Use of Asphalt Pavement Analyzer Testing for Evaluating Premium Surfacing Asphalt Mixtures for Urban Roadways

Arthur G. Johnston, C.E.T., Principal Consultant,
EBA Engineering Consultants Ltd., Calgary, Alberta

Ken Yeung, P.Eng., Materials and Research Engineer,
City of Calgary, Calgary, Alberta

Derrick Tannahill, E.I.T., Road Infrastructure Engineer,
City of Lethbridge, Lethbridge, Alberta

Paper prepared for presentation
at the Accelerated Pavement Testing - Pavements Session
of the 2005 Annual Conference of the
Transportation Association of Canada
Calgary, Alberta

ABSTRACT

Urban roadway pavement rutting, particularly at signalized intersections, is a significant issue and a challenge for those responsible for municipal pavement infrastructure. Agencies have, in recent years, been proactive in trying new strategies for dealing with this problem. These strategies have included premium hot mix asphalt (HMA) surfacing materials including the use of polymer modified or performance grade asphalt binder, stone matrix asphalt (SMA), Superpave mix types, sulfur extended asphalt modifier, and asphalt rubber mixes. The Cities of Calgary and Lethbridge have recently installed various types of pavement surfacing materials with the objective of assessing performance under in-service conditions. The limited experience with these types of hot mix asphalt materials has made it necessary for the municipal agencies to adopt available methods to provide some indication of their performance prior to their widespread use in construction. The Asphalt Pavement Analyzer (APA) has been shown to be a useful tool for the assessment of the permanent deformation (rutting) resistance of HMA materials.

This paper describes how APA testing was used for the assessment of HMA materials within the context of projects undertaken by the Cities of Lethbridge and Calgary, in 2003 and 2004. In some cases the APA testing was used to validate and/or optimize HMA mixture designs. This means of accelerated testing was also used to evaluate the rut resistance performance of constructed pavements, with the objective of assessing the different materials and construction strategies. Guidance regarding the use of APA results, including benefits as well as limitations, is provided.

INTRODUCTION

Urban roadway pavement rutting, particularly at signalized intersections, is a significant issue and a challenge for those responsible for municipal pavement infrastructure. Agencies have, in recent years, been proactive in trying new strategies for dealing with this problem. These strategies have included premium hot mix asphalt (HMA) surfacing materials including the use of polymer modified or performance grade asphalt binder, stone matrix asphalt (SMA), Superpave mix types, sulfur extended asphalt modifier, and asphalt rubber mixes. The Cities of Calgary and Lethbridge have recently installed the majority of these types of pavement surfacing treatments in Alberta, with the objective of assessing performance under in-service conditions.

This paper will describe how APA testing was used for the assessment of HMA materials within the context of projects undertaken by the Cities of Lethbridge and Calgary, in 2003 and 2004. The projects included both existing pavement rehabilitation and new construction. In some cases the APA testing was used to validate and/or optimize HMA mixture designs. This means of accelerated testing was also used to evaluate the rutting performance of constructed pavements, with the objective of assessing the relative cost/benefit of different materials and construction strategies.

BACKROUND

The recent adoption of the Superpave system has provided, what most would agree, better tools for selecting, specifying and testing asphalt binders, along with the specifying and design of asphalt concrete mixtures. However, this mix design system is based entirely on mix volumetric properties and has no stability or rut test to verify designed mixes. This, as well as the increased use of premium surfacing materials such as stone matrix asphalt (SMA) has led many agencies to rely on accelerated pavement testing techniques. The increased use of these materials and protocols in the urban context is often to enhance pavement performance (i.e. instability rutting, durability, skid resistance, noise).

In addition, limited experience with these types of hot mix asphalt (HMA) materials often serves as the incentive to use available methods to provide some indication as to the rutting susceptibility of a particular mixture prior to its use in construction. In some cases, for relatively unique mixture types such as SMA, designers are encouraged to use rut testing to validate mixture designs [1]. Currently the Superpave system does not typically include a true indication of the potential for permanent deformation of a mixture, nor does a true “performance based” test appear to be available for widespread use in the near future.

This has led most practitioners and agencies to rely on what are commonly referred to as “torture tests” to assess the potential rutting susceptibility of mixes.

