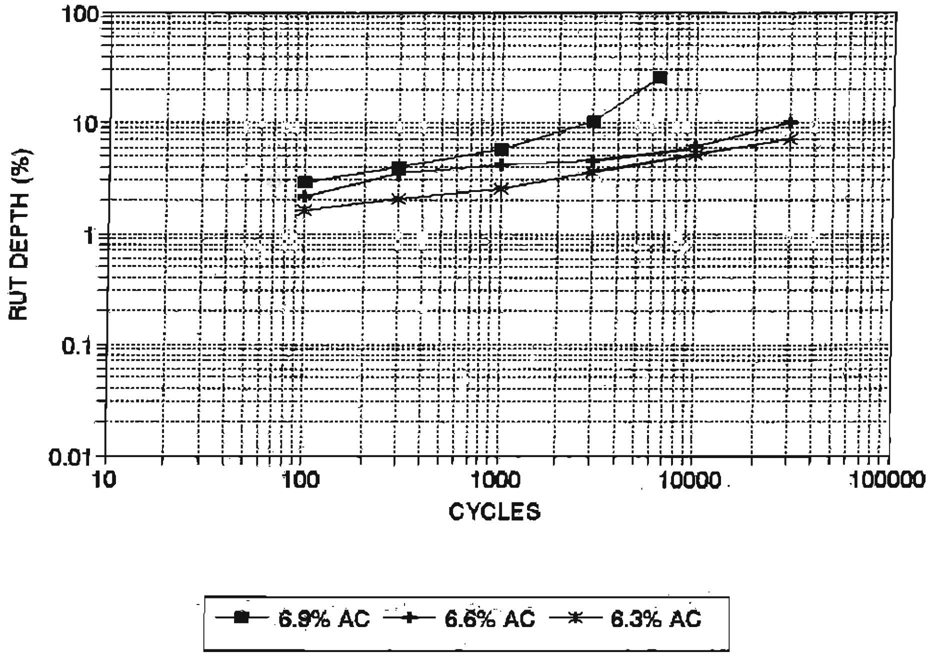


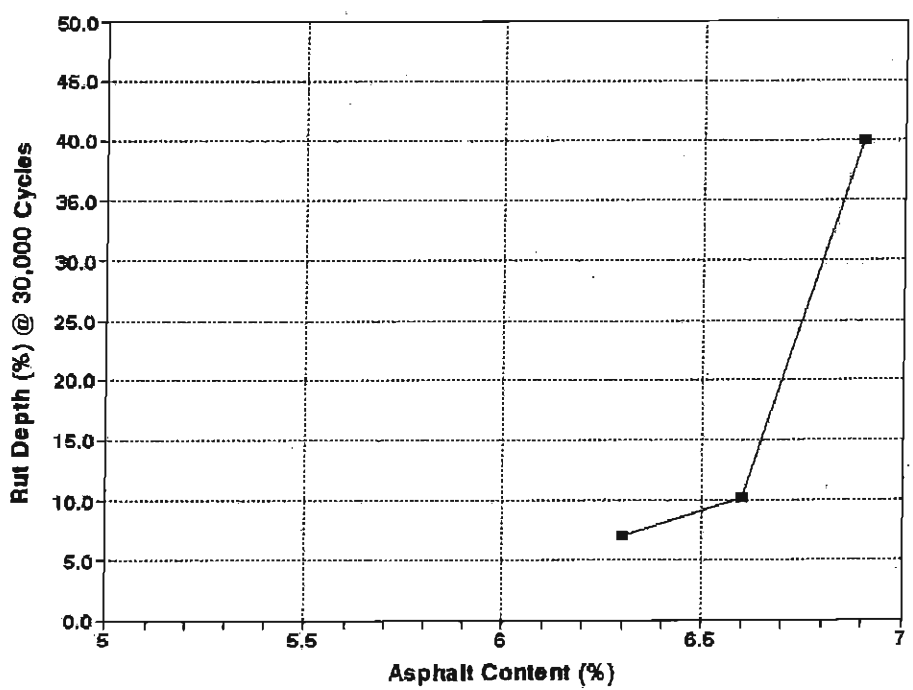
60 C Test Temperture
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.3% AC
5.7% AC
5.4% AC



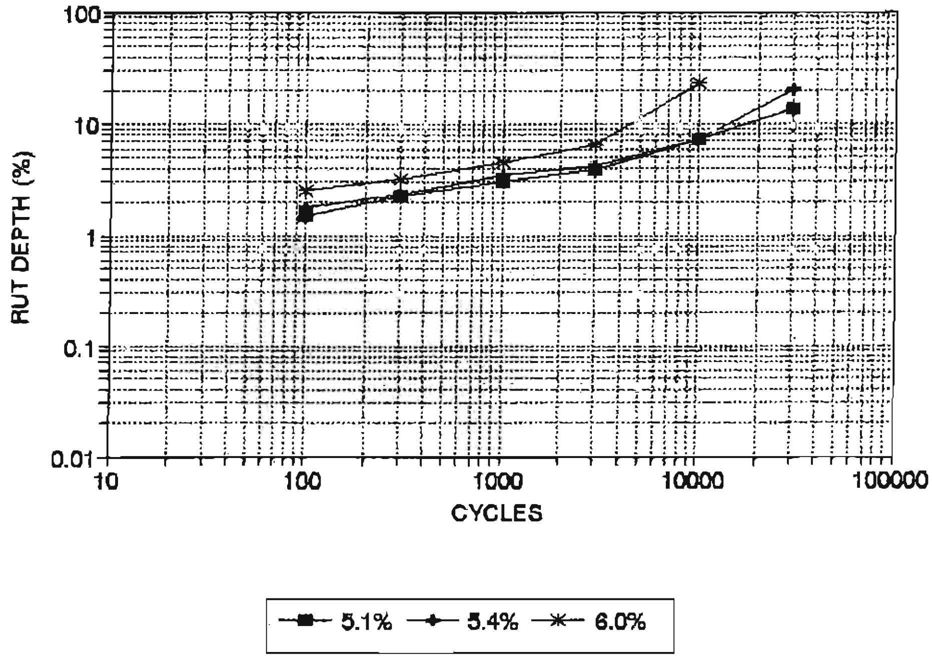
Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

