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Influence of Asphalt-Binder Source on CAM Mix Rutting and Cracking Performance: A Laboratory Case Study

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Abstract: Crack attenuating mixtures, denoted as CAM, are some of the mixes commonly used in the State of Texas (USA) to mitigate reflective cracking in overlays, both in flexible—hot mix asphalt (HMA) and rigid concrete pavements. Typically designed at 98% lab density, with high quality aggregates, these fine-graded HMA mixes are rich in asphalt-binder (minimum 6.5%), predominantly using PG 76-22. In this study, three PG 76-22 asphalt-binders from three different sources (denoted as A, B, and C) were evaluated in the laboratory for their potential to meet the CAM Balanced Mix-Design (BMD) requirements when used in combination with limestone aggregates and 1% hydrated lime. Laboratory tests conducted included the Hamburg wheel tracking test (i.e., for rutting and moisture damage [stripping] evaluation), the Overlay test (i.e., for cracking evaluation), and the asphalt-binder rheology, namely the dynamic shear rheometer (DSR) and the bending beam rheometer (BBR). The corresponding results indicated that not all PG 76-22 asphalt-binders are manufactured equally and that material source has a profound influence on both the asphalt-binder rheological properties and the overall performance of the resulting HMA mix. In fact, one of the PG 76-22 asphalt-binder graded out as a PG 82-22 and could not meet the BMD performance requirements for a CAM mix-design. As part of the quality control/assurance protocols and to ensure that the right materials "as designed and specified" are utilized, the overall findings of study suggests that it is imperative that all asphalt-binders delivered to a given construction site must be sampled and tested for its rheological properties and graded accordingly. Provided high quality materials are used, the study also indicated that a CAM mix could satisfactorily be designed at a lower lab density than 98% (i.e., 96.5 – 97.5%); which translates into cost savings in terms of the asphalt-binder content.

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Key words*: Asphalt-binder; Balanced mix-design (BMD); Cracking; Crack attenuating mix (CAM); Hot mix asphalt (HMA); PG grade; Rutting.*

Introduction

In an effort to minimize the prevalent occurrence of premature cracking on hot-mix asphalt (HMA) pavements, various new HMA mix-designs are being explored in the State of Texas [1-4]. For example, over the past few years, there has been a high interest in using rich asphalt-binder and high quality fine-graded aggregate mixes such as crack attenuating mixtures (CAM) that provide improved resistance to cracking [1, 2] as compared to traditional Texas dense-graded HMA mixes. While primarily designed to reduce reflective cracking in HMA overlays, the CAM mixes are also being experimented as the final riding surface layer on some in-service highway projects. Typically designed at 98% laboratory density, these mixes also exhibit high rut-resistant properties. Depending on the project requirements, CAM mixes may be designed and applied under one of the following Texas special specification (SS): Item SS 309, 3111, 3131, 3165, or 3228 [5].

Like any other HMA mix-design process, selecting the appropriate material combination is one of the key aspects to guaranteeing the satisfactory performance of a CAM mix as well as meeting the Balanced Mix-Design (BMD) requirements. In this context, material combination refers to the asphalt-binder (typically PG 76-22 for CAM mixes), aggregates, and other additives including hydrated lime, etc. For a specified aggregate type (limestone) and gradation (fine) as dictated by the Texas special specification Item SS 3131 [5], this case study was undertaken to address the following objectives:

1) Evaluate the influence of asphalt-binder source on the laboratory rutting and cracking performance of a CAM mix when subjected to the Hamburg wheel tracking test (HWTT) and the Overlay test (OT), respectively. PG 76-22 asphalt-binders from three different sources, herein denoted as A, B, and C, were evaluated.
2) Evaluate the influence of the asphalt-binder source on the general HMA mix-design volumetric properties in terms of satisfying the Texas Item SS 3131 specification [6].
3) Characterize the rheological properties of the asphalt-binders based on the dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests.
4) Investigate if the CAM and BMD requirements can be met at lower design laboratory densities (96.5%, 97%, 97.5%) in lieu of the standard 98% target design laboratory density (Item SS 3131).
5) Make mix-design (BMD) recommendations including the optimum asphalt-binder content (OAC) for placement as an overlay over a severely cracked in-service business highway.

In the paper, the general CAM mix-design requirements (SS 3131) are described first followed by the experimental design plan, the materials used, and the laboratory tests that were conducted. Next,

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the test results are presented and analyzed. The paper then concludes with a summary of key findings and recommendations.

