HMA-Related Research Activities for Airfield Pavements at the Federal Aviation Administration

N. Garg
Airport Technology R&D Branch, Federal Aviation Administration, Atlantic City Intl. Airport, NJ, U.S.A.

I. Song and H. Brar
SRA International Inc., Linwood, NJ, U.S.A.

ABSTRACT: Hot Mix Asphalt (HMA) design for commercial airports in the United States of America is performed in accordance with the Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-10E, “Standards for Specifying Construction of Airports,” Item P-401 – Plant Mix Bituminous Pavements (2009). A Marshall mix design criterion is used. For pavements designed for aircraft gross weights in excess of 60,000 lb (27.2 tonnes) and tire pressures exceeding 100 psi (0.69 MPa), a 75-blow mix is used. The trend in aircraft design is to produce aircraft with extended range capability, which results in higher gross weights and tire pressures. The effects of high tire pressure are localized and concentrated in the surface layers (HMA). This makes it imperative to study the effects of high tire pressures on the HMA surface and also develop HMA mix design procedures to produce mixes that can withstand these anticipated high tire pressures. The FAA has started two projects to achieve this objective. The first project is the “Research and Testing to Establish Updated Specifications for FAA Airfield Quality Hot Mix Asphalt.” The objective of this project is to establish specifications for designing asphalt mixes using the Superpave Gyratory Compactor (SGC) that provides performance equivalent to the specifications for the Marshall mix designs. The second project is the “HMA Design and Testing for High Pressure Aircraft Tires.” The main objective of this project is to conduct research into the design of HMA to resist damage from high pressure aircraft tires. This paper summarizes the HMA-related research activities at the FAA.

KEY WORDS: Hot mix asphalt, airport pavements, Marshall mix design, Superpave.

1 INTRODUCTION

The Federal Aviation Administration (FAA) pavement design procedure refers to the determination of the pavement thickness and its components (surface, base, and subbase layers) not to the design of the pavement materials (e.g., asphalt or concrete mixes) and are described in Advisory Circular (AC) 150/5320-6E (FAA, 2009). The materials and construction requirements are specified in AC 150/5370-10E (FAA, 2009). Pavements designed in accordance with these standards are intended to provide a structural life of 20 years that is free of major maintenance if no major changes in the forecasted traffic are encountered. It is likely that rehabilitation of surface grades and renewal of skid-resistant properties will be required before 20 years due to destructive climatic effects and deteriorating effects of normal usage. The FAA airport pavement thickness design standards, referenced in Chapter 3 of FAA AC 150/5320-6E are implemented in the computer program FAARFIELD.

The Hot Mix Asphalt (HMA) mix design for commercial airports in the United States of America is performed per guidelines set forth in the FAA AC 150/5370-10E, Item P-401 (FAA, 2009). A 75-blow Marshall mix design criterion is used for pavements designed for aircraft gross weights in excess of 60,000 lb (27.2 tonnes) and tire pressures exceeding 100 psi (0.69 MPa). The P-401 specifications are presented in section 2. In 2006, the FAA issued Engineering Brief (EB) 59A (FAA, 2006), that allows Superpave mix design technology to be used on airfield pavements. However, it is considered a modification of the standards and requires approval from the FAA authorities. This has led to limited use of Superpave mix design technology at commercial airports, and the Marshall mix design is still used extensively.

Aircraft manufacturers are designing aircraft with extended range capability, which results in high gross weight and tire pressures (Roginski, 2007). The new aircraft, such as the Boeing 787 and Airbus 350, are anticipated to have tire pressures in excess of 220 psi (1.52 MPa). The effects of high tire pressure are localized and concentrated in the surface layers of the pavement structure. This has necessitated the need to study the effects of high tire pressures on the HMA surfaces and also develop HMA mix design procedures to produce mixes that can withstand these anticipated higher tire pressures. Currently, the FAA has two ongoing projects to achieve these objectives. The first project is the “Research and Testing to Establish Updated Specifications for FAA Airfield Quality Hot Mix Asphalt.” This project’s objective is to establish specifications for designing asphalt mixes using the Superpave Gyratory Compactor (SGC) that provide an equivalent performance to the specifications of the Marshall mix designs. The second project is the “HMA Design and Testing for High Pressure Aircraft Tires.” The main objective of this project is to conduct research into the design of HMA to resist damage from high pressure aircraft tires.

