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Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Recommended Changes to FAA P-401/P-403 and P-404 Asphalt Mixture Design for Aircraft Loading Conditions

July 2023

Final Report

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16. Abstract

Rutting in asphalt airfield pavements can be a significant problem due to the increasing gross aircraft weight (GAW) and extremely high tire pressures associated with these aircraft. The generated high stresses and strains can reach significant distances below the pavement surface, impacting deeper asphalt layers previously not affected by earlier aircraft of lower weight and tire pressures. To mitigate the potential for rutting of asphalt mixtures, the Federal Aviation Administration (FAA) conducted a research study to evaluate and recommend potential changes to the current FAA P-401/P-403 and P-404 asphalt specifications to help improve the rutting resistance of the asphalt mixtures for different GAW groupings. An extensive literature review and a parametric study were used to determine critical parameters that influence the rutting potential of airfield asphalt mixtures. Proposed changes were selected to minimize detrimentally impacting the long-term cracking performance of the asphalt airfield mixes. As a result, recommendations were provided to change the following asphalt mixture characteristics for different GAW groupings: aggregate angularity criteria for fine and coarse aggregates, asphalt binder grade selection, and inclusion of and modification to asphalt mixture performance testing. Further validation testing using a controlled heavy-vehicle simulator and field test sections are recommended to validate the proposed recommendations.

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LIST OF ACRONYMS

AAPTP	Airfield Asphalt Pavement Technology Program
AASHTO	American Association of State Highway and Transportation Officials
AIMS	Aggregate Imaging System
APA	Asphalt Pavement Analyzer
APT	Accelerated Pavement Tester
ATADS	Air Traffic Activity System
COA	Certificate of Analysis
EHE	Equivalent highway ESAL
ELA	Elastic layer analysis
ESAL	Equivalent single-axle load
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
GAW	Gross aircraft weight
GLWT	Georgia Loaded Wheel Tester
HMA	Hot-mix asphalt
HVS	Heavy vehicle simulator
JFK	John F. Kennedy International Airport
LEX	Blue Grass Airport
LGA	Laguardia Airport
LRF	Little Rock AFB Airport
NAPA	National Asphalt Paving Association
NAPTF	National Airport Pavement Testing Facility
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NTU	Naval Air Station Oceana
PANYNJ	Port Authority of New York and New Jersey
PG	Performance grade
RPR	Resident Project Representative
QC	Quality control
SST	Superpave Shear Tester
TSR	Tensile strength ratio
VMA	Voids in mineral aggregate
VOK	Volk Field Airport

EXECUTIVE SUMMARY

Rutting in asphalt airfield pavements can be a significant problem due to the increasing gross aircraft weight (GAW) and extremely high tire pressures associated with these aircraft. The generated high stresses and strains can reach significant distances below the pavement surface, impacting deeper asphalt layers previously not affected by earlier aircraft of lower weight and tire pressures. To mitigate the potential for rutting of asphalt mixtures, the Federal Aviation Administration (FAA) explored modifying the existing P-401/P-403 and P-404 asphalt mixture specifications based on expected GAW. In preparation of the proposed revisions, an extensive literature review and parametric study was conducted to evaluate the most significant factors influencing the rutting performance of asphalt mixtures. However, it was also important to ensure that prospective changes to the P-401/P-403 and P-404 specifications would not be detrimental to the durability properties of the asphalt mixtures. Recommended changes reflected the concept that drastic changes to improve the rutting performance of asphalt mixtures could have severe consequences to the long-term performance, more specifically to fatigue cracking performance.

The proposed recommendations included changes to the aggregate angularity criteria for both coarse and fine aggregate, asphalt binder grade selection, and performance testing conducted during mixture design acceptance. The literature and parametric studies showed these parameters significantly influenced rutting performance of asphalt mixtures, while not being detrimental to the fatigue cracking performance. Additionally, because the asphalt binder was found to be significant with respect to the asphalt mixture performance, recommendations were also provided to ensure sampling and testing of the asphalt binder were conducted during production. Lastly, although the P-404 asphalt mixture was found to be the most rut-resistant asphalt mixture within the FAA specifications, slight modifications were made to the specification to be more consistent with the requirements of the P-401/P-403 asphalt mixtures.

1. INTRODUCTION

Technological advances in design and production have led to significantly larger and heavier aircraft with increasing tire pressures to support aircraft when on the ground. Although these technological advances continue to grow the aviation industry, they pose significant problems to the structural integrity of the airfield pavements. Rutting is one particular distress affected by higher wheel loads and tire pressures for flexible pavements (Figure 1). The vertical depressions on the pavement surface can present issues with skid resistance due to the channeling effect of water and ice, and the potential for closing up grooves and loss of surface texture. Pavement smoothness is obviously affected as well, potentially causing issues with aircraft safety while taxiing or traveling immediately after landing or during aircraft acceleration prior to takeoff.

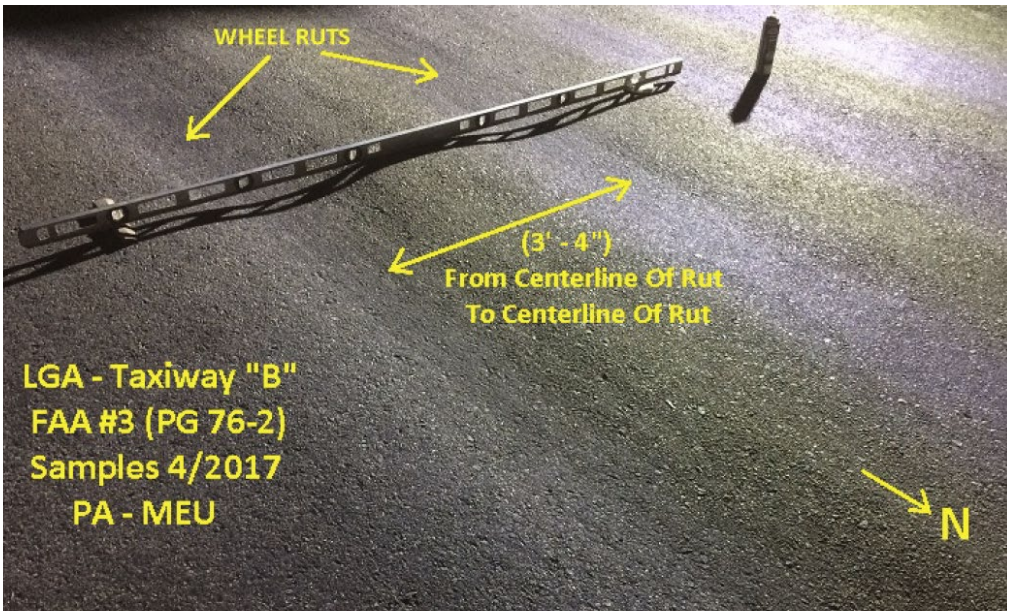


Figure 1. Asphalt Rutting at LaGuardia Airport, Taxiway “B”

To minimize the potential for rutting in asphalt airfield pavements, the Federal Aviation Administration (FAA) has provided asphalt mixture design and construction specifications that are related to the expected loading conditions of the respective airfield being constructed/rehabilitated. FAA P-401 asphalt mixtures are intended to be placed as the surface course of the asphalt pavement and used when gross aircraft weight (GAW) is greater than 30,000 lb. FAA P-403 asphalt mixtures are intended to be placed as leveling and base course asphalt mixtures, and are allowed to be used as surface course mixtures when the GAW is less than 30,000 lb. The FAA P-404 asphalt mixture was originally intended for use in areas where fuel spills are prevalent as its design and constituents provide a fuel-resistant surface. However, this mixture has also been found to be one of the more rut-resistant asphalt mixtures in the FAA specifications (further discussed in the report).

In 2018, the FAA implemented a laboratory performance test used to verify the rutting resistance of the P-401/P-403 asphalt mixture. The test method, called the Asphalt Pavement Analyzer (APA) (AASHTO T340), utilizes a 250-psi hose pressure applied to compacted asphalt specimens by a

250-lb rolling wheel load (Figure 2). Research studies conducted by the FAA showed that the test method was highly correlated for field performance and for heavy vehicle simulator (HVS) sections at the FAA Technical Center in Atlantic City, NJ, and could be implemented within the P-401/P-403 mixture design specification (Rushing et al., 2012; Rushing et al., 2014; Garg et al., 2018). The test method uses a test temperature of 64 °C and the specimens must not rut more than 10.0 mm after 4,000 passes to be considered rut resistant.

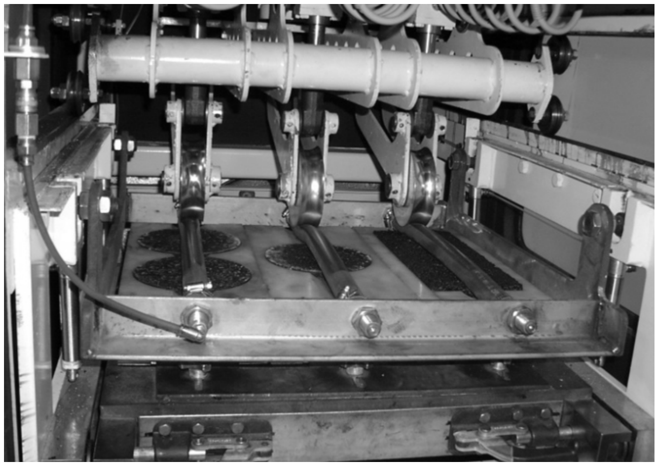


Figure 2. The APA at the FAA William J. Hughes Technical Center in Atlantic City, NJ

With the existing P-401/P-403 and P-404 specifications in place, and understanding that both GAW and tire pressures are continuing to increase, the FAA evaluated the potential for revising the asphalt mixture design and construction specifications to include a wider range of GAW: (a) less than 30,000 lb; (b) greater than 30,000 lb and less than 60,000 lb; (c) greater than 60,000 lb and less than 100,000 lb; and (d) 100,000 lb or greater. Meanwhile, changes to the specification to improve rutting resistance must also consider the effect on the fatigue cracking performance. Rutting and fatigue cracking performance of asphalt mixtures are inversely affected by the same parameters. For example, the inclusion of higher fines content will improve rutting performance yet dry out the mixture and create cracking problems. Conversely, to improve the fatigue cracking performance of asphalt mixtures, adding liquid asphalt is a common method; yet this method could create stability and rutting issues if not done correctly. Therefore, simply modifying specifications to solve one problem could lead to others if not properly considered. For example, this occurred during the original implementation of the Superpave mixture design (West et al., 2018).

2. OBJECTIVES

The objective of the study was to provide proposed revisions to the P-401/P-403 and P-404 specifications that would improve their respective rutting resistance. However, the study was conducted in a manner based on the expected GAW for the airfield pavement on which the asphalt mixture is to be placed. Therefore, any proposed revision must be done to incorporate the GAW ranges of: (a) less than 30,000 lb; (b) greater than 30,000 lb and less than 60,000 lb; (c) greater than 60,000 lb and less than 100,000 lb; and (d) 100,000 lb or greater.

3. FACTORS AFFECTING PERMANENT DEFORMATION OF ASPHALT MIXTURES

The focus of this study was to provide potential changes to P-401/P-403 and P-404 asphalt mixtures and to improve their respective rutting resistance for different GAW ranges. Therefore, it would be prudent to quickly summarize the major factors influencing the permanent deformation of asphalt mixtures.

3.1 AGGREGATE GRADATION

In general, aggregate gradations have been found to have the potential to be a contributing factor when produced outside of the intended design. However, very little evidence has been found to suggest that coarser or finer gradations provide better performance over the other. In a 2007 research study for the FAA William J. Hughes Technical Center in Atlantic City, NJ, Rutgers University evaluated a series of P-401 asphalt mixture gradations (coarse and fine). This was in conjunction with different levels of fine aggregate angularity, asphalt binder grade, and with and without lime filler to evaluate the influence on rutting potential in the APA (AASHTO T340). Testing was conducted at 64 °C, 100-psi hose pressure, and 100-lb wheel load. Figure 3 shows the results of the study.

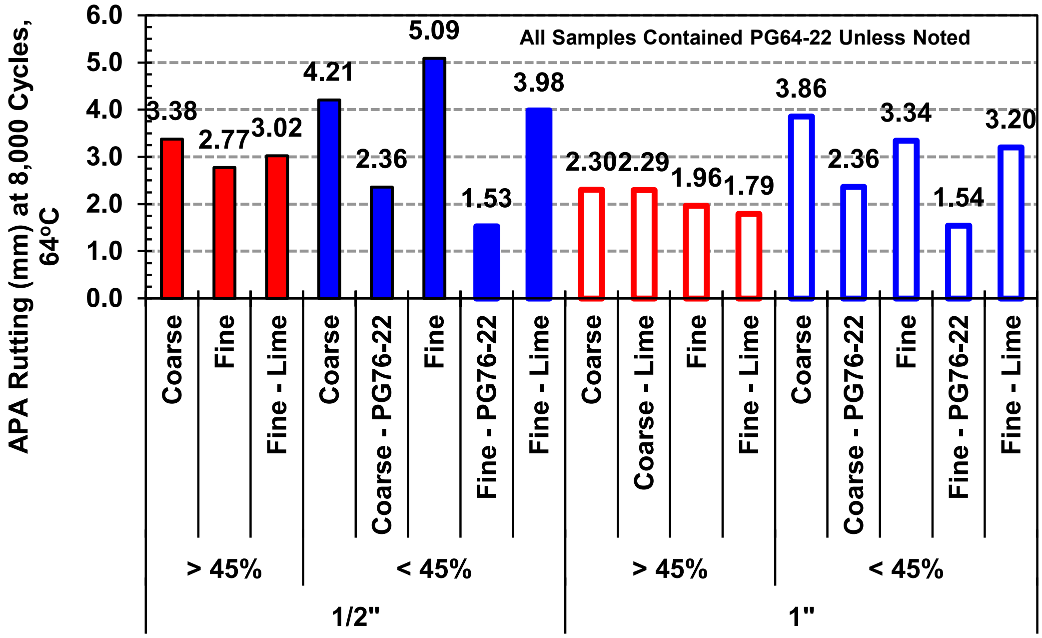


Figure 3.Impact of P-401 Gradation on APA Rutting Performance

Test results showed that the major parameters influencing the rutting of the asphalt mixtures was the fine aggregate angularity (AASHTO T340) and the asphalt binder grade. On average, the maximum aggregate size of the aggregate blends was found to impact APA rutting (i.e., smaller maximum size resulted in higher APA rutting), but this was found to not be statistically significant over the entire data set. It should be noted that the asphalt mixtures noted at <45% had natural sand contents of 15%. In a study by Rushing et al. (2012), natural sand and aggregate texture, as indexed by the Aggregate Imaging System (AIMS), were found to be the major contributing factors to rutting in the APA. The researchers also noted that maximum aggregate size did not statistically influence the rutting performance.

Similar studies have found the same general trends regarding highway asphalt mixtures, with the most significant study conducted at the National Center for Asphalt Technology (NCAT) test track. Full-scale testing of asphalt mixtures using the same aggregate source, compactive effort, and asphalt binder grade showed no difference in rutting performance statistically when comparing coarse- vs fine-graded aggregate gradations (Prowell et al., 2005).

3.2 AGGREGATE ANGULARITY AND TEXTURE

The aggregate angularity and texture are material properties that have long been known to influence rutting in asphalt mixtures. Some of the more comprehensive research has taken place in the past 30 years. Increased levels of angularity and texture improve the internal shear resistance of the asphalt mixture, aiding in the resistance to deformation and shear straining during loading at elevated temperatures (Figure 4). In fact, the internal shear strength of asphalt mixtures can be considered using the classical Mohr-Coulomb shear strength equation, shown in Figure 5. With its application to hot-mix asphalt (HMA), the cohesion factor (C) is directly related to the asphalt binder stiffness properties at the elevated temperature at the time of loading. The internal friction angle (ϕ) is directly related the aggregate contribution, which is highly correlated to the angularity and texture of the aggregate structure. More angularity and texture will provide greater magnitudes of ϕ, while lower values of ϕ can be expected with more rounded/smooth aggregates, such as natural sands and uncrushed gravels. Researchers and practitioners have made the analogy that increased amounts of natural sands act as “ball bearings” within the asphalt mixture, ultimately reducing the shear stability of the asphalt mixture (Von Quintus and Hughes, 2019).

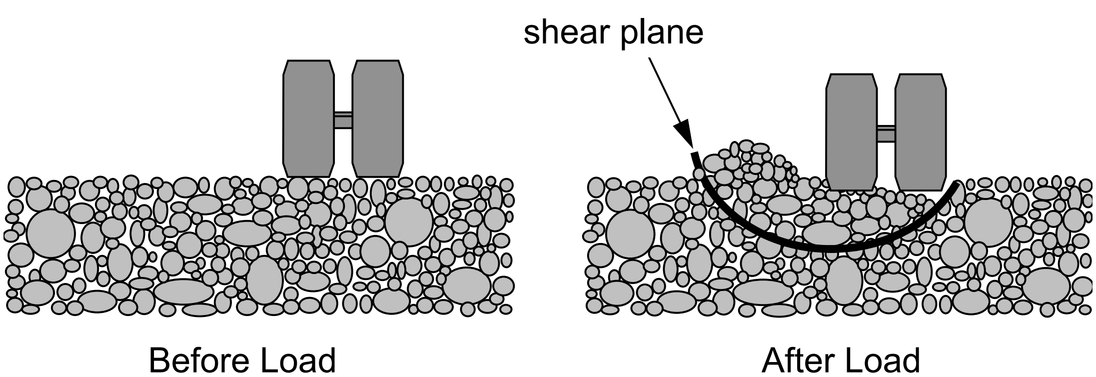


Figure 4. Illustration of Shear Plane Within HMA Under Loading
(NHI, 2000)

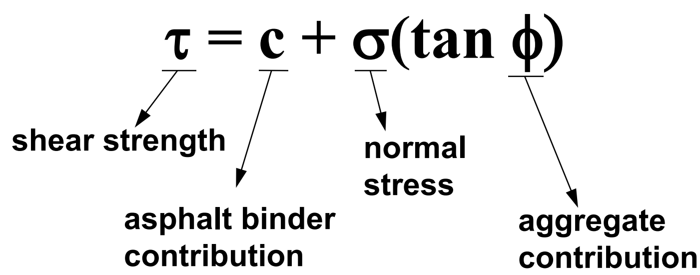


Figure 5. Application of Mohr-Coulomb Shear Strength Envelope Theory to HMA

The aggregate gradation bands for the P-401/P-403 and P-404 asphalt mixtures are shown in Table 1. Using the No. 4 sieve as the division between coarse and fine aggregates, it is clear that the coarse aggregate fraction can be between 22% and 55%, depending on P-401/P-403 gradation used, whereas the coarse fraction can be between 22% and 47% for the P-404 asphalt mixture. This would mean 45% to 78% and 53% to 78% for the fine aggregate fraction for the P-401/P-403 and P-404 asphalt mixtures, respectively. Therefore, the angularity and texture properties are critical for not only the coarse aggregates but also for the fine aggregates within the aggregate blend. In fact, on average, the fine aggregate fraction (passing the No. 4 sieve) has greater representation within the FAA asphalt mixtures than the coarse aggregate fraction.