The Asphalt Pavement Analyzer (APA) is a mix design "torture test" that can provide empirical testing of asphalt mixes at the design stage. The APA, which is an evolution of the Georgia Loaded Wheel Tester (LWT), is one of several loaded wheel testers used for accelerated performance testing of asphalt mixes.

The Georgia LWT was developed in 1985 through a partnership between the Georgia DOT and the Georgia Institute of Technology [2]. The Georgia LWT, originally designed to test slurry seals, was modified to perform efficient, effective, and routine laboratory testing and field production quality control of HMA. The APA, which was manufactured in 1996 by Pavement Technology Inc, is the second-generation of the Georgia LWT. The APA has additional features to allow the machine to evaluate not only the rutting potential of mixes, but also their moisture susceptibility and fatigue cracking under service conditions.

Currently, the APA is one of the most widely used loaded wheel tests in the United States and Canada. Many transportation agencies in the United States and Ontario are using the APA for mix design verification and optimization, pavement evaluation, quality control, assessment of new materials including modified binders and specialty mixes, and pavement failure investigation [3.4]. In Canada, the Ministère des Transports du Québec requires HMA rut resistance testing using the French Laboratory Rutting Tester on medium to high volume roads. However, most provinces currently do not routinely require rutting resistance testing.

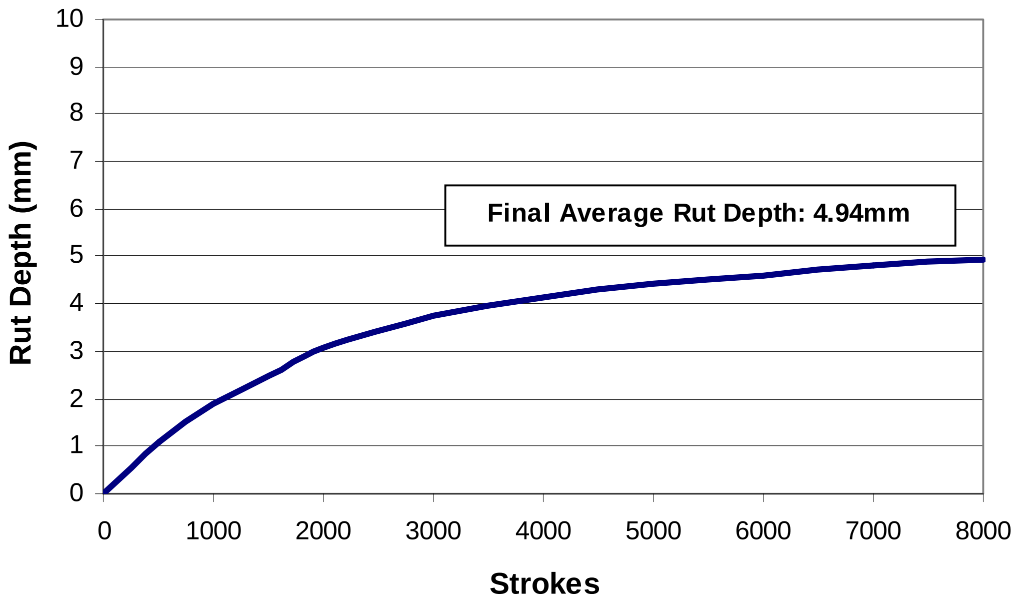
ASPHALT PAVEMENT ANALYZER METHODOLOGY

The APA is a multifunctional loaded wheel tester that uses pneumatic cylinders on a concave metal wheel to apply repetitive load applications through a pressurized rubber hose. Typically, 8000 repetitions or strokes are applied to the HMA specimens. Contact pressures up to 1378 kPa (200 psi) can be generated, but typically a contact pressure of 690 kPa (100 psi) contact pressure is used to simulate actual field loading conditions. Calibration of the applied load, contact pressure and deformation measurement is built in to the APA system and is computer controlled [5].

The APA can accommodate triplicate beam specimens (100mm x 300mm x 75mm thick) or three sets of two cylindrical specimens. Cylindrical specimens are 150mm diameter with a standard thickness of 75mm. Shimming can be used to accommodate cylindrical specimens less than 75mm. Specimens are tested in an environmentally controlled test chamber. Typically, the selected test temperature represents the high temperatures representative of the actual project environmental conditions. Superpave binder selection methodology is commonly used to select the appropriate test temperature (i.e. the standard high pavement temperature for the project location) [6].