This paper presents the summary of the HMA-related research activities being conducted by the FAA. These are ongoing projects, and information will be updated as it becomes available.

2 RESEARCH AND TESTING TO ESTABLISH UPDATED SPECIFICATIONS FOR FAA AIRFIELD QUALITY HMA

The Marshall mix design method has been successfully used for airfield quality HMA since the 1940s. The P-401 specifications are summarized in Table 1.

Table 1: Marshall mix design criteria for item P-401.

Test Property	Pavements Designed for Aircraft Gross Weights of 60,000 lb (27.2 tonnes) or More or Tire Pressures of 100 psi (0.69 MPa) or More	Pavements Designed for Aircraft Gross Weights Less Than 60,000 lb (27.2 tonnes) or Tire Pressures Less Than 100 psi (0.69 MPa)
Number of Blows	75	50
Stability, pounds (N)	2150 (9564)	1350 (6005)
Flow, 0.01 in. (0.25 mm)	10-14	10-18
Air Voids, %	2.8-4.2	2.8-4.2
Percent Voids in Mineral Aggregate (minimum)	Maximum Particle Size, in (mm)	Minimum Voids in Mineral Aggregate, percent
	0.5 (12.5)	16
	0.75 (19)	15
	1.0 (25)	14
	1.5 (37.5)	13

The Superpave design method was developed and adopted by most state Departments of Transportation (DOT) beginning in the mid 1990s. Since most of the paving work by the asphalt industry is funded by state DOTs and private work (which typically use DOT criteria), it is becoming more and more difficult to find laboratories and contractors that continue to use the Marshall method. Hence, it is important that the Superpave method be adopted for HMA design airfield pavements. Before the adoption of Superpave, it is necessary to determine the number of gyrations that are required to provide an adequate compactive effort for airfield pavements. This study evaluated the number of gyrations for a number of mixtures required to provide a density equal to 75 blows with the Marshall hammer. Since the 75-blow Marshall mixtures have performed well in the past, it was believed that providing a density with the gyratory compactor equal to that obtained with Marshall compaction would be a good way to adopt Superpave and still have confidence of good performance.

The FAA has three parallel efforts going on to achieve this objective. Work is being performed by -

- SRA International, Inc. (FAA's support contractor);
- Engineer Research and Development Center (ERDC) at Vicksburg, MS (Interagency Agreement); and
- Parallel project under Airfield Asphalt Pavement Technology Program (AAPTP).

A brief description of these projects is provided in the following sections.

2.1 Project 1: "Research and Testing to Establish Updated Specifications for FAA Airfield Quality HMA"

Research Team – Dr. Don Christensen (Advanced Asphalt Technologies), Thomas Bennert (Soiltek), Roy McQueen (Roy D. McQueen & Associates, Ltd.), Harkanwal Brar (SRA International, Inc.).

The objectives of the project are as follows:

- Establish guidance for N-design levels for HMA designed following P-401.
- Establish specifications for designing HMA using the SGC, which provides performance equivalent to 75-blow Marshall mixes.
- Verify range of mixes.

The work was divided into two phases. Phase I consisted of determining how many SGC gyrations will provide compaction equivalent to that achieved with 75 blows of a Marshall hammer for HMA mixtures designed according to FAA standards and exhibiting good field performance, referred to as "Well Performing Mixes." This equivalent number of gyrations is referred to as N-equivalent (N-equivalent is for the mix tested) and each mix will have an N-equivalent. This determination was made by evaluating a wide range of HMA mixtures, based upon existing mix designs in use at a range of airfields and covering different aggregate geologies (gneiss, dolomite, granite, basalt, limestone, crushed gravel, argillite, and diabase). Laboratory tests were performed at Advanced Asphalt Technologies (AAT) and Rutgers University laboratories (by Soiltek). The steps in the Phase I study included (i) identifying "well performing" mixes, (ii) collecting original materials used in these mixes from suppliers, (iii) verifying Marshall mix designs in the lab, and (iv) performing gyratory compaction and volumetric analysis. The procedure for determining N-equivalent is shown in Figure 1. Figure 1 illustrates the procedure and not the actual results from tests mentioned in the subsequent sections.

