Burns Cooley Dennis, Inc.

Geotechnical, Pavements and Materials Consultants

IMPLEMENTATION OF SUPERPAVE MIX DESIGN FOR AIRFIELD PAVEMENTS

Volume II : Guidelines on Mix Design and Mix Selection

for

AAPTP PROJECT 04-03

Submitted to

Airfield Asphalt Pavement Technology Program

By

Burns Cooley Dennis, Inc.
551 Sunnybrook Road
Ridgeland, Mississippi 39157

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2. H. D. Campbell
3. Ray Rollings
4. Jay Gabrielson
5. Casimir Bognacki

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Draft Final Report

for

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By

L. Allen Cooley, Jr., R. C. Ahlrich and Robert S. James
Burns Cooley Dennis, Inc.
551 Sunnybrook Road
Ridgeland, Mississippi 39157

Brian D. Prowell
Advanced Materials Services, LLC
1975 Mall Boulevard, Suite 202
Auburn, Alabama 36830

E. R. Brown
Engineer Research and Development Center
Corps of Engineers
3909 Halls Ferry Road
Vicksburg, Mississippi 39180

Andrea Kvasnak
National Center for Asphalt Technology
277 Technology Parkway
Auburn, Alabama 36830

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INTRODUCTION

Historically, hot mix asphalt (HMA) used for airfield pavements has been designed using the Marshall mix design method. This method of designing HMA was first developed by Mr. Bruce Marshall of the Mississippi Highway Department in the 1930's. During the 1940's, the Waterways Experiment Station (WES) conducted a research study to "… select suitable test properties, develop laboratory techniques for their measurement, and by their use establish limiting criteria for satisfactory asphalt mixtures" (*1*). In other words, the researchers at WES wanted to evaluate and adopt a method for proportioning and specifying HMA mixes to be used on airfield pavements. Based upon this research, the Marshall method of mix design was selected.

Throughout the 1940's and 1950's, research was conducted to improve the Marshall mix design method. One of the primary reasons that improvements were needed was aircraft size. During the period of World War II, the size and weight of aircraft increased (*2*). As a result of the increased aircraft sizes, gear tire pressures also increased.

The Marshall mix design method has served the HMA industry since the 1930's. Some evolution has taken place over the years but the method is still similar to the procedures adopted in the 1940's. However, during the 1980's problems arose on highway pavements with an increase in the occurrence of rutting. This increase in rutting was primarily caused by the allowance of increased tire pressure on tractor-trailer trucks. Because of the increase in rutting, the federal government initiated a large research program to improve our nation's highways (*3*). Approximately $50 million of research was conducted on developing tests and criteria for improving how HMA is designed and specified. The SUperior PERforming PAVEment (Superpave) mix design system was a product of this research. The Superpave mix design system and Superpave asphalt binder tests are currently the most widely used methods in the US for designing HMA and specifying asphalt binders. The vast majority of Departments of Transportation (DOTs) are using the Superpave system. As such, the majority of HMA placed in the US is designed and specified using the Superpave protocols.

There are three primary reasons that a transition is needed from the Marshall mix design method to the Superpave mix design system for designing HMA for airfields. First, the Superpave gyratory compactor (SGC) orients the aggregates in a laboratory compacted sample in a more similar way to how aggregates are oriented in the field than does the Marshall hammer.

Secondly, there is slightly higher variability in specimen density when compacting HMA with the Marshall hammer. Proficiency testing data over the last three years from the AASHTO Materials and Reference Laboratory (AMRL) shows that the SGC provided lower variability on measured compacted bulk specific gravity values (pooled standard deviation of 0.0129) than did the Marshall hammer (pooled standard deviator of 0.0137) (*4*). This lower variability should result in more consistent mix designs and allow quality control data to better compare to quality assurance data.

Finally, the vast majority of state DOTs utilize the Superpave mix design system. From a tonnage standpoint, this means most of the HMA currently being produced in the US has been designed using the Superpave mix design system. As such, it is becoming more difficult to find contractors and commercial laboratories having the proper experiences and accreditations with the Marshall mix design method. Since the Federal Aviation Administration requires the laboratories conducting mix designs and quality assurance to be accredited, this problem will likely increase in the future.

Because of the issues highlighted above, there is a need to adapt the Superpave mix design system for airfields. This objective was used to conduct the Airfield Asphalt Pavement Technology Program Project 04-03, Implementation of Superpave Mix Design for Airfield Pavements. This document provides guidance for designing and selecting HMA for airfield pavements layers using the SGC.

REPORT PURPOSE AND ORGANIZATION

The final report for AAPTP 04-03 is divided into three volumes. Volume I of the Final Report provides documentation of all research results. Detailed discussions are provided on the research approach, test results, analyses, conclusions and recommendations for adapting the Superpave gyratory procedures for designing airfield HMA. The second volume of the Final Report provides guidance on the recommended mix design method as well as guidance on the selection of mixes for airfield uses. The final volume presents a revised section of the Item P-401 to be placed in a guide specification for designing HMA mixes using the recommended mix design method.

This volume of the report, Volume II, provides a comprehensive overview of the Superpave mix design method for airfield HMA. Within this document, the term Superpave is used because the Superpave gyratory compactor is used in the design of the HMA mixtures. Also included within this volume is a section on mix selection. This infers that guidance is provided on when to specify different criteria for various airfield pavement sections. Volume II was prepared to assist in the implementation of Superpave mix designs for airfield HMA.

DESIGN OF HMA MIXTURES FOR AIRFIELD PAVEMENTS USING SUPERPAVE

The design of HMA using the Superpave mix design method for airfield pavements is very similar to the design of HMA using the Marshall procedure in that it involves four primary steps. The first step in designing mixes using the Superpave mix design method for airfields is materials selection. Materials needing selection include coarse aggregates, fine aggregates, asphalt binder, anti-stripping additives and/or mineral fillers. The second step in designing mixes is to select the design gradation. The design gradation is the properly proportioned aggregates that meets the gradation requirements and will provide the specified mixture properties. After selecting the design gradation, the third step involves varying the asphalt binder content using the design gradation in order to select the optimum asphalt binder content. Optimum asphalt binder content is based upon specified mixture properties. The final step in designing HMA using the Superpave airfield mix design method is to evaluate the moisture susceptibility of the designed mix.

