

Selecting a Rut Resistant Hot Mix Asphalt For Boston-Logan International Airport

Robert J. Pelland¹, Jonathan S. Gould² and Rajib B. Mallick³

Abstract

Hot weather pavement rutting and moisture induced damage have become problematic on several taxiways and aprons that are subject to slow moving and standing aircraft loads at Logan International Airport in Boston, MA. The Massachusetts Port Authority is evaluating the performance of seven mix designs that are presently in service by the testing of field cores at the Worcester Polytechnic Institute (WPI). Three mixes were tested for rutting and moisture susceptibility: a Trinidad Lake Asphalt (TLA)/latex modified P-401, a PG 64-28 P-401, and Densiphalt7, a semi-flexible pavement. Four mixes were selected for more extensive testing: a PG 76-28 modified P-401, a reclaimed asphalt pavement (RAP)/latex modified P-401, a latex modified stone matrix asphalt (SMA), and a Rosphalt 50TM modified P-401. Laboratory studies included use of loaded wheel track tests for determination and comparison of rutting and moisture induced damage at 60°C (140°F); determination of resilient modulus with the universal testing machine (UTM); determination of volumetric properties; and determination of the high temperature PG rating of the binders. Results indicate that significant improvement in rutting resistance can be achieved by providing a higher performance grade asphalt, a modified binder, or coarser gradation. The modification of mix designs comes with an increased cost of production. Not surprisingly, the two most expensive mixes, Densiphalt7 and Rosphalt 50TM, tested very well; they may be most cost effective in locally troublesome areas. Based on Massport's field experience, Densiphalt7, and probably Rosphalt 50TM, must be installed on a very stable subbase. These mixes may thus be best suited as the wearing course of new construction as opposed to an overlay or inlay of existing pavements. The TLA mix shows good rut resistance in the laboratory, but is prone to cracking and susceptibility to moisture after four to five years of service. The PG 64-28 P-401 also proved to be susceptible to moisture. Both mixes are no longer used at Logan Airport. The RAP mix has performed very well in the field through two summers and tested well in the laboratory. The PG 76-28 and SMA mixes have shown slight indications of rutting in the field. These last three mixes are the least costly to produce and should be studied further. It is recommended that long-term field performance of these mixes be evaluated, and that accelerated loading and testing of these mixes be conducted. Using the results of this program, proper specifications and quality control tests can be developed for assuring design and construction of economical and stable mixes.

¹ PE, MASCE, Project Manager, Massachusetts Port Authority, bpelland@massport.com

² Research Assistant, Worcester Polytechnic Institute, gouldj@wpi.edu

³ PhD, PE, Assistant Professor, Worcester Polytechnic Institute, rajib@wpi.edu

Introduction

The Massachusetts Port Authority (Massport) operates Logan International Airport (BOS). Logan is a busy place, ranking 18th in the nation for enplanements in 2001. The airfield is a very compact arrangement of intersecting runways and taxiways. Pavement rehabilitation/reconstruction projects cause delays for the airlines and increase the workload of air traffic controllers. Massport continues in its efforts to find more durable and cost-effective pavement systems to minimize the effects of these expensive disruptions of service. The first part of this paper discusses some recent pavement failures at Logan, the development of Massport's present P-401 specification, and the use of several unique pavement types for local repairs. The second part of this paper presents the results of a laboratory testing program on seven different pavements conducted by the pavement research laboratory at Worcester Polytechnic Institute (WPI).

Taxiway November

While pavements are designed for a twenty-year service life, the reality is that Logan's most heavily used hot mix asphalt (HMA) pavements last only ten to twelve years. Prior to the proliferation of heavy wide body aircraft, pavements were rehabilitated because of cracking and oxidation due to age. By the early 1990's Logan pavements were experiencing rutting and shoving, particularly in the summer months, caused by heavy aircraft braking, turning sharply, taxiing slowly or standing in queue.

At Logan Airport, the terminal aprons are Portland cement concrete (PCC) pavement. All of the runways, taxiways and terminal area taxiways (referred to as "alleyways") are HMA pavement. The only exceptions are two sections of Taxiway November that were reconstructed with PCC pavement. The first section was rebuilt in 1997 due to shoving and rutting, and the second in 2000 due to moisture induced damage. Taxiway November is the only access to Runways 22R and 22L. The taxiway is subjected to slow moving and standing aircraft during the summer hot months when Runway 22R is used as the primary departure runway.

During the mid-1990's, where Taxiway November makes a 90° turn just prior to joining Runway 22R, rutting and shoving became so severe that the centerline lights were moving. A repair using the then standard 12.5 mm (1/2") AC-20 P-401 did not stand up to the hot weather traffic. (Please note that aggregate sizes cited herein are nominal maximum aggregate size, NMAS.) This particular mix installed in the early 1990's is still performing well on other parts of the airfield which do not see hot weather traffic. Attempts to repair the corner of Taxiway November with larger aggregate P-401 failed as well. Tests showed that air voids went from 5% to 2% after failure due to consolidation from wheel loads. At this time the Port Authority of New York & New Jersey was having success with a rut resistant mix using Trinidad Lake Asphalt (TLA) and latex as a modifier to AC-20 binder (Bognacki, circa 1995). Massport used a TLA/latex modified P-401 from 1995 to 1998. Projects using the

TLA mix included the 1997 overlay of Taxiway November, except for the above-mentioned 90° turn which was reconstructed with full depth PCC.