Project Background

As part of the routine road maintenance program, it was desired to place a CAM mix – as a 25 mm thick overlay – on the severely cracked in-service highway (FM 158) in Bryan, Texas. However, during the initial HMA mix-design process, the Contractor had experienced problems in getting the mix designed with PG 76-22 Source C to simultaneously pass both the HWTT and OT requirements for a CAM design under specification Item 3131 [5]. More specifically, the mix was passing the HWTT for rutting evaluation, but failing in the OT—cracking evaluation—(i.e., less than 200 cycles). This was a concern as the Contractor had successfully designed and constructed an earlier project with an identical mix design. And hence, the need to evaluate other PG 76-22 asphalt-binder sources to assess if an even lower asphalt-binder content (AC) would satisfactorily meet the CAM requirements and in-turn potentially save the Contractor some money.

The Cam Mix-Design Requirements (SS 3131)

For this case study, the mix-design was based on the spec Item SS 3131 and the general requirements for a CAM mix using a PG 76-22 asphalt-binder are summarized in Tables 1 and 2 [5]. As noted in Table 1, to achieve a mix with 98-100% density a fine-graded aggregates with a nominal maximum aggregate size (NMAS) of ⅜ inches (9.5 mm), should generally be used.

Experimental Design Plan and Materials

The laboratory tests that were conducted for both the asphalt-binders and CAM mixes are discussed in this section. The materials used including the asphalt-binders, aggregates, and additives are also discussed in this section.

Laboratory Tests

To achieve the objectives of the study, the following laboratory tests were conducted: 1) the HWTT, 2) the OT, 3) the dynamic shear rheometer (DSR) test, and 4) the bending beam rheometer (BBR) test. Details of these standard tests can be found elsewhere [7]. Consistent with the Texas specification requirements, all HWTT- and OT-samples were molded and tested at 7±1% total air voids content [8].

Materials Used

Three PG 76-22 asphalt-binders from three different sources, denoted herein as A, B, and C were evaluated. Aggregate Class B, fine-graded limestone aggregates, were used with the blend characteristics and gradations as shown in Fig. 1. One percent hydrated lime was also added to minimize the effects of moisture damage due to stripping.

Table 1. CAM Item SS 3131 Aggregate Gradation Specification.

Sieve Size	Item SS 3131 Specification (%)	Gradation Used (%)
½ ″ (12.5 mm)	100 – 100	100.0
⅜″ (9.5 mm)	98 – 100	98.7
#4 (4.75 mm)	70 – 90	73.6
#8 (2.36 mm)	40 – 65	55.3
#16 (1.18 mm)	20 – 45	37.5
#30 (0.06 mm)	10 – 30	22.2
#50 (0.03 mm)	10 – 20	10.7
#200 (0.0075 mm)	2 – 10	4.4
Surface aggregate classification (SAC) = A or B; LA abrasion value ≤ 30; Magnesium soundness ≤ 20; H_2O absorption capacity (WAC) < 2%; linear shrinkage ≤ 3; deleterious material ≤ 1%		

Table 2. CAM SS 3131 Laboratory Mix-Design Property Requirements.

CAM Mix Property	Test Method	Threshold
Compactor	Tex-207-F (2008) [9]	SGC (Superpave Gyratory Compactor)
N_{design} Gyrations		50
Laboratory Design Density, %		98
Asphalt-binder Content (AC), %		≥ 6.5
Voids in Mineral Aggregate (VMA), %		≥ 16
Dust-asphalt Ratio		0.0 – 1.6
HWTT (Rutting Test)	Tex-242-F (2009) [10]	< 12.5 mm Rut Depth @ 20 000 Load Passes
OT (Cracking Test)	Tex-248-F (2009 [11]	≥ 750 Load Cycles

Laboratory Test Results and Analyses

For each asphalt-binder source, up to four asphalt-binder contents ranging from 6.5% to 7.1% were investigated; note that 6.5% is the minimum allowed under specification Item 3131 [5]. The results of these evaluations are plotted in Fig. 2 through 6 as a function of the laboratory density, VMA, HWTT, and OT performance.

