Evaluation of Hamburg Wheel-Tracking Device to Predict Moisture Damage in Hot-Mix Asphalt

TIM ASCHENBRENER

The Colorado Department of Transportation (CDOT) and FHWA's Turner-Fairbank Highway Research Center were selected to demonstrate several pieces of European equipment. The Hamburg wheel-tracking device was one of those pieces of equipment. It is used to predict moisture damage of hot-mix asphalt (HMA). This paper provides an evaluation of factors that influence the results from the Hamburg wheel-tracking device. There was excellent correlation between the Hamburg wheel-tracking device and pavements of known field performance. The Hamburg wheel-tracking device was found to be sensitive to (a) quality of aggregates, (b) asphalt cement stiffness, (c) length of short-term aging, (d) refining process or crude oil source of the asphalt cement, (e) liquid and hydrated lime antistripping treatments, and (f) compaction temperature. The Hamburg wheel-tracking device was demonstrated on two CDOT projects to improve the quality of HMA.

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

The purpose of this paper is to provide an evaluation of factors that influence the results from the Hamburg wheel-tracking device.

HAMBURG WHEEL-TRACKING DEVICE

Equipment and Procedure

The Hamburg wheel-tracking device is manufactured by Helmut-Wind, Inc. of Hamburg, Germany, as shown in Figure 1; a close-up is shown in Figure 2. A pair of samples are tested simultaneously. A sample is typically 260 mm (10.2 in.) wide, 320 mm (12.6 in.) long, and 40 mm (1.6 in.) thick. Its mass is approximately 7.5 kg (16.5 lb), and the sample is compacted to 7 ± 1 percent air voids. The samples are submerged in water at 50°C (122°F), although the temperature can vary from 25°C to 70°C (77°F to 158°F). A steel wheel 47 mm (1.85 inches) wide loads the samples with 705 N (158 lb). The wheel makes 50 passes over each sample per minute. The maximum velocity of the wheel is 34 cm/sec (1.1 ft/sec) in the center of the sample. Each sample is loaded for 20,000 passes or until 20 mm of deformation occurs. Approximately 6½ hr is required for a test.

Test Results and Specifications

The results from the Hamburg wheel-tracking device include the creep slope, stripping slope, and stripping inflection point as shown in Figure 3. The results have been defined by Hines (*2*). The creep slope relates to rutting from plastic flow. It is the inverse of the rate of deformation in the linear region of the deformation curve after postcompaction effects have ended and before the onset of stripping. The stripping slope is the inverse of the rate of deformation in the linear region of the deformation curve after stripping begins and until the end of the test. It is the number of passes for each 1 mm of impression from stripping. The stripping slope is related to the severity of moisture damage. The stripping inflection point is the number of passes at the intersection of the creep slope and the stripping slope. It is related to the resistance of the HMA to moisture damage.

The city of Hamburg specifies a rut depth of less than 4 mm after 20,000 passes. A previous study (*3*) has found this specification to be very severe for pavements in Colorado. A rut depth of less than 10 mm after 20,000 passes may be more reasonable.

COMPARISON WITH PAVEMENTS OF KNOWN FIELD PERFORMANCE

Pavements of known stripping performance were tested in the Hamburg wheel-tracking device (*3*). Seven good pavements (Sites 1 to 7), five pavements requiring high maintenance (Sites 8 to 12), and eight pavements that lasted less than 1 year (Sites 13 to 20) were tested. The high-maintenance pavements are still in service after 3 to 5 years but required excessive maintenance. The pavements that lasted less than 1 year were divided into two groups.

1. Pavements that were built in layers of different materials (Sites 13 to 16) and had a unique pavement design feature, a rut-resistant composite that utilized a plant-mixed seal coat.
2. Pavements built using conventional material design practices that were not covered or "sealed" (Sites 17 to 20).

The pavements of known stripping performance were tested in the Hamburg wheel-tracking device at the 50°C test temperature. The

---

Colorado Department of Transportation, 4340 East Louisiana, Denver, Colo. 80222.