In late summer of 1999 routine inspection of Taxiway November revealed that the asphalt was stripping from the aggregate in the wheel tracks and individual stones were starting to pop out. A coal-tar slurry was applied in October 1999 to prevent further stripping. During August and September of 2000, six emergency repairs requiring closure of the taxiway had to be performed. Every failure was the same with a small pavement shove becoming a pothole in just a few days. The TLA mix installed in 1997 appeared to be stripping; the underlying lift of pavement, installed in the early 1980's, was completely stripped at the point of failure. Repairs were done by milling out the two lifts of mix and installing a HMA patch, typically 4.5 m x 9.0 m (15' x 30'). The underlying lift offered no resistance to the milling machine and appeared to contain moisture throughout. Once the weather cooled in September, no more failures occurred.

Cores were taken along 425 m (1,400') of Taxiway November in the wheel tracks, as well as 18 m (60') either side of the centerline to serve as a study control. The subsequent evaluation offered that the probable primary cause of failure was the presence of mineral aggregates in the TLA mix and the underlying mix that are susceptible to moisture induced stripping (ATC, 2000). Logan Airport is surrounded by water and receives ample rain or snow every month of the year. Gravel subbase beneath the pavement was found to contain 7% to 10% moisture. Cores revealed stripping in the TLA and underlying layers in both the wheel track and the control areas. The cores failed to pass stripping tests using both ASTM D4867 and AASTHO T-283. Tests on core samples proved negative for possible jet fuel contamination. Recovered asphalt from the wheel track and control areas did not reveal anything suspect. Marshall tests on both the TLA mix and underlying mix revealed nothing suspect. Voids in the wheel track area were lower than those in the non-trafficked areas.

In November 2000, two different repair strategies were used. Full depth PCC pavement, 38 cm (15") thick, was installed in the wheel tracks on the northern half of taxiway, contiguous with the PCC pavement installed in 1997. This pavement is still performing well. In 2000 this portion of Taxiway November had an estimated 57,000 jet aircraft operations (9,400 equivalent A330 operations). (Please note that all traffic estimates cited herein are from the "Pavement Condition Survey and Evaluation for Logan International Airport" by Eckrose/Green Associates, Inc., March 2001. Only aircraft with a capacity of 100 or more passengers were counted.)

The southern section of taxiway November was milled to a depth of 20 cm (8") and inlaid with an unmodified 19 mm (3/4") PG 64-22 P-401. This portion of Taxiway November handles Runway 4R arrivals as well as Runways 22R and 22L departures, 100,000 operations annually (14,000 equivalent A330 operations). Although traffic does not typically queue up here, by July of 2001 one wheel track was shoving badly. It was milled and inlaid with 10 cm (4") of RAP/latex modified PG 64-22 P401. The other wheel track was showing similar distress by the end of the summer and in November 2001, it was milled and inlaid with 10 cm (4") of PG 76-28 P-401, the present standard P-401 for Logan Airport. Both pavements are

performing well with the RAP mix showing no signs of rutting and the PG 76-28 mix showing slight rutting.

Present Massport P-401 Specification

Several initiatives were set in motion as a result of the Taxiway November experience. The use of ground penetrating radar (GPR) is being investigated as a non-destructive means of locating and defining areas of stripping within an HMA pavement section. Also, a committee is being established to develop a comprehensive protocol for evaluating and testing the structural soundness of existing pavements to be overlaid or inlaid.

Another initiative, by Massport's consultant Edwards & Kelcey, resulted in modifications to the P-401 specification that required a "Waiver to Standards" from the FAA. In 2001, the modifications were requested and granted in anticipation of a four year program to rehabilitate several heavily used taxiways and Runway 4L-22R. Through five projects to date (approximately 97,000 tonnes or 107,000 tons) this mix is performing well.

Tensile Strength Ratio. The ability of an HMA to resist stripping is measured by the tensile strength ratio (TSR). On past projects at Logan, the required tensile strength ratio value of 75 was barely met. Most paving projects at Logan are supplied and installed by Aggregate Industries, Inc. from a nearby granite quarry. The specification now requires an anti-stripping agent for all job mix formulas (JMF) and a minimum TSR value of 92. Production must stop if the TSR value falls below 92 and any material in the field must be replaced, with the option to leave deficient material in place, to be paid at 50% of the contract price. The contractor has had no problems achieving a TSR of 92. The anti-stripping agent was added at the refinery.

Performance Graded Binder. Because of the failure of the PG 64-22 P-401 on Taxiway November, the rut resistance of the P-401 has been enhanced by bumping the PG rating two grades higher than the standard PG 64-28 used by the Massachusetts Highway Department (Mass Highway). The production crews have not had any problems with the laydown of this material.

Air Voids. On past projects the contractor has not had problems achieving compaction in the field. In the FAA P-401 specification, there is no upper limit in the acceptance criteria for in-place mat and joint density. There was a concern that the contractor could over compact the mix, leaving insufficient air voids to resist rutting and shoving. The in-place mat and joint density criteria have been replaced with in-place air void criteria to ensure that the contractor will not over compact. The in-place air void criteria has lower and upper limits, similar to the current Mass Highway specification. Mat air voids have a range of 3.0-7.0 and a target of 5.0; joint air voids have a range of 3.0-10.0 and a target of 6.5. The range for plant air voids was increased, 2.0-6.0, versus 2.0-5.0 in the standard FAA specification. Also, the range of Marshall design air voids was changed to 3.0-5.0, versus 2.8-4.2. Again, the laydown crews have had no problem meeting this criteria, despite the fact that there is a much greater effort required of the contractor to monitor compaction during the rolling process.