Mix 7

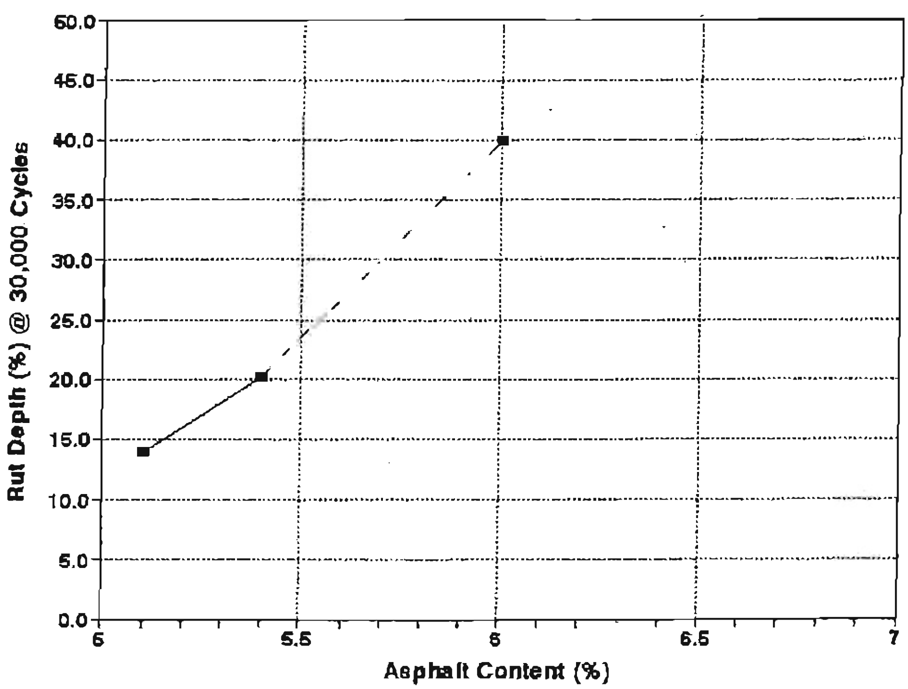

100
10
1
0.1
0.01
RUT DEPTH (%)
10
100
1000
10000
100000
CYCLES
6.9% AC
6.6% AC
6.3% AC


50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rut Depth (%) @ 30,000 Cycles
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 8