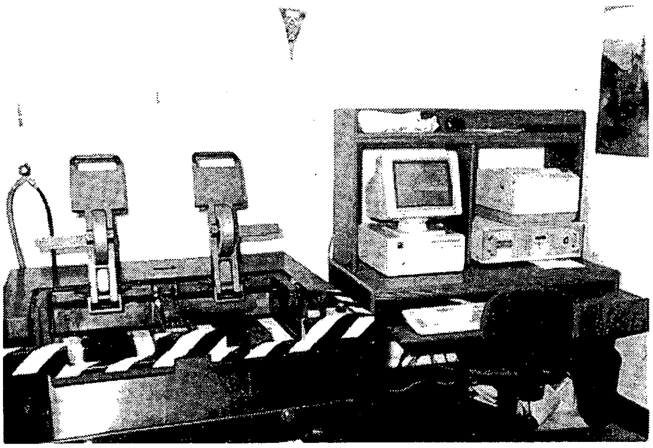

FIGURE 1 Hamburg wheel-tracking device.

stripping inflection point results are shown in Table 1. There was excellent correlation between the stripping inflection point and the known stripping performance. The good pavements (Sites 1 to 7) had stripping inflection points generally greater than 10,000 passes. The high-maintenance pavements (Sites 8 to 12) had stripping inflection points generally between 5,000 and 10,000 passes. The pavements that lasted less than 1 year (Sites 13 to 20) had stripping inflection points less than 3,000 passes. The Hamburg wheel-tracking device has the potential to discriminate between pavements of varying field stripping performance.

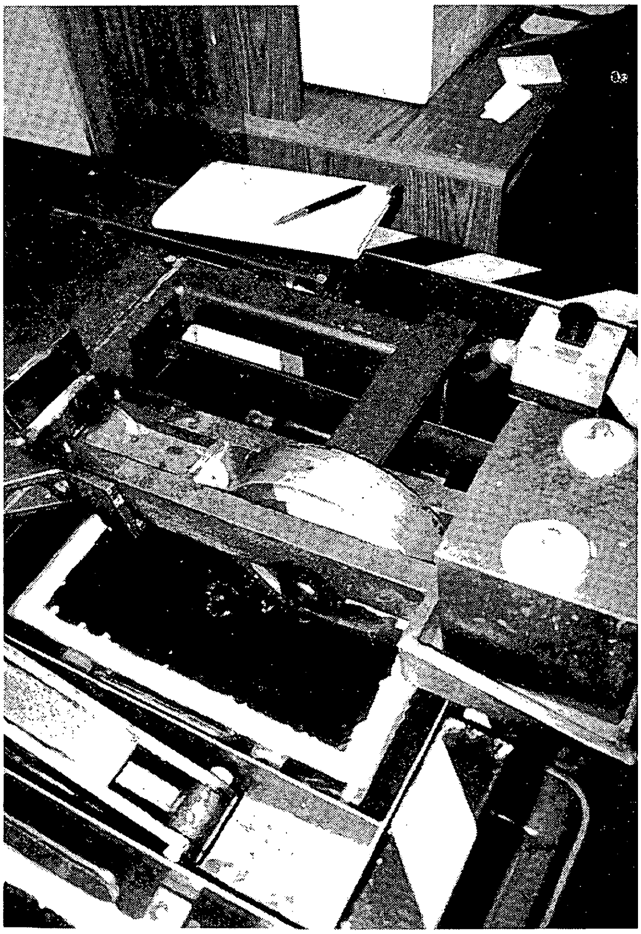

FIGURE 2 Close-up of Hamburg wheel-tracking device.

INFLUENCE OF MATERIAL PROPERTIES

Aggregate Properties

HMA from pavements of known field performance were tested, and in virtually all cases, aggregate problems were identified (*3*). Aggregate problems identified included

1. The presence of clay as identified by the methylene blue test,
2. Very high dust-to-asphalt ratios, and
3. Excessive dust coating on the aggregate.

A summary of results from these aggregate tests is shown in Table 1. Aggregate results that are considered unacceptable or marginal are enclosed in parentheses.

The methylene blue test is used to identify the quality of the material passing the 75-µm (No. 200) sieve. The test identifies deleterious clay or material with high surface activity. Test results greater than 10 mg/g are marginal and greater than 20 mg/g are unacceptable. Virtually all of the bad pavements (Sites 13 to 17, and 19 and 20) had unacceptable methylene blue values. Some of the good pavements (Sites 6 and 7) and high-maintenance pavements (Sites 8 and 9) were marginal.