Other Trouble Spots

Numerous repairs have been performed on local areas at Logan where HMA mixes have deformed due to standing loads. The cul-de-sac arrangement of gates, with a single taxiway (alleyway) in and out, necessitates that aircraft be pushed back and towed to a holding spot at the top of the alleyway for engine start. These holding spots are subject to the static weight of the tug and the aircraft, and to a variety of fluids that leak from the tugs and aircraft, softening the pavement. Massport would like to inlay and “armor plate” the HMA alleyways with a more durable product rather than convert to full depth PCC pavement with its greater cost and longer installation time. With three alleyways due for rehabilitation in 2005 and 2006, Massport opted to test three different pavements in severe duty areas.

The products selected for comparison with the RAP P-401 mix and the PG 76-28 P-401 mix were Densiphalt[®] (Densiphalt[®] is a registered trademark of Densit U.S.A., Inc.), Rosphalt 50TM (Rosphalt 50TM is a trademark of the Royston Laboratories Division of Chase Corporation), and a stone matrix asphalt (SMA).

Densiphalt[®] Densiphalt[®] is a composite pavement developed by Densit a/s in Denmark. It has been in use in Europe for over a decade as a solution for heavy traffic areas including aircraft parking aprons. Advertised as a “semi-flexible” pavement, it is an open graded HMA (25-30% voids) whose voids are filled a proprietary cementitious mortar. After the HMA mat has cooled to a recommended 30°C (86°F), the mortar is pumped from a continuous mixer onto the mat and spread by squeegee. The mortar requires 24 hours to cure. The surface must be treated to improve friction characteristics by texturing with sand, mechanical brooming, shot blasting or micro-grinding (Densiphalt[®] Handbook, 2000).

Massport has installed two Densiphalt[®] patches, each 15 m x 45 m (50' x 150'). The first patch was done in August 2000 at the alleyway holding spot between Terminals B and C. This was the fourth repair done at that location since it was overlaid with a TLA P-401 mix in 1995. All failures occurred during the summer months. This alleyway is the busiest, with 27,500 annual operations in 2000 (14,600 equivalent B767-300 operations). Densit worked with the contractor to develop the JMF for the HMA. Fiber and lime were added to the binder to prevent draindown. The mat was static rolled. The entire operation took 38 hours and required the closure of two gates to allow access in and out of cul-de-sac; two other gates were inaccessible. Because of time constraints, the mortar was applied when the mat temperature reached 50°C (120°F). Subsequent cores revealed that the mortar penetrated the full 10 cm (4") of the mat despite the high temperature. Densit is developing a system using a cold HMA mix and a rapid setting mortar which will dramatically cut installation time.

The patch is still in service after almost three years and although it is visibly distressed with rutting and alligator cracking in the wheel tracks, it is still intact. The rutting is most likely caused by inadequate support due to petrochemical contamination in the HMA below the Densiphalt[®]. This patch has far out performed any previous HMA patch at this location.

The other Densiphalt[®] patch was installed on Taxiway Whiskey in June of 2001 and is not faring as well. This is a chronic hot weather trouble spot where arriving aircraft hold for clearance before crossing Runway 22R. One side of the patch is 10 cm (4") thick. It started raveling during a thaw this winter and by March 2003 a 5 cm (2") deep rut developed with extensive raveling. The Densiphalt[®] was milled out and replaced with HMA. The other side is 15 cm (6") thick Densiphalt[®], with wire mesh installed between the 7.5 cm (3") lifts of HMA. This side is much less distressed but also starting to show signs of raveling. Again, the base below the Densiphalt may not be stable due to contamination and a weak subbase.

The cost for these patches was roughly three times the cost of a typical HMA repair. Densit now manufactures the mortar in the United States which should help to lower costs. Densiphalt[®] should be considered as a possible wearing course for new construction. Use of Densiphalt[®] on older pavements should be done judiciously, as seen by Massport's experience.

Rosphalt 50TM. Rosphalt 50TM is described as a concentrated thermoplastic virgin polymeric material which is added to an HMA to improve its rut resistance. Because the Rosphalt 50TM modified HMA is designed to have only 0.5% to 2.0% voids, it is impermeable. It has been primarily used as a wearing course on PCC bridge decks, eliminating the need for a waterproof membrane (Royston, 2001). Logan's Terminal E upper level roadway and a portion of Massport's Tobin Bridge were resurfaced with a Rosphalt 50TM HMA in 2002 and the mix is performing very well.

The Rosphalt 50TM is packaged in pellets and added to the mix at the plant, 2.25% by weight. Production and installation temperatures are much higher than those for conventional HMA mixes. The mix is batched at 220°C (425°F); recommended laydown temperature is 190°C to 210°C (315°F to 410°F); breakdown rolling temperature is 150°C to 210°C (300°F to 410°F); and finishing rolling temperature is 120°C to 150°C (250°F to 300°F). The pavement can be opened to traffic when it has cooled below 60°C (140°F). Tests performed for Royston at the National Center for Asphalt Technology (NCAT) in 1999 indicated that a Rosphalt 50TM modified PG-64-22 binder had a performance grade rating of at least PG 94-34.

Logan Airport is the first to use Rosphalt 50TM in an airfield pavement. Royston staff worked with Massport's contractor to develop a JMF based on the gradation of an FAA 19 mm (3/4") P-401. The JMF for bridge deck applications typically has a 12.5 mm (1/2") NMAAS.

A test strip of 54 tonnes (60 tons) was installed on a service road at Logan in July 2002. Cores were taken from this test strip for analysis by WPI. In November 2002, a Rosphalt 50TM patch was installed side by side with a PG 76-28 P-401 patch at the beginning of Runway 22R. Each patch is 10 cm (4") thick and 7.5 m x 45 m (25' x 150'). Aircraft turn onto the runway and hold for departure at this location. As mentioned before, this runway is heavily used in the summer. In 2000 there were 45,000 departures (7,200 equivalent A330 operations) from 22R. A repair has been done every five years since the runway was rehabilitated in 1987, to replace shovled and dimpled blacktop. The first 137m (450') of Runway 22R will be converted to full depth PCC in 2004.