As the reader goes through this document, there is one major difference between the airfield version of the Superpave mix design method and the Marshall mix design method; the Superpave gyratory compactor is used to compact specimens during design. Also, where in the past there were only two possible design compactive efforts, now there will be three. Selection of the appropriate design compactive effort is based upon the gear tire pressures for the design aircraft(s). However, when FAARFIELD is fully implemented for designing flexible airfield pavements, the aircraft with the highest tire pressure representing at least 3 percent of the annual departures in the traffic mixture should be considered the design aircraft for mix design purposes. There are three design tire pressure categories: light, moderate and high. Table 1 presents these categories along with the range of tire pressures and the design compactive effort (N_{design}). Some material properties change based upon the design tire pressures.

Table 1: Design Compactive Efforts Based Upon Tire Pressures

Tire Pressure Category	Range of Tire Pressures (psi)	N_{design}
Light	Less than 100	50
Moderate	100 to 200	65
High	More than 200	80

The four steps of designing airfield HMA using the procedure described in this document are equally important. The following sections describe each of these steps in detail.

Step 1 – Materials Selection

As stated above, materials needing selection include coarse aggregates, fine aggregates, asphalt binder, mineral filler, and/or anti-stripping additives. Within this mix design method, coarse aggregates are defined as the fraction of aggregates coarser than the No. 4 sieve while fine aggregates are those that pass through the No. 4 sieve. The following describe the criteria for each of these materials.

Coarse Aggregate

There are five primary coarse aggregate characteristics that are important to the performance of HMA: angularity/texture, shape, toughness, abrasion resistance, soundness and cleanliness. Angularity/surface texture is addressed in the mix design system by requiring a minimum percentage of coarse aggregates with one and two or more fractured faces in accordance with ASTM D 5821, Determining the Percentage of Fractured Particles in Coarse Aggregates. When two fractured faces are contiguous, the angle between the two places of fracture must be at least 30 degrees to count as two fractured faces. Also, fractured faces must be obtained by crushing. Coarse aggregate shape is addressed by requiring a minimum percentage of flat and elongated particles at a 5:1 ratio in accordance with ASTM D 4761, Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregates. When conducting this test, a particle is considered flat and elongated if the maximum dimension is more than five times greater than the minimum dimension. Abrasion resistance is addressed by requiring a maximum percent loss when tested with the Los Angeles Abrasion machine in accordance with ASTM C131, Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. The soundness of coarse aggregate is addressed by having a maximum aggregate loss during testing in accordance with ASTM C88, Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate. A caveat for both the abrasion resistance (toughness) and soundness requirements is that aggregates not meeting the stated requirements can be used provided a satisfactory performance history of use in similar conditions of service and exposure exists. The local DOT may be able to provide information on the performance history of a particular coarse aggregate source. Table 2 presents the requirements for coarse aggregates.

Table 2: Coarse Aggregate Requirements

N_{design}	Fractured Faces (1F/2F)[1]	Flat & Elongated Particles[2]	Toughness (% Loss)	Soundness (% Loss)[3]
50	85/80 min.	10 max.	40 max.	10/13 max.
65	95/90 min.	10 max.	40 max.	10/13 max.
80	95/95 min.	10 max.	40 max.	10/13 max.

[1] First number designates the minimum percentage of aggregates with one fractured face, while the second number designates the minimum percentage of aggregates with two or more fractured faces.

[2] Based upon a maximum dimension to minimum dimension of 5:1.

[3] First number designates requirements when utilizing sodium sulfate solution, while second number designates maximum allowable value when utilizing magnesium sulfate solution.

Requirements on the percent fracture faces and percent flat and elongated particles should be applied to the coarse fraction of the design aggregate blend. It is, however, good practice to measure these values on each individual coarse aggregate stockpile, though it is not required. Toughness and soundness requirements are to applied to individual coarse aggregate stockpiles.

Fine Aggregates

Fine aggregates must be clean, sound, durable, and angular shaped particles. The angularity of the fine aggregates is addressed by requiring a minimum percentage of uncompacted voids when tested in accordance with ASTM C1252, Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading). This test is commonly referred to as the Fine Aggregate Angularity test within the highways version of the Superpave mix design procedure. Though not specifically a test method, there are also requirements on the maximum percentage of natural (uncrushed) sands that can be utilized in the aggregate blend. Cleanliness of the fine aggregates is addressed as a minimum sand equivalency value when tested in accordance with ASTM D2419, Sand Equivalent Value of Soils and Fine Aggregate. Requirements, based on the design aircraft tire pressure, for fine aggregates are presented in Table 3.

Table 3: Fine Aggregate Requirements

N_{design}	Uncompacted Voids, %	Percent Natural Sand	Sand Equivalent Value
50	40 min.	20 max.	40 min.
65	45 min.	15 max.	40 min.
80	45 min.	15 max.	50 min.

Requirements for uncompacted voids and sand equivalent value should be applied to the design aggregate blend. Again, it is good practice to determine these values for individual stockpiles.

Asphalt Binder

The asphalt binder should be selected to provide the desired performance taking into account the loading and environmental conditions expected at the project site. Asphalt binders should be specified using the Superpave Performance Grading (PG) system outlined in AASHTO M320, Performance Graded Asphalt Binder. Guide recommendations for selection of the appropriate PG binder are contained in Item-P401.

Airfield Asphalt Pavement Technology Program Project 04-02, PG Binder Grade Selection for Airfield Pavements, was specifically conducted in order to help specifiers select the appropriate asphalt binder for an airfield construction project. These recommendations can be found at www.aaptp.com.

Mineral Fillers

There are occasions where the aggregates used to make an HMA do not have sufficient fines to meet project specified gradations. In these instances, commercial mineral fillers are sometimes required. Mineral fillers used in HMA produced for airfield pavements should meet the requirements of ASTM D242, Mineral Filler for Bituminous Paving Mixtures.

Anti-Stripping Additives

Anti-stripping additives are sometimes needed in order to minimize the potential for moisture damage in the field. Both liquid and solid (lime) anti-stripping additives have been successfully used in airfield HMA. Anti-stripping additives should be approved by the local DOT and added at the manufactures recommended rates.

