HOT MIX ASPHALT
MIX SELECTION GUIDE
FOR MISSISSIPPI

Prepared for
Mississippi Department of Transportation

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16. Abstract

Mississippi's roadway system is vital to the state's economy. As time passes, new and/or improved roadways will be needed in order to attract and hold industry. Hot mix asphalt constitutes the material used to construct and maintain the vast majority of roadways in Mississippi. However, not all hot mix asphalt mixtures perform the same.

The objective of this project was to develop guidance for hot mix asphalt mix selection in Mississippi. Three primary mix types were considered and included: dense-graded hot mix asphalt, stone matrix asphalt and open-graded friction courses.

Recommended guidance was developed and presented for when certain mix types should be used on Mississippi roadways. Recommendations were provided based upon the pavement layer and traffic category being considered.

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CHAPTER 1 – INTRODUCTION

1.1   Background

Mississippi's roadway system is vital to our state's economy. Roads are used to transport goods, supplies, workers, etc. around the state. As time passes, more and/or improved roads will be needed in order to attract industry. Hot mix asphalt (HMA) constitutes the material used to construct and maintain the vast majority of roadways in Mississippi. The HMA placed is expected to perform for extended periods of time under a variety of traffic and environmental conditions. However, it is important to note that all HMA mix types do not perform similarly.

Dense-graded HMA has been the mix type of choice in Mississippi for many, many years. This includes dense-graded mixes designed using the Marshall hammer and the Superpave gyratory compactor. Historically, HMA used in Mississippi was designed using the Marshall hammer. Using the Marshall method of designing mixes, the only variations were the number of blows the mix was designed with and the maximum aggregate size of the gradation. Gradation bands within a given maximum aggregate size were relatively narrow. Therefore, for a given set of aggregates and a maximum aggregate size, performance was generally similar, no matter the selected gradation. Since the mid-1990's, the Mississippi Department of Transportation (MDOT) has specified the Superpave mix design system to design dense-graded HMA. With the adoption of the Superpave mix design system, more choices became available for HMA mix selection. The Superpave system has three design compactive efforts as well as five different maximum aggregate size gradations. Additionally, the gradation control points specified in the Superpave mix design system allow a much wider range of gradations. Therefore, using the Superpave mix design system could result in differences in performance for a given set of aggregates.

During the last ten years, there have been several new or improved HMA types that have been introduced. Most notable of these are stone matrix asphalt (SMA) and open-graded friction course (OGFC). These specialty types of HMA have a place in the selection of mixes in Mississippi. However, guidance is needed on the proper application of these mixes for conditions unique to Mississippi. The purpose of this document is to provide pavement designers with the needed information to make informed decisions on the selection of appropriate mix types in Mississippi.

1.2   Objective

The objective of this project was to develop guidance for HMA mix selection in Mississippi. Three primary HMA types were considered and included in the mix selection process: dense-graded HMA, stone matrix asphalt, and open-graded friction course.

1.3   Scope

The guidance for mix selection was developed solely from information and data found in the Mississippi Standard Specifications for Road and Bridge Construction, MDOT Special Provisions, literature, and experience. No formalized laboratory research was conducted. Because dense-graded HMA has been the most common pavement material for many years, this report purposely highlights where SMA and OGFC are different during mix design and construction.

1.4   Organization of Report

This report includes seven chapters. Chapter 1 provides an introduction and background for the project. The second chapter provides definitions for terms used within the report. A general overview of the HMA mixes discussed in this report is provided in Chapter 3. The third chapter highlights the differences between the HMA types along with providing general information for each. Chapter 4 provides discussion on the design of each HMA type. Issues related to construction are discussed in Chapter 5. Chapter 6 is devoted to recommendations for mix selection. The final chapter provides conclusions and recommendations.

CHAPTER 2 - DEFINITIONS

This chapter presents definitions for terms used within this report. Terms are listed in alphabetical order.

Break Point Sieve: The finest sieve that retains at least 10 percent of the aggregate blends. The break point sieve is used to differentiate between fine and coarse aggregates for stone matrix asphalt and open-graded friction courses.

Dense-Graded 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.

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

Draindown: Separation of asphalt binder and fines from coarser aggregates during storage, transportation and/or laydown.

Mortar: Combination of asphalt binder, aggregates finer than No. 200 sieve, and stabilizing additives.

Nominal Maximum Aggregate Size (NMAS): One sieve size larger than the first sieve to retain more than 10 percent of the aggregate fraction.

Open-Graded Friction Course (OGFC): A hot mix asphalt having an open aggregate grading that is used as a surface course to improve frictional properties.

Primary Control Sieve: Sieve size and associated percent passing that differentiates a given gradation as coarse-graded or fine-graded. The primary control sieves and associated percent passing value to differentiate coarse- and fine-graded mixes are listed below. Gradations passing above the primary control sieve are considered fine-graded, while gradations passing below are coarse-graded.

Nominal Maximum Aggregate Size	Primary Control Sieve	% Passing
1 ½ (37mm)	No. 4	35
1 (25mm)	No. 4	40
¾ (19mm)	No. 8	35
½ (12.5mm)	No. 8	40
3/8 (9.5mm)	No. 8	45

Stabilizing Additives: Materials added to the asphalt binder or mixture to reduce the potential for draindown. Common stabilizing additives are polymers and fibers.

Stone Matrix Asphalt (SMA): A gap-graded hot mix asphalt that contains a coarse aggregate skeleton and an asphalt binder rich mortar.

Stone-on-Stone Contact: Used in the design of stone matrix asphalt and open-graded friction course. Refers to the existence of coarse aggregates being in contact with each other within a compacted mix.

Superpave: A methodology for designing dense-graded hot mix asphalt.

CHAPTER 3 – AVAILABLE HMA TYPES IN MISSISSIPPI

There are three primary HMA types that are available in Mississippi: dense-graded HMA, SMA and OGFC. Other proprietary products are available but are not discussed in this document. The following sections describe these three HMA types.

3.1   Dense-Graded HMA

A dense-graded HMA mix is a well-graded (relatively even distribution of aggregate particles sized from coarse to fine) HMA that is comprised of aggregates and asphalt binder (1). Figure 1 illustrates the gradation for a typical dense-graded mix. Without question, dense-graded HMA mixes have been the most common type of HMA placed in Mississippi.
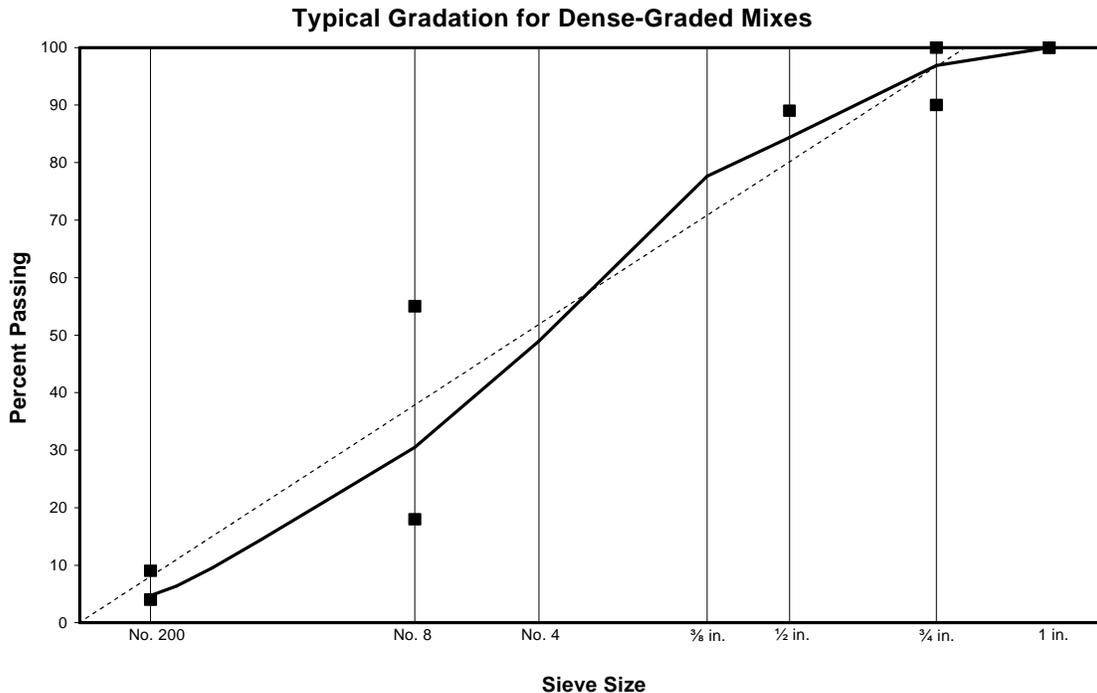
Figure 1: Typical Gradation for Dense-Graded HMA Mixes

Within Mississippi, dense-graded mixes are currently designed in accordance with Section 401 of the Mississippi Standard Specifications for Road and Bridge Construction and Mississippi Test (MT-78). Dense-graded mixes can be considered the workhorse HMA of Mississippi. The vast majority of pavements in Mississippi have been constructed using dense-graded HMA. These mix types have provided structural capacity as well as a safe driving surface.

Dense-graded mixes are generally labeled by their nominal maximum aggregate size (NMAS) and design compactive effort (N_{des}). For instance, a 12.5 MT refers to a 12.5mm NMAS gradation that is compacted using an N_{des} of 65 gyrations. According to MDOT specifications, there are 15 different combinations of NMAS and N_{des} that could be used in Mississippi (Table 1).

