Use Of The Asphalt Pavement Analyzer For Asphalt Mix Design And Evaluation

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SYNOPSIS

Establishing a link between laboratory testing and the potential field performance of asphalt mixes is very important to achieving improved asphalt pavement life-cycle performance. There have been many attempts to form this missing link by developing laboratory equipment and procedures for accelerated asphalt mix performance testing. The Asphalt Pavement Analyzer (APA) loaded wheel tester has been successfully used to evaluate the rutting resistance, fatigue endurance and moisture susceptibility of cold and hot-mix asphalt. With the APA, the asphalt engineer is able to check laboratory and field samples to assess how asphalt mixes designed using Marshall, Superpave, and other methods will perform under simulated field conditions. The APA is being regularly used for mix design verification (main current area of APA use), asphalt pavement evaluation, assessment of new asphalt materials including modified binders, quality control, and pavement failure investigation.

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INTRODUCTION

With the introduction of the Superpave asphalt mix design method, new aggregate and binder materials, and enhanced asphalt technologies, there is a need for accelerated asphalt pavement laboratory performance testing to give asphalt engineers information on potential asphalt mix field performance. There is consensus in the asphalt industry that a realistic, dependable performance test would greatly assist in deciding what materials to use in new and rehabilitated asphalt (flexible) pavements. If nothing else, such testing would indicate which asphalt mixes might result in poor performance, thereby helping to avoid the use of such inferior mixes. The Pavement Technology automated Asphalt Pavement Analyzer (APA) loaded wheel tester has been successfully used to evaluate the rutting resistance, fatigue endurance, and moisture susceptibility of cold and hot-mix asphalt. With the APA, the asphalt engineer is able to check both laboratory and field samples to assess how mixes designed using different materials and methods will perform under simulated field conditions.

The APA has been widely used in Ontario and the United States for mix design verification and optimization (main current area of APA use), pavement evaluation, assessment of new materials including modified binders, quality control, and pavement failure investigation. The results of APA rutting susceptibility and fatigue endurance testing have been correlated directly with the Nottingham Asphalt Tester (NAT) and with many users of the APA equipment in the United States (APA User Group). Most APA research in the United States has concentrated on rutting resistance testing, as this has been a fairly significant asphalt pavement distress, particularly in hot-climate zones. Rutting resistance acceptance criteria have been developed by the APA User Group in conjunction with the National Center for Asphalt Technology (NCAT). John Emery Geotechnical Engineering Limited (JEGEL) was involved with the development of the detailed APA fatigue testing procedure and asphalt mix fatigue acceptance criteria. The use of the APA to determine the rutting susceptibility of asphalt mixes is now a standard method of test in North America (AASHTO 2003).

BACKGROUND

Many agencies are investigating the use of improved overall methods of hot-mix asphalt design. In the United States, most transportation departments have switched from the Marshall method to the Superpave mix design system (asphalt cement grade selection, aggregate quality and gradation selection, and gyratory compaction/volumetrics). However, this mix design system is based on mix volumetric properties and has no performance test (stability for instance) to verify, or proof test, the designed hot-mix asphalt (HMA) for potential field performance parameters such as permanent deformation (rutting) resistance. One of the main objectives of the Strategic Highway Research Program (SHRP) was to develop a model or equation to predict field performance of asphalt pavements using physical properties of the asphalt cement and aggregates. This part of the program has proven to be very difficult because of the number of variables that impact on asphalt pavement performance. As a result, SHRP has not, as yet, been able to deliver a dependable and comprehensive laboratory performance-related test that can be readily applied to hot-mix asphalt.

When designing asphalt concrete pavements, the climate conditions, traffic volumes and vehicle loadings are major considerations. During the past ten, or more, years, asphalt engineers have focused their efforts on developing testing equipment and methods that would allow accelerated asphalt concrete performance prediction in the laboratory. The main asphalt mix and asphalt concrete performance properties to be considered are: permanent deformation (rutting); fatigue cracking; and moisture-induced (stripping) damage (Brock et al. 1998).

Many testing systems have been developed to measure these three potential performance characteristics, but most have fallen short in evaluating the wide variety of conditions to which asphalt pavements are exposed. The loaded wheel tester has demonstrated that it can be successfully used in evaluating the rutting potential of hot-mix asphalt in so called 'torture testing'. The Georgia Loaded Wheel Tester (GLWT) was developed to accommodate three samples simultaneously, but proved to be unable to provide good control of temperature during testing. The APA, developed in 1996, is the latest, multi-functional version of the GLWT. It is one of the few pieces of test equipment that can provide empirical testing of asphalt mixes during the design stage. The APA has been used to evaluate the rutting resistance, fatigue endurance and moisture susceptibility of cold and hot-mix asphalt (Brock et al. 1998; Hall and Williams 1999; Kandhal and Mallick 1999; Uzarowski and Emery 2000). The APA is considered to provide the missing link between laboratory testing and potential field performance of asphalt mixes as shown in Figure 1.