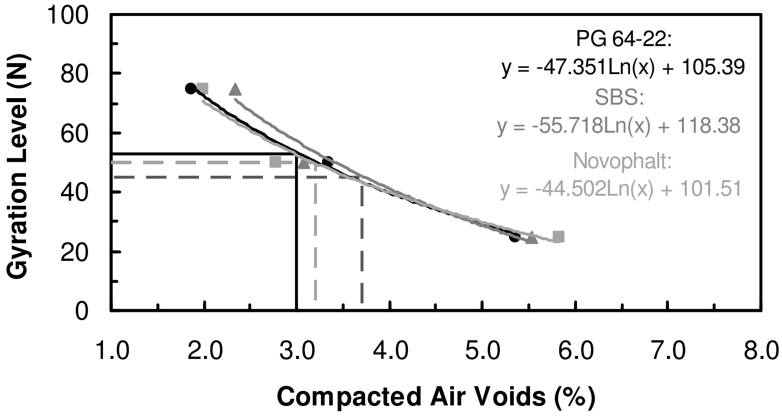

Figure 1: Determination of N-equivalent.

Phase I of the study is complete. The results show, on average, 70 gyrations provides equivalent compaction to a 75-blow Marshall. However, there is significant variation in the value of N-equivalent, both among different mixes and between the two laboratories involved in this study. Phase II of the study is presently underway. The main objective of the Phase II tests is to examine the variability in performance that occurs when designing HMA mixtures using the two different compaction methods. The general research approach in Phase II is to prepare specimens from each mix design and perform both rut resistance and durability tests using laboratory procedures. The performance of mixtures designed using the Marshall method (75-blow Marshall or N-equivalent designs) will be compared to designs prepared using 70 gyrations (N-design). The objective of the study is not only to evaluate differences in the overall level of performance between the two mix design methods, but more importantly to evaluate differences in the variability in performance between the two methods. A more effective design method would show a lower degree of variability in performance. The mix performance will be evaluated using laboratory tests. The tests will include Asphalt Pavement Analyzer (APA) tests, Asphalt Mixture Performance Tester (AMPT) (flow number test), and uniaxial fatigue testing. The APA tests will be performed using a modified APA device that has been acquired by the FAA, which has a capability to test at 250 psi (1.72 MPa), much higher than current APA devices and more representative of aircraft tire pressures. Details of this device are discussed in section 3.

2.2 Project 2: "Development of Criteria for Using the Superpave Gyratory Compactor to Design Airport Asphalt Pavement Mixtures"
Research Team – John Rushing (ERDC), Dr. Ray Brown (ERDC)

The study is complete, and the final report (Rushing, 2009) is in the editing process for publication. In this study, 32 aggregate combinations were tested. These combinations included variations in maximum aggregate size (½, ¾, and 1 inch (12.7, 19.05, 25.4 mm)), aggregate type (limestone, granite, and chert gravel), gradation (upper and lower limits of Item P-401 specification band), and percentage of mortar sand (0 and 10 percent). The Marshall method, 75-blow hammer (hand-operated) compaction effort, was used to identify the design binder content for each mixture. The design binder content in this study is the asphalt cement content that resulted in a compacted specimen having a density of 96.5 percent of the maximum theoretical density. This density corresponds to an air content of 3.5 percent. This air content was selected as the middle of the range of allowable air contents (2.8-4.2 percent) in Item P-401. SGC compacted specimens were prepared at this design binder content. The number of gyrations required to obtain 96.5 percent of the maximum theoretical density was determined. Data for all mixtures were then analyzed to identify the target gyration level for designing asphalt mixtures for airfield pavements. The study recommended an N-design of 70 gyrations and stated the value should be further researched in laboratory and field studies prior to acceptance in future FAA criteria.

2.3 Project 3: "Implementation of Superpave Mix Design for Airfield Pavements"
Research Team - L. A. Cooley, Jr., R. C. Ahlrich, R. S. James (Burns Cooley Dennis, Inc.), B. D. Prowell (Advanced Materials Services, LLC), E. R. Brown (ERDC), A. Kvasnak (NCAT).

