Report No. CDOT-DTD-R-93-19

I-70, SILVERTHORNE TO COPPER MOUNTAIN: A CASE HISTORY OF THE USE OF EUROPEAN TESTING EQUIPMENT

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

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Laboratory testing with the Hamburg wheel-tracking device and French rutting tester was performed by Kim Gilbert and Cindi Moya (CDOT-Staff Materials). Standard and SHRP asphalt cement tests were reported by Benja Bemelen (CDOT-Staff Materials), John D'Angelo (FHWA-Technical Applications), and Helen King (Koch Materials).

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16. Abstract

A project on I-70 from Copper Mountain to Silverthorne began to exhibit moisture related distress after one severe winter. The European testing equipment was used to improve the quality of the hot mix asphalt (HMA) pavement. The primary reason the Colorado DOT and the FHWA Turner Fairbank Highway Research Center obtained the equipment was to improve the quality of HMA pavements. The purpose of this report is to document a case history of the use of the European equipment to improve an HMA pavement on a project in Colorado.

Cost effective adjustments were identified to produce a high quality pavement that resists rutting and stripping. The three changes were: 1) increasing the optimum asphalt content, 2) adding a liquid anti-stripping additive with hydrated lime, and 3) changing the crude oil source and refinery. The cost of the HMA increased from $24.00 to $25.00, 4.2%, for a project cost increase of $80,000. These changes likely saved $5,000,000.

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of the Use of European Testing Equipment

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.

The primary reason for obtaining the European equipment was to improve the quality of hot mix asphalt (HMA). The purpose of this report is to document a case history of the use of this equipment to improve HMA on a project in Colorado.

2.0 PROJECT BACKGROUND

2.1 Project Overview

An $8 million project, IM-NH-I (CX)70-2(176), consisting primarily of 152,000 tons of a hot mix asphalt overlay was awarded to Asphalt Paving Co. in the summer of 1992. Approximately the first half of the project was constructed in the fall of 1992. The project extended along I-70 from Silverthorne to Copper Mountain, approximately 17.7 km (11 miles). The typical overlay section was 100 mm (4 inches). The elevation on the project was approximately 2,700 m (9,000 feet). The highest seven day pavement temperature on the surface is 49°C (120°F) and for the top 100 mm is 42°C (108°F).

2.2 Hot Mix Asphalt

2.2.1 Design Properties.

The mix design was performed in the Staff Materials laboratory using the Texas gyratory compactor (ASTM D 4013). A copy of the mix design information and gradation plotted on the 0.45 power gradation chart are shown in Appendix A. A summary of the mix design properties are shown in Table 1. The optimum asphalt content was 5.2% and included 1% hydrated lime.

Table 1. Summary of Mix Design and Field Produced Properties.

	Mix Design		Field Production		
	Spec.	Results	Average	S.D.	n
Air Voids (%)	2-4	2.4	2.95	0.64	45
VMA (%)	12.4	12.6	13.3	0.37	45
Stability	37	48	45.2	4.5	45
TSR	80	96	96	17.3	25
Dry Strength (kPa)	210	280	230	60	25

The VMA was calculated using the bulk specific gravity of the aggregates. The HMA met the VMA requirements of the Asphalt Institute. The dry strengths were measured using a loading rate of 5 mm/min (0.2 in/min). Maupin (2) has shown the TSR using the slower loading rate is no different than the faster loading rate of 50 mm/min (2.0 in/min), and the dry strengths at the faster rate are 2 to 3 times higher than at the slower rate.

2.2.2 Field Produced Properties.

The specifications for accepting the HMA were based on gradation, asphalt content, and percent relative compaction on the roadway. The percent relative compaction was based on the maximum specific gravity of the HMA (AASHTO T 209). The project had QA/QC specifications so contractor was performing the specification tests to control his quality. All of the material placed on the project met or exceeded the CDOT specifications, and the contractor was receiving a 3.1% bonus. A summary of the results is shown in Table 2.

Table 2. Summary of QA/QC Results.

	Asphalt Content (%)	Percent Relative Compaction	Gradation	Composite
Specification	4.9 - 5.5	92 - 96	Variable	---
n	40	130	34	---
Pay Factor	1.039	1.026	1.033	1.031

Additionally, the field produced material was being tested in a newly acquired testing trailer equipped to test loose mix from the plant with the Texas gyratory (ASTM D 4013), maximum and bulk specific gravities of the HMA (AASHTO T 209 and T 166), Hveem stability (AASHTO T 146), and modified Lottman (AASHTO T 283). The testing indicated the HMA had properties within acceptable deviations of the mix design. The results are summarized in Table 1.

2.3 Pavement Distress

Paving was suspended for the winter after 70,000 tons of HMA were produced. During a very harsh winter, the new HMA overlay began exhibiting signs of distress. The distress was related to moisture damage and was primarily ravelling (Fig. 1). The distress occurred most frequently at the transverse and longitudinal joints. Additionally there were approximately a dozen potholes. Although the distress was not a dramatic failure, the presence of the distress after such a short period of time was indicative of a reduced pavement life. It was estimated that the overlay would likely need rehabilitation in 3 to 5 years despite a structural design of 10 to 20 years.

2.4 Hot Mix Asphalt Improvement Strategy

Wes Goff, the resident engineer, scheduled a meeting May 3, 1993, with the contractor, Region materials and construction personnel, and Staff materials personnel. The purpose of the meeting was to identify potential improvements that could be made to the HMA before the final 82,000 tons were placed.

Based on past experience with the construction of HMA overlays in the mountains and previous experience with the aggregate source, recommendations were:

1) increasing the optimum asphalt cement content of the HMA,

2) trying various anti-stripping additives,

- B/A 2000 or Pave Bond Special (PBS),
- increasing the hydrated lime from 1% to 2%, or
- using lime and liquid anti-stripping additives, and

3) modifying the asphalt cement with a polymer.

The gradation was not investigated because all of the parties believed the gradation was acceptable.

The recently received European testing equipment would be used to determine which of the recommendations would provide the best HMA pavement with the most economical adjustments. Additional meetings were held June 1 and July 7 to provide updates in test results and new potential changes.

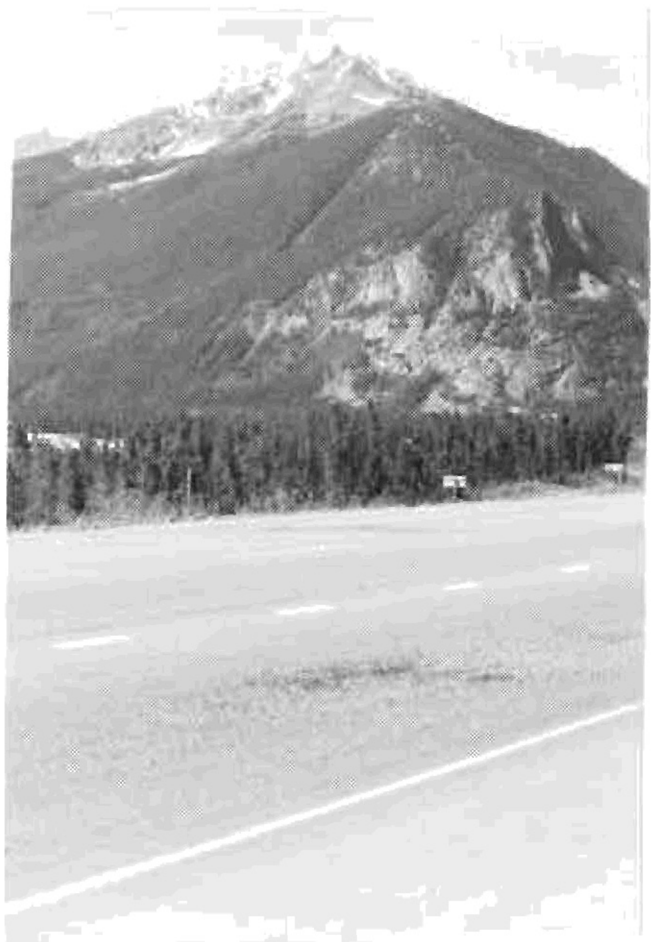


Fig. 1. Example of Pavement Distress on I-70, Silverthorne to Copper Mountain.

3.0 TEST RESULTS AND DISCUSSION

3.1 Aggregate Tests

Several aggregate tests specified by the Europeans were performed to determine if there were any aggregate problems.

3.1.1 P200 Quality.

The methylene blue test is used to identify the presence of harmful clays. Test results less than 10 mg/g are considered acceptable. The methylene blue value of the manufactured fines was 6.5 mg/g. The quality of the P200 was considered excellent.

3.1.2 P200 Quantity.

A maximum P200 to asphalt cement ratio is commonly used to prevent lean asphalt mixtures. The Rigden voids index test can be used to determine the maximum acceptable P200 to asphalt ratio for a specific mixture. For this particular asphalt mixture, the maximum P200 to asphalt ratio is 1.38. This is higher than the normally accepted value of 1.20, probably because of the high quality of P200. The actual P200 to asphalt cement ratio of the mixture investigated was 1.08. The quantity of P200 was acceptable.

3.1.3 Boiling Water Test.

The 10-minute boiling water test (ASTM D 3625) was used to identify the attraction between the asphalt cement and aggregate. The percent of aggregate retaining asphalt cement after boiling is summarized in Table 3.

Table 3. Summary of Boiling Water Test Results.

Treatment	Manufactured Sand	Washed Sand
None	60 %	70 %
1% Lime	40 %	60 %
BA-2000	50 %	100 %
PBS	95 %	100 %

The manufactured sands are very susceptible to stripping. The material finer than the 600 micron (No. 30) sieve size in the manufactured fines is highly susceptible to stripping. Pave Bond Special appears to be the most successful treatment for this HMA.

3.1.4 Fine Aggregate Angularity.

The National Aggregate Association flow meter was used to quantify the angularity of the washed and manufactured sands. Sands with uncompacted voids greater than 44% are considered angular. The manufactured sands had uncompacted voids of 47.6%, and the washed sands had uncompacted voids of 44.3%. The manufactured sands are more angular than the washed sands, but both are angular.

3.1.5 Summary.

The aggregate tests indicated that the aggregate had excellent quality. The use of some type of anti-stripping treatment might be necessary to minimize moisture damage.

3.2 French Rutting Tester Results

The asphalt mixture was designed using the Texas gyratory with a 1034 kPa (150 psi) end point stress at 2.4% air voids. The optimum asphalt content was 5.2%. Based on past experience on high volume roadways in the mountains, the asphalt content was considered low. A study was designed to use lower end point stresses on the Texas gyratory. The French rutting tester was then used to identify the highest allowable asphalt content for the mixture.

The French rutting tester measures the ability of an asphalt mixture to resist rutting. The test is performed in a high-temperature, air environment, typically 60°C (140°F). Since the maximum surface pavement temperature at the site is 49°C (120°F) and the maximum average pavement temperature for the top 100 mm is 42°C (108°F), the asphalt mixture was tested at 50°C (122°F) in the French rutting tester. Aschenbrener (3) found the 50°C test temperature in the French rutting tester acceptable for mountain sites.

The asphalt mixture with lime was tested at increasing asphalt cement contents until it failed in the French rutting tester. The test results are shown in Fig. 2. HMA likely to resist rutting will have less than 10% rutting depths after 30,000 cycles of loading. The highest allowable asphalt content for the mix is approximately 6.3% as shown by Fig. 3.

The Texas gyratory was used to obtain the optimum asphalt content of the mixture with lime at 3 different end point stresses as shown in Table 4. The end point stress that seemed to correlate best with the French rutting tester and the experience of past projects constructed on high volume roadways in the mountains was approximately 340 kPa (50 psi).

Table 4. Summary of Optimum Asphalt Contents at Various End Point Stresses.

End Point Stress	Optimum Asphalt Content (%) @ 4% air voids
340 kPa (50 psi)	5.7
690 kPa (100 psi)	5.3
1034 kPa (150 psi)	4.9

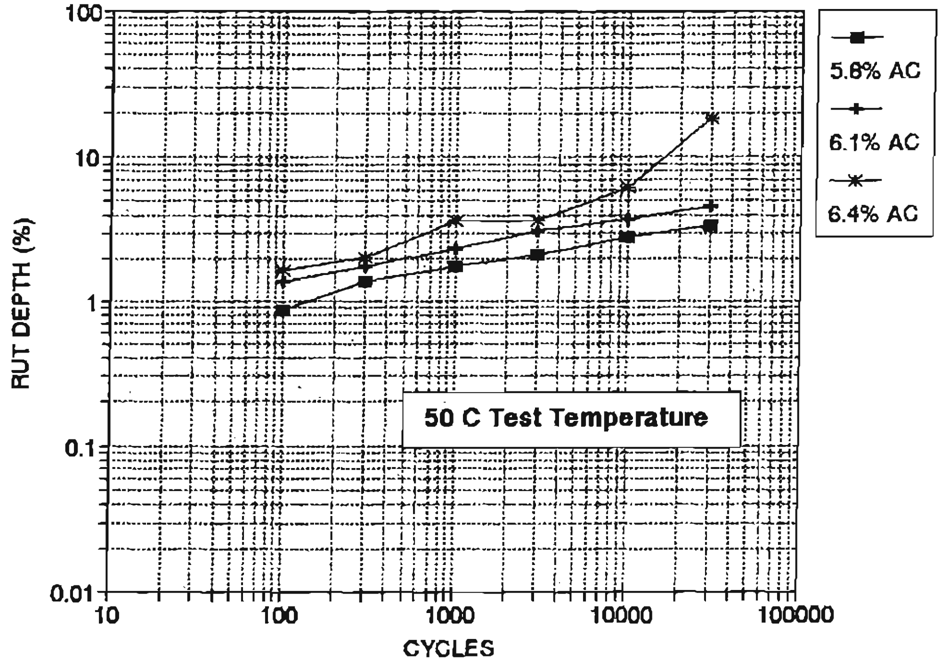


Fig. 2. Results from the French Rutting Tester.