Table 1. Gradation Bands for P-401/P-403 and P-404 Asphalt Mixtures

Sieve Size	P-401/P-403			P-404	
	Gradation 1	**Gradation 2**	**Gradation 3**	**3/4″ (19 mm)**	**1/2″ (12.5 mm)**
1″ (25 mm)	100	–	–	–	–
3/4″ (19 mm)	90–100	100	–	100	–
1/2″ (12.5 mm)	68–88	90–100	100	90–100	100
3/8″ (9.5 mm)	60–882	72–88	90–100	72–88	90–100
No. 4 (4.75 mm)	45–67	53–73	58–78	53–73	58–78
No. 8 (2.36 mm)	32–54	38–60	40–60	38–60	40–60
No. 16 (1.18 mm)	22–44	26–48	28–48	26–48	26–48
No. 30 (0.6 mm)	15–35	18–38	18–38	18–38	18–38
No. 50 (0.3 mm)	9–25	11–27	11–27	11–27	11–27
No. 100 (0.15 mm)	6–18	6–18	6–18	6–18	6–18
No. 200 (0.075 mm)	3–6	3–6	3–6	3–6	3–6

3.2.1 Coarse Aggregate Angularity

Currently, the FAA uses ASTM D5821 to define coarse aggregate angularity. The specification notes the following fractured face count for two different aircraft gross weights:

1. Aircraft gross weight ≥60,000 lb
    a. Fractured faces minimum of 85/75 (this means 85% of the aggregates have at least one face fractured with 75% of the aggregates having two or more faces fractured)
2. Aircraft gross weight <60,000 lb
    a. Fractured faces minimum of 65/50

There are a number of issues with using fractured faces as a means for requiring aggregate angularity. First, *ASTM D5821 does not directly measure angularity or texture. It is simply a way of validating the effectiveness of the aggregate crushing process while not providing any indication as to how much angularity or how much texture of the coarse aggregates*. Second, ASTM D5821 has been found to be highly user-dependent when selecting what is a "fracture face." Therefore, the test method has a moderate to high variability. Hand et al. (2000) conducted a round-robin study to determine the precision of ASTM D5821. The study was initiated because of concerns of insufficient fractured faces in the original gravel source used at WesTrack. Ten laboratories tested four aggregates used at WesTrack. The data collected through that study resulted in the precision statement shown in Table 2.

Table 2. Precision Statement for Both One or More and Two or More Fractured Faces (From Hand et al., 2000)

Property and Index Type	Standard Deviation (%)	Acceptable Range of Two Results (%)
	One or More Fractured Faces	
Single-Operator Precision	1.1	3.0
Multi-Laboratory Precision	1.8	5.1
	Two or More Fractured Faces	
Single-Operator Precision	1.8	5.1
Multi-Laboratory Precision	2.9	8.2

In a study similar to Hand et al. (2000), Carlberg et al. (2002) conducted a multi-laboratory study to determine the precision of ASTM D5821. The study used 34 "well-trained observers" to evaluate two samples of partially crushed gravel. The results of the study indicated that the multi-laboratory standard deviation of two or more fractured faces was 5.2% for "well-trained observers." The acceptable range between two properly conducted tests by two "well-trained observers" was reported to be 14.7%. With such a large range of acceptable results between operators, ASTM D5821 is difficult to enforce within a specification system.

A different test method that correlates well to the aggregate angularity and texture properties of coarse aggregates is the *Standard Method of Test for Uncompacted Void Content of Coarse Aggregate* (AASHTO T326). The test method was originally developed by Ahlrich (1996) for use on heavy-duty airfield pavements. Ahlrich (1996) developed an uncompacted voids test for coarse aggregate that was similar to ASTM C1252, which is used to measure fine aggregate angularity in the Superpave mix design system. The premise behind that test's development was to provide a means of indexing aggregate angularity related to HMA performance, subjective with minimal user bias, and less labor-intensive than current aggregate angularity indexing methods (i.e., ASTM D3398, *Index of Aggregate Particle Shape and Texture*). Ahlrich (1996 and 1998) found that the coarse aggregate uncompacted voids correlated well with percent fractured faces and ASTM D3398. It also correlated well with the confined, repeated load permanent deformation test results conducted on compacted HMA specimens of varying coarse aggregate mineralogy and angularities.

Kandhal and Parker (1998) evaluated the aggregate angularity properties of highway asphalt mixtures using nine different test methods. This was done while using the Superpave Shear Tester (SST) and the Georgia Loaded Wheel Tester (GLWT) to measure the resultant rutting properties of the asphalt mixtures. The study showed that the uncompacted void content of the coarse aggregate had one of the best relationships with the asphalt mixture rutting. It should also be noted that the study found the uncompacted voids content of the coarse aggregate to be highly correlated to ASTM D3398.

White et al. (2006) further validated the use of the uncompacted void for coarse aggregates using full-scale rutting tests at the Purdue Accelerated Pavement Tester (APT). The full-scale rutting results showed that the coarse aggregate uncompacted voids were found to be the best single predictor of rutting performance of the coarse-graded mixtures, as indicated by the descriptive ranking. The test appears to capture information related to particle shape and texture, and rutting decreases as the coarse aggregate uncompacted void content increases. A relationship between traffic and coarse aggregate seemed less sensitive for uncompacted void content values in the range of 40% to 45%. The relationship becomes stronger in the coarse aggregate uncompacted void content range of 45% to 50%.

Previous testing in Purdue's APT has indicated that one APT pass is equivalent to approximately 2,500 equivalent single-axle loads (ESALs). The authors applied this relationship to the coarse aggregate uncompacted void content/wheel pass data, which shows that a performance limit occurs at 100,000 ESALs. For expected traffic below 100,000 ESALs, a minimum coarse aggregate uncompacted void content of 40% would be required. A coarse aggregate uncompacted void content of at least 45% would be required for traffic above 100,000 ESALs.

In 2010, Bennert et al. (2011) evaluated the American Association of State Highway and Transportation Officials (AASHTO) T326 and ASTM D5821 by comparing the results to aggregate imaging procedures and asphalt mixture rutting tests using the APA (AASHTO T340) and repeated load permanent deformation testing. This was done with and without confining pressure, using the Asphalt Mixture Performance Tester (AASHTO T378). The testing results showed that the measurements determined from ASTM D5821 did not correlate to the other angularity and texture test procedures (AASHTO T326 and AIMS). Coarse aggregates having identical fractured face counts resulted in much different measurements when tested with AASHTO T326 and the AIMS device. Additional aggregate angularity testing also showed that AASHTO T326 was sensitive and performed rationally with respect to slight additions to rounded coarse aggregate particles. When comparing the permanent deformation properties of the asphalt mixtures, it was clear that better performance predictions were found when comparing with AASHTO T326 than with ASTM D5821.

3.2.2 Fine Aggregate Angularity

The current FAA specification does not provide any guidance regarding the angularity of the fine aggregate fraction of the aggregate blend. The specification allows as much as 15% natural sand, and notes: "The addition of natural sand tends to decrease the stability of the mixture, therefore, it is recommended to not use natural sand."

Although this is generally a true statement, one can use natural sand and still maintain rutting resistance if there is sufficient angular fine aggregate to help "offset" the rounded nature of the natural sands. However, there should be a means for evaluating and indexing the amount of angularity in the fine aggregate fraction to make this decision.

A significant amount of research on highway asphalt pavements has been conducted looking at the fine aggregate angularity and its impact on asphalt mixture performance. Brown and Cross (1992) looked at the rutting of 42 different asphalt pavements in 14 states. The study showed that a clear relationship exists between fine aggregate angularity, as measured by ASTM C1252, and rutting for all pavements evaluated (Figure 6).

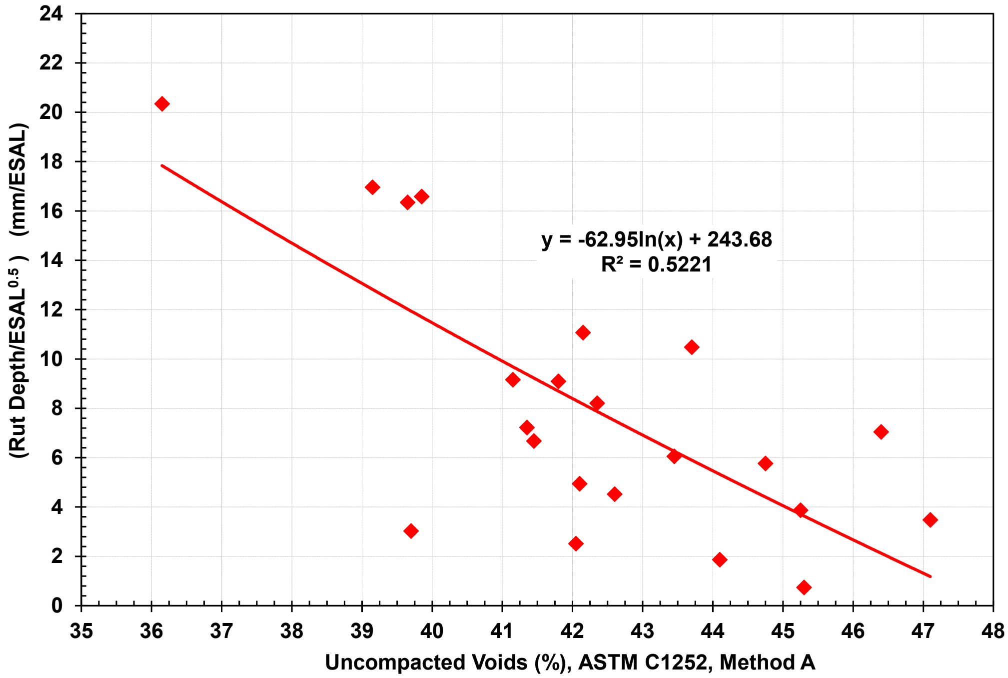


Figure 6. Fine Aggregate Angularity Compared to Field Rutting of Highway Asphalt Pavements

Kandhal and Parker (1998) and Stiady et al. (2001) concluded that uncompacted voids were significantly related to the total rut depth measured in full-scale accelerated loading tests. Bennert et al. (2006) looked at the inter-relationship between fine aggregate angularity and asphalt binder grade using AASHTO T304, *Standard Method of Test for Uncompacted Void Content for Fine Aggregates*, and the APA as a rutting test. The study conducted by Bennert et al. (2006) illustrated the effect of the fine aggregate angularity (as measured by the AASHTO T304) and the rutting in the APA (Figure 7). The test results show that as the fine aggregate angularity increases, the amount of rutting/permanent strain decreases.

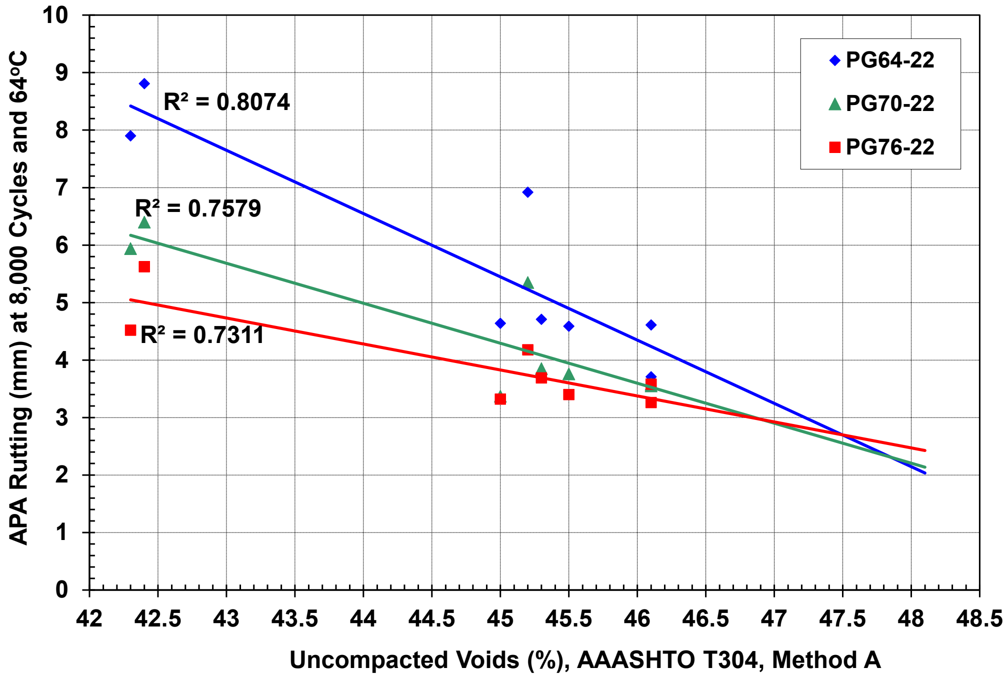


Figure 7. Fine Aggregate Angularity (as measured using the Uncompacted Void Content) Influence on Rutting in the APA (after Bennert et al., 2006)

In 2009, research conducted by Rutgers University for the FAA Technical Center in Atlantic City, NJ focused on the APA rutting performance of two different "well performing" P-401 asphalt mixtures. A ½″ and a 1″ maximum aggregate size P-401 were evaluated while changing the general shape of the gradation (coarse and fine) and also changing the fine aggregate angularity. The fine aggregate angularity was modified by increasing or decreasing the amount of natural sand in the P-401 asphalt mixture (0% and 15% natural sand). The APA rutting results were shown earlier in Figure 3. The test results clearly show that the fine aggregate angularity had a significant influence on the APA rutting results for both the ½″ and 1″ maximum aggregate size P-401 mix.

Rushing et al. (2012) showed that 0% and 10% natural sand in a P-401 asphalt mixture had statistically the same rutting performance in the APA, but increasing to 30% natural sand significantly decreased the rutting resistance of the asphalt mixtures. It should be noted that fine aggregate angularity of the fine aggregate fraction was not measured. Therefore, it was difficult to ascertain what the uncompacted voids of the 0% and 10% natural sand blends were.

3.3 ASPHALT BINDER GRADE/STIFFNESS AT HIGH TEMPERATURES

The asphalt binder grade selection for the FAA P-401/P-403 asphalt mixtures are shown in Table 3. The asphalt binder is first to be selected based on the initial asphalt binder performance grade (PG) consistent with the recommendations of the applicable state DOT requirements for local pavement environmental conditions. Once the PG grade is determined, the high-temperature PG grade is adjusted, or "bumped," based on the aircraft gross weight shown in Table 3.

Table 3. Asphalt Binder Grade Selection for P-401/P-403 Asphalt Mixtures

Aircraft Gross Weight	High Temperature Adjustment to Asphalt Binder	
	All Pavement Types	**Pavement Area With Slow or Stationary Aircraft**
≤12,500 lb (5,670 kg)	–	1 grade
<100,000 lb (45,360 kg)	1 grade	2 grades
≥100,000 lb (45,360 kg)	2 grades	3 grades

The asphalt binder for the P-404 is a PG grade of PG82-28FR or PG88-22FR. The asphalt binder is specially formulated to provide additional resistance to degradation due to the exposure to jet fuel (FAA, 2018 [Section 404-3.4]).

The asphalt binder grade selection can make a significant difference with respect to the high and low temperature performance of the asphalt mixture. As this project is directed at the high-temperature stability of the asphalt mixture, it is the high-temperature PG grade that is of significant importance. Figure 8 shows the results from a study conducted for the FAA Technical Center in Atlantic City, NJ that Rutgers University participated in (AAT, 2013). The study looked at the impact of high tire pressure stresses on the performance of P-401 asphalt mixtures. Figure 8 summarizes the APA rutting at 4,000 cycles using an earlier version of the FAA APA rutting test criteria.

In this study, a test temperature of 65 °C and a hose pressure of 254 psi were used. Current procedures use a test temperature of 64 °C and hose pressure of 250 psi. Three well-performing asphalt mixtures were selected and are described as per the airport they were placed. To evaluate the influence of asphalt binder grade on rutting performance, the asphalt binder grades were varied and the APA rutting measured. As shown in Figure 8, the high-temperature asphalt binder grade makes a significant difference in the rutting performance. According to the LTPPBind 3.1 software, all three airport locations would have selected a PG64-22 as the base asphalt binder before any grade bumping. Without grade bumping, all three of the asphalt mixtures would not have met the current minimum criterion of 10.0 mm of APA rutting at 4,000 cycles. However, the asphalt mixtures at both the Blue Grass Airport (LEX) and John F. Kennedy International Airport (JFK) had adjusted asphalt binders. These were adjusted to PG70-22 for LEX and PG82-22 for JFK when constructed and placed at their respective airports. As shown in Figure 8 and noted in *red italics*, the Lexington mixture just barely failed the criteria; whereas the JFK mix clearly passed the criteria. Overall, the study clearly illustrated the beneficial impact the asphalt binder grade can provide on the rutting performance of P-401/P-403 asphalt mixtures. It should be noted that a slight increase in the APA rutting was observed in both the National Airport Pavement Testing Facility (NAPTF) and JFK mixtures when bumping the asphalt binder grade from a PG76-22 to PG82-22. At the time, this was attributed to testing variability and potential testing error.

