Effect of PG Binder Grade and Source on Performance of Superpave Mixtures under Hamburg Wheel Tester

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ABSTRACT

Rutting and stripping of hot-mix asphalt pavements continue to be major problems even after the Superpave mixture design has been implemented. In this study, the effects of Performance Grade (PG) binder and source on the Superpave mixtures used on a project on US-169 in Kansas have been studied with the Hamburg wheel tester. The objective of the study was to assess whether the PG binder grade (and its source) used on this project had any impact on the premature rutting observed. The effect of compaction of the Superpave mix before wheel testing was also investigated. The test results were statistically analyzed using the Analysis of Variance (ANOVA) technique. The PG 70-28 binder grade appeared to perform better than all other PG binders used in the study. The Superpave mixtures showed significant difference in performance in terms of the numbers of repetitions to reach maximum 20 mm rut depth and to show stripping when compared by the binder source. Mixture compacted with lower air voids performed much better than the mixtures compacted with only two percent higher air voids. This implies that better compaction is a prerequisite for better performance of the Superpave pavements.

Key words: binder— hot-mix asphalt —pavement—wheel testing

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INTRODUCTION

Two of the most common problems associated with hot-mix asphalt pavements are rutting and stripping. Rutting is the channelized depression on the wheel paths and results from accumulation of small amounts of unrecoverable strain due to repeated wheel loads. Stripping is the separation of the binder and aggregates in the presence of moisture**.** Both problems tend to occur during the early stages in the life of a pavement and trigger early undesirable maintenance actions. Thus asphalt mixtures should be designed so that they are rut resistant and are not susceptible to stripping. Many highway agencies have been using Loaded Wheel Testers (LWT's) for accelerated evaluation of the rutting and stripping potential of designed mixes (*1-6*). The absence of a mechanical test for the Superpave volumetric mixture has also made this type of LWT very attractive for evaluating potentially undesirable mixtures. The Hamburg wheel tester is one such device that can be used to predict the rutting and stripping potential of asphalt mixes.

In 1998, a newly placed Superpave pavement on US-169 in Neosho County, Kansas showed rutting immediately after construction. The pavement section consists of 200 mm of a 19 mm Superpave mixture with a PG 52-28 binder and 100 mm of a 19 mm Superpave mixture with a PG 58-28 binder in the base layer, and a 25 mm surface layer of a 9.5 mm Superpave mixture with a PG 64-28 binder. Due to unavailability of the binders from a single supplier, two different sources of binder were also used. It is presumed that higher PG binder grades would have prevented this premature rutting. In this study, performance of four different PG binder grades and two different sources in the 19 mm Superpave mixture, used on US-169, was evaluated in the Hamburg wheel tester.

HAMBURG WHEEL TESTER AND LINEAR KNEADING COMPACTOR

The Hamburg wheel-tracking device used in this study was manufactured by PMW, Inc. based out of Salina, Kansas, and is capable of testing a pair of samples simultaneously. Figure 1 shows the Hamburg wheel tester at Kansas State University. The sample tested is usually 260 mm wide, 320 mm long, and 40 mm deep. This slab sample has an approximate mass of 7.6 kg and is compacted to 7 ± 1 % air voids. The samples are submerged under water at 45°C. The wheel of the tester is made of steel and is 4.7 cm wide. The wheel applies a load of 705N and makes 52 passes per minute. Each sample is loaded for 20,000 passes or until 20 mm deformation occurs. The maximum velocity of the wheel reached is 340 mm/sec, which is at the center of the sample.

FIGURE 1. Hamburg Wheel Tester

Around 6 to 6 ½ hours are required for a test for maximum of 20,000 passes. Rut depth or deformation is measured at 11 different points along the length of each sample with a Linear Variable Differential Transformer (LVDT).

The various results that are obtained from the Hamburg Wheel Tester are creep slope, stripping slope and the stripping inflection point as illustrated in Figure 2 (*7*). The creep slope relates to rutting from plastic flow and is the inverse of the rate of deformation in the linear region of the deformation curve, after post compaction effects have been 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 required to create one mm impression from stripping, and 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 and is related to the resistance of the HMA to moisture damage. An acceptable mix is specified by the City of Hamburg to have less than 4 mm rut depth after 20,000 passes at a 50°C test temperature (*7*). However, this criterion was found to be very harsh in subsequent studies of the Colorado Department of Transportation (*7*,*8*).

