HIGH TIRE PRESSURE AND TEMPERATURE EFFECTS ON HOT MIX ASPHALT CONCRETE PERMANENT DEFORMATION USING CUSTOMIZED ASPHALT PAVEMENT ANALYZER (APA)

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ABSTRACT

New pavement standards are needed due to the advent of newer aircraft exceeding the current International Civil Aviation Organization (ICAO)'s 217 psi (1.50 MPa) tire pressure limit. The Federal Aviation Administration (FAA) owns a customized Asphalt Pavement Analyzer (APA) which can apply higher tire pressures and loads for aircraft loading conditions. Cores with 6 inches (152 mm) diameter by 3 inches (76 mm) high were taken from the FAA's National Airport Pavement Test Facility (NAPTF) high tire pressure area and prepared for tests at two different contact pressures of 100 psi and 250 psi using the customized APA. The test was also performed at two different temperatures of 70°F and 140°F. The APA test results were analyzed in terms of rut depth and rut slope with different tire pressures and temperatures. The recorded rut depth measurements by the APA were compared and confirmed by manual measurements after the testing. The gradation of the Hot Mix Asphalt (HMA) mix in the cores is provided with test results. The results show that the rut depth increased significantly with higher contact pressures and temperatures. Also, the permanent deformation was more sensitive to temperature than to the contact pressure changes.

INTRODUCTION

The International Civil Aviation Organization (ICAO) uses ACN (Aircraft Classification Number) / PCN (Pavement Classification Number) system for rating airport pavements [1]. There are four tire pressure categories assigned to the PCN rating, and are denoted by four code letters Z, Y, X and W which correspond to the four tire pressure limits of 72.5 psi (0.5MPa), 145 psi (1.0MPa), 217.5 psi (1.5MPa), and unlimited respectively. ICAO does not make any formal recommendations on how an airport should assign these tire pressure limits.

Aircraft manufacturers Boeing and Airbus are designing aircraft with extended range capability, which results in high gross weight and tire pressures. The new aircraft, such as the Boeing 787 and Airbus 350, will have tire pressures exceeding 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 Hot Mix Asphalt (HMA) surfaces 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." The main objective of this project is to conduct research into the design of HMA to resist damage from high pressure aircraft tires.

PREVIOUS RESEARCHES USING ASPHALT PAVEMENT ANALYZER (APA)

APA machine is a modified and improved version of the Georgia load wheel tester. APA measures permanent deformation in asphalt mixtures subject to a loaded wheel under repetitive loading conditions in a controlled chamber temperature to determine the rutting susceptibility of the mixtures. The APA is one of the most popular and commonly used loaded wheel accelerated pavement tester in the lab conditions, even though no fundamental properties can be computed.

There have been a number of studies to match the APA test results to field data or other laboratory tests such as Shami et al. [2], Kandhal and Mallick [3] etc. They used APA for characterizing HMA permanent deformation in their researches. NCHRP research was conducted to identify test conditions within the APA that produced results most related to field rutting performance [4]. Based on their findings, samples tested in the APA at a test temperature corresponding to the high temperature of the standard performance grade for a project location better predicted field rutting performance than did samples tests at 6°C higher than the high temperature of the standard performance grade. Song [5] used a concept of the vertical surface displacement of an elastic layer on a rigid base for his static creep test and APA test to compute stiffness changes in the elastic layer. The fundamental assumptions of the APA test are that the two layers are infinite in horizontal direction and the lowest layer is infinite in the vertically downwards direction. He correlated HMA stiffness that is directly related to test temperatures using ELSYM5 computer program to APA test results. The fundamental assumptions of the APA test are that the two layers are infinite in horizontal direction and the lowest layer is infinite in the vertically downwards direction. Poisson's ratio of the both layers take fixed values of 0.28. Testing with the APA was conducted according to the procedures recommended by the Georgia Department of Transportation test method GDT-115. The 100 psi (0.69MPa) and 104°F (40°C) are adopted for APA test conditions. The reason for selecting 104°F (40°C) temperature is that it represents the highest air temperature in Georgia. The test carried out to 8000 cycles continuous rut depth measurements. One set of forward and backward strokes comprises one cycle.