The project is complete, and the final report can be downloaded from http://www.aaptp.us/Report.FinalVolI.04-03.pdf. The main objective of this study was to provide comparative information between Superpave and Marshall mix designs and develop guidance on the procedures needed to implement the Superpave mix designs for design, quality control, and acceptance of airfield HMA projects. The evaluation included all of the Superpave mix design requirements, such as, but not limited to, volumetric properties, gyration levels and aggregate requirements, and related production and acceptance tolerances. The ten mixes used in this study were from airports located in the Southwest and the West Coast of the United States (Colley, 2009) and included mixes from military airfields. Not all mixes were "well performing" mixes. Their approach for N-design involved comparing in-place densities to original N-design densities. Performance tests included repeated load permanent deformation tests (flow number). More details about the research approach and test procedures can be obtained from the final report (Cooley, 2009). Based on the obtained materials from the original sources for the ten airfields, the study found that 43 to 55 gyrations provide an equivalent compactive effort to the 75-blow Marshall mix design, and 32 to 40 gyrations provide an equivalent compactive effort to the 50-blow Marshall mix design. The recommendations from this study are given in Table 2.

Table 2: Recommended N-design values for designing airfield mixes (from AAPTP study).

Tire Pressure, psi (MPa)	N-design
Less than 100 (0.69)	50
100 to 200 (0.69 to 1.38)	65
More than 200 (1.38)	80

After the completion of the Phase II study by SRA International, Inc., the results from projects 1-3 will be discussed and used to develop guidelines and specifications for a new HMA mix design for airfield pavements using the SGC.

3 HMA DESIGN AND TESTING FOR HIGH PRESSURE AIRCRAFT TIRES

With the emergence of newer and larger aircraft, wheel loads and tire pressures have been steadily increasing. The impact this will have on HMA pavements has been investigated to some degree at the FAA National Airport Pavement Test Facility (NAPTF), which is located at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The primary objective of these tests is to generate full-scale pavement performance and response data for development and verification of airport pavement design criteria. A construction cycle at the NAPTF includes test pavement construction with embedded instrumentation, traffic tests to failure, posttraffic tests (trenching activities and other tests), and pavement removal. Four construction cycles (CC1, CC2-OL, CC3, CC5 Test Strip) to test flexible pavements under heavy aircraft loading have been completed, and a fifth one is under way. The primary objective for flexible pavement testing has been to generate shear failure in the subgrade, as evidenced by subgrade flow and upheaval outside the traffic path. The research results have been widely published and accepted. The most common distresses observed in the HMA surface layer were shoving at the longitudinal joint, fatigue (alligator) cracking, and tearing in the surface layer (Figure 2). Rutting of the asphalt layer has not been an issue. Delamination of the HMA layers was related to the tack coat and dust left during construction. Providing sufficient time for the emulsion tack coat to break eliminated the delamination problem. Using alternate longitudinal joint construction techniques, such as the Michigan Wedge joint, yielded satisfactory results. Rutting was not an issue. Alternate mix designs and longitudinal joint construction techniques were tried and were quite successful. The detailed findings were published in a separate paper (Garg, 2009). However, all the FAA NAPTF tests were performed at pavement surface temperatures less than 90ºF (32.2ºC). Effects of high tire pressures and heavy wheel loads are accentuated at higher pavement surface temperatures (in excess of 100ºF (37.8ºC)).

Figure 2: HMA distresses observed during full-scale, accelerated pavement testing at the NAPTF.

The effects of high tire pressure are localized and concentrated in the surface layers (like HMA). This makes it imperative to study the effects of high tire pressures on the HMA surface and also develop HMA mix design procedures to produce mixes that can withstand these anticipated higher tire pressures. The FAA has an ongoing project, “HMA Design and Testing for High Pressure Aircraft Tires,” to achieve these objectives. Figure 3 shows the research approach for this project.

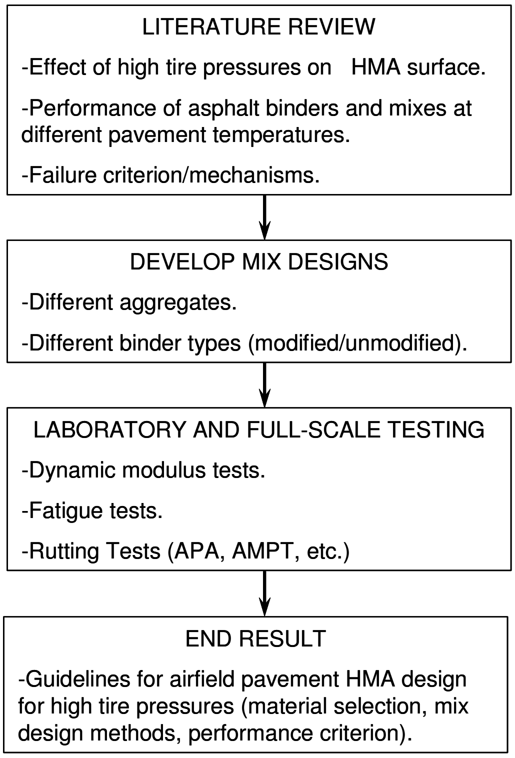

Figure 3: Research approach.