Step 2 – Selection of the Design Gradation

The next step in the design of airfield HMA is to select the design gradation. This step is accomplished by proportioning the selected aggregates to develop a trial gradation(s) that meets the gradation requirements. Table 4 presents the gradation bands for airfield HMA. As shown in Table 4, there are four gradation bands for airfield HMA. Each gradation is designated by the maximum aggregate size of the gradation.

Depending upon the experience of the mix designer, it may be prudent to develop several trial gradations. If multiple blends are developed, the selected materials should be proportioned to result in gradations that pass near the upper and lower limits of the gradation bands as well as one that passes near the middle of the bands. If a solid anti-stripping additive is utilized, such as hydrated lime, it should be included when proportioning the trial blends.

Table 4: Airfield HMA Gradation Requirements

Sieve Size	**Percentages of Mass Passing Each Sieve (Maximum Aggregate Size)**			
	1 ½” max.	**1” max.**	**¾” max.**	**1/2” max.**
1 ½ in.	100	---	---	---
1 in.	86-98	100	---	---
¾ in.	68-93	76-97	100	---
½ in.	57-81	67-87	77-98	100
3/8 in.	49-69	58-80	68-89	77-98
No. 4	34-54	42-62	50-70	58-78
No. 8	22-42	29-48	35-55	40-60
No. 16	13-33	19-40	23-34	27-47
No. 30	8-24	12-30	16-34	18-36-
No. 50	6-18	8-22	12-28	11-25
No. 100	4-12	6-17	7-20	6-18-
No. 200	3-6	3-6	3-6	3-6

Very, very rarely will a single stockpile of aggregates meet the gradation bands shown in Table 4. Therefore, the vast majority of the time multiple stockpiles of aggregates will be proportioned to meet the gradation requirements. A property of the aggregates that will be needed during the mix design method to calculate volumetric properties is the combined bulk specific gravity of the aggregate blend which can be calculated as follows:

$$G_{sb} = \frac{P_1 + P_2 + ..P_i}{\left[\frac{P_1}{G_1} + \frac{P_2}{G_2} + \dots \frac{P_i}{G_i}\right]} \qquad \text{Equation 1}$$

Where;

G_{sb} = combined bulk specific gravity of the aggregate blend.

P_i = percent by mass of each component aggregate in the blend (note all of the percentage should sum to 100).

G_i = bulk specific gravity of each component aggregate stockpile in the blend.

In a similar manner, the combined apparent specific gravity of the aggregate blend can be calculated using the above equation by simply replacing the G_{sb} with apparent specific gravity (G_{sa}). The combined apparent specific gravity of the blend is not needed to calculate mix volumetric properties, but is needed along with the combined aggregate bulk specific gravity to estimate the absorption characteristics of the aggregate blend. As will be noted in a subsequent discussion, the absorption characteristics of the aggregate blend are needed during mix design.

$$Abs, \% = \left(\frac{1}{G_{sb}} - \frac{1}{G_{sa}} \right) \qquad \text{Equation 2}$$

Where;
Abs. = water absorption of combined aggregate blend
G_{sb} = combined bulk specific gravity of the aggregate blend
G_{sa} = combined apparent specific gravity of the aggregate blend

For each of the trail blends, asphalt binder is added and the mixture compacted using the specified N_{design} value. The asphalt binder content used for preparing these trial mixes should be based upon experience with the selected materials. If the designer has no experience with the selected materials, an asphalt binder content between 5.0 and 5.5 percent is a good starting point for most mixes. Aggregates to be used in each trial mixture should be dried to a constant mass and separated by dry-sieving into individual size fractions. The following size fractions are recommended for each aggregate source:

1 ½ in. to 1 in.
1 in. to ¾ in.
¾ in. to ½ in.
½ in. to 3/8 in.
3/8 in. to No. 4
No. 4 to No. 8
Passing No. 8

Mixing and compaction temperatures for the mixes are determined using temperature-viscosity charts. These charts are generally provided by the asphalt binder supplier. Mixing temperature will be the temperature needed to produce an asphalt binder viscosity of 170 ± 20 cst. Compaction temperature will be the temperature required to produce an asphalt binder viscosity of 280 ± 30 cst. However, while these temperatures work for neat asphalt binders, the selected temperatures may need to be changed for polymer modified asphalt binders. The asphalt binder supplier's guidelines for mixing and compaction temperatures should be used when polymer modified asphalt binders are utilized.

In some instances, recycled asphalt pavement (RAP) is utilized within airfield HMA. Airfield Asphalt Pavement Technology Program Project 05-06, Use of Reclaimed Asphalt Pavement (RAP) in Airfield HMA Pavements, should be consulted on specifics about inclusion of RAP. However, during mix design, the RAP sources should be heated in an oven to 220 – 240°F for two hours prior to combining the RAP with the heated aggregates.

When preparing the mixtures, a mechanical mixing apparatus should be utilized. Aggregates (excluding RAP) and asphalt binder should be heated approximately 20 to 30°F above the established mixing temperature. The heated aggregate batch and RAP, if used, is then placed into the mechanical mixing container. Next the appropriate mass of asphalt binder is added. Mix the materials rapidly until thoroughly coated. After mixing, the mix should be short-term aged in accordance with AASHTO R30, Practice for Mixture Conditioning of Hot Mix Asphalt (HMA). For combined aggregate blends having water absorption values less than 2 percent (from Equation 2), the mixture should be aged for 2 hours in accordance with AASHTO R30. However, if the combined water absorption is greater than 2 percent, the mixture should be aged at the compaction temperature for 4 hours. Mixtures prepared for determining the theoretical maximum specific gravity in accordance with ASTM D2172, Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures, should also be short-term aged as described above.