Both patches on Runway 22R are performing well but have not been subjected to hot weather at the time of this writing. The laydown crew had no difficulties with the Rosphalt 50™ installation. It is very important for the breakdown rolling to be done right behind the paver. Also an ample supply of water for the roller must be on hand because of the higher temperature of the mat. It is interesting to note the Rosphalt 50™ mix has a more uniform texture and appearance than the PG 76-28 mix placed at the same time, by the same crew on Runway 22R. Friction test results by a Saab on the Rosphalt 50™ mix are similar to those of the PG 76-28, 0.90 dry and 0.80 wet at 48 km/hr (30mph). The installed unit cost for Rosphalt 50™ was four times the cost of PG 76-28 P-401.

Stone Matrix Asphalt. Stone Matrix Asphalt was developed more than twenty years ago in Germany as a studded-tire resistant HMA. The use of SMA in the US started in the early 1990's after a study tour of several European nations by a group of US pavement experts. Through 1999, more than half of the states in the US have constructed over 100 SMA projects. The majority of the pavements were constructed in high volume/slow moving traffic areas. Most of these projects have shown excellent performance, particularly with respect to resistance against permanent deformation or rutting (Brown et al, 1997).

The basic design for SMA consists of a stone-on-stone contact skeleton for resisting loads and high asphalt content for achieving adequate durability. The stone-on-stone contact criterion is met by providing a very coarse gradation. This coarse gradation and high asphalt content necessitate the use of a high amount (compared to conventional dense graded HMA) of filler material and fibers, for resisting draindown of asphalt binder. Quite often additives are used for modifying the properties of asphalt binder, in order to achieve a mix with less temperature sensitivity. WPI developed a JMF for Logan that called for lime and fiber for resisting draindown, an anti-stripping agent, and latex to lessen temperature susceptibility.

The alleyway hold point at Terminal D was selected for an SMA patch in July 2001. In 2000 this alleyway had 18,500 operations (7,600 equivalent B767-300 operations). An area 15m x 60m (50' x 200') was milled and inlaid with 10 cm (4") of SMA. There was a problem at the plant with temperature control and the mix was batched hotter than normal. Bleeding occurred in a few very small spots, a common problem with SMA mixes. The alleyway was returned to service before the patch completely cooled, resulting in slight rutting initially. No further deformation was observed until August of 2002, on a day that reached 39°C (102°F), when a wheel dent 2.5 cm (1") deep occurred. The SMA is rich looking due to its high asphalt content. The surface is very textured, and when wet it has an appearance reminiscent of a grooved pavement. The cost for this repair was one and a half times more than a conventional HMA patch.

Results of Laboratory Testing by Worcester Polytechnic Institute

Laboratory testing of different HMA mixes was conducted in several phases. In the first and third phases, in-place field cores were tested, whereas in the second phase, loose mix was compacted in the laboratory and tested. All of the testing focused on

evaluation of rutting potential. Additional tests for evaluation of moisture susceptibility were also conducted in some cases. The Asphalt Pavement Analyzer (APA), made by Pavement Technology, Inc., was used for evaluation of rutting potential. The APA is a loaded wheel tester with an automated data acquisition system. The APA is capable of testing both cylindrical samples and beam samples. For this project, only cylindrical, 150-mm (6-inch) samples were used. The APA can rut samples in three molds during one test and each mold can hold two cylindrical samples. Therefore, the APA can test a maximum of 6 samples during one test. Once the molds are loaded and secured to the sample tray and the test chamber doors are closed, the loaded wheels are automatically lowered on to the samples. The pressure exerted by the loaded wheels can be adjusted to a maximum load of 113.4kg (250lbs). Rut testing can be performed at specific temperatures on dry samples and on samples that are immersed in water.

Another feature of the APA is its capability to control the temperature in both the test chamber and a storage chamber located at the bottom machine. This storage chamber enables extra samples to be stored overnight to prepare for the next days test. The actual rut test is a hands free activity. Once the load and number of cycles are selected from the control panel for a project, and the start button is pressed, the APA conducts the test without need of assistance. During the test, the APA continuously measures the depth of rutting at five points along the loaded wheel path. This information is transmitted to the data acquisition system and recorded on a personal computer which is connected to the APA. The computer has a program that analyzes the data it receives from the APA. The program plots the rutting at 80 cycle increments and then produces a line graph for each mold being tested. The program also yields the rutting depth continuously throughout the entire test and can produce a table giving specific depth at a specified increment.

Phase 1 tests were conducted on field cores of a TLA P-401 installed in 1997 on Taxiway November, a PG 64-28 P-401 installed in 1999 at TWA Cargo, and Densiphalt7 installed in 2000 at the Terminal B-C alleyway.

Phase 2 tests were conducted on laboratory fabricated samples of the PG 76-28 P-401 mix.

Phase 3 tests were conducted on field cores of the PG 76-28 P-401 installed on Taxiway November in 2001, a RAP P-401 installed on Taxiway November in 2001, an SMA mix installed in 2001 at the Terminal D alleyway, and a Rosphalt 50™ P-401 installed in 2002 on a service road.