FAA CUSTOMIZED ASPHALT PAVEMENT ANALYZER (APA)

The rutting resistance of asphalt mixture is generally evaluated using the Asphalt Pavement Analyzer (APA). 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 more than 260 psi (1.79 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). The APA test was conducted at three different conditions, 100 psi (0.69MPa) at 140°F (60°C), 250 psi (1.72 MPa) at 70°F (21°C), and 250 psi (1.72 MPa) at 140°F (60°C), to simulate effects by high tire pressures and high pavement temperatures in airport pavements. Data analysis was performed by direct rut depth measurements, rut depth slope, and rut rate comparisons. Additionally, VESYS method was adopted to predict permanent deformation at extended APA stroke numbers. The model incorporates the concepts of serviceability and reliability. The reliability concept in the model was incorporated in 1986 American Association of State Highway and Transportation Officials (AASHTO) design guide.

The rutting resistance of HMA has been successfully evaluated using APA for lab scale accelerated pavement test. However, the loading conditions in the APA are more commonly associated with highway conditions. FAA customized APA equipment is capable of applying tire pressure representative of a heavy commercial aircraft and shown in the Figure 1 and 2. Hose pressures more than 260 psi (1.79 MPa) can be achieved with controlling temperatures in between 39°F (4°C) and 162°F (72°C) in the test chamber.

Figure 1. FAA Customized APA Machine.

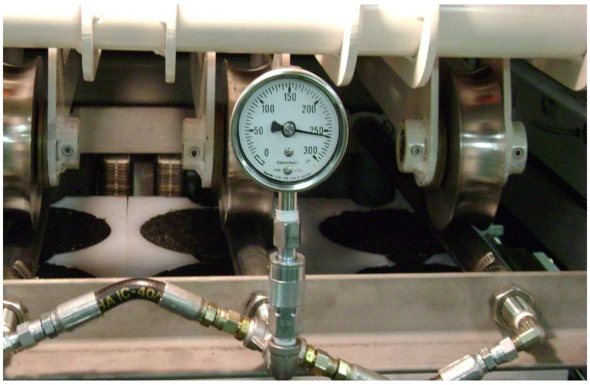


Figure 2. Pressure Gage Installation for High Pressures.

TEST SAMPLE PREPARATION

In the High Tire Pressure (HTP) pavement test area at the Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF), flexible pavement test items will undergo full-scale testing at high tire pressures exceeding 220 psi with high pavement temperatures. All the test items have 5 inches thick P401 HMA surface, 8 inches thick P209 crushed stone aggregate base, 6 inches (152 mm) econocrete subbase. Figure 3 shows the pavement cross section. FAA's P401 specification based on Marshall mix design procedure was used for the HMA mix design. PG 64-22 is selected and used for the HTP test area construction.