The trial mixture specimens should be compacted at the established compaction temperature after laboratory short-term aging to the appropriate N_{design} value. After the samples have been compacted, extruded from the mold, and allowed to cool, each is tested to determine bulk specific gravity in accordance with ASTM D2726, Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures. After determining the bulk specific gravity of each sample and the theoretical maximum specific gravity of each trial mix, the properties of interest for each specimen should be calculated. Volumetric properties of interest are the air voids in total mix (VTM), voids in mineral aggregate (VMA), percent theoretical maximum specific gravity at the initial number of gyrations ($\%G_{\text{mm}}@N_{initial}$), voids filled with asphalt (VFA) and volume of effective asphalt (VEA). The VEA is not utilized during mix design but will be utilized during construction. Other properties that need to be determined include: percent effective asphalt content (by mass) and the dust-to-binder ratio (D/B). Table 5 presents the initial and design gyration levels for the different tire pressure categories. Each of these properties are calculated as follows:

$$VTM,\% = 100 \times \left(\frac{G_{mm} - G_{mb}}{G_{mm}} \right) \qquad \text{Equation 3}$$

$$VMA,\% = 100 - \left(\frac{G_{mb} \times P_s}{G_{sb}} \right) \qquad \text{Equation 4}$$

$$VFA,\% = \left(\frac{VMA - VTM}{VMA} \right) \times 100 \qquad \text{Equation 5}$$

$$\%G_{mm} @ N_{initial} = \frac{G_{mb} \ x \ \frac{Ht_{des}}{Ht_{ini}}}{G_{mm}} \times 100 \qquad \text{Equation 6}$$

$$VEA,\% = VMA - VTM \qquad \text{Equation 7}$$

$$P_{be,\%} = P_b - \frac{P_{ba}}{100} \times P_s \qquad \text{Equation 8}$$

$$P_{ba},\% = 100 \times \left(\frac{G_{se} - G_{sb}}{G_{sb} G_{se}} \right) \times G_b$$ Equation 9

$$\frac{D}{B} = \frac{P_{200}}{P_{be}}$$ Equation 10

Where,
G_{mb} = bulk specific gravity of the compacted specimen (ASTM D2726)
G_{mm} = theoretical maximum specific gravity (ASTM D2172)
G_{se} = effective specific gravity of aggregate (calculated from ASTM D2127)
G_b = specific gravity of asphalt binder
P_b = total asphalt binder content by mass, %
P_{be} = effective asphalt binder content by mass, %
P_{ba} = absorbed asphalt binder content by mass, %
P_s = percent stone in mixture ($100-P_b$)
P_{200} = percent passing No. 200 sieve by mass
Ht_{ini} = height of sample at initial number of gyrations
Ht_{des} = height of sample at design number of gyrations

Table 5: Superpave Gyratory Compaction Effort

Tire Pressure (psi)	Initial Gyration Level	Design Gyration Level
Less than 100	6	50
100 to 200	7	65
Greater than 200	7	80

Once the desired properties are determined, each is compared to the mixture requirements. Table 6 presents the requirements for airfield HMA mixes designed using the Superpave gyratory compactor. A trial blend that will meet all of the requirements of Table 5 is selected as the design aggregate gradation.

Step 3 – Selection of Optimum Asphalt Content

Once the design gradation has been selected, it is necessary to evaluate various asphalt contents in order to select optimum asphalt binder content. Additional specimens will need to be prepared using the selected design gradation and at least three additional asphalt binder contents. At least two samples should be prepared at each asphalt binder content.

Once the samples have been compacted, extruded and cooled, the bulk specific gravity of each is determined. As described in the previous section, the VTM, VMA,VFA, $\%G_{mm}@N_{initial}$, and D/B should be calculated for each sample. These results are then averaged for each asphalt binder content. Graphical plots are then prepared for the following relationships with "best-fit" lines developed for each relationship:

VTM vs. Asphalt binder content
VMA vs. Asphalt binder content
VFA vs. Asphalt binder content
$\%G_{mm}@N_{initial}$ vs. Asphalt binder content
D/B vs. Asphalt binder content

Table 6: Mix Design Requirements

Tire Pressure, psi	Required Relative Density, Percent of Theoretical Maximum Specific Gravity		Voids in the Mineral Aggregate (VMA), Percent Minimum Maximum aggregate Size, mm				Voids Filled with Asphalt (VFA) Range, Percent	Dust – to-Binder Ratio Range
	$N_{initial}$	N_{design}	1 ½	1	¾	1/2		
<100	≤90.5	96.0	12.0	13.0	14.0	15.0	70-80	0.6-1.4
100 to 200	≤90.5	96.0	12.0	13.0	14.0	15.0	65-78	0.6-1.4
>200	≤90.0	96.0	12.0	13.0	14.0	15.0	65-75	0.6-1.4

Optimum asphalt binder content is defined as the asphalt binder content that results in 4.0 percent air voids. In order to find this asphalt binder content, evaluate the graphical plot between VTM and asphalt binder content. Determine the asphalt binder content that produces 4 percent air voids. After determining the asphalt binder content that produces 4 percent air voids, use the other graphical plots to determine the other required properties at this asphalt binder content. Compare the values to the requirements presented in Table 6. If all of the requirements of Table 6 are met, optimum asphalt binder content will be that asphalt binder content that results in 4 percent air voids. If all requirements are not met, another gradation should be evaluated.

Step 4 – Evaluate Moisture Susceptibility

The final step in the design of airfield HMA using the Superpave gyratory compactor is to evaluate the designed mixture for moisture susceptibility. Testing is conducted in accordance with ASTM D4867, Effect of Moisture on Asphalt Concrete Paving Mixtures. A minimum tensile strength ratio of 80 is required.

GUIDELINES ON MIX SELECTION

Requirements presented in the previous section on designing airfield HMA using the Superpave gyratory compactor showed that there are a number of potential combinations for specifying airfield pavement layers. Tables 4 and 5 showed that there are a total of four different gradation bands and three design laboratory compactive efforts available, respectively. Each of these 12 combinations would be expected to have different performance characteristics. Use of polymer modified asphalt binders would also change the expected performance characteristics when compared to mixtures containing neat asphalt binders. This section provides discussion on issues a specifying engineer may want to consider when selecting a particular HMA for an airfield HMA layer.

Definitions and Terms

Prior to discussing the guidelines on mix selection, some terms and definitions are provided. These terms are used within these guidelines and are provided here to help the reader.

Apron: Aprons are pavements on airfields that exist as storage/parking areas for aircraft. Terminal aprons are located near the terminal building and are used for storing aircraft during loading and unloading. The holding apron is a location where aircraft can queue in order to allow other aircraft to bypass.