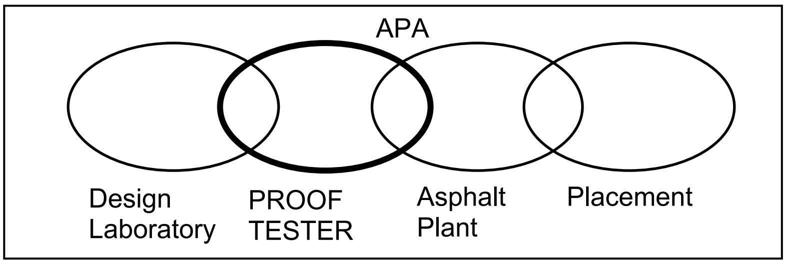


Figure 1: The Asphalt Pavement Analyzer is considered to provide the missing link between laboratory testing and potential field performance of asphalt mixes

THE ASPHALT PAVEMENT ANALYZER AND ASSOCIATED EQUIPMENT

Asphalt Pavement Analyzer

The APA is a multifunctional loaded wheel tester used for accelerated performance testing of asphalt mixes. The APA features controllable wheel loads of up to 113 kg (250 lb) and variable contact pressure. Pneumatic cylinders apply a repetitive load through a high pressure rubber hose to generate contact pressures up to 1378 kPa (200 psi) that are representative of actual field loading conditions. Calibration of the applied load, contact pressure and deformation measurement is built into the APA system and is computer controlled. Triplicate beam samples or six cylindrical samples can be tested under controllable high temperatures and in dry or submerged (in water or other liquid) environments. Testing is completed in a microprocessor-controlled temperature chamber having a temperature range of 5° to 71°C (41° to 160°F). The APA water submersion system includes a tank that can be automatically raised or lowered as needed. The tank is used to place samples completely under water during the testing. The automated data acquisition system features software for measuring permanent deformation and fatigue, and displaying the results in both numeric and graphical format. A computer is used to operate the APA. The APA includes a preconditioning chamber used to bring samples to the desired temperature. Photograph 1 shows the APA in operation.

Photograph 1: Asphalt Pavement Analyzer (APA) in operation

Photograph 2: A single pugmill Asphalt Laboratory Mixer (ALM) is capable of producing up to 16 kg of an asphalt mix in a single batch

Asphalt Laboratory Mixer

The Asphalt Laboratory Mixer (ALM) fills the need for an efficient mixing system in the asphalt mix testing laboratory (Photograph 2). The single pugmill ALM mixer can produce batches as small as 4.5 kg or as large as 16 kg. This capacity is necessary for preparation of APA beam specimens which require about 8 kg of asphalt mix for a single beam. The ALM mixer simulates asphalt plant mixing. Practical experience has shown that the mixer can be successfully used for cold mixes (foamed asphalt, cold in-place recycled and emulsion stabilized mixes for instance) as well as for hot-mix asphalt. The heated mixing chamber is automatically controlled and the temperature is selected and shown on a digital display. The chamber has also been used to simulate short-term aging of asphalt mixes.

Asphalt Vibratory Compactor

The Asphalt Vibratory Compactor (AVC) is used to prepare rectangular (beam) and cylindrical specimens of asphalt mixes (Photographs 3 and 4). The samples are then used in the APA to evaluated the susceptibility to permanent deformation (rutting), fatigue and moisture damage of the mix. The AVC compacts these specimens at a similar amplitude, frequency and relative mass as applied by a construction vibratory roller on the road. Compaction time depends mainly on the type of mix and the air voids level to be achieved. Fine, compactible asphalt mixes may take only 5 seconds to compact to the required air voids level while coarse, harsh mixes could require 30 seconds to compact to the same air voids level.

Photograph 3: Asphalt Vibratory Compactor (AVC) in operation

Photograph 4: One beam and four cylindrical specimens made in the AVC, positioned and ready for testing in the APA

TEST SAMPLES

The APA can be used to test the following laboratory and field samples:

Laboratory samples: beam samples (75 mm x 125 mm x 300 mm) prepared in the AVC; cylindrical samples (150 mm diameter x 75 mm thickness) prepared in the AVC; and cylindrical samples prepared in the Superpave gyratory compactor (150 mm diameter with the thickness trimmed to 75 mm); and

Field samples: cores (150 mm diameter with the thickness trimmed to 75 mm); and
slabs (75 mm x 125 mm x 300 mm).