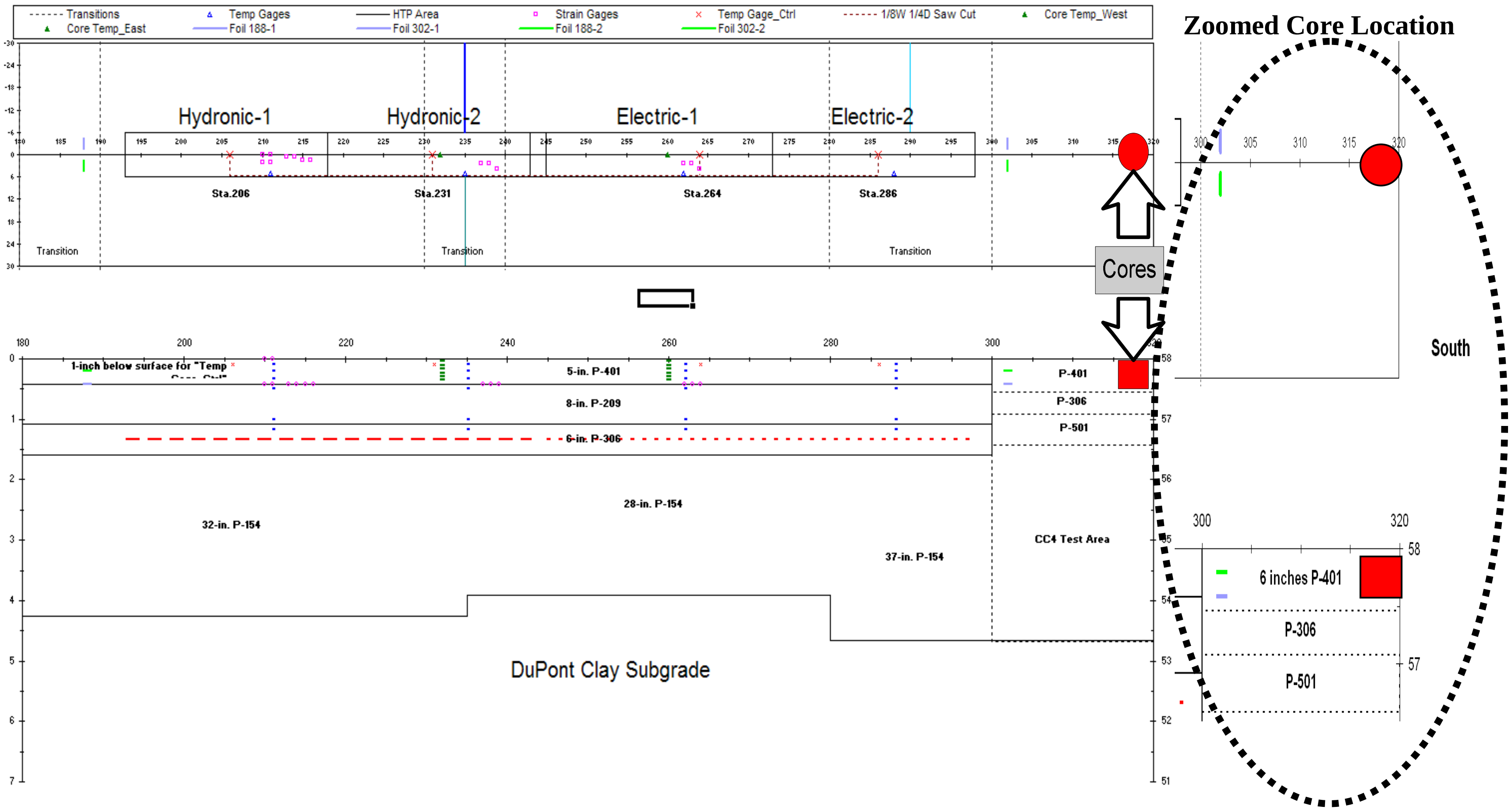


Figure 3. Pavement Cross Section and Core Location in High Tire Pressure Testing Area at the NAPTF.

The dense gradation for the mixture is depicted in the Figure 4. The cylindrical sample, 6 inches (152 mm) diameter by 3 inches (76 mm) high, from the HTP test section was used for the APA testing. The core locations are marked in the Figure 3. The cores with 6 inches (152 mm) diameter by 6 inches (152 mm) high were taken first from the HTP transition area, and then cut them so that the original top 3 inches (76 mm) were left. The original top 3 inches (76 mm) were used for testing in the APA. 2 or 4 cylindrical samples are prepared for the different test conditions.