Blast Pad: The blast pad is a paved area at the end of runways to prevent erosion caused by jet blast. These pavements are not designed to carry aircraft loadings except in an emergency.

Hot Mix Asphalt: A combination of asphalt binder and well-graded aggregates that are mixed at elevated temperatures in a production facility.

Design Compactive Effort: The laboratory compactive effort applied to hot mix asphalt during mix design with the Superpave gyratory compactor. This value is given as a specified number of gyrations.

Design Gradation: Blend of aggregate stockpiles in which the optimum asphalt binder content has been determined.

Maximum Aggregate Size: This is a term describing the gradation of the mixture. The maximum aggregate size is the finest sieve which has 100 percent of the aggregates passing. Table 4 presents the gradation bands for airfield HMA by maximum aggregate size.

Nominal Maximum Aggregate Size (NMAS): One sieve size larger than the first sieve to retain more than 10 percent of the aggregate fraction. This term is used in the highways version of the Superpave mix design method.

Raveling: Wearing away of the pavement surface caused by dislodging of aggregates and loss of asphalt binder. Raveling is a major cause of FOD.

Runway: A runway is a pavement on an airfield that is primarily used for the acceleration and takeoff and/or landing and deceleration of aircraft.

Rutting: A longitudinal surface depression in wheel paths. Rutting can allow rain water to pool causing an increase in the potential for hydroplaning. Rutting can also lead to operational control issues.

Segregation: Separation of a mix constituent from the other parts of the mix. This is generally observed as the coarse aggregates separating from the fine aggregates creating coarse spots in the finished pavement.

Shoulder: The shoulder pavement of an airfield is located adjacent to structural pavements and resists jet blast erosion and accommodates maintenance and emergency equipment. Shoulders are not designed to receive aircraft loadings.

Shoving: Shoving is a longitudinal displacement of the HMA in a localized area of the pavement surface. Shoving can cause operation control problems for aircraft.
Superpave: A methodology for designing dense-graded hot mix asphalt using the Superpave gyratory compactor.

Taxiway: Taxiways are defined paths on an airfield that are established for the taxiing of aircraft from one area of the airport to another.

HMA Mixture Constituents and Properties Related to Mix Selection

Hot mix asphalt is predominantly comprised of aggregates and asphalt binder. Both of these constituents are important in the performance of airfield HMA. The following sections describe how these constituents affect HMA performance.

Influence of Asphalt Binder on Airfield Pavement Layers

Important Properties of Binders for Airfields

Asphalt binder is one of the most unique construction materials. As a viscoelastic material, asphalt binder is extremely sensitive to both temperature and time of loading. There are three different temperature regimes that an asphalt binder affects the performance of HMA pavement layers: high, intermediate and low temperatures. At high pavement temperatures, rutting and shoving is the main cause of concern. In these instances, a stiff asphalt binder is desirable. Stiff asphalt binders will help resist the stresses created in the pavement by aircraft tires.

At intermediate temperatures, fatigue cracking is a concern. Fatigue cracking is caused by the repetitive loading of aircraft passing over the pavement. Tensile stresses develop at the bottom of the pavement layer; therefore, fatigue cracking is generally more related to the total thickness of the HMA layer. However, proper selection of the asphalt binder can reduce the potential for fatigue cracking.

Asphalt binders play a significant role in resisting low temperature thermal cracks. Asphalt binders must be elastic enough at low temperatures to resist the stresses caused by low temperatures.

Airfield Asphalt Pavement Technology Program Project 04-02 was conducted to provide guidance on selecting the appropriate asphalt binder for airfield HMA. This report should be consulted to help specifiers select the appropriate asphalt binder for airfields. The Superpave Performance Grading (PG) system recommended in this report does evaluate asphalt binders at high, intermediate and low temperatures.

Effect of Binder Content on Performance

The asphalt binder content needs to be optimized to balance stability (resistance to rutting and shoving) with long-term durability (raveling, cracking, and resistance to moisture). This is the goal of the mix design procedure presented within this document. Asphalt binder contents that are too low can result in raveling, segregation, and/or insufficient compaction, while asphalt binder contents that are too high can result in bleeding, shoving and rutting. Figure 1 graphically illustrates the relationship between asphalt content and pavement performance, in terms of durability and stability.

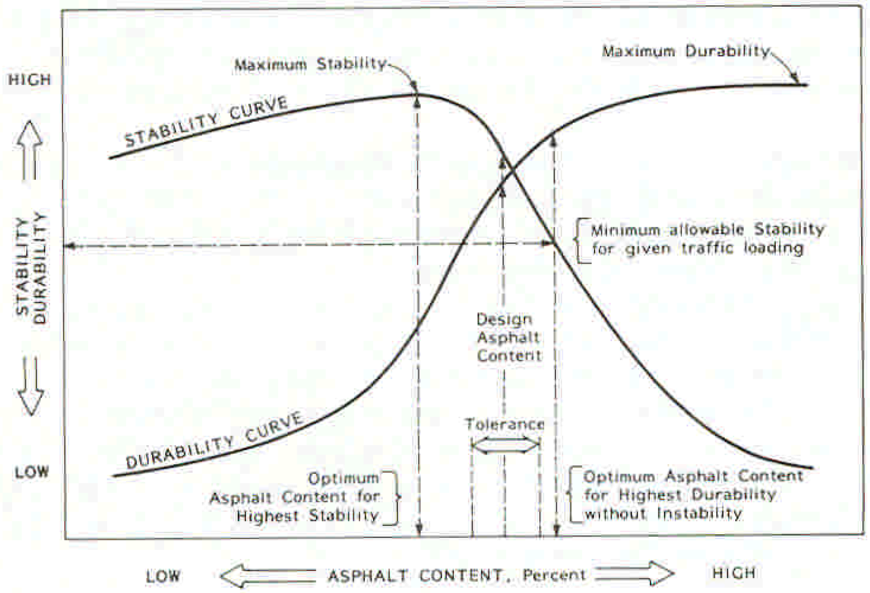

Figure 1: Relationship Between Asphalt Content and Performance (5)

One issue that is addressed within the Superpave mix design method for airfields that was not addressed in the previous Marshall mix design method is aggregate absorption. This property is discussed within this section on the effect of asphalt binder content on performance because aggregate absorption can affect the selected asphalt binder content. When highly absorptive aggregates are utilized, the aggregates will absorb asphalt during production, storage, transportation, and laydown. It has also been hypothesized that some asphalt binder is absorbed during the early life of the pavement when temperatures are high. Any asphalt binder absorbed by the aggregates is not available to resist the actions of asphalt binder aging. When the asphalt binder ages, it becomes brittle which can lead to durability problems, such as raveling. Raveling is a major cause of FOD. Therefore, the absorption characteristics of the aggregates must be accounted for during mix design through the short-term aging procedure in order to optimize the appropriate asphalt binder content.