All of these sample types can be used for rutting resistance (Photographs 5 and 6) and moisture susceptibility testing. Only laboratory prepared beam samples and field slabs can be used for fatigue endurance testing. Laboratory prepared specimens are typically compacted to 7 $\pm$ 0.5 percent air voids. Recent studies have shown that samples compacted with different laboratory compaction devices may have significantly different rutting resistance and moisture susceptibility (Hall and Williams 2000). It has also been shown that AVC beam samples have different density gradients than Superpave gyratory cylindrical specimens (Cooley and Kandhal 1999).

Photograph 5: Beam samples used for APA rutting resistance testing. The mix on the left developed a deep rut during testing and is considered to have poor resistance to rutting. The mix on the right has good resistance to rutting

Photograph 6: The laboratory prepared cylindrical sample on the left developed a deep rut during APA testing. This mix is considered to have poor resistance to rutting. The field core on the right has good resistance to rutting

APA TESTING

The APA is a relatively new piece of equipment developed in 1996. Most APA research in the United States has been concentrated on rutting resistance testing, as this has been a significant asphalt pavement distress, particularly in hot-climate zones. The APA rutting test procedure and acceptance criteria were developed by the APA User Group in conjunction with the National Center for Asphalt Technology (NCAT) (Cooley and Kandhal 1999). The fatigue test procedure and criteria are still under development, and JEGEL is involved in this research (APA User Group).

Permanent Deformation (Rutting) Resistance Test

The rutting resistance of asphalt mixes is assessed by placing beam or cylindrical samples in the test chamber under repetitive wheel loads and measuring the amount of permanent deformation in the wheel path. The test temperature should be representative of the field environment to which the asphalt concrete will be subjected. The SHRP LTPPBind software is typically used to determine the pavement temperature for any project location in North America. The asphalt engineer selects the following LTPP variables: position of a particular asphalt mix in the pavement structure (depth from surface); reliability; and type of traffic. The APA performs rutting resistance testing using three beam or six cylindrical samples simultaneously. It simulates actual road conditions by rolling a concave metal wheel over a rubber hose pressurized at 690 to 827 kPa (100 to 120 psi) to represent the effect of high tire pressures. A load of 100 kN is typically applied to the wheel (Photograph 7). The hose stays in contact with the sample surface while the metal wheel rolls back and forth along the length of the hose for 8,000 cycles, creating a rut in the sample. The rut depth is continuously monitored by a computer and displayed in a numeric and graphical format, or can be measured manually using a precision micrometer.

Photograph 7: Load application system used in the rutting resistance test in the APA

Photograph 8: Fatigue endurance test set-up in the APA. Solid steel wheels are used in the test

Fatigue Endurance Test

The fatigue endurance of an asphalt concrete beam sample is determined by subjecting it to a repeated wheel load of controlled magnitude and contact pressure, typically 1724 kPa (250 psi), in a low temperature environment (typically the test is run at a temperature of 20°C). A beam sample is placed in a mould with supports at both ends. Solid steel wheels are used for this fatigue cracking test (Photograph 8). The fatigue monitoring software averages the two end readings of a beam specimen and plots a solid reference line. A measurement is taken at the midpoint of the beam and is plotted as a dotted line. As fatigue progresses, the lines diverge until a spike (rapid vertical line) occurs and the sample fails (breaks). A divergence of one mm indicates the point of initiation of a fatigue crack at the bottom of the sample.

Moisture Susceptibility Test

The moisture susceptibility of asphalt mixes can be determined in the APA by conducting the test for rutting susceptibility on both dry and pre-conditioned specimens and comparing the results. The samples can be vacuum saturated and soaked in warm water, which is considered appropriate for hot climates, or vacuum saturated, frozen then thawed, and soaked in warm water, which is considered appropriate for cold climates. The water tank is raised to immerse the samples, and the water is brought to the test temperature. The rutting test is then run on samples completely immersed in water. The permanent deformations of dry and wet samples are then compared. The ratio of the permanent deformation of samples conditioned in water to the permanent deformation of dry samples is considered to be an indicator of the moisture susceptibility of the mix.