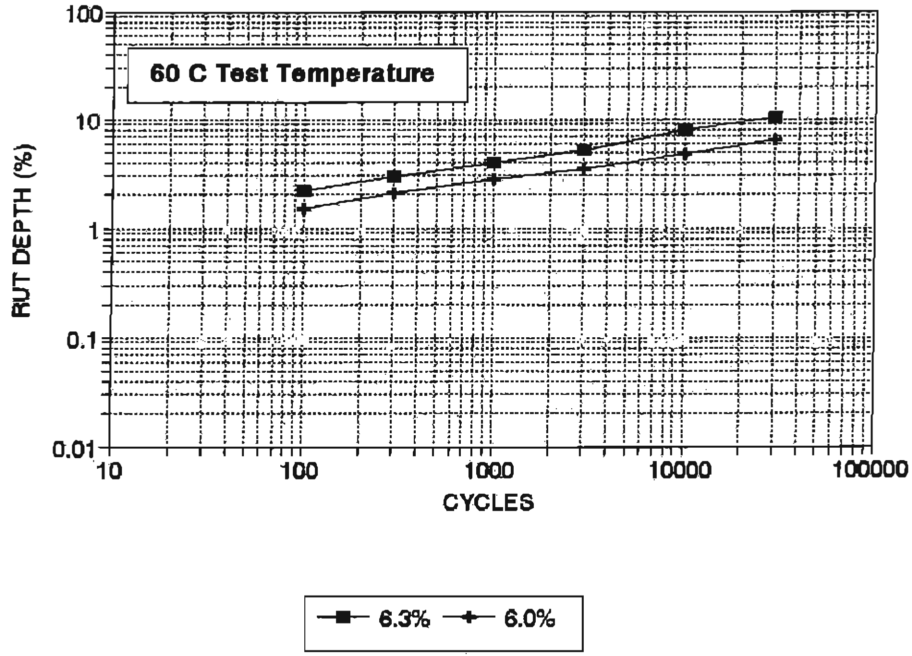


100
10
1
0.1
0.01
RUT DEPTH (%)
10
100
1000
10000
100000
CYCLES
5.1%
5.4%
6.0%

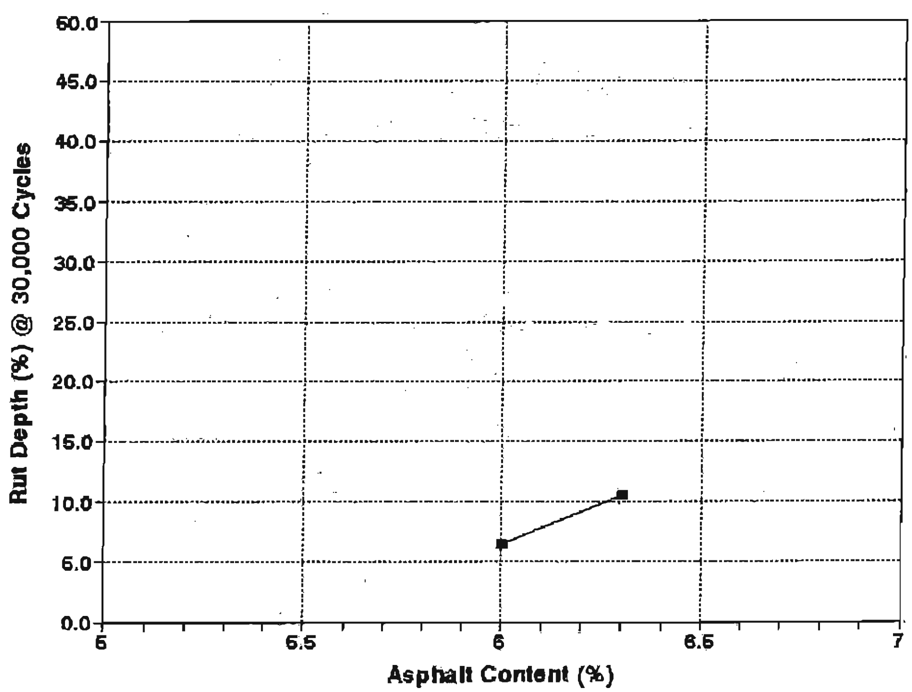


50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rut Depth (%) @ 30,000 Cycles
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 9