Effect of Binder Stiffness on Performance

The stiffness of the asphalt binder can play a very important role in the performance of airfield HMA layers. Stiffer asphalt binders help prevent rutting and shoving. However, stiffer binders also tend to reduce the workability of an asphalt mixture, making it harder to achieve the necessary density to ensure optimum performance. Asphalt binders that are too stiff may also suffer from long-term performance issues in the form of cracking. The appropriate asphalt binder should be based upon the climatic and loading conditions that are expected at the project site.

Influence of Aggregate Properties on Airfield Pavement Layers

Aggregates make up approximately 95 percent of an HMA, by mass. Therefore, their properties are of paramount importance to the performance of airfield pavements. The aggregate requirements recommended within the Superpave mix design method for airfields were developed to provide an HMA with desirable properties. The following sections describe issues related to aggregate properties for airfield pavements.

Important Properties of Aggregates

There are a number of aggregate properties that are important to HMA performance, including: angularity, shape, surface texture, toughness, soundness and angularity. In order to resist the high tire pressures encountered on many airfields, angular aggregates with rough surface texture are needed. Angular/rough aggregates reduce the potential for rutting and shoving. Angularity requirements contained within the Superpave mix design method should not be reduced. Durable aggregates that exhibit toughness and are resistant to the effects of weather (soundness) are desirable.

Microtexture refers to the fine scale roughness contributed by the small, individual aggregate particles in the asphalt mixture. Microtexture will provide frictional properties for aircraft operating at slower speeds. Macrotexture is defined as the visible roughness of the pavement as a whole. Macrotexture provides the frictional properties for higher speeds while also assisting in providing a path for water to escape from beneath aircraft tires. Together, they provide adequate frictional properties for aircraft throughout their landing/takeoff speed range. If there is concern about the polish resistance (related to microtexture) of a particular aggregate source, the local Department of Transportation should be consulted. Polish resistance is a very important aggregate property for airfield pavements.

Influence of Natural Sands on Performance

Even though the use of fine, crushed material will increase a mixture’s stability, it will also reduce the mixture’s ability to be compacted. Therefore, small percentages of rounded natural sand will aid in the workability of hot mix asphalt. However, excessive amounts of rounded natural sand can lead to instability problems and result in tenderness, rutting and/or shoving. Excessive amounts of natural sand should not be allowed within airfield HMA. The mix design requirements for the maximum percentage of natural sand and a minimum percentage of uncompacted voids in the fine aggregates were recommended to limit the use of “rounded” sands.

Influence of Aggregate Absorption on Performance

Excessive aggregate absorption of asphalt binder may lead to incorrect determination of voids in mineral aggregate (VMA) and voids filled with asphalt (VFA). Also, an excessive amount of asphalt binder being absorbed by the aggregates will result in insufficient effective asphalt binder in the mixture if not taken into account. Insufficient effective asphalt binder may lead to raveling and cracking or stripping, possible premature hardening, and low-temperature cracking.

Influence of Gradation for Airfields

Gradation affects almost all important mixture performance properties, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. Fine graded mixes (those having gradations passing near the upper gradation band limits) tend to produce tighter surface textures, reducing permeability to water and air, and increasing durability. Fine graded mixtures also generally offer improved workability over coarse graded mixes (those gradations passing near the lower gradation band limits) as finer gradations will generally require a higher optimum asphalt binder content. However, coarser gradations improve the macrotexture of pavement surfaces. With the requirements for grooving at most airports, the need for coarser gradations is minimized.

Construction Issues Related to Mix Selection

When constructing airfield HMA layers, there are mix characteristics that will influence the ability to compact the mixture. These characteristics are important because achieving the proper density is vital to the performance of HMA pavement layers. Layers that are not properly compacted will often exhibit durability distresses that can lead to FOD.

Ratio of Lift Thickness to Nominal Maximum Aggregate Size (t/NMAS)

Early standard practice in pavement construction was to use a lift thickness to maximum aggregate size (t/MAS) ratio of approximately 2 or 3:1. Research conducted as part of NCHRP 9-27, *Relationships between HMA In-place Air Voids, Lift Thickness, and Permeability,* investigated this ratio to determine the optimum ratio of lift thickness to aggregate gradation size *(6)*.

NCHRP 9-27 evaluated the relationships between lift thickness and NMAS in several different ways: through the gyratory compactor, through the vibratory compactor, and through field test sections constructed at the National Center for Asphalt Technology Test Track. Results based on these evaluations showed that the test sections provided the best approach for determining the minimum t/MAS ratio. From the results, it was shown that a t/MAS of 2 to 2.5 or greater was needed to be able to achieve the proper density with a reasonable compactive effort. As an example, the layer thickness of a 1 in. maximum aggregate size gradation should be placed at a minimum thickness of 2.5 in. or greater. Likewise, ½ in. maximum aggregate size gradations should be placed 1 ¼ in. or greater. Table 7 presents recommended lift thicknesses for the different maximum aggregate size gradation bands.

Table 7: Recommended Lift Thicknesses by Maximum Aggregate Size

Gradation Maximum Aggregate Size	Minimum Lift Thickness (in.)	Maximum Lift Thickness (in.)
½	1.0	2.0
¾	1.5	3.0
1	2.5	3.5
1 1/2	3.0	4.5

Pavement Grooving

Airfield pavements are routinely grooved to provide two main functions: to reduce the occurrence of hydroplaning, and to provide adequate friction, especially during wet pavement conditions. Grooving essentially provides additional pavement macrotexture that allows water to escape. Studies dating back to 1968 (*AC 150/5320-12C*) confirm that a high level of friction could be achieved on wet pavements through grooving, which allows water to escape from beneath the tires of landing aircraft. Pavement grooving can be installed in several different orientations, including transverse, longitudinal, and angled. Groove shapes that have commonly been used include rectangular, trapezoidal, and rounded. The current FAA grooving specification requires grooves to be rectangular in shape, ¼ inch deep by ¼ inch wide.