Table 1: NMAS - Ndes Combinations for Dense-Graded HMA in Mississippi

Nominal Maximum Aggregate Size, mm	Design Compactive Effort (N_{des})		
	50 gyrations (ST)	65 gyrations (MT)	85 gyrations (HT)
4.75	X	X	X
9.5	X	X	X
12.5	X	X	X
19.0	X	X	X
25.0	XXX[1]		

[1] 25mm NMAS mixes for HT and MT applications are designed using 50 gyrations.

Each of the combinations shown in Table 1 would be expected to perform differently. Generally, smaller NMAS gradations will have higher optimum asphalt binder contents than larger NMAS gradations. The higher asphalt content means that these mixes are generally more durable. Additionally, within Mississippi where gravels are the predominant aggregate source, HMA mixes having a smaller NMAS will generally be more rut resistant because the smaller aggregates will tend to have more fractured faces (Figure 2). In general, for a given aggregate source and gradation, optimum asphalt binder content depends upon the gyration level used to design the mix. As the N_{des} goes up, the optimum asphalt binder content will go down. Therefore, HT mixes would be expected to have less asphalt binder than ST mixes. Hence, HT mixes will be more rut resistant, while ST mixes would be expected to be more durable.
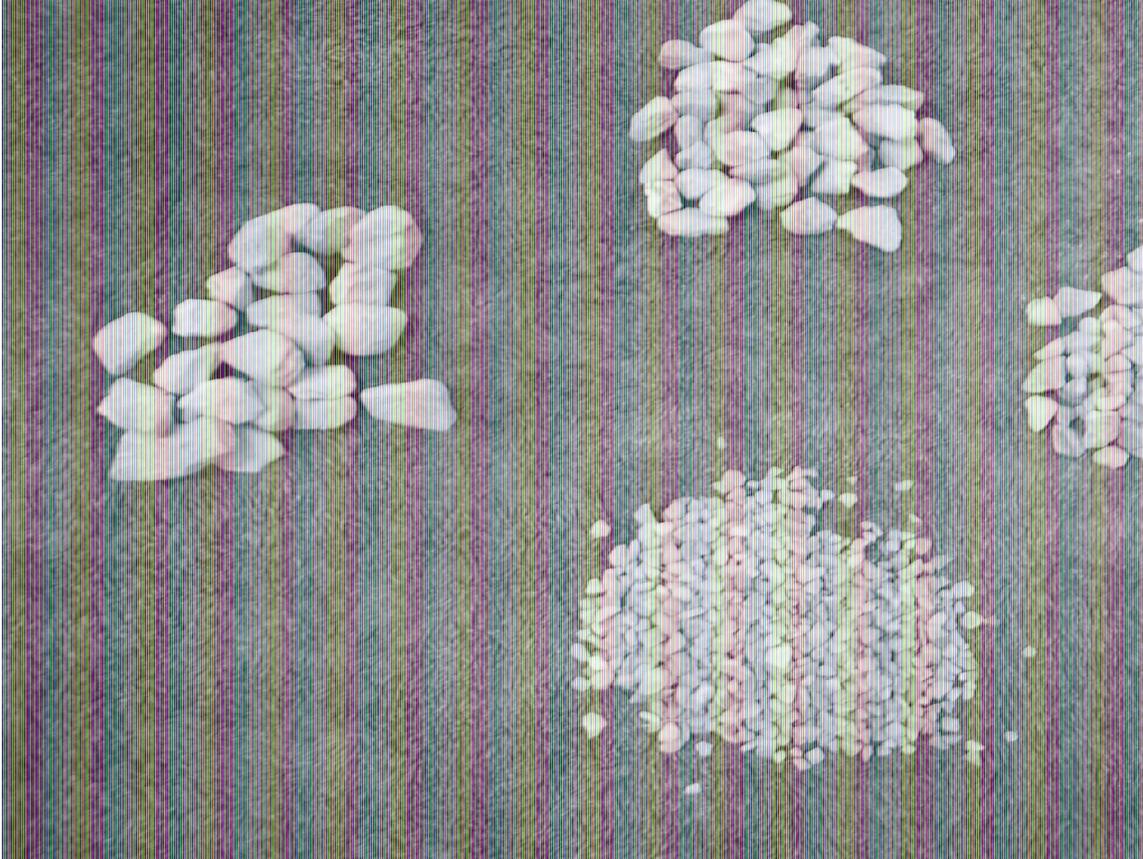
Figure 2: Typical Angularities of Mississippi Crushed Gravels

Another variable that can influence the performance of dense-graded HMA is gradation shape. The term coarse-graded has been adopted by the industry to describe HMA gradations passing below the primary control sieve (PCS) while HMA mixes having gradations passing above the PCS are called fine-graded. Both of these gradation types have proven to be resistant to rutting; however, fine-graded HMA has less potential for being permeable to water and air. When an HMA pavement 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 3 and 4. Figure 3 shows that for 12.5mm NMAS mixes, fine-graded HMA tends to be less permeable than coarse-graded HMA at a given in-place air void content. Figure 4 illustrates the influence of 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. Note, however, that 9.5mm and 12.5mm mixes have a similar relationship between density and permeability. Therefore, permeability is related to the amount of fine aggregate within the gradation. Layers that are less permeable will tend to be more durable.
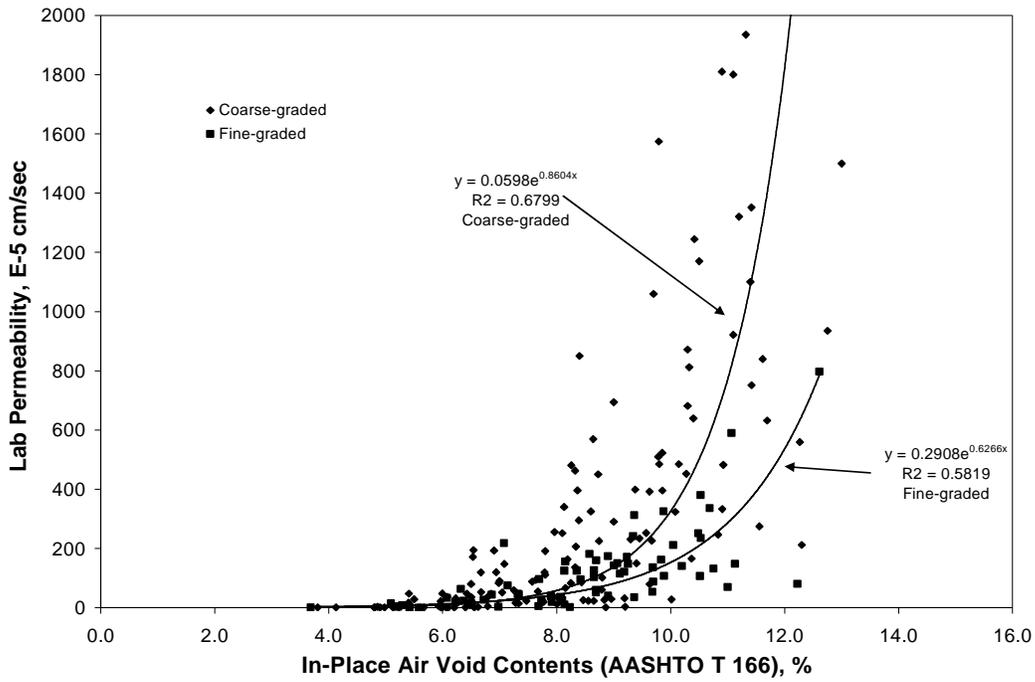
Figure 3: Effect of Gradation Shape on Permeability of Dense-Graded Layer

In Figure 3, the y-axis is labeled "Lab Permeability, E-5 cm/sec" and the x-axis is labeled "In-Place Air Void Contents (AASHTO T 166), %". Legend: ◆ Coarse-graded, ■ Fine-graded.

Coarse-graded: $y = 0.0598e^{0.8604x}$, $R2 = 0.6799$

Fine-graded: $y = 0.2908e^{0.6266x}$, $R2 = 0.5819$
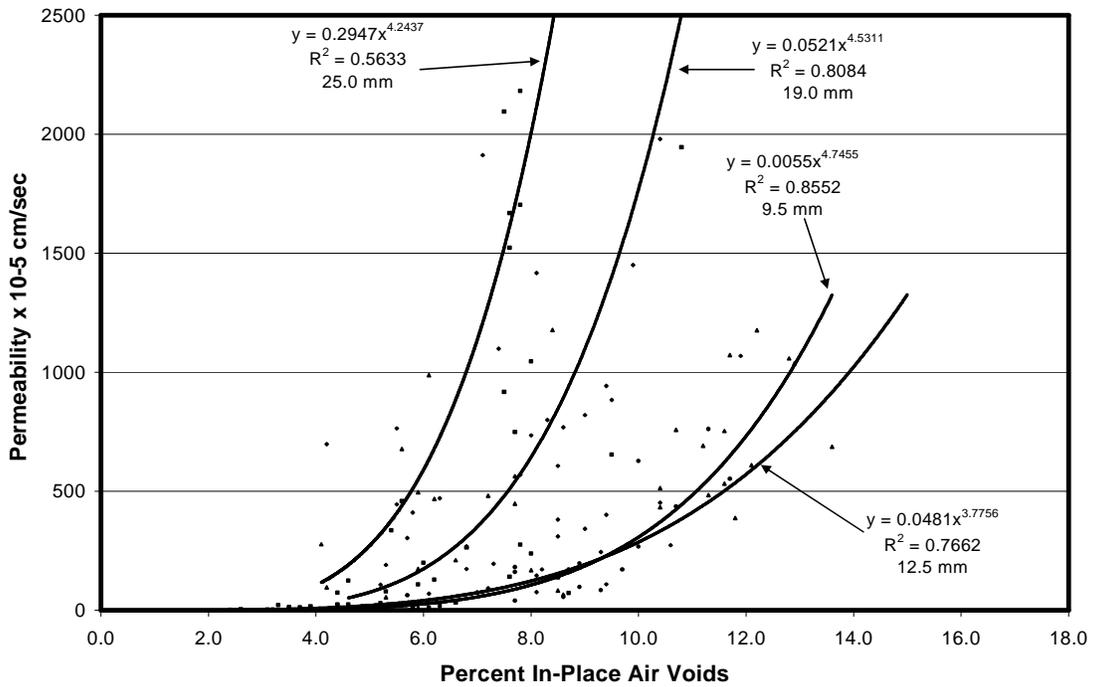
Figure 4: Effect of Nominal Maximum Aggregate Size on Permeability

In Figure 4, the y-axis is labeled "Permeability x 10-5 cm/sec" and the x-axis is labeled "Percent In-Place Air Voids".