The maximum dust-to-asphalt cement ratio can be defined by the quantity of 75-µm material that increases the ring-and-ball softening point (AASHTO T 53) at 11°C (*4*). All 13 of the stripping pavements except 3 (Sites 9, 13, and 17) had dust-to-asphalt cement ratios in excess of the maximum. Four of the seven good pavements (Sites 3, 4, 6, and 7) had dust-to-asphalt cement ratios less than the maximum.

The amount of dust coating the coarse aggregate was identified by dry sieving the blended aggregate over the 4.75-mm (No. 4) sieve size and then washing the material over the 4.75-mm (No. 4) sieve size. The difference in weight before and after washing was defined as the dust coating. Two pavements (Sites 17 and 18) had dust coatings of 3 percent or more.

A combination of these results is shown in Table 2. Materials that failed two of the three tests were unlikely to have good performance in the field and in the Hamburg wheel-tracking device. Materials that passed all three tests had good performance in the field and in the Hamburg wheel-tracking device.

Based on pavements of known performance, results from the Hamburg wheel-tracking device appear sensitive to aggregate properties that include: clay content, high dust-to-asphalt ratios, and dust coating on the aggregates.

Asphalt Cement Properties

Asphalt Cement Stiffness

We wanted to test asphalt cements with a variety of high-temperature properties to investigate the change in asphalt cement stiffness based on results from the Hamburg wheel-tracking device (*5*). The gradings of asphalt cement tested were three neat asphalt

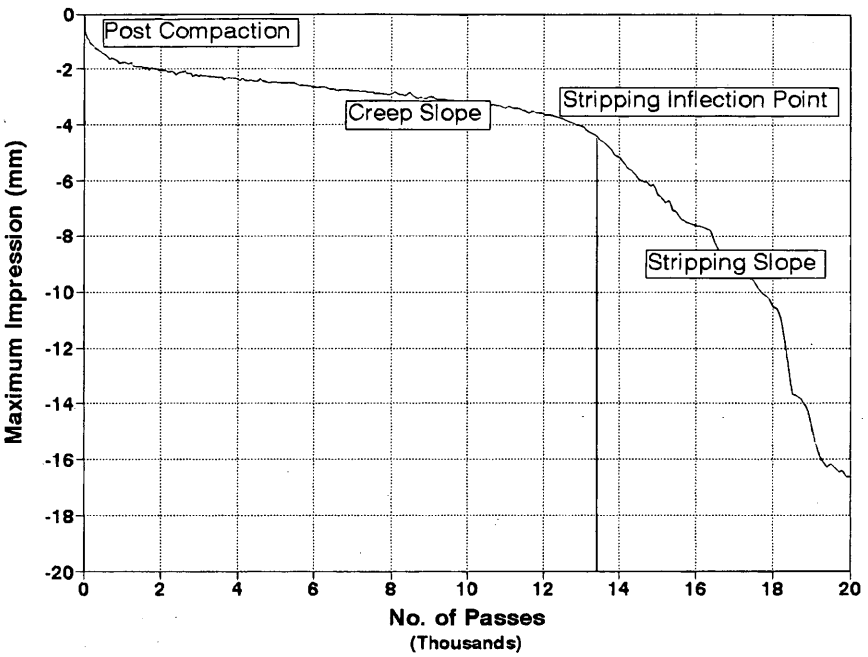

FIGURE 3 Definition of results from Hamburg wheel-tracking device.