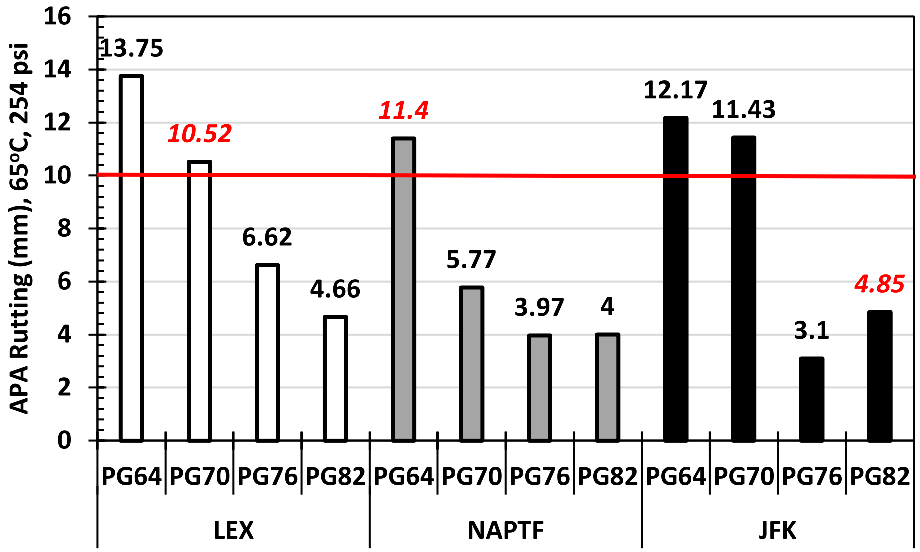


Figure 8. The APA Results Using the FAA Criterion

3.4 VOLUMETRICS

It is well accepted that the main premise of asphalt mixture design is to determine the proper amount of asphalt binder to ensure the asphalt mixture is flexible and durable enough to withstand cracking, while not resulting in stability issues. The "balancing" between durability and stability has long been a challenge for asphalt mixture designers. This is because lower asphalt contents will provide rutting resistance, yet can create cracking problems, and vice versa. Currently, whether using the Superpave- or Marshall-based procedures, asphalt mixture design relies heavily on volumetric properties to design and produce asphalt mixtures. Design target air voids of 3.5% have been carefully monitored and evaluated with decades of field performance. This is to ensure that the optimum asphalt content at this design air void condition provides long-lasting performance (stability and durability). The current P-401/P-403 asphalt mixtures are designed at a target air void of 3.5% (Table 4), whereas the P-404 asphalt mixtures have a target design air void of 2.5% (±0.2%). The reason for these differences will be discussed further in this section.

Voids in mineral aggregate (VMA) ensure that proper effective asphalt content and resultant film thickness are provided to achieve durable asphalt mixtures. The minimum VMA requirements are a function of the maximum aggregate size, as shown in Table 4, to ensure that minimum effective asphalt binder content and film thickness are provided. Low-design VMA values, with respect to the maximum aggregate size of the asphalt mixture, can indicate dry asphalt mixtures with durability issues. High-design VMA values relating to the maximum aggregate size can indicate over-asphalted mixtures with stability issues.

The wide acceptance of polymer-modified asphalt binders has enabled asphalt mixture designers to "bend the volumetric design rules" by designing asphalt mixtures at lower design air void contents and higher design VMA values. This allows for the achievement of greater strain tolerance while still maintaining rutting performance.

Table 4. Design Volumetric Requirements for P-401/P-403 Asphalt Mixtures

Sieve Size	Percentage by Weight Passing Sieves		
	Gradation 1	**Gradation 2**	**Gradation 3[a]**
1″ (25.0 mm)	100	–	–
3/4″ (19.0 mm)	90–100	100	–
1/2″ (12.5 mm)	68–88	90–100	100
3/8″ (9.5 mm)	60–82	72–88	90–100
No. 4 (4.75 mm)	45–67	53–73	58–78
No. 8 (2.36 mm)	32–54	38–60	40–60
No. 16 (1.18 mm)	22–44	26–48	28–48
No. 30 (600 μm)	15–35	18–38	18–38
No. 50 (300 μm)	9–25	11–27	11–27
No. 100 (150 μm)	6–18	6–18	6–18
No. 200 (75 μm)	3–6	3–6	3–6
Minimum VMA	14.0	15.0	16.0
Asphalt percent by total weight of mixture:			
Stone or gravel	4.5–7.0	5.0–7.5	5.5–8.0
Slag	5.0–7.5	6.5–9.5	7–10.5
Recommended minimum construction lift thickness	3″	2″	1½″

[a] Gradation 3 is intended for leveling courses. FAA approval is required for use in other locations.

An example of the interchange between volumetrics and asphalt binder grade is shown in a parametric study using the Resistivity model developed by Christensen and Bonaquist (2006). The Resistivity model was originally developed as part of National Cooperative Highway Research Program (NCHRP) Projects 9-25 and 9-31. It is based on the hypothesis that resistance to permanent deformation in HMA is inversely related to the permeability of the aggregate structure to the binder used in the mix at the temperature of interest. The model has been verified using a number of highway asphalt mixtures with known field performance. It was used to help establish PG grading recommendations during the Airfield Asphalt Pavement Technology Program (AAPTP) 04-02 project (Christensen et al., 2008). It was later modified to allow the use of the asphalt binder high-temperature properties from the Multiple Stress Creep Recovery test (Christensen and Bonaquist, 2015). The model is shown as Equation 1 through 6.

$$TR = (1.31 \times 10^{-4}) N_{des}^{1.578} (P K_a K_s)^{1.238} \left(\frac{V_{QC}}{V_{IP}}\right)^{1.09} \quad (1)$$

where,

TR = million ESALs to a maximum rut depth of 12.0 mm (95% confidence interval)

P = Resistivity, s/nm

$$\mathrm{P} = \frac{S_a^2 G_a^2}{4.9(J_{nr})(VMA)^3} \quad (2)$$

J_{nr} = the non-recoverable compliance at 1 second loading, 3.2 kPa stress, Pa
K_a = age hardening ratio

$$Ka = 0.62 \text{ x } (t/2)^{0.37} \tag{3}$$

where t is the total design/performance life in months
K_s = speed correction

$$K_s = (v/70) \tag{4}$$

where v is the average traffic speed in km/hr

S_a = specific surface area of aggregate in mixture, m2/kg

$$S_a = \text{sum of passing 75, 150, and 300 micron sieves divided by 5.0} \tag{5}$$

$$S_a = 2.05 + (0.623 \text{ x \% passing 75 micron sieve}) \tag{6}$$

Ga = bulks specific gravity of the aggregate blend
VMA = voids in mineral aggregate
N_{des} = design gyrations or Marshall compaction
50 gyration for 35 blows; 75 gyrations for 50 blows; 100 gyrations for 75 blows
V_{QC} = air void content during quality control (QC) testing at design gyrations
V_{IP} = air void content in-place

The J_{nr} value must be determined using LTPPBind 3.1 for a 7-day average maximum pavement temperature at 20 mm below the pavement surface.

The resultant TR value is the maximum number of equivalent single axle loads, in millions, before resulting in a rut depth of 12.0 mm in the asphalt mixture. Although this does not directly relate to airfield traffic, the relationship developed in AAPTP 04-02 relating equivalent highway ESALs (EHEs) to GAW and annual departures can be used to provide an initial approach to relating the Resistivity rutting model to airfield asphalt pavements (Equation 7). It should be noted that the accuracy of the rutting when converting to GAW and annual departures has not been verified. It is used as an example of the relative differences in asphalt mixture performance when different asphalt mixture parameters are evaluated. Therefore, the parametric data generated would represent the GAW and annual departure that would result in 12.0 mm of rutting in the asphalt mix.

For Central Taxiways:

$$EHEs = 0.171 \times \text{annual departures} \times (GAW)^{0.5} \tag{7}$$

where,
EHEs = equivalent highway ESALs

GAW = gross aircraft weight

For the study, the NAPTF used a ¾″ maximum aggregate mix with a PG64-22 asphalt binder. Designed at 3.7% air voids, the optimum asphalt content was 5.5%, and the design VMA was 17.3%. The identical mixture was evaluated as part of a 2010 study for the FAA William J. Hughes Technical Center in Atlantic City, NJ regarding the use of the Superpave gyratory compactor to design P-401/P-403 asphalt mixtures (Christensen et al., 2010). In addition to the volumetric data, the parametric study also used the following:

- 52.1 °C high temperature based on Atlantic City, NJ location and 20 mm below the surface
- Aircraft speed of 37 km/hr (23 mph) to simulate taxiway speed, no stacking
- 6 months of service to simulate early life aging

First, to show the general impact of asphalt binder grade selection, Figure 9 was generated using the model. Although the impact of asphalt binder high-temperature performance was shown earlier in Figure 8, it needs to be reiterated that asphalt binder grade is the easiest parameter to change to significantly improve rutting performance. As shown in Figure 9, significant increases in the allowable number of departures and GAW can be achieved by selecting an asphalt binder with an improved high-temperature PG grade.

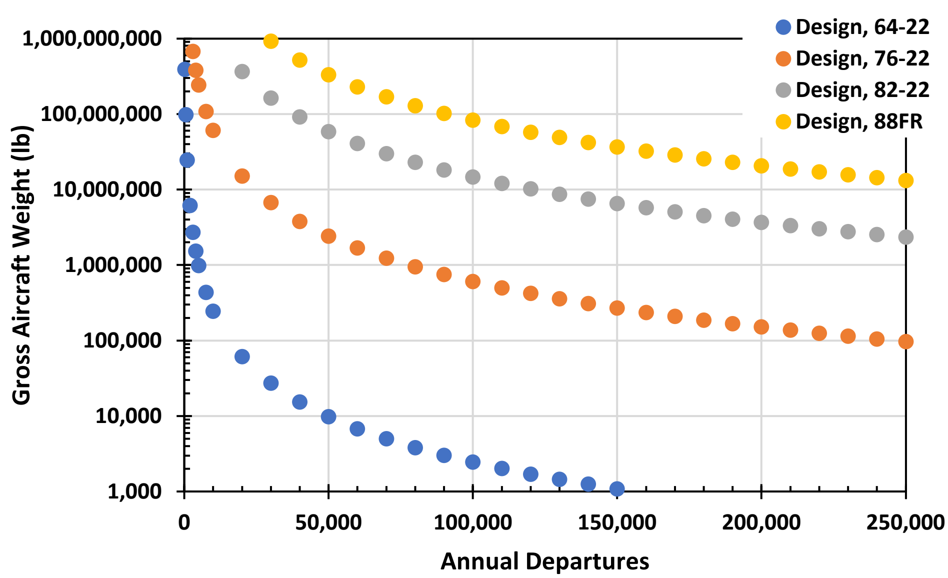


Figure 9. Influence of Asphalt Binder Grade on Rutting Performance of NAPTF P-401 Mix

Figure 10 shows the impact of VMA on the predicted rutting performance of the NAPTF P-401 asphalt mixture. Using the mix design's PG64-22, a 1% decrease in VMA would slightly improve the rutting resistance of the asphalt mixture, although it can be assumed this would negatively impact the durability properties. An increase of 1% in the design VMA shows that would negatively impact rutting performance. Meanwhile, if a PG76-22 asphalt binder was used, the asphalt mixture rutting performance significantly increases, even when a 1% increase over the design VMA is encountered. The P-404 asphalt mixture is designed in this manner (i.e., low airs and higher VMA), but it is still rut resistant because of the high-temperature PG grade properties of the asphalt binder used in the mix. Overall, Figure 10 illustrates that VMA will impact asphalt mixture rutting performance, but its effects are minimized when stiffer asphalt binders are used.

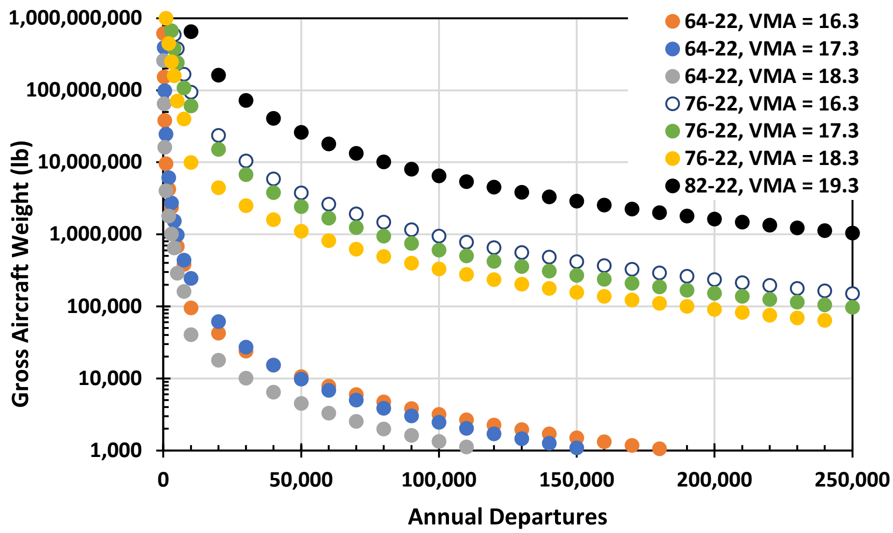


Figure 10. Interaction Between VMA and Asphalt Binder Grade on Rutting Performance of NAPTF P-401 Mix

Figure 11 was developed to determine how the interaction of the in-place air voids and asphalt binder grade impact rutting performance. It is clear that for each asphalt binder grade, as in-place air voids increase, rutting resistance decreases. Again, when “bumping” asphalt binder grades occur, even when in-place air void levels are not desirable, an improvement in the rutting performance can be witnessed.

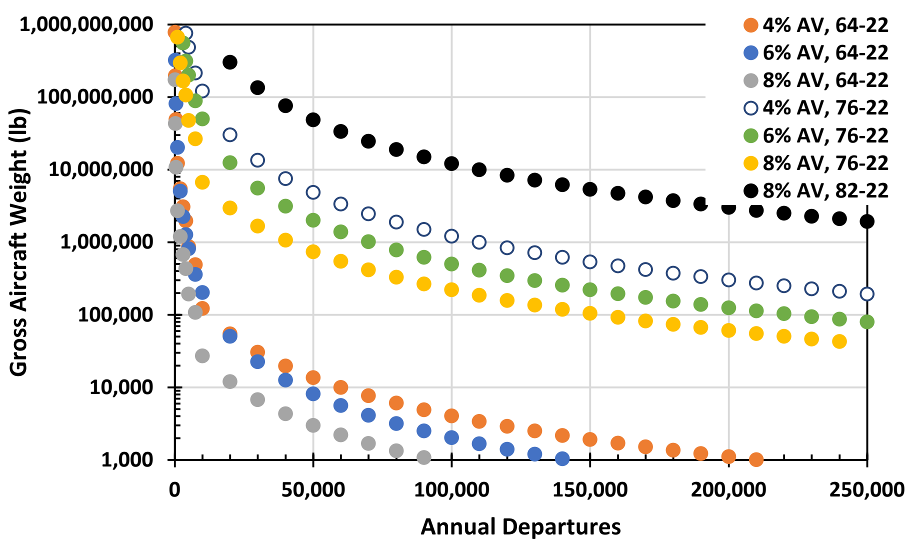


Figure 11. Interaction Between Field Compacted Air Voids and Asphalt Binder Grade on Rutting Performance of NAPTF P-401 Mix

In summary, the Rutting Resistivity model developed by Christensen and Bonaquist (2006) is a means of evaluating the impacts of volumetric and asphalt binder properties on rutting performance of asphalt mixtures. Overall, the model indicates the following:

- A decrease of 1% in design VMA or a decrease of 1% in in-place air voids will provide a 25% improvement in rutting performance when the same asphalt binder grade is used;

- A bump in binder grade will greatly improve the rutting resistance of the asphalt mixture, but the improvement will depend on the properties of the asphalt binder and the volumetrics of the mix. For the NAPTF mix, a significant improvement was found when bumping from a PG64-22 to a PG76-22. In the original model development by Christensen and Bonaquist (2006), one bump in high-temperature grade improved the rutting resistance by a factor of 2.5. Larger improvements were observed using the modified model used in this study.

3.5 DESIGN COMPACTION LEVEL

The compaction level selected during asphalt mixture design is supposed to represent the anticipated traffic level the asphalt mixture is to experience. The greater the traffic level, the larger the laboratory compactive effort. The theory behind this is that higher traffic levels will most likely create additional compaction/consolidation of the asphalt mixture in the field. Therefore, to ensure the asphalt mixture is designed to be stable and durable during its design life, a higher compactive effort needs to be used in the laboratory to simulate the traffic-induced field compaction (Roberts et al., 1996).

In the laboratory, higher compaction levels (i.e., 75 blows vs 50 blows per side) force the aggregate structure closer together. By doing so, the non-mineral volume of the asphalt mixture is lowered, ultimately reducing the available space for effective asphalt. Closer aggregate structure, combined with lower effective asphalt contents, will generally result in greater rutting resistance.