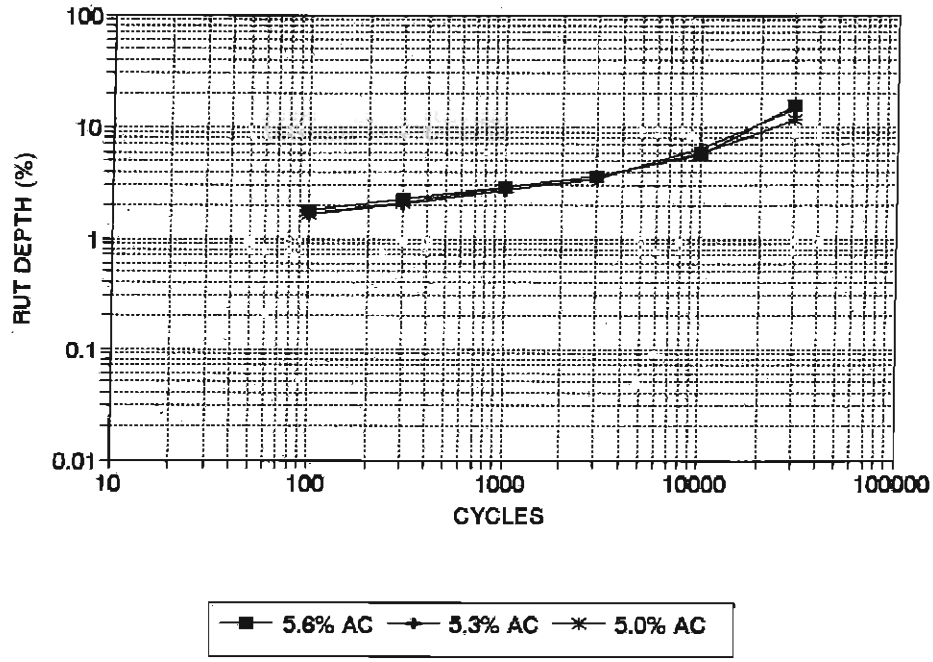


60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.3%
6.0%

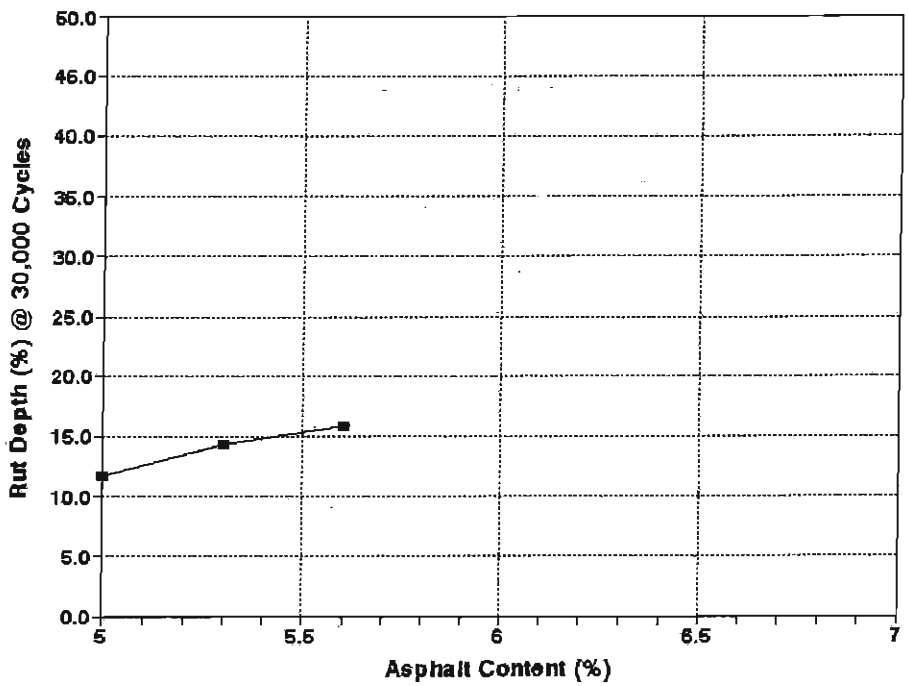


Rut Depth (%) @ 30,000 Cycles
60.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

MIX 10

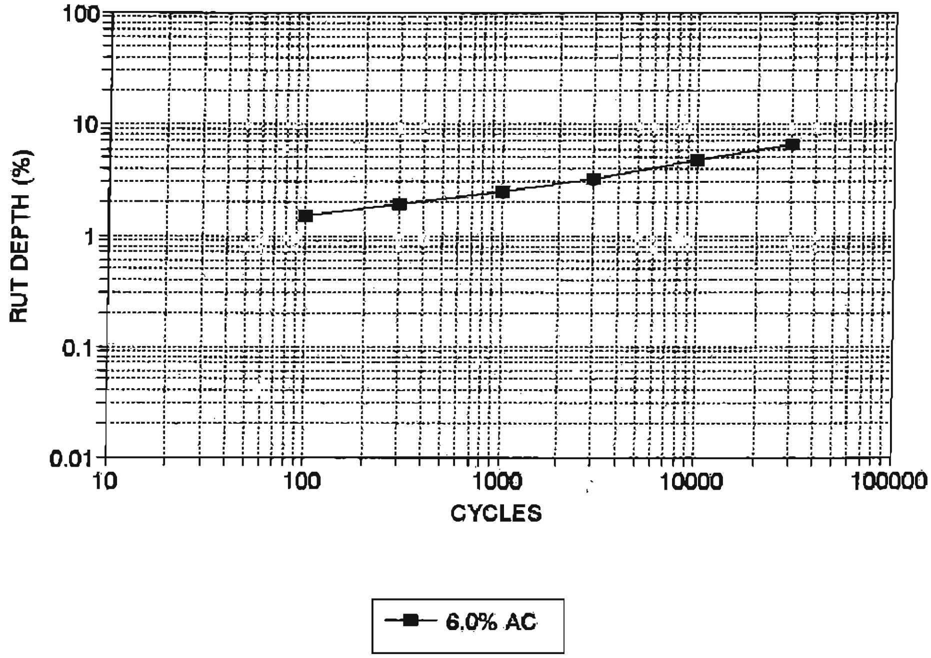


100
10
1
0.1
0.01
10
100
1000
10000
100000
RUT DEPTH (%)
CYCLES
5.6% AC
5.3% AC
5.0% AC

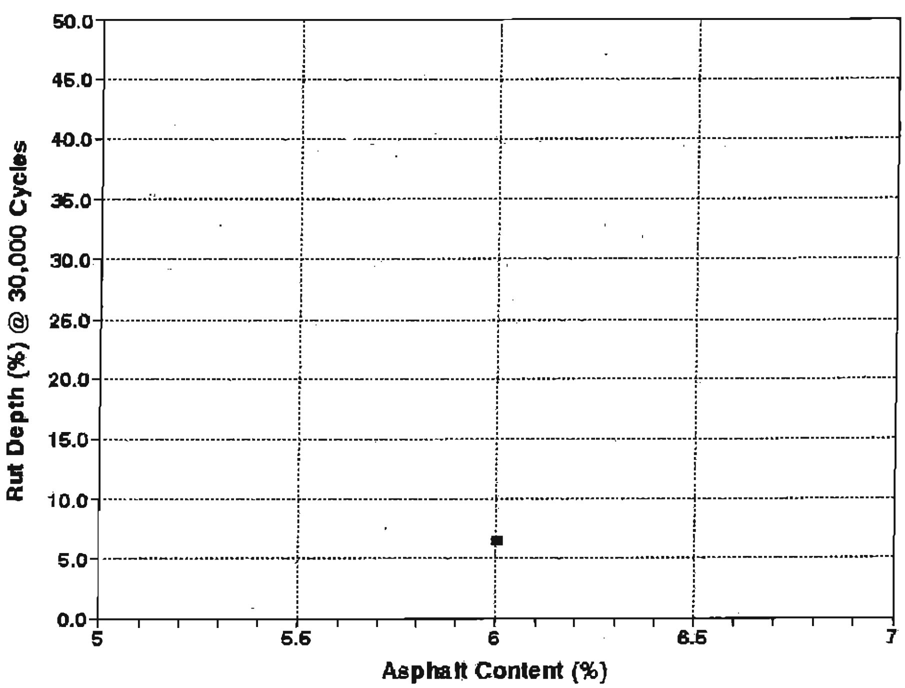


50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Rut Depth (%) @ 30,000 Cycles
Asphalt Content (%)

