Effects of Asphalt Binder Grade on the Performance of Rhode Island Hot-Mix Asphalt

K. Wayne Lee
Department of Civil & Environmental Engineering, University of Rhode Island, Kingston, RI,USA

Satish Kumar Gundapuneni
Engineering & Research Int'l Inc., Savoy, IL, USA

Ajay Singh
Department of Civil & Environmental Engineering, University of Rhode Island, Kingston, RI,USA

ABSTRACT: The primary objective of the present study was to formulate guidelines to select an appropriate asphalt binder grade to produce high performing Hot-Mix Asphalt (HMA) in Rhode Island. Three different Performance Grade (PG) asphalt binders were used: PG64-28, 70-28 and 76-28. A series of volumetric mix-designs utilizing the Superpave technologies was performed. HMAs used was dense grade asphalt mixes and wearing course mixes, i.e., dense graded friction mixes and Paver Placed Elastomeric Surface Treatment (PPEST). Dense graded mixes studied were RI Class I-1 and Superpave mixes using Bailey gradations. APA test results indicated that higher temperature grading (or harder) asphalt binder would reduce rutting, but it has to be examined not to have a cracking problem in the field. Interestingly, HMA specimens with PG76-28 binder did not produce lower rut depth than the ones with PG70-28 specimen. It also has been observed that HMA with crushed fine aggregates have lower rut depth than the ones with natural sands. It was found that mixes with PG64-28 binder exhibited lowest tensile strength. However, HMA specimens with PG76-28 did not provide higher strength than the ones with PG70-28. In addition, there were no significant differences in tensile strength between specimens prepared with crushed fine aggregates and natural sands. It was also observed that the specimens prepared at Optimum Binder Content (OBC) provided highest tensile strengths compared to the ones with other binder contents. The outcome of the study will provide highway agencies and contractors with guidelines to select proper asphalt binders for HMAs.

KEY WORDS: Asphalt binder grade, hot-mix asphalt, performance, asphalt pavement analyzer, indirect tensile test.

1 INTRODUCTION

For over a century, paved roadways have been constructed using asphalt concrete mixes. However, a major problem still exists involving premature distresses and failures, e.g., rutting, cracking and potholes etc. To reduce and prevent the problems, the strategic Highway Research Program (SHRP) produced a new system referred to as Superpave. One portion of Superpave is a new asphalt binder specification with a new set of tests to match. The new asphalt binder grading system is mostly based on air temperature distribution to select appropriate asphalt binder which can produce suitable asphalt mixes at extreme high and low temperature within a certain statistical confidence level (McGennis et al. 1994).

A study was initiated with the Accelerated Loading Facility (ALF) to validate the Superpave specification and analysis system, and the results indicated that the mix with the higher $G^*/\sin\delta$ binder had less rutting (Sherwood et al. 1998). A study was also conducted to examine whether the binder stiffness is related to the performance (Khaled et al. 2001), and suggested that binder properties influenced more in fatigue than rutting performance. Since the Asphalt Pavement Analyzer (APA) provided a potential to evaluate the rutting performance (Kandhal et al. 2003), it was used in this study. In addition, the Indirect Tensile Tester (IDT) was utilized to characterize the low-temperature cracking.

The purpose of this research was: (1) to develop and conduct volumetric mix-designs for various mix types utilizing the Superpave mix design system; (2) to predict the performance of asphalt mixes fabricated with Rhode Island asphalt binders and aggregates using an automatic APA and IDT; (3) to identify significant parameters on the selection of binder grade for selected mixes and (4) to formulate and recommend a guideline to select the appropriate binder grade for mixes to be used in Rhode Island and similar environment.

2 EXPERIMENTAL WORKS

2.1 Asphalt Binder

The asphalt binder used for this study was obtained from the Hudson Companies located in Providence, RI. Three different Performance Graded asphalt binders (PG 64-28, PG 70-28 and PG 76-28) were used. Binder specification tests were performed to check whether the obtained asphalt binders were within the specification limits.