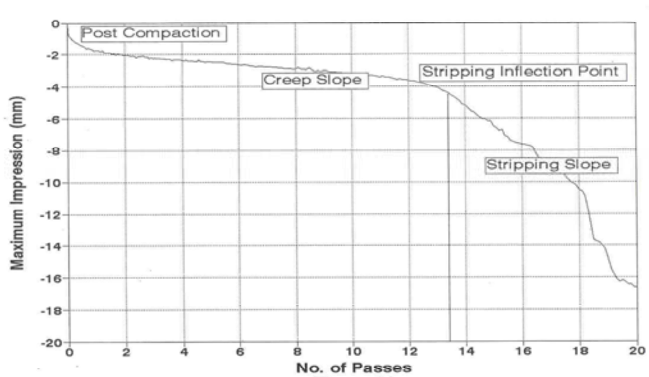


FIGURE 2. Interpretation of Results from the Hamburg Wheel Tester (*7*)

A linear kneading compactor was used to produce samples for the Hamburg wheel tester. Two slab samples of 320 × 260 mm and 40 mm or 80 mm height can be produced at a time. The samples are compacted to a known height; hence the target air void of the compacted sample can be achieved easily. The mold is filled with a pre-determined weight of the mixture from the knowledge of the theoretical maximum specific gravity of the mix. The sample can then be compacted within ± 1% of the targeted air voids, by a series of 12 mm wide steel plates, which are placed on the loose, mix in the mold. A linear compression wave is produced in the mix by the bottom edges of the plates as the roller pushes down on each plate. This kneading action allows the mixture to be compacted without fracturing the aggregates and is probably very similar to a steel wheel roller (*8*). The compaction time is less than 10 minutes.

MIXTURES TESTED

PG Binder and Sources

Four different binders were used in this study. The binders were obtained from two different refineries – Source 1 and Source 2. For source 1, PG 52-28 and PG 64-22 were used. PG 58-28 and PG 70-28 binders from source 2 were also used in the study.

Aggregates

The coarse and fine aggregates, used in the Superpave mixes in this study, were obtained from a number of sources. Two very similar 19 mm mix designs (corresponding to different binder sources) were developed using aggregates from three sources. Figure 3 shows the gradation of the aggregate blends used. In both cases, the gradation passed below the restricted zone. Blend 1 corresponds to mix number 3 and Blend 2 corresponds to mix number 2. Mix #2 consists of 31% Nelson crushed limestone, 29% Nelson crushed limestone screening, 20% Nelson manufactured sand, 10% Bingham chat (a slag aggregate from the zinc smelting industry in southeast Kansas), and 10% Ritchie sand. Mix #3 used 31% Nelson crushed limestone, 29% Nelson crushed limestone screening, 25% Nelson manufactured sand, 10% Bingham chat, and 5% Ritchie sand. The significant difference between these two mixtures is the proportion of river sand (from Ritchie Corp.). Five percent river sand in mix #2 has been replaced by 5% manufactured sand in mix #3. This increased the fine aggregate angularity of blend #2 by three per cent.

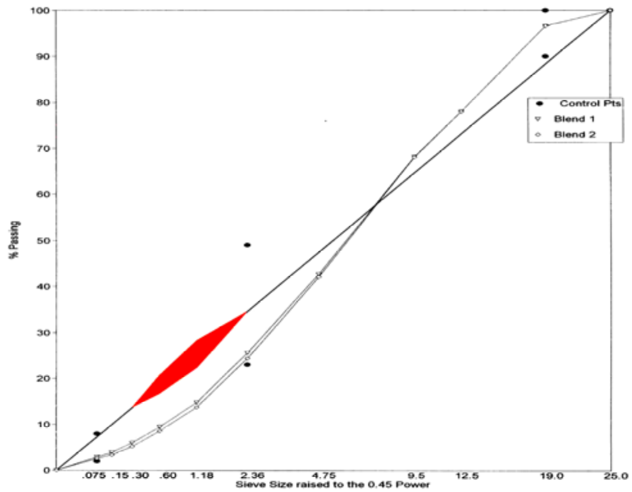


FIGURE 3. Aggregate Gradation of the Mixes Studied

Superpave Mixtures

A 19 mm nominal maximum size mix (#2) for the mainline base (bottom 200 mm) and shoulder was used for the binders from source 1, and a 19 mm nominal maximum size mix (#3) for the mainline base layer (top 100 mm) was used for the binders from source 2. The $N_{initial}$, N_{design}, and N_{final} for this project were 7, 86 and 134, respectively. Table 1 shows the required and achieved volumetric and aggregate properties. The asphalt contents of mix #2 and mix #3 were 5.5% and 5.4%, respectively.