The rutting resistance of asphalt mixture is generally evaluated using the Asphalt Pavement Analyzer (APA) (AASHTO TP63). However, the loading conditions in the APA are more commonly associated with highway conditions. The FAA was interested in APA equipment capable of applying tire pressures representative of heavy commercial aircraft (around 250 psi (1.72 MPa)). The existing equipment is capable of applying up to 200 psi (1.38 MPa) pressure with an aluminum wheel. A customized APA was purchased by the FAA which can apply 250 psi (1.72 MPa) hose pressure and up to 500 psi (3.45 MPa) with an aluminum wheel with variable rate of loading (to simulate different aircraft speeds). Figure 4 shows the FAA customized APA.

APA tests were conducted on P-401 samples from the high tire pressure (HTP) test section using the standard APA and the FAA customized APA. Figure 5 show the results. At 250 psi (1.72 MPa) hose pressure, tests were performed at two different temperatures: 70ºF (21.1ºC) and 140ºF (60ºC).

Figure 4: FAA customized APA.

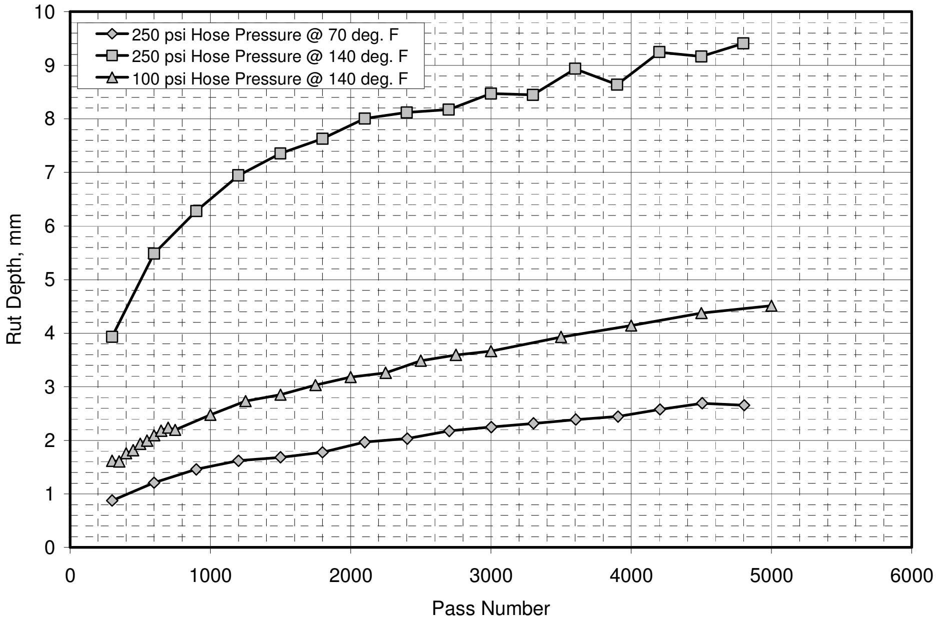

Figure 5: APA test results on P-401 samples from HTP test section (1 psi = 6.89 kPa).

Figure 6 shows the effect of temperature and hose pressure on rutting in the APA tests. The effect of increasing temperature (from 70ºF (21.1ºC) to 140ºF (60ºC)) at constant hose pressure (250 psi (1.72 MPa)) is more severe than increasing hose pressure (from 100 psi (0.69 MPa) to 250 psi (1.72 MPa)) at constant temperature (140ºF (60ºC)). How this relates to an actual pavement surface can only be confirmed by full-scale, accelerated pavement tests (which will be performed at NAPTF in the near future). Additional APA tests at different temperatures and pressures will also be performed in the future.