2.2 Mineral Aggregates

Aggregates were obtained from P.J. Keating in Cranston, RI and J.H. Lynch & Sons in Cumberland, RI (Lee et al. 2005). The test specimens were prepared in two different ways: (1) Keating coarse and fine aggregates; and (2) Keating coarse and Lynch fine aggregates. When these aggregates were obtained from stock piles, they were sieved and separated to each fraction. The sieves used were ¾”, ½”, 3/8”, #4, #8, #30, #50 and #200.

Two different types of mixes were used: dense mix and surface treatment. Dense mix was subdivided into Rhode Island Department of Transportation (RIDOT) Class I-1 Marshall mix and Superpave mixes using Bailey gradations. The Superpave mixes were divided into five gradations, (1) Straight fine, (2) Crossover fine to coarse), (3) Median, (4) Crossover coarse to fine and (5) Straight coarse. The surface treatment mix type was divided into two gradations, which are (1) Paver Placed Elastomeric Surface Treatment (PPEST) and (2) Dense Friction Course (DFC). Therefore, the tests were performed on eight different mixes.

2.3 Optimum Binder Content (OBC)

The OBC was determined using the Superpave mix design system, and specimens were compacted to 7% air voids. This is typical air void when they are placed in the field. After compaction by vehicular traffic over time, the roadway reaches its optimum 4% air void level. Compaction based on number of gyrations to control density results in large variances in air void (Robertson 2000). Because of the different sizes of aggregate in each sieve size, each replicated mix has a different total volume, while the total mass is the same. Compacting based on height results in more uniform air void, thus this method was used for compaction (Romero et al. 2001). After compaction, bulk specific gravities of the specimens were taken. Rice tests were performed to attain the theoretical max. densities on 1000-gram uncompacted test mixes. Then, the air void was determined.

It had been proposed that the APA test would be performed in two different combinations: full and partial combination. In the full combination, specimens were prepared using three different binder grades (PG64-28, PG70-28 and PG76-28), three different binder contents (OBC–0.5%, OBC and OBC+0.5%), and same coarse aggregate source, Keating, but two different fine aggregates, i.e., Keating and Lynch. Each test was performed using two specimens and four different gradations (Class I-1, Bailey Median, PPEST and DFC).

Similarly, specimens for the Partial Combination was prepared using one asphalt binder grade (PG 64-28), three different asphalt binder contents (OBC–0.5%, OBC and OBC +0.5%), and two different fine aggregate sources (Keating and Lynch). Each test was performed using two specimens and four different Gradations, i.e., Bailey straight fine, Bailey crossover fine to coarse, Bailey Crossover coarse to fine and Bailey straight coarse.

3 ANAYSIS OF TEST RESULTS AND DISCUSSION

3.1 APA Test Results and Analysis

APA tests were performed to evaluate the HMA's resistance to rutting. Previous work reported that it provides a good indication of field performance (Williams et al. 1999). This research used RIDOT approved Superpave coarse and fine mixtures. Mixes were produced using the same aggregates and gradation, but varying grades of asphalt binder. Average rut depths for each test were computed from a set of three pairs of cylindrical specimens in the left, center, and right positions in the APA. The testing temperature was 64°C. Final results were taken as the average of a pair of specimens for all three positions. The cutoff point for rutting was 14 mm as recommended by the APA manufacturer.

3.1.1. Effects of Different PG Graded Asphalt Binder

A full combination experiment was carried out mainly to evaluate the effects of different PG graded asphalt binders on the performance of the HMA (Tables 1 and 2).

Table 1: APA Test Results for Full Combination with Keating Coarse and Fine Aggregates

HMA Gradation	PG 64-28			PG 70-28			PG 76-28		
	OBC -0.5%	OBC (5.0%)	OBC +0.5%	OBC -0.5%	OBC (5.5%)	OBC +0.5%	OBC -0.5%	OBC (5.3%)	OBC +0.5%
Bailey Median	5.1	6.4	8.5	1.1	1.8	2.0	1.4	2.7	3.1
Class I-1	8.2	9.8	10.4	0.8	1.0	1.4	1.0	1.8	2.3
PPEST	3.5	4.1	4.8	0.4	0.7	1.1	0.6	1.0	1.7
DFC	9.3	10.6	11.2	1.7	2.1	2.6	2.0	3.1	3.7

Note: Rut Depth in mm
The value in each cell is the average of two different tests.