In spite of their widespread use, pavement grooves in asphalt airfield pavements are subject to several pavement distresses that reduce the pavement's serviceability. Among these distresses are groove wear, groove closure, migration, and rounding. A more thorough listing is shown in Table 8.

Table 8: Common Distresses Found in Grooved Asphalt Runways (*7*)

Distress	Definition
Groove Wear	Groove depth measuring 0.125 in. or less compared to the standard depth of 0.25 in.
Groove Closure	Groove width measuring 0.1875 in. or less compared to the standard width of 0.25 in.
Rubber Deposits	Rubber in grooves and or runway
Cracking	Reflective cracks and cold seam cracks propagated along grooves
Migration	Flowing of pavement resulting in a wavy groove pattern
Deep/Shallow Cutting	Adjacent grooves of varying depths caused by defective cutting methods
Rounding	Wearing away of sharp groove edges
Chipping	Breaking away of aggregate and/or filler material in sharp edges of grooves
Erosion	Washing out of fine filler or binder material leaving exposed aggregate

The combination of groove wear, groove closure, and migration can lead to what is commonly termed groove collapse. Several studies have evaluated the cause of groove collapse, and concluded that groove collapse was generally caused by large aggregate particles breaking loose from the grooves, mainly during high ambient temperatures, and occurred within the first three years of placement. Once binder aging had occurred, groove collapse was eventually mitigated. Generally, it has been recommended that grooving only take place in pavements with aggregates less than ⅜ in.

Segregation

Segregation can be a problem when placing airfield pavement layers. Segregation is the separation of one portion of the HMA mix. This is most often seen in the coarse aggregate fraction. Segregation is generally observed on the pavement surface as an area with much more surface texture than surrounding areas.

Segregation in HMA layers can cause performance problems. Segregated areas generally have an insufficient amount of fines and asphalt binder. As such, the potential for raveling in these areas is increased. In most cases, HMA mixtures with smaller maximum aggregate size gradations and/or finer gradations (for a given maximum aggregate size) will have lower potential for segregation.

Permeability

Layers of HMA that have low density or are in segregated areas have a potential to be permeable to air and water. When an HMA pavement layer is permeable to water and air, the potential for moisture damage and/or oxidative aging is increased. Permeability of in-place dense-graded HMA layers is affected by the amount of fine aggregates, as illustrated in Figures 2 and 3. Figure 2 shows that for ¾ in. maximum aggregate size mixes, fine-graded HMA tends to be less permeable than coarse-graded HMA at a given in-place air void content. Figure 3 illustrates the influence of maximum aggregate size (shown as nominal maximum aggregate size (NMAS)) on permeability. This figure shows that larger NMAS mixes tend to be more permeable at a given in-place air void content than smaller NMAS mixes. Therefore, permeability is related to the amount of fine aggregate within the gradation. Layers that are less permeable will tend to be more durable and, thus, less potential for raveling.

