Development and Field Evaluation of High Performance and Fuel Resistant Asphalt Mixture

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ABSTRACT

Exposure of asphalt pavements to fuel spills and oil leaks often results in excessive softening of the asphalt cement binder in the surface mix. This can translate into premature surface defects such as rutting and ravelling. There are number of surfacing options available (e.g. coal tar sealers) to protect the surface, but such options often only last two to three years before exhibiting severe cracking and losing their intended purpose. Also, coal tar sealers are known to be carcinogenic and their use places undesirable material into a pavement that may be recycled.

This paper provides information concerning the design of a high shear and jet fuel resistant mixture, including (1) designing an asphalt binder containing specialty modifiers and additives to resist the softening effect of fuels and lubricants, (2) developing an aggregate blend to provide high level of stability to match the requirements of the Federal Aviation Administration (FAA) P-601 specification, and (3) performance testing to capture the mechanical properties of the mixture compared to a conventional FAA approved mixture. Production and paving experience with the jet fuel resistant mix is also included in this paper, as well as more than ten years of field performance across major international airports.

RÉSUMÉ

L'exposition des chaussées en asphalte aux déversements de carburant et aux fuites d'huile entraîne souvent un ramollissement excessif du bitume dans la couche de surface. Cela peut se traduire par des défauts de surface prématurés tels que l'orniérage et le désenrobage. Il existe un certain nombre d’options de traitements (par exemple les scellants à base de goudron) pour protéger la surface, mais ces options ne durent souvent que deux ou trois ans avant de présenter de graves fissures et de perdre leur utilité. En outre, les scellants de goudron sont connus pour être cancérigènes et leur utilisation introduit des matériaux indésirables dans la chaussée qui pourrait éventuellement être recyclée.

Ce document fournit des informations concernant la conception d’un mélange résistant au cisaillement et au carburéacteur, comprenant (1) la conception d’un bitume contenant des modificateurs et additifs spéciaux pour résister à l’effet de ramollissement des carburants et lubrifiants, (2) la conception d’une granulométrie assurant au haut niveau de stabilité pour répondre aux exigences de la spécification P-601 de la Federal Aviation Administration (FAA) et (3) les essais de performance pour comparer les propriétés mécaniques du mélange par rapport à un mélange conventionnel approuvé par la FAA. L'expérience de la production et du pavage avec le mélange résistant au carburéacteur est également incluse dans ce document, ainsi que plus de dix ans de performance sur le terrain dans d’importants aéroports internationaux.

1.0 INTRODUCTION

The primary purpose of a pavement is to provide a functional driving surface for a specific mode of transportation including cars, trucks, buses, or aircraft. There are different types of pavement for each transportation need, but all types share a key function, which to distribute stress caused by loads downward to the underlying soil foundation in an acceptable stress level under different climatic conditions. Other mutual functional performance is providing a smooth surface with adequate skid resistance. This is referred to as serviceability. However, over time with usage, a number of pavement distresses can contribute to reducing the serviceability and causing deterioration of the pavement layers. In the case of a flexible pavement composed of asphalt-bound layers, distresses such as permanent deformation, fatigue cracking, low-temperature cracking, moisture damage, and aging are proven to be contributing distresses [1]. Such deterioration can be further accelerated when asphalt layers are exposed to fuel spills and oil leaks.

Fuels and mineral oils originate from crude oils, which makes them extremely compatible with the asphalt cement binder. Such compatibility allows fuels and oils to act as solvents to asphalt cement. This is the main reason that fuel spills on Hot Mix Asphalt (HMA) can lead to softening of the surface and reduce the service life resulting in premature replacement and repair (Figure 1). Fuel spills are uncommon on highways, but when HMA is used in airports, jet fuel can be spilled onto the runways and taxiways while aircraft are parked at the gates or awaiting clearance. While there are a number of factors contributing to fuel spills, spillage mainly occurs either through thermal expansion of fuel from the overflow port of the storage tank of an aircraft or a refueling vehicle, or from fuel being spilled during the refueling process. Fuel spills are also common at sea ports, gas stations, truck and bus stops, and any industrial sites or distribution centres.

Figure 1. Depressions in Asphalt Surface Due to Fuel Spill Softening

Until now, there were two solutions available to address this problem: (1) using a Portland Cement Concrete (PCC) surface in lieu of an HMA surface, especially in those areas prone to continual fuel spills, or (2) using coal tar sealers to protect the existing HMA from the damaging effects of fuels. The option of using PCC has the drawback of being relatively more expensive and requiring greater construction time, which can be problematic in busy airports. On the other hand, while the use of coal tar sealers is a much cheaper and faster solution, these materials pose two problems: (1) they exhibit block cracking within the first few years of being in service due to a different oxidation rate and coefficient of thermal expansion between the sealer and asphalt surface as shown in Figure 2, and (2) they are classified as a probable human carcinogen (also referred to as "Carcinogenic" material) and outlawed in many countries including Canada.

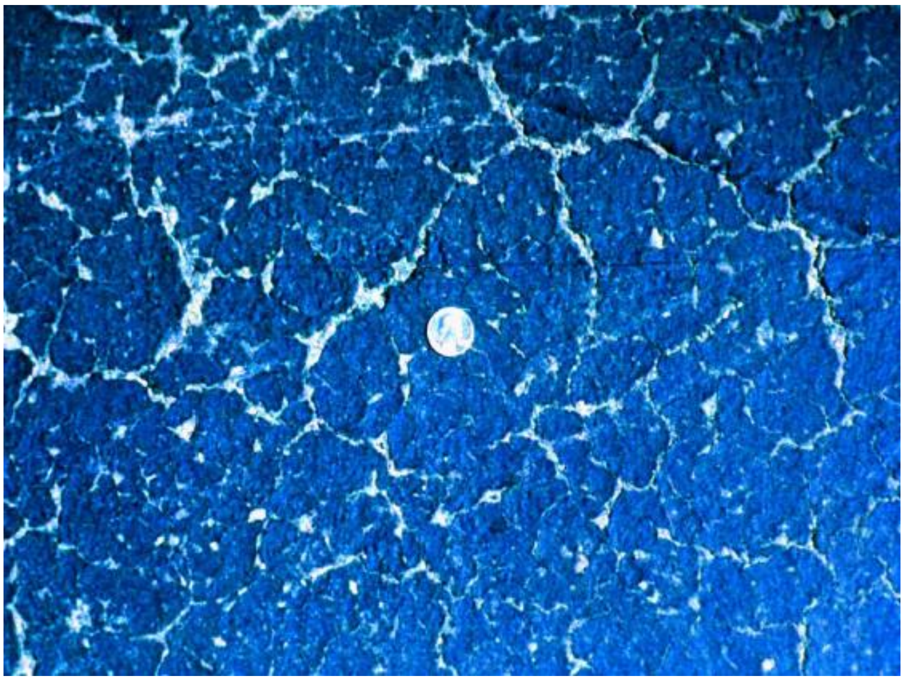


Figure 2. Block Cracking of Coal Tar Sealer

These issues led to the development of a fuel-resistant, polymer-modified asphalt solution that can be used to resist the detrimental effects of fuel and hydraulic fluid spills that also provides an increased level of resistant to load-associated and environmental surface distresses. This paper provides information on this high shear and jet fuel resistant mixture, including (1) the development of an asphalt binder containing specialty modifiers and additives to resist the softening effect of light hydrocarbon fractions, and (2) performance testing to capture the mechanical properties of the mixture compared to a conventional Federal Aviation Administration (FAA) approved asphalt mixture.

2.0 MIXTURE DEVELOPMENT

2.1 Overview

The development of fuel-resistant mixes was a process that started in Europe in the 1990s and the first trials were constructed in Malaysia and Egypt [2]. As the technology evolved, more trials were executed, and eventually the technology was transferred to the United States during the early 2000s.

The main component of this technology is a patented Fuel-Resistant (FR) asphalt binder [3] that contributes significantly to the resistance against fuels and hydraulic fluids. The FR binder further provides an increased level of resistance to permanent deformation, fatigue, and thermal cracking.

In the late 1990s, CITGO asphalt, a predecessor to Axeon Specialty Products and Associated Asphalt Partners in the United States transferred the technology of producing FR asphalt binder from the Ooms Avenhorn Holding in the Netherlands. Early studies on the physical properties of FR binder was conducted by Rooijen et al. [4] who compared the visco-elastic behaviour of the FR asphalt binder (referred to as "PMA JR") with two other asphalt binders: (1) standard Penetration Graded asphalt (Pen 40/60), and (2) a polymer-modified asphalt binder with proven good performance at Amsterdam Airport Schiphol (referred to as "PMA S"). The binder testing included: repeated creep-recovery tests at 40°C, and the development of master curves for complex shear modulus (G*) and phase angle (δ). It should be noted that the tested asphalt binders were recovered from laboratory-produced asphalt mixtures that were unconditioned and immersed in jet fuel for three hours.