Phase 1: Testing of TLA P-401, PG 64-28 P-401 and Densiphalt7 Mixes

The study consisted of obtaining HMA cores, conditioning the cores, testing the cores with the APA, and analyzing the results from the tests. The test matrix is shown in Table 1. The samples were kept at the test temperature, 50°C (122°F) and 60°C (140°F), overnight and then loaded into the molds inside the APA. The chamber temperature in the APA was set at test temperature, the load on the wheel was set at 45 kg (100 lb), and the hose pressure was set at 690 kPa (100 psi), to produce a combined effect of 690 kPa (100 psi) pressure on the samples. Tests were conducted

for 8,000 cycles. The rut depth for each sample and the average rut depth for each mix are shown in Table 2.

In terms of rutting the mixes can be ranked as (from best to worst mixes): Densiphalt7, TLA P-401 and PG 64-28 P-401. Comparing the rut depths with the recommended threshold value of 7.5 mm when tested at 60°C (between poor and good mixes, Lai et al, 1996 and Kandhal and Mallick, 1999), it can be concluded that the Densiphalt7 mix is the best and an excellent mix, and the PG 64-28 P-401 mix is the worst. It was noted that the rut depth for PG 64-28 P-401 increased significantly when tested under water at 60°C (compared to testing dry at 60°C). An examination revealed significant stripping of asphalt from the aggregate surface. Hence, it can be concluded that the PG 64-28 P-401 mix is also susceptible to stripping damage.

Table 1. Test matrix.

Mix	Rutting, mm			
	Dry		Wet	
	Temperature		Temperature	
	50°C	60°C	50°C	60°C
Taxiway November (TLA P-401)	XX	XX	XX	XX
TWA Cargo (PG 64-28 P-401)	XX	XX	XX	XX
Alley Way (Densiphalt7)	XX	XX	XX	XX

Note: X denotes one sample

Table 2. Results of rut testing.

Mix	Rutting, mm			
	Dry		Wet	
	Temperature		Temperature	
	50°C	60°C	50°C	60°C
Taxiway November (TLA P-401)	3.14	6.05	3.62	2.50
	2.77	6.06	1.92	2.40
	Average: 2.96	Average: 6.06	Average: 2.78	Average: 2.45
TWA Cargo (PG 64-28 P-401)	8.45	9.29	5.31	13.73
	5.14	7.71	3.38	10.09
	Average: 6.80	Average: 8.49	Average: 4.33	Average: 11.91
Alley Way (Densiphalt7)	0.59	2.82	0.51	0.57
	0.69	1.05	0.35	0.55
	Average: 0.64	Average: 1.94	Average: 0.43	Average: 0.56

Phase 2: Testing of PG 76-28 P-401

The objective of the work conducted in this phase was to evaluate a P-401 mix prepared with PG 76-28 instead of the standard PG 64-28. Loose mix was obtained during production, and samples were compacted with the Superpave gyratory compactor at 174°C (345°F). A design density (percent of theoretical maximum density) of 96 percent was noted at 100 gyrations. The two samples were compacted in a special mold, equipped with a lateral pressure indicator. Results of testing are shown in Figure 1 in the form of a plot of lateral pressure generated in the mix during compaction versus VTM. It can be noted that there is no significant change/increase in lateral pressure between anticipated construction VTM (approximately 7 percent) and design VTM (4 percent).

Tests with several poor and good performing mixes have shown that a significant increase in lateral pressure between construction and design VTM is indicative of a significant rutting potential (Mallick et al, 2002). Since in this case there is virtually no increase in lateral pressure between construction and design VTM, it can be concluded that the mix does not have significant rutting potential. This conclusion was supported by the results of rut testing conducted on two samples (compacted with a Superpave gyratory compactor to approximately 7 percent VTM).

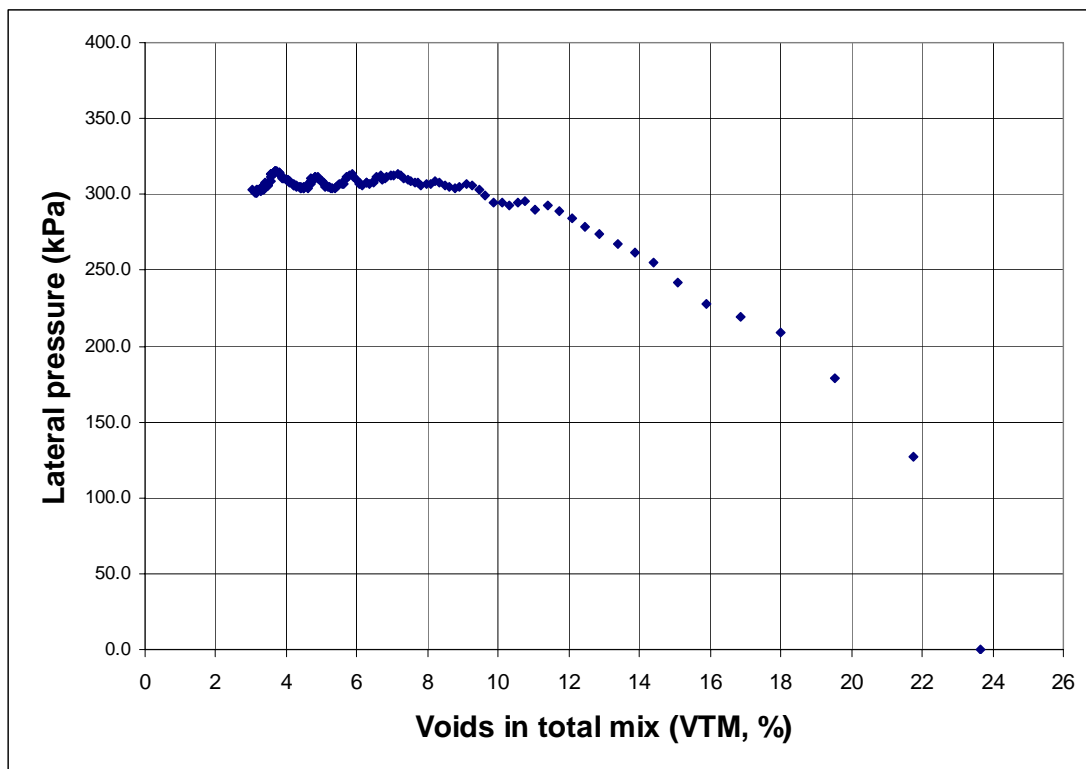


Figure 1. Plot of voids in total mix versus lateral pressure.