Table 2: APA Results for Full Combination with Keating Coarse and Lynch Fine Aggregates

HMA Gradation	PG 64-28			PG 70-28			PG 76-28		
	OBC -0.5%	OBC (5.7%)	OBC +0.5%	OBC -0.5%	OBC (5.8%)	OBC +0.5%	OBC -0.5%	OBC (5.6%)	OBC +0.5%
Bailey Median	8.4	Failed	9.8	2.7	2.3	3.1	4.1	3.2	4.7
Class I-1	9.3	8.6	11.2	3.8	2.6	4.9	3.2	2.7	4.3
PPEST	2.9	2.1	3.6	1.1	0.8	1.7	1.8	1.3	2.1
DFC	11.3	8.7	9.8	1.3	1.0	1.9	2.7	2.1	3.3

Figure 1 shows APA test results performed on HMA specimens prepared with Keating coarse and fine aggregates at OBC. It was observed that PG64-28 (the softest asphalt) specimens provided the highest rut depths. It was also interesting to learn that PG76-28 (or harder asphalt) specimens do not provide lower rut depth than PG70-28 (or softer asphalt) ones. Same observations were made with specimens prepared with OBC-0.5% and OBC+0.5%. However, it was observed that the mixes with PG70-28 had higher OBCs than the ones with PG64-28 and PG76-28.

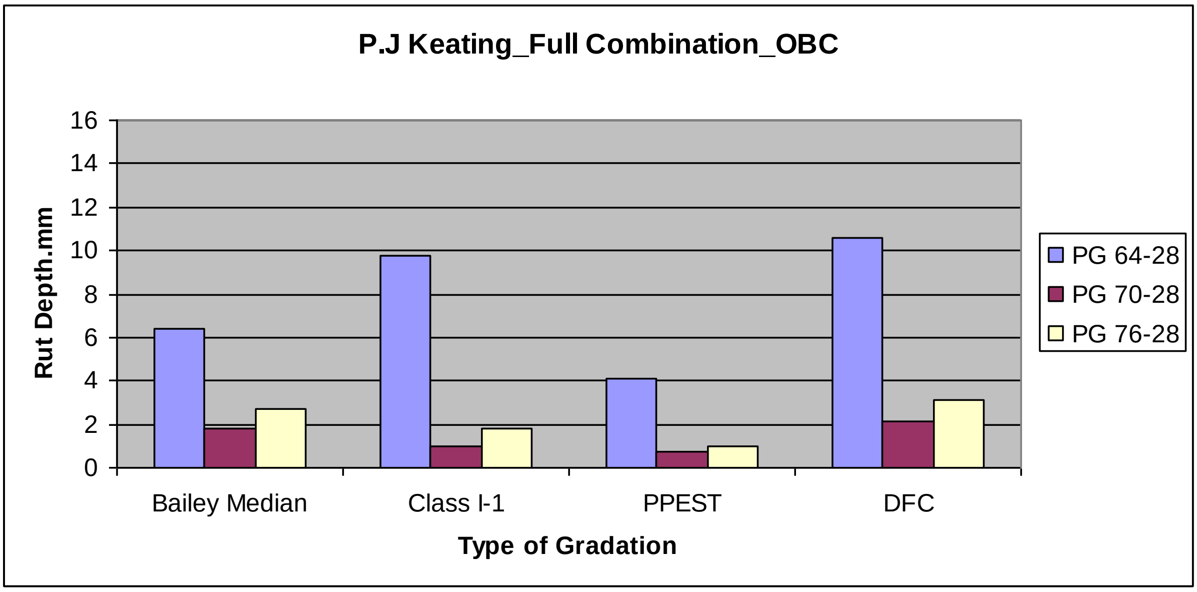

Figure 1: Effects of different PG grading on specimens prepared with OBC asphalt Keating coarse and fine aggregates on rutting.