Figure 12 shows the use of the Resistivity model to evaluate the impact of laboratory design compactive effort on the rutting resistance of P-401/P-403 asphalt mixtures. Similar to the figures shown earlier, the asphalt mixture properties from the NAPTF were used in the simulations. The model shows the relative sensitivity to design compaction to rutting resistance, It predicts that when using unmodified asphalt binders, a decrease in compaction level (75 blows to 50 blows) would reduce the rutting resistance of the asphalt mixture by close to 40%. However, as noted earlier, this can be overcome by the inclusion of polymer-modified asphalt binders.

A perfect example of this is the P-404 asphalt mixture design. P-404 is designed at lower air voids (2.5%) and lower compactive effort (50 blows) to increase the effective asphalt content of the asphalt mixture. In doing so, the asphalt mixture becomes impermeable and highly fatigue resistant, yet the asphalt binder grade provides the rutting resistance required on heavy aircraft asphalt pavements. Figure 13 shows the P-404 mixture compared to the NAPTF P-401 asphalt mixture with PG76-22 and PG82-22 asphalt binders. The P-404 asphalt mixture in Figure 13 was designed by Rutgers University for a research study with the Port Authority of New York and New Jersey (PANYNJ).

The P-404 had a design VMA of 21.4% and design air voids of 2.5%, resulting in an effective asphalt content by volume of 18.9%. Figure 12 shows that even at that high effective asphalt content, the P-404 is still more rut resistant than the NAPTF P-401, even with the PG82-22 asphalt binder.

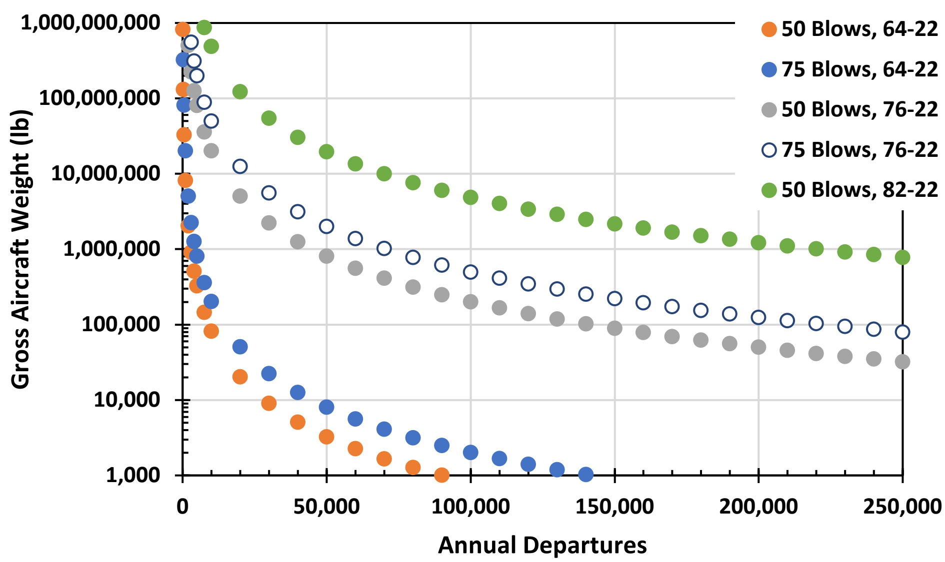


Figure 12. Influence of Compactive Effort (50 Blows vs 75 Blows) on FAA P-401/P-403 Asphalt Mixtures

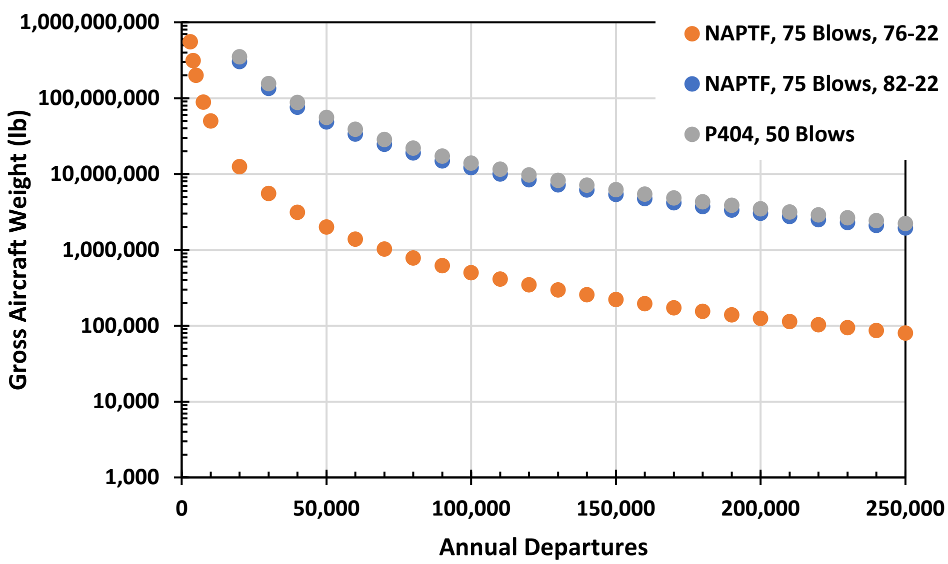


Figure 13. Comparison of P-401 vs P-404 Asphalt Mixture Predicted Rutting Resistance

The results in Figures 12 and 13 show that P-401/P-403 asphalt mixtures, when using the identical aggregate gradation and asphalt binder grade, will have a higher rutting resistance when designed at 75 blows, as opposed to 50 blows. This is due to lower effective asphalt contents associated with an aggregate structure compacted closer together. However, as shown when comparing the P-404 asphalt mixture, airfield asphalt mixtures can be designed to be impermeable, fatigue resistant, and rut resistant by using lower design air voids and lower compactive efforts when incorporating more robust asphalt binders, such as the PG88-22FR.

3.6 LOADING FACTORS—TIRE PRESSURES

One of the major issues facing the performance of asphalt airfield mixtures is the increased loading conditions associated with higher tire pressures and increased GAW. It should be obvious that higher GAW will inflict greater stress on the asphalt airfields. However, it must also be emphasized that the higher tire pressures will cause these stresses to travel deeper into the asphalt pavement system. This can potentially create rutting issues in the underlying asphalt layers if not properly designed/constructed.

An example is a recent project involving Rutgers University and the PANYNJ on LGA in 2017. A recent surface course consisting of a PANYNJ Mix 3 with a PG82-22 asphalt binder was placed in 2014. In 2017, rutting was observed in the asphalt pavement on Taxiway “B” (Figure 14). Field cores were recovered in a manner that allowed for visual evaluation of a cross-section of the rutting (Figure 15). The rutting profile from the cores clearly showed that the rutting did not originate at the surface, but at depths greater than 4″ from the surface. Rutgers University recovered the asphalt binder of the different layers and determined the resultant high-temperature PG in accordance with ASTM D7643, *Standard Practice for Determining the Continuous Grading and Continuous Grades for PG Graded Asphalt Binders*, with the results superimposed on Figure 15. As the figure indicates, the third layer, with a continuous high-temperature PG grade of 75.3 °C (PG70), and the fourth layer (65.9 °C, PG64) were the major contributors to the pavement distortion in the wheel paths.

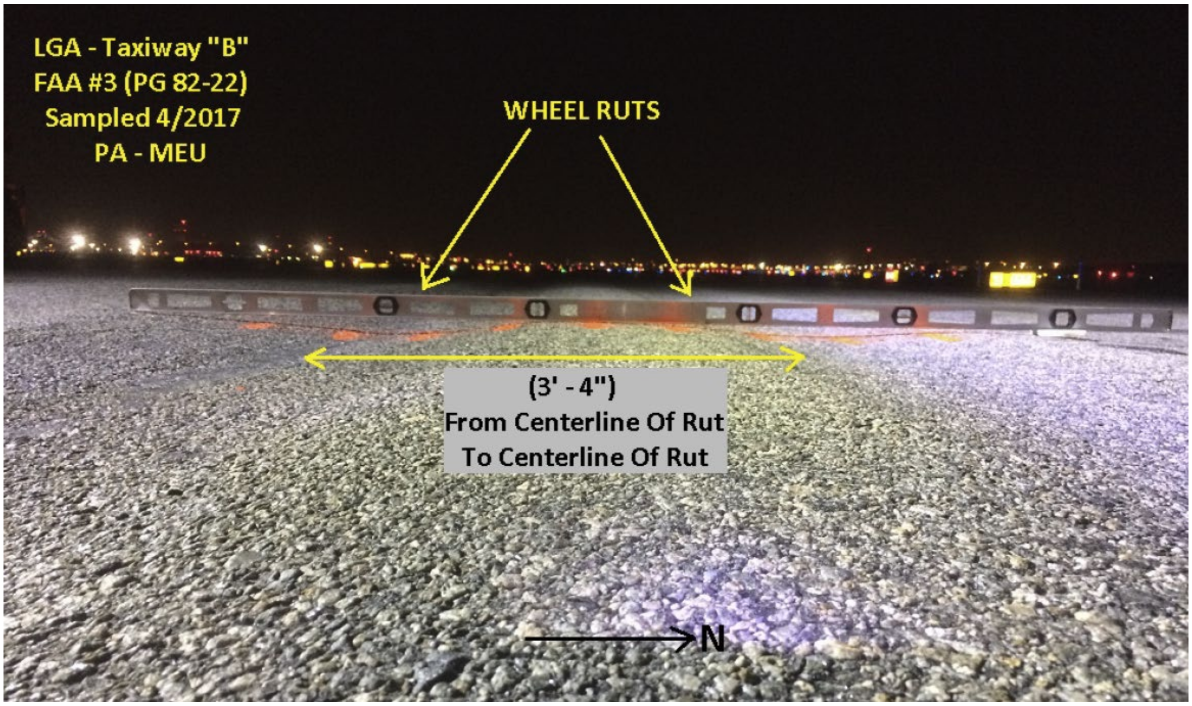


Figure 14. Rutting Measured on Taxiway "B" at LGA

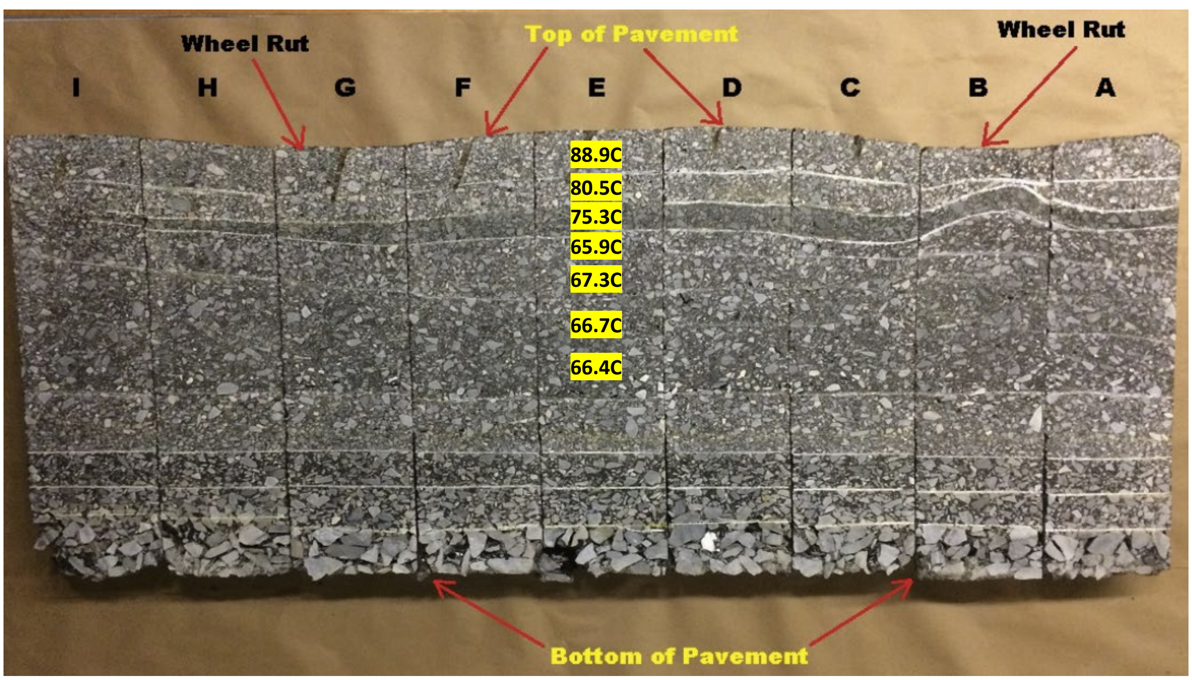


Figure 15. Deeper Layer Rutting in Asphalt Pavement at LGA

It is not surprising that the deeper asphalt layers were the main contributing factor to the rutting in the HMA when considering the impact of the GAW and high tire pressures imparted on the asphalt pavement. A brief analysis was conducted of the vertical stress and strains developed immediately under the tire of a Boeing 737 and an Airbus 320, which are known as the "workhorse" aircraft in the United States, as well as other aircraft of varying GAW and tire pressures (Table 5), to highlight the impact of tire pressures. The GAW, tire pressure, contact area, and tire-spacing information was taken directly from FAARFIELD. The elastic layer analysis (ELA) was conducted using the program JULEA, which is the same ELA engine in the AASHTO PAVEMENT-ME design software. The pavement cross-section selected was simply the example cross-section used in FAARFIELD: 10 inches of P-401 (200 ksi), 10 inches of P-209 (75 ksi), and CBR = 10 subgrade.

Figure 16 shows the developed vertical stresses and strains in the asphalt layer reaching a maximum value approximately 5″ deep. This corresponds to the approximate area in the LGA asphalt pavement that underwent permanent deformation. However, the figure also shows that the vertical strains do not decrease as significantly for the Boeing 737 and Airbus 320 as the other aircraft. This is due to the combination of higher tire pressures and higher wheel loads in the Boeing 737 and Airbus 320.

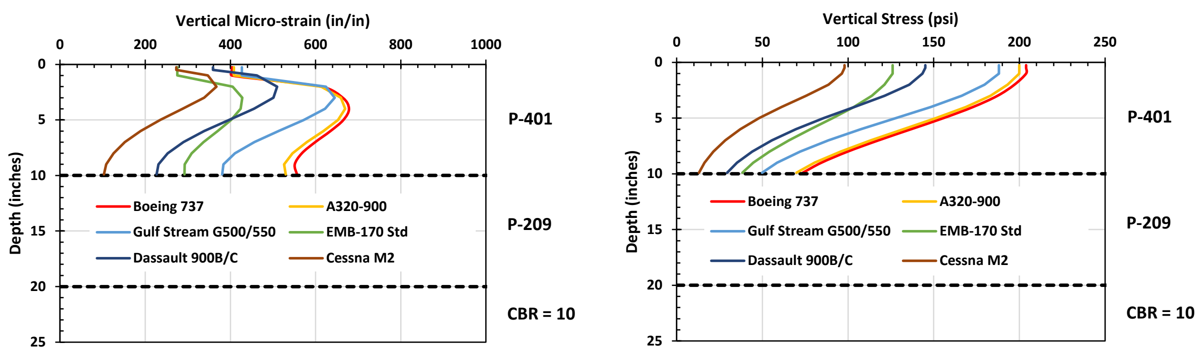


Figure 16. Vertical Strain and Stress Under Wheel Load of Different Aircraft

Table 5. Aircraft Loading Characteristics Used in ELA

Aircraft	Gross Weight (lb)	Tire Pressure (psi)	% GAW on Main Gear	Dual Tire Spading (in.)	Contact Area (in.^{2})
Boeing 737-900	174,700	204	47.5	34	203.4
Airbus A320-200 Std	162,925	200	47.5	36.5	193.5
Gulf Stream G500/550	90,900	188	47.5	18.5	114.8
EMB 170-Std	79,697	126	47.5	28	150.2
Dassault Falcon 900B/C	45,500	145	47.5	14	74.5
Cessna Citation M2	10,500	98	47.5	151	50.9

The tire pressures used in the Figure 16 analysis were standard for the Boeing 737 (204 psi) and Airbus 320-200 Std (200 psi), respectively. It can be expected that at combinations of higher wheel loads and higher tire pressures, the vertical stress and strain within the asphalt layer will be even greater. Research conducted during the development of the AASHTO PAVEMENT-ME estimated that the amount of rutting in an HMA pavement, all other parameters being the same, is proportional to the tire pressure raised to the 2.09 power. This results in a 27% decrease in pavement life due to rutting when increasing the tire pressure from approximately 200 psi to approximately 250 psi (AAT, 2013). Therefore, for higher GAWs that are commonly associated with tire pressures in excess of 200 psi, it is critical to consider the impact of the deeper asphalt layers on the overall rutting performance of the asphalt airfield pavement during design.

It should be noted that the ELA shown in Figure 16 was not used to develop any models or predictions of what occurred at LGA, but simply to show that deeper asphalt layers are subjected to significant stress and strains when higher GAW and tire pressures are exhibited.

3.7 RUTTING SENSITIVITY—SUMMARY

A number of asphalt mixture properties were discussed that were found to be highly influential with respect to asphalt mixture rutting performance. In addition, a parametric study was conducted using the Rutting Resistivity prediction equation to illustrate the relative change in rutting performance with respect to multiple parameters at the same time (e.g., volumetrics, asphalt binder content, high-temperature grade). The parameters highlighted will be the basis for the recommended potential changes to the P-401/P-403 and P-404 specifications with respect to asphalt mixture stability at different GAW. In addition, the brief ELA using aircraft of varying GAW and tire pressures clearly showed the importance of needing to consider more rut-resistant mixtures deeper within the asphalt pavement.

It should be noted that the Rutting Resistivity model has not been calibrated for aircraft loading and traffic conditions. The data presented only provide relative changes between values. Further research would be needed to calibrate the highway loading-based model to airfield loading conditions.