TABLE 1 Summary of Test Results on Sites of Known Stripping Performance

Site	Methylene Blue (mg/g)	Dust:Asphalt Ratio Max.	Dust:Asphalt Ratio Actual	Dust Coating (%)	Stripping Inflection Point (Passes)
1	6.8	1.17	(2.01)	0.3	>20,000
2	9.5	1.18	(1.40)	0.6	>20,000
3	2.5	1.17	1.05	0.2	>20,000
4	6.4	1.34	0.99	0.2	14,200
5	5.0	1.21	(1.35)	0.4	14,500
6	(12.6)	1.48	0.92	0.3	(3,500)
7	(11.9)	1.29	0.78	0.1	>20,000
8	(13.0)	1.14	(1.67)	NT	(9,600)
9	(10.6)	1.21	0.97	0.7	(1,500)
10	8.7	1.32	(1.63)	0.2	(6,200)
11	4.3	1.24	(1.69)	0.7	>20,000
12	8.3	1.35	(1.60)	0.2	(4,600)
13	(>20)	1.19	0.94	0.5	(2,300)
14	(>20)	1.23	(1.38)	1.9	(1,500)
15	(>20)	1.20	(1.26)	NT	NT
16	(14.2)	1.29	(1.45)	0.3	(1)
17	(>20)	1.24	1.23	(3.8)	(1)
18	6.6	1.08	(1.21)	(2.8)	(2,200)
19	(>20)	0.96	(2.01)	NT	(1)
20	(>20)	1.10	(1.21)	0.5	(1)

() - Indicates Unacceptable Test Result
NT - Not Tested

TABLE 2 Ability of Tests on 75-μm Material To Predict Stripping Performance

Methylene Blue Dust:Asphalt Ratio Dust Coating	Sites of Known Performance		
	Good	High Maintenance	Less Than 1 Year
Pass All 3	2	0	0
Fail 1 of 3	5	4	1
Fail 2 of 3	0	1	7
Fail All 3	0	0	0

cements, AC-5, AC-10, and AC-20 meeting AASHTO M 226 (Table 2), and one polymer-modified asphalt cement, AC-20P, meeting AASHTO Task Force 31, Type I-D. The properties of the asphalt cements are shown in Table 3. The high-temperature performance grade (PG) of each asphalt cement as classified by SHRP is included.

Four different aggregates were mixed with each grade of asphalt cement and tested over a wide range of temperatures in the Hamburg wheel-tracking device. Table 4 shows the test temperatures required to obtain a constant stripping inflection point for each mix as the grade of asphalt cement is changed. For example, using Mix 2, an AC-5 tested at 43°C had the same stripping inflection point as an AC-20 tested at 52°C.

When one testing temperature was used and the asphalt cement stiffness was increased, the stripping inflection point occurred at a larger number of passes. When one grade of asphalt cement was used and the testing temperature was decreased, the stripping inflection point occurred at a larger number of passes. Improved moisture resistance as asphalt cement stiffness increased was expected.

In the mountainous parts of the state, softer asphalt cements are used. In the desert parts of the state, stiffer asphalt cements are used. The Hamburg wheel-tracking device should not penalize softer asphalt cements that are used in the colder parts of the state. In order to obtain the same stripping inflection point for one aggregate as the asphalt cement stiffness decreases because of environmental conditions, the test temperature should decrease.

Generally, each time the asphalt cement increases one grade in stiffness, the test temperature should increase approximately 6°C to result in the same stripping inflection point.

It was extremely interesting to compare the temperature differential required to obtain equal stripping inflection points shown in Table 4 with the temperature differential required to obtain 1 kPa stiffness from the Dynamic Shear Rheometer (DSR) shown in Table 3. The differences in high-temperature properties of each asphalt cement measured by the Hamburg wheel-tracking device were almost identical to the differences measured by the DSR.

TABLE 3 Unaged Asphalt Cement Properties

	Viscosity (60°C) (Poises)	Penetration (25°C) (dmm)	Ring & Ball Softening (°C)	DSR @ 1 kPa (°C)	High Temp. PG
AC-5	520	155	45.0	56.2	52
AC-10	1030	99	47.7	61.6	58
AC-20	1980	67	52.8	67.5	64
AC-20P	10280	74	62.2	77.4	70

TABLE 4 Test Temperatures Providing Equal Stripping Inflection Points for Various Asphalt Cement Grades

	Temperature (°C)				
	Mix 1	Mix 2	Mix 3	Mix 4	Avg.
AC-5	42	43	NP	39	41
AC-10	46	49	NP	48	48
AC-20	52	52	NP	52	52
AC-20P	NP	64	NP	58	61

NP - Not Possible to Determine
(Sample Did Not Fail or Failed Very Quickly)

TABLE 5 Recommended Testing Temperatures for Hamburg Wheel-Tracking Device

High Temperature Performance Grade (PG) °C	Viscosity Grade Meeting the High Temperature PG	Recommended Test Temperature for the Hamburg Device
46		35°C
52	AC-5	40°C
58	AC-10	45°C
64	AC-20	50°C
70*	AC-20P	55°C

* - No pavements in Colorado are at this temperature. A binder with this grade may be appropriate for locations with very heavy and slow moving traffic.