The APA provides the average deformation measured for two "in line" cylindrical specimens, or three points on each beam specimen. Figure 1 provides a typical graphical output from the APA.

Figure 1
Typical APA Output



CITY OF LETHBRIDGE EXPERIENCE

Mix Design Optimization

In 2003 a Value Engineering (VE) process was used to select the surfacing for the Mayor Magrath Drive Upgrade project in the City of Lethbride. This project comprised the reconstruction of approximately three kilometers of a six lane divided arterial roadway. Although the VE process identified SMA as the preferred surfacing material, a risk management issue identified that APA testing would be needed to validate the design job mix formula (JMF), using a 5mm APA rut depth as the "pass – fail" criteria [7].

Traditionally, the design compaction effort for SMA mixtures has been 50 blows per side using the Marshall method. More recently the Superpave gyratory compactor (SGC) has been used for SMA mixture design. In general, 100 gyrations is recommended for the design compactive effort, but 75 gyrations is used for base mixtures or mixtures using relatively soft aggregates.

For the Mayor Magrath Drive project, the SMA mixture design process considered all three compactive efforts. Although emphasis was placed on maintaining an adequate binder content to address durability, e.g. 6% minimum for a 12.5mm nominal maximum size (NMS) mixture, care should be exercised to ensure that this level of binder and mastic volume does not sacrifice rut resistance performance.

Table 1 provides the binder content, volumetric properties and APA rut depth for the three design compaction efforts. As shown, the APA specimens were prepared at air void contents that were expected to represent field compaction.

Table 1
APA Validation of 2003 SMA Mixture Design

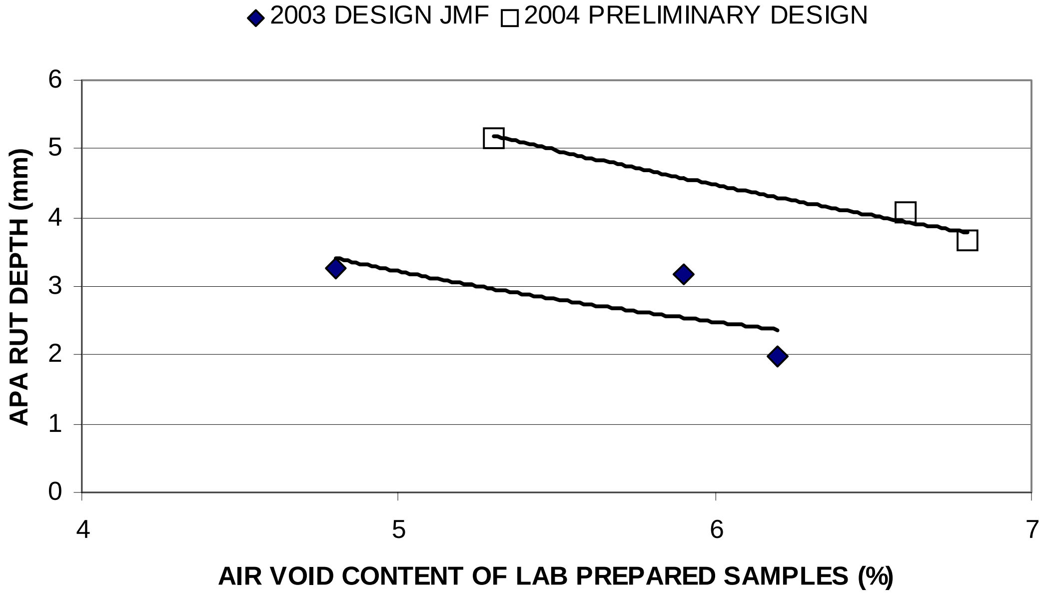
Binder Content (%)	Air Void Content (%)	APA Rut Depth (mm)
5.5	6.1	2.78
5.5	5.4	3.26
5.9	6.2	1.98
6.3	5.9	3.18
6.3	4.8	3.27

Note: All testing at 58°C
Binder contents derived for 4% air void content at:
- 100 gyrations in SGC for 5.5% binder content.
- 50 blow Marshall for 5.9% binder content.
- 75 gyration in SCG for 6.3% binder content.