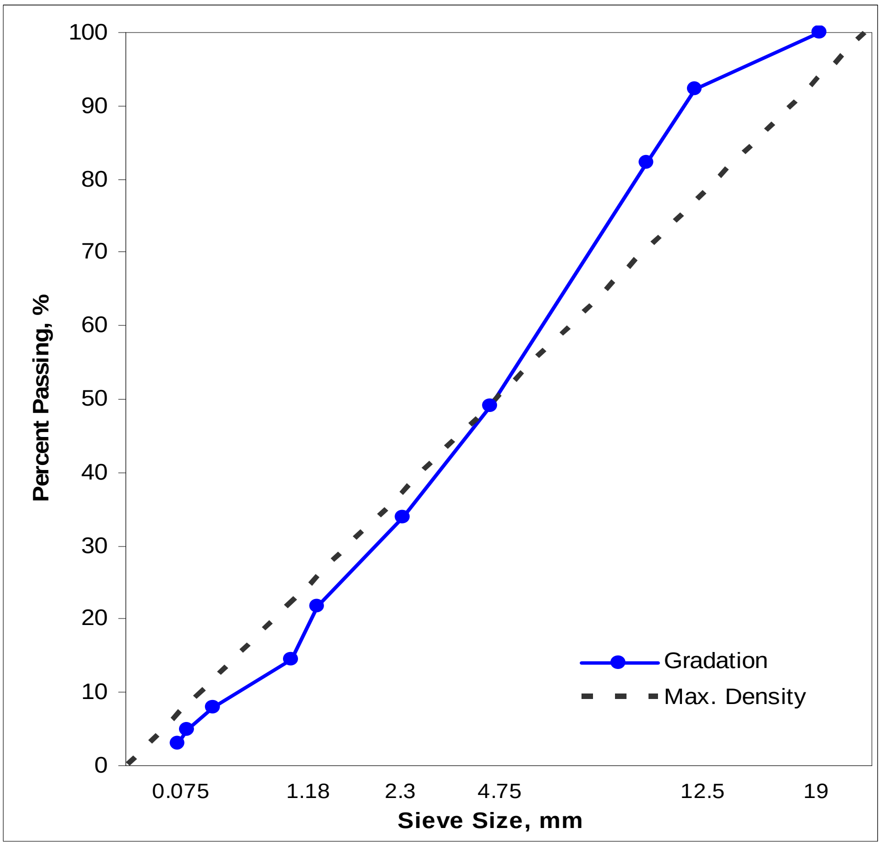


Figure 4. Gradation for HMA Surface Layer in High Tire Pressure Testing Area.

TEST CONDITIONS

Three test conditions are selected to simulate effects by high tire pressures and high pavement temperatures in airport pavements. Tests were conducted at 70°F and 140°F, and 100 psi and 250 psi contact pressures with the frequency of 1 pass a second after checking temperature uniformity in the APA chamber. For the Table 1 shows the APA test conditions for contact pressures and temperatures.

Table 1. APA Test Conditions for Contact Pressures and Temperatures.

Contact Pressure, psi	Temperature, °F
100 (0.69 MPa)	140 (60°C)
250 (1.72 MPa)	70 (21°C)
250 (1.72 MPa)	140 (60°C)

All the tests conducted in this research were in dry condition. At least a pair of samples was tested at a single test conditions.

DATA ANALYSIS

Data analysis was performed by directly comparing rut depth, rut depth slope, and rut rate. Additionally, VESYS method was adopted to predict permanent deformation for extended APA stroke numbers.

Rut Depth

Figure 5 and 6 show rut depth comparisons at different test temperature levels and under different contact pressure levels respectively. Figure 5 shows the cores tested at 70°F (21°C) have greater resistance to rutting than the cores at 140°F (60°C).

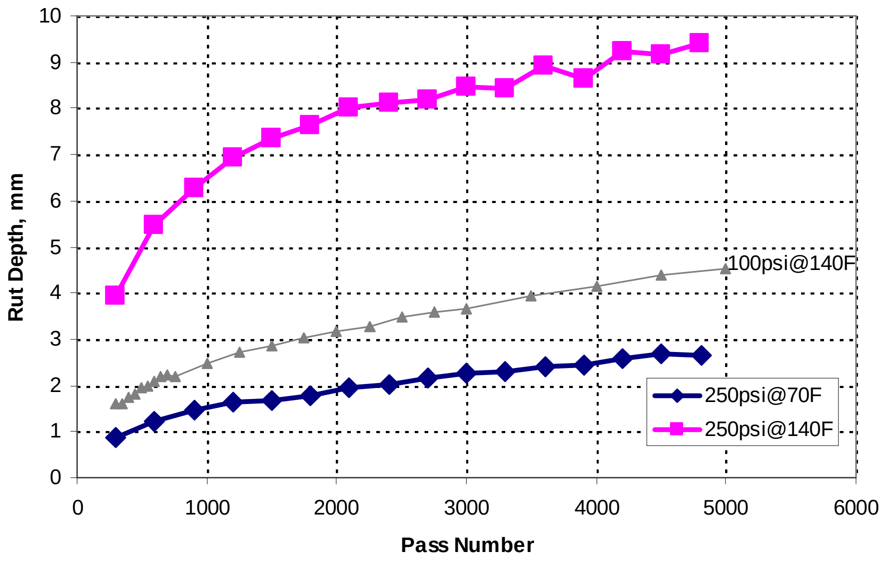


Figure 5. APA Rut Depth Comparisons at 70°F (21°C) and 140°F (60°C) Test Temperatures under High Contact Pressure 250 psi (1.72 MPa).

Figure 6 shows the rut depth measurements at 100 psi (0.69 MPa) and 250 psi (1.72 MPa) contact pressures at 140°F (60°C).