TABLE 1. Properties of the Superpave Mixtures (N_{design} = 86)

Mixture/Aggregate Blend Property	Required/ Criteria	Mix #2	Mix #3
Asphalt Content (%)	-	5.50	5.40
Air Voids (%) at Ndes	4.0	4.0	4.00
VMA (%)	13 min.	14.0	14.0
VFA (%)	65-78	71	70.5
Dust-Binder Ratio	0.6 - 1.2	0.62	0.67
TSR	80% min.	98	95
%Gmm at Nini	89% max.	84	85
%Gmm at Nmax	98% max.	97	97.7
Sand Equivalent (%)	40 min.	93	95
Fine Aggregate Angularity (%)	40 min.	45	47
Coarse Aggregate Angularity (%)	50* or 75 min.	95.5	99
Flat & Elongated Particles (%)	10% max.	0.5	0.0

* for Mix #2

TESTING

The aggregates and the binders were mixed in the laboratory and tested following an experimental plan prepared by the Kansas Asphalt Pavement Association to extract specific information with a minimum amount of testing. The mixing and compaction temperatures were determined corresponding to the PG binder viscosities of 0.17 Pa.s and 0.28 Pa.s, respectively. The mixtures were aged for two hours at the compaction temperature before compaction in the kneading compactor. Maximum specific gravity tests were performed on each mix and the results were used for calculating the quantity of asphalt mix required to reach the desired air void content (7 ± 1%) in the compacted sample. Testing of the samples was usually done in the Hamburg wheel tester 24 hours after molding. All tests were done with the samples submerged under water at 45^{o} C. The test temperature was selected following manufacturer's recommendation. Testing in this study continued until the rut depth at any of the 11 points on the specimen reached a maximum value of 20 mm or the maximum number of wheel passes (20,000) was reached. Two replicate samples were tested side by side. All samples, except the mixture with PG 70-28 binder, showed signs of severe stripping and shoving during tests. Fines were observed to come out of the mixes during testing.

The Hamburg wheel tester automatically records deformation (in mm) at 11 different points along the specimen for each wheel pass. After the test, the wheel pass number versus deformation curve, similar to the one shown in Figure 2, was plotted using the Excel spreadsheet. Using the curve fitting technique available in Excel, the creep slope, stripping slope and stripping inflection point were determined. The results are summarized in Table 2. It appears that higher binder grade enhances mixture performance.

TABLE 2. Summary of Hamburg Test Results

Mix Type	Binder Source	Number of Passes		Average Number of Passes	Average Creep Slope	Average Stripping Inflection Point	Average Stripping Slope
		Specimen #1 (Left)	Specimen #2 (Right)				
PG 52-28	1	4260	4840	4550	465	3131	289
PG 64-22	1	5741	7881	6811	571	5081	266
PG 58-28	2	4701	2700	3700	217	3220	138
PG 70-28	2	9180	10781	9980	952	6971	281

STATISTICAL ANALYSIS

Experimental Design and Variables Studied

Comparison among different factors that might affect the performance of the Superpave mixes was made using the Analysis of Variance (ANOVA) technique and the SAS software (9). The statistical experiment analyzed is a randomized balanced experiment with blocking on the wheel/specimen. ANOVA was performed using the Least Square Means (LSMeans) approach (10) to test the effect of different factors on the dependent (response) variable.

In this study four response variables were studied: (a) Number of repetitions to reach a 20 mm maximum rut depth, (b) Creep slope, (c) Stripping Slope, and (d) Stripping inflection point. The effect of PG grade is studied in the ANOVA with the model in Equation (1):

$$(\text{Response Variable})_{ij} = \text{Binder}_i + \text{Wheel}_j + \varepsilon_{ij} \quad (1)$$

Where, $(\text{Response Variable})_{ij}$ = The various response variables studied;
Binder_i = ith binder effect;
Wheel_j = jth wheel effect (of the Hamburg wheel tester); and
ε_{ij} = Error term.