Fig. 3 depicts that the VMA does not show any definitive response trend to increasing binder content. In contrast, Fig. 2 shows the theoretically expected increase in the laboratory density as the asphalt-binder content is increased. With the exception of the PG 76-22 Source A, that depicts a near linear relationship between the laboratory density and asphalt-binder content. For PG 76-22 Source A, however, the target laboratory density is only met at 7.1% AC where as it at 6.9% for the PG 76-22 Source B. By contrast, PG 76-22 Source C has a wider margin of meeting the target lab density starting from 6.7%. Overall, all the PG 76-22 sources met the minimum VMA requirements (≥ 16) at all the AC levels evaluated.

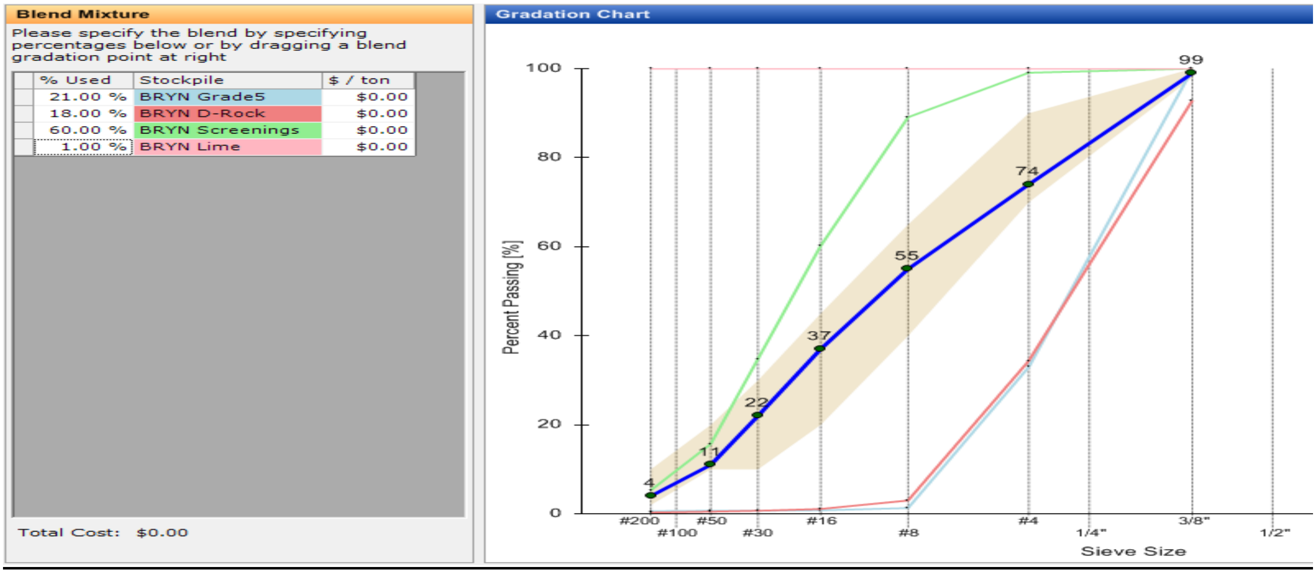

Fig. 1. Aggregate Gradations.

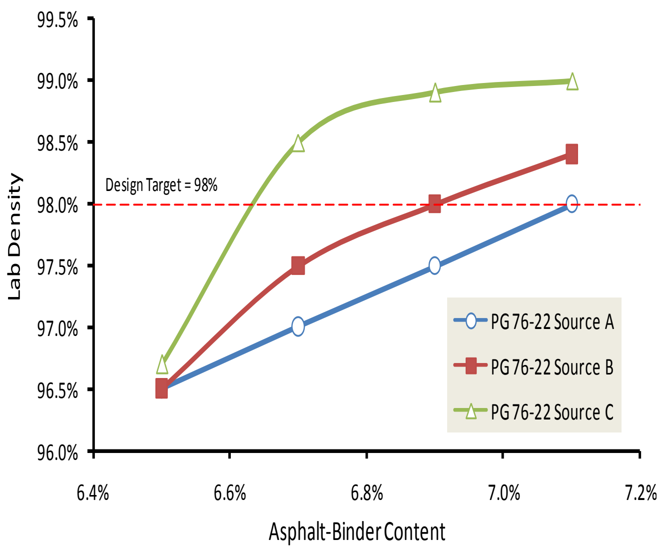

Fig. 2. Asphalt-Binder Content vs. Laboratory Density.