On this basis, a design JMF binder content of 5.9% was selected, which corresponded to a compaction effort of 50 blows. The rational was that for this aggregate blend, 5.9% binder was the highest volume of binder that did not appear to negatively impact rutting performance.

In 2004, a second SMA mix design for the next section of Mayor Magrath Drive was undertaken using a different aggregate and mineral filler source. A preliminary design JMF was evaluated with the APA. Although this preliminary JMF was very similar to the 2003 JMF, the rutting potential, as indicated by the APA results illustrated in Figure 2, was significantly increased for a range of binder content between 5.9% and 6.3%.

Figure 2
Comparison of APA Rut Depth Between 2003 an 2004 SMA Designs



In examining the reason for this potential performance deficiency, it was noted that although the 2004 design gradation blend was essentially identical to the 2003 JMF, the "volume" (not mass) of mineral filler was greater. To provide an indication of the impact of this increased mineral filler volume further APA testing was undertaken. This involved evaluating a revised aggregate blend containing approximately 1% less mineral filler, by volume. Table 2 summarizes the results of the mixture design optimization.

Table 2
APA Optimization of 2004 SMA Mixture Design

Binder Content (%)	Mineral Filler Volume (%)	Air Void Content (%)	APA Rut Depth (mm)
6.2	11.3	5.3	5.17
6.2	11.3	6.6	4.07
5.9	11.3	6.8	3.68
6.2	10.2	6.4	2.67
5.9	10.2	5.6	2.24

As shown in Table 2, for a given binder content the APA rut depth was significantly less (30% to 40%) for the aggregate blend with the lower mineral filler volume. On this basis, the lower filler content was selected for the project JMF. This installation is slated for construction in 2005.

Performance Assessment

In 2005, the City of Lethbridge undertook an assessment of several premium HMA installations using APA testing of field core samples. The primary objective of this program was to potententially gain some early indication of the rutting performance of the mixture types. This would hopefully provide some support for the additional cost associated with most premium surfacing materials.

Generally, all of the mixtures included in the performance assessment used high quality aggregates including high coarse aggregate fracture (95% to 100%) and relatively high proportions of manufactured fine aggregate (70% or more of the fine fraction). Therefore the assessment was primarily related to mixture type (fine or coarse gradation, SMA etc.) and binder / modifier composition. Table 3 summarizes the results of the APA test program.

Table 3
Field Core APA Test Results

Set	Year	Mixture Type	Binder Type	Binder Content (%)	Air Void Content (%)	APA Rut Depth (mm)
A	2003	SMA 12.5mm NMS	PG 70-31 (PMA)	5.9	4.8	4.12
B	2003	SMA 12.5mm NMS	PG 70-31 (PMA)	5.9	4.4	4.90
C	2003	Superpave 12.5mm NMS - Fine	PG 70-31 (PMA)	5.1	2.1	9.58
D	2004	Superpave 12.5mm NMS - Fine	PG 70-31 (PMA)	5.1	5.1	6.54
E	2004	Superpave 12.5mm NMS - Fine	PG 62-37 (Rubber)	5.6	4.1	8.67
F	2004	Superpave 12.5mm NMS - Fine	PG 62-37 (Rubber)	5.6	2.9	7.23
G	2004	Marshall – 75 Blow 16mm NMS	150/200 A	4.8	4.7	7.15
H	2000	Superpave 12.5mm NMS - Coarse	150/200 A	5.2	5.9	7.37
I	2003	Superpave 12.5mm NMS - Coarse	150/200 A	5.4	2.8	7.98

Note: All APA testing at 58°C
“Year” refers to year constructed
“Fine” and “Coarse” refer to Superpave Gradation Designation
PG 62-37 (Rubber) is asphalt cement blended with crumb rubber

With respect to the information in Table 3, the following is provided regarding the various surfacing materials and installations, along with comparative observations.

- All installations comprised mill and inlay rehabilitation projects with the exception of Sets A and B, which were new construction.

- Sets A and B represent the SMA mixture placed on Mayor Magrath Drive in 2003, for which the mixture design optimization using APA testing was described previously. The samples tested had acceptable air void content and provided the lowest APA rut depths for the program.