25.0 mm: $y = 0.2947x^{4.2437}$, $R^2 = 0.5633$

19.0 mm: $y = 0.0521x^{4.5311}$, $R^2 = 0.8084$

9.5 mm: $y = 0.0055x^{4.7455}$, $R^2 = 0.8552$

12.5 mm: $y = 0.0481x^{3.7756}$, $R^2 = 0.7662$

3.2   Stone Matrix Asphalt

Stone matrix asphalt (SMA) is an HMA consisting of two parts: a coarse aggregate skeleton and an asphalt binder rich mortar. The philosophy of SMA mixtures is, therefore, two fold. First, the mixture must have an aggregate skeleton with coarse aggregate-on-coarse aggregate contact (generally called stone-on-stone contact). Secondly, sufficient mortar (combination of asphalt binder, fines and stabilizing additives of the desired consistency must be provided. Satisfactory mortar consistency, and thus a durable SMA, requires that a relatively high asphalt binder content be used.

SMA has been used in Europe for almost 40 years (2). It was first used in Europe to resist the abrasive nature of studded tires in snow regions; however, a benefit observed about SMA was its resistance to rutting. Because of the success of SMA in Europe, five agencies within the US constructed SMA pavements in 1991 (2). Since that time, the use of SMA has increased significantly. Some DOT's have a policy that SMA is used on all interstate pavements.

There are three primary differences between SMA and conventional dense-graded mixes: gradation, asphalt binder content and the presence of stone-on-stone contact. Gradations for SMA are more gap-graded than dense-graded HMA (Figure 5). SMA mixes typically have a large percentage of aggregate retained on each individual sieve down to a certain sieve, after which the percentage of aggregate retained on each sieve is small. The sieve that separates these sieves retaining large percentages from sieves retaining small percentages is called the break-point sieve (2). Aggregates coarser than the break-point sieve are considered the coarse aggregates.
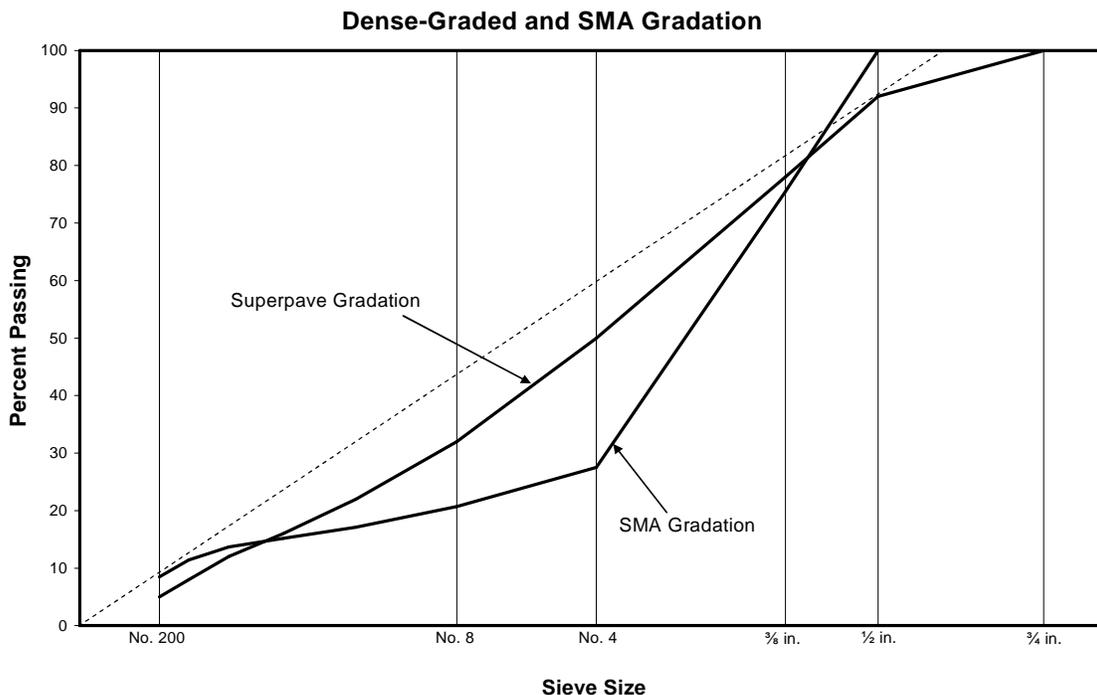
Figure 5: Comparison of Typical Superpave and SMA Gradations

Another gradation difference between SMAs and conventional dense-graded mixes is that a relatively large percentage of aggregate passing the No. 200 (0.075mm) sieve is used. SMA mixes typically have between 8 and 10 percent of the aggregate passing the No. 200 sieve, which sometimes necessitates the addition of a mineral filler or some other material passing the No. 200 sieve. Dense-graded mixes typically have 3 to 7 percent.

The asphalt binder content for SMA mixes is generally 6 percent or higher. Minimum asphalt binder contents are specified by MDOT and are based upon the bulk specific gravity of the aggregates used in the aggregate blend. This is to ensure the proper volume of asphalt binder within the mixt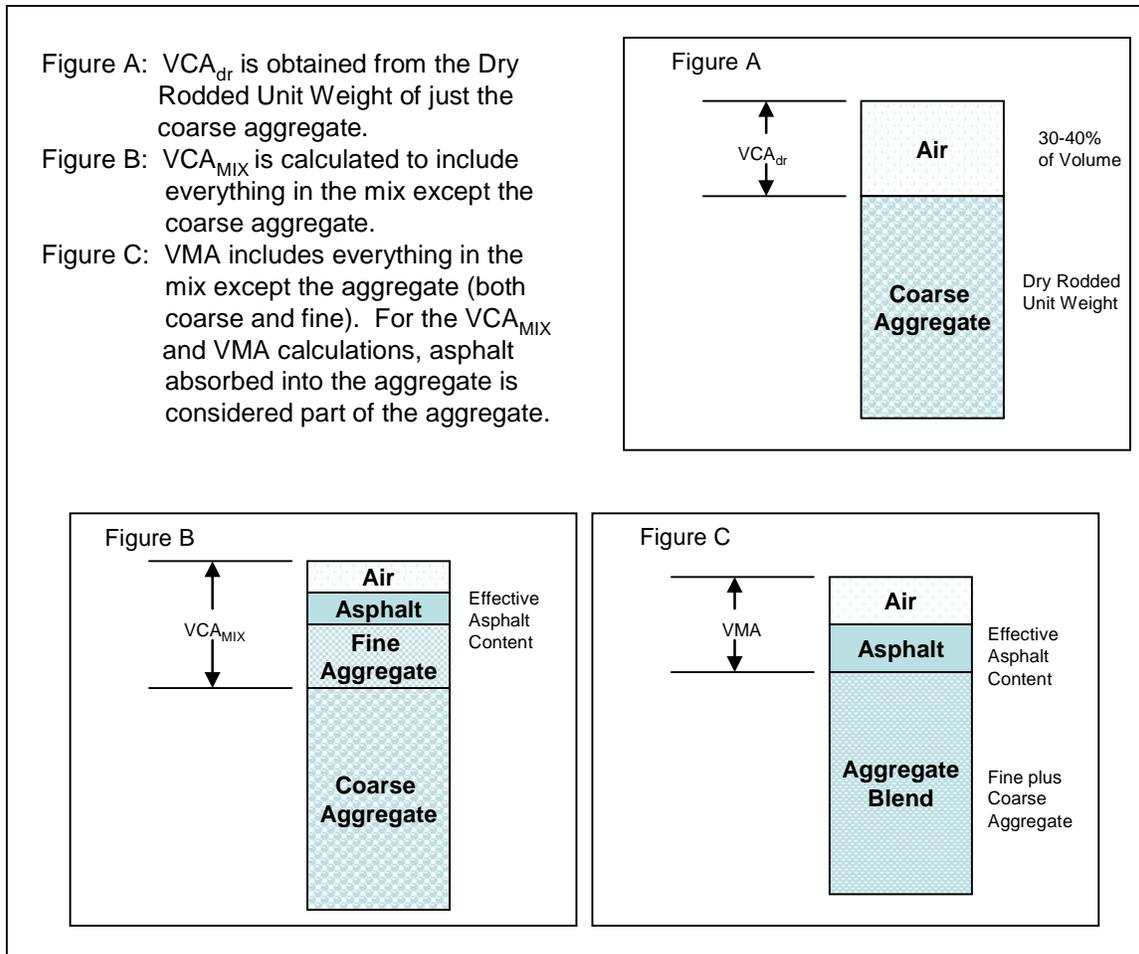ure. Because of the coarse nature of SMA gradations, the voids in mineral aggregate (VMA) is generally specified to be 17.0 percent or higher. In order to achieve the 4.0 percent air void content requirements at design, the volume of asphalt binder content has to be relatively high.