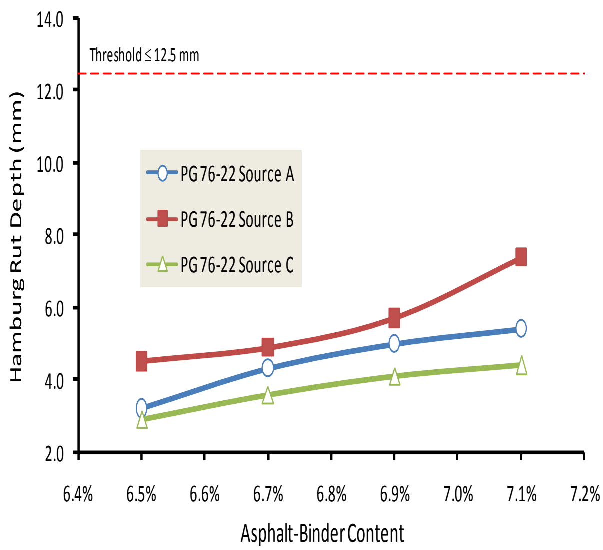

Fig. 4. Asphalt-Binder Content vs. HWTT Rut Depth.

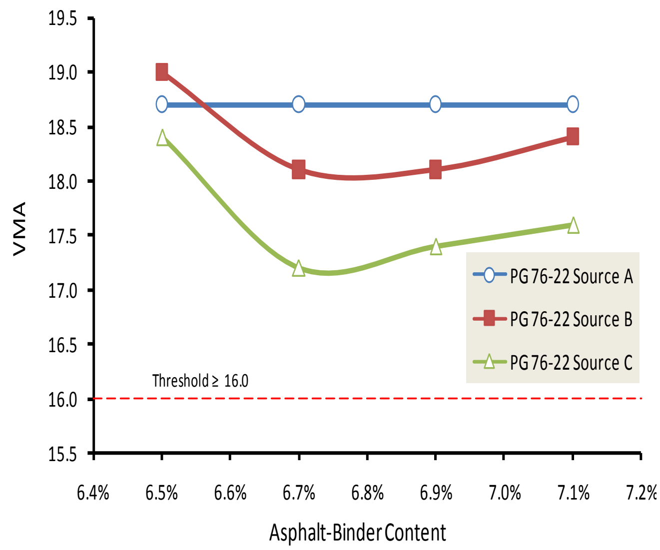

Fig. 3. Asphalt-Binder Content Versus VMA.

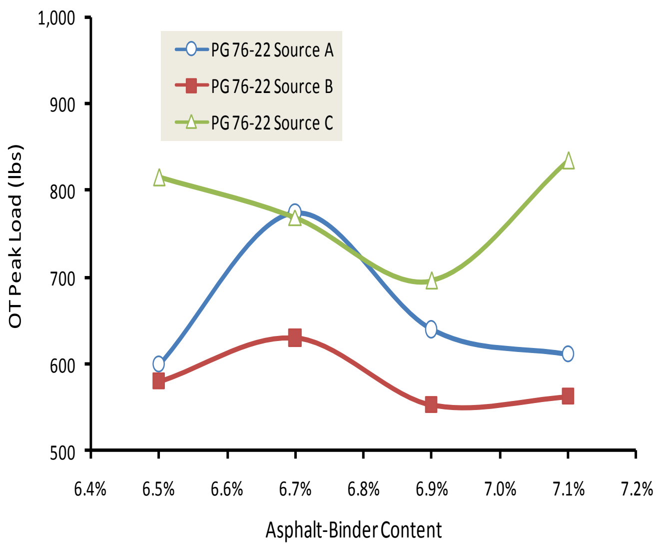

Fig. 5. Asphalt-Binder Content Versus Overlay Peak Load.

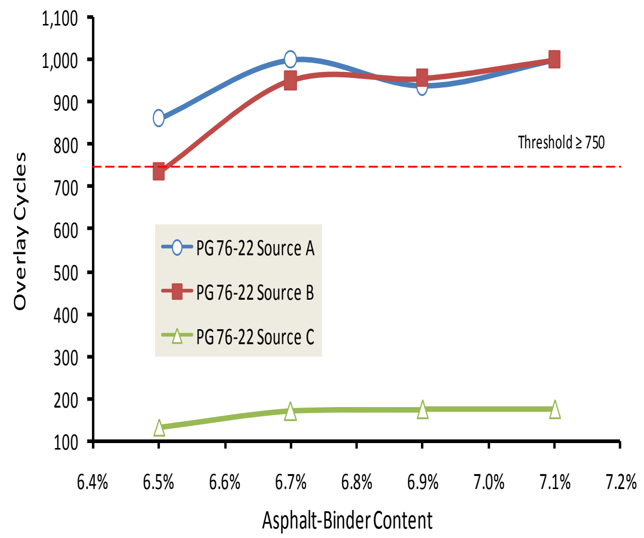

Fig. 6. Asphalt-Binder Content versus Overlay Cycles.