The repeated creep-recovery tests included 17 creep-recovery cycles; each cycle applied at 10 kPa for 11 seconds followed by a recovery period of 11 seconds. Figure 3 illustrates the clear difference between the behaviour of the two PMAs and the Pen 40/60 asphalt, which clearly proved the benefits of the polymer modification. Such difference was found to be even greater when the asphalt was recovered from the fuel-immersed specimens, as the permanent deformation of the two PMAs remained at the same level compared to the untreated specimens. It was suggested that the jet fuel affected the stiffness of PMAs but did not significantly influence the elasticity.

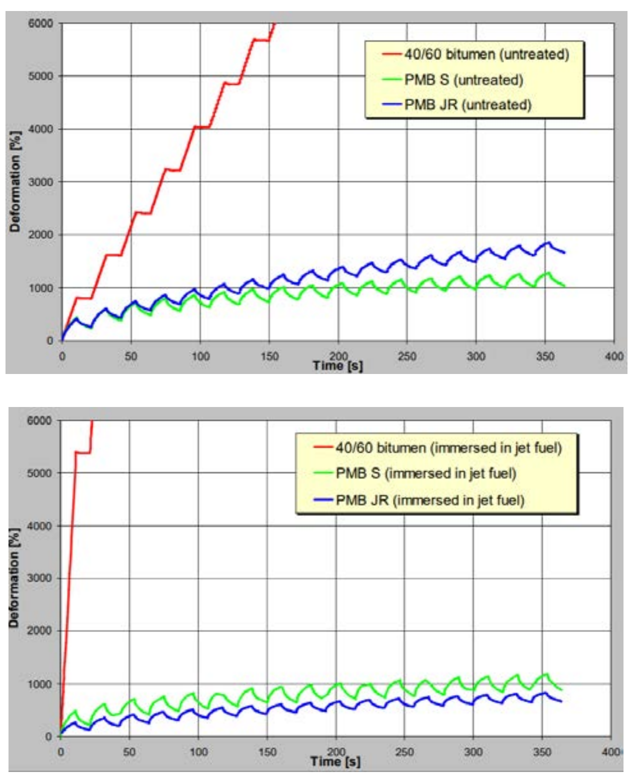


Figure 3. Creep-Recovery Test of Asphalt Binders Recovered from Untreated (Top) and Fuel-Immersed (Bottom) Compacted Specimens [4]

To illustrate the effect of the fuel resistant asphalt modification, Figure 4 shows complex shear modulus master curves constructed at a reference temperature of 20°C, before and after fuel immersion. It is visible that the effect of the fuel on the properties of FR asphalt binders are substantially different from the regular asphalt and the effect of the fuel immersed is much reduced [4].

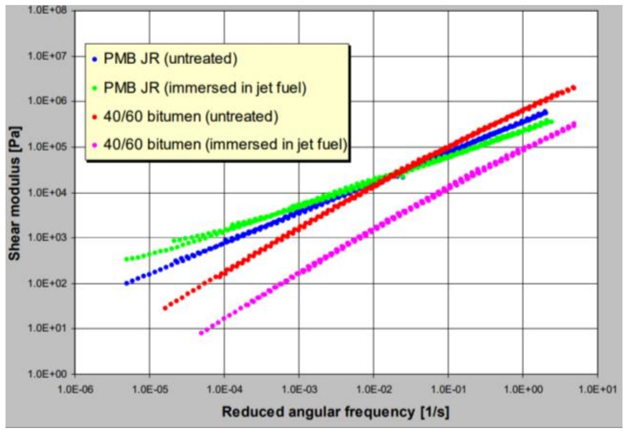


Figure 4. Complex Shear Modulus Mastercurves of Asphalt Binders Recovered From Untreated and Fuel-Immersed Compacted Mixtures [4]

In this paper, results of a research study are presented in which a conventional P401 Federal Aviation Administration (FAA) No. 2 aggregate blend asphalt mixture was compared to a modified P401 version. Traditionally, the P-401 asphalt mixture is designed using 75 Marshall blows and a target air voids of 3.5 percent. For the current study, the traditional P-401 asphalt mixture contained a PG 82-22 asphalt binder and was designated as the baseline asphalt mixture for comparison. The experimental asphalt mixture utilized the same aggregate blend and aggregate source but was designed using the compactive effort (50 Marshall blows) and air voids target of 2.5 percent as the P-601 specification listed in Table 1. The "P-401 FR" asphalt mixture also contained an asphalt binder specially formulated by Associated Asphalt that is resistant to common fuels.

Table 1. Mixture Properties of Federal Aviation Administration Item P601 and P401, and a Typical Pearson Airport Surface Course

Property		P601 (StellarFlex FR)	FAA #2 FR	P401 #2	Typical Pearson Airport Mix
	Sieve Size (mm)				
Gradation (% Passing)	12.5	100	92.9		97.8
	9.5	98.1	77.8		80.7
	4.75	66.9	57.0		55.2
	2.36	45.4	39.1		46.5
	0.600	19.1	19.9		20.5
	0.075	5.3	4.4		3.1
Air Voids (%)		2.5	2.5	3.5	4.2
Voids in Mineral Aggregate (%)		21.4	17.4	16.3	16.4
Asphalt Cement Content (%)		8.5	6.7	5.8	5.0
Binder Performance Grade		PG 88-22P FR		PG 88-22P	PG 70-28P

Note: P is polymer modified, FR is Fuel Resistant, and FAA is Federal Aviation Administration.

In Table 1, two asphalt mixture designs were conducted using a Granite-Gneiss aggregate from the Tilcon, Mt. Hope quarry in New Jersey. The identical aggregate source blend and gradation was used for the FAA #2 Fuel Resistant (FR) mixture and the FAA #2 P401 asphalt mixture. There are two major differences between the P401 and P601 asphalt mixture design. First, the design Marshall compactive efffort for the P401 mixture is 75 blows per side, while it is only 50 blows per side for the P601 mixture. Second, the P401 mixture has a design air void content of 3.5 percent, while the P601 mixture uses a design air void content of 2.5 percent. The reduction in compactive effort combined with a lower design air void target results in an asphalt mixture with a higher design asphalt content.

The laboratory testing program consisted of a variety of asphalt mixture test methods to evaluate the respective stiffness, rutting potential, and cracking potential after Short-Term Oven Aging (STOA) and Long-Term Oven Aging (LTOA) protocols. The short-term aging was completed on the loose mix by conditioning for two hours at the respective compaction temperatures to simulate the early life (0 to 2 years). For the long-term conditioning, mixtures were conditioned loose for 24 hours at 135°C to simulate the late life (greater than 10 years) aged condition of the asphalt mixture. For this study, test specimens were compacted to a target of 2 to 3 percent higher air voids than the P401 design target. For the FAA #2 FR, this resulted in test specimen air voids ranging between 4.5 to 5.5 percent. For the P401 FAA #2, this resulted in test specimen air voids ranging between 5.5 to 6.5 percent. Mixtures used in the comparison were lab-produced and testing was performed by the Centre for Advanced Infrastructure and Transportation (CAIT) located at the Rutgers University (The State University of New Jersey) [5].

2.2 Dynamic Modulus

Dynamic modulus and phase angle data were measured in uniaxial compression using the Asphalt Mixture Performance Tester (AMPT) following the method outlined in AASHTO TP 79, “Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)” [6]. Data was collected at temperatures of 4, 20, and 45°C using loading frequencies of 25, 10, 5, 1, 0.5, 0.1, and 0.01 Hz (Figure 5). Specimens were evaluated under both STOA and LTOA conditions.

Figure 5. The Centre for Advanced Infrastructure and Transportation (CAIT) Asphalt Mixture Performance Tester (AMPT)

The collected modulus values at the varying temperatures and loading frequencies were used to develop Dynamic Modulus master stiffness curves and temperature shift factors using numerical optimization of Equations 1 and 2. The reference temperature of 20°C was used to generate master curves in accordance with AASHTO PP 62-09 procedure, "Standard Practice for Developing Modulus Master Curve for Hot-Mix Asphalt" [7].

$$\log|E^*| = \delta + \frac{(Max - \delta)}{1 + e^{\beta + \gamma\left\{\log\omega + \frac{\Delta E_a}{19.14714}\left[\left(\frac{1}{T}\right) - \left(\frac{1}{T_r}\right)\right]\right\}}} \tag{1}$$

Where: $|E^*|$ is dynamic modulus in psi;
ω_r is reduced frequency in Hz;
Max is limiting maximum modulus in psi; and
δ, β, and γ are fitting parameters.