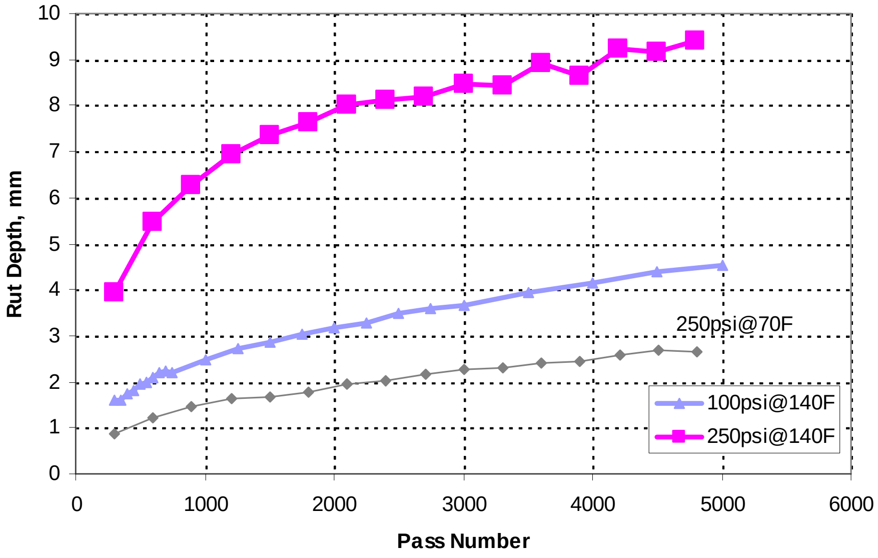


Figure 6. APA Rut Depth Comparisons under 100 psi (0.69 MPa) and 250 psi (1.72 MPa) Contact Pressures at High Test Temperature, 140°F (60°C).

Rut Rate

Figure 7 shows rutting slope changes at different APA test conditions. The rut slope, which is computed by Δ(rut depth) / Δ(pass number), is significantly effected by higher contact pressure and temperatures. Additionally, change in temperature from .70°F to 140°F is more significant than change in pressure from 100 psi to 250 psi.

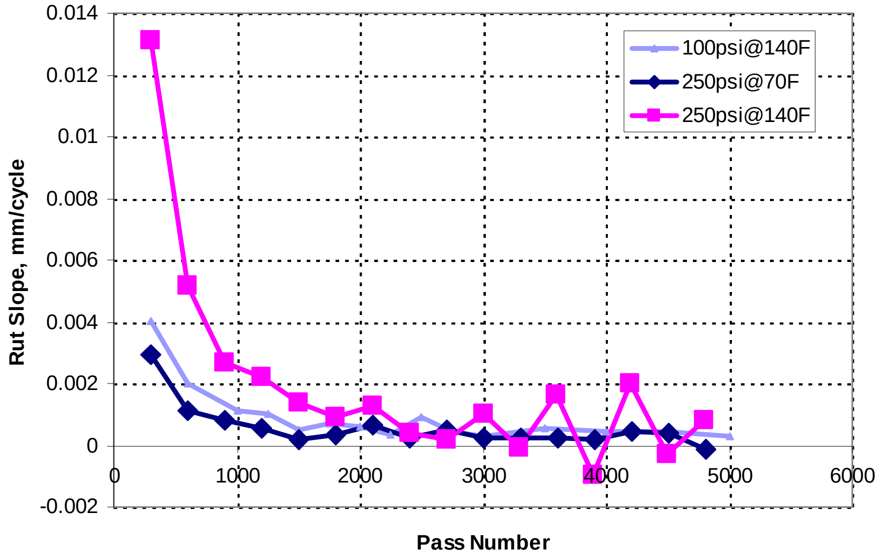


Figure 7. Rutting Slope Changes at Different APA Test Conditions.

Generally, for viscoelastic materials, three types of creep curves can be identified. Each of them can occur for every material, depending on the stress level and temperature. Song [5] defined and characterized the three stages, primary, secondary, and tertiary, in HMA performances using Dynamic Mechanical Analysis (DMA) and Dynamic creep tests. The first and second inflection points in the permanent deformation curve were defined as the starting points of secondary and tertiary respectively. Based on his findings, the three stages are depicted in Figure 8 using the APA test data under 250 psi contact pressure at 140°F.

Creep rate, also known as steady state, has been used to characterize material behaves at the secondary stages. The rut rate values, which is computed by Δ(rut depth at secondary stage) / Δ(pass number at secondary stage), are shown in Table 2. The rut rate in the table is computed based on the pass number in between 1500 and 5000.