Mix 11

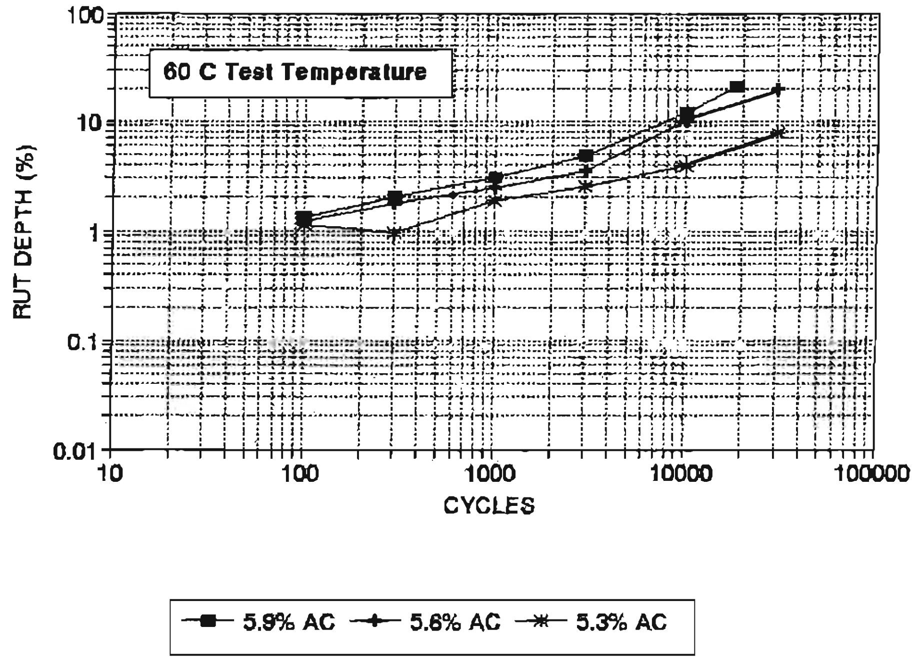


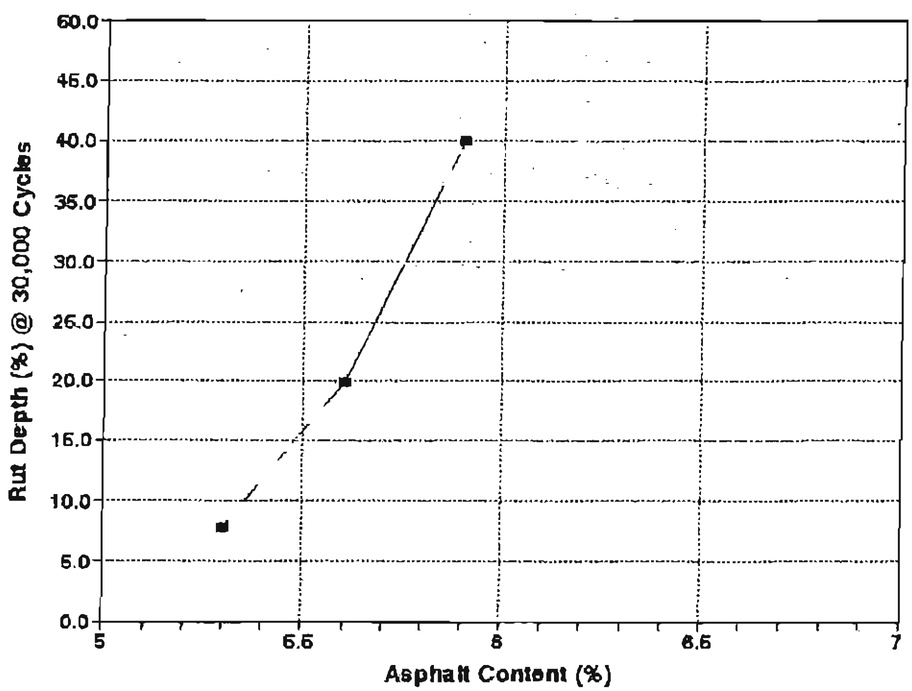
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.0% AC



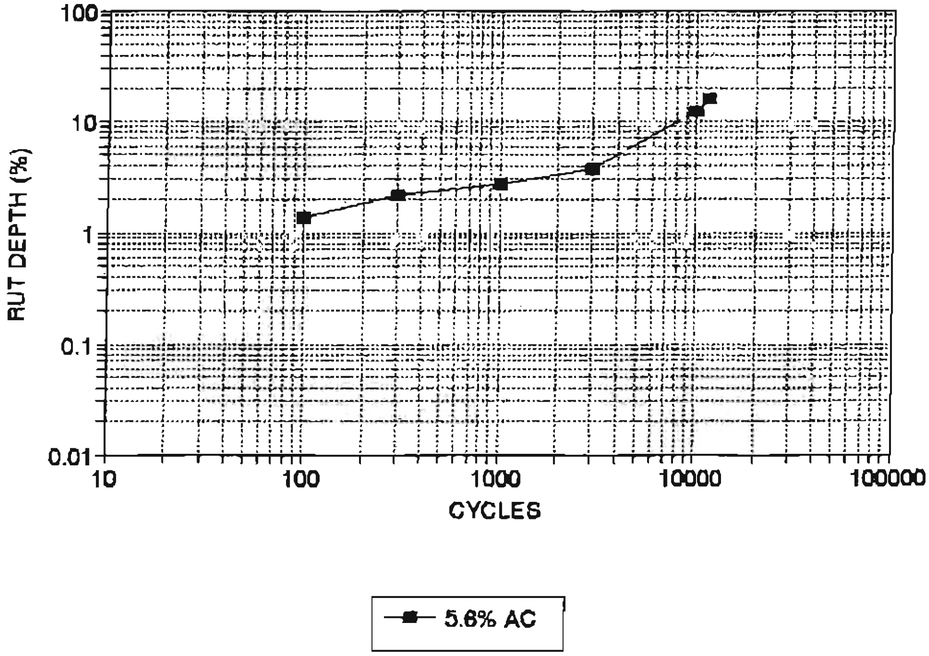
Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