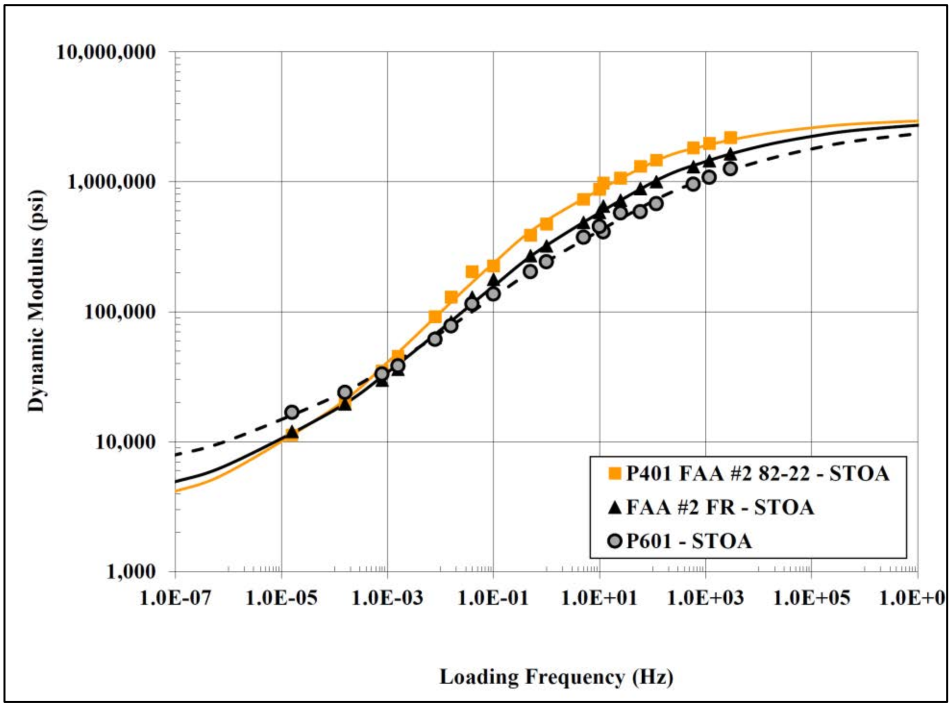
$$\log[a(T)] = \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \tag{2}$$

Where: a(T) is shift factor at temperature T;
T_r is reference temperature in °K;
T is test temperature in °K; and
ΔE_a is activation energy (treated as a fitting parameter).

Well-performing asphalt mixtures should maintain adequate modulus at high temperatures to help resist rutting while providing low modulus at intermediate/lower temperatures to help resist fatigue and thermal cracking. The dynamic modulus master stiffness curves for STOA and LTOA samples are shown in Figure 6 and 7.

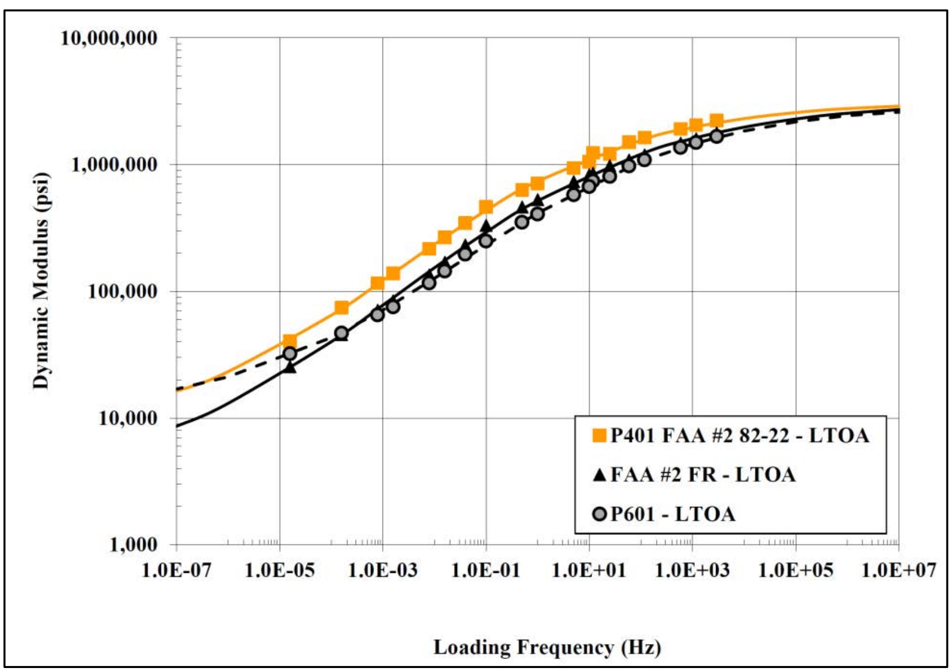
In Figure 6, the stiffness properties for the FAA #2 FR asphalt mixture are lower at low and intermediate temperatures (right side of the figure), while equal to and greater at the higher temperatures (left side of the figure). In general, high asphalt mixture stiffness is needed to help resist rutting. Meanwhile, it is generally better to have lower asphalt mixture stiffness at intermediate and low temperatures to help resist cracking.

In Figure 7, after the asphalt mixtures have been conditioned to simulate greater than 10 years of field aging, the dynamic modulus master stiffness curves show that the P401 FAA #2 asphalt mixture had a higher asphalt mixture stiffness at all temperatures and loading frequencies. Since the asphalt mixture stiffness was similar at the STOA condition, the larger differences in mixture modulus after LTOA would suggest the P401 FAA #2 asphalt mixture underwent a higher degree of age-hardening than the FAA #2 FR asphalt mixture due to the LTOA procedure.



Note: STOA is Short-Term Aged Oven and LTOA is Long-Term Oven Aged

Figure 6. Dynamic Modulus Master Stiffness Curve for Short-Term Oven Aged Asphalt Mixtures



Note: STOA is Short-Term Aged Oven and LTOA is Long-Term Oven Aged

Figure 7. Dynamic Modulus Master Stiffness Curve for Long-Term Oven Aged Asphalt Mixtures

2.3 Permanent Deformation Evaluation

The rutting resistance of the asphalt mixtures was evaluated using two different test methods commonly used to assess the permanent deformation of asphalt mixtures. The first test method is the AMPT Flow Number (AASHTO T 378) and the Asphalt Pavement Analyzer (AASHTO T 340).

2.3.1 Flow Number

Repeated Load permanent deformation testing was measured and collected in uniaxial compression using the AMPT following the method outlined in AASHTO TP 79, “Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)” [7]. The unconfined repeated load tests were conducted with a deviatoric stress of 600 kPa and a test temperature of 54°C, which corresponds to average 50 percent reliability high pavement temperature at a depth of 20 mm according the LTPPBind 3.1 software. Such parameters of temperature and applied stress conform to the recommendations currently proposed in NCHRP Project 9-33, titled as “A Mix Design Manual for Hot Mix Asphalt” [8]. Testing was conducted until a permanent vertical strain of 5 percent or 10,000 cycles was obtained.

The permanent deformation results are shown in Figure 8. The results show that the FAA #2 FR asphalt mixture is far superior in rutting resistance than the P401 FAA #2 asphalt mixture. Table 2 provides Recommended Minimum Flow Number Values as a function of design traffic level based on the work in NCHRP Project 9-33 [9]. Although airport traffic varies from highway traffic, the table still provides a means of comparison. The recommended values were also used to compare the performance of the asphalt mixtures. The test results of FAA #2 FR and P401 FAA #2 mix would be sufficient to resist highway traffic of 10 to 30 million ESAL’s, while the P-601 asphalt mixture would be sufficient to resist highway traffic greater than 30 million ESAL’s.