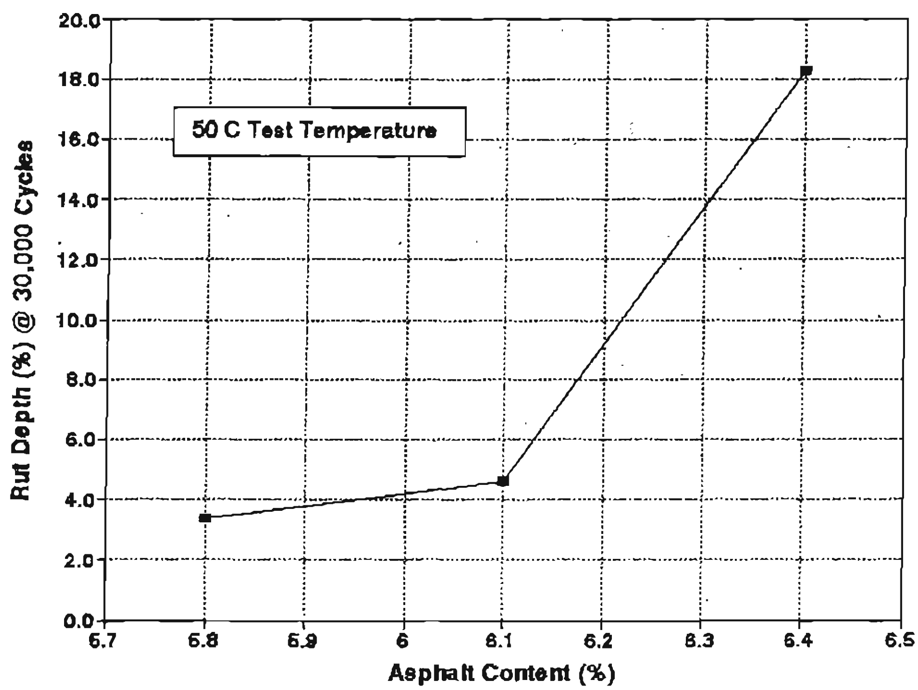


Fig. 3. Summary of Results from the French Rutting Tester.

3.3 Hamburg Wheel-Tracking Device Results

Samples testing in the Hamburg wheel-tracking device were prepared using the French plate compactor. Samples were 360 mm (14.2 in.) long, 180 mm (7.1 in.) wide, and 50 mm (2 in.) thick and were compacted to an air void level of 7 $\pm$ 1 %. The sample is submerged under water at 50°C (122°F). A steel wheel, 47 mm (1.85 in.) wide, loads the sample with 705 N (158 lbs.) The wheel makes 50 passes over the sample per minute. The sample is loaded for 20,000 passes or until 20 mm of deformation occur. The device has previously been described by Aschenbrener and Stuart (4).

Over 30 samples were tested in the Hamburg wheel-tracking device for this study. Some of the results are summarized in Table 5 and plotted in Appendix B. The definition of results from the Hamburg wheel-tracking device are summarized in Fig. 4. The stripping inflection point is the number of passes required to initiate stripping.

A test temperature of 50°C (122°F) was used to compare mixtures. Although this might be too high a temperature for the mountain site, it was acceptable for comparative purposes. By selecting a mixture based on the 50°C test temperature, the error would be on the side of a higher quality pavement.

Although the asphalt cement from the Conoco refinery in Colorado did not pass the Hamburg wheel-tracking device, it is believed that the refinery in Colorado can produce asphalt cement that passes the Hamburg wheel-tracking device. Unfortunately, the short time frame allocated to improve the HMA did not allow for testing of all the crude oil sources and chemicals used in the refining process in Colorado. A study will be undertaken in the winter to investigate these variables.

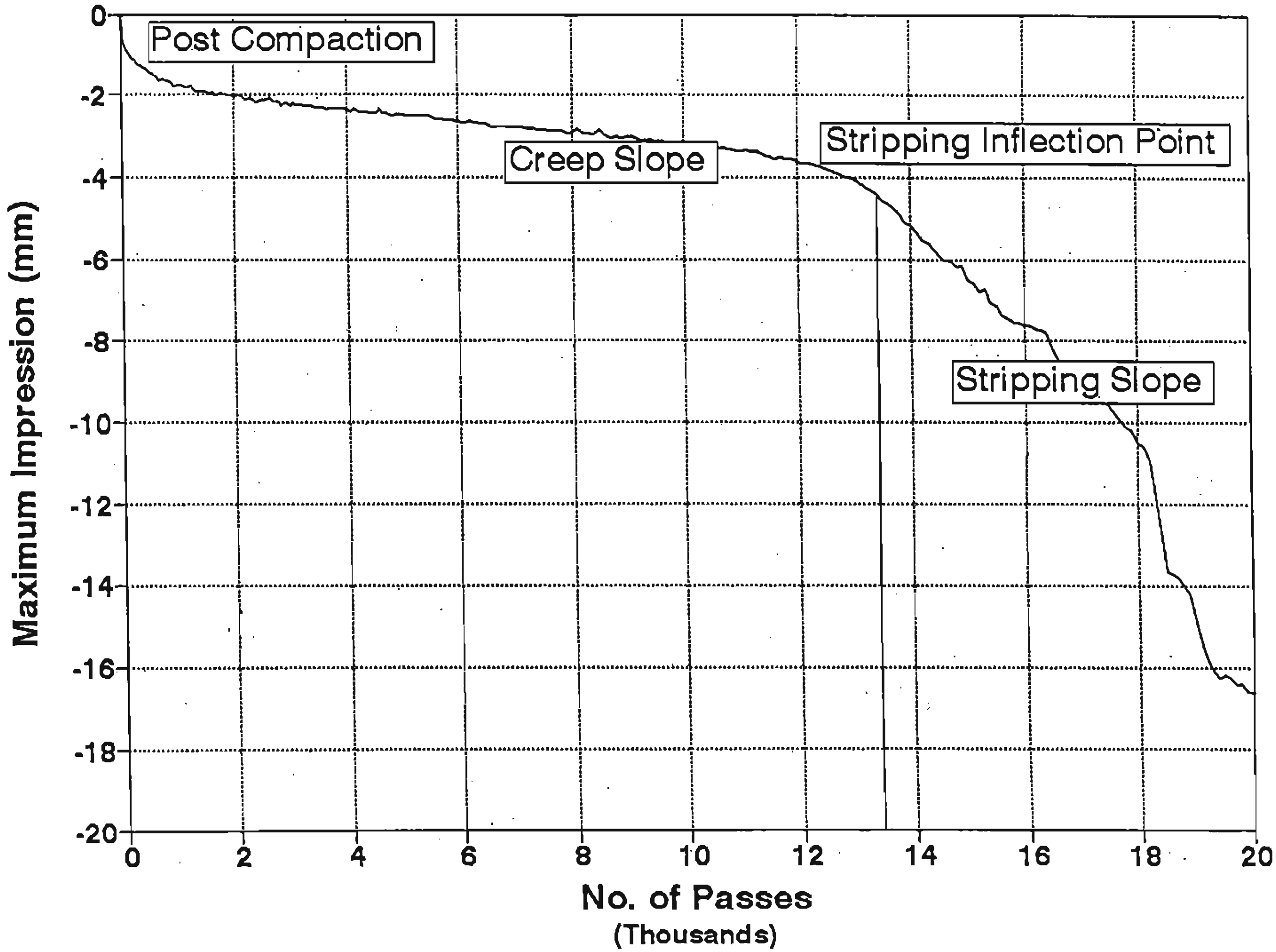


Fig. 4. Summary of Results Obtained from the Hamburg Wheel-Tracking Device.

Table 5. Summary of Hamburg Wheel-Tracking Results.

Rank	Asphalt Cement Manufacturer and Grade	Additive	Stripping Inflection Point (Passes)	Estimated Cost Increase* ($ per ton of HMA)
1	Conoco 10 (OK)	1% Lime	+20,000	0.50
1	Conoco 10 (OK)	1% Lime, PBS	+20,000	1.00
1	Frontier 10	1% Lime	+20,000	1.50
1	Frontier 10	1% Lime, 8162	+20,000	2.00
1	Koch 10P	1% Lime	+20,000	6.00
1	Koch 10P	1% Lime, PBS	+20,000	6.50
1	Koch 10P	2% Lime	+20,000	8.00
8	Koch 10P	BA-2000	11,000	5.00
9	Koch 10P	PBS	8,500	4.00
9	Conoco 10 (CO)	1% Lime, PBS	8,500	1.00
9	Conoco 10 (CO)	Shell RP-6569	8,000	0.50
9	Conoco 10 (CO)	1% Lime, PBS	7,200	0.50
13	Conoco 10 (CO)	BA-2000	3,300	0.50
13	Conoco 10 (CO)	1% Lime	2,700	0.50
15	Conoco 10 (CO)	PBS	500	-1.00
16	Koch 10R	PBS	1	6.00
16**	Conoco 10 (CO)	1% Lime	1	0.00

* Cost increase compared to HMA originally used on the project
** Original HMA used on project
(CO) Refinery in Denver, Colorado
(OK) Refinery in Ponca City, Oklahoma
P - Polymerized (Type I-B) by Shuler (5)
R - Rubberized (Type II-B) by Shuler (5)
PBS - Morton International Pave Bond Special
8162 - Unichem 8162
BA-2000 - Carstab BA-2000

3.4 Asphalt Cement Tests

The quality of the asphalt cement appears to be a variable that influences the acceptability of the results in the Hamburg wheel-tracking device. Various asphalt cements used in this study were tested with the standard penetration and viscosity tests as well as some of the new SHRP asphalt cement tests. Results are shown in Table 6.

Table 6. Summary of Asphalt Cement Testing

Asphalt Cement Refinery and Grade	Pen 25°C (dmm)	Viscosity 60°C (poises)	Temperature (°C)		
			Bending Beam (PAV) m = 0.30	DSR (RTFO) S=2.2 kPa	DSR (PAV) S=5000kPa
Conoco AC-10 (OK)	100	890	-16.7	59.2	14.2
Conoco AC-10 (CO)	106	976	-17.1	57.9	?
Frontier AC-10	103	947	-14.0	63.9	?
Koch Materials 10P	91	3910	-21.2	69.3	10.8
Koch Materials 10R	141	1120	-19.1	61.5	13.4

? value could not be determined from the test

After aging in the pressure aging vessel (PAV), the bending beam rheometer is used to identify the minimum temperature to achieve a stiffness (S) of 300,000 kPa or a slope (m) of 0.30 to resist thermal cracking. The slope controlled in all five asphalt cements tested in this study. After aging in the rolling thin-film oven (RTFO), the dynamic shear rheometer (DSR) is used to identify a maximum temperature to achieve a stiffness of 2.2 kPa to resist early rutting. After PAV aging, the DSR is also used to identify the minimum temperature to achieve a stiffness of 5,000 kPa to resist fatigue cracking.

These results are shown for information only. The test result summary sheets are shown in Appendix C.

4.0 RECOMMENDATIONS

4.1 Increased Asphalt Cement Content

Based on the testing with the French rutting tester, it is recommended to increase the optimum asphalt cement content from 5.2% to 5.8%. The increase of 0.6% asphalt cement should provide an HMA pavement that has better durability against moisture and provide an HMA pavement that is still resistant to rutting. Field verification should be performed on the HMA to monitor the void properties during construction.

4.2 Moisture Resistance

In order to resist moisture damage, it is recommended to add a liquid anti-stripping additive in addition to lime. Pave Bond Special is recommended because of the slightly improved results obtained with the Hamburg wheel-tracking device and the boiling water test. PBS can be added easily at the refinery.

Additionally, the use of asphalt cement from the Conoco refinery in Ponca City, Oklahoma is recommended. Although the asphalt cement from Frontier and the polymerized asphalt cement from Koch Materials both had acceptable results on the Hamburg wheel-tracking device, the asphalt cement from Oklahoma is more cost effective. It is believed the asphalt cement from Conoco's Colorado refinery could pass the Hamburg wheel-tracking device, but insufficient time was available to test the many variables. A research project will be performed this winter.

4.3 Other Considerations

All of the parties recognize that the existing HMA pavement placed in the summer and fall of 1992 has an inferior quality. Ideally, this material should be removed and replaced. It will be a weak link in the future performance of the pavement. Realistically, there is not sufficient funding to entirely remove and replace this material. Therefore, the inferior material should be removed where it has been placed as a wearing surface. Where the inferior material remains, it should be treated with a thick tack coat prior to paving. Hopefully, the thick tack coat should provide a seal against moisture.

The tests performed in this study did not measure the cold temperature performance of the HMA pavement. The polymerized asphalt cements will provide better cold temperature performance than the neat asphalt cements recommended. However, the low temperature cracking was not the primary concern of the pavement being investigated, and the funds to polymerize the asphalt cement were not readily available.

5.0 COST ANALYSIS

The approximate increase in cost per ton of HMA (including asphalt cement, haul and placement) of each of the samples tested is listed in Table 5. The cost values used for the calculations in Table 5 are summarized below and should be considered approximate.

$ 0.50 - 0.6% additional asphalt cement
$ 0.50 - Liquid anti-stripping additive (PBS or 8162)
$ 1.00 - Asphalt cement from the Frontier refinery
$ 1.00 - Liquid anti-stripping additive (BA-2000)
$ 2.00 - Liquid anti-stripping additive (1% Lime or Shell RP-6569)
$ 5.50 - Polymerized or Rubberized asphalt cement

For the HMA recommended for the project, there will be an increase of approximately $1.00 per ton of HMA. The HMA bid for the project was approximately $24.00 per ton including asphalt cement, haul, and placement. The increase to $25.00 per ton is a 4% increase in the cost of the HMA and resulted in a total increase of $80,000 for the remaining HMA to be placed on the project. Considering the new HMA placed will extend the life of the pavement approximately 10 years, the benefit is approximately $5,000,000.

6.0 CONCLUSIONS

The European testing equipment obtained by the Colorado DOT and the FHWA Turner-Fairbank Highway Research Center can be used to improve the quality of HMA pavements. Cost effective adjustments were identified to produce a high quality pavement that resists rutting and stripping.

7.0 RECOMMENDATIONS FOR FUTURE RESEARCH

A test section of the inferior HMA pavement placed in the summer and fall of 1992 should remain. The 1992 and 1993 pavements can then be monitored and compared. Results of these comparisons should then be reported in approximately 5 years.

Tests with various crude oil sources and chemicals used by the Conoco refinery in Colorado should be performed. The asphalt cements that pass the Hamburg wheel-tracking device can then be identified.

8.0 REFERENCES

1. Report on the 1990 European Asphalt Study Tour (June 1991), American Association of State Highway and Transportation Officials, Washington, D.C., 115+ pages.

2. Maupin, Jr., G.W. (1979), "Implementation of Stripping Test for Asphaltic Concrete," Transportation Research Record 712, Transportation Research Board, Washington, D.C., pp. 8-12.