Mix 12

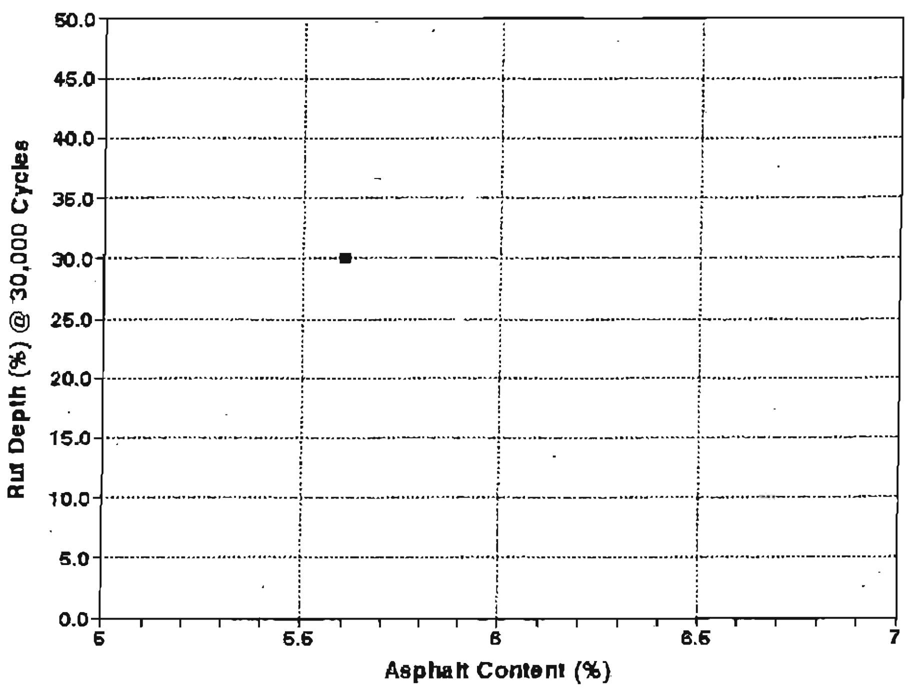

60 C Test Temperature
100
10
1
0.1
0.01
RUT DEPTH (%)
10
100
1000
10000
100000
CYCLES
5.9% AC
5.6% AC
5.3% AC


Rut Depth (%) @ 30,000 Cycles
Asphalt Content (%)