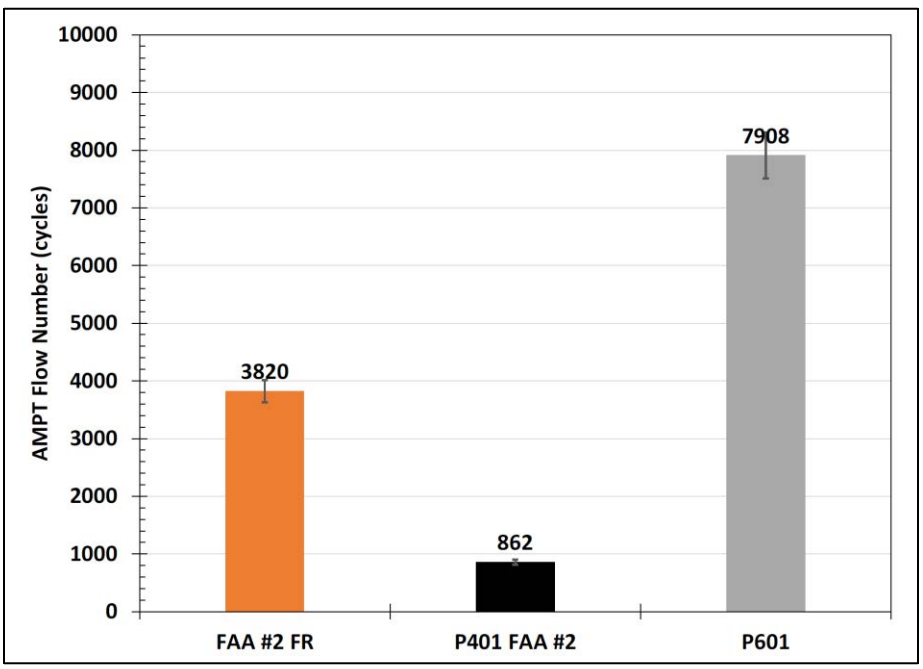


Figure 8. Asphalt Mixture Performance Tester (AMPT) Repeated Load Flow Number Results

Table 2. Minimum Flow Number Requirements Recommended by National Cooperative Highway Research Program (NCHRP) [9]

Traffic Level (Million ESALs)	Minimum Flow Number (cycles)	General Rut Resistance
< 3	--	Poor to Fair
3 to < 10	53	Good
10 to < 30	190	Very Good
≥ 30	740	Excellent

Note: ESAL is Equivalent Single Axle Load

2.3.2 Asphalt Pavement Analyzer

The Asphalt Pavement Analyzer (APA) was conducted in accordance with AASHTO T340, Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA) [9]. A hose pressure of 100 psi (690 kPa) and a wheel load of 100 lb (45.4 kg) was used in the testing. Testing was continued until 8,000 loading cycles and APA rutting deformation was recorded at each cycle. The APA device used for testing at Rutgers University is shown in Figure 9.

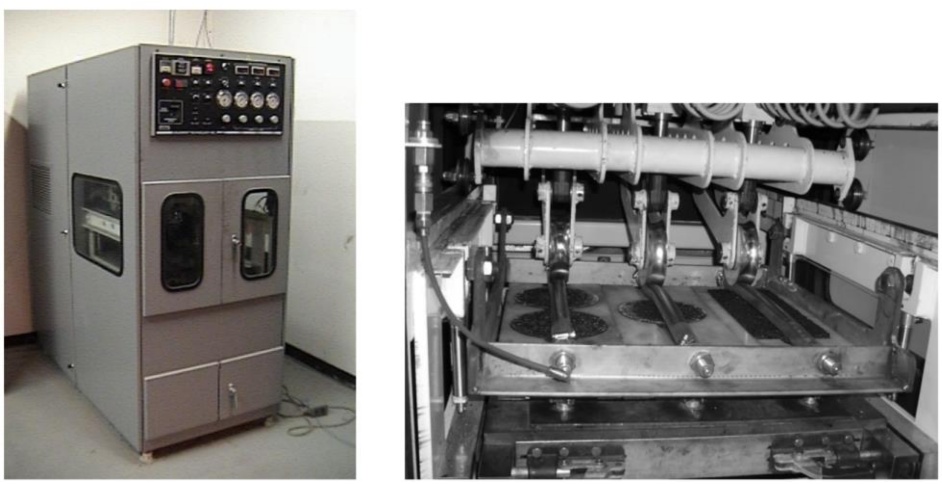


Figure 9. Asphalt Pavement Analyzer (APA) at Rutgers University (Left) and Inside View of Different Size Specimens Being Tested (Right)

Prior to testing, each sample was heated for six hours at the testing temperature to ensure temperature equilibrium within the test specimen was achieved. Testing started with 25 cycles used as a seating load to eliminate any sample movement during testing followed by 8,000 loading cycles. The APA rutting for the asphalt mixtures is shown in Figure 10. Both asphalt mixtures show relatively good rutting resistance in the APA at a test temperature of 64°C. Based on preliminary APA rutting criteria for the FAA, it would appear that both asphalt mixtures would meet their minimum rutting resistance requirements as shown in Figure 10. The relationship in Figure 11 also shows the high pressure APA testing procedure under development by the FAA Technical Center in Atlantic City, NJ [10]. The relationship between the high pressure APA and the AASHTO T 340 would indicate that APA rutting under 5.0 mm using AASHTO T 340 should be relatively rut resistant.

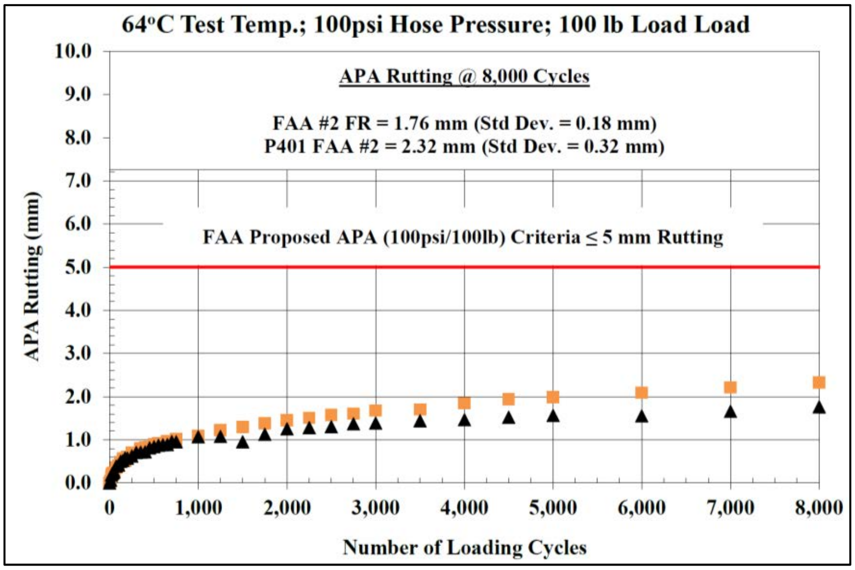


Figure 10. Asphalt Pavement Analyzer (APA) Rutting Performance

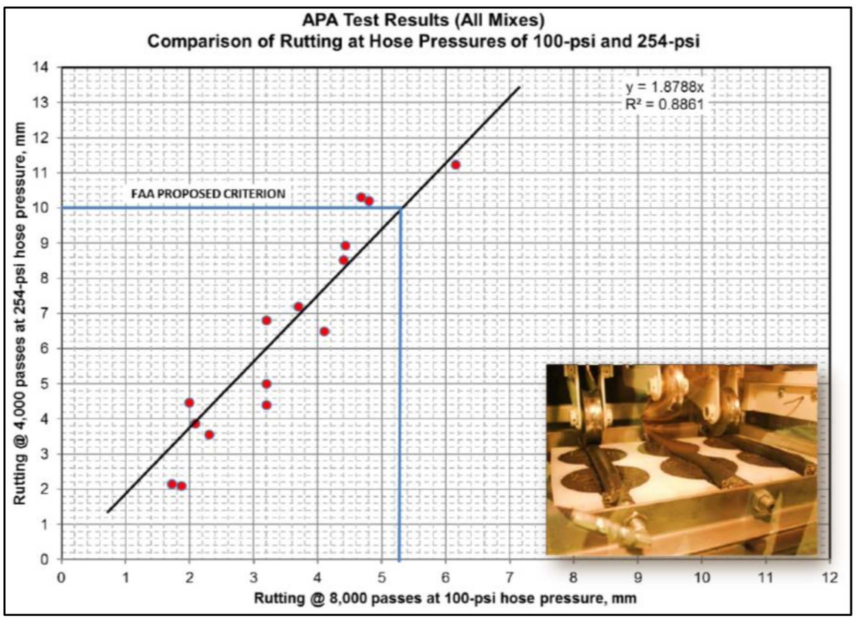


Figure 11. Federal Aviation Administration (FAA) Relationship Between High Pressure APA Versus AASHTO T340 [10]

2.4 Fatigue Cracking Evaluation

The fatigue cracking properties of the mixtures were evaluated using three test procedures: (1) Semi-Circular Bend (SCB) Flexibility Index (AASHTO TP124), (2) Flexural Beam Fatigue (AASHTO T321), and (3) IDEAL-CT. Fatigue cracking tests were conducted on both short-term conditioned and long-term conditioned asphalt mixtures. Figure 12 displays the laboratory apparatus for the IDEAL-CT and SCB tests.