In terms of rutting performance, as theoretically expected, Fig. 4 shows an increasing rutting response trend in magnitude with an increase in the asphalt-binder content. All the PG 76-22 sources satisfied the specification requirements with the PG 76-22 Source C exhibiting superior performance followed by Source A and lastly, Source B. Thus, any asphalt-binder source and AC level would be satisfactory in terms of meeting the HWTT rutting requirements [9].

With respect to the OT cracking performance, while the peak load in Fig. 5 shows no definitive response trend to AC. Fig. 6 shows that only the PG 76-22 Source C failed to meet the specification requirement and thus, cannot be selected as the CAM mix-design under specification Item 3131 [5]. As shown in Fig. 6 and photographically demonstrated in Fig. 7, the PG 76-22 Source C hardly reached 200 OT cycles prior to crack failure and thus, does not qualify to be used for a CAM mix with the given aggregates.

Fig. 6 further shows that the cracking performance of the PG 76-22 Sources A and B are insignificantly different, particularly at the high asphalt-binder content of 6.7% or more. Any of these two sources would thus be the appropriate selection in terms of meeting the cracking performance requirements. While theoretically expected to decrease with an increase in the asphalt-binder content, the OT peak loads in Fig. 5 do not seem to exhibit a definitive trend.

To investigate the cause of the poor laboratory performance of the PG 76-22 Source C in the OT test, DSR and BBR tests were conducted to characterize the rheological properties of the asphalt-binders. The results are shown in Fig. 8 and Table 3, respectively.

As shown in Fig. 8 and Table 3, the PG 76-22 Source C was found to be a stiffer asphalt-binder that finally graded out as a PG 82-22, i.e., the true grade temperature range is 82.46-22 °C (Table 3). It is evident from these results that not all PG76-22 asphalt-binders are manufactured equally; it is apparent that material source has an influence and needs to be considered when selecting the appropriate material combinations during the mix-design stage. The State of Texas currently does not test the upper temperature end, and therefore, an asphalt-binder can be a PG 82- but still be accepted as a PG 76; which as shown herein could be a potential issue in terms of both the asphalt-binder rheological properties and the overall mix performance. Nonetheless, this is not

Fig. 7. Photos of the OT Test Specimens.

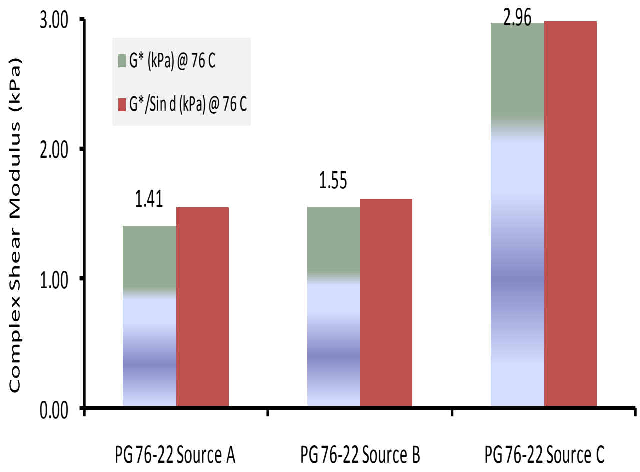

Fig. 8. Comparison of Asphalt-Binder Shear Modulus at 76 °C.

Table 3. Asphalt-Binder DSR and BBR Test Results.

Asphalt-Binder	DSR (Higher Temp)			BBR (Lower Temp)			True Grade Temp (°C)	Final PG Grade
	Temp (°C)	G* (kPa)	G*/Sin δ (kPa)	Temp (°C)	S (MPa)	m-value		
PG76-22 Source A	76.03	1.41	1.54	-12	174	0.325	80.05-22	PG 76-22
PG76-22 Source B	76.03	1.55	1.61	-12	132	0.316	80.58-22	PG 76-22
PG76-22 Source C	81.97	1.03	1.05	-12	277	0.317	82.46-22	PG 82-22
Threshold		≥ 1.00 kPa			≤ 300	≥ 0.300		

Legend: G* = complex shear modulus; S = stiffness to discount the fact that the performance of the PG 76-22 Source C would have probably been different if a different aggregate type was explored; however, this was beyond the scope of this study.