To examine the effect of fine aggregate, the same experiments were carried out with Lynch fine aggregate instead of Keating ones, and Figure 2 shows test results. Similar trends were observed with the Lynch fine aggregate as were observed with the Keating. It also has been observed that the mixes with Lynch fine aggregate (natural sands) exhibited relatively higher rut depths than the Keating ones (crushed limestone screenings). It explains that rough surfaced fine aggregates have higher resistance against rutting than round ones.

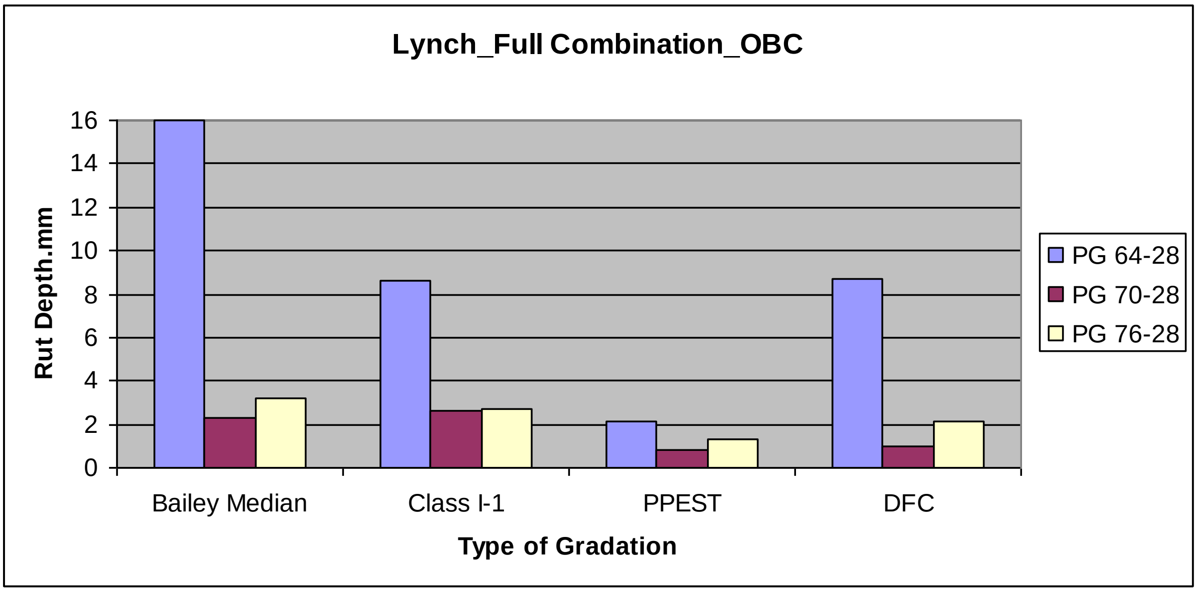

Figure 2: Effects of PG grading on specimens prepared with OBC asphalt, P.J. Keating coarse and Lynch fine aggregates on rutting.

3.1.2 Effects of Asphalt Content for Different HMA

Figure 3 shows test results for HMA specimens with Keating coarse and fine aggregates with Bailey median. Although specimens with OBC–0.5% asphalt provided less rut depth, the differences were not significant statistically. It also may be noted that specimens with lower asphalt content than OBC may experience lower fatigue and/or thermal cracking resistance.