USE OF APA AND TESTING EXAMPLES

The APA has been widely used in Ontario and across the United States for the following purposes: mix designs (the main area of APA use); pavement evaluation; assessment of new materials including modified binders; quality control; and pavement failure investigations. As a link between the laboratory testing and potential field performance, the APA is considered a particularly useful tool in the mix design process (Kandhal and Mallick 1999; Watson et al. 1997). It effectively allows the ranking of asphalt mixes in terms of their rutting resistance, fatigue endurance and moisture susceptibility. Some States use an APA maximum permanent deformation of 5.0 mm (one uses 3.5 mm) as the fail-pass criterion in designing asphalt mixes for use on interstate highways. It is anticipated that the APA will soon become part of the SHRP performance testing.

JEGEL has been involved with a number of pavement evaluation and failure investigation projects where the APA was used to determine the rutting potential of asphalt mixes. When the mix exhibited excessive rutting in the APA test and the mix volumetrics were poor, it was recommended that the rut susceptible asphalt concrete be removed (milled) and replaced with a rut resistant mix.

The results of APA rutting susceptibility and fatigue endurance testing were correlated internally with the Nottingham Asphalt Tester (NAT), and externally with numerous users of the APA equipment in the United States. Good correlation has been found between the predicted rutting results provided by the APA and the actual field performance of asphalt concrete pavements. For example, pavement samples from the SHRP WesTrack have been evaluated in a number of laboratory devices including wheel trackers and a simple shear tester (SST) (Williams and Prowell 1999). The APA differentiated between, and properly ranked, the performance of the WesTrack sections. Although a fairly good correlation between APA and WesTrack rut depth was determined, additional work is needed to develop shift factors for normal traffic and varying asphalt pavement structures. For reasons of client confidentiality, specific project details are not given for the following APA case history examples.

Example 1

On a typical county road in Ontario, the asphalt pavement reconstructed eight years ago exhibited moderate to severe rutting in the lane carrying heavy truck loads. Coring investigation indicated that the pavement consisted of 50 mm of surface course, 80 to 110 mm of recycled binder (base) course and about 50 mm of old hot-mix asphalt. The in-situ air voids were low, only 1.6 to 2.5 percent in the surface course and 1.9 to 3.5 percent in the top half of the recycled binder course. Two cores of the surface course asphalt concrete and four cores of the recycled binder course asphalt concrete were tested for rutting susceptibility in the APA. The test was run at a temperature of 58 °C. Figure 2 shows the plot of permanent deformation for both mixes in the APA. Based on the poor performance in the APA, and poor volumetrics, for both asphalt concrete mixes, it was recommended that 100 mm of the existing pavement be removed (milled) and replaced with two lifts of rut-resistant surface and binder course mixes.

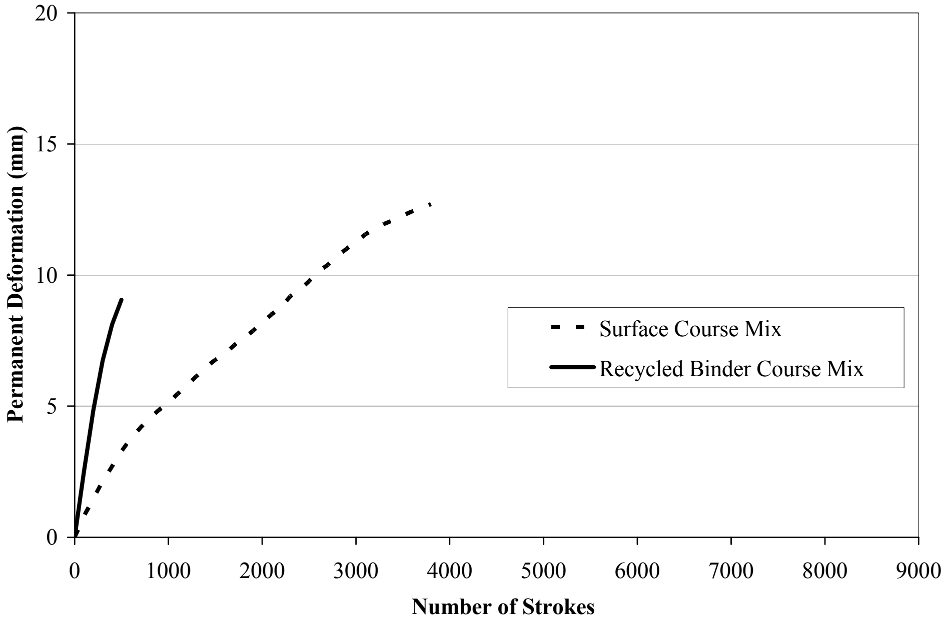


Figure 2: Permanent deformation of surface course and binder course asphalt concrete in the APA rutting resistance test