4. AIRPORT TRAFFIC AND LOADING COMPARISONS TO SUPERPAVE-BASED ASPHALT MIXTURE DESIGN REQUIREMENTS

The premise of the project is to evaluate the potential changes to the FAA P-401/P-403 and P-404 asphalt mixture specifications relative to the GAW at the airfield pavement at which the asphalt mixture is to be designed and constructed, respectively. Currently, the FAA specifications only acknowledge that coarse aggregate fractured faces and asphalt binder grade selection should be modified to account for GAW, as well as allowing lower levels of coarse aggregate toughness (i.e., LA Abrasion) in lower layers of the asphalt pavement (i.e., P-403).

4.1 SUPERPAVE-BASED ESALS

The Superpave asphalt mixture design system bases its material selection on traffic and location in the pavement (depth from pavement surface). Materials closest to the pavement surface under the highest traffic levels require the best performing materials, whereas lesser materials could be used with asphalt mixes placed deeper in low-traffic-volume roadways. Table 6 shows the aggregate consensus property requirements for the Superpave mixture design (AASHTO M323).

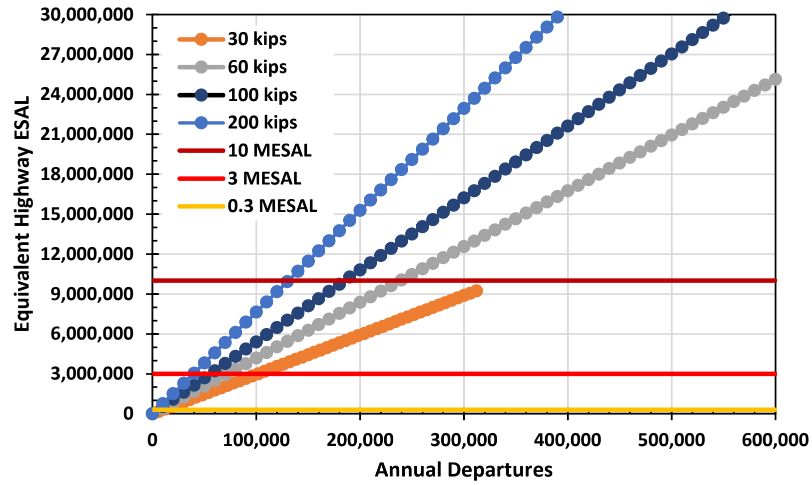
Although the table works with ESALs (defined as a single axle of 18,000 lb or 4,500 lb per tire) and not with aircraft loading parameters, it provides some guidance on how the aggregate properties are selected based on traffic level and depth in pavement.

Table 6. Consensus Aggregate Requirements for Superpave Design

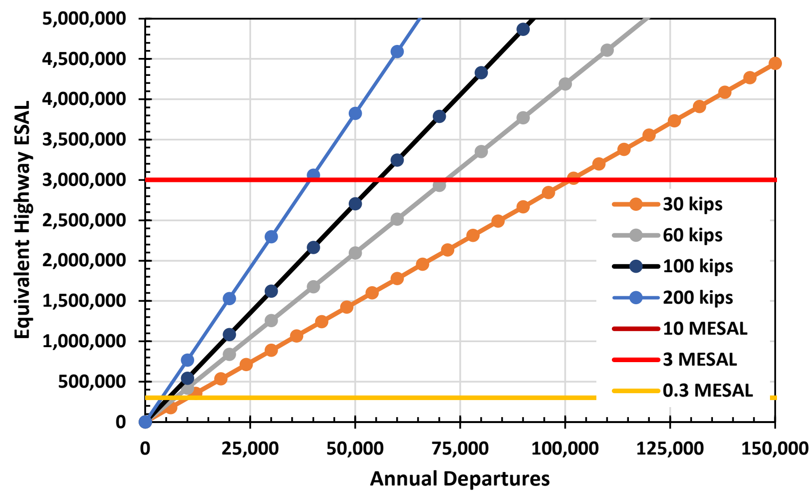
Design ESALs[a] (Million)	Fracture Faces, Coarse Aggregate[c], % Minimum		Uncompacted Void Content of Fine Aggregate, % Minimum		Sand Equivalent, % Minimum	Flat and Elongated[c], % Maximum
	Depth from Surface		Depth from Surface			
	≤100 mm	>100 mm	≤100 mm	>100 mm		
<0.3	55/---	---/---	---[d]	---	40	---
0.3 to <3	75/---	50/---	40[e]	40	40	10
3 to <10	85/80[b]	60/---	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥30	100/100	100/100	45	45	50	10

[a] The anticipated project traffic level expected on the design lane over a 20-yr period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 yr.
[b] 85/80 denotes that 85 percent of the coarse aggregate has one fractured face and 80 percent has two or more fractured faces.
[c] This criterion does not apply for 4.75-mm nominal maximum size mixtures.
[d] For 4.75-mm nominal maximum size mixtures designed for traffic levels less than 0.3 million ESALs, the minimum Uncompacted Void Content is 40.
[e] For 4.75-mm nominal maximum size mixtures designed for traffic levels equal to or more than 0.3 million ESALs, the minimum Uncompacted Void Content is 45.

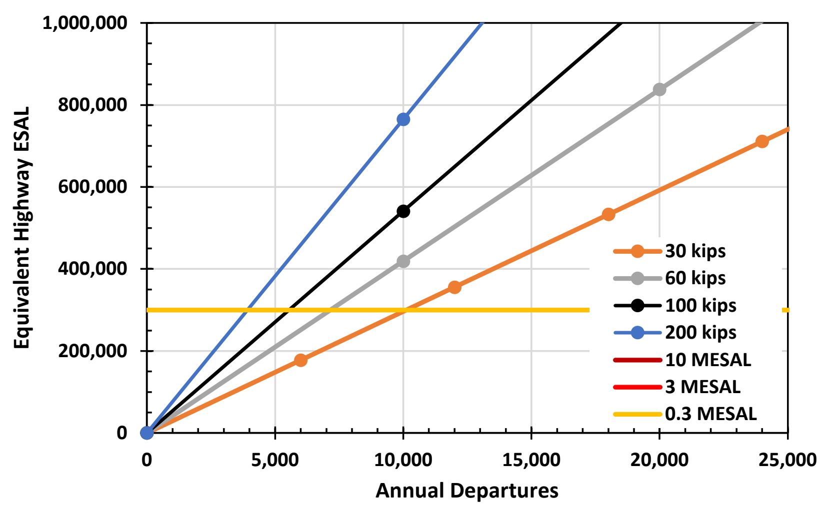
The work in AAPTP Project 04-02 provided a methodology to calculate an EHE based on GAW and airport departures. The relationship for a central taxiway using this methodology was shown earlier in Equation 7. Other relationships were developed for parallel taxiways, but the central taxiway was found to be the most severe condition. The AAPTP 04-02 approach can provide some guidance on how the Superpave-based traffic criteria are related to airfield traffic conditions. Figures 17 (a), (b), and (c) provide the relationship between the EHE and GAW with departures. The relationship is based on developing the equivalent damage (rutting) between GAW with a certain number of departures and highway ESALs. Although it was a theoretical approach developed by Christensen et al. (2008), it was the basis for the PG grade selection and grade bumping currently shown in P-401/P-403.



(a)



(b)



(c)

Figure 17. The EHE Relationship to GAW and Annual Departure

Using the relationship shown in Figure 17, general comparisons between airfield and highway traffic levels can be conducted, allowing for a comparison of Superpave asphalt mixture aggregate properties from Table 6.

- For GAW = 200,000 lb
    - 30 million ESALs ≈ 390,000 departures
    - 10 million ESALs ≈ 130,000 departures
    - 3 million ESALs ≈ 39,000 departures

- For GAW = 100,000 lb
    - 30 million ESALs ≈ 550,000 departures
    - 10 million ESALs ≈ 185,000 departures
    - 3 million ESALs ≈ 55,000 departures

- For GAW = 60,000 lb
    - 30 million ESALs ≈715,000 departures
    - 10 million ESALs ≈240,000 departures
    - 3 million ESALs ≈71,000 departures

- For GAW = 30,000 lb
    - 30 million ESALs >1 million departures
    - 10 million ESALs ≈340,000 departures
    - 3 million ESALs ≈100,000 departures
    - 0.3 million ESALs ≈10,000 departures

The fact that departures are included in the relationship makes a direct comparison between ESALs and GAW difficult without knowing the exact airport in question. To help provide some context to the departure variable, the FAA Air Traffic Activity System (ATADS) was used to provide typical airport traffic levels of more than 70 different airports across the United States (Table 7). Based on the data shown in Figures 17 and 18 and in Table 6, the following general relationships can be made:

1. GAW >100,000 lb is equivalent to Superpave >10 million ESALs with some of the more heavily trafficked airports (e.g., Orlando, Atlanta, Dallas - Forth Worth, Los Angeles, Newark) being equivalent to the Superpave >30 million ESALs. For the sake of consistency and to be slightly more conservative on heavily loaded airport pavements, it can be assumed to be >30 million ESALs.

2. GAW of 30,000 to 100,000 lb is equivalent to Superpave 3 to <10 million ESALs.

3. GAW <30,000 lb would be equivalent to <3 million ESALs.

Facility	State	Itinerant					Local			Total Operations
		Air Carrier	Air Taxi	GA	Military	Total	Civil	Military	Total	
ORD	IL	649,732	265,051	4,862	59	919,704	0	0	0	919,704
ATL	GA	812,320	84,647	7,102	232	904,301	0	0	0	904,301
DFW	TX	625,731	88,137	5,937	202	720,007	0	0	0	720,007
LAX	CA	634,515	38,505	17,853	384	691,257	0	0	0	691,257
DEN	CO	487,725	148,223	4,059	91	640,098	0	0	0	640,098
CLT	NC	475,042	78,614	24,689	802	579,147	0	0	0	579,147
LAS	NV	377,120	134,080	41,814	1,013	554,027	0	0	0	554,027
IAH	TX	380,049	87,921	9,959	141	478,070	0	0	0	478,070
JFK	NY	418,720	31,425	12,614	439	463,198	0	0	0	463,198
SFO	CA	393,869	50,917	11,002	2,714	458,502	0	0	0	458,502
SEA	WA	443,817	4,456	2,135	79	450,487	0	0	0	450,487
EWR	NJ	351,734	86,220	11,233	356	449,543	0	0	0	449,543
PHX	AZ	385,461	30,935	20,401	2,094	438,891	0	0	0	438,891
BOS	MA	355,579	62,235	14,617	422	432,853	0	0	0	432,853
MIA	FL	356,243	45,178	14,919	433	416,773	0	0	0	416,773
MSP	MN	329,323	64,980	9,732	2,038	406,073	0	0	0	406,073
DTW	MI	328,192	62,856	5,772	89	396,909	0	0	0	396,909
PHL	PA	269,651	105,666	14,560	444	390,321	0	0	0	390,321
LGA	NY	320,052	49,268	5,003	216	374,539	0	0	0	374,539
MCO	FL	337,510	13,512	14,648	495	366,165	4	0	4	366,169
SLC	UT	231,238	57,191	47,711	4,064	340,204	4,557	4	4,561	344,765
FLL	FL	264,515	35,810	30,125	1,005	331,455	0	0	0	331,455
HNL	HI	164,373	101,675	47,492	13,248	326,788	25	24	49	326,837
SNA	CA	91,105	21,715	104,992	841	218,653	99,688	144	99,832	318,485
IAD	VA	182,843	90,995	33,939	382	308,159	0	0	0	308,159
LGB	CA	33,192	8,103	99,853	658	141,806	162,539	12	162,551	304,357
DCA	DC	240,704	51,944	2,807	2,855	298,310	0	0	0	298,310
ANC	AK	107,623	78,513	71,505	2,930	260,571	9,275	56	9,331	269,902
BWI	MD	218,944	30,542	12,123	1,185	262,794	0	0	0	262,794
OAK	CA	131,072	33,322	38,729	539	203,662	38,708	387	39,095	242,757
PDX	OR	195,747	20,634	15,589	3,870	235,840	2,537	7	2,544	238,384
BNA	TN	167,153	27,607	36,966	3,238	234,964	0	0	0	234,964
MDW	IL	171,926	26,988	32,922	248	232,084	0	0	0	232,084
DAL	TX	146,744	30,656	53,507	972	231,879	0	0	0	231,879
SAN	CA	208,133	12,775	9,682	764	231,354	0	0	0	231,354
MEM	TN	189,157	20,233	18,512	1,393	229,295	121	35	156	229,451
RDU	NC	136,440	26,437	56,168	2,581	221,626	1,335	288	1,623	223,249
TPA	FL	174,551	18,800	23,562	447	217,360	118	24	142	217,502
VNY	CA	127	27,720	124,722	485	153,054	59,037	4	59,041	212,095
AUS	TX	142,150	16,061	42,755	7,588	208,554	842	330	1,172	209,726
SJC	CA	148,712	21,378	32,328	203	202,621	3,204	61	3,265	205,886
HOU	TX	123,631	25,038	52,241	583	201,493	0	0	0	201,493
STL	MO	141,242	43,868	6,462	1,482	193,054	584	301	885	193,939
IND	IN	125,100	47,359	14,166	866	187,491	0	0	0	187,491
SDF	KY	138,987	24,018	9,959	2,083	175,047	470	149	619	175,666
TEB	NJ	87	81,613	91,583	342	173,625	0	0	0	173,625
SAT	TX	96,557	20,359	42,103	4,653	163,672	154	44	198	163,870
CVG	KY	128,469	28,373	4,934	330	162,106	681	29	710	162,816
SJU	PR	71,806	69,045	15,596	1,453	157,900	1,339	22	1,361	159,261
OGG	HI	56,277	78,342	12,121	1,370	148,110	10,723	128	10,851	158,961
HPN	NY	19,340	51,448	73,911	147	144,846	13,826	0	13,826	158,672
ISP	NY	10,985	7,271	51,973	1,912	72,141	76,286	551	76,837	148,978
PIT	PA	101,735	34,017	7,096	4,922	147,770	22	327	349	148,119
ABQ	NM	55,653	25,802	32,757	15,489	129,701	10,278	6,984	17,262	146,963
BUR	CA	61,643	26,316	32,116	551	120,626	25,814	0	25,814	146,440
MSY	LA	121,062	8,304	13,383	902	143,651	0	0	0	143,651
PBI	FL	55,074	32,571	53,339	1,072	142,056	466	0	466	142,522
SMF	CA	117,817	10,706	6,342	995	135,860	1,678	985	2,663	138,523
TUS	AZ	38,540	15,021	37,412	14,062	105,035	21,204	3,837	25,041	130,076
CLE	OH	87,433	32,085	7,216	265	126,999	0	0	0	126,999
MCI	MO	114,349	4,333	3,646	839	123,167	188	44	232	123,399
JAX	FL	68,776	17,407	12,934	4,780	103,897	974	4,864	5,838	109,735
MKE	WI	64,113	29,398	11,037	1,699	106,247	284	30	314	106,561
BHM	AL	33,994	20,366	38,096	9,180	101,636	2,354	857	3,211	104,847
ONT	CA	73,372	13,721	9,015	307	96,415	4,720	0	4,720	101,135
OMA	NE	55,435	18,216	17,267	1,959	92,877	5,151	565	5,716	98,593
BDL	CT	62,858	13,494	12,652	2,379	91,383	0	0	0	91,383
RSW	FL	72,981	4,056	7,190	932	85,159	10	58	68	85,227
BUF	NY	50,394	17,889	11,312	373	79,968	68	0	68	80,036
OXR	CA	3	4,826	26,927	156	31,912	39,142	42	39,184	71,096
PVD	RI	34,679	11,714	15,284	249	61,926	7,761	102	7,863	69,789
PSP	CA	24,120	11,605	17,828	1,115	54,668	3,974	64	4,038	58,706
MHT	NH	20,839	14,126	12,042	368	47,375	3,720	44	3,764	51,139
DAY	OH	19,089	18,041	11,152	342	48,624	1,243	240	1,483	50,107
RFD	IL	19,541	1,223	13,457	1,181	35,402	5,820	176	5,996	41,398
SWF	NY	4,647	6,656	17,154	3,682	32,139	5,093	3,006	8,099	40,238
GYY	IN	454	2,027	12,460	1,265	16,206	3,855	776	4,631	20,837

Figure 18. Airport Facilities and Their Respective Aircraft Operations From FAA ATADS

4.2 AAPTP 04-03—IMPLEMENTATION OF SUPERPAVE MIX DESIGN FOR AIRFIELD PAVEMENTS

Cooley et al. (2009) conducted a study for the AAPTP program, *Implementation of Superpave Mix Design for Airfield Pavements*, to look at how the Superpave mixture design approach could be applied to P-401 and P-403 asphalt mixtures. Part of the research workplan looked at obtaining materials from various airfield asphalt pavements and determining the respective number of gyrations to achieve the same P-401 design volumetrics used on the respective project. Laboratory testing also included repeated load permanent deformation testing at different stress levels to mirror the effects of different tire pressures on the asphalt pavements. Table 7 shows the airfields used in the study. Most of the air-carrier-type aircraft had tire pressures greater than 200 psi when GAW was greater than 100,000 lb. There were exceptions with the military aircraft at Little Rock Air Force Base (LRF), Naval Air Station Oceana (NTU), and Volk Field (VOK) airports.