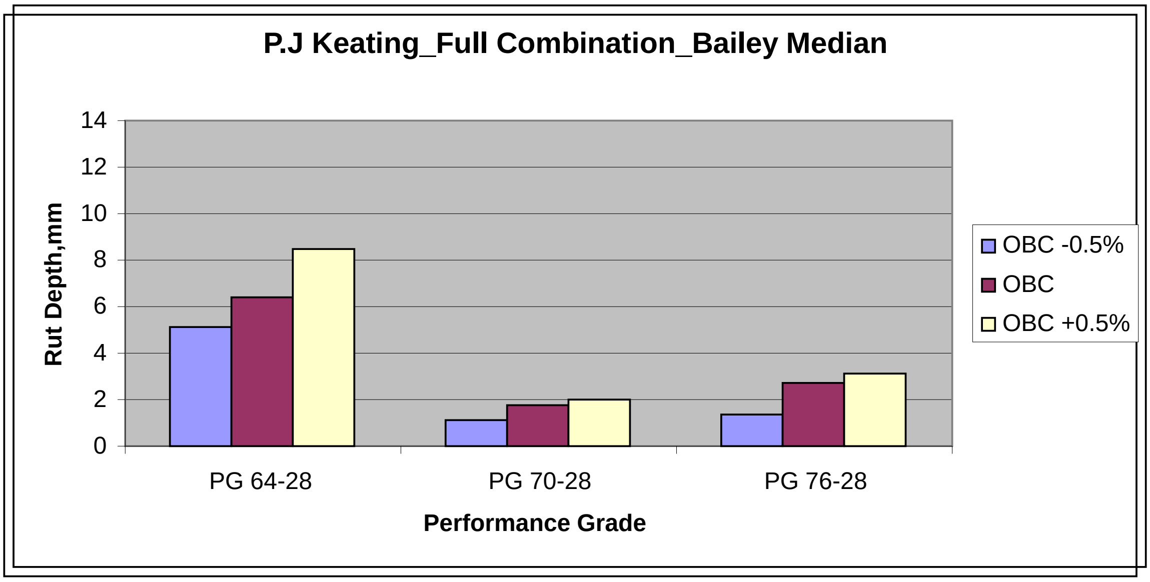

Figure 3: Effects of different asphalt content for HMA with Bailey Median gradation, Keating coarse and fine aggregates on rutting.

To examine the effect of fine aggregates in the mix, the same experiments were carried out with Lynch fine aggregates instead of Keating's. Similar trends have been observed, but in most cases the specimens with lower OBCs provided less rut depths.

3.1.3. Effects of Different Bailey Gradations on Performance

A partial combination experiment was carried out to examine the effects of various dense graded mixes (Tables 3 and 4). Figure 4 shows the effects of different Bailey gradations with Keating aggregates. As can be seen, the mixes with fine gradation exhibit much higher rut depth than the ones with the other three gradations.

Table 3: APA Test Results for Partial Combination for Keating Coarse and Fine Aggregates

Bailey Gradation	PG 64-28		
	OBC – 0.5%	OBC	OBC + 0.5%
Straight (fine)	10.3	failed	Failed
Cross over (fine to coarse)	1.8	2.1	2.6
Cross over (coarse to fine)	1.1	1.3	1.9
Straight (coarse)	1.4	1.8	2.6

Table 4: APA Results for Partial Combination for Keating Coarse and Lynch Fine Aggregates

Bailey Gradation	PG 64-28		
	OBC – 0.5%	OBC	OBC + 0.5%
straight (fine)	Failed	12.6	Failed
Cross over (fine to coarse)	2.7	2.3	3.2
Cross over (coarse to fine)	3.1	1.8	4.6
Straight (coarse)	2.9	1.6	3.7