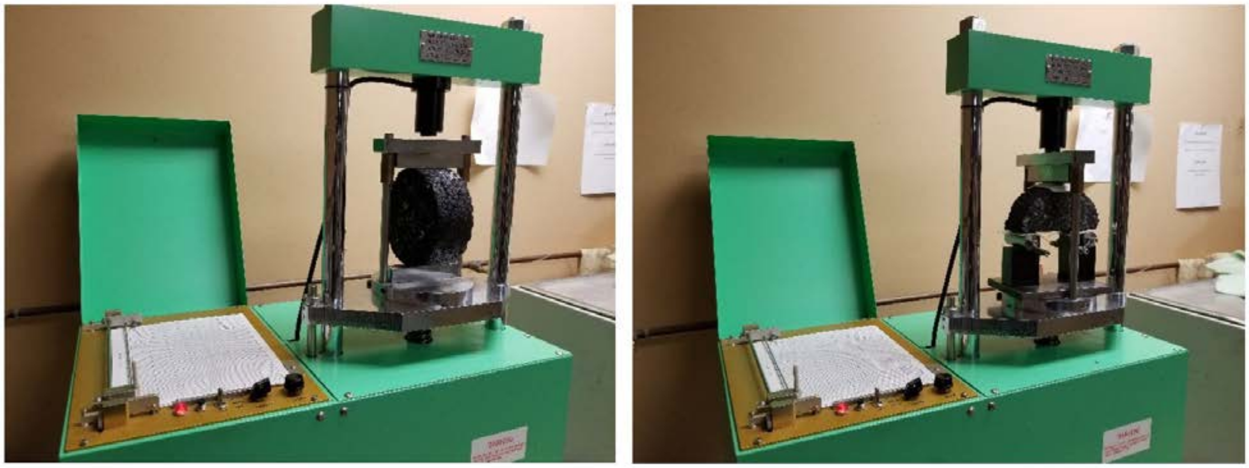


Figure 12. Marshall Compression Machine Test Set-up: IDEAL-CT Test (Left), and Semi-Circular Bend (SCB) Flexibility Index Test (Right)

2.4.1 Semi-Circular Bend Test

The Illinois SCB test was used to determine Illinois Flexibility Index (I-FI) in accordance with AASHTO TP 124, "Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature" [11]. For this test, specimens were cut from the middle of gyratory sample to the thickness of 50 mm. Strength and displacement were recorded during a 50 mm/min deformation rate. Testing was performed at 25°C and each SCB sample also has 15.0 mm notch depth to initiate the location of the crack. The FI was then calculated by dividing the fracture energy by the slope of the post-peak load-displacement curve at the inflection point shown in Figure 13. In general, as the SCB Flexibility Index (FI) value increases, the asphalt mixture's fatigue cracking resistance increases.

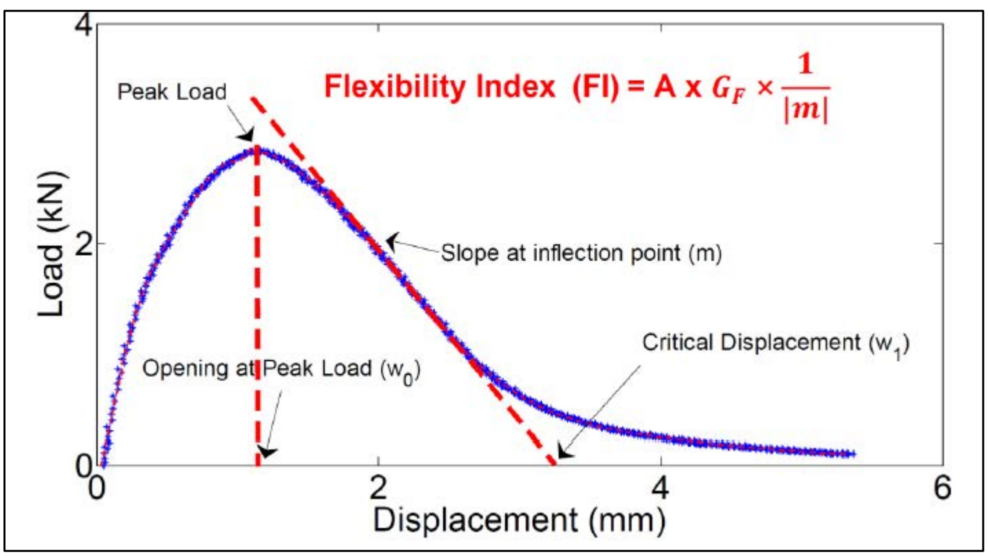
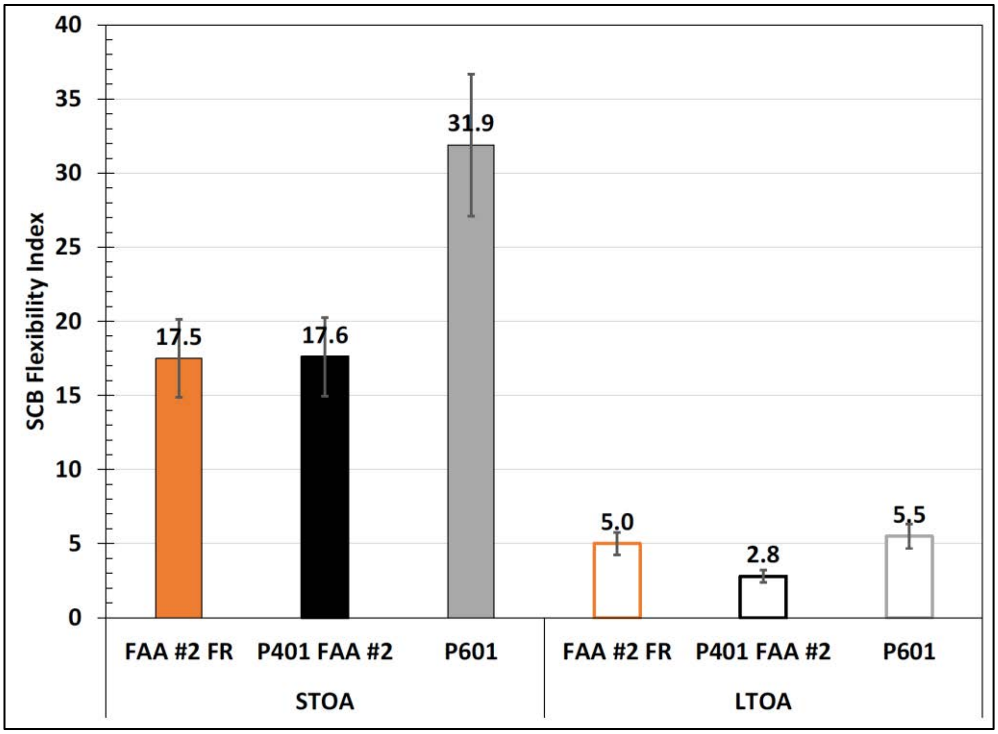


Figure 13. Typical Graph Used After Illinois Semi-Circular Bend (SCB) Test to Calculated Flexibility Index (FI)

The SCB Flexibility Index fatigue cracking test results are shown in Figure 14. The test results show that at the STOA condition, both asphalt mixtures had similar resistance to fatigue cracking. However, after the LTOA conditioning, the FAA #2 FR asphalt mixture had almost twice the SCB Flexibility Index than the P401 FAA #2 asphalt mixture.