3. Aschenbrener, T. (1992), "Comparison of Results Obtained from the French Rutting Tester with Pavements of Known Field Performance," Colorado Department of Transportation, CDOT-DTD-R-92-11, 73 pages.

4. Aschenbrener, T. and K. Stuart (1992), "Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement," Colorado Department of Transportation, CDOT-DTD-R-92-10, 23 pages.

5. Shuler, T.S., Chairman (1991), AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Materials, Task Force 31, "Proposed Specifications for Polymer Modified Asphalt," 18 pages.

Appendix A

Original Mix Design

Division of Transportation
State of Colorado
Form DOH 429 Flex 1.98

Date Received 7 /16/92

Project No: IMNHICX-CX70-2(176)
Location: Copper Mtn. to Silverthorne
District # 1 Subaccount: 89003
Lab # 513x-516x
Field Sample # 62612

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading SF Conoco AC-10
Pit name: Alpine Rock & LG Eve Contractor/Supplier: Asphalt Paving

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	513x	554x	515x	516x	Hyd	As Used		Job Mix
% used-->	17.0	20.0	42.0	20.0	1.0			
1 1/2	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	1	
3/4	100	100	100	100	100	100	3/4	100
5/8	100	100	100	100	100	100	5/8	
1/2	42	100	100	100	100	90	1/2	89
3/8	3	83	100	100	100	80	3/8	80
4	1	7	95	98	100	62	4	62
8	0	2	69	79	100	46	8	46
16	0	2	50	55	100	33	16	
30	0	2	37	30	100	23	30	23
50	0	2	26	11	100	15	50	
100	0	1	17	4	98	9	100	
200	0.0	1.2	10.7	1.5	97.0	6.0	200	6

%AC in aggr.
Combined Aggregate: Bulk SpG: 2.622 Sand Equivalency: 75.0

Ret .10

TEST RESULTS				
Percent bitumen	4.5	5.0	5.5	6.0
Max Sp. Gr. T209	2.507	2.487	2.467	2.447
Bulk Sp. Gr. T166	2.388	2.416	2.422	2.408
% Voids CPL 5105	4.7	2.8	1.8	1.6
Stability CPL 5105	53	51	44	26
Modulus CPL 5110				
Strength coefficient	0.44	0.44	0.44	0.44
VMA (effective)	15.3	14.7	14.9	15.8
VMA (bulk)	13.0	12.5	12.7	13.7
% of bulk VMA filled	63	76	85	87
Dust / AC ratio	1.28	1.14	1.03	0.94

IMMERSION-COMPRESSION CPL 5104
% bitumen
PSI Wet
PSI Dry
% Absorption
% Swell
% Ret. Strength
% Additive used
Asphalt additive type

LOTTMAN	CPL 5109
4.6	% bitumen
39	Wet D.T.St
41	Dry D.T.St
7.31	% Voids
62	% Saturation
96	% T.S.Ret.
	% Additive

Optimum asphalt content 5.0
Stability at Optimum A.C. 51
Asphalt film thickness at Optimum A.C.: 9.1 microns

Lab Max. SpG at Optimum 2.487
% Voids at Optimum A.C. 2.84

Bob LaForce 757-9724
Flexible Pavement Engineer

Date Reported 8/6/92

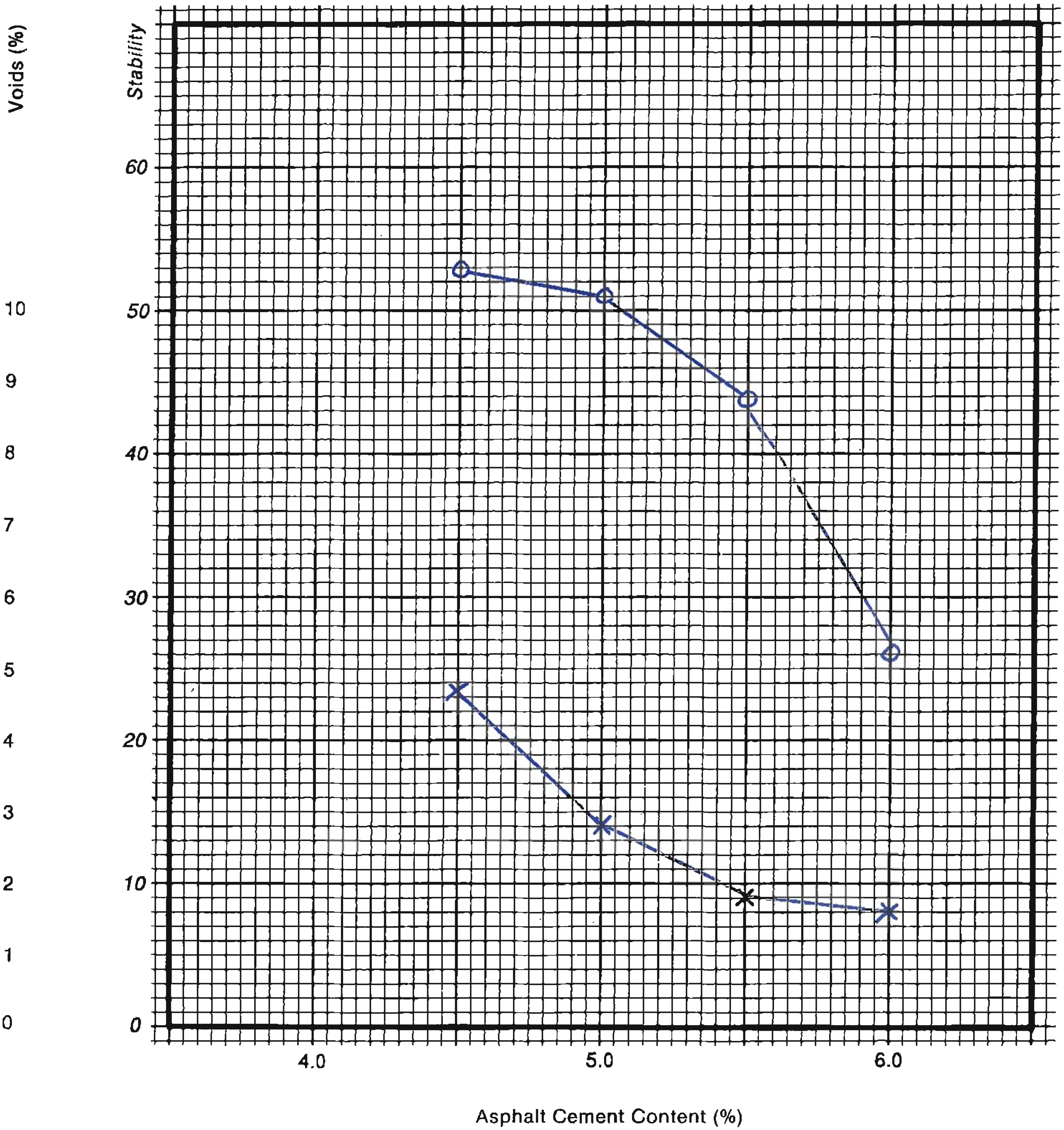
COLORADO DEPARTMENT OF HIGHWAYS

ASPHALT MIX DESIGN GRAPH

Project No. IMNHICX-CX 70-2 (176)

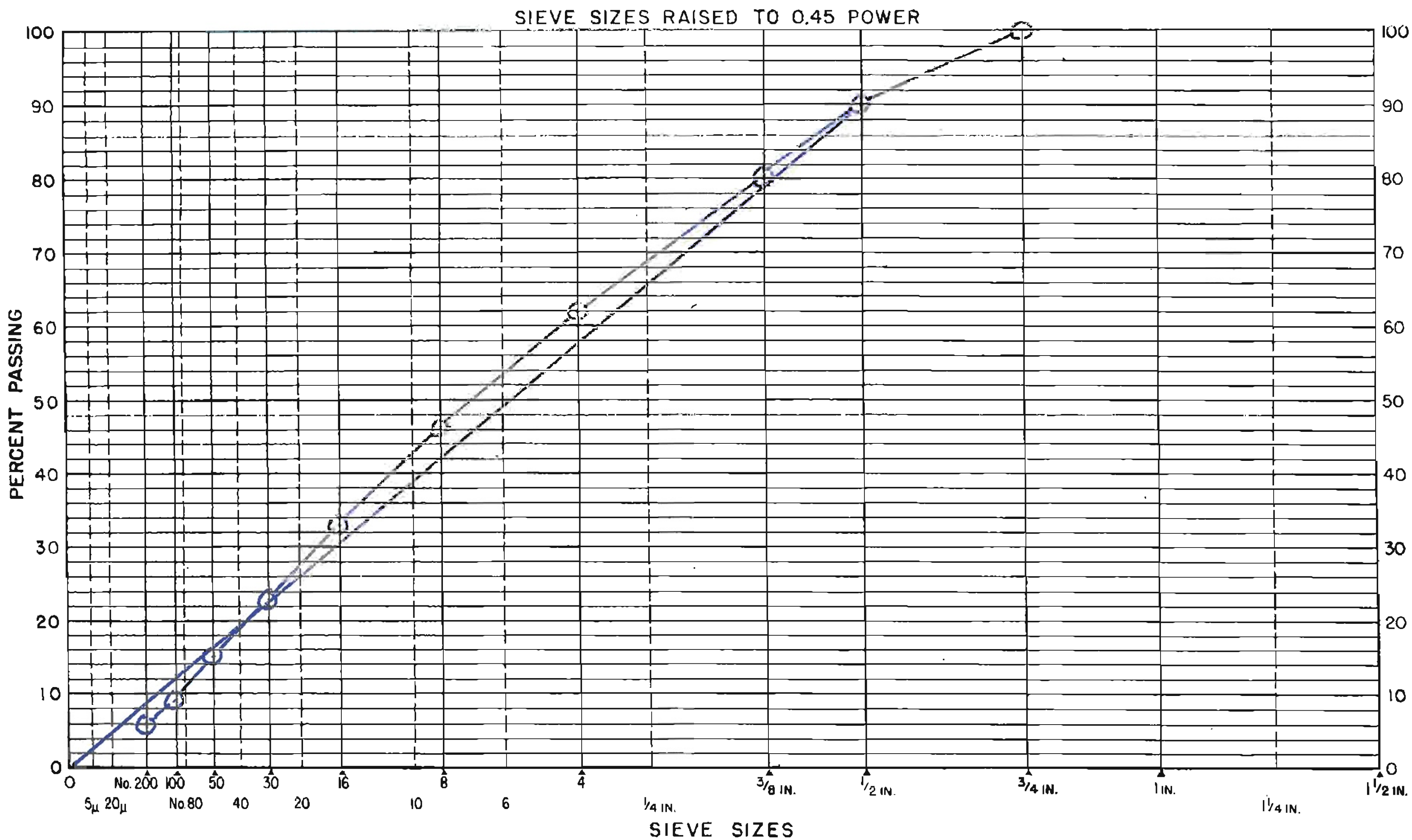
Location I-70, Silverthorne to Copper Mountain

Field Sheet No. 62612



COLORADO DEPARTMENT OF TRANSPORTATION

GRADATION CHART



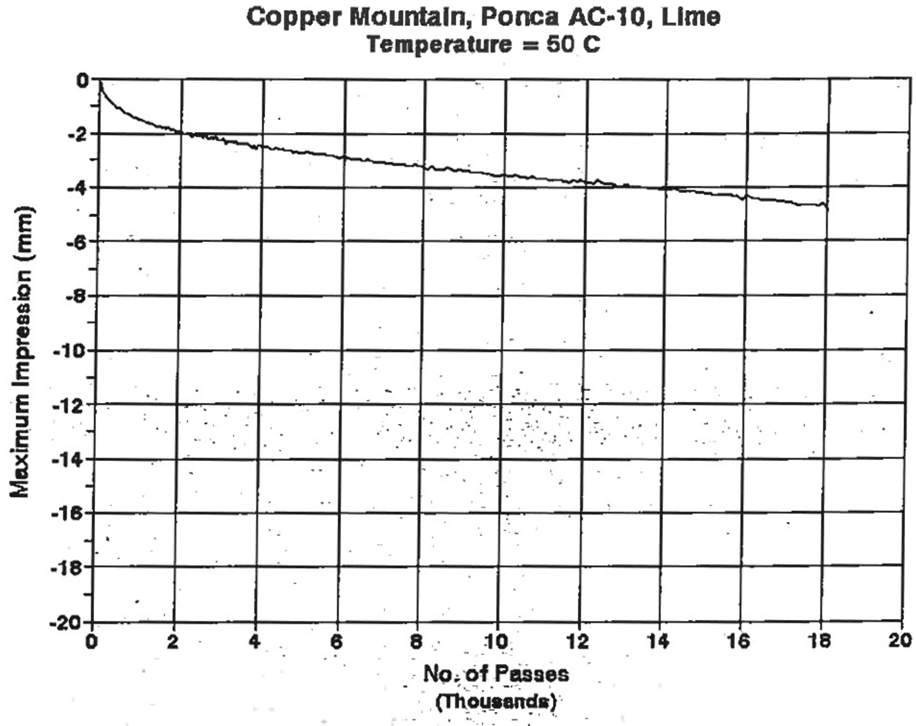
REMARKS:

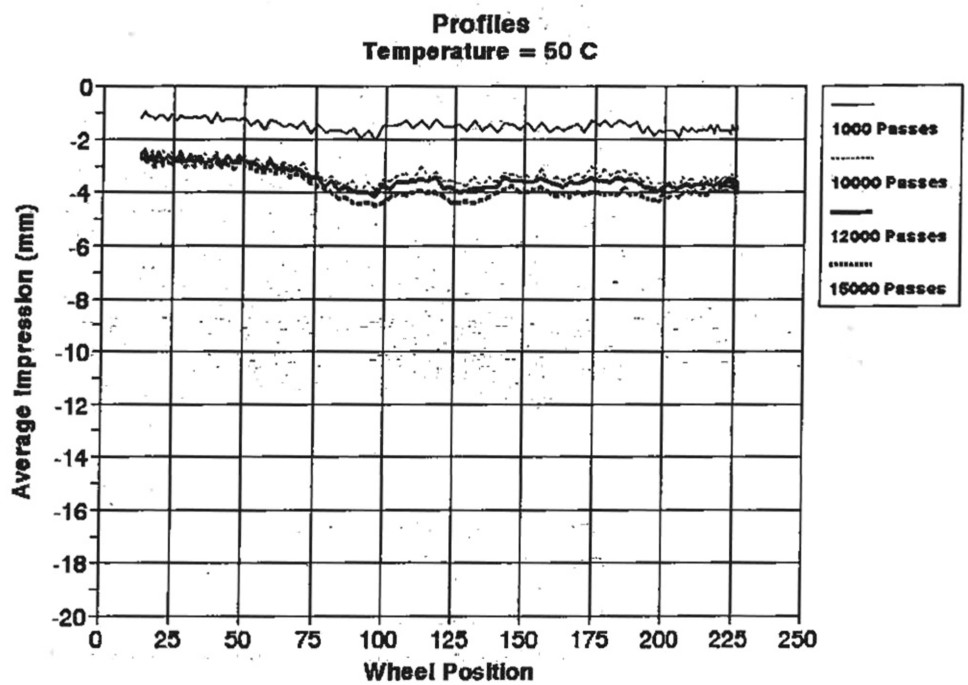
Alpine Rock / LG Everist

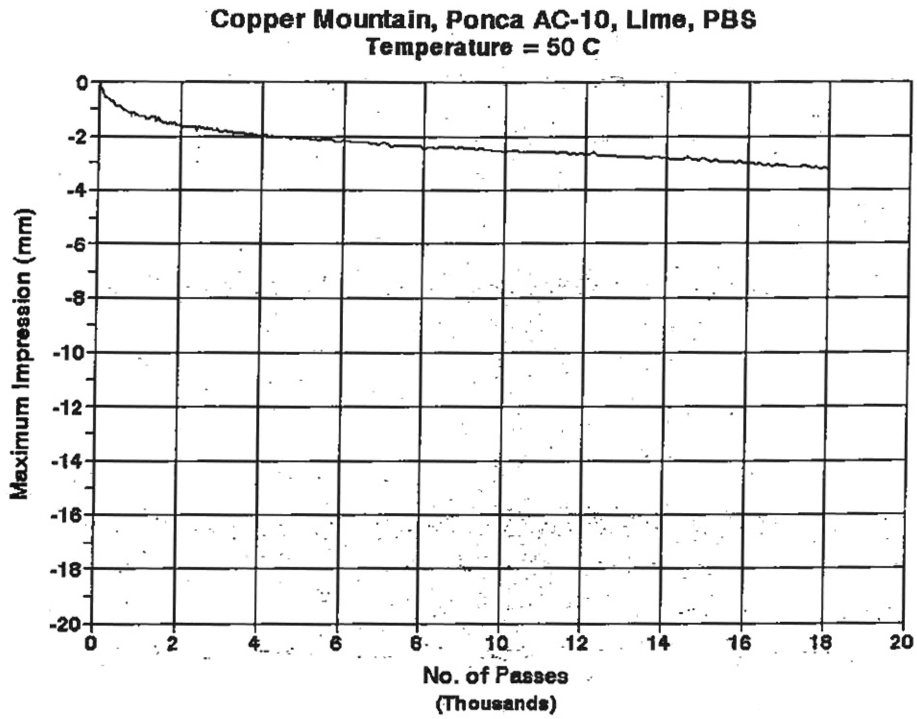
FS # 62612

Appendix B

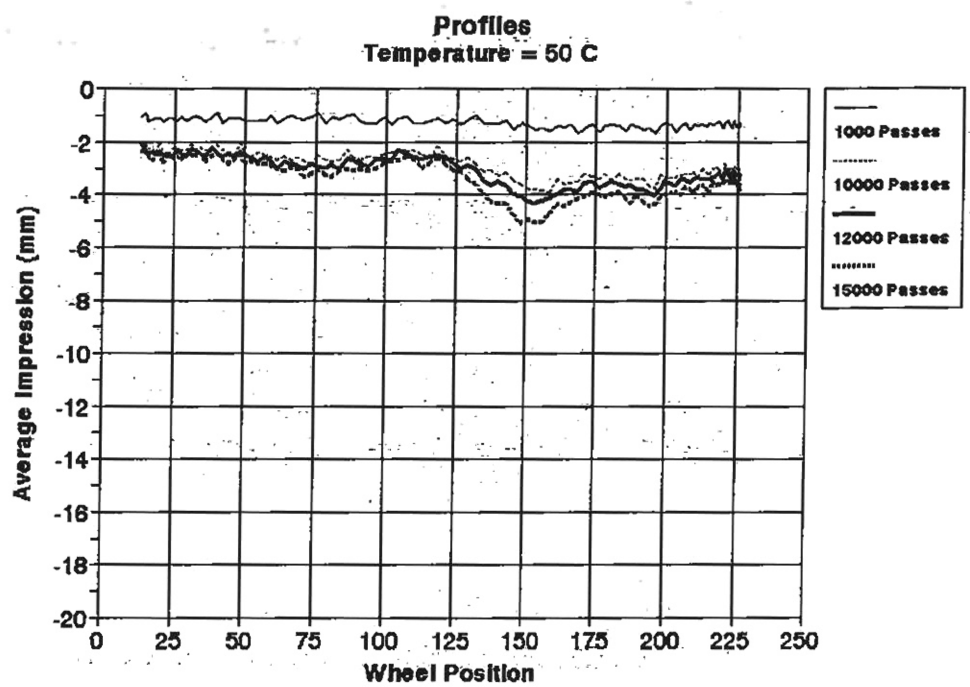
Hamburg Wheel-Tracking Device Results


Copper Mountain, Ponca AC-10, Lime
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

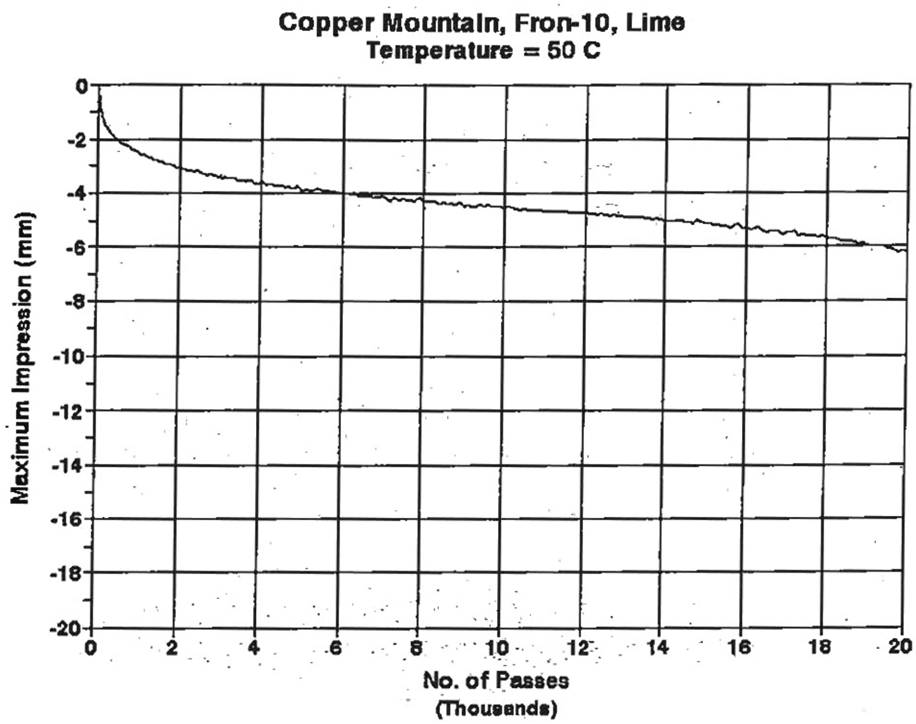

Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
12000 Passes
15000 Passes

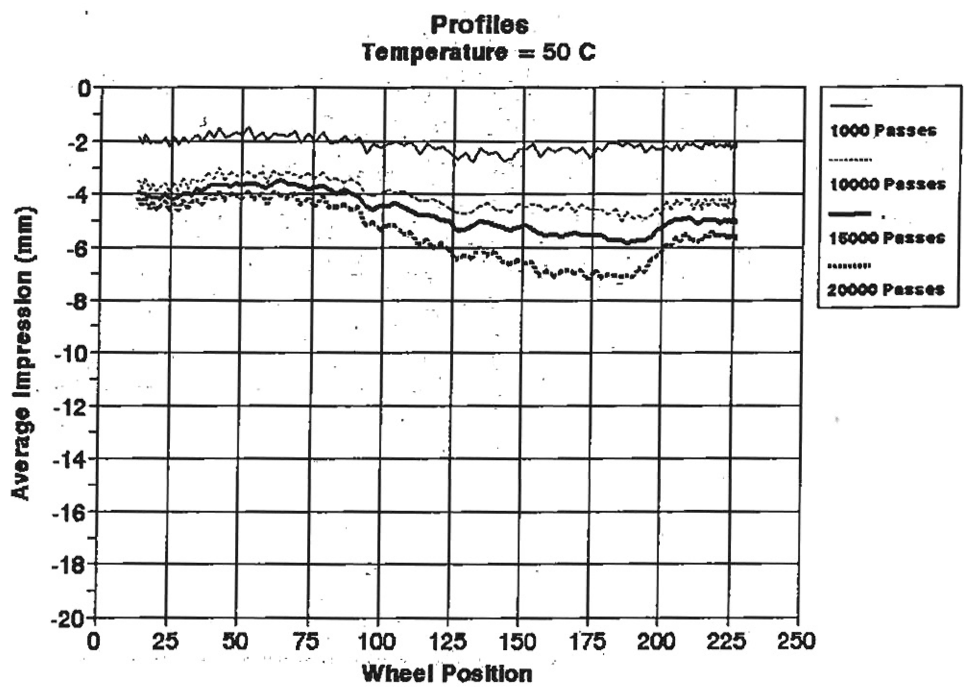


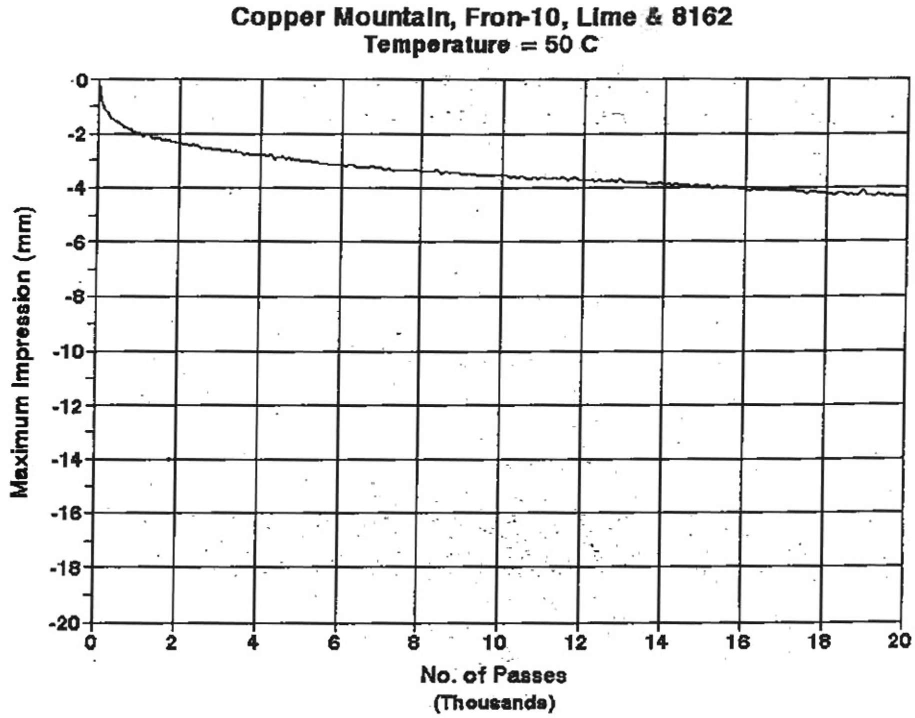
Copper Mountain, Ponca AC-10, Lime, PBS
Temperature = 50 C
Maximum Impression (mm)
No. of Passes
(Thousands)

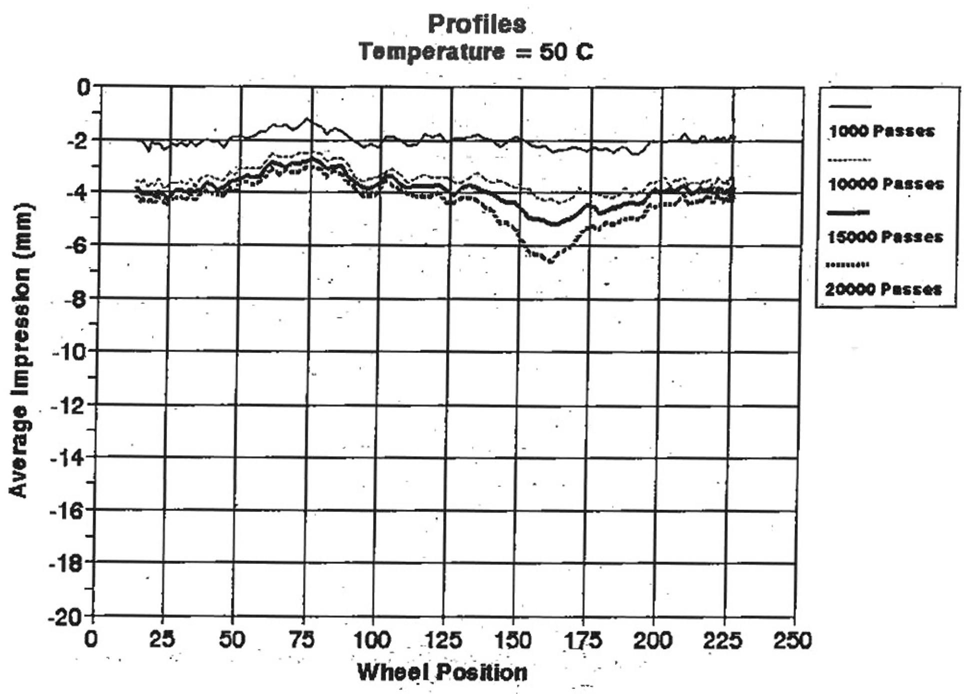


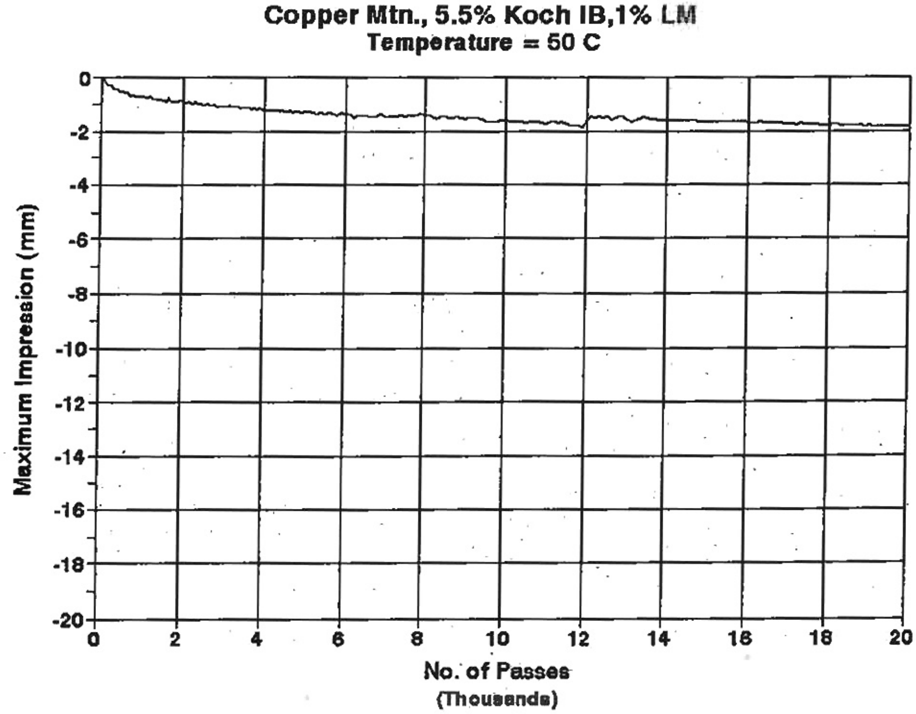
Profiles
Temperature = 50 C
Average Impression (mm)
Wheel Position
1000 Passes
10000 Passes
12000 Passes
15000 Passes