The recommended testing temperatures for the Hamburg wheel-tracking device should be selected based on the high-temperature environment the pavement will experience, as shown in Table 5. These testing temperatures should provide equal stripping inflection points for a mix as the asphalt cement grade is changed. Consideration should be given to using test temperatures 5°C lower. These temperatures would likely correspond with the city of Hamburg procedure, in which high-temperature performance asphalt cement grades of 64 or 70 and a 50°C test temperature are used.

Short-Term Aging

A study was performed to investigate the influence of short-term aging on the results from the Hamburg wheel-tracking device (*5*). The results are shown in Table 6. As short-term aging time increases, samples become more resistant to moisture damage. If allowed to short-term age for 8 hr, all of the mixtures resist moisture damage.

The increase in resistance to moisture damage as short-term aging increases is expected. This could be caused by (a) a stiffening of the asphalt cement with increased aging, (b) the development of better adhesion between the aggregate and asphalt cement with aging, or (c) a combination of the two.

Refining Process and Crude Oil Source

A study was performed to determine if the refining process or crude oil source could influence the results from the Hamburg wheel-tracking device (*6*). Four refineries provide most of the asphalt cement used by CDOT. Each refinery produced one to three different types of AC-10 or PG 58-22 grading asphalt cement. The asphalt cement properties are shown in Table 7.

The test results from the Hamburg wheel-tracking device are shown in Table 8. Each refinery was able to produce an asphalt cement that was compatible with the better aggregates (Mixes 1 and 2). Most of the asphalt cements failed in the Hamburg wheel-tracking device with the poorer aggregates (Mixes 3 and 4). Although two of the asphalt cements worked with the poorer aggregates (A1 and C2), an asphalt cement cannot be expected to overcome aggregate deficiencies.

Test results in the Hamburg wheel-tracking device are sensitive to aggregate quality. When a mix fails, the aggregate quality should be investigated. When the aggregate quality is acceptable, the refin-

TABLE 6 Deformation (mm) After 20,000 Passes Versus Short-Term Aging Period

	Deformation (mm) After 20,000 Passes			
	Short-Term Aging Period (Hours)			
Mix	0	2	4	8
1	(>20.0)	6.1	8.6	1.7
2	(>20.0)	3.3	(11.0)	1.5
3	(>20.0)	(11.8)	(13.8)	2.3
4	(>20.0)	3.5	5.5	3.1

() - Indicates Unacceptable Test Result

TABLE 7 Asphalt Cement Test Results from Various Refineries and Crude Oil Sources

Refinery	Pen. (25°C) dmm	Vis. (60°C) Poises	DSR (Tank) °C @ 1 kPa	DSR (TFOT) °C @ 2.2 kPa	Performance Grade (PG)
A1	92	1300	58.0	64.1	58-22
A2	110	940	61.7	62.1	58-22
A3	100	1060	62.4	62.7	58-22
B1	105	1030	62.1	62.3	58-22
B2	128	820	60.2	59.8	58-22
B3	103	1060	62.5	62.7	58-22
C1	100	1010	61.8	62.6	58-22
C2	90	1000	62.4	61.2	58-22
D1	87	1100	62.3	60.7	58-22
Vn	129	1040	61.7	62.1	58-22

TABLE 8 Deformation (mm) After 20,000 Passes from Various Refineries and Crude Oil Sources

	Deformation (mm) After 20,000 Passes			
Refinery	Mix 1	Mix 2	Mix 3	Mix 4
A1	9.2	7.6	(17.9)	4.2
A2	8.5	6.9	(>20.0)	(15.9)
A3	7.9	(14.8)	(12.1)	(17.6)
B1	7.2	9.2	(15.1)	(15.6)
B2	(14.8)	(>20.0)	(>20.0)	(>20.0)
B3	(14.3)	(16.7)	(16.6)	(17.4)
C1	8.4	4.0	(14.6)	(>20.0)
C2	4.4	(12.7)	5.2	5.9
D1	(>20.0)	7.3	(>20.0)	(>20.0)
Vn	(11.5)	(10.5)	(>20.0)	(>20.0)

() - Indicates Unacceptable Test Result

ing process and crude oil source should be investigated. Not all AC-10 or PG 58-22 grading asphalt cements have the same adhesion properties.