Because of the relatively high asphalt binder contents, one potential problem encountered with SMA that is not generally observed with dense-graded mixes is draindown. Draindown is a term that refers to an occurrence where the asphalt binder drains from the coarse aggregate structure during storage, transportation and/or laydown. In essence, draindown is a form of segregation; however, it is the asphalt binder and fines separating from the coarser particles. Draindown can lead to flushed spots on the finished pavement surface (2).

Two approaches are typically used to prevent draindown. First, as stated above, a high filler content (aggregate passing No. 200 sieve) is used with SMA. The filler particles stiffen the asphalt binder (by design) helping prevent the asphalt binder from draining off the coarse aggregates. Secondly, SMA generally contains some type of stabilizing additive. Stabilizing additives can be either an asphalt binder modifier, such as polymer or other type modifier, or can be in the form of a fiber. Both cellulose and mineral fibers have been used with success in SMA. Similar to the effect of the high fines content, the use of asphalt binder modifiers and/or fibers tend to stiffen the asphalt binder helping prevent draindown. MDOT requires the use of fibers and modified binders.

The final major difference between SMA and dense-graded HMA is the accounting for stone-on-stone contact. Because of the gap-graded nature of SMA gradations, SMAs are specifically designed to have coarse aggregate-on-coarse aggregate contact. This characteristic is what results in the rut resistance of SMA mixes. The method for determining when a SMA mix has achieved stone-on-stone contact is to measure a property called the voids within the coarse aggregate (VCA). The VCA is a volumetric property that is very similar to VMA. Figure 6 illustrates the concept of VCA. This figure shows that the VCA of the compacted mix (VCA_{mix}) includes the volumes of air, effective asphalt binder and aggregates finer than the break point sieve.

Figure A: VCA_{dr} is obtained from the Dry Rodded Unit Weight of just the coarse aggregate.

Figure B: VCA_{MIX} is calculated to include everything in the mix except the coarse aggregate.

Figure C: VMA includes everything in the mix except the aggregate (both coarse and fine). For the VCA_{MIX} and VMA calculations, asphalt absorbed into the aggregate is considered part of the aggregate.

Figure 6: Concept of Voids in Coarse Aggregate

To evaluate the existence of stone-on-stone contact, the VCA is measured for two conditions. First, the VCA is determined for the coarse aggregate fraction. After the SMA is mixed and compacted, the VCA of the compacted mix is calculated. If the VCA of the compacted mix is lower than the VCA of the coarse aggregate fraction, then the SMA is said to have stone-on-stone contact.

The existence of stone-on-stone contact is vital for SMA mixes. Because of the relatively high asphalt binder content of SMA, if stone-on-stone contact does not exist, the coarse aggregate will essentially be floating within the mortar leading to a rut prone mixture.

SMAs should be considered a premium HMA because they are more expensive than conventional dense-graded HMA. The increased costs result from the use of modified binders and fibers. Additionally, high quality, crushed aggregates are needed for SMA. Therefore, because of the increased costs, SMA will not have applicability in all situations.

3.3   Open-Graded Friction Courses

In the United States, the term open-graded friction course (OGFC) is used to describe a HMA having an open aggregate grading that is used as a wearing surface to improve frictional properties of the roadway. These mix types were first developed in Oregon in the 1930's and evolved through experimentation with plant mix seal coats. OGFCs were identified as an alternative to improve skid resistance by the Federal Highway Administration (FHWA) in the 1970's after initiating a program to improve the frictional characteristics of our nation's highways. In 1980, the FHWA published a formalized mix design method for OGFCs.

During the 1980's, many state agencies placed OGFCs as wearing layers. However, a number of agencies noted that the OGFC layers were susceptible to sudden and catastrophic failures. These failures were caused by material specification, mix design and construction problems. These problems were primarily related to mix temperature during construction. Gradations associated with OGFCs are much coarser than typical dense-graded HMA (Figure 7). Because of the open nature of OGFCs, there were problems with draindown during transportation. To combat the draindown problems, most owners would allow for lower production temperatures. Allowing the reduced production temperatures increased the stiffness of the asphalt binder, thus reducing the potential for draindown, but also led to other issues that increased the potential for raveling and delamination (the primary distresses leading to failure in OGFCs). First, when the production temperatures were reduced, sufficient heat was not developed to adequately dry the aggregates during production. This led to moisture remaining in the aggregates and the increased potential for stripping. Additionally, reducing the mix production temperature resulted in the OGFC arriving at the project site cooler than the desired compaction temperature. When this occurred, the OGFC did not always bond with the underlying layer (through the tack coat) and resulted in an increased potential for raveling and delamination. During the 1980's the catastrophic raveling and delamination problems were of such magnitude that a number of agencies placed a moratorium on the use of OGFC, including Mississippi.

Dense-Graded and OGFC Gradation
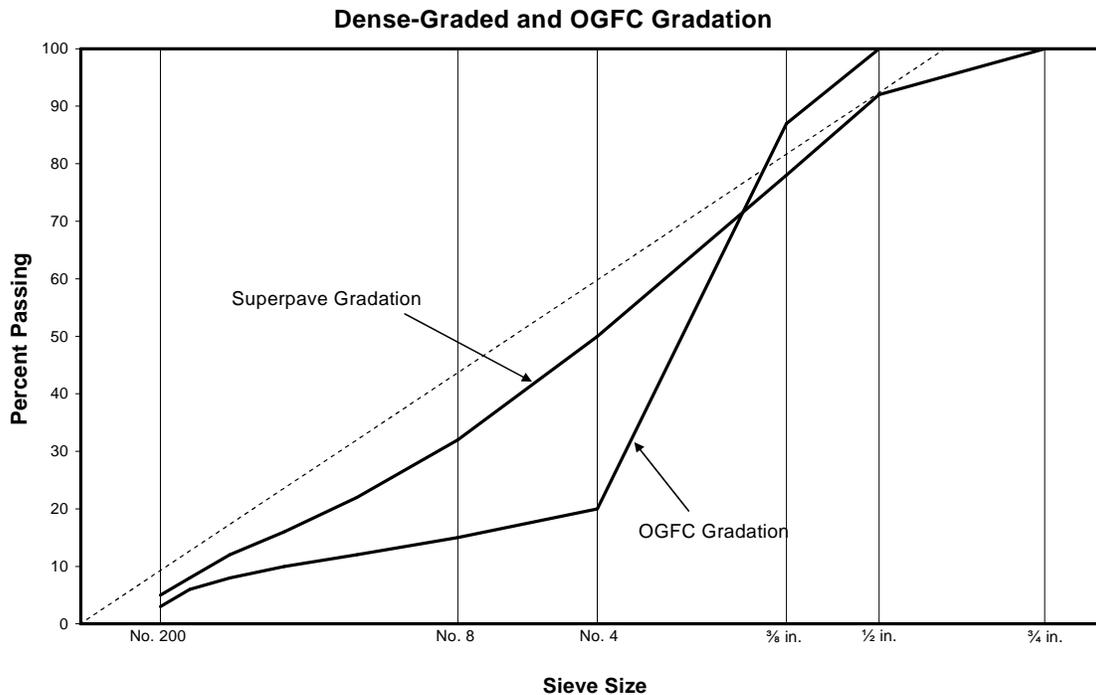
Figure 7: Comparison of Typical Superpave and OGFC Gradations

A survey of state agencies conducted by the National Center for Asphalt Technology in 1998 indicated that nineteen states were still using OGFCs (3). The vast majority of these states that reported good performance indicated the use of coarser gradations than the FHWA mix design method developed in the 1980's and were also using stiffer, polymer-modified asphalt binders. Therefore, state agencies continued to evolve OGFCs. Respondents to the survey that indicated good performance stated that service lives of 8 years or more were expected.

There is a single reason that state agencies continued to evolve OGFC mixes past the problematic 1980's and that was safety. OGFCs likely provide the safest HMA wearing surface available. OGFCs have been shown to have excellent friction (most dramatically in wet weather), reduce splash and spray, reduce the potential for hydroplaning and improve nighttime visibility (by reducing glare). Additional benefits of using OGFCs include reduced tire/pavement noise, smoother pavements (thereby increased fuel economy) and use of relatively thin layers.

The property of OGFC that leads to the safety benefits mentioned above is the relatively high permeability of OGFC compared to dense-graded HMAs. Because of the very coarse gradation and lack of fines, OGFCs have very high air void contents in the range of 15 to 22 percent. These high air void contents result in interconnected voids that allow water to infiltrate into the OGFC layer during a rain event. Without water on the pavement surface, the wet weather frictional properties of the pavement improve, splash/spray is reduced and the potential for hydroplaning is greatly reduced.

There are three primary types of OGFC that are being used in the US. All three types utilize an open aggregate gradation. The primary difference in the three types is the design air void content and asphalt binder type/content. OGFCs that are designed to have at least 18 percent air voids are termed Permeable Friction Courses (PFC). PFCs are a special type OGFC that are specifically designed to have high air void contents, typically 18 to 22 percent, for removing large volumes of water from the pavement surface. Another type of OGFC used in the US is the Asphalt Rubber Friction Course (ARFC). The purpose of ARFC mixes is to specifically reduce tire/pavement noise. This mix type is commonly used in Arizona and southern California. ARFC mixes do utilize open gradations; however, asphalt binder modified by rubber is used. Typically, asphalt rubber binder contents for ARFCs are near 8 percent and air void contents are around 12 to 15 percent. The final OGFC type used in the US can be termed an Asphalt Concrete Friction Course (ACFC). These OGFC types are not generally as coarse as PFCs and, therefore, are not designed at as high of an air void content. Air voids within ACFCs are generally above 15 percent. OGFCs should be considered a premium type of HMA. Because of the use of modified binders and fibers, costs are increased. OGFCs are only used as wearing layers on the top of the pavement structure in high speed locations.