Table 7. Typical Aircraft Characteristics for Selected Airfields (After Cooley et al., 2009)

<table>
<tr><th>Airfield</th><th>Design Typical Aircraft[a]</th><th>Main Gear Wheels</th><th>Gross Taxi Weight (lb)[b]</th><th>Gross Taxi Wt. Per Tire (lb)</th><th>Tire Pressure (psi)</th></tr>
<tr><td>Jacqueline Cochran Regional Airport (TRM)</td><td>Generic Single Wheel-20</td><td>2</td><td>20,000</td><td>10,000</td><td>75</td></tr>
<tr><td>Mineral County Memorial Airport (C24)</td><td>Generic Single Wheel-12.5</td><td>2</td><td>12,500</td><td>6,250</td><td>90</td></tr>
<tr><td>Oxford-Henderson Airport (KHNZ)</td><td>Generic Single Wheel-30</td><td>2</td><td>30,000</td><td>15,000</td><td>75</td></tr>
<tr><td>Little Rock Air Force Base (LRF)</td><td>C-130</td><td>4</td><td>155,000</td><td>38,750</td><td>105</td></tr>
<tr><td rowspan="2">Naval Air Station Oceana (NTU)</td><td>F/A -18</td><td rowspan="2">2</td><td>66,000</td><td>33,000</td><td>180</td></tr>
<tr><td>F-13</td><td>45,000</td><td>22,500</td><td>240</td></tr>
<tr><td>Volk Field (VOK)</td><td>F-16</td><td>2</td><td>42,500</td><td>21,250</td><td>215</td></tr>
<tr><td rowspan="4">Jackson International Airport (JAN)</td><td>Generic Single Wheel-75</td><td>2</td><td>75,000</td><td>37,500</td><td>120</td></tr>
<tr><td>Generic Dual Wheel-200</td><td>4</td><td>200,000</td><td>50,000</td><td>200</td></tr>
<tr><td>Generic Dual Tandem-400</td><td>8</td><td>390,000</td><td>48,750</td><td>200</td></tr>
<tr><td>DDTW[c]</td><td>16</td><td>890,000</td><td>55,625</td><td>200</td></tr>
<tr><td rowspan="3">Newark Liberty International Airport (EWR)</td><td>Generic Dual Wheel-200</td><td>4</td><td>191,000</td><td>47,750</td><td>200</td></tr>
<tr><td>Generic Dual Tandem-400</td><td>8</td><td>358,000</td><td>44,750</td><td>200</td></tr>
<tr><td>DDTW</td><td>16</td><td>873,000</td><td>54,563</td><td>200</td></tr>
</table>

Airfield	Design Typical Aircraft[a]	Main Gear Wheels	Gross Taxi Weight (lb)[b]	Gross Taxi Wt. Per Tire (lb)	Tire Pressure (psi)
Palm Springs International Airport (PSP)	Generic Single Wheel-75	2	105,000	52,500	120
	Generic Single Wheel-200	4	200,000	50,000	200
	Generic Dual Tandem-300	8	330,000	41,250	180
	DDTW	16	800,000	50,000	200
Spokane International Airport (GEG)	Generic Single Wheel-75	2	200,000	100,000	120
	Generic Dual Wheel-200	4	200,000	50,000	200
	Generic Dual Tandem-400	8	400,000	50,000	200

[a] LEDFAA provided design aircraft tire pressure and main gear wheel numbers except for LRF, NTV, and VOK.
[b] All gross taxi weights are from Master Airport List except for LRF, NYV, and VOK.
[c] DDTW = Double dual-tandem wheel

Cooley et al. (2009) based the gyratory compactive effort, aggregate consensus properties, and design volumetrics on the anticipated tire pressure the asphalt pavement would witness. Tables 8 and 9 show the recommended asphalt mixture design tables.

Table 8. Recommended Compactive Effort Based on Tire Pressure for P-401 and P-403 Asphalt Mixtures (After Cooley et al., 2009)

Tire Pressure (psi)	N_{design}	Required Relative Density, Percent of Theoretical Maximum Specific Gravity		VMA, Percent Minimum Maximum Aggregate Size (mm)				Voids Filled with Asphalt (VFA) Range (%)	Dust-to-Binder Ratio Range
		$N_{initial}$	N_{design}	1–1/2	1	3/4	1/2		
<100	50	≤90.5	96.0	12.0	13.0	14.0	15.0	70–80	0.6–1.2
100 to 200	65	≤90.5	96.0	12.0	13.0	14.0	15.0	65–78	0.6–1.2
>200	80	≤89.0	96.0	12.0	13.0	14.0	15.0	65–75	0.6–1.2

Table 9. Recommended Aggregate Consensus Requirements Based on Aircraft Tire Pressure for P-401 and P-403 Asphalt Mixtures (After Cooley et al., 2009)

N_{design}	Minimum % Fractured Faces	Uncomp. Voids of Fine Aggregate, % Minimum	Maximum % Natural Sand	Maximum % Flat and Elongated Particles (5:1)	Minimum Sand Equivalency
50	85/80	40	20	10	40
65	95/90	45	15	10	40
80	95/95	45	15	10	50

5. PRELIMINARY RECOMMENDED CHANGES TO P-401/P-403 FOR LOADING CONDITIONS

The main premise of the study was to determine where appropriate changes could be made to the current P-401/P-403 and P-404 with respect to GAW. Currently, the P-401/P-403 specifications are based on the following weight limits:

- GAW ≥30,000 lb
    - P-401 for surface course
    - P-403 for binder/leveling/base course

- GAW <30,000 lb
    - P-403 for all lifts

- P-404 recommended to be used in areas where fuel spill issues have been noted

As per the request of the FAA, the study was to look at potential recommendations to a wider range of GAW, as follows:

- ≥100,000 lb
- <100,000 to ≥60,000 lb
- <60,000 to ≥30,000 lb
- <30,000 lb

Based on the literature review and data developed in Section 3, and the mix design/traffic loading comparison in Section 4, a preliminary recommended mixture design criteria based on the GAW requested by the FAA is discussed in the upcoming sections. However, there are a number of areas where, based on the literature and field experience, there are no immediate needs for changes. In particular:

- Aggregate gradation: Rutting resistance was found to be achieved with all three of the P-401/P-403 gradation bands and was on the coarse or fine side of the gradation band.

- Source aggregate properties: Source aggregate property requirements (e.g., LA Abrasion, soundness) are not recommended to be modified at this time. Currently, the existing properties and criteria appear to provide adequate aggregate sources for asphalt mixtures. Changes in the requirements could be highly restrictive to certain regional areas that have a history of well-performing asphalt mixtures.

- Design Volumetrics: Design air voids and design VMAs are not recommended to be modified. The FAA has a performance history designing at 3.5% air voids. There does not appear to be a need to modify this. Although the parametric study with the Resistivity model did show that rutting increases with increased design VMA, current design VMA requirements have been shown to provide sufficient film thickness and effective asphalt content to provide acceptable levels of durability.

- Quality Control/Assurance Thresholds/Requirements: At this time it does not appear to be prudent to change the existing mixture QC thresholds/requirements for the P-401/P-403 asphalt mixtures. Historical data and experience have shown that the current procedures provide a strong control on the desired field properties.

- Compactive effort: There is no evidence to show an immediate need to change the compactive effort during mixture design. The FAA requires 75 blows per side for all asphalt mixes but allows 50 blows per side when the GAW is less than 60,000 lb. At this time, this seems appropriate. Greater design compactive efforts lead to more rutting resistance but typically to lower asphalt contents. By allowing 50 blows per side for lesser GAW, one can expect a slightly higher asphalt content that would provide greater durability while still providing appropriate rutting resistance for the lower GAW airports.

5.1 RECOMMENDED CHANGES TO P-401

The following sections highlight where revisions are recommended and provide updated changes to the specification.

The first recommended change to the P-401 asphalt mixture design is the requirements for coarse aggregate angularity (Tables 10 and 11). The concept of fractured faces does not guarantee angularity or texture, but simply that the stone has been crushed. Incorporating a test method shown to be highly correlated to the rutting properties of asphalt mixtures should be a priority. In Table 12, the Coarse Aggregate Angularity, as determined by AASHTO T326 Uncompacted Voids, is specified to be greater than 45% for GAW of more than than 60,000 lb. Fractured faces for GAW greater than 100,000 lb is specified to be 100/100, wherease GAW of 60,000 lb to 100,000 lb must be 95/90. GAW under 60,000 lb uses the same fractured faces as previously shown in P-401, but without a requirement for AASHTO T326.

Table 10. Current P-401 Table for Coarse Aggregate Material Requirements

Material Test	Requirement	Standard
Resistance to Degradation	Loss: 40% maximum	ASTM C131
Soundness of Aggregates by Use of Sodium Sulfate **or** Magnesium Sulfate	Loss after 5 cycles: 12% maximum using sodium sulfate - or - 18% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0 % maximum	ASTM C142
~~Percentage of Fractured Particles~~	~~For pavements designed for aircraft gross weights of 60,000 pounds (27200 kg) or more:~~ ~~Minimum 75% by weight of particles with at least two fractured faces and 85% with at least one fractured face[1]~~	~~ASTM D5821~~
	~~For pavements designed for aircraft gross weights less than 60,000 pounds (27200 kg):~~ ~~Minimum 50% by weight of particles with at least two fractured faces and 65% with at least one fractured face[1]~~	
Flat, Elongated, or Flat and Elongated Particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles at 5:1[a]	ASTM D4791
Bulk density of slag[b]	Weigh not less than 70 pounds per cubic foot (1.12 Mg/cubic meter)	ASTM C29.

[a] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than five 5.

[b] Only required if slag is specified.

Table 11. Proposed Revised P-401 Coarse Aggregate Material Requirements Table

Material Test	Requirement	Standard
Resistance to degradation	Loss: 40% maximum	ASTM C131
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 12% maximum using sodium sulfate - or - 18% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0 % maximum	ASTM C142
Coarse aggregate angularity	For pavements designed for aircraft gross weights of ≥100,000 lb (45,360 kg) or more; Uncompacted Voids[a] >45% Minimum 100% by weight of particles with at least two fractured faces and 100% with at least one fractured face[b]	AASHTO T326 ASTM D5821
	For pavements designed for aircraft gross weights of <100,000 lb (45,360 kg) to ≥60,000 lb (27,200 kg): Uncompacted Voids[a] >45% Minimum 90% by weight of particles with at least two fractured faces and 95% with at least one fractured face[b]	
	For pavements designed for aircraft gross weights of <60,000 lb (27,200 kg) to ≥30,000 lb (13,608 kg): Minimum 75% by weight of particles with at least two fractured faces and 85% with at least one fractured face[b]	
	For pavements designed for aircraft gross weights less than <30,000 lb (13,608 kg): Minimum 50% by weight of particles with at least two fractured faces and 65% with at least one fractured face[b]	
Flat, elongated, or flat and elongated particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles at 5:1[c]	ASTM D4791
Bulk density of slag[d]	Weigh not less than 70 lb per cubic foot (1.12 Mg/cubic meter)	ASTM C29

[a] Uncompacted voids as determined using AASHTO T326.

[b] The area of each face shall be equal to at least 75% of the smallest mid-sectional area of the piece. When two fractured faces are contiguous, the angle between the planes of fractures shall be at least 30° to count as two fractured faces.

[c] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than 5.

[d] Only required if slag is specified.

The second recommended change to the P-401 specifications is regarding fine aggregate angularity. In the current specification, fine aggregate angularity requirements are simply based on limiting the percent of natural sand (Table 12). This does guarantee angularity and texture. Literature has shown that natural sand levels as high as 15% can create issues with rutting. Therefore, the proposed specification change includes the determination of fine aggregate angularity using the ASTM C1252, Uncompacted Voids, while also reducing the percent of natural sand to 10%. This is for GAW ≥60,000 lb. When GAW is <60,000 lb, ASTM C1252 is not required, and the amount of natural sand increases to 15% (Table 13).

Table 12. Current P-401 Table for Fine Aggregate Material Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity Index	4 maximum	ASTM D4318
Soundness of Aggregates by Use of Sodium Sulfate **or** Magnesium Sulfate	Loss after five cycles: 10% maximum using sodium sulfate - or - 15% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0% maximum	ASTM C142
Sand equivalent	[45 minimum]	ASTM D2419
~~[Natural Sand~~	~~[0% to 15%] maximum by weight of total aggregate~~	~~ASTM D1073]~~

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The addition of natural sand to a mix containing all crushed coarse and fine aggregates will normally increase its workability and compactability. The addition of natural sand tends to decrease the stability of the mixture. Therefore, it is recommended not to use natural sand. However, if natural sand is used, use the minimum amount necessary to achieve a workable mixture.

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Table 13. Proposed Revised P-401 Fine Aggregate Material Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity Index	4 maximum	ASTM D4318
Soundness of Aggregates by Use of Sodium Sulfate **or** Magnesium Sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 15% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0% maximum	ASTM C142
Sand equivalent	**[** 45 minimum **]**	ASTM D2419
Uncompacted Voids	For pavements designed for aircraft gross weights ≥60,000 lb (27,200 kg): Uncompacted Voids >45% For pavements designed for aircraft gross weights <60,000 lb (27,200 kg): Uncompacted voids not required	ASTM C1252, Method A
[Natural Sand	For pavements designed for aircraft gross weights ≥60,000 lb (27,200 kg): **[** 0% to 10% **]** maximum by weight of total aggregate For pavements designed for aircraft gross weights <60,000 lb (27,200 kg): **[** 0% to 15% **]** maximum by weight of total aggregate	ASTM D1073

****

The addition of natural sand to a mix containing all crushed coarse and fine aggregates will normally increase its workability and compactability. The addition of natural sand tends to decrease the stability of the mixture. Therefore, it is recommended not to use natural sand. However, if natural sand is used, use the minimum amount necessary to achieve a workable mixture.

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It is also recommended that the high-temperature PG grade bumping be modified (Tables 14 and 15). The methodology from AAPTP 04-02 provided a great method for selecting when to bump the high-temperature grade. The proposed revisions simply include more detailed GAW divisions based on this project's requirements. Similar to the other recommended corrections, GAW >60,000 lb generally have the same requirement due to the higher tire pressures of some of the aircraft. GAW of approximately 70,000 lb to 90,000 lb, even though below the 100,000-lb threshold, can result in significant stress/strain to the asphalt pavement. These stresses/strains migrate deeper into the asphalt layer with significant magnitudes when higher tires pressures are incorporated.

Table 14. Current P-401 High-Temperature Grade Adjustment

Aircraft Gross Weight	High-Temperature Adjustment to Asphalt binder Grade	
	All Pavement Types	**Pavement area with slow or stationary aircraft**
~~≤12,500 lbs (5670 kg)~~	~~--~~	~~1 Grade~~
~~<100,000 lbs (45360 kg)~~	~~1 Grade~~	~~2 Grade~~
~~≥100,000 lbs (45360 kg)~~	~~2 Grade~~	~~3 Grade~~

****

Typically, when the PG spread between the high and low temperature is 92 or more, the asphalt binder has been modified. The engineer may use the PG Plus Test found in the Asphalt Institute's State Binder Specification Database for the project location, which requires modification of the table. If the PG spread is less than 92, delete the Asphalt Binder PG Plus Test Requirements table.

The asphalt industry is in a state of change regarding binder designations. Some states are following ASTM D6373, while others are following AASHTO M332. Ensure that the binder supplied meets minimum requirements of ASTM D6373.

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Table 15. Proposed Revised P-401 High-Temperature Grade Adjustment

Aircraft Gross Weight	High-Temperature Adjustment to Asphalt Binder Grade	
	All Pavement Types	Pavement area with slow or stationary aircraft
≤30,000 lb (13,608 kg)	--	1 Grade
≥30,000 lb (13,608 kg) <60,000 lb (27,200 kg)	1 Grade	2 Grade
≥60,000 lb (27,200 kg) <100,000 lb (45,360 kg)	2 Grade	3 Grade
≥100,000 lb (45,360 kg)	2 Grade	3 Grade

****

Typically, when the PG spread between the high and low temperature is 92 or more, the asphalt binder has been modified. The engineer may use the PG Plus Test found in the Asphalt Institute's State Binder Specification Database for the project location, which requires modification of the table. If the PG spread is less than 92, delete the Asphalt Binder PG Plus Test Requirements table.
The asphalt industry is in a state of change regarding binder designations. Some states are following ASTM D6373, while others are following AASHTO M332. Ensure that the binder supplied meets minimum requirements of ASTM D6373.

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The final recommendation to the P-401 mixture design is regarding Table 1 of the specification. The major changes are based on the use of performance testing during the design phase (Table 16). Recommended changes (Table 17) include:

- Currently, no guidance is provided as to the compacted air void requirements of the APA test specimens. Based on previous conversations with Dr. Navneet Garg from the FAA Technical Center in Atlantic City, NJ, the intent of the specification was to have testing conducted at the design air voids. Therefore, this is included in the notes area with a tolerance of ±0.5% air voids.

- The test temperature of the APA testing is recommended to be based on the high-temperature conditions of the area of interest. Currently, the specification only requires a test temperature of 64 ºC. Although this temperature is sufficient for most of the United States, there are areas where the temperature may be too high or too low. Therefore, it is recommended that the test temperature follow the same methodology as selecting an appropriate asphalt binder grade based on the local state agency recommendations.

- It is recommended that the Hamburg Wheel Tracking test be removed until more data can be generated to ensure a strong correlation between the Hamburg Wheel Tracking criteria and the APA criteria, respectively. Also, with the potential inclusion of using regional environmental conditions when selecting a test temperature, more research is necessary to correlate the rutting of the Hamburg Wheel Tracking test and the rutting of the APA test. Work under the National Asphalt Paving Association (NAPA) – AAPTP Project, *Balanced*

Mix Design: Rutting Performance Tests, will provide important information regarding this relationship. Work on this progress is scheduled to begin by the later part of 2022.

- Lastly, it is recommended that the APA criterion be modified. It is recommended that for GAW >100,000 lb, APA rutting be ≤8.0 mm when using the FAA test method or ≤4.0 mm when using the AASHTO T340 test procedure. For GAW <100,000 lb but ≥60,000 lb, the criteria are recommended to stay as they currently are, as stated in the specifications.