Rut testing was conducted using 8,000 cycles, under a load of 690 kPa (100 psi) and using a pressure of 690 kPa (100 psi) at a temperature of 60°C (140°F). The average rut depth (from two samples) was found to be 1.8 mm (average of 2.0 and 1.6 mm)

It should be noted that there are unavoidable differences between laboratory fabricated samples and in-place cores. Thus, there can be a difference between test data obtained from laboratory compacted samples and in-place cores, as was evident in the next phase of work, presented below. This difference can be partly due to compaction methods (gyratory compaction in the laboratory and roller compaction in the field) and the resulting difference in aggregate orientation in the mix.

Phase 3: Comparison of PG 76-28 P-401, RAP P-401, Stone Matrix Asphalt and Rosphalt 50™ P-401.

The objective of this work was to evaluate the four recently used HMA's in terms of their resistance against rutting, moisture damage and fatigue. The mixes were PG 76-28 P-401, RAP/latex modified PG 64-28 P-401, SMA and Rosphalt 50™ P-401. These mixes have been described earlier. The scope of work consisted of obtaining cores from pavements, cutting cores to proper heights, determination of bulk specific gravities and theoretical maximum densities, conducting dry and wet rutting test with the APA, determination of resilient modulus with universal testing machine (UTM), calculation of voids in total mix (VTM), and analysis of rutting and resilient modulus test results. For each mix, thirty 150 mm-diameter (6") cores were received. The cores were trimmed to proper size and shape, and then used for determination of bulk specific gravity (BSG), theoretical maximum density (TMD), dry and wet testing in the APA and resilient modulus testing.

APA testing was carried out at 60°C, using a pressure of 690 kPa and 8,000 cycles. Wet rut tests were carried out with the same conditions on samples submerged in water. For both dry and wet tests, the samples were conditioned for at least 4 hours before starting tests.

Resilient modulus (ASTM D4123) tests were carried out with a UTM, using a sinusoidal load, with a loading duration of 0.1 second and rest period of 0.9 second.

Test Mixes. Table 3 shows the materials for the four different in-place mixes. All four mixes can be characterized as 19 mm nominal maximum aggregate size (NMAS) mixes. The asphalt contents ranged from 4.6 percent in the RAP P-401 to 6.8 in the Rosphalt 50™ P-401. However, the four mixes had entirely different asphalt types – specifically because of the use of modifiers, either as part of the asphalt binder or as solids. Assuming that each mix was designed properly to obtain adequate voids, the performance of these mixes are inferred to be significantly dependent on the binder grade. Note that the binder grade for standard P-401 is PG 76-28, that of SMA and RAP P-401 are modified PG 64-28, and the grade for Rosphalt 50™ P-401 is probably PG 94-34 (Royston). The gradations of all of the mixes except that for SMA, are the same. The gradation for SMA is significantly coarser – 26 percent passing the 4.75 mm sieve, compared to approximately 45

Table 3. Mixes used in the study.

Mix	Gradation			Asphalt	Asphalt Content, %
	Sieve Size mm	US	% Passing		
PG 76-28 P-401	25 19 12.5 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075	1" ¾" ½" ⅜" # 4 # 8 #16 # 30 # 50 # 100 # 200	100 94 70 60 45 33 21 14 10 6 4	PG 76-28	5.40
RAP P-401	25 19 12.5 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075	1" ¾" ½" ⅜" # 4 # 8 #16 # 30 # 50 # 100 # 200	100 94 66 57 44 31 20 14 10 6 4	PG 64-28, RAP (18.5 %), SBR Latex (4 % by weight of binder), 0.5 % antistrip	4.60
SMA	25 19 12.5 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075	1" ¾" ½" ⅜" # 4 # 8 #16 # 30 # 50 # 100 # 200	100 88 45 26 21 16 14 12 --- 8.8	PG 64-28, SBR Latex (4 % by weight of binder), lime, fiber, antistrip	6.00
Rosphalt50™ P-401	25 19 12.5 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075	1" ¾" ½" ⅜" # 4 # 8 #16 # 30 # 50 # 100 # 200	100 94 70 60 45 33 21 14 10 6 4	PG 64-28 + Rosphalt 50™	6.85

percent passing the 4.75 mm sieve for the other three mixes. Hence, any difference in the performance of all other mixes versus the performance of SMA can at least be partially explained in terms of a difference in gradation.

Voids and Rut Testing Results. Table 4 shows the average voids (VTM) of the different cores used in this work. It is noted that the voids are low, compared to commonly observed values in highway construction. This could very well be due to presence of adequately compacted layers below and around the patches in which these mixes were placed. It is noted that in all of the mixes except Rosphalt 50™ P-401, the voids range from 3 to 4.5 – close to design air voids expected in HMA. In Rosphalt 50™ P-401, voids are close to 2 %.

Table 4. Voids of mixes.