CHAPTER 4 -MIX DESIGN CONSIDERATIONS

The design of all three general HMA mix types discussed in the previous section is similar in that they involve four primary steps. The first step in designing all three mix types is to select appropriate materials. Secondly, the selected aggregates need to be blended and evaluated to determine the design gradation. The next step is to determine the optimum asphalt binder content. Finally, the designed mix performance is evaluated.

Another commonality in the design of the three mix types is that the Superpave gyratory compactor is used as the laboratory compactive effort. However, the N_{des} for the different mixes are different. For dense-graded mixes, there are three different design compactive efforts, while for SMA and OGFC there is a single design compactive effort.

The following sections describe the design of each HMA type. The discussion focuses on the differences in design methodologies.

4.1   Design of Dense-Graded HMA

Being the workhorse HMA type in Mississippi, many dense-graded mixes have been designed. In the 1990's, the MDOT adopted the Superpave mix design system for designing dense-graded HMA. Since that time there have been slight modifications in specification values; though, the overall methodology has stayed the same. As stated above, there are four primary steps in designing dense-graded HMA. The first step is selection of appropriate materials. Materials needing selection for dense-graded HMA include coarse aggregates, fine aggregates, anti-stripping agents and asphalt binder. For each of these materials, MDOT provides specification values depending upon NMAS, N_{des} or other criteria.

The next step in the design of dense-graded HMA is to blend the selected aggregates into a gradation that meets the project specification, called a trial blend. As stated previously, MDOT specifies five different NMAS gradation ranges which include: 4.75 mm, 9.5 mm, 12.5 mm, 19.0 mm, and 25.0 mm. The trial blend is mixed with a trial asphalt binder content and compacted to the appropriate N_{des}. After compaction, the volumetric properties of the compacted mix should be evaluated and compared to the specifications. If the volumetric properties will not meet requirements, additional trial blends should be developed and evaluated. A blend of aggregates which will meet all volumetric criteria is selected as the design gradation.

The third step in designing dense-graded HMA is to determine the optimum asphalt binder content for the selected aggregate blend. This process entails adding asphalt binder to the selected aggregate blend and compacting with the Superpave gyratory compactor to the design gyration level. Typically, 0.5 percent increments in asphalt binder content are utilized. The aggregate blend is combined with binder at several different asphalt binder contents and the volumetric properties evaluated.

Optimum asphalt binder content is selected as the asphalt binder content that results in 4 percent air voids and meets all other volumetric properties.

The final step is designing dense-graded mixes is to conduct moisture susceptibility testing. In Mississippi, the tensile strength ratio (MT-63) and Boiling Water Test (MT-59) are specified. While hydrated lime is required in all HMA mixes, liquid anti-strips are sometimes needed when moisture susceptibility testing results do not meet requirements.

For HT surface mixes, there is also a required maximum rut depth in The Asphalt Pavement Analyzer. The maximum rut depth is 10mm.

4.2   Design of Stone Matrix Asphalt

Similar to the design of dense-graded HMA, the design of SMA mixes includes four steps. The first step is select appropriate materials. Materials requiring selection include coarse aggregates, fine aggregates, asphalt binder, mineral filler, anti-stripping agents, and stabilizing additives. Because SMA derives its stability from stone-on-stone contact, the quality of the aggregates is generally required to be slightly better than for dense-graded mixes. In Mississippi, the percent mechanically fractured faces must be 95 percent two or more for all SMA mixes. Additionally, a maximum of 20 percent flat and elongated at 3:1 is specified.

Asphalt binders used in SMA shall be a PG 76-22 for all SMA mixtures in Mississippi. Polymers used to modify the asphalt binder must meet the requirements of Section 702.08.3 of the Standard Specifications.

Mineral fillers are generally required within SMA in order to provide sufficient fines in the gradation. Hydrated lime is also required in SMA as an anti-stripping agent.

The next step in the design of SMA mixes is to select the design aggregate structure (gradation). Specified gradations for SMA are based upon aggregate volume and not mass. Table 2 presents MDOT's specified gradations for SMA. An example of how to proportion aggregate stockpiles volumetrically to meet SMA gradation requirements is provided in MT-80.

Table 2: Mississippi's SMA Gradations (Percent Passing by Volume)

Sieve Size	Nominal Maximum Aggregate Size					
	19.0mm		12.5mm		9.5mm	
	Lower Control	Upper Control	Lower Control	Upper Control	Lower Control	Upper Control
1 in.	100	100				
¾ in.	90	100	100	100		
½ in.	50	74	90	100	100	100
3/8 in.	25	60	26	78	90	100
No. 4	20	28	20	28	26	60
No. 8	16	24	16	24	20	28
No. 16	13	21	13	21	13	21
No. 30	12	18	12	18	12	18
No. 50	12	15	12	15	12	15
No. 200	8.0	10.0	8.0	10.0	8.0	10.0

In order to select the design gradation, it is good practice for the mix designer to develop three trial blends that fall within the gradation specification range. The three trial gradations should fall along the coarse and fine limits of the gradation band with the third falling in the middle. The percent passing the No. 200 sieve should be about 10 percent for all three trial blends.

For best performance, the SMA mixture must have stone-on-stone contact; therefore, also included within this second step is the determination of the VCA of the coarse fraction of the trial blends. The coarse fraction of the trial blend is defined as the portion of aggregate coarser than the break point sieve. The break point sieve is defined as the finest sieve to retain 10 percent or more of the aggregate blend. The definition of the break point sieve is illustrated in Figure 8.
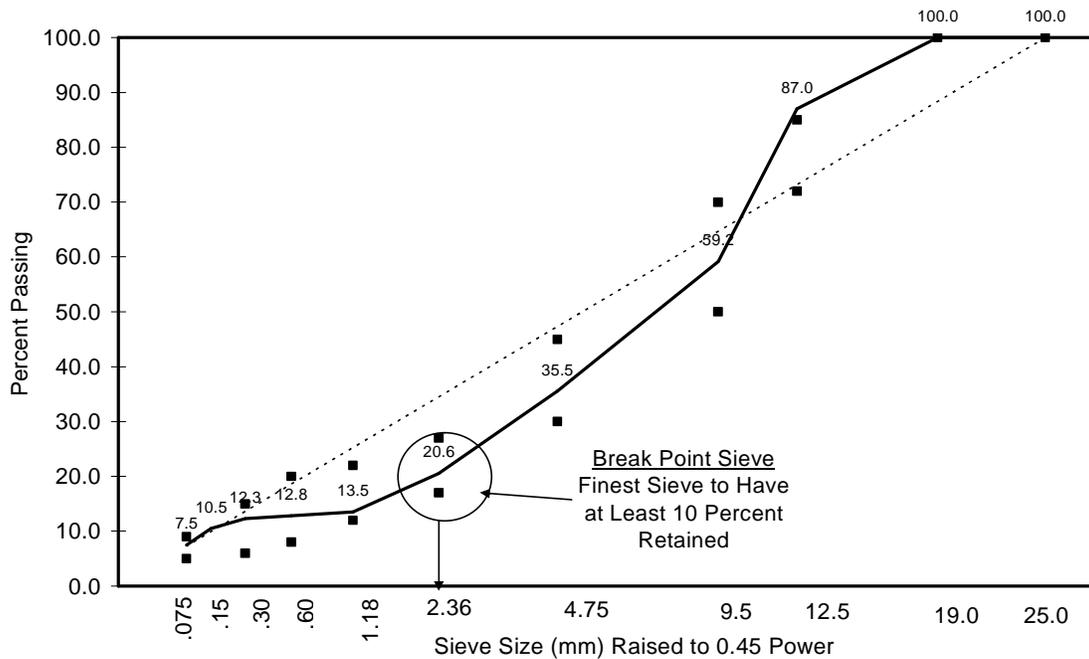
Figure 8: Illustration of Definition for Break Point Sieve

The VCA of the coarse aggregate fraction (VCA_{dr}) is determined using AASHTO T19. When the dry-rodded density of the coarse aggregate fraction has been determined, the VCA_{dr} for the fraction can be calculated.

The final activity of the second step is to select the design gradation. This involves adding a trial asphalt binder content to the trial gradation blends, compacting trial mixes in the Superpave gyratory compactor and evaluating the volumetric properties of the trial mixes. Because the specifications for SMA design call for a minimum optimum asphalt binder content, a starting trial asphalt binder content should be slightly higher than the minimum requirement. Samples of SMA are compacted in the Superpave gyratory compactor to 75 gyrations.

After compacting each of the trial blends, the volumetric properties of the mixes are determined. Three volumetric properties are of interest: voids in total mix (VTM), voids in mineral aggregate (VMA), and the VCA ratio. For the VCA ratio, the VCA of the compacted mix is calculated (VCA_{mix}) and compared to the VCA_{dr}. If the VCA_{mix} is less than VCA_{dr}, then stone-on-stone contact is assumed to have occurred. Once the VTM, VMA and VCA ratio are determined, each is compared to the specification values. A trial blend that meets or exceeds the VMA requirement and has stone-on-stone contact should be selected as the design gradation.

Once the design gradation has been chosen, the third step in the design of SMA mixes is to determine the optimum asphalt binder content. This step entails compacting SMA mixes at varying asphalt binder contents, generally 0.5 percent apart, in order to

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develop the relationships between the asphalt binder content and different volumetric properties. Optimum asphalt binder content is defined as the binder content that produces 4 percent air voids in the compacted mix and meets all other volumetric properties.