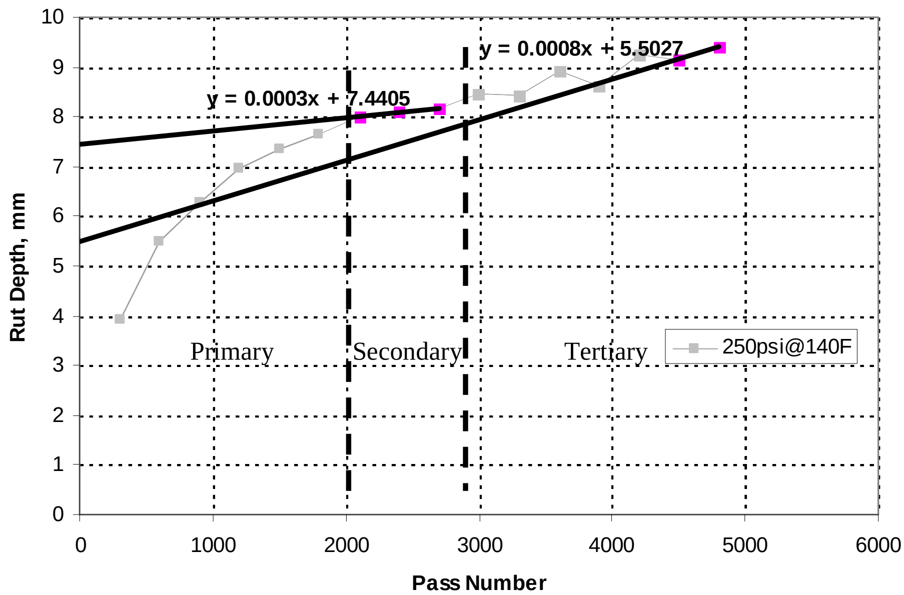


Figure 8. Three Rutting Stages using the APA Test Data under 250 psi (1.72 MPa) Contact Pressure at 140°F (60°C).

Table 2. Rut Rate Computations at Different Test Temperatures and Contact Pressures.

Pressure, psi	Temperature, °F	Rut Rate, mm/pass number
100 (0.69 MPa)	140 (60°C)	0.000475
250 (1.72 MPa)	70 (21°C)	0.000294
250 (1.72 MPa)	140 (60°C)	0.000622*

*The rut rate would be 0.000275 mm/pass with the secondary stage in Figure 8.

Figure 9 shows HMA behavior at increased pressures and temperature. Different test conditions are compared based on the 250 psi (1.72 MPa) and 70°F (21°C) curve to monitor the performance changes. Same rut depth at 300 passes for the equal start point is used for the all three test conditions. Definitely, the primary and secondary stages are occurred for all the conditions. All stages seem like to occur at high enough stress and temperature levels like at 250 psi (1.72 MPa) and 140°F (60°C). The test condition shows stabilization from 1900 passes to 2700 followed by zigzag rut depth and slope changes which are believed to be similar to rupture stage. The zigzag slope changes are caused by the APA mold which restricts expedited permanent deformation by viscous properties that is generally shown in the previous HMA lab studies.

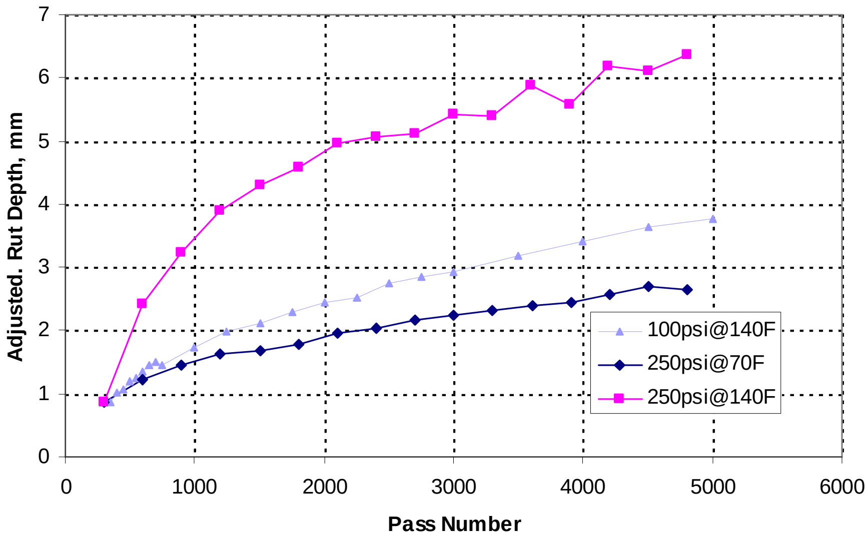


Figure 9. Rutting Changes at Different APA Test Conditions with Same Start Point.