Mix	Voids in Total Mix, VTM	
	Average, %	Standard Deviation, %
PG 76-28 P-401	4.5	1.06
RAP P-401	3.0	0.83
SMA	4.1	2.2
Rosphalt 50™ P-401	1.9	1.21

Table 5 shows the dry rut test results. Rut results below and above 6 mm can be used for differentiating good and poor mixes, if the samples are tested with 7-8 percent air voids (Lai et al, 1996). In this case, with samples at much lower air voids, the results can be used for a qualitative comparison rather than for identifying good and poor mixes. The observation of rut depths show that the PG 76-28 P-401 mix has the highest rutting, whereas the RAP P-401 has the lowest. Statistical analyses were carried out to identify significant differences in rutting and to rank the mixes. The results (Table 6) indicate that there is a significant difference in rutting, and that the RAP P-401 and Rosphalt 50™ P-401 mixes can be ranked above the PG 76-28 P-401 and SMA mixes.

However, it must be noted that voids in total mix (VTM) have a significant effect on rutting, and the relatively high VTM of the PG 76-28 P-401 samples could have contributed to rutting. Also, the RAP P-401 was constructed earlier than the other mixes – the slightly higher in-place aging of the RAP P-401 mix could be at least partly responsible for the low rutting of the samples. The RAP P-401 has the lowest asphalt content (4.60 percent) and 18.5% RAP material – both of which could have made the mix stiffer, compared to the other mixes.

Table 5 also shows the wet rut test results. Note that the wet ruts are lower than or equal to the dry ruts, except that for the RAP P-401. This seems to indicate that the rutting in the RAP P-401 mix gets aggravated in the presence of moisture. However, since none of the wet rut depths are above 4.5-5 mm range, it is difficult to predict whether any of these mixes is moisture susceptible or not. In fact, a visual observation showed no evidence of stripping in these mixes. From a purely ranking point of view, the results indicate that the Rosphalt 50™ P-401 mix has the lowest wet rutting, and the PG 76-28 P-401 has the highest wet rutting. However, as results

Table 7. Results of statistical analyses, wet rutting.

ANOVA Table for Wet Rut Depth, mm

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Mix	3	9.183	3.061	3.033	.0578	9.100	.602
Residual	17	17.156	1.009				

Note: This table shows that the p value is > 0.05, and hence there is no significant difference in dry rut depths of the different mixes

Student-Newman-Keuls for Wet Rut Depth, mm

Effect: Mix

Significance Level: 5 %

	Mean Diff.	Crit. Diff.
A, B	.693	1.664
A, C	.525	1.366
A, D	1.720	1.843
B, C	-.168	1.366
B, D	1.027	1.366
C, D	1.195	1.664

Because the cell counts are not equal, the harmonic mean is used to estimate n.

Note: Since all of the mean differences are less than critical differences (critical for defining significant difference), the wet rut depths are not significantly different.

Based on the criteria presented by Kandhal and Mallick, 1999 (for samples with approximately 4 percent VTM), the PG 76-28 P-401 mix can be termed as a rut susceptible mix, since the rutting exceeds 4.5-5 mm. However, this criterion is probably not applicable in this case, since it was developed on the basis of highway pavements, which were densified from 7-8 percent VTM to 4 percent VTM by traffic compaction. Therefore, the rut test results obtained in this phase should probably be used only for comparative purposes and not to draw any conclusion regarding the actual rutting potential of these mixes. As noted above, this mix is performing well in the field with only slight rutting evident.

Resilient Modulus Tests. The results of resilient modulus tests are shown in Table 8. The PG 76-28 P-401 has the highest modulus, whereas the Rosphalt 50™ P-401 has the lowest. SMA has the second highest modulus. For comparison, the resilient modulus of the PG 76-28 P-401 mix is very close to those observed in typical 12.5 mm NMA surface course mix used by Maine Department of Transportation.

Several things should be noted here. First, the Poisson's ratio is assumed to be 0.35 for all of these mixes. Most likely, the polymer modified mixes have higher Poisson's ratio (close to 0.45), although a difference in the Poisson's ratio will not, most likely cause a significant change in the resilient moduli values. Second, the low values of the moduli for some mixes, especially Rosphalt 50™ P-401, are due to the high value of the elastic recoverable strain (note that modulus is basically calculated as stress over strain). This test is not appropriate for a polymer modified mix. The high recoverable strain actually helps this type of material to be flexible and

Table 8. Resilient modulus.

Mix	Resilient Modulus, MPa		Average Total Recoverable Strain, 10 ⁻⁶ ,
	Average, %	Standard Deviation, %	
PG 76-28 P-401	3218	1543.2	12.1
RAP P-401	1391	525.8	18.1
SMA	1911	979.7	18.7
Rosphalt 50™ P-401	495	266.8	68.3

resistant to rutting.

It is important to note that the Rosphalt 50™ P-401 mix (as in elastomeric polymers) offers high resistance against rutting not by providing high stiffness, but by providing the ability to stretch and regain its shape once load is removed. Therefore, although the strain is high (and this results in a low modulus), it should be noted that this strain is completely recoverable, and hence in no way contributes to permanent deformation, or rutting. These mixes can be compared to rubber, which can get compressed under load, but regains its shape once the load has moved away from the point of interest. Because of this fundamental difference with conventional unmodified HMA in providing resistance against deformation, running resilient modulus and comparing moduli values with moduli values of unmodified mixes is not justified. For fair comparison one should look at accumulated shear strain under dynamic loading. However, as shown in Table 8, the high recoverable strain demonstrates the resilience characteristics of Rosphalt 50™ P-401. Again, the moduli values are of no significance, except for the unmodified asphalt mixes. For the PG 76-28 P-401 mix, the moduli values can be used with appropriate flexible pavement design program for determination of adequate thickness.