- Sets C and D represent the same JMF placed in successive years. The rut depth for Set D was nearly double that of Set C. This is likely due to the lower in-place air void content of Set C (and potentially less than desirable volumetric properties).

- Sets E and F, from the same installation, are an experimental mix using the same aggregate source and blend as Sets C and D. The binder consists of a terminal blend of 200/300 A asphalt cement and approximately 8% crumb rubber. The PG grading (PG 62-37) is based on Superpave binder testing on the product produced. Generally, for a similar air void content, the mix has slightly higher rut depths than the same aggregate blend using PG 70-31, which would seem reasonable.

- Set G represents the standard mix type used by the City of Lethbridge over the past 15 years for higher traffic applications. The mix has similar coarse and fine aggregate angularity as the Superpave Fine mixes with a somewhat coarser gradation. This mix has historically provided good rutting performance other than localized areas at heavily trafficked intersections, but is typically prone to surface raveling.

- Sets H and I are the same JMF placed in two different installations three years apart. The mix placed where Set H was sampled had less than desirable void properties, and has exhibited substantial rutting. The mix represented by Set I had acceptable void properties and rutting performance has been good. Although the APA results rank the mixes as expected, the difference in rut depths is not considered significant.

CITY OF CALGARY EXPERIENCE

Performance Assessment

In 2004, the City of Calgary undertook a series of full-scale demonstration projects aimed at evaluating the potential performance enhancement offered by several premium surfacing materials, including:

1. SMA, 12.5mm nominal maximum size (NMS) using 6.0% Performance Grade (PG) 70-31 polymer modified binder (PMA).

2. 12.5mm NMS SMA, modified with 3% manufactured shingle modifier (MSM), with PG 67-37 PMA, for a total binder content of 6.0%.

3. Superpave (12.5mm NMS, Fine Graded) using the same PG binder and content as 1.

4. Superpave (12.5mm NMS, Fine Graded) using the same percentage of PG binder and MSM modification as 2.

5. A gap graded 12.5mm NMS mixture using 8.0% asphalt rubber (AR) binder, comprising 150/200 A asphalt cement blended with 18.5% (by mass of binder) crumb rubber.

6. Superpave (12.5mm NMS, Fine Graded) incorporating 3.9% 150/200 A asphalt cement and 2.6% sulfur extended asphalt modifier (SEAM).

Again all of these mixtures had very good aggregate characteristics. Typically the coarse aggregate fracture was greater than 95%, and the fine aggregate fraction angularity was enhanced by 70% or more manufactured fine aggregate in the fine graded mixtures, and typically 100% in coarse or gap graded mixtures.

These matrixes of mix types, binders and modifiers offered several comparisons. In terms of binder selection PG 70-31 represents a 98% reliability for the high temperature climate conditions in Calgary, with two high temperature bumps, i.e. 12°C, in recognition of the impact of signalized intersections (standing traffic condition) in all locations [8]. When MSM was used as a modifier PG 67-37 PMA was incorporated in both the Superpave fine and SMA mix types. This was done in recognition of the relatively stiff asphalt cement contribution from the MSM. At the MSM dosage rate used for these mixes, the high temperature grade of the virgin binder is typically increased 3°C to 4°C [9]. The objective was to have the two binder / modifier combinations provide, as close as practical, the same high temperature grade. This could then enable the comparison of the rutting performance, based on two mix types, on an “equal” basis and thereby identify any potential benefits offered by MSM.

The matrix also offered the direct comparison of SMA and Superpave fine graded mixtures, based on the two binder / modifier combinations described. The mix incorporating SEAM used the same Superpave fine aggregate gradation, and therefore an additional comparison. Although from a different aggregate source, the asphalt rubber mix had a similar gradation as the SMA mixtures, albeit without the filler.

All of the mixtures were placed in a mill and inlay rehabilitation application. Typically for these installations the depth of placement varied not only from one project to another, but also within a project where depth was increased within the areas more significantly affected by signalized intersections.

APA testing was again used to provide an assessment of the rutting potential of the various mixture types. For this program, field cores were acquired from the various installations within several months of construction. Table 4 provides the APA results for the core specimens along with the air void content determined for the cores.