MIX 13

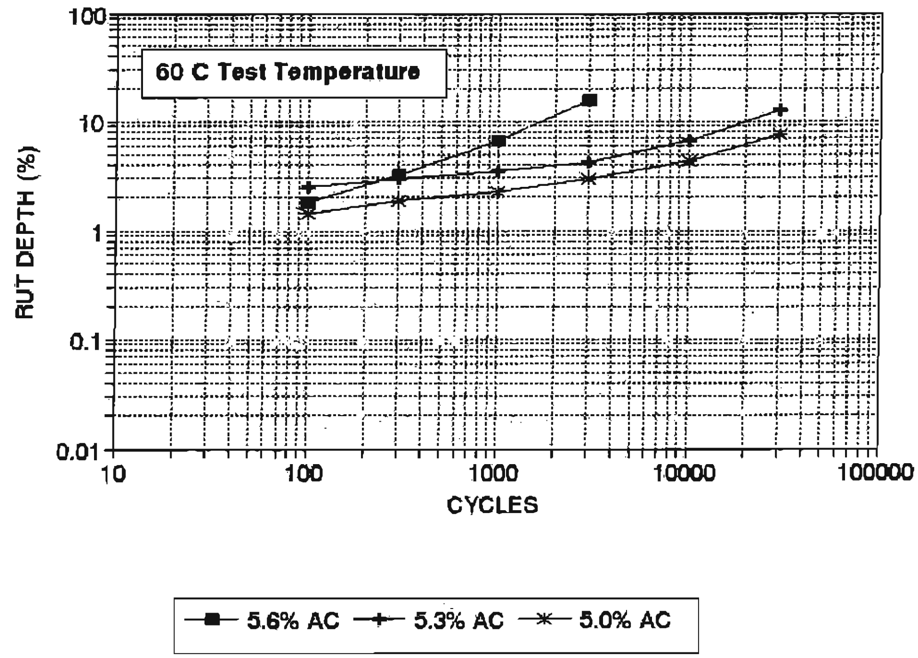


RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
5.6% AC

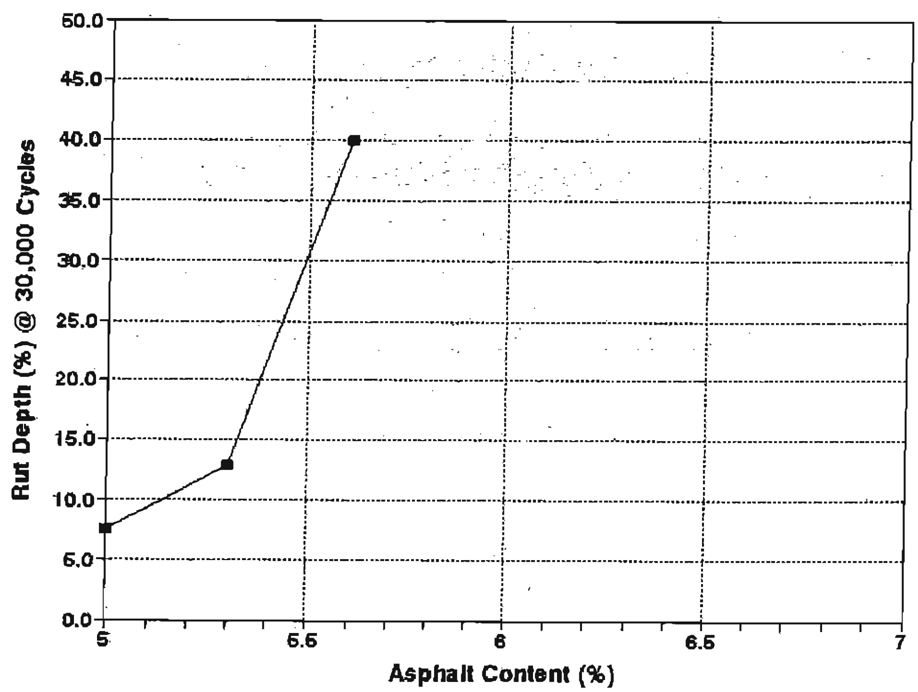


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

Mix 14

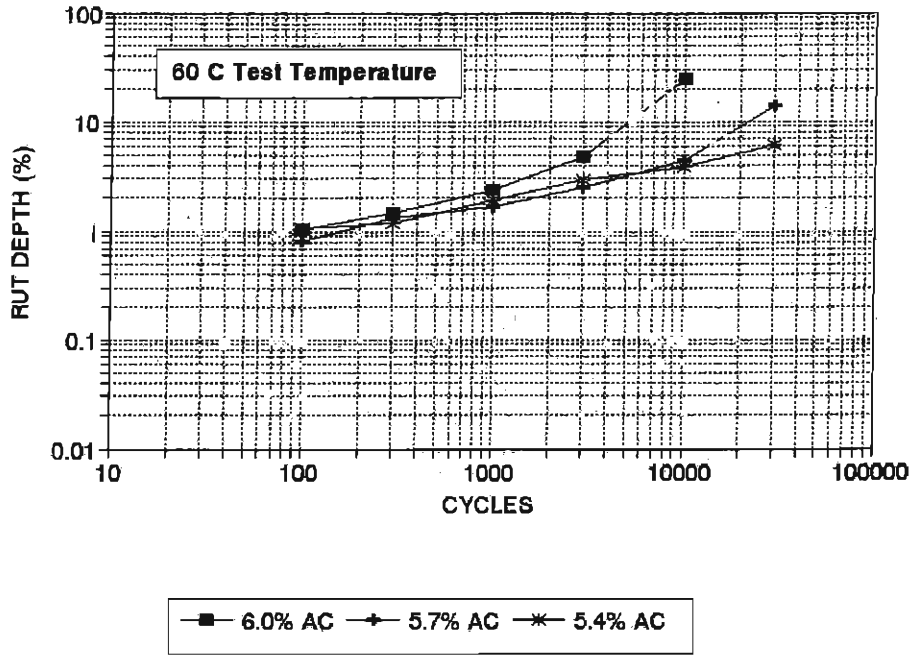


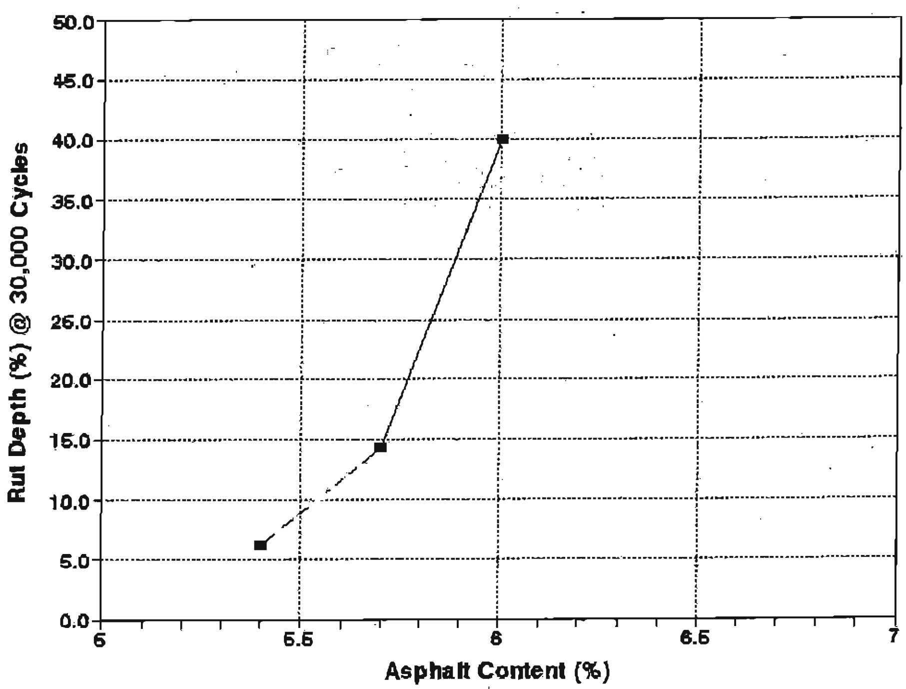
60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
5.6% AC
5.3% AC
5.0% AC