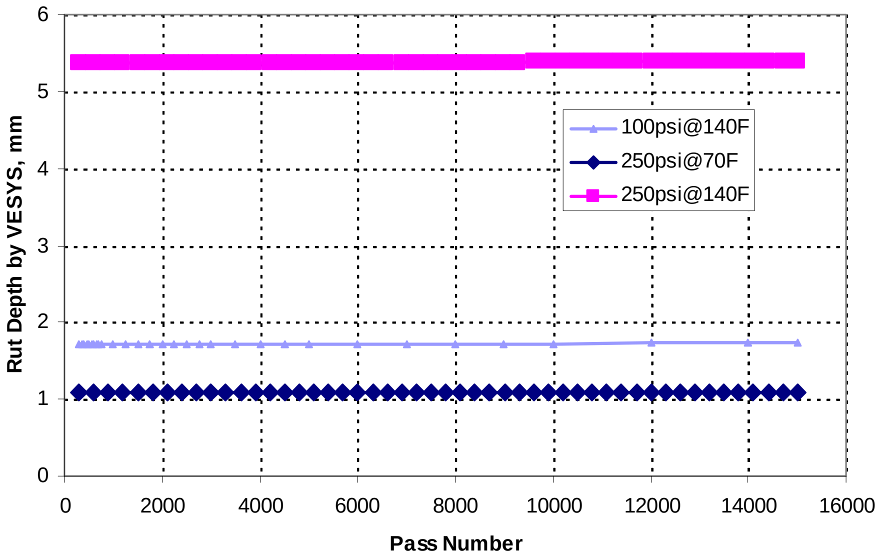
VESYS Method for Rutting Prediction

VESYS is a probabilistic and mechanistic flexible pavement analysis computer program for prediction of rut depth. The method is based on the assumption that the permanent strain is proportional to the resilient strain [6]. It has system rutting formulation considering the pavement system as a whole structure including all the layers as shown in Equation (1).

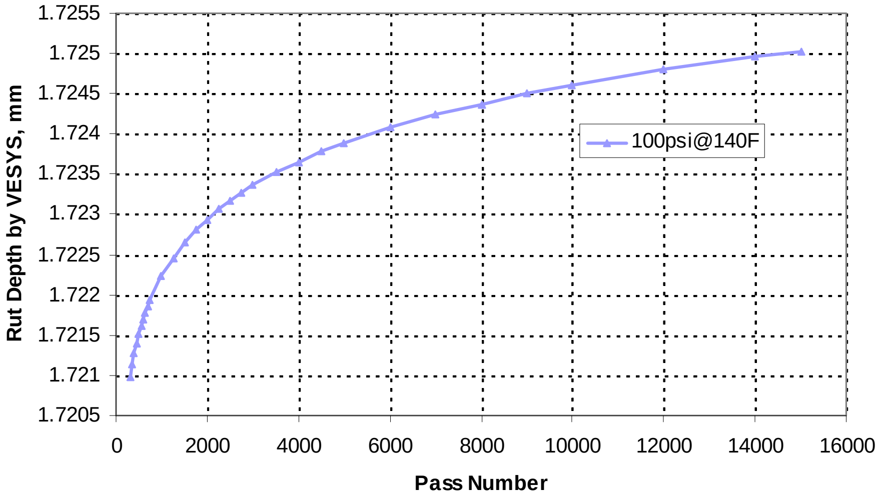
$$RD = \int_{N1}^{N2} U \mu_{sys} N^{-\alpha_{sys}} dN \quad (1)$$

where U, $N1$, and $N2$ are pavement surface deflection, initial pass number, final pass number respectively. The permanent deformation parameters, μ_{sys} and $-\alpha_{sys}$ in the equation are decided from the APA test results.