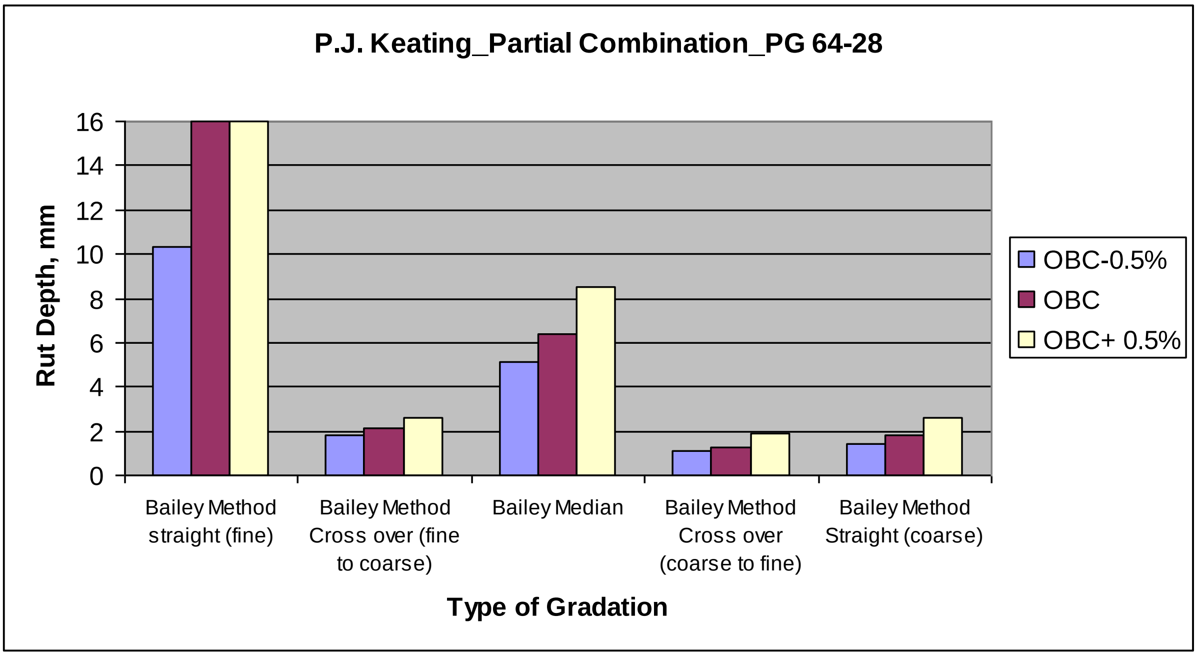

Figure 4: Effects of different Bailey aggregate gradations on specimens prepared with PG 64-28 asphalt, Keating coarse and fine aggregates on rutting.

3.2 IDT Test Results and Analysis

All specimens were tested at room temperature, i.e., 25°C (77°F) to set up a base line data for the future studies.

3.2.1 Effects of Different Asphalt Binder on Tensile Strength

A full combination experiment was carried out to evaluate the effects of different PG graded asphalt binder on the performance of HMA (Tables 5 and 6).

Table 5: IDT Test Results for Full Combination for Keating Coarse and Fine Aggregates

HMA Gradation	PG 64-28			PG 70-28			PG 76-28		
	OBC -0.5%	OBC	OBC +0.5%	OBC -0.5%	OBC	OBC +0.5%	OBC -0.5%	OBC	OBC +0.5%
Bailey Median	138	149	125	173	194	167	151	163	147
Class I-1	128	134	113	168	184	161	148	160	141
PPEST	153	173	144	214	243	201	173	193	162
DFC	132	149	131	178	190	165	157	175	148

Table 6: IDT Results for Full Combination for Keating Coarse and Lynch Fine Aggregates

HMA Gradation	PG 64-28			PG 70-28			PG 76-28		
	OBC -0.5%	OBC	OBC +0.5%	OBC -0.5%	OBC	OBC +0.5%	OBC-0.5%	OBC	OBC +0.5%
Bailey Median	155	163	125	186	205	179	168	189	160
Class I-1	134	147	123	181	202	179	164	187	162
PPEST	172	194	167	235	263	229	186	212	177
DFC	144	162	138	189	219	177	172	196	168

Figure 5 shows IDT test results performed on specimens with Keating coarse and fine aggregates at OBC. It was observed that PG64-28 (softest asphalt) specimens provided lower tensile strength. It was also interesting to learn that PG 76-28 (or harder asphalt) specimens did not provide higher tensile strength than PG 70-28 (or softer asphalt) ones.