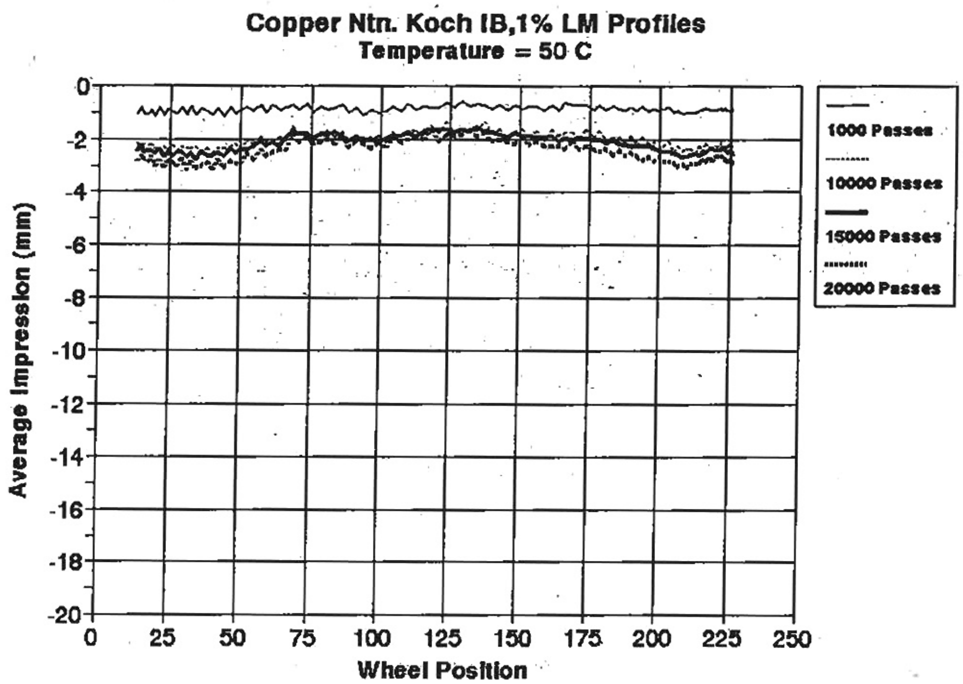

Copper Mountain, Fron-10, Lime
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
15000 Passes
20000 Passes

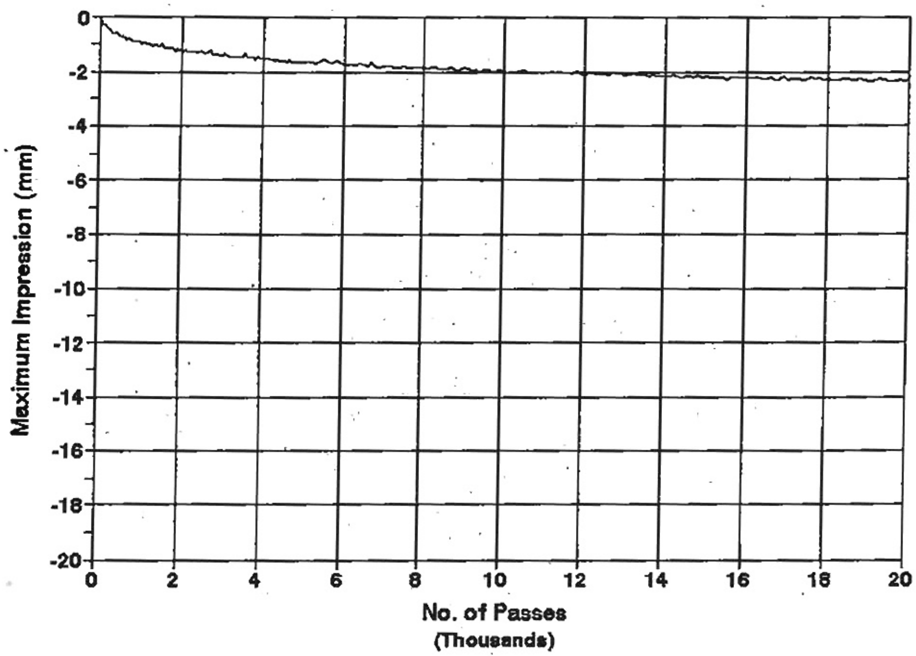

Copper Mountain, Fron-10, Lime & 8162
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
15000 Passes
20000 Passes

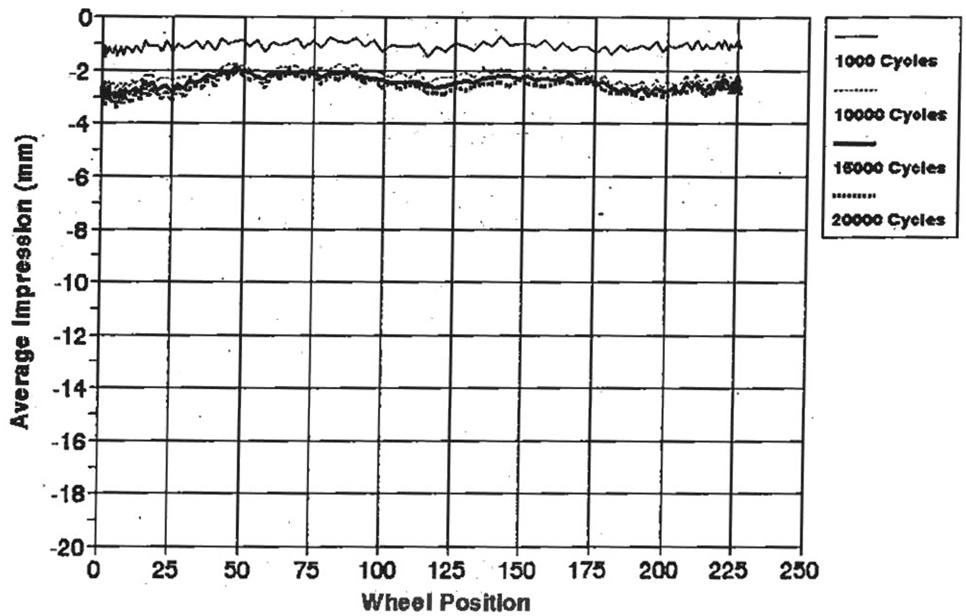

Copper Mtn., 5.5% Koch IB,1% LM
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

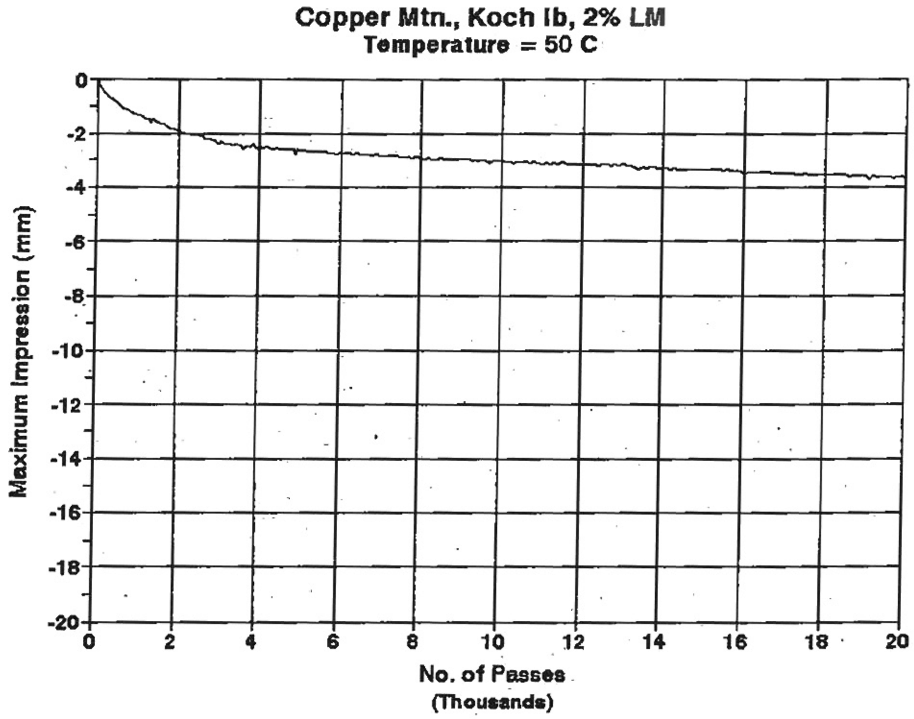

Copper Ntn. Koch IB,1% LM Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
15000 Passes
20000 Passes

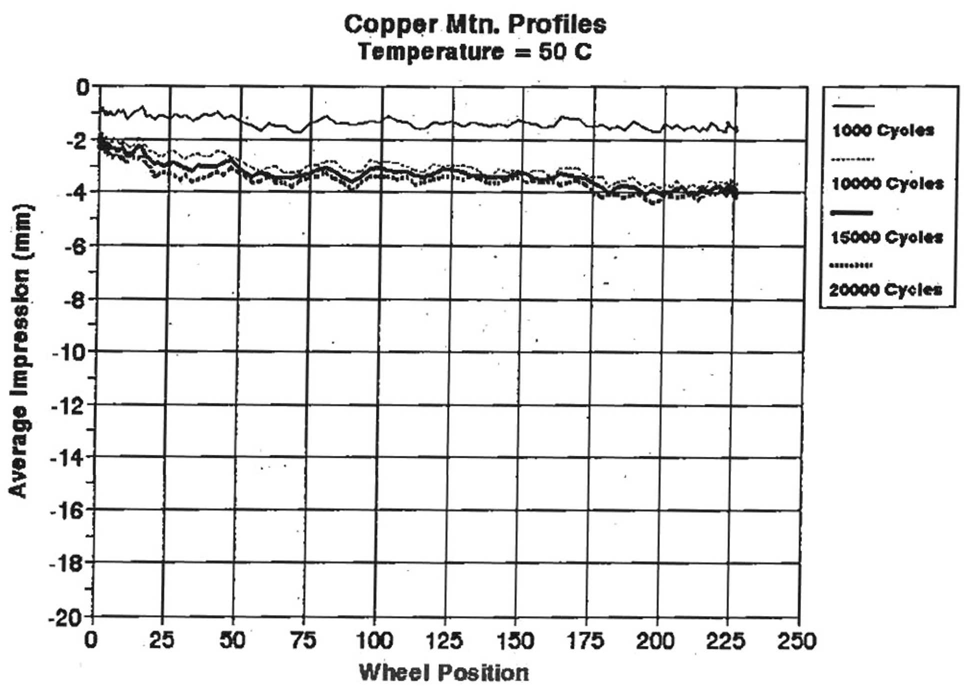
Copper Mtn. Koch Ib, 1% LM, PBS
Temperature = 50 C