RESULTS AND DISCUSSIONS

Effect of PG Binder Grade

The results of the ANOVA are shown in Table 3 incorporating all variables shown in Equation 1. All conclusions were drawn at a 95% confidence interval. For the number of wheel passes to reach a 20 mm maximum rut depth any where in the sample, significant differences were found between the binder grades PG 52-28, PG 58-28 and PG 70-28. PG 64-22 and PG 70-28 were found to be statistically similar in terms of the number of wheel passes to reach maximum 20 mm rut depth. Significant difference was also found between the binders PG 58-28 and PG 70-28 when the creep slope was analyzed. This probably was mainly due to the poorly performing Sample #2 for the PG 58-28 mixture. However, the statistical conclusions are still valid since during analysis “blocking” was done on the “wheel/sample” to take into account this variability. The results indicate that the rate of rutting of the mixture #3 with PG 58-28 binder is higher than PG 70-28 binder. Since PG 58-28 in mixture #3 was used on US-169, a PG 70-28 binder might have prevented early rutting on this project. For the stripping slope, results are similar to that for the creep slope. Significant differences were also obtained between PG 52-28 and PG 58-28. The stripping inflection point was found different for PG 70-28 when compared to the other three binder grades. This indicates that as far as moisture susceptibility is concerned, PG 70-28 would perform the best.

TABLE 3. Effect of the PG Binder Grade on the No. of Wheel Passes, Creep Slope, Stripping Slope and Stripping Inflection Point

Number of Wheel Passes to reach 20mm rut depth					Creep Slope				
PG Grade	52-28	58-28	64-22	70-28	PG Grade	52-28	58-28	64-22	70-28
52-28	-	Similar	Similar	Different	52-28	-	Similar	Similar	Similar
58-28	Similar	-	Similar	Different	58-28	Similar	-	Similar	Different
64-22	Similar	Similar	-	Similar	64-22	Similar	Similar	-	Similar
70-28	Different	Different	Similar	-	70-28	Similar	Different	Similar	-
Stripping Slope					**Stripping Inflection Point**				
PG Grade	52-28	58-28	64-22	70-28	PG Grade	52-28	58-28	64-22	70-28
52-28	-	Different	Similar	Similar	52-28	-	Similar	Similar	Different
58-28	Different	-	Different	Different	58-28	Similar	-	Similar	Different
64-22	Similar	Different	-	Similar	64-22	Similar	Similar	-	Similar
70-28	Similar	Different	Similar	-	70-28	Different	Different	Similar	-

Effect of Binder Source

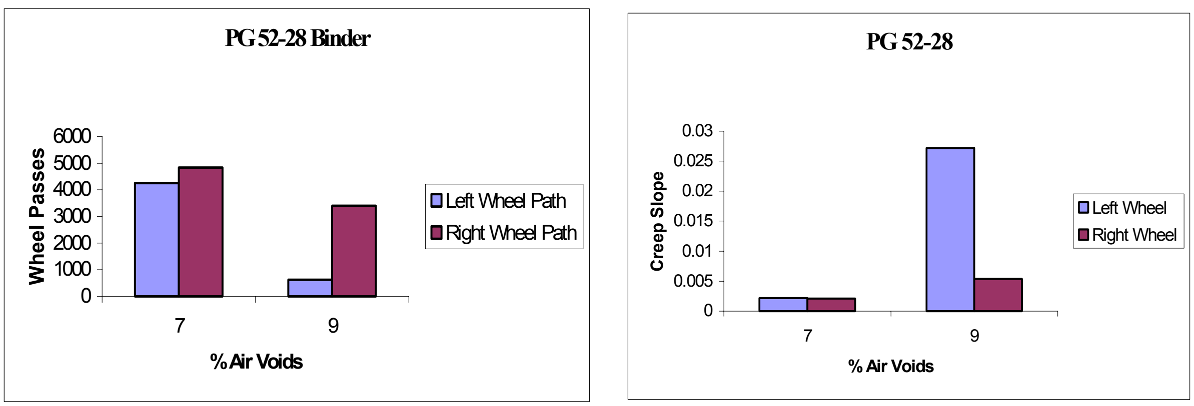
ANOVA analysis was done to compare the two different sources of binder using "CONTRAST" for the variable "source" over the PG grades used. Note that although the experiment factorial is not a "complete" one, such comparison is still valid since there is very little difference in aggregate gradations between mix #2 and mix #3. The results of this analysis are presented in Table 4. All comparison was done at a 95% confidence interval. Significant differences were found between the sources of binder for the two mix designs with respect to the number of repetitions to reach 20 mm maximum rut depth and the stripping inflection point. For other variables i.e., creep slope and stripping slope, no significant differences were found between the binder sources. This supports the conclusion drawn earlier – use of PG 70-28 binder from any source might have prevented the early rutting on US-169.