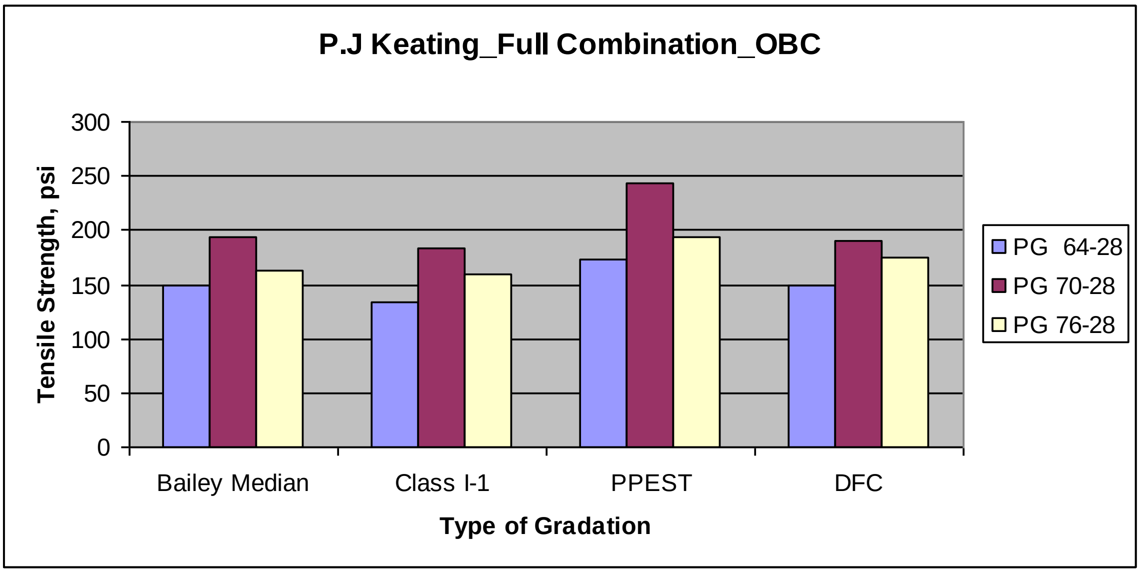

Figure 5: Effects of different PG grading on specimens prepared with OBC asphalt, Keating coarse and fine aggregates on IDT strength.

To examine the effect of fine aggregates, the same experiments were carried out with Lynch fine aggregates instead of Keating ones. Similar trends have been observed with the ones prepared with Keating fine aggregates.

3.2.2 Effects of Asphalt Content for Different HMA

Figure 6 shows test results for HMA specimens with P.J. Keating coarse and fine aggregates with Bailey median. It was observed that specimens with OBC provided higher tensile strength. It also may be noted that specimens with lower and higher asphalt contents than OBC may experience lower fatigue and/or thermal cracking resistance.

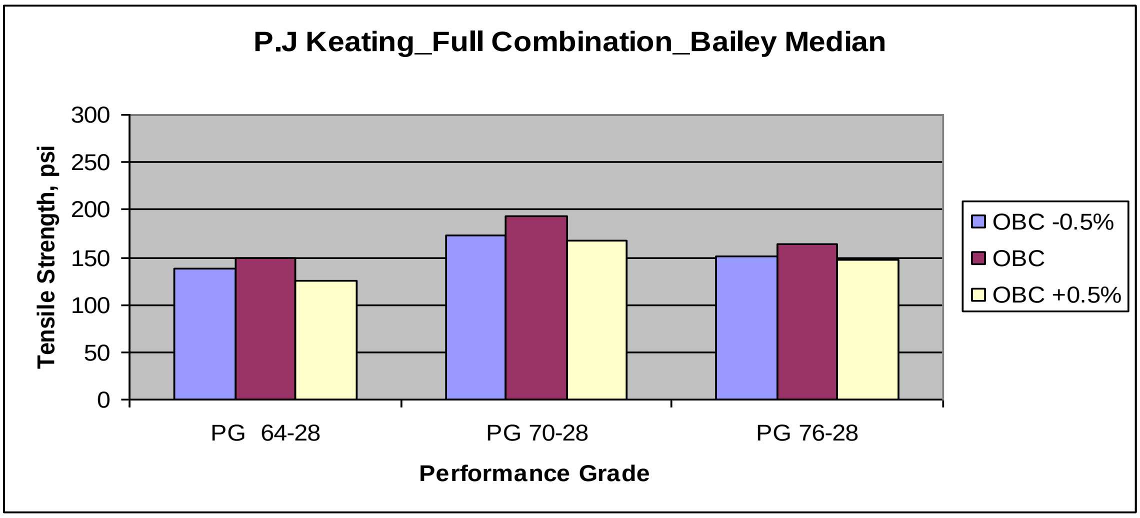

Figure 6: Effects of different asphalt content for HMA with Bailey Median gradation Keating coarse and fine aggregates on IDT strength.