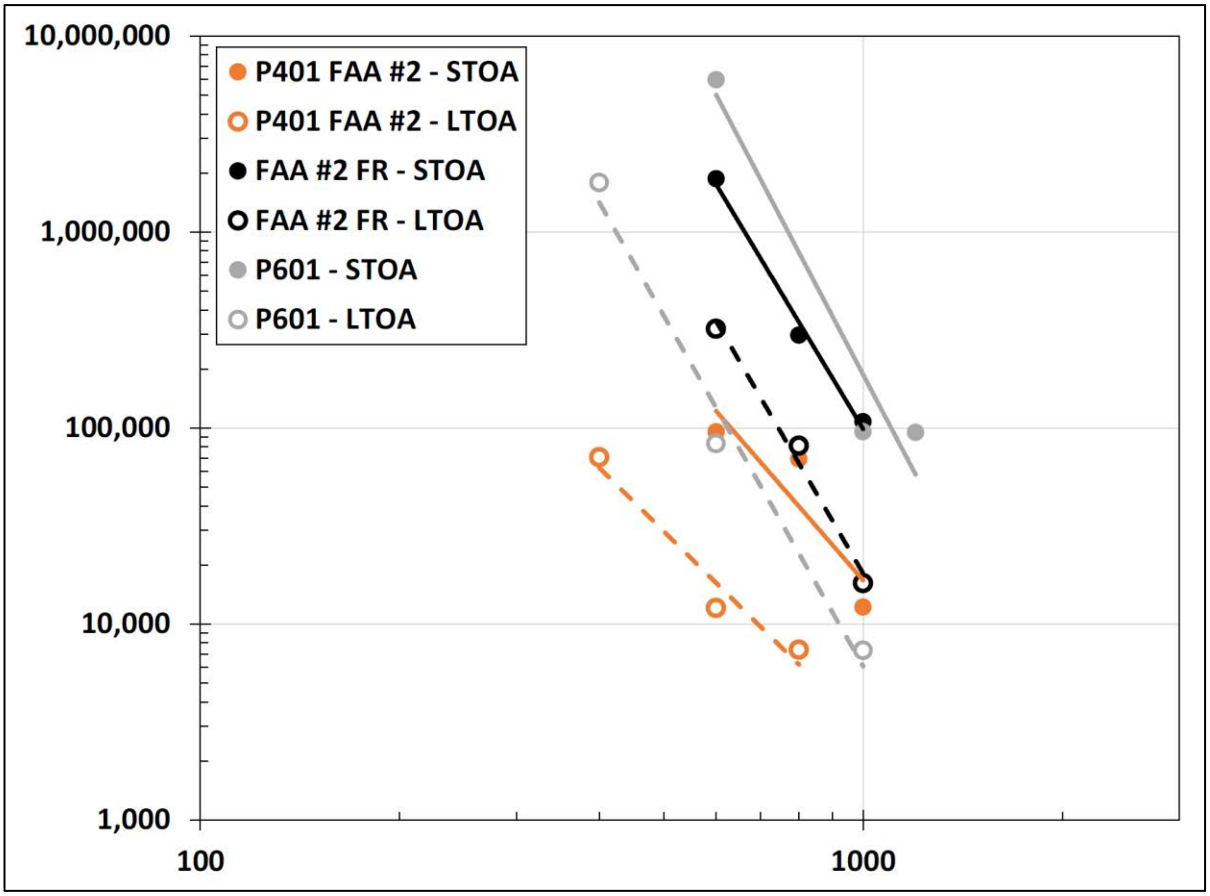
Note: SCB is Semicircular Bend Test, STOA is Short-Term Oven Aged, and LTOA is Long-Term Oven Aged.

Figure 14. Semi-Circular Bending (SCB) Test Results For P-601 and Logan Airport Asphalt Mixtures

2.4.2 Flexural Beam Fatigue Beam Test

The flexural beam fatigue test was performed in accordance with the AASHTO T 321-07, "Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) subjected to Repeated Flexural Bending" [12]. For this testing, beams measuring 380 mm long by 63 mm wide by 50 mm thick were saw-cut from asphalt slabs and compacted using an Asphalt Vibratory Compactor (AVC).

The testing procedure involved subjecting an asphalt beam to flexural loading applied in a sinusoidal waveform with loading frequency of 10 Hz at a micro-strain level. Fatigue failure was then defined as the number of load cycles until initial stiffness is reduced by 50 percent. The applied strain levels were ranged between 400 to 1000 micro-strains, depending on the asphalt mixture evaluated. Samples were tested at short-term and long-term aged conditions. All samples were tested at a test temperature of 15°C. The flexural beam fatigue results are shown in Figure 15. At each respective condition, STOA and LTOA, the FAA #2 FR asphalt mixture had a far superior resistance to flexural fatigue failure. In fact, the results in Figure 14 show that even after Long Term Oven Aged, the FAA #2 FR achieved a better flexural fatigue cracking resistance than the P401 FAA #2 asphalt mixture after only STOA.



Note: STOA is Short-Term Oven Aged, and LTOA is Long-Term Oven Aged

Figure 15. Flexural Fatigue Results for P601 and Logan Airport Asphalt Mixtures

2.4.3 IDEAL-CT Fatigue Cracking Test

The IDEAL-CT is similar to the traditional indirect tensile strength (IDT) test used for Tensile Strength Ratio (TSR). The test is conducted at 25°C by either Superpave or Marshall sized specimens at a loading rate of 50 mm per minute. The test is not sensitive to specimen thicknesses and can be conducted on a range of thicknesses such as: 38, 50, 62, 75, or others. For mix design, and laboratory quality control/assurance, the authors proposed to use the same specimen size as the Hamburg Wheel Tracking (HWT) test (150 mm in diameter and 62 mm height) with air voids target of 7 ± 0.5%. It should be mentioned that either lab-compacted specimens or field cores can be directly tested with no need for instrumentation, gluing, cutting, notching, coring or any other preparation. Figure 16 shows a typical IDEAL-CT load versus displacement curve.

After carefully examining the typical load-displacement curve and associated specimen conditions at different stages (Figure 16), the Authors chose the post-peak segment to extract cracking resistance property of asphalt mixes. Note that with the initiation and growth of the macro-crack, the load bearing capacity of any asphalt mix will obviously decrease, which is the characteristic of the post-peak segment. Based on Paris' law [13] and the work done by Bazant and Prat [14], a cracking parameter named CT_{Index} was derived and listed in Equation 3.

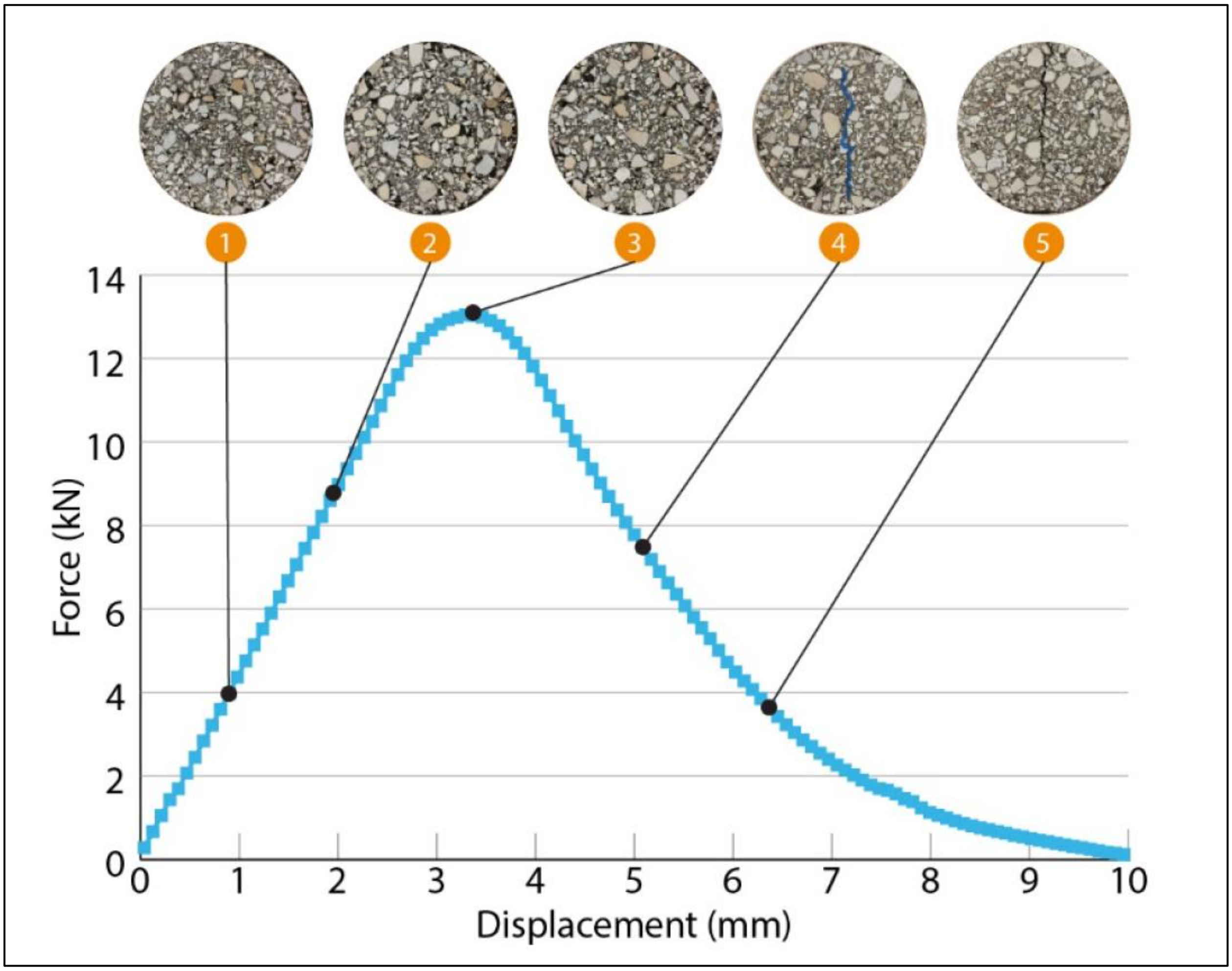


Figure 16. IDEAL-CT Typical Result [14]

$$CT_{Index} = \frac{G_f}{|m_{75}|} \times \left(\frac{l_{75}}{D}\right) \tag{3}$$