Once the optimum asphalt binder content is selected, performance testing is conducted. The MDOT specification requires the testing of mortars using the Superpave asphalt binder testing equipment. The mortar is comprised of the asphalt binder, aggregate fraction finer than the No. 200 sieve, and stabilizing fiber. For this testing, the constituents of the mortar are mixed and tested with the dynamic shear rheometer (DSR) and bending beam rheometer (BBR). Mortars are tested with the asphalt binder in three aged conditions. The asphalt binder is added to the other constituents in an unaged condition, rolling thin-film oven aged condition and pressure aging vessel aged material.

Another performance related test conducted on the designed SMA is draindown sensitivity. According to MT-82, draindown testing must be completed at three temperatures: at anticipated plant production temperature and plus-or-minus 27°F from the anticipated plant production temperature. The draindown value at each temperature must be below 0.3 percent, based upon total mix mass.

The final performance related testing is to evaluate the resistance to stripping. Both TSR's and the boil test are required for evaluating the resistance to stripping.

4.2.1   Troubleshooting SMA Mix Designs

If the mix designer is unable to produce a mixture that meets all requirements, remedial action will be necessary. Some suggestions to improve mix properties are provided below.

The amount of air voids in the mix can be controlled by the asphalt binder content. However, a problem occurs when low voids exist at the minimum asphalt binder content. Lowering the asphalt binder content below the minimum to achieve the proper air voids violates the minimum asphalt binder content requirement. Instead, the aggregate gradation must be modified to increase the VMA so that additional asphalt binder can be added without decreasing the voids below an acceptable level.

The VMA may be raised by decreasing the percentage of aggregate passing the break point sieve or by decreasing the percentage of material passing the No. 200 sieve. Changing aggregate sources or stockpiles may also be required to increase VMA.

If the VCA_{mix} is higher than the VCA_{dr} then the gradation must be modified. This is generally accomplished by decreasing the percent passing the break point sieve.

If the mix fails to meet moisture susceptibility requirements, the type and/or dosage of anti-stripping additive may need to be changed. If this proves ineffective, the aggregate source and/or asphalt binder source can be changed to obtain better aggregate/binder compatibility.

Problems with draindown sensitivity can be remedied by increasing the amount of stabilizing additive or by selecting a different stabilizing additive. Cellulose fiber contents for 0.3 percent and mineral fiber contents of 0.4 percent, by total mix mass, have worked well to minimize draindown potential.

4.3   Design of Open-Graded Friction Course

The design of OGFC mixes has many similarities to this design of SMA, primarily because both mix types are designed to have stone-on-stone contact. Because of the desired stone-on-stone contact, the selected aggregates for OGFCs must be of high quality. Similar to SMA, the aggregate quality requirements are slightly higher than for dense-graded mixes. The percent of coarse aggregates with two or more fractured faces requirements is 90 percent. Flat and elongated particles are measured at a 3 to 1 ratio, with a maximum of 20 percent. A PG 76-22, polymer modified asphalt binder is required for OGFCs along with stabilizing additives (fibers).

The second step in the design of OGFC mixes is to select the design gradation. For OGFCs, MDOT specified gradations are based upon mass and not volume. MDOT's two specified gradations are provided in Table 3. In order to select the design gradation, three trial blends should be developed. One trial gradation should fall along the coarse limits for OGFC while one should fall along the fine limits and one falling in the middle.

Table 3: Mississippi's OGFC Gradations

Sieve Size	12.5 mm	9.5 mm
½ in. (12.5 mm)	100	100
3/8 in. (9.5 mm)	80-89	90-100
No. 4 (4.75 mm)	15-30	15-30
No. 8 (2.36 mm)	10-20	10-20
No. 200 (75 μm)	2-5	2-5

Similar to SMA, the VCA_{dr} should be determined for the coarse fraction of the aggregate blend. The coarse fraction is defined as the portion of the aggregate retained on the breakpoint sieve. VCA_{dr} is determined using AASHTO T19 similar to for SMA mixes.

To select the design gradation, asphalt binder is added to each trial blend at a trial asphalt binder content. Similar to SMA, OGFCs have a minimum asphalt binder content specified; therefore, the trial asphalt binder content should be slightly higher than the minimum.

Each trial blend should be compacted to 50 gyrations in the Superpave gyratory compactor. After compaction, the volumetric properties of the compacted OGFC trial blends should be evaluated. One difference required for OGFCs is that the bulk specific gravity of the compacted OGFC is measured using the vacuum sealing method outlined in ASTM D6752. Volumetric properties of interest are VTM and VCA_{mix}. The voids in total mix must be greater than 15 percent and the VCA_{mix} must be less than VCA_{dr}.

The third step in designing OGFC is to determine the optimum asphalt binder content. The process for selecting optimum asphalt binder content for OGFC mixes is different than the methods presented previously for dense-graded and SMA mixes. Instead of targeting an asphalt binder content that results in a specific air void content, optimum binder content is selected as a asphalt binder content that meets all specified properties. An asphalt binder content that meets all of the following criteria is selected as optimum asphalt binder content:

1. Air voids must be 15 percent or greater.
2. Laboratory permeability determined in accordance with MT-84 must be 30 meters per day or greater.
3. Asphalt draindown shall not exceed 0.3 percent when tested in accordance with MT-82.
4. The aged abrasion loss shall not exceed 40 percent and unaged abrasion loss shall not exceed 30 percent as determined by MT-85.

Of the above tests, the one that most designers would be least familiar is the abrasion loss test. In the literature, this test is referred to as the Cantabro Abrasion Loss test. The Cantabro Abrasion Loss test is used as a durability indicator. For this test, three OGFC specimens are prepared at each asphalt binder content. A single specimen is placed into a Los Angeles Abrasion drum without the charge of steel spheres. The drum is then rotated for 300 revolutions at 30 revolutions per minute. At the conclusion of the 300 revolutions, the mass loss from the specimen is calculated based upon the original specimen mass. Figure 9 illustrates a test specimen after the Cantabro Abrasion Loss test.

Figure 9: Illustration of Specimen after Cantabro Abrasion Loss Test

The final step in the design of OGFCs is to evaluate moisture susceptibility in accordance with MT-59 and MT-63. When conducting MT-63, samples should be compacted at the selected optimum asphalt binder content to the design compactive effort (or design air voids) instead of targeting 7 percent air voids. Also, vacuum saturation is not required.

4.3.1   *Troubleshooting OGFC Mix Designs*

If the mix designer is unable to successfully design an OGFC mixture that meets all requirements, remedial action will be required. Some troubleshooting suggestions to improve mix properties are provided below.

The amount of air voids can be controlled by the asphalt binder content. However, the designer must still meet the minimum asphalt binder content requirements as well as the other three criteria listed above: laboratory permeability, draindown and abrasion loss. If sufficient air voids are not produced, the designer will generally have to modify the gradation of the aggregate blend. To increase air voids, the designer should decrease the percent passing the breakpoint sieve. Permeability and air voids are related; therefore, permeability can be increased by reducing the asphalt binder content or decreasing the percent passing the break point sieve.

If the VCA_{mix} is higher than the VCA_{dr}, then the aggregate gradation must be modified. This is accomplished by decreasing the percent passing the breakpoint sieve.

The abrasion loss is affected by two characteristics: the stiffness of the asphalt binder and the asphalt binder content. If the abrasion loss is greater than the maximum requirement, either more asphalt binder or a stiffer asphalt binder is needed.
If the mixture fails to meet moisture susceptibility requirements, the type and/or dosage rate of anti-stripping additive may need to be changed. If this proves ineffective, the aggregate source and/or asphalt binder source can be changed to obtain better aggregate/binder compatibility.

Problems with draindown sensitivity can be remedied by increasing the amount of stabilizing additive or by selecting a different stabilizing additive. Cellulose fiber contents of 0.3 percent and mineral filler contents of 0.4 percent, by total mix mass, have worked well to minimize draindown potential.

CHAPTER 5 - CONSTRUCTION ISSUES

During construction of any HMA mixture, there are four primary phases: production, transportation, placement and compaction. The construction of dense-graded, SMA, and OGFC mixes have many similarities. When different than dense-graded mixes, construction of SMA and OGFC are very similar. The following sections discuss construction of HMA mixes and highlight differences that are specific to SMA and/or OGFC.

5.1   Plant Production

Any HMA production facility that is capable of producing high quality HMA can produce high quality SMA and OGFC. This section provides for procedures involving aggregate handling, stabilizing additives, liquid asphalt, mixing times, and plant calibration along with other issues that require special attention when compared to conventional HMA production.

5.1.1   Aggregates

As with the construction of any HMA pavement layer, quality begins with proper aggregate stockpile management. Stockpiles should be built on sloped, clean, stable surfaces with the different stockpiles kept separated. Every effort should be made to maintain a relatively low moisture content within the aggregate stockpiles. Low moisture contents and low moisture content variability will allow for easier control of mixing temperature (4).

SMA and OGFC mixtures must contain a high percentage of coarse aggregate in order to provide the desired stone-on-stone contact. While it is typical to blend two or three different aggregate stockpiles in the mixture (coarse aggregate, immediate aggregate, and fine aggregate), the coarse aggregate (defined as the material retained on the break point sieve) is usually a high percentage of the gradation blend. Since the coarse aggregate gradation can have a tremendous effect on the quality of the mixture produced, it is necessary that the aggregates be carefully handled and stockpiled. For best control of the coarse aggregate fraction, course aggregate stockpiles should be fractionated into single sizes down to the 3/8 in. size. Consideration should be given to feeding the coarse aggregate stockpile through more than one cold feed bin to provide better control over the production process. Using more than one cold feed bin for the coarse aggregate sizes will minimize variability in the coarse aggregate gradation (2).