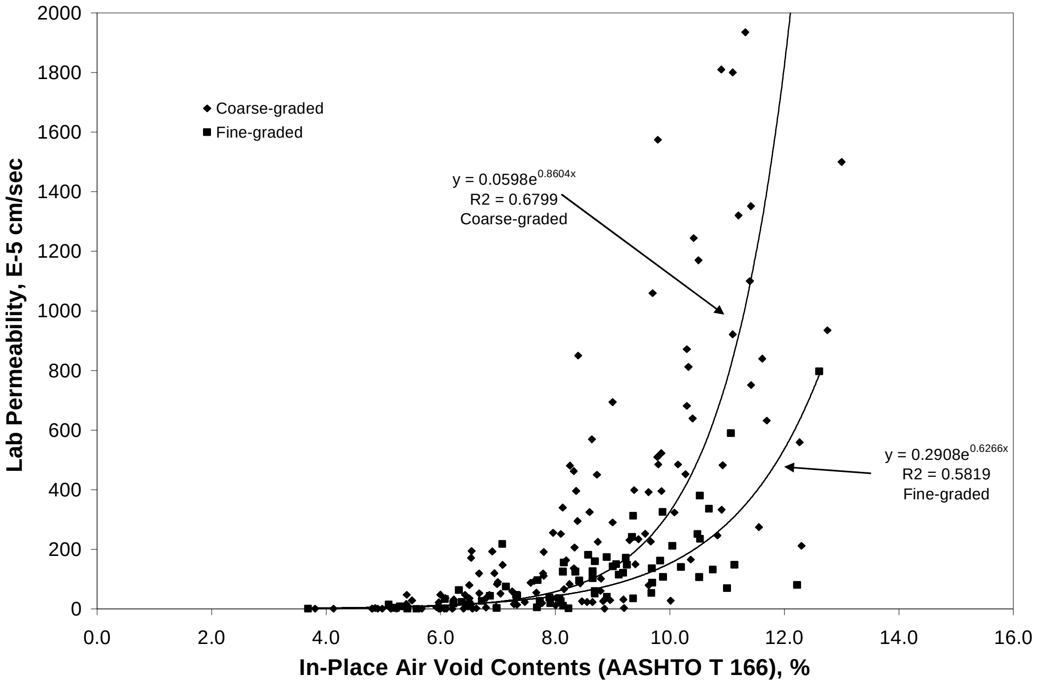

Figure 2: Effect of Gradation Shape on Permeability of Dense-Graded Layer

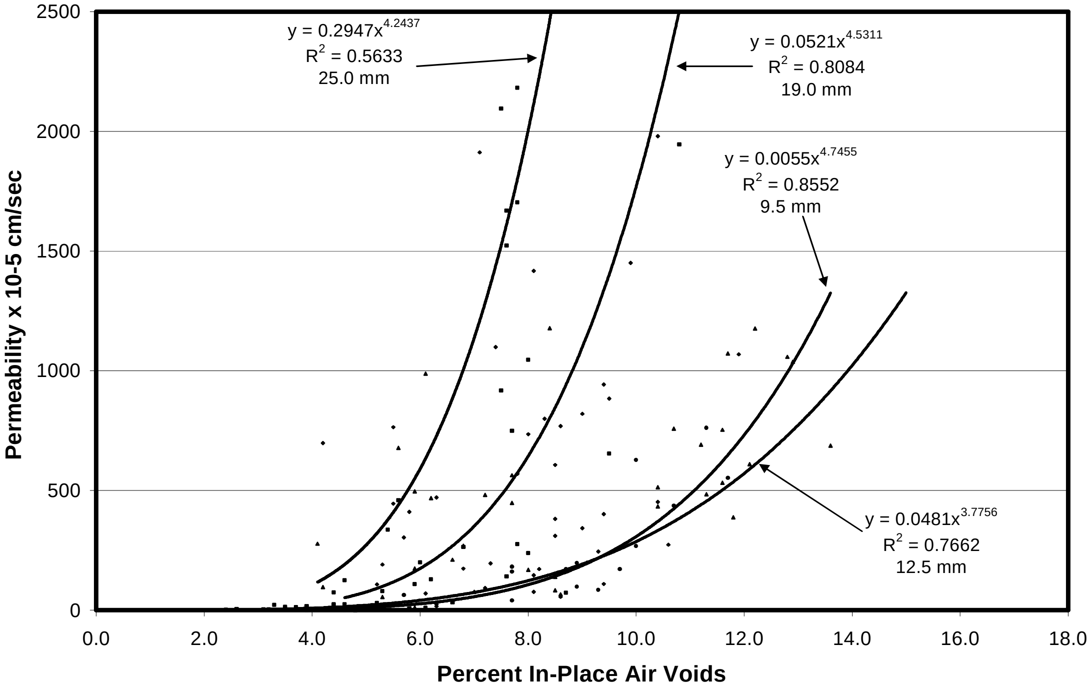

Figure 3: Effect of Nominal Maximum Aggregate Size on Permeability

Pavement Layer Issues Related to Mix Selection

This section describes the different types of HMA pavement layers generally utilized on airfields and discusses issues related to mix selection for these different layers. For the purposes of pavement layer characterization, this report will include two categories of HMA layers: surface courses and base courses. Surface courses generally contain the highest quality materials within the pavement structure. The surface course must be smooth, durable, rut resistant and possess good frictional properties. Surface courses can be placed in multiple layers. Surface courses located below the pavement surface help distribute the loads from the pavement surface to the underlying layers. Base courses are generally placed upon the prepared subgrade, aggregate base, or stabilized base and are used to distribute loads to the underlying layers. Multiple base courses any be placed within the structure.

Surface courses are generally directly in contact with loadings and with the elements. To minimize the potential for premature distresses, the constituents should be properly selected based upon the expected loadings and climate. The Superpave mix design procedure for airfield pavements should be utilized to properly select the constituent materials. Because surface courses are in contact with the elements, the layer should be impermeable. Achieving proper density in the field will help minimize the potential for permeable pavements; however, selection of HMA mixes with smaller maximum aggregate size gradations will also help minimize the potential for permeability. Surface courses should in most cases be an HMA with a ½ in. or ¾ in. maximum aggregate size gradation. These gradations are also preferable because smaller maximum aggregate size gradations will generally have higher optimum asphalt binder contents which, when combined with the lower potential for permeability, will reduce the potential for raveling. From a construction standpoint, these smaller maximum aggregate size gradations will also minimize the potential for segregation. Grooves also tend to last longer when smaller aggregate sizes are used.

Surface courses placed immediately underneath the pavement surface must assist the overlying courses in resisting deformations and distribute loads to the lower pavement layers. These courses should in most cases be an HMA with a ¾ in. or 1 in. maximum aggregate size gradation. Use of ½ in. maximum aggregate size gradations is also acceptable.

Base courses are generally the lowest layers of HMA placed in the pavement structure. The primary purpose of the base layer is to provide a construction platform for the overlying layers and the distribute loads to the underlying layers. Base courses should in most cases be an HMA having a ¾ in., 1 in. or 1 ½ in. maximum aggregate size gradation.

Pavement Location Issues Related to Mix Selection

Airfields are made up of numerous pavement areas. Each of these areas has a specific role in the aviation industry. Some pavements receive very heavy loads while some may never have an aircraft pass over. The following paragraphs describe some pavement location issues that could affect the selection of the appropriate HMA mixture.

Aprons are pavement areas where aircraft are generally moving at very slow speeds or are stationary. As such, the stiffness of the HMA should be relatively high in order to resist permanent deformation. HMA mixes used on aprons should have very angular aggregates that have the proper shape. When large aircraft, having high tire pressures, are to utilize the apron, some polymer modification to the asphalt binder may be warranted. Aprons are generally very large areas in which aircraft will not always traffic over the entire area. Smaller maximum aggregate size gradations should generally be used for surface courses on aprons in order to enhance durability.

Runways are used for aircraft to take-off and land. Once the aircraft have landed, they are generally traveling at great speeds; however, the impact forces that occur upon landing or the acceleration forces encountered during takeoff are high. HMA mixes should be selected that will minimize the potential for rutting and raveling for runways. Rutting can affect the operational control of aircraft and raveling can result in FOD. Any of the HMA mixes can work well for runways provided they are selected for their intended pavement layer within the structure and at the appropriate design gyration level.

Taxiways are pavements on an airfield that are established for taxiing of aircraft from one area to another. Generally, the speeds at which the aircraft travel are low indicating that rutting is a major concern. As such, the use of polymer modified binders should be considered if the size of the aircraft or tire pressures warrant their use. This is especially true at larger airports where aircraft may stack near runway ends. Any of the HMA mixes can work well for taxiways provided they are selected as described above for their intended pavement layer and at the appropriate design gyration level.

There are a number of pavement locations at airfields that may receive few if any aircraft loadings. These will be lumped into a category called non-load pavements. Areas such as blast pads and shoulders fit within this category. The major concern at these pavement locations is durability type distresses. Cracking and/or raveling are of main concern. For these non-load pavements, HMA mixes should be designed at 50 gyrations during mix design. The surface course in these areas should be either ½ in. or ¾ in. maximum aggregate size gradation, with the ½ in. preferable.

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