Also, the compatibility of the materials (i.e., asphalt-binder from different sources and aggregates) is another aspect that might have influenced the laboratory test results. As noted in Figs. 2 through to 6, there is a differences in the VMA values, density attainment, rutting, and cracking performance for the three different asphalt-binder sources. Material compatibility including adhesion/bonding of the asphalt-binder and aggregate might have placed a role, i.e., an asphalt-binder from one source may compatibly bond well with the aggregate (limestone) considered in this study versus an asphalt-binder from another source. And this ultimately could have led to the differences in the laboratory performance of the three asphalt-binder sources as was evident in Figs. 2 through to 6.

Discussion and Sythensis of the Results

From the results presented and considering the three asphalt-binder sources that were evaluated, the following are evident:

- The cause of the problems with the PG 76-22 Source C asphalt-binder is that it actually graded out as a relatively stiffer PG 82-22 compared to the other asphalt-binder sources. While having superior rutting performance in the Hamburg test because of the stiff asphalt-binder, the CAM mix made with this asphalt-binder (from Source C) could not meet the OT requirements (< 200 OT cycles) as dictated by the specification Item SS 3131.
- By contrast, both the PG 76-22 Source A and B asphalt-binders met the CAM Item 3131 specification requirements at all the laboratory design densities (96.5 to 98%) that were evaluated. These results are listed in Table 4 and clearly show that the PG 76-22 Source A had superior laboratory performance.
- Consistent with the specification Item SS 3131 and because of its superior rutting performance, it was decided to consider PG 76-22 Source A at 98% laboratory density as the potential CAM mix design standard with an OAC of 7.1%. At this OAC, the HWTT rut depth was 5.4 mm after 20,000 passes and 1000 OT cycles.

However, Table 4 shows that all the performance test requirements were satisfactorily met even at a lower lab density of 96.5% on the PG 76-22 Sources A and B while using about 0.5% less asphalt-binder compared to that at 98% laboratory density, i.e., 6.5 versus 7.1%. On the basis of being conservative, it was elected to use 6.7% PG 76-22 from Source A, which is allowable under the CAM specification Item 3131 where the asphalt-binder is paid for as a separate bid item. Based on Table 4, the 6.7% PG 76-22 Source A corresponds to 97% laboratory density; with a HWTT of 4.3 mm rutting after 20 000 load passes and OT cycles of 1 000; which satisfactorily meets the specification Item 3131 [5].

This CAM mix-design (6.7% PG 76-22 Source A plus limestone aggregates plus 1% hydrated lime) was accordingly placed on a severely cracked in-service highway FM 158 in 2010 as a 1-inch thick overlay. Figs. 9 and 10 illustrate the highway FM 158 before and just after placement of the CAM mix, respectively.

As a means to validate the mix-design, laboratory tests were also conducted on plant-mix materials hauled from the project site. The extracted asphalt-binder content was close to the design value (6.55% versus 6.7%) and the measured HWTT and OT also did not differ significantly from the design values. These results are summarized in Table 5. As evident in Figs. 11 and 12, the 0.8 mile

Table 4. Tentative CAM Mix-Design Recommendations.

Lab Density	PG 76-22 Source A				PG 76-22 Source B			
	AC	VMA	HWTT	OT	AC	VMA	HWTT	OT
96.5%	6.5%	18.7	3.2 mm	861	6.6%	18.6	4.8 mm	951
97.0%	6.7%	18.7	4.3 mm	1 000	6.7%	18.1	4.9 mm	956
97.5%	6.9%	18.7	5.0 mm	938	6.9%	18.1	5.7 mm	1 000
98.0%	7.1%	18.7	5.4 mm	1 000	7.1%	18.4	7.4 mm	951
Threshold		≥ 16.0	≤ 12.5 mm	≥ 750		≥ 16.0	≤ 12.5 mm	≥ 750

Legend: AC = asphalt-binder content; VMA = voids in mineral aggregates; HWTT = Hamburg; OT = Overlay.

Fig. 9. FM 158 Before CAM Mix Overlay Placement.

Fig. 10. FM 158 After CAM Mix Overlay Placement in 2010.