ANTISTRIPPING TREATMENT

Various Types of Antistripping Treatment

A study was performed to investigate the influence of the use of various types of antistripping additives with the Hamburg wheel-tracking device (*7*). Mixes were tested with no treatment, four different types of liquid antistripping additives, and hydrated lime.

The results are shown in Table 9. When the mixes had no treatment, the results from the Hamburg wheel-tracking device were unacceptable for Mixes 1, 2, and 3. The use of hydrated lime improved the test results dramatically for all of the mixes. Passing test results were always obtained. Mixes treated with liquid antistripping additives performed better than those with no treatment with one exception. Passing test results were obtained for some of the mixes treated with liquid antistripping additives but not with others. Mixes treated with liquid antistripping additives did not perform as well as those treated with lime but still improved the HMA.

Method of Lime Addition

A study was performed to investigate if the method of lime addition influenced the results from the Hamburg wheel-tracking device (*5*). The amount of water used for mixing and the results are summarized in Table 10.

When lime was not present, all of the mixes did poorly. When dry lime was added to dry aggregate and thoroughly mixed, there was a dramatic improvement in the results. Just the presence of lime

TABLE 9 Deformation (mm) After 20,000 Passes for Various Antistripping Treatments

	Deformation After 20,000 Passes					
			Additive A		Additive B	
Mix	No Treatment	Hydrated Lime	Type 1	Type 2	Type 1	Type 2
1	(17.0)	1.4	2.2	3.1	6.3	7.4
2	(>20.0)	2.3	8.1	8.4	5.3	(14.6)
3	(>20.0)	2.5	(13.7)	8.5	(>20.0)	(12.4)
4	8.7	2.3	6.2	4.6	5.0	4.3

() - Indicates Unacceptable Test Result

TABLE 10 Deformation (mm) After 20,000 Passes Versus Method of Lime Addition

	Deformation (mm) After 20,000 Passes				
	Method of Lime Addition				
Mix	No Lime No Water No Mellow	1% Lime No Water No Mellow	1% Lime 2% Water No Mellow	1% Lime 4% Water No Mellow	1% Lime 4% Water 3-Day Mellow
1	(>20.0)	1.5	5.9	4.6	5.7
2	(>20.0)	5.1	(13.0)	9.1	2.5
3	(>20.0)	4.5	(11.2)	5.0	4.6
4	(>20.0)	5.1	4.1	3.1	5.6

() - Indicates Unacceptable Test Result

helped significantly, regardless of moisture. The improvement did not continue as water was added. We still recommend using water when adding lime to facilitate the mixing.

COMPACTION METHODS

Field Versus Laboratory Compaction

Seven projects were selected for comparison of test results between field- and laboratory-compacted samples (*8*). Samples of loose mix were taken behind the paver and compacted in the laboratory to the same density as in the field project. The laboratory samples were compacted with the French plate compactor (pneumatic tire) and linear kneading compactor (steel wheel). Field-compacted samples were sawn from the pavement.

The comparison of test results from the Hamburg wheel-tracking device is shown in Table 11. Samples compacted with the linear kneading compactor gave slightly better results than samples compacted with the French plate compactor. In general, the samples compacted by two different methods in the laboratory performed similarly.

The field-compacted samples performed significantly worse than the laboratory-compacted samples. This might have been caused by either the additional short-term aging received by the laboratory-compacted samples or the difference in field and laboratory compaction temperatures.

The loose mix used to perform laboratory compaction had to be reheated to achieve compaction temperature. The additional heating increased the short-term aging. Additionally, the loose mix compacted in the laboratory achieved density at a much higher temperature than the field-compacted samples.

Compaction Temperature

A study was performed to investigate the influence of compaction temperature on results from the Hamburg wheel-tracking device (*7*). Samples of loose HMA were compacted in the laboratory at four different temperatures. All samples were compacted to the same percent of air voids. The results are shown in Table 12. When compaction was achieved at higher temperatures, the test results improved.