Example 2

The permanent deformation resistance of two asphalt mixes (12.5 mm and 9.5 mm nominal maximum size) incorporating aggregates from three different quarries was determined in the APA at a temperature of 58 °C. All mixes incorporated the same performance grade asphalt cement. Twenty-four Superpave gyratory compactor cylindrical specimens, which had been compacted to a constant air voids level, were prepared for the testing. A summary of this permanent deformation testing is presented in Table 1. From the results of the APA rutting resistance testing it appears that the finer asphalt mix (9.5 mm nominal maximum size) had better resistance to permanent deformation than the coarser mix (12.5 mm nominal maximum size), noting that other mix parameters would also influence the rutting resistance, particularly compactive effort and air voids.

Table 1: Summary of permanent deformation testing of asphalt mixes using APA

MIX TYPE (Nominal Maximum Size)	QUARRY	RUT DEPTH (mm)	
		Set of Two Samples	Average for the Mix
12.5 mm	A	6.5	5.8
		5.2	
9.5 mm	A	5.8	5.4
		5.0	
12.5 mm	B	5.6	5.8
		6.0	
9.5 mm	B	5.0	4.9
		4.9	
12.5 mm	C	6.7	6.3
		5.9	
9.5 mm	C	5.8	5.8

Example 3

In order to evaluate the impact of air voids level and fine aggregate characteristics on the performance of asphalt mixes, beam samples of two different mix types (surface and binder course mixes) were prepared in the laboratory at 4, 6 and 10 percent air voids using the AVC. Four surface course asphalt mixes having the same gradation but incorporating different aggregates were prepared. These mixes were tested in the APA for resistance to rutting and moisture susceptibility. Three binder course mixes were also tested for resistance to rutting. Figures 3 to 5 show some of the APA test results. The plot in Figure 3 shows that there is a direct relationship between the air voids level and permanent deformation in the APA test for Surface Course Mix 1. Similar relationships have been observed by some researchers in the United States. Kandhal and Mallick (1999), on the other hand, have indicated that this relationship is not clear for some asphalt mixes. Further investigation is required to clarify this relationship for Ontario asphalt mixes, noting that other parameters also influence rutting resistance.

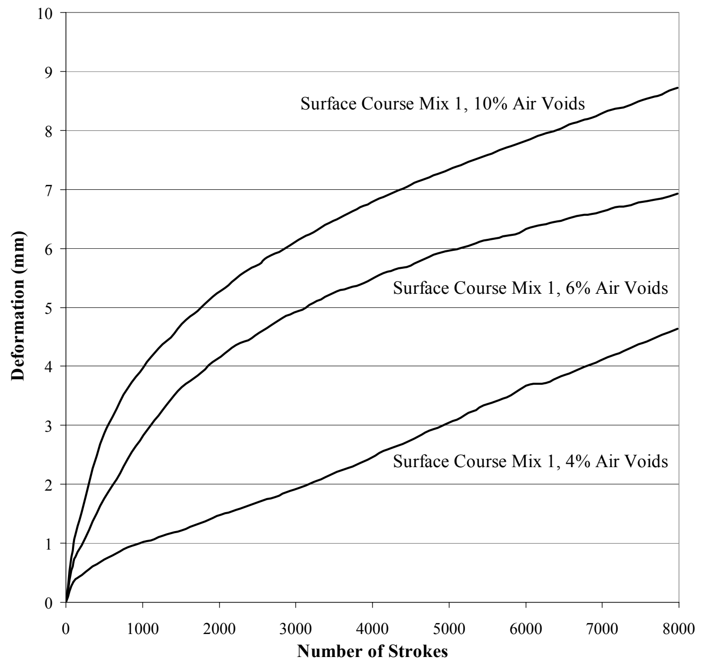


Figure 3: Permanent deformation of Surface Course Mix 1 at 4, 6 and 10 percent air voids