Where: G_f is the energy required to create a unit surface area of a crack;
$|m_{75}| = \left|\frac{P_{85}-P_{65}}{l_{85}-l_{65}}\right|$ is the secant slope is defined between the 85 and 65 percent of the peak load point of the load-displacement curve after the peak (Figure 17); and
l75 is deformation tolerance at 75 percent maximum load.

Generally, the larger the G_f, the better the cracking resistance of asphalt mixes. The stiffer the mix, the faster the cracking growth, the faster the load reduction, the higher the $|m_{75}|$ value, and consequently the poorer the cracking resistance. It is obvious that the mix with a larger $\frac{l_{75}}{D}$ and better strain tolerance has a higher cracking resistance than the mix with a smaller $\frac{l_{75}}{D}$. The IDEAL CTIndex test results are show in Figure 18. The results from the testing clearly show FAA #2 FR asphalt mixture has a higher cracking resistance than the P401 FAA #2 asphalt mixture.

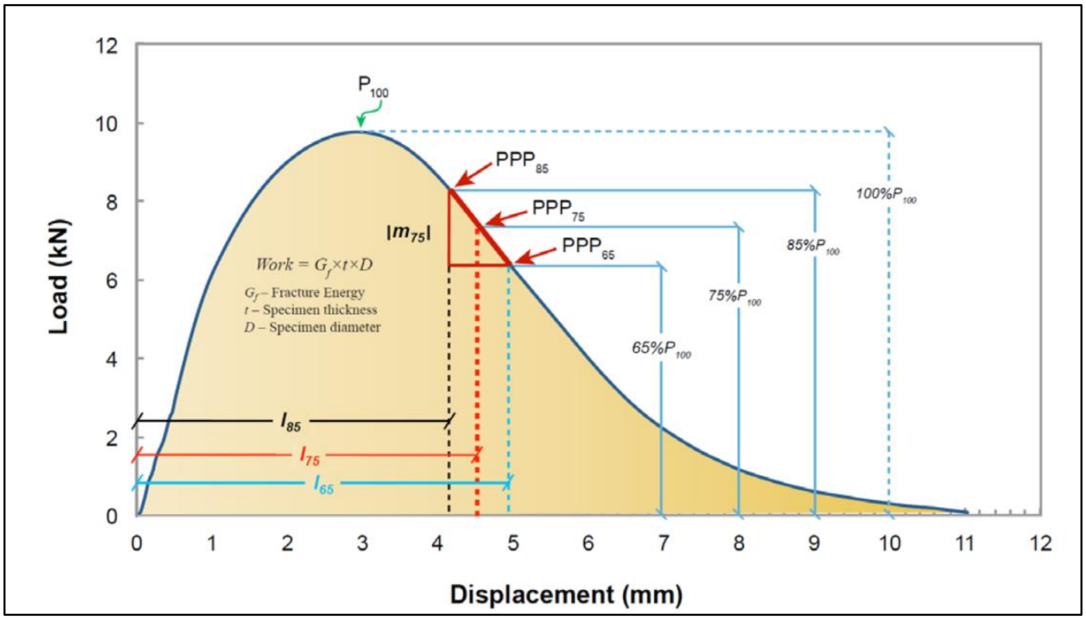
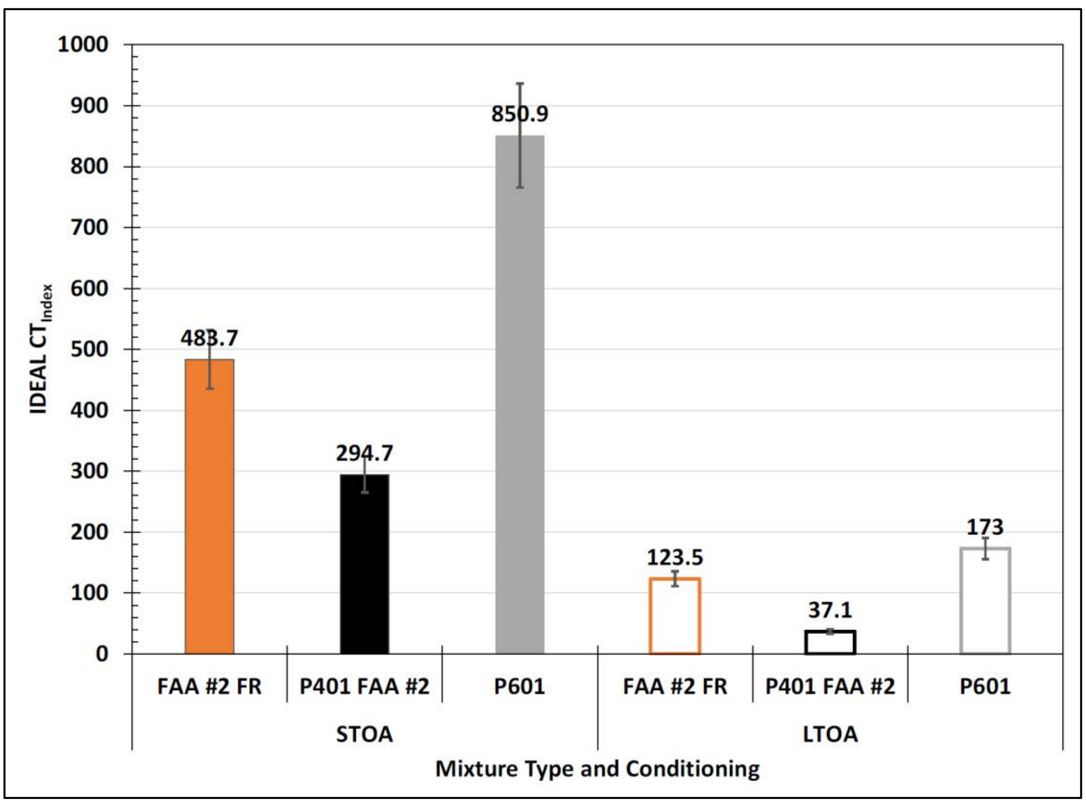


Figure 17. Illustration of the PPP75 Point and Slope $|m75|$ [14]



Note: STOA is Short-Term Oven Aged, and LTOA is Long-Term Oven Aged.

Figure 18. IDEAL CT_{Index} Test Results

2.5 Fuel-Immersion Test

FAA Item P-601 specification requires a certain degree of fuel resistance from the mix and describes the methodology on how to measure such behaviour. For this test, specimens are compacted to a target of 2.5 ± 0.7 percent air voids and evaluated for resistance to fuel damage using the test procedure noted in FAA P-601, Section 3.3 [15]. For this procedure, specimens are first immersed in an aviation type of kerosene (VV-K-211) for two minutes and surface dried to with a paper towel and record the weight. Specimens are then re-submerged in the same kerosene for 24 hours. After conditioning in kerosene, specimens are placed on a paper towel to absorb the free kerosene and dry under a fan for 24 hours at 25°C to record the weight and calculated the mass loss using Equation 4:

$$Fuel\ Immersion\ Mass\ Loss\ (\%) = \left(\frac{A-B}{A}\right) \times 100 \qquad (4)$$

Where: A is weight (kg) after 2 minutes immersion in kerosene type VV-K-211; and
B is weight (kg) after 24-hour immersion in kerosene

The Fuel Immersion test was performed on a typical mixture placed as surface course on a relatively busy runway at the Pearson International Airport in Toronto. Furthermore, a similar FR binder used in this study was developed by McAsphalt Industries in Canada in partnership with Associated Asphalt to modify the existing Pearson Airport mix to a FAA P-601 type of mix with properties listed in Table 3. It should be noted that the same aggregate source was used for both mixes.