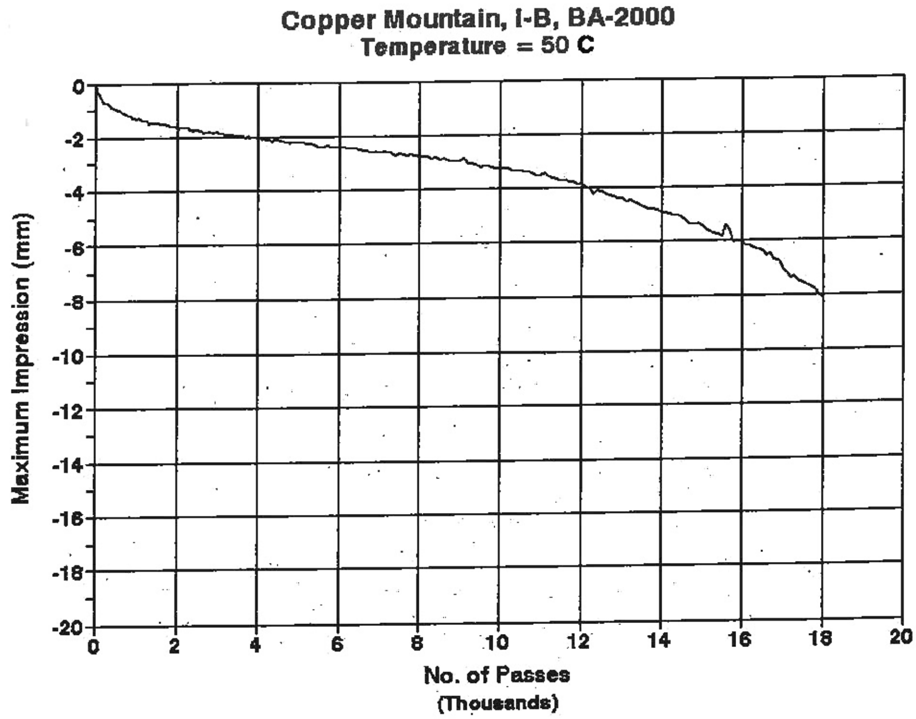


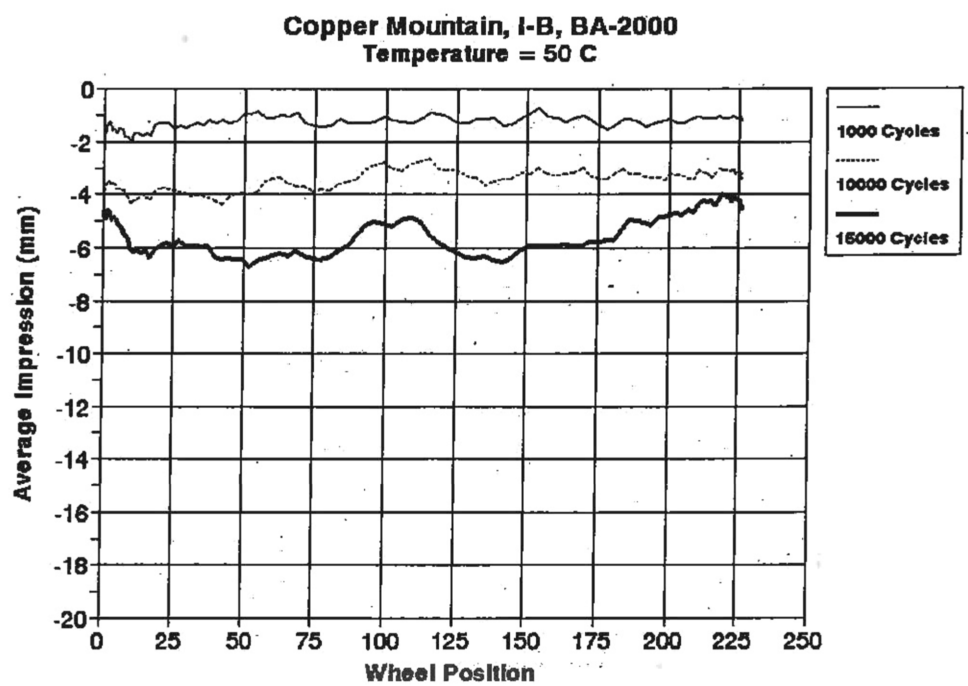
Copper Mtn. Profiles
Temperature = 50 C

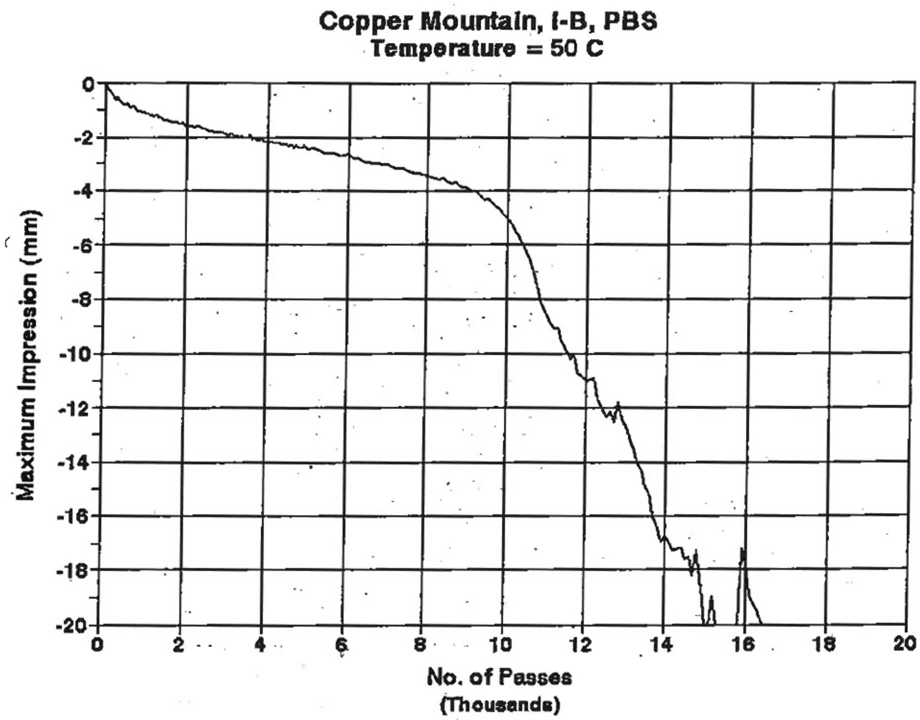



Copper Mtn., Koch Ib, 2% LM
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

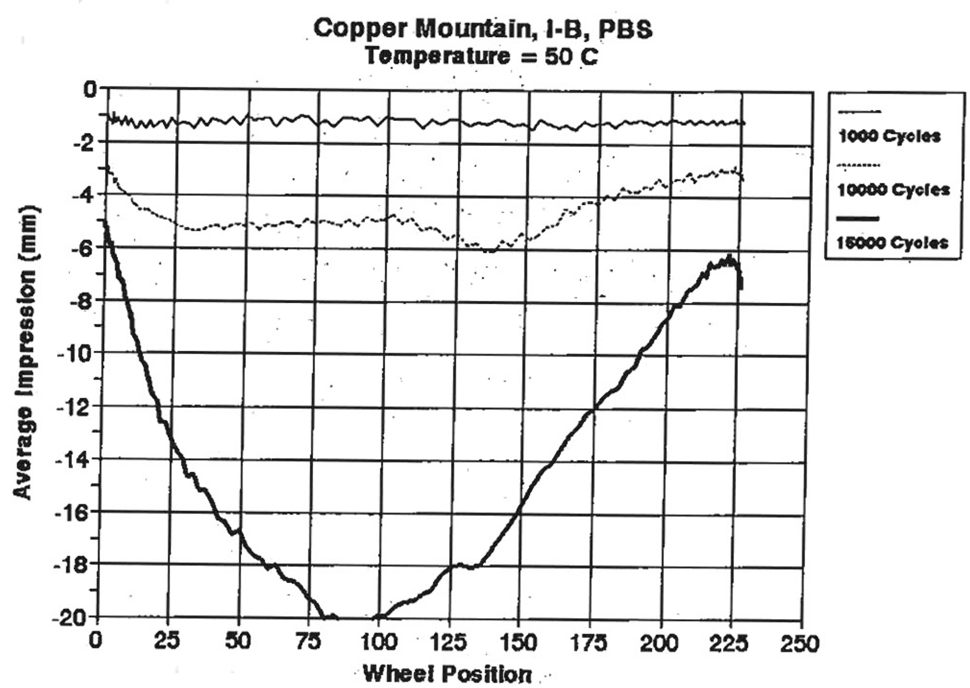

Copper Mtn. Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles


Copper Mountain, I-B, BA-2000
Temperature = 50 C
Maximum Impression (mm)
No. of Passes
(Thousands)

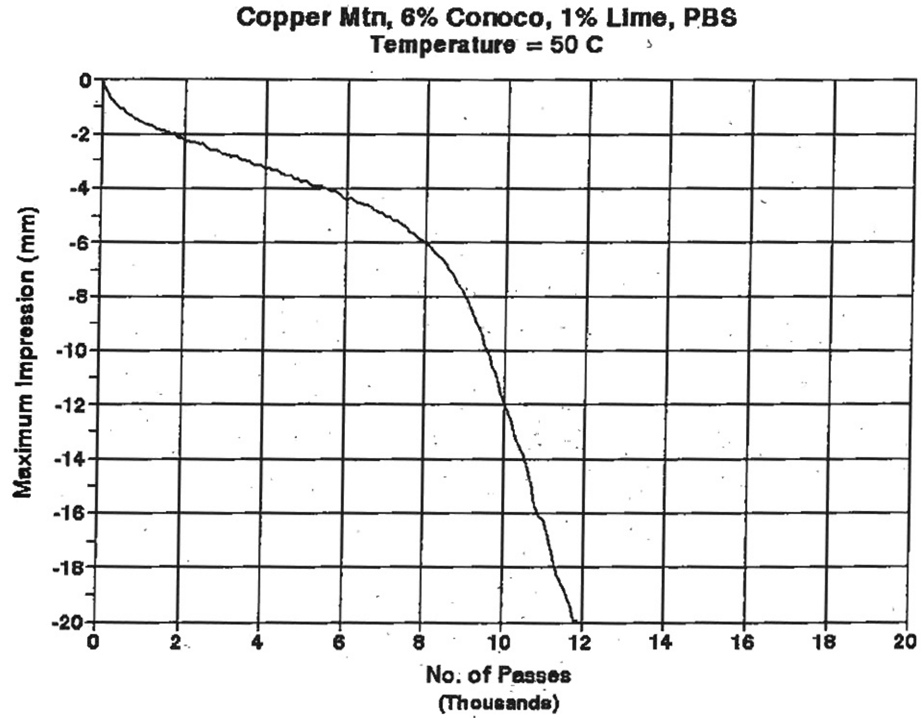

Copper Mountain, I-B, BA-2000
Temperature = 50 C
Average Impression (mm)
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles



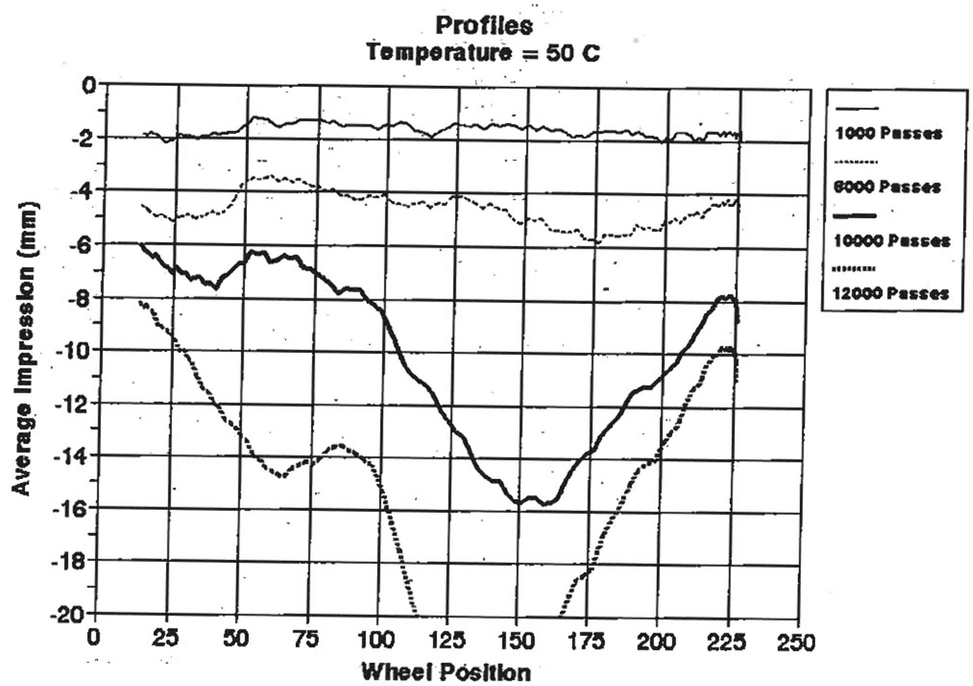
Copper Mountain, I-B, PBS
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)



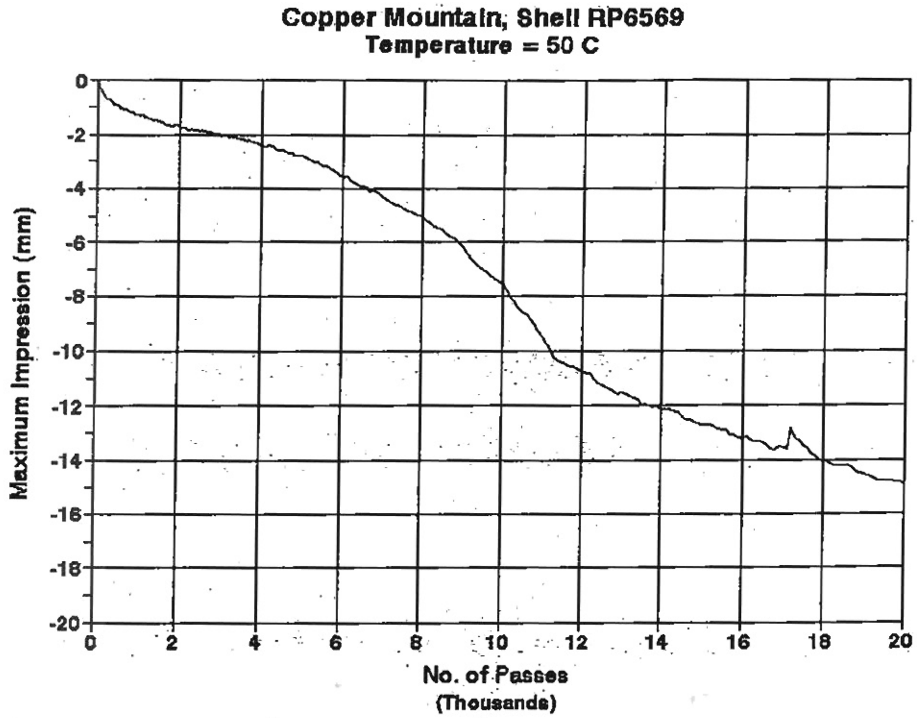
Copper Mountain, I-B, PBS
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles

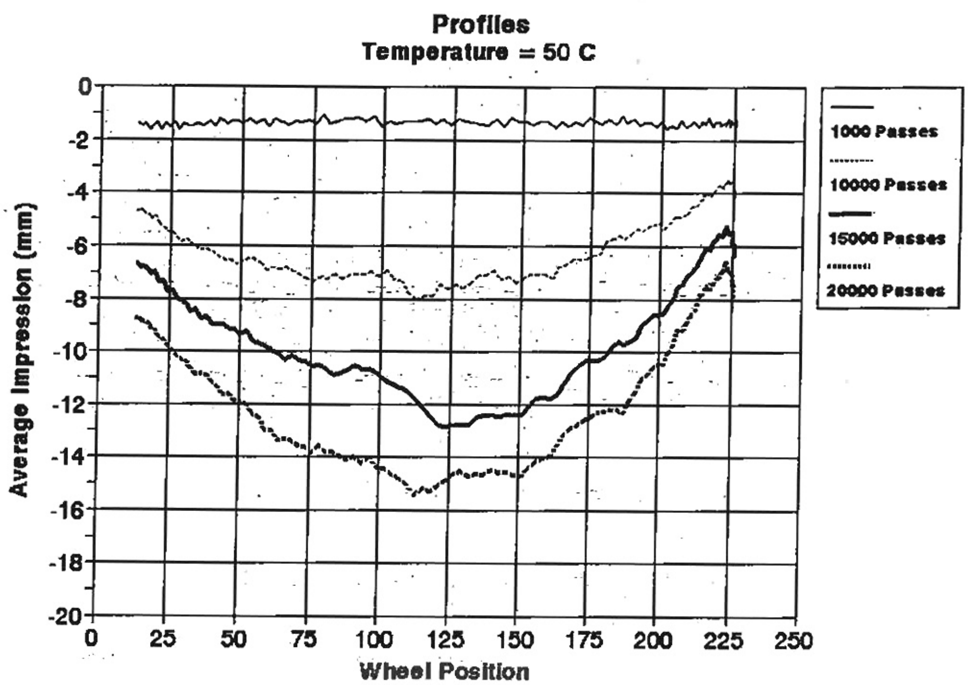


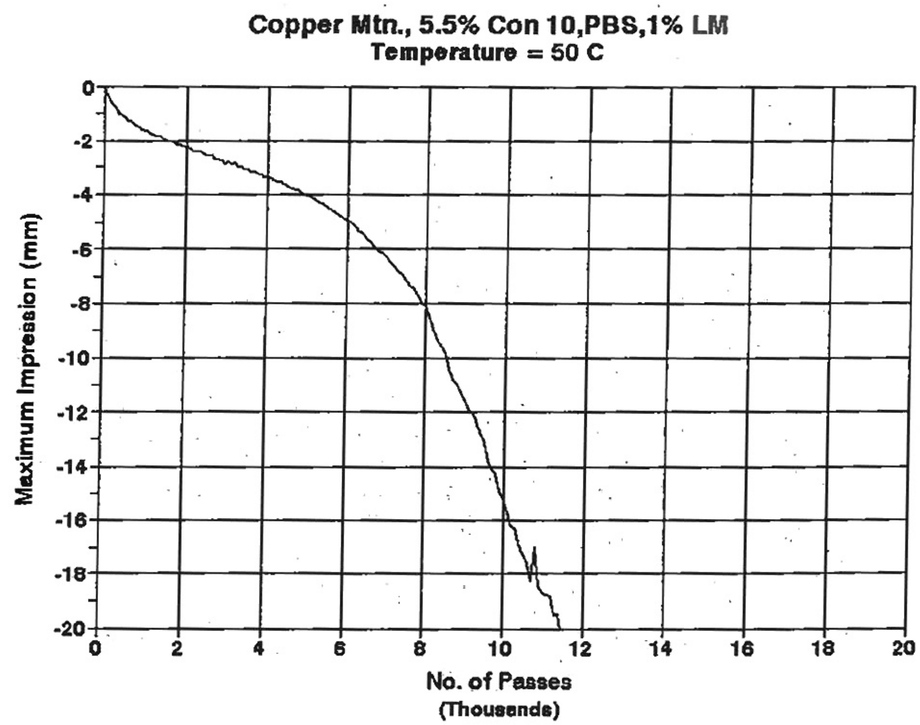
Copper Mtn, 6% Conoco, 1% Lime, PBS
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

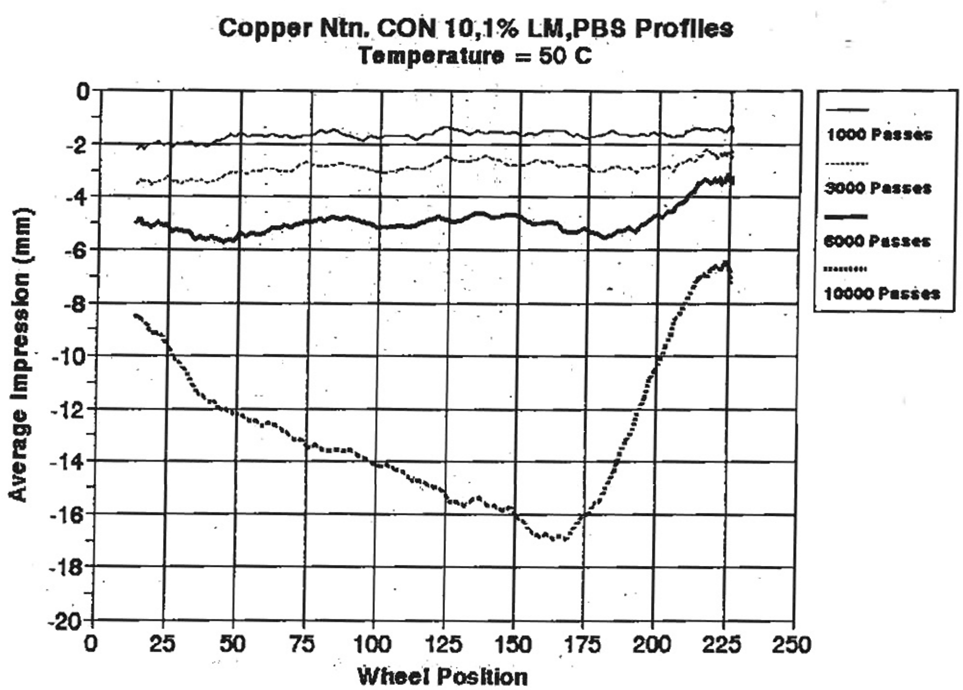


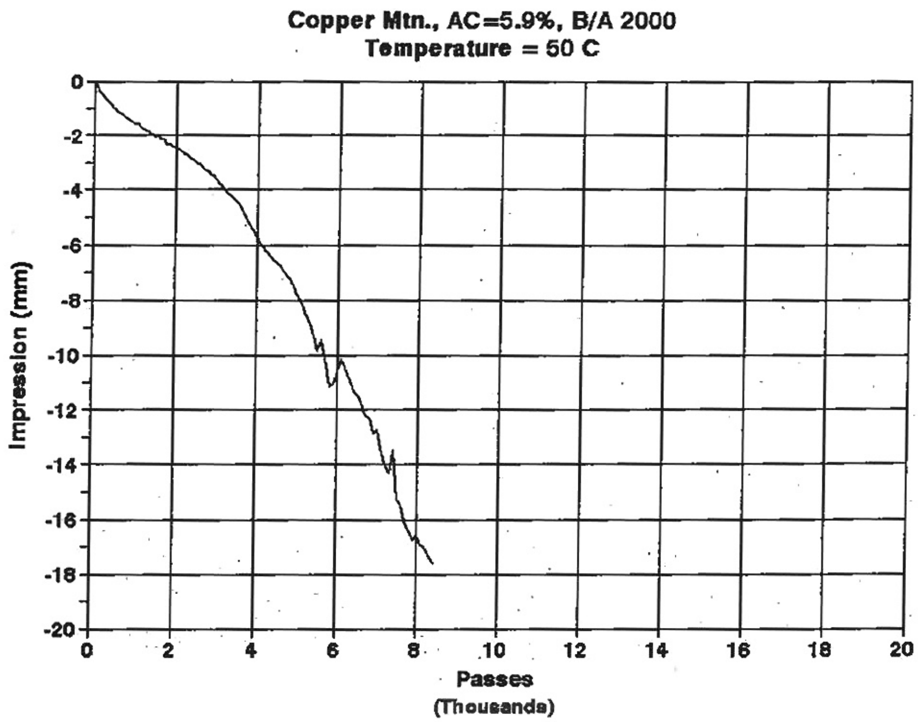
Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
6000 Passes
10000 Passes
12000 Passes

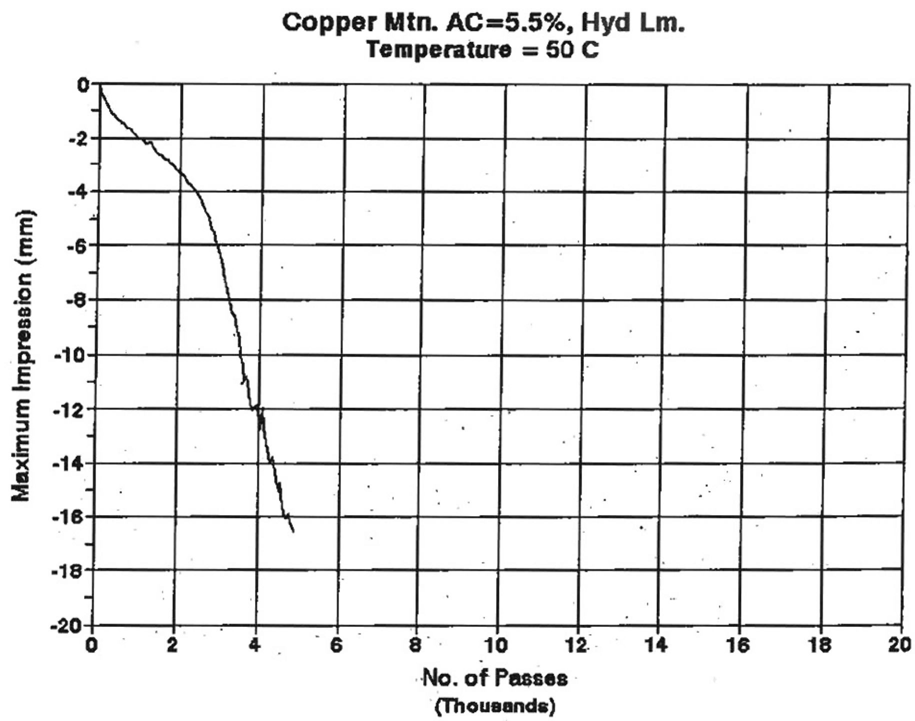

Copper Mountain, Shell RP6569
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

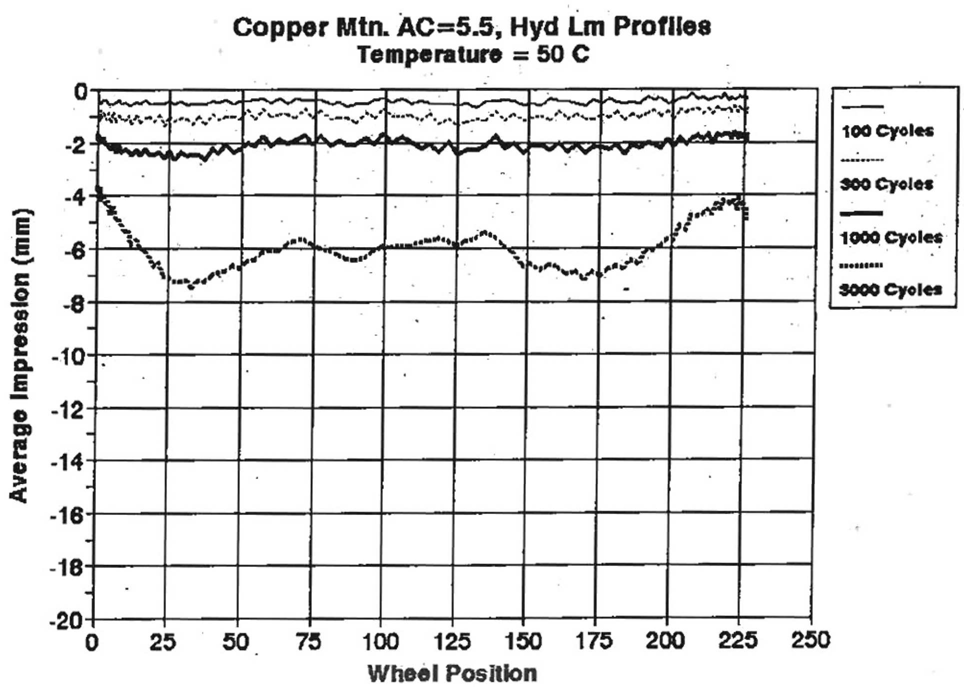

Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
15000 Passes
20000 Passes

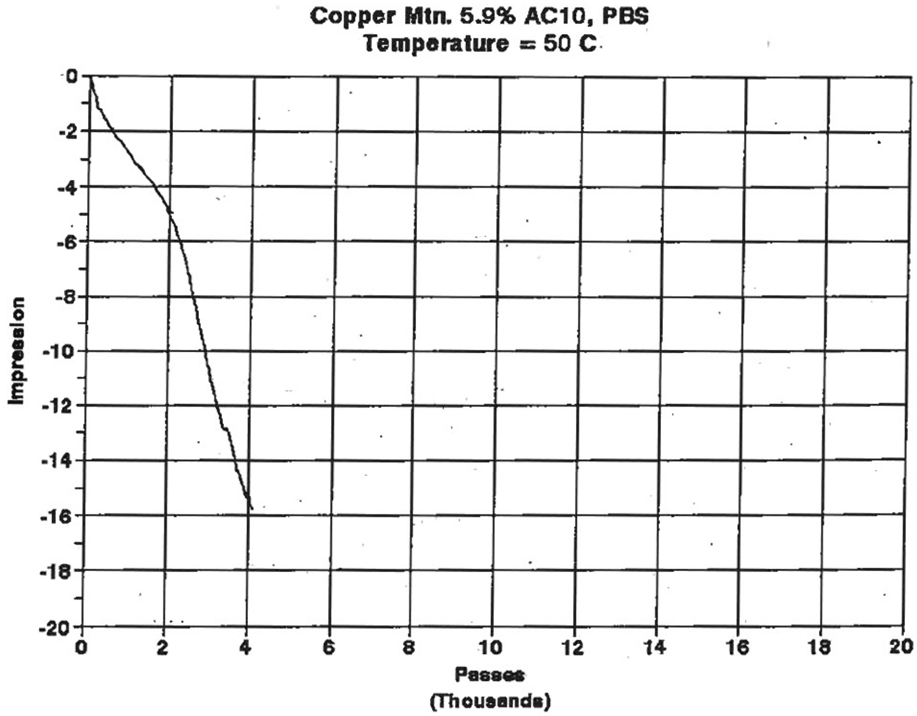

Copper Mtn., 5.5% Con 10,PBS,1% LM
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousends)


Copper Ntn. CON 10,1% LM,PBS Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
3000 Passes
6000 Passes
10000 Passes