To examine the effect of fine aggregates, the same experiments were carried out with Lynch fine aggregate instead of Keating ones. Similar trends have been observed as when using Keating fine aggregate.

3.2.3. Effects of Different Bailey Gradations on Tensile Strength

A partial combination experiment was carried out to examine the effects of various dense graded mixtures (Table 7). As can be seen, there were no significant differences among different gradations.

Table 7: IDT Test Results for Partial Combination for Keating Coarse and Fine Aggregates

Bailey Gradation	PG 64-28		
	OBC – 0.5%	OBC	OBC + 0.5%
Straight (fine)	180	191	174
Cross over (fine to coarse)	166	174	160
Cross over (coarse to fine)	193	212	188
Straight (coarse)	196	221	189

Same experiments were performed with Lynch fine aggregates rather than Keating ones (Table 8). Again, there were no significant effects due to different gradations on tensile strength.

Table 8: IDT Results for Partial Combination for Keating Coarse and Lynch Fine Aggregates

Bailey Gradation	PG 64-28		
	OBC – 0.5%	OBC	OBC + 0.5%
Straight (fine)	197	218	186
Cross over (fine to coarse)	184	195	179
Cross over (coarse to fine)	217	235	203
Straight (coarse)	213	248	201

4 CONCLUSIONS AND RECMMENDATIONS

1. APA test results indicated that the HMA with PG 70-28 and PG 76-28 exhibit less rutting than the PG 64-28. Thus, high temperature grade (or harder) asphalt would reduce rutting in the field, but it has to be examined for cracking problems in the field. It was also observed that mixtures with PG 76-28 did not have lower rut depth than the ones with PG 70-28. Thus, it is not necessary to use hardest asphalt to avoid rutting.
2. It has been observed that the mixtures with crushed fine aggregates produce lower rutting depths than ones with the natural sands.
3. It was observed that the specimens with OBC +0.5% have higher rutting than specimens prepared with OBC and OBC-0.5%.
4. APA test results show that the mixture with fine gradation exhibits much higher rut depth than the ones prepared with other gradations.
5. It was observed that mixtures with PG 64-28 exhibited lowest tensile strength. However, HMA specimens with PG 76-28 did not provide higher strength than the ones with PG 70-28. There were no significant differences in tensile strength between specimens prepared with crushed fine aggregates and natural sands.
6. It was observed that specimens with OBC provided higher tensile strengths.
7. There were no significant differences in tensile strength when HMA specimens were prepared with different Bailey gradations.
8. It is recommended to use harder asphalt where rutting is expected in the field. However, using too hard asphalt, e.g., two PG grade bumping up may not be effective, and may invite cracking problem in the field. It is also recommended to use crushed fine aggregate if rutting is expected in the field.
9. Over asphalting would not be desirable particularly where rutting could be problem. When rutting would occur, coarse graded mixtures would be desirable.
10. Although the APA threshold value for the samples having a rut depth higher than 8mm is said to be not acceptable for paving roads, further testing and analysis are needed to refine this value. It may be considered for RIDOT to send the HMA specimens to URI for APA testing to develop correlation between laboratory test results and field performance.
11. To examine the thermal cracking resistance, it would be highly desirable to conduct a research program with different low temperature PG grading, e.g., PG 64-22, PG 64-28 and PG 64-34.

12. Test temperatures for the IDT creep and strength test could be linked to binder grade: - 10, 0°C and 10°C for PG XX-16 or harder; -20°C, -10°C and 0°C for PG XX-22; and -30°C -20°C and -10°C for PG XX-28 binder and softer.
13. Reasonable adjustments should be made for testing field cores, which may exhibit substantial age hardening.
14. Further research could be undertaken to evaluate the accuracy of critical cracking temperatures.

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