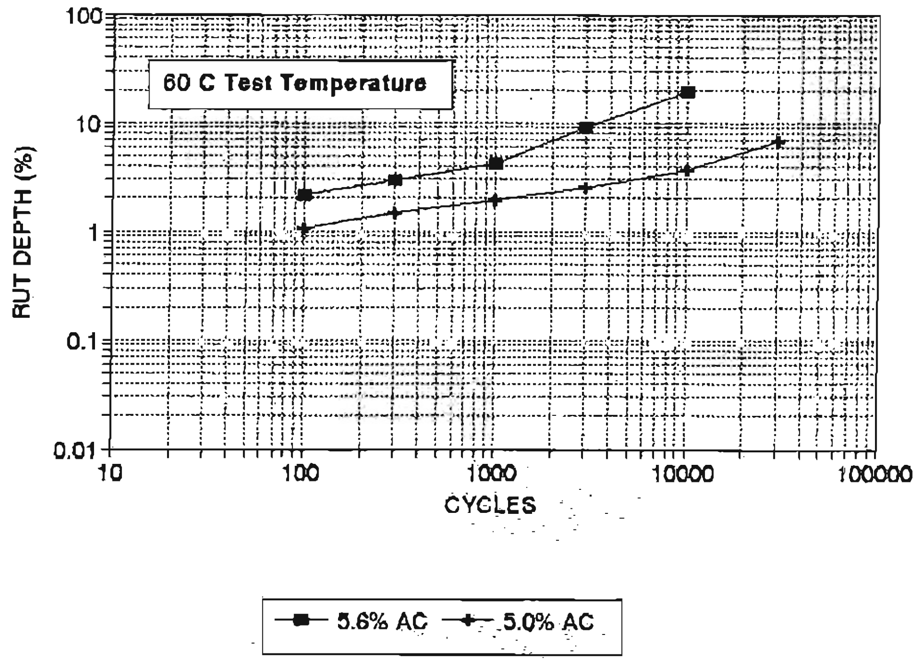
Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7
Asphalt Content (%)

Mix 15

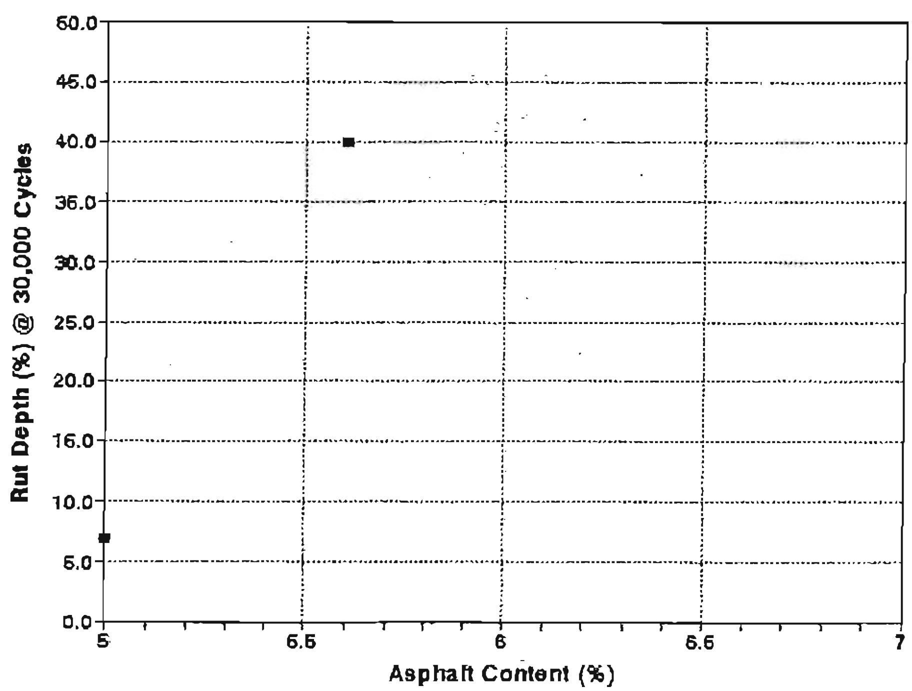

60 C Test Temperature
RUT DEPTH (%)
100
10
1
0.1
0.01
10
100
1000
10000
100000
CYCLES
6.0% AC
5.7% AC
5.4% AC


Rut Depth (%) @ 30,000 Cycles
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
6
5.5
6
6.5
7
Asphalt Content (%)

MIX 16



60 C Test Temperature
RUT DEPTH (%)
CYCLES
100
10
1
0.1
0.01
10
100
1000
10000
100000
5.6% AC
5.0% AC



Rut Depth (%) @ 30,000 Cycles
Asphalt Content (%)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
5
5.5
6
6.5
7