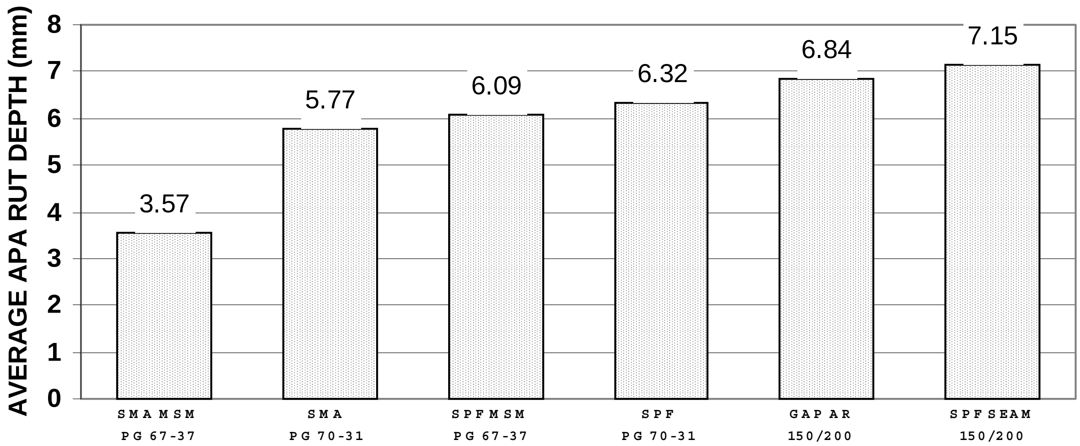
Table 4
Field Core APA Test Results

Set	Mixture Type	Binder Type	Modifier	Air Void Content (%)	APA Rut Depth (mm)
A	Asphalt Rubber – Gap Graded, 12.5mm NMS	150/200 A	Crumb Rubber	7.0	6.69
B	Asphalt Rubber – Gap Graded, 12.5mm NMS	150/200 A	Crumb Rubber	8.9	12.74
C	Asphalt Rubber – Gap Graded, 12.5mm NMS	150/200 A	Crumb Rubber	8.5	7.00
D	Superpave 12.5mm NMS - Fine	150/200 A	SEAM	6.1	6.92
E	Superpave 12.5mm NMS - Fine	150/200 A	SEAM	8.3	7.39
F	Superpave 12.5mm NMS - Fine	PG 70-31 (PMA)	None	5.6	4.67
G	Superpave 12.5mm NMS - Fine	PG 70-31 (PMA)	None	7.8	7.97
H	Superpave 12.5mm NMS - Fine	PG 67-37 (PMA)	MSM	6.2	8.62
I	Superpave 12.5mm NMS - Fine	PG 67-37 (PMA)	MSM	7.3	6.55
J	Superpave 12.5mm NMS - Fine	PG 67-37 (PMA)	MSM	6.2	5.62
K	SMA 12.5mm NMS	PG 70-31 (PMA)	Cellulose Fibre	7.2	5.16
L	SMA 12.5mm NMS	PG 70-31 (PMA)	Cellulose Fibre	6.8	8.25
M	SMA 12.5mm NMS	PG 70-31 (PMA)	Cellulose Fibre	7.4	6.38
N	SMA 12.5mm NMS	PG 67-37 (PMA)	MSM	3.7	3.35
O	SMA 12.5mm NMS	PG 67-37 (PMA)	MSM	5.4	3.78

Note: All APA testing at 58°C
“Fine” refers to Superpave Gradation Designation
SEAM denotes sulphur extended asphalt modifier
MSM denotes manufactured shingle modifier

The average APA result was used to compare the relative rutting performance of the various mixes. As the majority of the mixes had only two sets of specimens tested, the average of the two lowest rut depth results was used where three sets of results existed for a particular mix type. The ranked APA results, based on core testing, are presented in Figure 3.