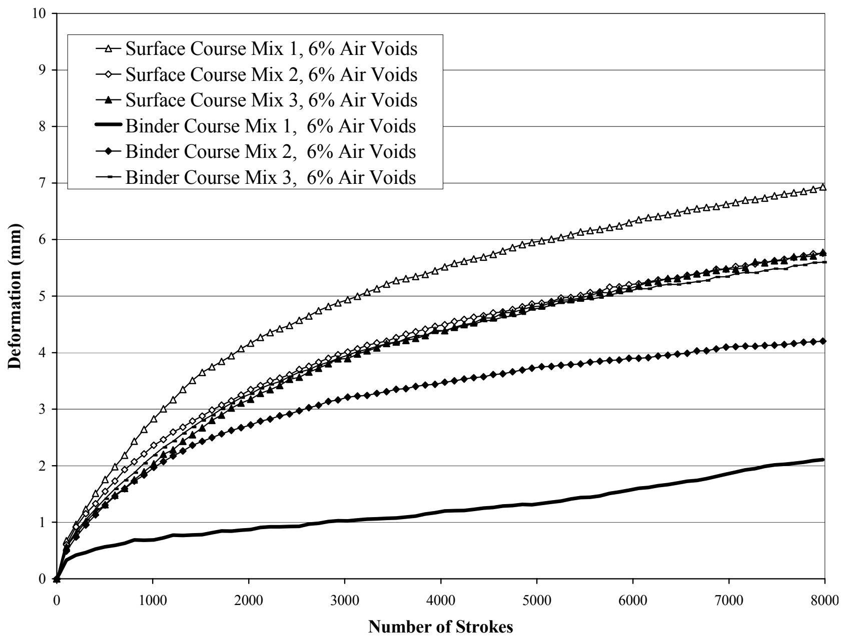


Figure 4: Permanent deformation of binder and surface course asphalt mixes incorporating different types of aggregate

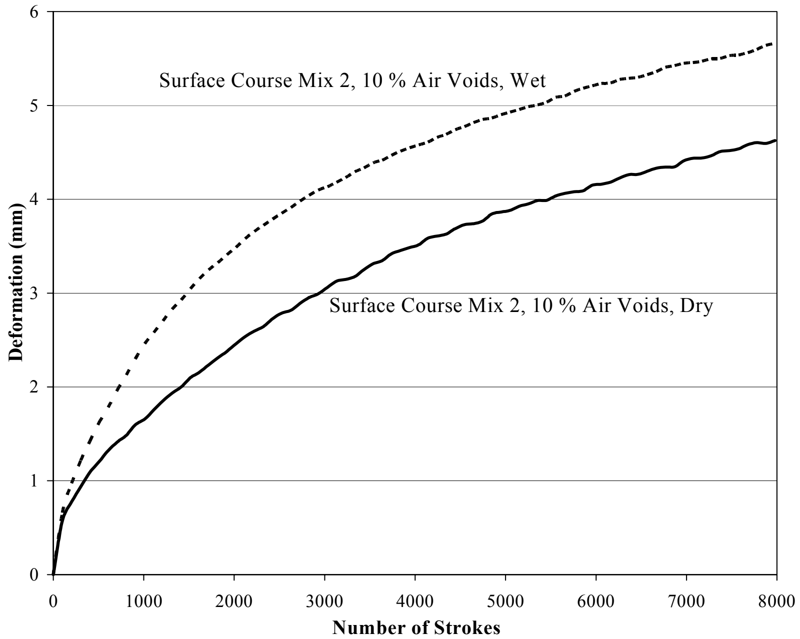


Figure 5: Permanent deformation of Surface Course Mix 2 tested dry and conditioned in water

The asphalt mixes tested incorporated aggregates of different origin and cubicity (Mix 1 incorporating high cubicity aggregates, Mix 2 medium cubicity aggregates and Mix 3 low cubicity aggregates). As shown in Figure 4, there does not appear to be a clear relationship between the shape of aggregate and the permanent deformation of the asphalt mixes. The asphalt mixes incorporating high cubicity aggregates were more difficult to compact and therefore the samples prepared at a similar compactive effort had higher air voids, which likely had an adverse impact on their resistance to permanent deformation. As expected, the permanent deformation in the APA of Surface Course Mix 2, conditioned in water, is greater than that of the dry mix (Figure 5), indicating the presence of some moisture damage in the water conditioned samples.

Example 4

JEGEL has completed an evaluation, including APA testing, of the impact of different deicing chemicals on asphalt concrete. Cylindrical specimens of non-moisture susceptible asphalt mix compacted in the Superpave gyratory compactor to approximately 7 percent air voids were conditioned in four different deicing chemical solutions. Dry samples and samples conditioned in water were used as controls. The AASHTO T 283 freeze-thaw cycle was modified for conditioning: chemical solution saturation to about 70 percent; freezing at -18°C for 16 hours; soaking in chemical solution at 60°C for 24 hours; and removing and placing in chemical solution at 25°C for 2 hours.