5.1.2   Liquid Asphalt

The handling and storage of liquid asphalt binder for SMA and OGFC production is similar to that for any HMA mixture. If not already equipped, the plant facility should have a different, or second, storage tank designated strictly for modified binders. When modified asphalt binders are used, the storage temperature may increase slightly from

those of neat asphalt binders. Mechanical agitators may be required within storage tanks when modified binders are used (4). Contractors should follow the manufacturers' recommendations for circulation and storage of modified asphalt binders. Metering and introduction of asphalt binder into the mixture may be done by any of the standard methods using a temperature compensating system. It is very important however that the asphalt binder be metered accurately (5).

5.1.3   Stabilizing Additives

With the high asphalt binder contents and large fraction of coarse aggregate inherent to SMA and OGFC mixtures, a stabilizing additive of some type is specified to hold the asphalt binder within the coarse aggregate structure during storage, transportation and placement. Draindown will generally occur at typical production temperatures if a stabilizing additive is not used.

Both cellulose and mineral fibers have been used in SMA and OGFC mixture production. Dosage rates vary, but typically the rates are 0.3 percent for cellulose and 0.4 percent for mineral fiber, by total mixture mass (5). Fibers can generally be purchased in two forms, loose and pelletized (5). Fibers in a dry, loose state come packaged in plastic bags or in bulk. Fibers can also be pelletized with the addition of some amount of a binding agent. Asphalt binder and waxy substances have both been used as binding agents within pelletized fibers. Both fiber types (loose or pelletized) have been added into batch and drum-mix plants with success.
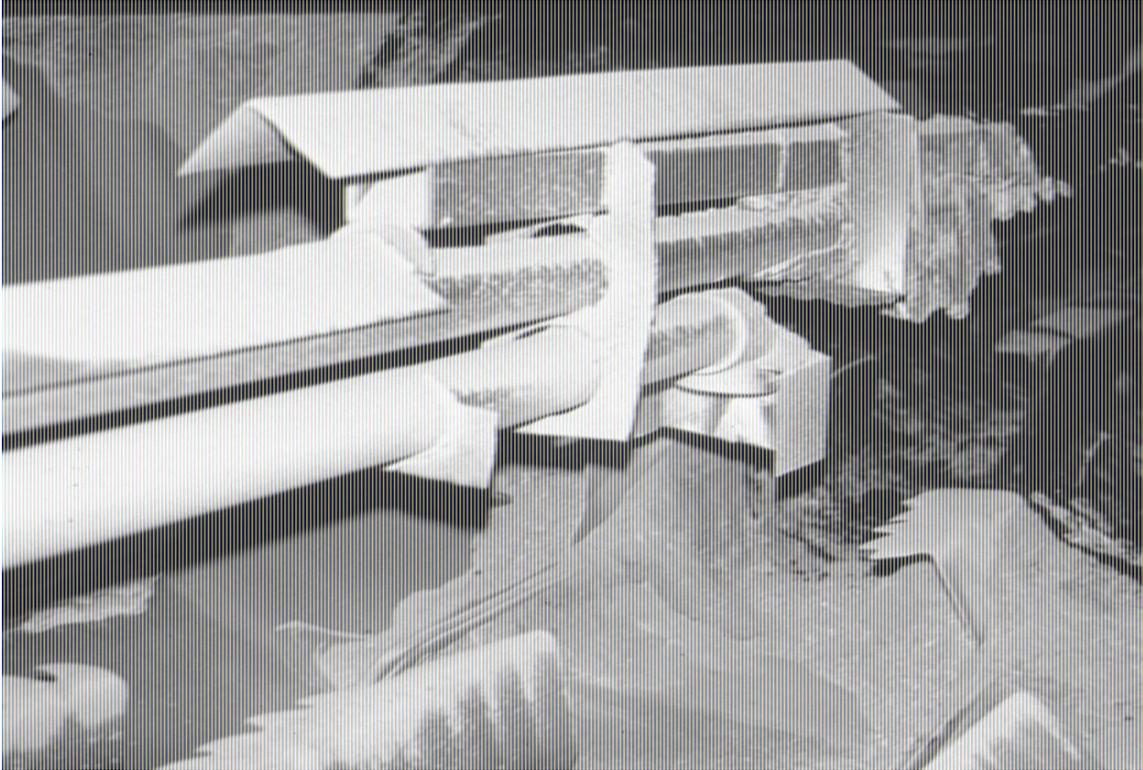
For batch plant production, loose fibers are sometimes delivered to the plant site in bags. The bags are usually made from a material which melts easily at typical mixing temperatures. Therefore, the bags can be added directly to the pugmill during each dry mix cycle. When the bags melt only the fiber remains. Addition of the bags of fibers can be done by workers on the pugmill platform. At the appropriate time in every dry mix cycle, the workers add the correct number of bags to the pugmill. The bags of fiber can be elevated to the pugmill platform by the use of a conveyor belt. While this method of manual introduction works satisfactorily, it is labor intensive.

Another method for addition of fibers into a batch plant is by blowing them into the plant using a machine typically designed and supplied by the fiber manufacturer (Figure 10). The dry, loose fiber is placed in the hopper of the machine where it is fluffed by large paddles. The fluffed fiber next enters an auger system which conditions the material to a known density. The fiber is then metered by the machine and blown into the pugmill or weigh hopper at the appropriate time. These machines can meter in the proper amount of fiber by mass or blow in a known volume (5).

Figure 10: Fiber Introduction System

This fiber blowing method can also be used in a drum mix plant. The same machine is used and the fibers are simply blown into the drum. When using this method in a drum mix plant the fiber introduction line should be placed in the drum within 1 ft upstream of the asphalt binder line (Figure 11) (5). It is imperative that fibers be captured by the asphalt binder before being exposed to the high velocity gases in the drum. If the fiber gets into the gas stream, they will enter the dust control system of the plant (5).

Figure 11: Typical Location for Introduction of Fibers into Drum-Mix Plant

Whenever loose fibers are blown into the production process, whether a drum mix or batch plant is used, the fiber blowing equipment should be tied into the plant control system (2). The fiber delivery system should be calibrated and continually monitored during production. A common practice is to include a clear section on the hose between the fiber blowing equipment and the introduction point within the production process (Figure 12). This clear section can provide a quick, qualitative evaluation of whether the fiber is being properly blown into the drum. Variations in the amount of fibers within SMA and OGFC mixes can have a detrimental impact on the finished pavement.

Figure 12: Clear Section of Fiber Introduction Line

The pelletized form of fibers can be used in both drum-mix and batch plants. The pellets are shipped to the plant in bulk form and when needed are placed into a hopper (Figure 13). From the hopper they can be metered and conveyed to the drum or pugmill via a calibrated conveyor belt. Addition of the pellets generally occurs at the RAP collar of a drum mix plant or they are added directly into the pugmill of a batch plant. Whether in the drum or the pugmill, the pellets are mixed with the heated aggregate and the heat from the aggregates cause the binding agent in the pellets to become fluid. This allows the fiber to mix with the aggregate (5). Some forms of pelletized fibers do contain a given amount of asphalt binder. In most instances, this amount of asphalt binder is very small and is not included within the total asphalt binder content (6). Check with the fiber manufacturer to determine the asphalt contents of the pellets.

Figure 13: Typical Fiber Hopper for Pelletized Fibers

It is again imperative that the fiber addition, whether it is loose or pelletized, be calibrated to ensure that the mixture continually receives the correct amount of fiber. If the fiber content is not accurately controlled at the proper level, fat spots can result on the surface of the finished pavement. Also, portions of the mixture will be dry and unworkable. For assistance with the fiber storage, handling, and introduction into the mixture, the fiber manufacturer should be consulted.

5.2   Mixture Production

Production of SMA and OGFC is similar to the production of standard dense-graded HMA from the standpoint that care should be taken to ensure a quality mixture is produced. Production is discussed in this section with special emphasis on production areas where SMA and OGFC quality may be significantly affected.

5.2.1   Plant Calibration

It is important that all the feed systems of the plant be carefully calibrated prior to production of SMA and OGFC. Operation of the aggregate cold feed bins can have a significant influence on the finished mixture, even in a batch plant where hot bins exist (2, 6). Calibration of the aggregate cold feed bins should therefore be performed with care.

The stabilizing additive delivery system should be calibrated and continually monitored during production. Variations in the amount of stabilizing additive can have a detrimental impact on the finished pavement. Stabilizing additive manufacturers will usually assist the hot mix producer in setting up, calibrating, and monitoring the stabilizing additive system.

5.2.2   Plant Production

Similar to the production of typical HMA mixtures, mixing temperatures during the production of SMA and OGFC mixes should be based upon the properties of the asphalt binder (2). Mixing temperatures should not be arbitrarily raised or lowered. Elevated mixing temperatures increase the potential for damage to the asphalt binder due to rapid oxidation, which can lead to premature distresses (2). Additionally, artificially increasing the mixing temperature can increase the potential for draindown problems during storage, transportation and placement (2, 6). MDOT has a maximum temperature requirement of 340°F during production. Arbitrarily lowering the mixing temperature can result in not removing the needed moisture from the aggregates within the drying process. Moisture remaining within the aggregates can increase potential of moisture induced damage. Arbitrarily lowering the mixing temperature will also likely result in mixture delivered to the construction project that is cooler than the desired compaction temperature. If this occurs, the mix may not bond with the underlying layer (through the tack coat) and result in increased potential for raveling and delamination. Experience seems to indicate that normal HMA production temperatures or slightly higher are adequate. In addition to the properties of the asphalt binder, the mixing temperature should be chosen to ensure a uniform mixture that allows enough time for transporting, placing, and compaction of the mixture.

When using a batch plant to produce SMA or OGFC, the screening capacity of the screen deck will need to be considered. Since gradations of these mixes are generally a single-sized aggregate, override of the screen deck and hot bins may occur (5). If this occurs, the rate of production should be decreased.