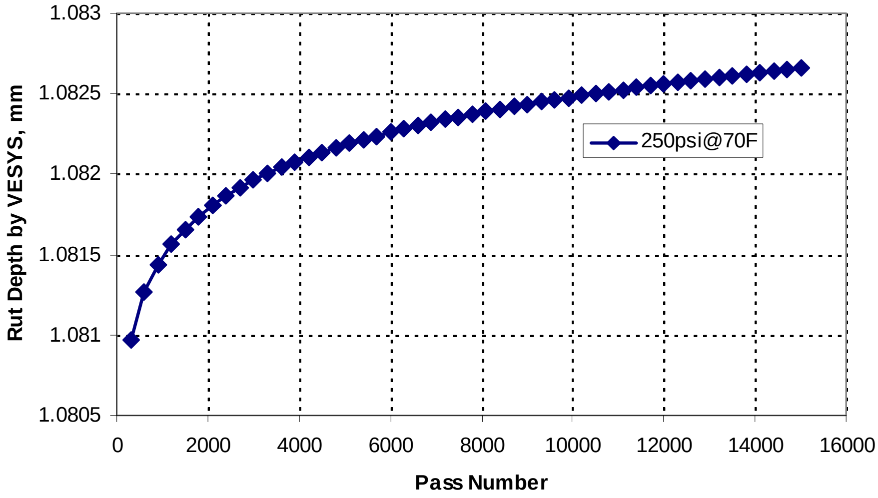
VESYS method was adopted to predict permanent deformation for extended APA stroke numbers until 15000 passes. The APA testing was stopped at 5000 passes under 250 psi (1.72 MPa) contact pressure at 140°F (60°C) temperature to prevent the breaking of rubber hoses. The predicted rut depth using VESYS model is plotted as shown in Figure 10. The graph shows the predicted rut depth is much smaller than the actual measurements because the computations consider only surface layer deformation even though the Equation (1) is originally developed for a whole pavement structure. As we discussed early, the predicted rut depth with higher contact pressure and temperatures shows definite increases. The temperature changes by increasing 70°F (21°C) were more significant on the rut depth than pressures changes by increasing 150 psi (1.04 MPa).



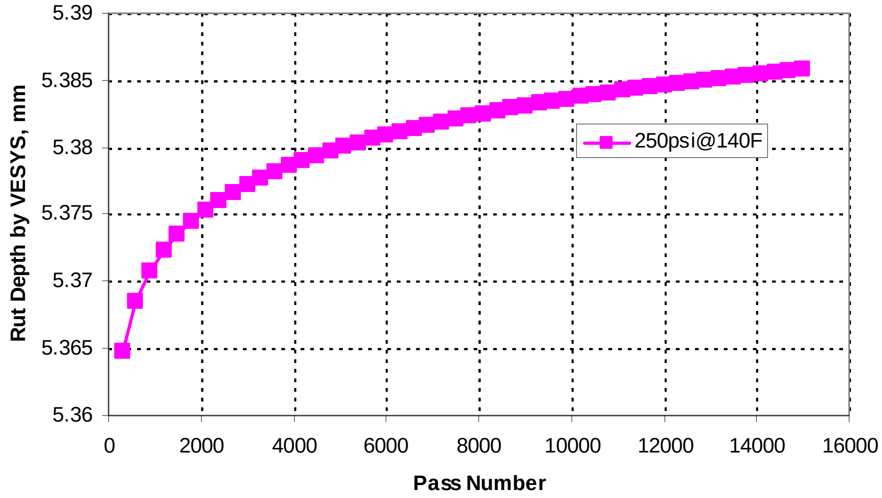
(a) Comparisons of Three Test Conditions



(b) 100psi at 140°F



(c) 250psi at 70°F



(d) 250psi at 140°F

Figure 10. Rut Depth Predictions for Extended APA Pass Numbers by VESYS Method for the Three Test Conditions.

CONCLUSIONS

This paper presents APA test results on HPT HMA cores. The APA tests were conducted and the acquired data was analyzed. These test results will be used to augment the full scale testing program at the NAPTF.

FAA customized APA equipment is capable of applying tire pressure representative of a heavy commercial aircraft. It can apply hose pressure more than 260 psi (1.79 MPa) with temperature controls between 39°F (4°C) and 162°F (72°C). NAPTF cores were tested using FAA owned APA. Tests were conducted at 70°F (21°C) and 140°F (60°C) for 100 psi (0.69 MPa) and 250 psi (1.72 MPa) contact pressures after checking temperature uniformity in the APA chamber. Data analysis was performed by direct rut depth, rut depth slope, and rut rate comparisons. Additionally, VESYS method was adopted to predict permanent deformation for extended APA stroke numbers. The analyses show that the rut depth increased significantly with higher contact pressures and temperatures. Also, the permanent deformation was more sensitive to temperature than to the contact pressure changes.

ACKNOWLEDGEMENT/DISCLAIMER

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The APA tests in this paper were conducted by Pavement Technology, Inc. and Soiltek, Inc.

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