The unacceptable results at low temperatures can be explained by the following reasons: (a) aggregates break, (b) microcracks develop in the HMA, or (c) the air voids might be interconnected and not be small and dispersed. Any of these reasons or combination of reasons might explain the importance of achieving the

TABLE 11 Differences in Stripping Inflection Point (Passes) for Field- and Laboratory-Compacted Samples

Site	French vs. Kneading	French vs. Field	Kneading vs. Field
1	-2,300	3,600	5,900
2	-1,900	4,400	6,300
3	0	5,400	5,400
4	-2,600	2,600	5,200
5	0	1,500	1,500
6	0	0	0
7	0	6,800	6,800
Avg.	-970	3,470	4,440

Negative numbers indicate a stripping inflection point was higher in the second sample of the comparison.

required compaction in the field at the highest possible temperature. Short-term aging might also be a factor.

DEMONSTRATION PROJECTS

I-70 at Silverthorne

A very large project was undertaken in the fall of 1992 and summer of 1993. After a severe winter in 1992, the pavement exhibited signs of moisture damage. The Hamburg wheel-tracking device was used to improve the quality of the HMA placed in 1993 (*9*). The cost of the improvements was approximately $1.00/ton of HMA.

Two improvements were made. First, the asphalt content was increased from 5.3 percent to 5.7 percent to provide better durability. The increased asphalt content did not create rutting from permanent deformation in the Hamburg wheel-tracking device. Second, the crude oil source used for the project was changed. With a combination of these two changes, the results from the Hamburg wheel-tracking device improved dramatically. All of the aggregates were tested and found to have excellent quality; no aggregate changes were made.

I-25 at Longmont

This project was bid using the test results from the Hamburg wheel-tracking device as an incentive payment. If the HMA produced from the plant passed the Hamburg wheel-tracking test, an incentive of $1.50/ton of HMA would be awarded to the contractor. There were no provisions for disincentives for failing tests.

The contractor who was awarded the project typically used a natural sand that was not plastic but had an unacceptable methylene blue value. The contractor's typical mix did not pass the Hamburg wheel-tracking device specification. For this project, the contractor bid included an HMA that used a washed concrete sand in place of the "dirty" natural sand.

The first two samples represented 10,000 tons and passed the 10-mm specification. The contractor was awarded a bonus on this material. The final three samples failed miserably. Unfortunately, the quality control was very poor, and the contractor was shut down over 10 times and required to take corrective actions. Although the material had the potential to pass the test, a lack of a consistent and successful quality control was probably the cause of the failing tests.

TABLE 12 Deformation (mm) After 20,000 Passes for Samples Compacted at Various Temperatures

	Deformation (mm) After 20,000 Passes			
	Compaction Temperature (°C)			
Mix	66	93	121	149
1	(>20.0)	7.9	7.0	1.4
2	(>20.0)	(13.9)	(11.4)	2.3
3	(>20.0)	(>20.0)	9.2	2.5
4	(>20.0)	8.6	10.0	2.3

() - Indicates Unacceptable Test Result

CONCLUSIONS

1. The Hamburg wheel-tracking device has the potential to discriminate between pavements with known field stripping performance and several levels of severity of moisture distress.

2. Results from the Hamburg wheel-tracking device are sensitive to aggregate properties that include clay content, high dust-to-asphalt ratios, and dust coating on the aggregates. The aggregate quality is important to obtain passing results.

3. When using one testing temperature and increasing the asphalt cement stiffness, the stripping inflection point occurred at a larger number of passes. When using one grade of asphalt cement and decreasing the testing temperature, the stripping inflection point occurred at a larger number of passes. Moisture resistance improved as asphalt cement stiffness increased.

The recommended testing temperatures for the Hamburg wheel-tracking device should be selected based on the high-temperature environment the pavement will experience as shown in Table 5.

4. Results from the Hamburg wheel-tracking device are sensitive to the amount of short-term aging. As short-term aging time increases, samples become more resistant to moisture damage.