    - The main reason for the change is the necessity to have greater rutting resistance as the GAW and tire pressures are significantly increasing. Examples have been shown of the impact of GAW and tire pressure, but Table 16 and Figure 19 are added for further evidence. These references include APA (AASHTO T340) test data for work conducted by Rutgers University for asphalt suppliers over the past 2 years. The airport loading information was taken from www.airportiq5010.com. The results indicate that the current APA rutting resistance is quite easily obtained for all the asphalt mixtures tested, regardless of GAW or Total Aircraft Operations. Two mixes, ROC P-403 and SYR P-401, were possibly "borderline" asphalt mixtures. Mix design information was not provided at this time. With the APA criteria easily met (less than 5.0 mm for AASHTO T340 with 100 psi hose pressure), this would be an opportunity to strengthen the criteria, especially for the >100,000 lb GAW airports. Table 17 shows the existing table with recommended deletions shown as "strikethrough" with the recommended table with additions and modifications shown as Table 18 highlighted.

Table 16. The APA (AASHTO T340) for Various P-401 and P-403 Mixes Tested in 2020 and 2021

Airport (Mix Type)	AASHTO T340 Rutting (mm)	Total Operations	GAW (lb)		
			Single	Dual	Dual Tandem
IPT (P-401)	2.81	16,000	65,000	100,000	190,000
HPN (P-403)	1.57	100,000	70,000	120,000	120,000
HPN (P-403)	1.35				
HPN (P-401)	2.00				
HPN (P-401)	1.80				
ABE (P-401)	1.20	87,000	75,000	209,000	370,000
ISP (P-401)	1.50	140,000	100,000	210,000	300,000
SYR (P-401)	4.93	72,000	115,000	156,000	257,000
SYR (P-403)	3.32				
ROC (3/4″ P-401)	2.36	61,500	126,000	160,000	265,000
ROC (1″ P-403)	4.63				
PHL (P-401)	1.55	390,000	100,000	210,000	350,000
PHL(P-401)	2.90				
PHL (P-401)	2.09				
EWR (P-401, 1/2″)	2.31	449,000	N.A.	210,000	520,000

Airport (Mix Type)	AASHTO T340 Rutting (mm)	Total Operations	GAW (lb)		
			Single	Dual	Dual Tandem
EWR (P-401, 1/2″)	2.70				
EWR (P-401, 1/2″)	2.98				

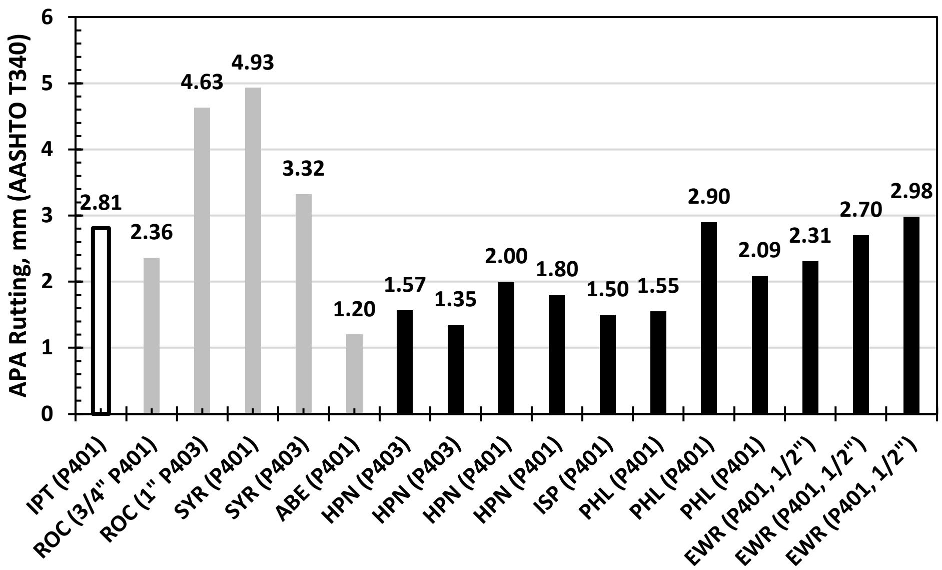

Figure 19. The APA for Various P-401 and P-403 Mixes Tested in 2020 and 2021 (Black: ≥100,000 Total Aircraft Operations; Gray: <100,000 to ≥50,000 Total Aircraft Operations; White: <50,000 Total Aircraft Operations)

Table 17. Current Table 1 for P-401 Asphalt Design Criteria

Test Property	Value	Test Method
Number of blows or gyrations	**[75]**	
Air voids (%)	3.5	ASTM D3203
Percent VMA, minimum	See Table 2	ASTM D6995
Tensile Strength Ratio (TSR)[1]	not less than **[** 80 **]** at a saturation of 70–80%	ASTM D4867
[Asphalt Pavement Analyzer (APA)[2,3]]	[Less than 10 mm @ 4000 passes]	[AASHTO T340 at 250 psi hose pressure at 64°C test temperature]

1 Test specimens for TSR shall be compacted at 7 ± 1.0 % air voids. In areas subject to freeze-thaw, use freeze-thaw conditioning in lieu of moisture conditioning per ASTM D4867.

2 AASHTO T340 at 100 psi hose pressure at 64°C test temperature may be used in the interim. If this method is used the required Value shall be less than 5 mm @ 8000 passes

3 Where APA not available, use Hamburg Wheel test (AASHTO T-324) 10mm @ 20,000 passes at 50°C.

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75 blows or gyrations shall be specified for airports serving aircraft greater than 60,000 lb, and 50 blows or gyrations may be specified for airports serving aircraft 60,000 lb or less.

The APA procedure has shown that mixes meeting the requirements above perform well under aircraft loading. If APA is not available in an area, compacted mix design samples may be sent to a laboratory that has an APA or the Hamburg wheel test (AASHTO T 324) 10mm @ 20,000 passes at 50°C may be used with FAA approval of ADO. The use of APA or Hamburg is not required for pavements serving aircraft less than 60,000 lb.

Specify a TSR of not less than 85 in areas with aggregate that have a history of stripping.

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Table 18. Proposed Revised Table 1 for P-401 Asphalt Design Criteria

Test Property	Value	Test Method
Number of blows or gyrations	**[75]**	
Air voids (%)	3.5	ASTM D3203
Percent VMA, minimum	See Table 2	ASTM D6995
Tensile Strength Ratio (TSR)[a]	Not less than **[** 80 **]** at a saturation of 70%–80%	ASTM D4867
APA[b,c,d]	For pavements designed for aircraft gross weights of ≥100,000 lb (45,360 kg) or more; [Less than 8.0 mm @ 4,000 passes] For pavements designed for aircraft gross weights of <100,000 lb (45,360 kg) to ≥60,000 lb (27,200 kg): [Less than 10.0 mm @ 4,000 passes]	[AASHTO T340 at 250 psi hose pressure, 250-lb wheel load at test temperature[d]

[a] Test specimens for TSR shall be compacted at 7 ±1.0 % air voids. In areas subject to freeze-thaw, use freeze-thaw conditioning in lieu of moisture conditioning per ASTM D4867.

[b] AASHTO T340 at 100 psi hose pressure and 100-lb wheel load may be used. If these test parameters are used, the rutting requirement shall be:

a. For aircraft gross weights ≥100,000 lb (45,360 kg), less than 4.0 mm @ 8,000 passes
b. For aircraft gross weights <100,000 lb (45,360 kg) to ≥60,000 lb (27,200 kg), less than 5.0 mm @ 8,000 passes

[c] Test specimens for AASHTO T340 shall be compacted to the design air voids ±0.5%

[d] Test temperature for AASHTO T340 shall be the asphalt binder PG grade consistent with the recommendations of the applicable state DOT requirements for pavement environmental conditions.

****

75 blows or gyrations shall be specified for airports serving aircraft greater than 60,000 lb, and 50 blows or gyrations may be specified for airports serving aircraft 60,000 lb or less.

The APA procedure has shown that mixes meeting the requirements above perform well under aircraft loading. The use of APA is not required for pavements serving aircraft less than 60,000 lb.

Specify a TSR of not less than 85 in areas with aggregate that have a history of stripping.

■■

5.1.1 Addition to Quality Control Testing for P-401

Under section 401-5.3 Quality Control (QC) testing (FAA, 2018), the P-401 specification outlines the sampling and testing required as part of the QC testing at the asphalt plant. Asphalt content, gradation, moisture contents, and temperatures of the asphalt mixture are all part of the requirements. However, the current specifications do not include the sampling and verification testing of the asphalt binder during production. As shown throughout the study, the asphalt binder grade is critical to the performance of the asphalt mixture. When polymer-modified asphalt binder grades, such as PG82-22, PG76-28, and PG88-22FR, are used, the cost of the asphalt mixture can be significant. Therefore, it is recommended that sampling of the asphalt binder is conducted during production.

401-5.3 Quality Control (QC) Testing

i. **Asphalt Binder.** The plant QC technician shall sample the asphalt binder in the presence of the RPR from the in-line sampling valve. The RPR can have the binder sampled at any time during production of the lot. Prior to sampling, the plant QC shall flush over a gallon of asphalt binder out of the in-line valve before taking the QC sample. Take 1 quart sample per Lot for unmodified asphalt binder and 2 quart can samples per Lot for polymer modified asphalt binder. The sample can shall be labeled with the date and time of sampling, project identification, asphalt mixture type being produced, and specified asphalt binder grade at the time of sampling and mixture production.

5.1.2 Addition to Material Acceptance for P-401

401-6.1 Acceptance Criteria

e. Asphalt Binder. Sampled asphalt binder shall be tested for the high temperature performance grade in accordance with ASTM D6373. For polymer modified asphalt binders, the sampled binder shall also be tested for elastic recovery in accordance with ASTM D6084, Procedure B. Failure to meet the project's required performance grade shall result in the removal of that Lot at the Contractor's expense.

5.2 RECOMMENDED CHANGES TO P-403

The P-403 specification (FAA, 2018) reflects similar changes to the P-401 specification. Some of the aggregate requirements have been relaxed because the P-403 is located deeper in the asphalt pavement and is placed at lower GAW airfields (Tables 19 to 24).

Table 19. Current P-403 Coarse Aggregate Requirements

Material Test	Requirement	Standard
Resistance to Degradation	Loss: 40% maximum for surface, asphalt binder, and leveling course Loss: 50% maximum for base course	ASTM C131
Soundness of Aggregates by Use of Sodium Sulfate **or** Magnesium Sulfate	Loss after 5 cycles: 12% maximum using sodium sulfate - or - 18% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0 % maximum	ASTM C142
~~Percentage of Fractured Particles~~	~~For pavements designed for aircraft gross weights of 60,000 pounds (27200 kg) or more:~~ ~~Minimum 75% by weight of particles with at least two fractured faces and 85% with at least one fractured face~~[1]	~~ASTM D5821~~
	~~For pavements designed for aircraft gross weights less than 60,000 pounds (27200 kg):~~ ~~Minimum 50% by weight of particles with at least two fractured faces and 65% with at least one fractured face~~[1]	
Flat, Elongated, or Flat and Elongated Particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles with a value of 5:1[a]	ASTM D4791
Bulk density of slag[b]	Weigh not less than 70 lb per cubic foot (1.12 Mg/cubic meter)	ASTM C29.

[a] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than 5.

[b] Only required if slag is specified.

Table 20. Proposed Revised P-403 Coarse Aggregate Requirements

Material Test	Requirement	Standard
Resistance to degradation	Loss: 40% maximum	ASTM C131
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 12% maximum using sodium sulfate - or - 18% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0 % maximum	ASTM C142
Coarse aggregate angularity	For pavements designed for aircraft gross weights of 100,000 lb (45,360 kg) or more; Uncompacted Voids[a] >45% Minimum 90% by weight of particles with at least two fractured faces and 95% with at least one fractured face[2]	AASHTO T326 ASTM D5821
	For pavements designed for aircraft gross weights of <100,000 lb (45,360 kg) to ≥60,000 lb (27,200 kg): Minimum 75% by weight of particles with at least two fractured faces and 85% with at least one fractured face[b]	
	For pavements designed for aircraft gross weights of less than 60,000 lb (27,200 kg): Minimum 50% by weight of particles with at least two fractured faces and 65% with at least one fractured face[b]	
Flat, elongated, or flat and elongated particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles at 5:1[c]	ASTM D4791
Bulk density of slag[d]	Weigh not less than 70 lb per cubic foot (1.12 Mg/cubic meter)	ASTM C29

[a] Uncompacted voids as determined using AASHTO T326.

[b] The area of each face shall be equal to at least 75% of the smallest mid-sectional area of the piece. When two fractured faces are contiguous, the angle between the planes of fractures shall be at least 30° to count as two fractured faces.

[c] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than 5.

[d] Only required if slag is specified.

Table 21. Current P-403 Fine Aggregate Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity index	4 maximum	ASTM D4318
Soundness of aggregates by use of sodium sulfate or magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 15% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0 % maximum	ASTM C142
Sand equivalent	[45 minimum]	ASTM D2419
~~Natural Sand~~	~~[0 to 15%] maximum by weight of total aggregate~~	~~ASTM D1073~~

****

The addition of natural sand to a mix containing all crushed coarse and fine aggregates will normally increase its workability and compactability. The addition of natural sand tends to decrease the stability of the mixture. Therefore, it is recommended not to use natural sand. However, if natural sand is used, use the minimum amount necessary to achieve a workable mixture.

Table 22. Proposed Revised P-403 Fine Aggregate Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity index	4 maximum	ASTM D4318
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 15% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	1.0% maximum	ASTM C142
Sand equivalent	**[** 45 minimum **]**	ASTM D2419
Uncompacted voids	For pavements designed for aircraft gross weights ≥100,000 lb (45,360 kg): Uncompacted Voids >45% For pavements designed for aircraft gross weights <100,000 lb (45,360 kg): Uncompacted voids not required	ASTM C1252, Method A
[Natural sand	For pavements designed for aircraft gross weights ≥100,000 lb (45,360 kg): **[** 0% to 10% **]** maximum by weight of total aggregate For pavements designed for aircraft gross weights <100,000 lb (45,360 kg): **[** 0% to 15% **]** maximum by weight of total aggregate	ASTM D1073 **]**

****

The addition of natural sand to a mix containing all crushed coarse and fine aggregates will normally increase its workability and compactability. The addition of natural sand tends to decrease the stability of the mixture. Therefore, it is recommended not to use natural sand. However, if natural sand is used, use the minimum amount necessary to achieve a workable mixture.

▪▪

Table 23. Current Asphalt Binder Requirements for P-403

Aircraft Gross Weight	High-Temperature Adjustment to Asphalt Binder Grade	
	All Pavement Types	Pavement area with slow or stationary aircraft
~~≤12,500 lbs (5670 kg)~~	~~--~~	~~1 Grade~~
~~<100,000 lbs (45360 kg)~~	~~1 Grade~~	~~2 Grade~~
~~≥100,000 lbs (45360 kg)~~	~~2 Grade~~	~~3 Grade~~

****

Typically, when the PG spread between the high and low temperature is 92 or more, the asphalt binder has been modified. The engineer may use the PG Plus Test found in the Asphalt Institute's State Binder Specification Database for the project location, which requires modification of the table. If the PG spread is less than 92, delete the Asphalt Binder PG Plus Test Requirements table.
The asphalt industry is in a state of change regarding binder designations. Some states are following ASTM D6373, while others are following AASHTO M332. Ensure that the binder supplied meets minimum requirements of ASTM D6373.

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Table 24. Proposed Revised Asphalt Binder Requirements for P-403

Aircraft Gross Weight	High-Temperature Adjustment to Asphalt Binder Grade	
	All Pavement Types	Pavement area with slow or stationary aircraft
≤30,000 lb (13,608 kg)	--	1 Grade
≥30,000 lb (13,608 kg) < 60,000 lb (27,200 kg)	1 Grade	2 Grade
≥60,000 lb (27,200 kg) <100,000 lb (45,360 kg)	1 Grade	2 Grade
≥100,000 lb (45,360 kg)	2 Grade	3 Grade

****

Typically, when the PG spread between the high and low temperature is 92 or more, the asphalt binder has been modified. The engineer may use the PG Plus Test found in the Asphalt Institute's State Binder Specification Database for the project location, which requires modification of the table. If the PG spread is less than 92, delete the Asphalt Binder PG Plus Test Requirements table.
The asphalt industry is in a state of change regarding binder designations. Some states are following ASTM D6373, while others are following AASHTO M332. Ensure that the binder supplied meets minimum requirements of ASTM D6373.

****

5.2.1 Addition to Quality Control Testing for P-403

Under section 403-5.3 Quality Control (QC) testing, the P-403 specification outlines the sampling and testing required as part of the QC testing at the asphalt plant. Asphalt content, gradation, moisture contents and temperatures of the asphalt mixture are all part of the requirements. However, the current specifications do not include the sampling of the asphalt binder during production. As shown throughout the study, the asphalt binder grade is critical to the performance of the asphalt mixture. When polymer-modified asphalt binder grades, such as PG82-22, PG76-28, and PG88-22FR, are used, the cost of the asphalt mixture can be significant. Therefore, it is recommended that sampling of the asphalt binder is conducted during production.

403-5.3 Quality Control (QC) Testing

i. Asphalt Binder. The plant QC technician shall sample the asphalt binder in the presence of the RPR from the in-line sampling valve. The RPR can have the binder sampled at any time during production of the Lot. Prior to sampling, the plant QC shall flush over a gallon of asphalt binder out of the in-line valve before taking the QC sample. Take 1 quart sample per Lot for unmodified asphalt binder and 2 quart can samples per Lot for polymer modified asphalt binder. The sample can shall be labeled with the date and time of sampling, project identification, asphalt mixture type being produced, and specified asphalt binder grade at the time of sampling and mixture production.

5.2.2 Addition to Material Acceptance

403-6.1 Acceptance Criteria

e. Asphalt Binder. Sampled asphalt binder shall be tested for the high temperature performance grade in accordance with ASTM D6373. For polymer modified asphalt binders, the sampled binder shall also be tested for elastic recovery in accordance with ASTM D6084, Procedure B. Failure to meet the project's required performance grade shall result in the removal of that Lot at the Contractor's expense.