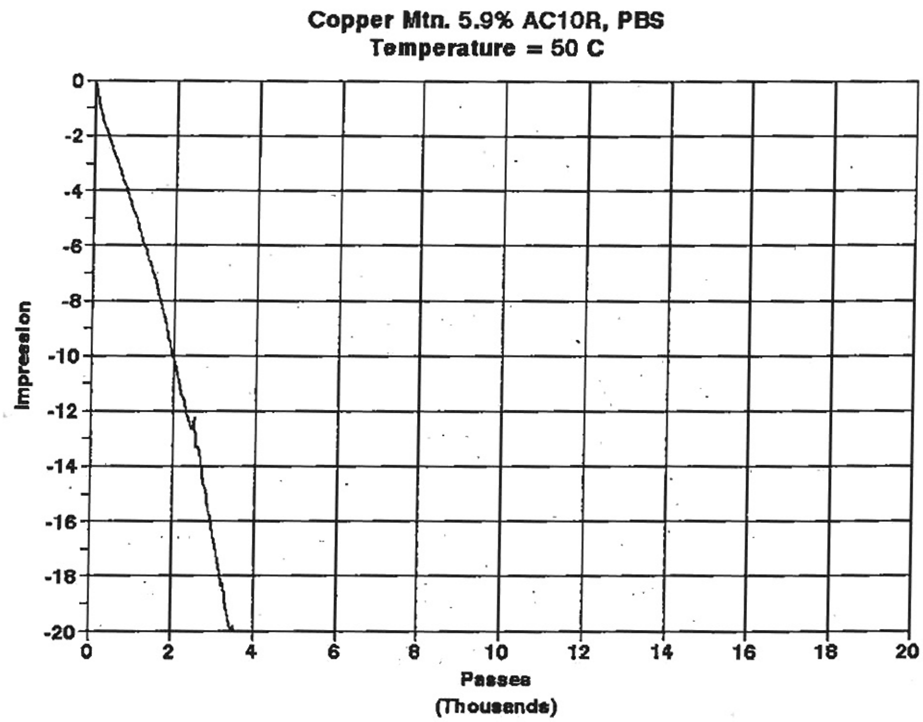

Copper Mtn., AC=5.9%, B/A 2000
Temperature = 50 C
Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
Passes
(Thousands)

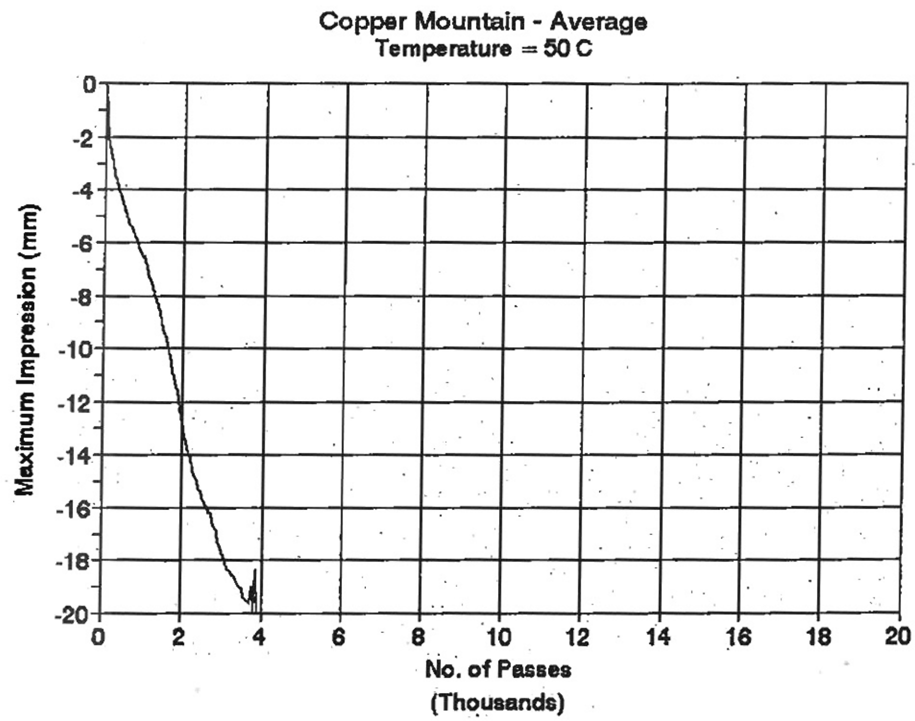

Copper Mtn. AC=5.5%, Hyd Lm.
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

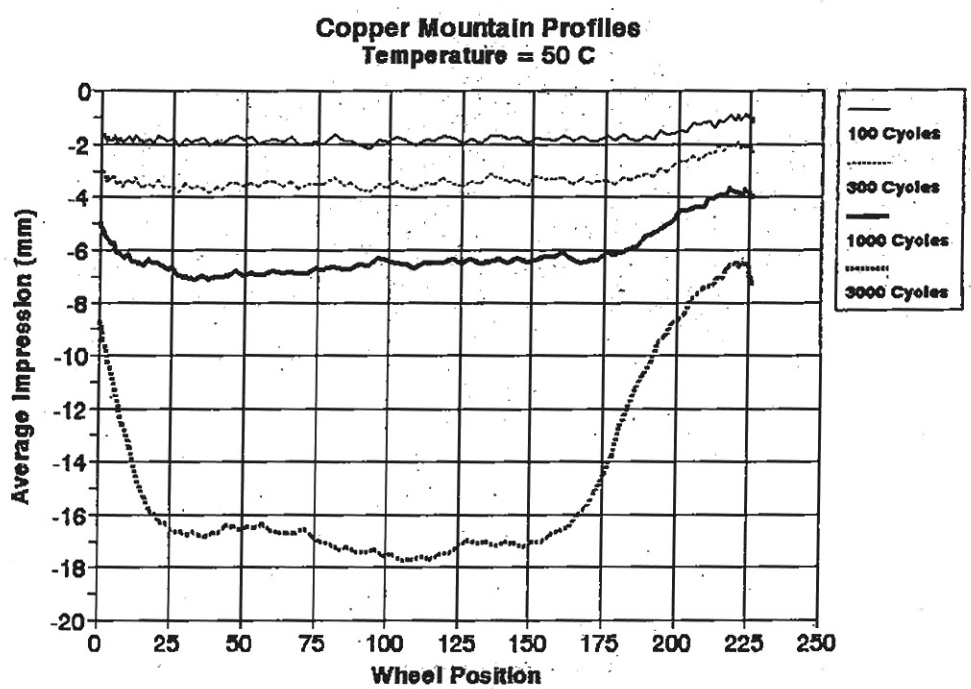

Copper Mtn. AC=5.5, Hyd Lm Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
100 Cycles
300 Cycles
1000 Cycles
3000 Cycles



Copper Mtn. 5.9% AC10, PBS
Temperature = 50 C
Impression
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
Passes
(Thousands)


Copper Mtn. 5.9% AC10R, PBS
Temperature = 50 C
Impression
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
Passes
(Thousands)


Copper Mountain - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Copper Mountain Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
100 Cycles
300 Cycles
1000 Cycles
3000 Cycles

Appendix C

Summary of SHRP Binder Test Results

Federal Highway Administration

Test & Evaluation Project No. 19

SUMMARY PAGE

Sample ID	OK AC-10 Conoco	Start Testing 09-10-93 Finish Testing 9-13-93
Performance Grade (PG)	PG ~~58~~-22 (52°K) 52-22	

Original Binder		
Flash Point Temp, AASHTO T 48 Min Temp 230°C, °C	°C > 230°C	
Viscosity, ASTM D 4402, Brookfield Max. 3 Pa-s (3000 cSt) Test Temp, °C	238.3 cSt < 3000 cSt	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 1.0 kPa Test Temp @ 10 rad/s, °C	~~1190~~ ~~2747~~ Pa > 1000 Pa ~~58~~ ~~52~~ °C	[OK]
Specific Gravity, AASHTO T 228	1.015	
Penetration, AASHTO T 49		
Viscosity, AASHTO T 201 Kinematic Absolute	0 cSt ? 0 cSt ?	
Rolling Thin Film Oven Residue (AASHTO T 240)		
Mass Loss, Max 1.00 percent	0.0 pecent < 1.0 pecent	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 2.2 kPa Test Temp @ 10 rad/s, °C	4943 Pa > 2200 Pa 52 °C	[OK]
Pressure Aging Vessel Residue (AASHTO PP1)		
Dynamic Shear, AASHTO TP5 G* x sin(delta), Max. 5000 kPa Test Temp @ 10 rad/s, °C	2873 kPa < 5000 kPa 19 °C	[OK]
Creep Stiffness, AASHTO TP1 S, Max, 300,000 kPa m - value, Min. 0.30 Test Temp @ 60 s, °C	136 kPa < 300,000 kPa 0.36 slope > 0.30 -12 °C	[OK] [OK]
Direct Tension, AASHTO TP3 Failure Strain, Min. 1.0% Test Temp @ 1.0mm/min, °C	pecent > 1.0 pecent °C	
Physical Hardening Index, h	0	

Federal Highway Administration

Test & Evaluation Project No. 19

SUMMARY PAGE

Sample ID	Colorado AC-10 Conoco	Start Testing 9/10/93 Finish Testing 9/13/93
Performance Grade (PG)	PG 58 -22	

Original Binder		
Flash Point Temp, AASHTO T 48 Min Temp 230°C, °C	°C > 230°C	
Viscosity, ASTM D 4402, Brookfield Max. 3 Pa-s (3000 cSt) Test Temp, °C	247.7 cSt < 3000 cSt	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 1.0 kPa Test Temp @ 10 rad/s, °C	1306 Pa > 1000 Pa 58 °C	[OK]
Specific Gravity, AASHTO T 228	1.035	
Penetration, AASHTO T 49		
Viscosity, AASHTO T 201 Kinematic Absolute	 0 cSt ? 0 cSt ?	
Rolling Thin Film Oven Residue (AASHTO T 240)		
Mass Loss, Max 1.00 percent	0.0 pecent < 1.0 pecent	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 2.2 kPa Test Temp @ 10 rad/s, °C	2917 Pa > 2200 Pa 58 °C	[OK]
Pressure Aging Vessel Residue (AASHTO PP1)		
Dynamic Shear, AASHTO TP5 G* x sin(delta), Max. 5000 kPa Test Temp @ 10 rad/s, °C	1235 kPa < 5000 kPa 22 °C	[OK]
Creep Stiffness, AASHTO TP1 S, Max, 300,000 kPa m - value, Min. 0.30 Test Temp @ 60 s, °C	 71 kPa < 300,000 kPa 0.33 slope > 0.30 -12 °C	 [OK] [OK]
Direct Tension, AASHTO TP3 Failure Strain, Min. 1.0% Test Temp @ 1.0mm/min, °C	 pecent > 1.0 pecent °C	
Physical Hardening Index, h	0	

Federal Highway Administration

Test & Evaluation Project No. 19

SUMMARY PAGE

Sample ID	Frontier AC -	Start Testing 09-10-93 Finish Testing 09-13-93

Performance Grade (PG)	PG 58 -22

Original Binder		
Flash Point Temp, AASHTO T 48 Min Temp 230°C, °C	°C > 230°C	
Viscosity, ASTM D 4402, Brookfield Max. 3 Pa-s (3000 cSt) Test Temp, °C	250.5 cSt < 3000 cSt	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 1.0 kPa Test Temp @ 10 rad/s, °C	1422 Pa > 1000 Pa 58 °C	[OK]
Specific Gravity, AASHTO T 228	1.028	
Penetration, AASHTO T 49		
Viscosity, AASHTO T 201 Kinematic Absolute	0 cSt ? 0 cSt ?	
Rolling Thin Film Oven Residue (AASHTO T 240)		
Mass Loss, Max 1.00 percent	0.0 pecent < 1.0 pecent	[OK]
Dynamic Shear, AASHTO TP5 G* / sin(delta), Min. 2.2 kPa Test Temp @ 10 rad/s, °C	5001 Pa > 2200 Pa 58 °C	[OK]
Pressure Aging Vessel Residue (AASHTO PP1)		
Dynamic Shear, AASHTO TP5 G* x sin(delta), Max. 5000 kPa Test Temp @ 10 rad/s, °C	1685 kPa < 5000 kPa 22 °C	[OK]
Creep Stiffness, AASHTO TP1 S, Max, 300,000 kPa m - value, Min. 0.30 Test Temp @ 60 s, °C	81 kPa < 300,000 kPa 0.31 slope > 0.30 -12 °C	[OK] [OK]
Direct Tension, AASHTO TP3 Failure Strain, Min. 1.0% Test Temp @ 1.0mm/min, °C	pecent > 1.0 pecent °C	
Physical Hardening Index, h	0	

SAMPLE #		S34385	S34384
Material		AC-10P	AC-10R
		Type I-B	
Ductility 4C	D113	40	73.2
ER 25C SS 10cm	D113 Mod	71.7	75
Force Ductility pk ratio	P226	0.38	0.53
ratio at 30 cm	P226	0.36	0.38
Area under curve	P226	8.8	8.9
Elongation at break	P226	80.1	100+
Pen 4C	D5	35	44
Pen 25C	D5	91	141
Softening Point	D36	128.8	118.6
2day Separation	TG 31	0.9	1.3
Toughness	Benson	89	90
Tenacity	Benson	59	80
Absolute Vis	D2171	3910	1120
Kinematic Vis	D2170	420	713
RTFO tests:	D2872		
RTFO Pen 25°C	D2872	56	74
RTFO Pen 4°C	D2872	30	34
RTFO Retained Pen (25°C)	D2872	61.5%	52.5%
Physical Hardening °C		-24	-24
h=(S24/S1)m1/m24		1.49	1.59
Temp @ DMA G*/sin delta=1.0kPa @10rad/s, °C		69.6	62.6
Temp @ RTFO Residue DMA G*/sin delta=2.2kPa @10rad/s, °C		69.3	61.5
Temp @ PAV residue DMA G* X sin delta=5000kPa @10rad/s, °C		10.8	13.4
Temp @ PAV residue BBR Creep Stiffness=300,000kPa @60s, °C		-25.6	-25.2
Temp @ PAV residue BBR m=0.30 @60s, °C		-21.2	-19.1
SHRP Temp @ PAV residue failure strain @1.0mm/min=1.0%, °C			
Serviceable Temperature Range, °C		100.5	90.6
This material passes PG grades:		52-10, -16, -22, -28 58-16, -22, -28 64-16, -22, -28	52-10, -16, -22, -28 58-16, -22, -28