Initially, six dry asphalt concrete samples were tested as controls. A set of six cylinders was then conditioned in each chemical solution or water. After the freeze-thaw cycle was completed, the samples were placed in the APA. Each sample was submerged in a chemical solution or in water at a temperature of 52°C during testing, then 8000 loading cycles were applied and the rut depth was monitored by the automated system. The permanent deformation ratio was then calculated as the ratio of the permanent deformation of asphalt concrete samples conditioned in chemical solutions, or water, to the permanent deformation of dry samples. This APA permanent deformation testing is summarized in Figure 6.

The dry samples, and samples conditioned in water and in the Chemical 1 solution, exhibited very similar permanent deformation in the APA test; therefore, the impact of Chemical 1 on this asphalt mix can be considered as insignificant. The impact of other chemicals was somewhat greater as the rut depth in the APA test increased from 20 to 32 percent. The findings of the APA moisture/ chemical solution susceptibility tests were confirmed in another test where 25 freeze-thaw cycles were applied and asphalt concrete mechanistic properties were measured. The impact of Chemical 1 was again shown to be less severe than that of other tested chemicals. It appears that chemical deicers do not have any significant detrimental impact on high quality hot-mix asphalt as tested in the APA.

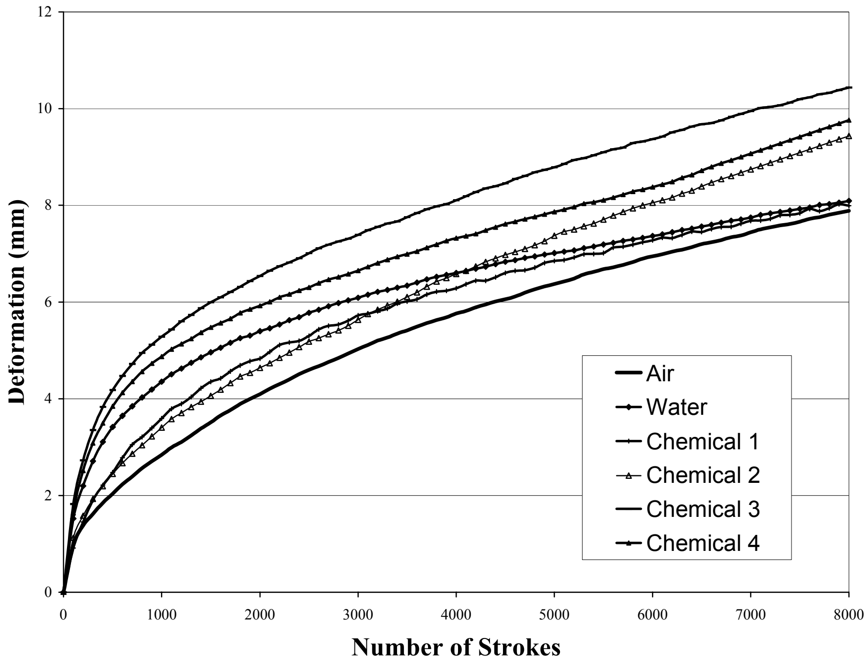


Figure 6: Permanent deformation of asphalt concrete samples conditioned in four different chemical solutions and water

Example 5

Crack sealing is one of the most common and effective routine maintenance treatments for road and airport asphalt pavements. Recent practical experience in Ontario (roads) and Newfoundland (airport) has shown that crack sealant failures (debonding) can occur in asphalt pavements incorporating aggregates that are hard, brittle, and prone to stripping, probably as a function of sealant reservoir preparation (routing) and geometry. As part of applied research on crack sealant performance (Carrick, Emery and Uzarowski 2002), APA crack sealant moisture sensitivity tests were completed on samples in both dry and wet conditions as shown schematically in Figure 7.

Asphalt concrete slabs from sites experiencing crack sealant failures were trimmed to 300 mm long by 125 mm wide by 75 mm deep. Crack sealant reservoirs 20 mm wide by 20 mm deep were cut using both routing and saw-cutting methods. The reservoirs were then cleaned and filled with hot-poured, rubberized, crack sealant, as indicated in Photograph 9, for a typical routed reservoir. It was observed that the router, as compared to the saw, caused some damage to the edges of the reservoir and many coarse aggregate particles were shattered (similar to field observations). Wet APA conditioning included a 24 hour saturation period with the test then run on the sample submerged in water. Control samples were conditioned in air and tested dry. In order to prevent the sealant from sticking to the APA test wheel (30 mm wide solid rubber), the surface of the sample was covered with a layer of polyethylene. Generally 8000 cycles, with a contact pressure of 1725 kPa at 20ºC, were applied, unless a total bond failure occurred earlier. The bond between the sealant and the asphalt concrete was examined at 500 cycle intervals.