TABLE 4. Effect of the Source of Binder on the No. of Wheel Passes, Creep Slope, Stripping Slope and Stripping Inflection Point

No. of Wheel Passes			Creep Slope		
Source	Source 1	Source 2	Source	Source 1	Source 2
Source 1	-	Different	Source 1	-	Similar
Source 2	Different	-	Source 2	Similar	-
Stripping Slope			**Stripping Inflection Point**		
Source	Source 1	Source 2	Source	Source 1	Source 2
Source 1		Similar	Source 1		Different
Source 2	Similar		Source 2	Different	

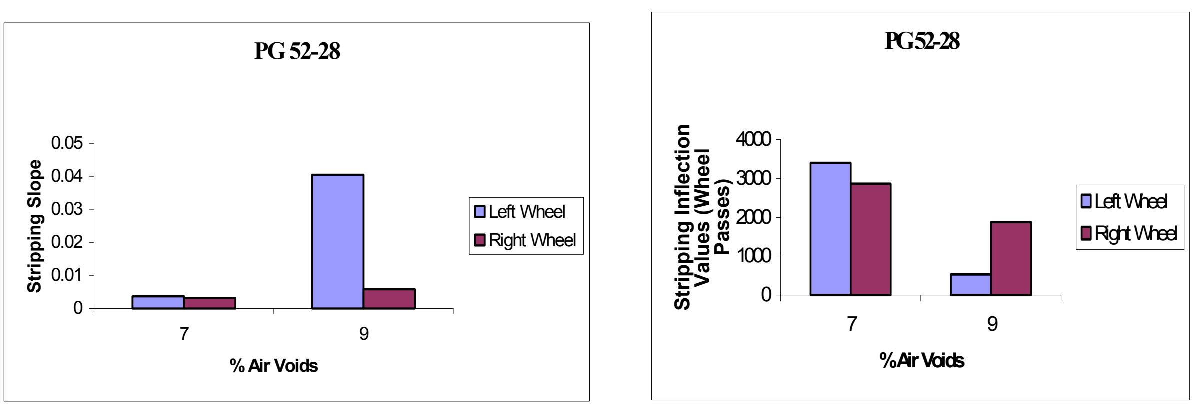
Effect of Compaction

There is some opinion that early rutting on US-169 was due to compaction variability although the contractor achieved bonus payments for the in-situ density. The density variability was also studied. An earlier study in Colorado (*8*) found significant differences in mixture performance in the Hamburg wheel testing of the asphalt mixes compacted in the laboratory and those from the field. Effect of compaction in this research was done on the mix #2 with PG 52-28 binder from source 1 at two different air voids, 7% and 9%. Figures 4 and 5 show the comparison of the number of wheel passes to reach a 20 mm rut depth, creep slope, stripping slope and stripping inflection point for the two different compaction levels studied. It is obvious that the samples with 9% air voids failed earlier compared to those with 7% air voids with respect to the number of repetitions to reach maximum 20 mm rut depth. Large variations were also observed between the samples under the left and right wheels of the Hamburg tester. Higher creep and higher stripping slopes for the 9% air void samples indicate that inadequate compaction will lead to both accelerated rutting and stripping failure. The higher stripping inflection point values for the 7% air void samples also suggest that these samples are more resistant to moisture damage compared to the 9% air void samples.



(a) Number of Wheel Passes to 20 mm rut depth (b) Creep Slope

FIGURE 4. Results from PG 52-28 with Different Air Voids



(a) Stripping Slope (b) Stripping Inflection Values

FIGURE 5. Results from PG 52-28 with Different Air Voids

CONCLUSIONS

Based on the results of this study the following conclusions are made:

1. The PG 70-28 binder grade appeared to perform the best when compared with all other PG binder grades used in this study.

2. The Superpave mixtures showed significant differences in performance in terms of the number of repetitions to reach maximum 20 mm rut depth and the stripping inflection point when compared by binder source.

3. Superpave mixture compacted to 7% air voids performed much better than the mixture compacted to 9% air voids.

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