5.3 RECOMMENDED CHANGES TO P-404

The FAA P-404 asphalt mixture is a specially designed asphalt mixture to help mitigate issues pertaining to fuel spills on asphalt airfield pavements. However, the P-404 asphalt mixture is extremely rut-resistant because of the asphalt binder stiffness and highly angular aggregate requirements, as well as demonstrating exceptional fatigue/durability performance due to the lower design air voids, which results in higher effective asphalt contents (Varamini et al., 2018). The stability of the P-404 is not jeopardized by the high VMA values due to the stiffness of the asphalt binder at high temperatures. However, there are a few recommended changes to the P-404 specification to maintain consistency with the P-401/P-403 specifications.

Tables 25 to 30 illustrate the proposed revisions to the P-404 specification.

Table 25. Current P-404 Table for Coarse Aggregate Requirements

Material Test	Requirement	Standard
Resistance to degradation	Loss: 40% maximum	ASTM C131
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 13% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	0.3% maximum	ASTM C142
~~Percentage of Fractured Particles~~	~~Minimum 70% by weight of particles with at least two fractured faces and 85% with at least one fractured face[1]~~	~~ASTM D5821~~
Flat, elongated, or flat and elongated Particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles at 5:1[a]	ASTM D4791
Bulk density of slag[b]	Weigh not less than 70 lb per cubic foot (1.12 Mg/cubic meter)	ASTM C29

[a] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than 5.

[b] Only required if slag is specified.

Table 26. Proposed Revised Table for P-404 Coarse Aggregate Requirements

Material Test	Requirement	Standard
Resistance to degradation	Loss: 40% maximum	ASTM C131
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 13% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	0.3% maximum	ASTM C142
Coarse aggregate angularity	For pavements designed for aircraft gross weights of 100,000 lb (45,360 kg) or more; Uncompacted voids[a] >45% Minimum 100% by weight of particles with at least two fractured faces and 100% with at least one fractured face[2]	AASHTO T326 ASTM D5821
	For pavements designed for aircraft gross weights of <100,000 lb (45,360 kg) to ≥60,000 lb (27,200 kg): Uncompacted Voids[a] >45% Minimum 90% by weight of particles with at least two fractured faces and 95% with at least one fractured face[2]	
	For pavements designed for aircraft gross weights of < 60,000 lb (27,200 kg) to ≥30,000 lb (13,608 kg): Minimum 75% by weight of particles with at least two fractured faces and 85% with at least one fractured face[b]	
	For pavements designed for aircraft gross weights less than 30,000 lb (13,608 kg): Minimum 50% by weight of particles with at least two fractured faces and 65% with at least one fractured face	
Flat, elongated, or flat and elongated particles	8% maximum, by weight, of flat, elongated, or flat and elongated particles at 5:1[c]	ASTM D4791
Bulk density of slag[d]	Weigh not less than 70 lb per cubic foot (1.12 Mg/cubic meter)	ASTM C29.

[a] Uncompacted voids as determined using AASHTO T326.

[b] The area of each face shall be equal to at least 75% of the smallest mid-sectional area of the piece. When two fractured faces are contiguous, the angle between the planes of fractures shall be at least 30° to count as two fractured faces.

[c] A flat particle is one having a ratio of width to thickness greater than 5; an elongated particle is one having a ratio of length to width greater than 5.

[d] Only required if slag is specified.

Table 27. Current P-404 Table for Fine Aggregate Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity index	4 maximum	ASTM D4318
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 13% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	0.3% maximum	ASTM C142
~~Sand equivalent~~	~~35 minimum~~	~~ASTM D2419~~

~~[1]Natural sand is not allowed.~~

Table 28. Proposed Revised P-404 Table for Fine Aggregate Requirements

Material Test	Requirement	Standard
Liquid limit	25 maximum	ASTM D4318
Plasticity index	4 maximum	ASTM D4318
Soundness of aggregates by use of sodium sulfate **or** magnesium sulfate	Loss after 5 cycles: 10% maximum using sodium sulfate - or - 13% maximum using magnesium sulfate	ASTM C88
Clay lumps and friable particles	0.3% maximum	ASTM C142
Sand equivalent	[45 minimum]	ASTM D2419
Uncompacted voids	Uncompacted voids >45%	ASTM C1252, Method A
Natural sand	0% maximum by weight of total aggregate	ASTM D1073

Table 29. Current P-404 Marshall Design Criteria Table

Test Properties	All Aircraft	Test Method
Number of blows	50	ASTM D6926
Stability, minimum	2,150 lb	ASTM D6927
Air Voids[a]	2.5 ±0.2%	ASTM D3203
~~Minimum voids in mineral aggregate (VMA)~~	~~14%~~	~~ASTM D6995~~
Maximum weight loss by fuel immersion	1.5%	In accordance with procedures outlined in paragraph 404-3.4
Tensile Strength Ratio (TSR)[b]	not less than 80 at a saturation of 70–80%	ASTM D4867
~~Asphalt Pavement Analyzer (APA)[3]~~	~~Less than 10 mm @ 4000 passes~~	~~AASHTO T340 at 250 psi hose pressure at 64°C test temperature~~

[a] If the water absorption of the combined aggregates in the mix exceeds 1.7% (ASTM C127 and ASTM C128), then the mix must be short-term aged in accordance with AASHTO PP-2 – Section 7.2. The short-term aged material will then be used for the Marshall specimens and the maximum specific gravity test (ASTM D2041).

[b] Test specimens for TSR shall be compacted at 7±1.0% air voids. Use freeze-thaw conditioning in lieu of moisture conditioning per ASTM D4867.

~~1 AASHTO T340 at 100 psi hose pressure at 64°C test temperature may be used in the interim. If this method is used the required value shall be less than 5 mm @ 8000 passes.~~

****

The APA procedure has shown that mixes meeting the above requirements perform well under aircraft loading.
Specify a TSR of not less than 85 in areas with aggregate that have a history of stripping.

****

Table 30. Proposed Revised P-404 Marshall Design Table

Test Properties	All Aircraft	Test Method
Number of blows	50	ASTM D6926
Stability, minimum	2,150 lb	ASTM D6927
Air voids[a]	2.5 ±0.2 %	ASTM D3203
Minimum VMA	See Table 2	ASTM D6995
Maximum weight loss by fuel immersion	1.5%	In accordance with procedures outlined in paragraph 404-3.4
Tensile Strength Ratio (TSR)[b]	not less than 80 at a saturation of 70–80%	ASTM D4867
Asphalt Pavement Analyzer (APA)[c.d.e]	For pavements designed for aircraft gross weights of 100,000 lb (45,360 kg) or more; [Less than 8.0 mm @ 4,000 passes] For pavements designed for aircraft gross weights of less than 100,000 lb (45,360 kg); [Less than 10.0 mm @ 4000 passes]	[AASHTO T340 at 250 psi hose pressure, 250-lb wheel load at test temperature[d]

[a] If the water absorption of the combined aggregates in the mix exceeds 1.7% (ASTM C127 and ASTM C128), then the mix must be short-term aged in accordance with AASHTO PP-2 – Section 7.2. The short-term aged material will then be used for the Marshall specimens and the maximum specific gravity test (ASTM D2041).

[b] Test specimens for TSR shall be compacted at 7±1.0% air voids. In areas subject to freeze-thaw, use freeze-thaw conditioning in lieu of moisture conditioning per ASTM D4867.

[c] AASHTO T340 at 100-psi hose pressure and 100-lb wheel load may be used. If these test parameters are used, the rutting requirement shall be;

a. For aircraft gross weights ≥100,000 lbs (45,360 kg), less than 4.0 mm @ 8,000 passes
b. For aircraft gross weights <100,000 lbs (45,360 kg), less than 5.0 mm @ 8,000 passes

[d] Test specimens for AASHTO T340 shall be compacted to the design air voids ±0.5%

[e] Test temperature for AASHTO T340 shall be the asphalt binder PG grade consistent with the recommendations of the applicable state DOT requirements for pavement environmental conditions.

****

The APA procedure has shown that mixes that meet the requirements above perform well under aircraft loading. The use of APA is not required for pavements serving aircraft less than 60,000 lb.
Specify a TSR of not less than 85 in areas with aggregate that have a history of stripping.

5.3.1 Asphalt Binder Requirements for P-404

The asphalt binder requirements for the P-404 asphalt mixture are called out in Section 404-2.3 (FAA, 2018). However, it does not provide enough guidance as when to use the PG82-28FR or the PG88-22FR. Therefore, recommendations have been proposed to help clarify which asphalt binder grade to use.

5.3.1.1 Existing P-404 Asphalt Binder Language

404-2.3 Asphalt binder. Asphalt binder shall conform to the following requirements of ASTM D6373 for performance grade (PG) 82-28 or 88-22 with the changes annotated below:

- The original asphalt binder shall be tested according to ASTM D6084 Elastic Recovery at 25 °C and shall be a minimum of 85%, using procedure A on the RTFO aged binder.
- The original asphalt binder shall be tested according to ASTM D7173 and meet the maximum binder temperature difference of 4 °C when using the ASTM D36 Ring-and-Ball apparatus.
- The asphalt specimens prepared with the asphalt binder must also meet the fuel resistance requirements in Table 1 when tested in accordance with paragraph 404-3.4. After passing the requirements of Table 1, the grade of the asphalt binder shall be identified as PG 82-28FR or 88-22FR.

The Contractor shall provide a copy of the manufacturer's Certificate of Analysis (COA) for the asphalt binder. The test reports shall be provided to and approved by the RPR before the asphalt binder is applied. The furnishing of the vendor's certified test report for the asphalt material shall not be interpreted as a basis for final acceptance. The manufacturer's COA may be subject to verification by testing the material delivered for use on the project.

5.3.1.2 Proposed P-404 Asphalt Binder Language

404-2.3 Asphalt binder. Asphalt binder shall conform to the following requirements of ASTM D6373 for PG 82-28 or 88-22 with the changes annotated below:

- It is recommended to use the PG82-28FR when the low temperature binder grade required, as determined by LTPPBind 3.1 at a 98% reliability, is determined to be a -28 ºC or colder. The PG88-22FR should be used when the low temperature binder grade is determined to be a -22 ºC or warmer. Figure 20 shows a map of the United States with the recommended low-temperature PG grade and provides an idea of where the deviation is across the United States. Locations immediately near the border area should be verified with the LTPPBind software. https://infopave.fhwa.dot.gov/Tools/LTPPBindOnline
- The original asphalt binder shall be tested according to ASTM D6084 Elastic Recovery at 25 °C and shall be a minimum of 85%, using procedure A on the RTFO aged binder.
- The original asphalt binder shall be tested according to ASTM D7173 and meet the maximum binder temperature difference of 4 °C when using the ASTM D36 Ring-and-Ball apparatus.
- The asphalt specimens prepared with the asphalt binder must also meet the fuel-resistance requirements in Table 1 when tested in accordance with paragraph 404-3.4 (FAA, 2018). After passing the requirements of Table 1, the grade of the asphalt binder shall be identified as PG 82-28FR or 88-22FR.

The Contractor shall provide a copy of the manufacturer's COA for the asphalt binder. The test reports shall be provided to and approved by the RPR before the asphalt binder is applied. The furnishing of the vendor's certified test report for the asphalt material shall not be interpreted as a basis for final acceptance. The manufacturer's COA may be subject to verification by testing the material delivered for use on the project.

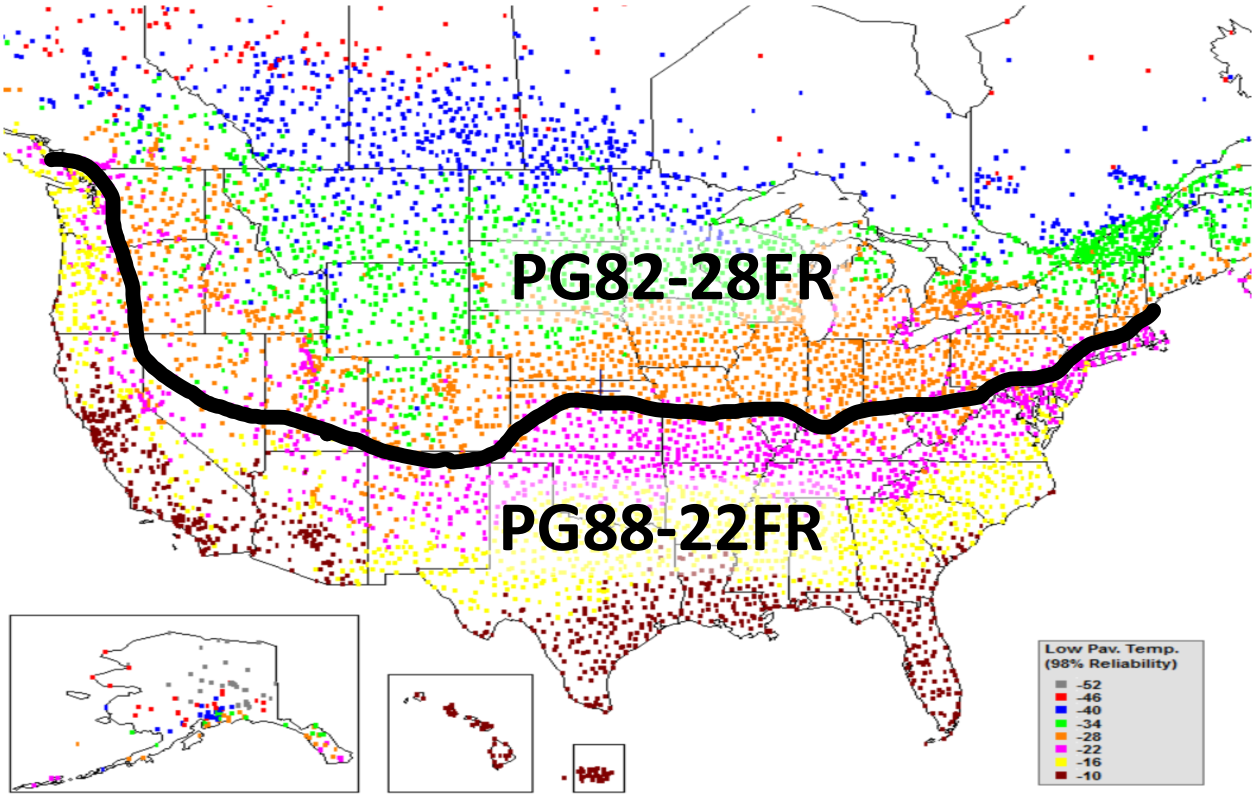

Figure 20. Recommended Fuel Resistant Asphalt Binder Grade for P-404 Asphalt Mixtures

<u>5.3.2 Addition to Quality Control Testing for P-404</u>

Under section 404-5.3 Quality Control (QC) testing, the P-404 specification outlines the sampling and testing required as part of the QC testing at the asphalt plant. Asphalt content, gradation, moisture contents, and temperatures of the asphalt mixture are all part of the requirements. However, the current specifications do not include the sampling of the asphalt binder during production. As shown throughout the study, the asphalt binder grade is critical to the performance of the asphalt mixture. And when polymer-modified asphalt binder grades, such as PG82-22, PG76-28, and PG88-22FR, are used, the cost of the asphalt mixture can be significant. Therefore, it is recommended that sampling of the asphalt binder is conducted during production.

404-5.3 Quality Control (QC) Testing

i. Asphalt Binder. The plant QC technician shall sample the asphalt binder in the presence of the RPR from the in-line sampling valve. The RPR can have the binder sampled at any time during production of the Lot. Prior to sampling, the plant QC shall flush over a gallon of asphalt binder out of the in-line valve before taking the QC sample. Take 2 quart can samples per Lot for fuel resistant asphalt binder. The sample can shall be labeled with the date and time of sampling, project identification, asphalt mixture type being produced, and specified asphalt binder grade at the time of sampling and mixture production.

5.3.3 Addition to Material Acceptance

404-6.1 Acceptance Criteria

e. Asphalt Binder. Sampled asphalt binder shall be tested for the performance grade in accordance with ASTM D6373. The sampled asphalt binder shall also be tested for elastic recovery in accordance with ASTM D6084, Procedure B. Failure to meet the project's required performance grade shall result in the removal of that Lot at the Contractor's expense.

6. CONCLUSIONS

Section 5 shows the recommended revisions to the P-401/P-403 and P-404 specifications in an attempt to improve the stability of the asphalt mixtures. The revisions were based on an extensive literature review, parametric study, and experience regarding the performance of asphalt mixtures and asphalt airfield pavements. In summary, the most significant recommended changes were:

- Improving both fine and coarse aggregate angularity through the combination of the uncompacted voids test to index the level of angularity and texture
- Limiting rounded aggregates by reducing the amount of uncrushed coarse aggregate and natural sands at the higher gross aircraft weights (GAWs
- Slightly modifying the asphalt binder high-temperature performance grade "bump" to reflect the changes in GAW
- Strengthening the APA criteria to be stricter at GAW >100,000 lb

In addition to the changes to the materials and mixture design components of the P-401/P-403 and P-404 specifications, the sampling and testing of the asphalt binder were added to the QC and quality assurance portions of the specification. As shown in Section 3, the asphalt binder grade plays a significant role in the stability/rutting resistance of the asphalt mixture. Therefore, at a minimum, the asphalt binder should be sampled during production and verified that the asphalt liquid used during mixture production reflects the needs of the pavement.

Other areas showed an impact on the rutting performance of asphalt mixtures (i.e., air voids, VMA, fines content), but these were found to be sufficient at their current requirements. Restricting VMA could result in under-asphalted mixes, whereas too much fines (dust) could lead to dry, brittle asphalt mixtures. The recommended changes provided in the report were made not only to improve the rutting resistance, but also to avoid detrimentally impacting the fatigue/durability performance of the asphalt mixture.

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