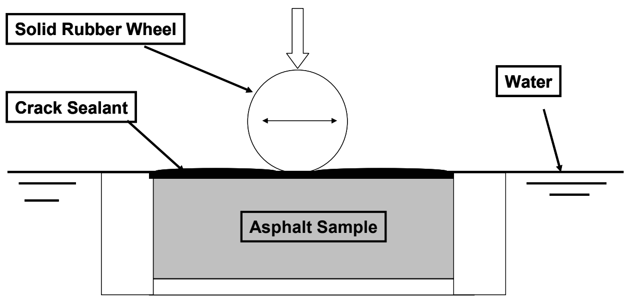
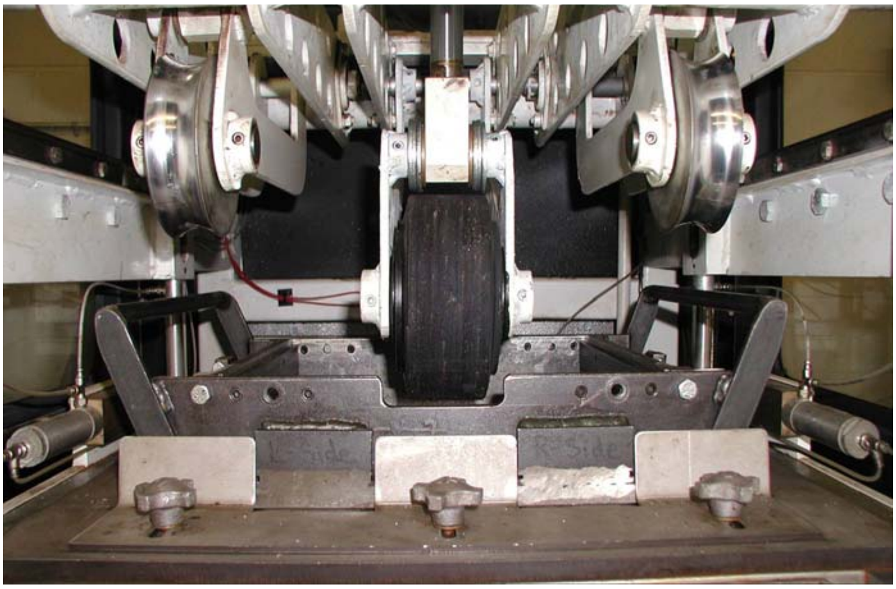


Figure 7: APA Crack Sealant Bonding Test

Photograph 9: A sample of asphalt concrete with routed reservoir filled with crack sealing material

This APA crack sealant moisture sensitivity testing indicated routed reservoir failure typically at 2000 cycles, with the sealant fully debonded from the asphalt concrete. For the saw-cut reservoir there typically was only partial failure after 8000 cycles, but still some bond between the sealant and the asphalt concrete in the reservoir. The field observations and laboratory testing confirmed that the loss of sealant appears to be mainly the result of impact damage to brittle aggregate caused by the conventional routing equipment. The use of a random-crack saw (sawn reservoirs) was recommended for asphalt pavements containing brittle aggregates. It was also recommended that a wider wheel (70 mm) be developed for APA testing and used to evaluate the performance of other reservoir geometrics (Ontario 40 mm wide by 10 mm deep, for instance). This wider wheel and larger mould have now been developed and put into regular APA use (Photograph 10) to continue the evaluation of sealant reservoir preparation and geometry influences on crack sealant performance. Additionally, the larger mould and wider APA wheel are being used to assess asphalt concrete pavement interface (lift) shear resistance (slippage under heavy traffic action, for instance) and its improvement (polymer modified tack coats, for instance).



Photograph 10: APA interface shear resistance and 'large slab' resistance to rutting tests equipment (70 mm wide solid rubber wheel, slab 300 mm x 300 mm)

SUMMARY

The APA is considered to provide a missing 'link' between laboratory testing and the potential field performance of asphalt mixes. Good correlation has been found between the rutting resistance predicted by the APA and the actual field performance of asphalt concrete pavements.

There are two important criteria that have to be considered for APA testing of asphalt mixes: one is the selection of an appropriate test temperature that reflects the in-service environment in which the asphalt pavement will be expected to perform; and the second is that the laboratory compaction should simulate field compaction. The statistically significant differences in rut depth, as determined by the APA, have been found to be sensitive to aggregate gradation and the asphalt cement performance grade.

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