Results of Binder Testing. Asphalt binder was extracted from cores of the different mixes using a solvent extraction process (Rotovap method – ASTM D5404). These asphalts were then tested with the dynamic shear rheometer (DSR). The asphalts were treated as RTFOT – Rolling Thin Film Oven Test aged asphalts, and the test results ($G^*/\sin \delta$) were compared against criteria for PG grading (high temperature). The fail temperatures were determined, as indicated in Table 9. It can be observed that the PG 76-28 binder does meet the high temperature grade, the latex modified P401 binder shows a high temperature grade of 64°C, whereas the SBR modified SMA binder and the Rosphalt 50™ binder have high temperature grades of about 90°C and 138°C, respectively.

The relatively low fail temperature of the RAP P-401 asphalt binder is suspect. Since the SMA and the RAP P-401 were both prepared with 4 % SBR latex, the high temperature grade of the RAP P-401 should not be that low (65°C) compared to the high temperature grade of the SMA (91.6°C). Most likely, there are two reasons for this discrepancy. It is suspected that the extraction process was not successful in obtaining a good asphalt binder sample from the RAP P-401, and also,

Table 9. Results of DSR Tests conducted on extracted asphalt.

Sample	Temp. Deg C	G*/sin(delta) kPa
PG 76-28 P-401	70	4.162
	76	2.196
Fail Temperature, C: 76		
RAP P-401	64	2.483
	70	1.400
Fail Temperature, C: 65.3*		
SMA	82	4.833
	88	2.959
Fail Temperature, C: 91.6		
Rosphalt 50™ P-401	82	29.48
	88	22.46
Fail Temperature, C: 139.3		

Note: Samples were tested as RTFO aged material.

* Result suspect

the SMA mix experienced excessive increase in stiffness during production (production records show that mix temperature was 20-40°C above the recommended temperature).

Conclusions and Recommendations

From the work conducted in the three phases, the following conclusions can be made:

1. Use of the PG 64-28 P-401 mix, with available aggregates, can result in rut and moisture susceptible mixes.
2. Use of a higher grade/modified binder results in significant improvement in rutting resistance.
3. Use of Stone Matrix Asphalt (SMA) with its coarser gradation could help in achieving a strong and rut-resistant mix.
4. Rosphalt 50™ provides a highly resilient and rut resistant pavement mix.

Since the improvement in binder grade helped in increasing the rutting resistance, it is recommended that further research be conducted in order to select the optimum asphalt binder grade appropriate for anticipated traffic volumes. To achieve this, more testing of extracted asphalt binder is needed. Also, accurate and adequate pavement temperature data should be obtained from the Logan International Airport. This data should be analyzed to determine the most appropriate binder grade. Specifically, the frequency of different temperatures should be analyzed and a grade

should be selected that has a very low chance of being exceeded during the summer months.

The PG 76-28 P-401, RAP P-401 and SMA mixes that were used are prepared with commercially available products and are not dependent on proprietary and patented products (such as the Densiphalt or the Rosphalt), and hence more economical. More focused laboratory and field study should be conducted with the PG 76-28 P-401, RAP P-401 and SMA mixes, since for large volumes of work these mixes would provide the best solutions. Specifically, one needs to identify the prevalent mechanism in rutting in these two types of mixes, and separate the contribution of densification versus shear flow. Such analysis is possible with in-place results, although a more reliable method would be the use of accelerated testing under controlled conditions. This step is needed for identifying key mix components that can be controlled for improving the mixes, as well as for determination of proper density levels needed for in-place compaction during construction. Mixes should also be tested for stripping potential using dynamic loading or any method capable of generating pore pressure (Mallick et al., 2003).

References

ATC Associates Inc. and VHB, Inc., Pavement Failure Investigation: Taxiway
November, 2000.

Bognacki, Casimir, Asphalt Mix Design Changes to Minimize Rutting, circa 1995.

Brown, E. R., Mallick, Rajib B., John E. Haddock, and John Bukowski, Performance of Stone Matrix Asphalt (SMA) in the United States, Journal of the Association of Asphalt Paving Technologists, Volume 66, 1997.

Densit U.S.A., Inc., Densiphalt7 Handbook, 2000.

Eckrose/Green Associates Inc., Pavement Condition Survey and Evaluation for Logan International Airport , March 2001

Kandhal, P. S and Rajib B. Mallick. Evaluation of Asphalt Pavement Analyzer for HMA Mix Design, National Center for Asphalt Technology, NCAT Report # 99-4, Auburn University, June 1999.

Lai, James, Lamar Caylor, John D'Angelo and Thomas Harman. Development and Evaluation of Loaded Wheel Tester to Evaluate Rutting of Asphalt Mixtures. Georgia Department of Transportation, October 1996

Mallick Rajib B., Matthew Teto and John E. Haddock. Use of the Concept of Pore Pressure in Unsaturated Soils for Evaluation of Rutting Potential of Asphalt Paving Mixes, Presented and published at the 2002 International Conference on Asphalt Pavements in Copenhagen, August 2002.

Mallick, Rajib B., Jonathan S. Gould, Sudip Bhattacharjee, Ali Regimand, Lawrence H. James and Elton Ray Brown. Development of a Rational Procedure for Evaluation of Moisture Susceptibility of Asphalt Paving Mixes. Paper submitted for presentation and publication at the 82nd Annual Meeting of the Transportation Research Board, January 12-16, 2003, Washington DC.

Pavement Technology, Inc. PO Box 1184, Covington, GA 30015 (Phone: 770 388 0909).

Royston Rosphalt 50 Brochure, Royston Laboratories Division, Chase Corporation, Pittsburgh, PA, 2001.