5. The results from the Hamburg wheel-tracking device are sensitive to the refining process and crude oil source. Not all AC-10 or PG 58-22 grading asphalt cements have the same adhesion properties.

6. Liquid antistripping additives improved the results from the Hamburg wheel-tracking device with some aggregates but did not improve the results with other aggregates. Hydrated lime improved the test results with all of the mixes tested.

When dry lime was added to dry aggregate and thoroughly mixed, there was a dramatic improvement in the results from the Hamburg wheel-tracking device with all aggregates. Just the presence of lime helped significantly, regardless of moisture. We still recommend using water when adding lime to facilitate the field mixing. However, additional studies should be performed to examine dry mixing.

7. Samples compacted in the laboratory with the linear kneading compactor (steel wheel) gave slightly better results than samples compacted with the French plate compactor (pneumatic tire). In general, the laboratory-compacted samples performed similarly. The field-compacted samples did significantly worse than the laboratory-compacted samples.

8. When the target density was achieved at higher temperatures, the test results from the Hamburg wheel-tracking device improved.

9. Results from the Hamburg wheel-tracking device have been used successfully on two field projects. At Silverthorne, two adjustments were made to improve an existing HMA. At Longmont, an incentive payment was used to allow an improved quality of aggregate to be used in the HMA from the beginning of the project.

10. The short-term aging of laboratory-prepared samples to match the short-term aging in the field needs to be defined. A future research study should investigate short-term aging.

ACKNOWLEDGMENTS

This study was funded with Colorado State Planning and Research funds.

The author would like to express his gratitude to the many people who made this report possible. The testing was performed by Kim Gilbert, Benja Bemelen, Cindi Moya, Nava Far, Dave Price (CDOT-Staff Materials), and J.D. Stevenson and Richard Zamora (FHWA-Colorado Division). The trial projects were successful because of cooperation from Wes Goff, Art Wilcoxon, and CDOT-Construction.

The research study panel 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). The panel of Colorado experts included Bud Brakey (Brakey Consulting Engineers), Jim Fife (Western Colorado Testing), Joe Proctor (Morton International), Scott Shuler (CAPA), and Eric West (Western Mobile).

Significant insight and guidance were provided by Mickey Hines and Gayle King (Koch Materials Co.) throughout the study.

REFERENCES

1. *Report on the 1990 European Asphalt Study Tour.* AASHTO, Washington, D.C., 1991.
2. Hines, M. The Hamburg Wheel-Tracking Device. *Proceedings of the Twenty-Eighth Paving and Transportation Conference*, Civil Engineering Department, University of New Mexico, Albuquerque, New Mexico, 1991
3. Aschenbrener, T., R. L. Terrel, and R. A. Zamora. *Comparison of the Hamburg Wheel-Tracking Device and the Environmental Conditioning System to Pavements of Known Field Performance.* Colorado Department of Transportation, CDOT-DTD-R-94-1, 1994.
4. Kandhal, P. S. Evaluation of Baghouse Fines in Bituminous Paving Mixtures. Proc., *Association of Asphalt Paving Technologists*, Vol. 50, 1981, pp. 150–210.
5. Aschenbrener, T., and G. Currier. *Influence of Testing. Variables on the Results from the Hamburg Wheel-Tracking Device.* Colorado Department of Transportation, CDOT-DTD-R-93-22, 1993.
6. Aschenbrener, T. *Influence of Refining Processes and Crude Oil Sources on Results from the Hamburg Wheel-Tracking Device.* Colorado Department of Transportation, CDOT-DTD-R-94-7, 1994.
7. Aschenbrener, T., and N. Far. *Influence of Compaction Temperature and Anti-Stripping Treatment on Results from the Hamburg Wheel-Tracking Device.* Colorado Department of Transportation, CDOT-DTD-R-94-9, 1994.
8. Stevenson, J. D., and T. Aschenbrener. *Comparison of Test Results from Laboratory and Field Compacted Samples.* Colorado Department of Transportation, CDOT-DTD-R-94-3, 1994.
9. Aschenbrener, T. *I-70, Silverthorne to Copper Mountain: A Case History of the Use of European Testing Equipment.* Colorado Department of Transportation, CDOT-DTD-R-93-19, 1993.

Publication of this paper sponsored by Committee on General Asphalt Problems.