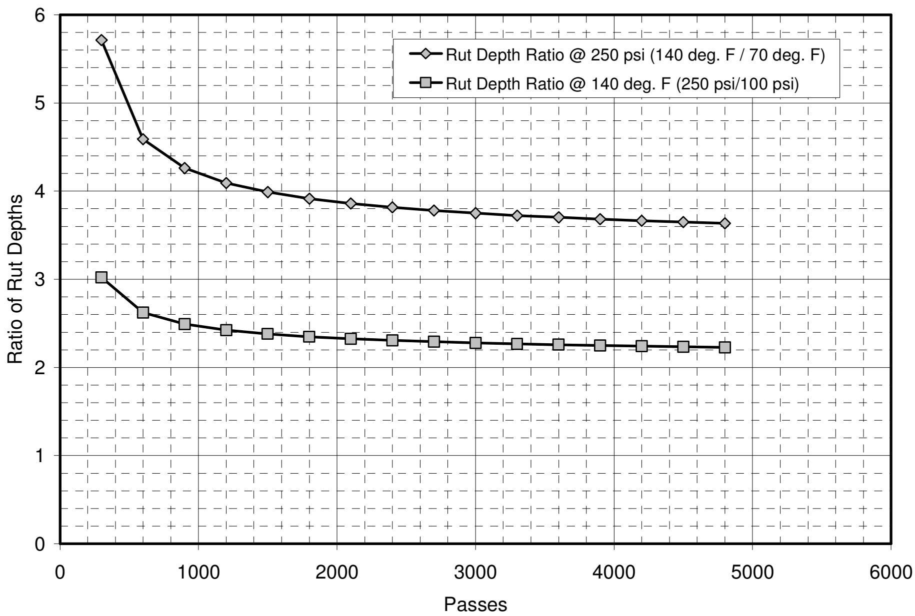

Figure 6: APA test results on P-401 samples from HTP test section (1 psi = 6.89 kPa).

Dynamic modulus tests were conducted to evaluate the time-temperature dependency of the HMA. The recommended procedure from NCHRP Report 614 (Bonaquist, 2008) was used. The data was collected at three temperatures: 39º, 68º, and 95ºF (4º, 20º, and 35ºC) using loading frequencies of 25, 10, 5, 1, 0.5, 0.1, and 0.01 Hz. The dynamic modulus test results were used to construct a dynamic modulus master curve, shifted to 77ºF (25ºC), which represented the average in situ temperature of the asphalt layer. Figure 7 shows the resultant dynamic modulus master curve.

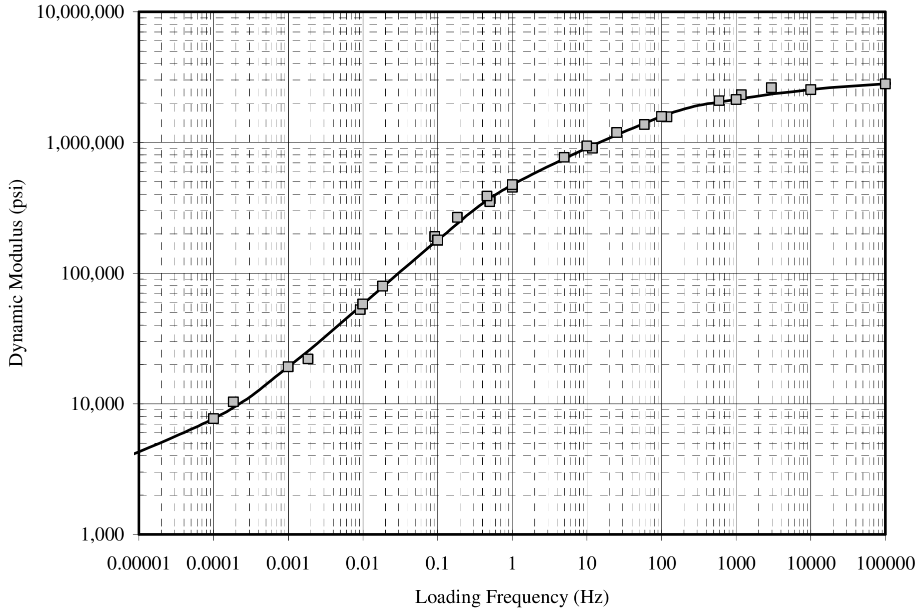

Figure 7: Dynamic modulus master curve of HMA used at the NAPTF (1 psi = 6.89 kPa).