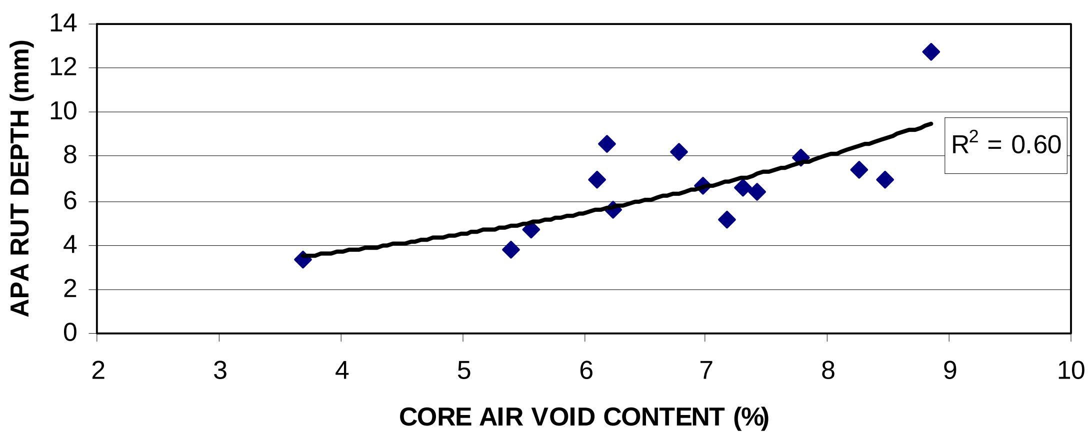
Figure 3
APA Ranking Based on Field Core Testing



Although this comparison is generally consistent with "expected performance", some inconsistencies are evident. For example, the rut depth of the two Superpave mixes with similar high temperature binder characteristics is similar, but the rutting depth of the two SMA mixes is not similar.

Previous research had indicated that the air void content of core samples may be a variable that influences the APA rut depth. Figure 4 illustrates the APA rut depth / air void content relationship for all field core sets.

Figure 4
Comparison of Core Air Voids and Rut Depth



Although only a fair correlation exists (R^2=0.60), there appears to be a clear trend that as air void content increases the APA rut depth increases. Based on this limited data, core samples with air void contents greater than 7% when tested using the APA may not provide a good indication of rutting susceptibility. This is most likely the case when this air void level is not typical of the installation.

For five of the six mixtures used in Calgary (excluding the asphalt rubber mix), Superpave gyratory compactor specimens were fabricated from plant mix produced for the projects. The target air void content was ± 4%. The results of this APA testing program are provided in Table 5.