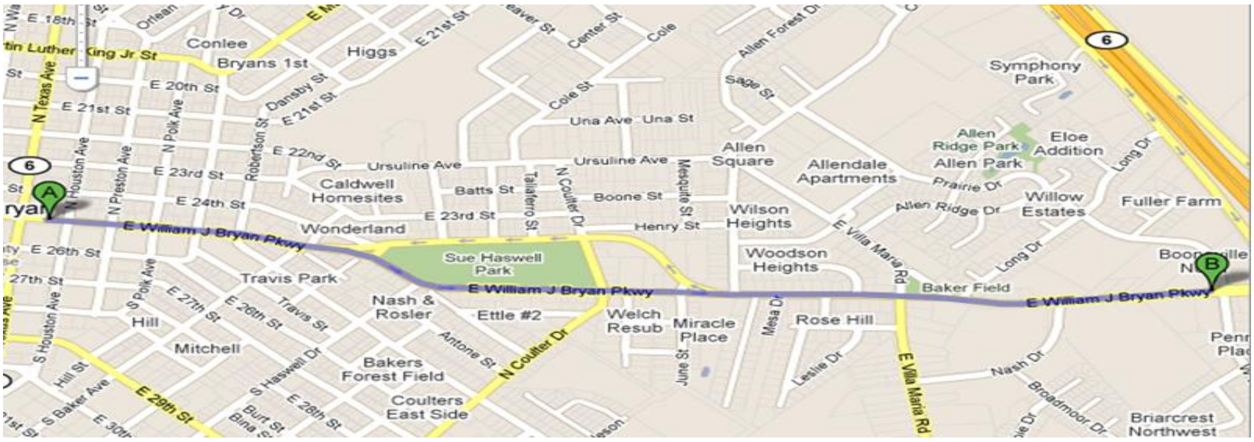

Fig. 11. Aerial View of FM 158 where the CAM Mix was Constructed in 2010.

Fig. 12. Pictorial View of FM 158 as of July 2013.

(1.3 km) highway where the mix was placed is also still performing well after 3 years of service.

Summary and Recommendations

From this case study and based on the results presented in this paper, the lessons learnt along with the recommendations can be summarized as follows**:**

(1) Not all PG 76-22 asphalt-binders are manufactured equally; it is apparent that material source has an influence. As at the time of this paper, there was no test requirement on the upper

Table 5. Laboratory Results of Plant-Mix Material from the Project Site.

Item	Specification SS 3131	Design	Plant-Mix Material from Project Site
OAC	≥ 6.5%	6.7%	6.55%
Hamburg Rutting after 20 000 Load Passes	≤ 12.5 mm	4.3 mm	4.4 mm
OT Crack Test	≥ 750	1 000 cycles	796 cycles

temperature end, and, therefore, an asphalt-binder that is graded as PG 82- can still be accepted as a PG 76-; which as shown herein could be a potential issue in terms of the overall mix performance. Nonetheless, this is not to discount the fact that the performance of the PG 76-22 Source C would have probably been different if a different aggregate type was explored.

(2) Contractors should be cautious to always check the quality of all their material sources and ensure that they satisfactorily meet the specification requirements.

(3) In addition to the standard 98% target laboratory density, performance tests on future CAM designs should also be run at asphalt-binder contents found at lower laboratory densities such as 96.5, 97, or 97.5%. As shown herein, this could lead to a potential cost saving while still satisfying the CAM lab performance requirements and being construct-able in the field.

(4) The usage of a PG 76-22 with 1% lime for CAM designs to be placed as surface layers in high traffic locations appears to be working well; considerations should thus be made to incorporating these requirements into future specifications.

(5) Caution needs to be exercised when selecting materials during the mix-design process so as to optimize material compatibility and maximize performance. In the case of asphalt-binders, high and low temperature testing is recommended. For the HMA (i.e., combination of asphalt-binders and aggregates), cracking and rutting tests along with moisture susceptibility tests are recommended as a minimum.

Based on this study's findings, a 6.7% PG 76-22 Source A CAM mix (with limestone aggregates and 1% hydrated lime) corresponding to 97% laboratory density (as opposed to 7.1% at 98% lab density) was selected to be placed over a severely cracked in-service highway FM 158 as a 25 mm thick overlay. No construction problems were experienced with the mix. Performance monitoring is currently ongoing to correlate with the laboratory results and findings will be reported in future publications. But as at the time of writing this paper, no major distressed had been observed on FM 158 after over three years of service.

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