The work to-date for HTPs primarily has been performed in a laboratory. Full-scale tests are needed so the HMA performance prediction models from laboratory tests can be validated/calibrated to the in situ pavements. Full-scale tests at high HMA temperatures are very crucial for the success of these projects. In the projects related to pavement material properties and surface layers, wheel load and tire pressures in combination with surface temperature are more critical than the gear load (due to minimum wheel load interaction affects). The NAPTF is an indoor facility, and there are limitations on achievable pavement temperatures. One way to increase the indoor pavement temperature is to heat the asphalt pavement section from underneath. The estimated cost to heat a 300-ft (91.4-m) long by 60-ft (18.3-m) wide test section is approximately $2.25 million.

The preferred option is to use a Heavy Vehicle Simulator (HVS) to perform these tests since the tests on surface layers are more a function of tire pressure and wheel loads rather than the gear loads. The pavement test lane will be narrower for the HVS compared to the test lane for the existing test vehicle. It will be easier and more economical to insulate and heat the test pavement under the HVS. Also, heating is applied from the top, which is more representative of an in situ pavement. For testing pavement rehabilitation techniques, the structurally failed pavement under NAPTF test vehicle during a construction cycle can be rehabilitated with different techniques (different reflective cracking resistant HMA mixes, concrete overlays, etc.) and then tested with HVS. The FAA has requested funds to purchase an HVS and hope to receive the funds during fiscal year 2011. In the meantime, full-scale, accelerated pavement tests to evaluate HTP effects on an HMA surface will continue at the NAPTF.

4 SUMMARY

The Marshall mix design method has been successfully used for HMA mix design for airfield pavements since the 1940s. Since most state DOTs use Supperpave technology, the FAA should move towards replacing the Marshall mix design method with Superpave technology. However, prior to adoption of Superpave, it is necessary to determine the number of gyrations required to provide an adequate compactive effort and performance for airfield pavements. High tire pressures in the new generation aircraft also warrant research into mix design procedures to prevent premature rutting, cracking, and other distresses in the HMA surface. This paper summarizes the FAA's research efforts in the area of airfield pavement HMA design. The objectives of these research efforts are to develop asphalt mix design guidelines and methodologies that will help HMA surface sustain future heavy aircraft wheel loads with high tire pressures safely and provide a structural life that is free of major maintenance. These projects involve laboratory testing as well as full-scale, accelerated pavement testing at the NAPTF.

5 ACKNOWLEDGMENTS/DISCLAIMER

The work described in this paper was supported by the FAA Airport Technology Research and Development Branch, Dr. Satish K. Agrawal, Manager. The contents of the paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA. The paper does not constitute a standard, specification, or regulation.

REFERENCES

Bonaquist, R. 2008. *Refining the Simple Performance Tester for Use in Routine Practice*. NCHRP Report 614. National Cooperative Highway Research Program, NCHRP, Transportation Research Board, Washington, D.C.

Cooley, Jr. L. A., Ahlrich, R. C., James, R. S., Prowell, B. D., Brown, E. R., Kvasnak, A., 2009. *Implementation of Superpave Mix Design for Airfield Pavements*. Final Report, AAPTP Project 04-03.

Federal Aviation Administration, Office of Airport Safety and Standards. *Airport Pavement Design and Evaluation*. Advisory Circular 150/5320-6E, U.S. Department of Transportation, 2009 (also see http://www.faa.gov/airports/resources/advisory_circulars/ for updates).

Federal Aviation Administration, Office of Airport Safety and Standards. *Standards for Specifying Construction of Airports.* Advisory Circular 150/5370-10E, U.S. Department of Transportation, 2009 (also see http://www.faa.gov/airports/resources/advisory_circulars/ for updates).

Federal Aviation Administration, Office of Airport Safety and Standards. *Engineering Brief No. 59A. "Item P-401 Plant Mix Bituminous Pavements (Superpave),"* U.S. Department of Transportation, Federal Aviation Administration, 2006.

Garg, N., Gagnon, J., 2009. *Behavior of HMA Surface Under Full-Scale Testing at the FAA NAPTF.* Proceedings of the 6th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control, Torino, Italy.

Roginski, M. J. 2007. *Effects of aircraft tire pressures on flexible pavements*. Proceedings, Advanced Characterisation of Pavement and Soil Engineering Materials. Athens, Greece.

Rushing, J. F., 2009. *Development of Criteria for Using the Superpave Gyratory Compactor to Design Airport Asphalt Pavement Mixtures*. Draft Final Report submitted to the FAA by ERDC, Vicksburg, MS.