Table 3. Mix Properties of a P-601 Alternative Mix to the Typical Pearson Airport Asphalt Mixture

Properties	**P-601 Alternative to Pearson Airport Mix**	**Typical Pearson Airport Mix**
Asphalt Binder Content (%)	6.0	5.0
Air Voids (%)	2.3	4.2
Performance Grade	PG 82-28 FR	PG 70-28P
Mass Loss by Fuel-Immersion	0.83%	10.4%
Retained Marshall Stability after Fuel-Immersion	74.4%	34.4%
Images of Before (Top) and After (Bottom) Fuel Immersion Test		

Note: PG is Performance Graded, FR is Fuel Resistant, and P is Polymer modified.

It is evident from values listed in Table 3 that there is a tremendous difference in fuel-immersed mass loss and retained stability after the 24-hour fuel-immersion. The visual aspect of the two specimens help better understand the magnitude of the difference between the 0.83 percent mass loss for the fuel resistant mix that could be used at the Pearson Airport compared to the existing mix at the airport with 10.4 percent mass loss.

3.0 PLANT PRODUCTION AND PAVING EXPERIENCE

Associated Asphalt's FR binder was used to develop a mixture in collaboration with the Massachusetts Port Authority (MASSPORT), the owner agency of Logan International Airport in Boston, Massachusetts. This mix was intended to provide far better performance to those mixes that were previously placed and could not resist rutting and shoving caused by slow-moving aircraft taxing or awaiting clearance. Figure 19 shows the location of those sections (marked as "A") where the most severe rutting and shoving were observed to the point that MASSPORT was only left with the option of milling and paving every summer.

StellarFlex FR is produced by using conventional production and paving equipment. For this paper, details on production and paving of the StellarFlex FR mix placed at Logan AIP in Boston is provided. A drum plant was used to produce the mix at 165 ± 5°C without any issues pumping the FR binder through the plant, nor any issues mixing the binder with aggregate blend to achieve proper coating.

The StellarFlex FR was then delivered to the jobsite by conventional haulage equipment and placed with conventional paving equipment shown in Figure 20. The paving crew testified that they could see no difference between the StellarFlex FR and any other mix containing high polymer modified binders such as PG 82-22 or PG 70-28. The mat texture and appearance were similar to any other dense-graded HMA.

Figure 19. Runway, Taxiway, and Alleyway Sections at Boston Logan International Airport Surfaced with StellarFlex FR Asphalt Mixture [16]

Figure 20. Placement of StellarFlex Fuel-Resistant (FR) on Boston Logan International Airport Runway 4L-22R (Left) and Alleyway B-C (Right)

4.0 FIELD PERFORMANCE

4.1 Previous Projects with StellarFlex FR

The StellarFlex FR mix has placed at number of International Airports [IAP], including Kuala IAP in 1996, Cairo IAP in 1997, and Aden AIP in 1999. This mix was then introduced in the U.S. under modified P-401 mix at La Guardia Airport in New York in 2002, Boston Logan IAP in Massachusetts in 2004, and Douglas IAP in North Carolina in 2006. The StellarFlex FR has also been placed across number of General Aviation Airports (GAA) across the U.S., including Williston Airport and Herlong Recreational Airport in Florida, and Georgetown County Airport in South Carolina.

It should be noted that the StellarFlex FR mix is not limited to airport pavements. The knowledge and methodology in development of the StellarFlex FR has been used to develop a surface course for projects including:

- Florida Department of Transportation I-10 Agricultural Inspection Station (AIS) in Florida;
- Bus lanes across the Logan AIP;
- MarineMax boat storage warehouses across the East Coast of U.S.; and
- Central Park in New York.

For this paper, only field performance of the StellarFlex FR at Boston Logan AIP is presented.

4.2 Boston Logan International Airport

In June 2004, 1300 tons of the StellaFlex FR mix was placed in a 50 mm lift at Boston Logan Airport on Taxiway N and Runway 22R-4L as shown in Figure 19 (marked as area “A”). At the time, severe rutting and shoving was problematic after each summer season and the only option available to MASSPORT was to mill and resurface every year by using FAA Item P-401 approved mix.

The finished texture of StellarFlex FR at Logan IAP is shown in Figure 22, which after a decade has not shown any sign of rutting, raveling and weathering, cracking, and the grooves showed no deterioration. Moreover, Figure 21 illustrates a visual comparison between the StellarFlex FR and FAA Item P-401 mix that were used to pave Runway 22R-4L. It is evident that StellarFlex FR has provided far better in-service performance than the FAA Item P-401 mix.

Figure 21. StellarFlex Fuel Resistant Texture at Boston Logan International Airport in 2004 (Left) and the Same Texture in 2014 (Middle and Right).

Figure 22. StellarFlex Fuel Resistant at Boston Logan International Airport Runway 4L-22R in 2014 after Ten Years of Service (Left) and a Federal Aviation Administration Item P-401 Mix in 2014 After Ten Years of Service at Boston Logan International Airport Runway (Right).

In October 2015, after observing excellent performance of StellarFlex FR on the Taxiway N and Runway 4L-22R, MASSPORT decided to extend the usage of the StellarFlex FR to the alleyways around between those aprons marked as “C” on Figure 19. The purpose of using StellarFlex FR was to combat fuel spillage distress in addition to the rut resistance. Re-Surfacing of the alleyways involved milling 200 mm of existing HMA and constructing the first 150 mm of the 12.5 mm Item P-401 as a binder course containing PG 82-22 graded asphalt binder, and a 50 mm of the StellarFlex FR as surface course. Figure 23 shows the newly paved Alleyway B-C, as well as the same alleyway after 12 years of being in-service with no signs of any surface defects or distresses. It should be noted that at de-icing at the Logan IAP is often performed at the gates on concrete pads surrounding the alleyways. This causes the pavement structure used for the alleyways to be exposed to harsh de-icing chemicals. But, Figure 23 suggests excellent performance of the StellarFlex

FR in providing an impermeable surface for protecting the pavement structure as no signs of damage has been observed to date. Since placement of the StellarFlex FR on Alleyway B-C, other alleyways shown in Figure 19 (marked as B and A) were also surfaced with the same mix including: the Alleyway C-E in 2006, and Alleyway C in 2007. All the sections are displaying excellent performance to date.

Figure 23. Newly Paved StellarFlex Fuel Resistant (FR) at Boston Logan International AirportAlleyway B-C in 2005 (Left) [17] and after 12 Years of Service (Right)

5.0 SUMMARY

This paper provides information on steps employed in the design of a high shear and jet fuel resistant mixture for use in heavily traveled airfield pavements, including: (1) the development of an asphalt binder containing specialty modifiers and additives to resist the softening effect of fuels and lubricants, and (2) the design of an aggregate blend to provide high level of stability to provide high level of resistant to rutting and fatigue cracking.

The first mixture was designed using the current P401 specification and used a PG82-22 asphalt binder (called P401 FAA #2). The second mixture was designed using the identical aggregate gradation, but used the compactive effort and volumetric targets of the P601 (called FAA #2 FR). High temperature asphalt mixture stiffness, AMPT Flow Number and the APA test results showed that the FAA #2 FR asphalt mixture had far better resistance to permanent deformation than the P401 FAA #2 asphalt mixtures. Meanwhile, intermediate/low temperature asphalt mixture stiffness, SCB Flexibility Index, and IDEAL CTIndex test results showed that the FAA #2 FR asphalt mixture had far better fatigue cracking resistance. Overall, the research study validated modifying the P401 asphalt mixture design procedure with the P601 compactive effort and design target air voids while utilizing the Stellarflex FR asphalt binder within the FAA Aggregate Gradation #2.

The methodology of developing StellarFlex FR explained in this paper can be used to tailor specific volumetric properties and performance criteria for other applications, including: heavily-loaded pavements with high volumes & slow truck traffic, fuelling/gas stations and fuel storage tank areas, truck and bus stops, seaports or commercial loading/off-loading areas. Results of this paper suggest that a high-performance asphalt mix can be designed for any loading application, but the design process needs to be well-planned and include performance testing. This also suggests that moving toward performance-based mix development could provide tremendous information on how a mix can perform under specific loading and climatic conditions. With successful stories at different airports throughout U.S., major airports in Canada are expressing a keen interest in trying this technology in the near future.

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