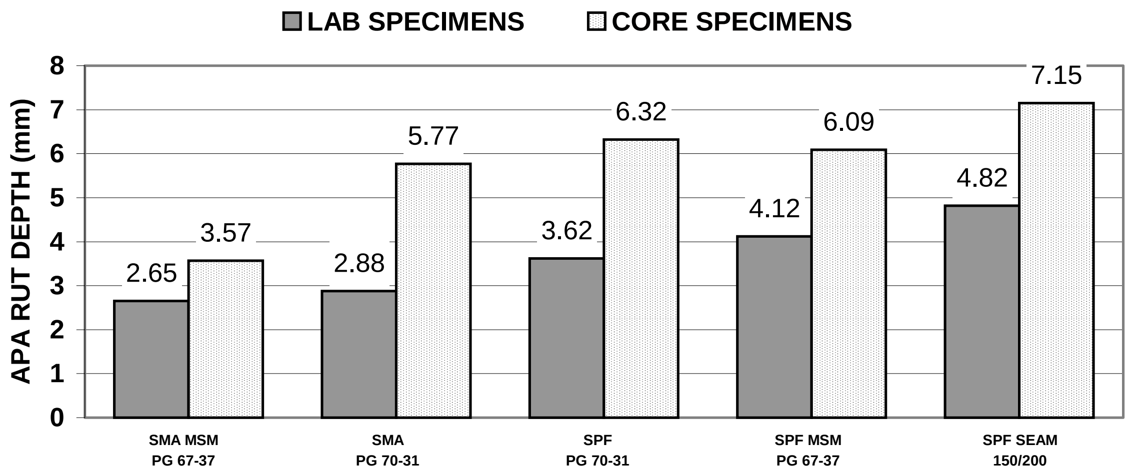
Table 5
Laboratory Prepared APA Results

Set	Mixture Type	Binder Type	Modifier	Air Void Content (%)	APA Rut Depth (mm)
1	Superpave 12.5mm NMS - Fine	150/200 A	SEAM	4.0	4.79
2	Superpave 12.5mm NMS - Fine	150/200 A	SEAM	4.0	4.73
3	Superpave 12.5mm NMS - Fine	150/200 A	SEAM	4.1	4.94
4	Superpave 12.5mm NMS - Fine	PG 70-31 (PMA)	None	4.0	3.62
5	Superpave 12.5mm NMS - Fine	PG 67-37 (PMA)	MSM	4.1	4.12
6	SMA 12.5mm NMS	PG 70-31 (PMA)	Cellulose Fibre	4.1	2.88
7	SMA 12.5mm NMS	PG 67-37 (PMA)	MSM	3.8	2.49
8	SMA 12.5mm NMS	PG 67-37 (PMA)	MSM	4.0	2.81

Note: All APA testing at 58°C
“Fine” refers to Superpave Gradation Designation
SEAM denotes sulphur extended asphalt modifier
MSM denotes manufactured shingle modifier

These results seem to be consistent, in that the results for a given mixture type have less variability and fit with “expected performance”. Figure 5 presents the average APA results, ranked based on laboratory fabricated samples. The average APA field core test results are shown for comparison.

Figure 5
Comparison of Lab Prepared and Core Specimen APA Rut Depths



The lab prepared samples appear to not only have less variability than field core specimens, but appear to better discriminate between mixture types. A comparison of these results indicates a clear superiority of SMA mixtures in terms of rutting performance. This is consistent with previous evaluations of rut resistant HMA materials.

Based on the laboratory results, all of these mixtures would satisfy an APA rutting criteria of 5mm. Consequently, this type of approach may have promise for QA/QC applications. With more experience, a correlation between test results from laboratory specimens and field performance may have some application [2].

CONCLUSIONS

The APA provides both agencies, mix design practitioners, and QA/QC practitioners with a useful tool for assessing the instability rutting potential of HMA materials. This tool has been shown to provide methods wereby:

- An agency can establish rutting criteria for acceptance of mix design job mix formulae.

- Mix design practitioners can assess various mix characteristics (e.g. aggregate blends, binder type and proportion etc), in order to optimize HMA rutting susceptibility.

- An early indication of the relative instability rutting potential of mixes can be obtained before the performance under field conditions is available, but laboratory prepared specimens, at 4% air void content, using production mix appear to provide more reliable results.

CLOSURE

Those involved with asphalt technology may find this information useful when interpreting APA results and utilizing this information for the rutting potential.

It should be noted that although rutting may be a key factor related to the overall performance of HMA for urban applications, it is not the only factor. To fully measure the potential benefits of premium HMA surfacing mixtures, attributes such as durability, skid resistance, noise level, constructability, and others, should, and are being assessed by both the Cities of Lethbridge and Calgary.

ACKNOWLEDGEMENTS

The authors would like to acknowledge both Lafarge Canada Inc. and John Emery Geotechnical Engineering Ltd., who conducted the APA testing presented in this paper and Imants Deme of Asphalt Services and Husky Energy for their financial contribution to the APA testing.

REFERENCES

1. Designing and Constructing SMA Mixtures – State of the Practice, National Asphalt Pavement Association (2002)

2. Kandhal, P., Cooley Jr, L. "Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer" NCHRP Report 508 (2003)

3. Emery, J. "Use of the Asphalt Pavement Analyzer for Asphalt Mix Design and Evaluation" John Emery Geotechnical Engineering Ltd.

4. Uzarowski, L., Paradis, M. "Accelerated Performance Testing of Canadian Asphalt Mixes using Three Different Wheel Rut Testers" Transportation Association of Canada (2004)

5. John Emery Geotechnical Engineering Ltd., Standard Report, Rut Resistance Using the Asphalt Pavement Analyzer, (2004)

6. Federal Highway Administration (FHWA), LTPPBind Software (1999)

7. ALIS Consulting Team, Mayor Magrath Drive Upgrade 2003 Final Lift Paving, Value Engineering Workshop, Final Report (2003)

8. Association of American State Highway and Transportation Officials (AASHTO), Specification M320, (2003)

9. Lum, P., Greko, M., Yonke, E. "Field Performance and Laboratory Evaluation of Manufactured Shingle Modifier in Hot Mix Asphalt" Canadian Technical Asphalt Association (2004)