5.2.3   Mixing Time

When adding fibers to SMA or OGFC mixtures, experience has shown that the mixing time should be increased slightly over that of conventional HMA (5). This additional time allows for the fibers to be sufficiently distributed within the mixture. In a batch plant, this requires that both the dry and wet cycles be increased from 5 to 15 seconds each. In a parallel flow drum plant, the asphalt binder injection line may be relocated, usually extended when pelletized fibers are used (2). This allows for more complete mixing of the pellets before the asphalt binder is added. In both cases, the proper mixing times can be estimated by visual inspection of the mixture. If clumps of fibers or pellets still exist intact in the mixture at the discharge chute, or if aggregate particles are not sufficiently coated, mixing times should be increased or other changes made. For other plants such as double-barrel drum mixers and plants with coater boxes,

the effective mixing time can be adjusted in a number of ways including a reduction of the production rate, slope reduction of the drum, etc.

5.2.4 *Mixture Storage*

SMA and OGFC mixtures should not be stored at elevated temperatures for extended periods of time as this could facilitate draindown (5). In general, experience has shown that these mixes can be stored for 2 hours or less hours without detriment (2, 6). In no instance should the mixture be stored in the silo overnight.

5.3 Transportation

The mixture is transported to the project site using the same equipment used for dense-graded HMA (4). Generally, no additional precautions are required; however, there are some best practices that should be followed.

One of the keys to successful SMA and OGFC projects is having adequate transportation to supply mix to the paver so that the paver does not have to stop and wait on materials (2). Since the contractor often does not own the trucks, communication with the trucking operator is essential to avoid delays.

Because of the bonding tendency of the modified asphalt binder generally used in SMA and OGFC, the truck beds should be cleaned frequently and a thorough coat of an asphalt release agent applied. Also, truck beds should be raised after spraying to drain any puddles of the release agent. Excess release agent, if not removed, will cool the mix and cause cold lumps in the mix. MDOT has an approved list of release agents. Use of fuel oils, including diesel, in any form are strictly prohibited.

Haul trucks should be covered tightly with a tarp to prevent excessive crusting of the mix during transportation (4). Cold lumps do not break down readily and cause pulls in the mat. Since long haul distances will compound this problem, the haul distance should be kept under approximately 50 miles. To combat this problem, some agencies require insulated truck beds (4).

As an alternative to insulated truck beds, a "Heated Dump Body" may be used. A "Heated Dump Body" refers to a transport vehicle that is capable of diverting engine exhaust (Figure 14) and transmitting the heat evenly throughout the dump body to help keep the mix from excessively cooling.
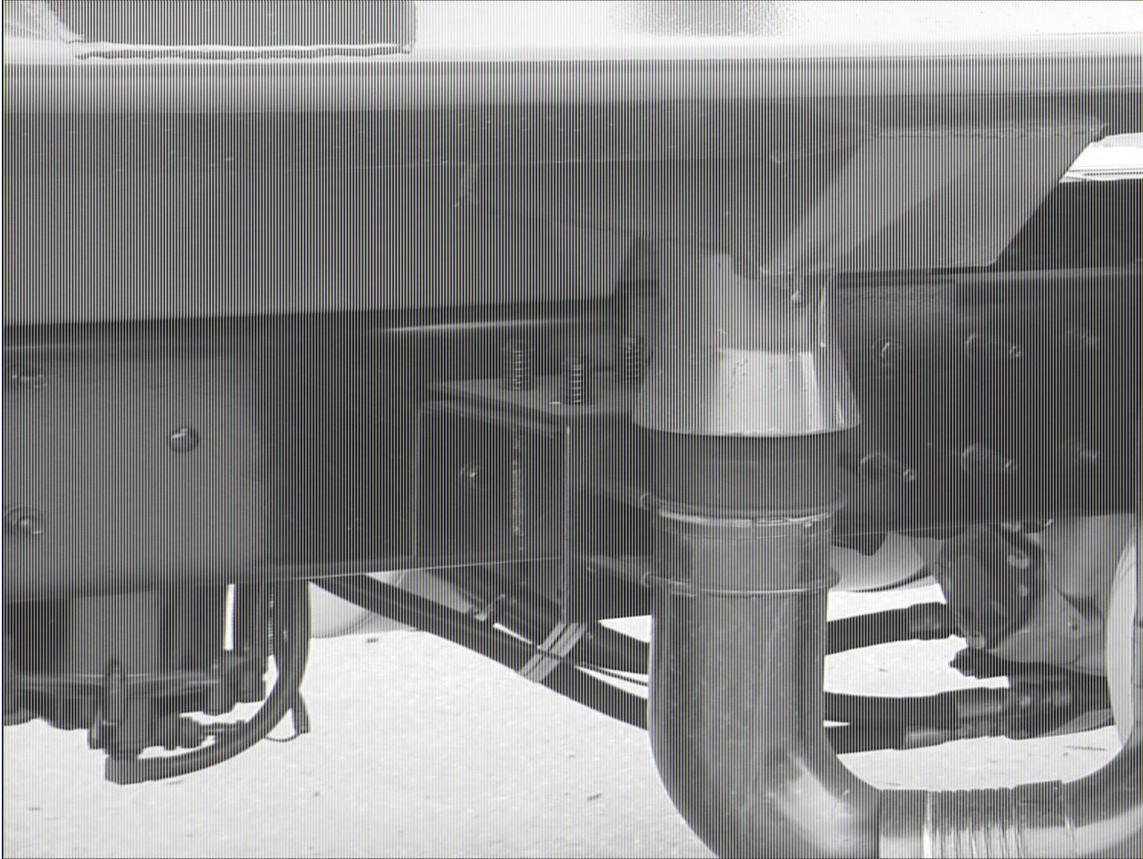
Figure 14: Exhaust System for Heated Dump Body

5.4   Placement

Placement of SMA and OGFC is very similar to placement of dense-graded HMA. Typical asphalt pavers are utilized.

5.4.1   Weather Limitations

In order to achieve proper placement and compaction, SMA and OGFC should not be placed in cold or inclement weather. Ambient air and pavement temperatures must be at least 55ºF (10ºC). However, the ability to place these mixes will also depend on wind conditions, humidity, the lift thickness being placed, and the temperature of the existing pavement. Local experience with paving mixtures that include very stiff asphalt binders (polymer-modified) should be considered when considering weather limitations.

5.4.2   Pavement Surface Preparation

Prior to placing SMA and OGFC, preparation of the surface to be covered will depend on the type of surface onto which the mix will be placed. The preparation method used is generally the same as for conventional HMA mixtures. OGFC should enable rain water to penetrate the layer and be laterally drained off to the side of the road by flowing on an impermeable interface between the OGFC and underlying layer.

Therefore, the OGFC should only be placed on an impermeable HMA layer ($\underline{6}$). Placement on an impermeable layer will help ensure that during rainfall, the water will pass laterally through the OGFC and not be trapped in the underlying pavement layer, thus helping to eliminate the potential for moisture damage (stripping) in the underlying layer. OGFC should not be placed on rutted asphalt pavement. The rutted surface should first be milled or reshaped to that depth which allows the water to flow to the side of the road before placement of the OGFC mixture. The OGFC mat should be day-lighted on the shoulder so that rainwater percolating through the OGFC can drain out freely at its edge ($\underline{7}$). A strip at least 4 inches wide should be left between the OGFC and any grass area. If the OGFC is not laid over the entire width of an existing pavement, including the paved shoulder, then it should extend at least 12 to 20 inches onto the paved shoulder.

5.4.3   Paver Operation

Both SMA and OGFC mixtures are placed using conventional asphalt pavers. However, a hot screed is very important to prevent pulling of the mat. A propane torch or some other means to heat the paver screed before each startup is important.

The SMA and OGFC mixture is normally delivered to the paver in the traditional manner of backing in trucks. A Material Transfer Vehicle (MTV) with remixing capabilities can also be used. The use of a remixing MTV for transferring the mix from the trucks to the paver is required in Mississippi. It remixes most cold lumps produced during transportation, and also allows continuous operation of the paver for smoother surfaces.

5.4.4   Placement and Finishing

Immediately behind the paver, SMA and OGFC mixtures are known to be harsh and very sticky. For this reason a minimum of raking and hand working should be performed ($\underline{7}$). When needed, hand placement of the material can be accomplished with care.

Longitudinal joints are constructed by placing the mix approximately 10 to 15 percent of the lift thickness above the previously placed and compacted lane ($\underline{6}$). In other words, the hot lane should be placed 5 to 8 mm higher than the cold lane if the layer were 50mm in thickness. Therefore, it is important for the edge of the screed or extension to follow the joint exactly to prevent excessive overlap.

5.5   Compaction

SMA mixes are compacted in a manner similar to dense-graded mixes. However, close attention should be paid to mix temperature. Experience has shown that operating two breakdown rollers in vibratory mode works well for SMA mixes. Only conventional steel wheel rollers are used to compact OGFC, while vibratory and static rollers can be used for compaction of SMA. No pneumatic tire rolling is required on either SMA or OGFC.

5.5.1   Rolling

No minimum density is required for OGFC. Compaction of OGFC mixture should be accomplished as quickly as possible after placement. By its very nature, OGFC becomes difficult to compact once it begins to cool. For this reason it is imperative that the rollers be kept immediately behind the paver (6). Generally, only two to four passes of the breakdown roller are needed. A finish roller can be used to remove any roller marks.

Rolldown of OGFC and SMA mixtures is slightly less than one-half that for conventional mixtures. While conventional HMA mixtures roll down approximately 20-25 percent of the lift thickness, SMA and OGFC will normally rolldown 10 to 15 percent of the lift thickness (2, 6)). If the rolling operation gets behind, placement should slow until the rollers catch up with the paver (2).

It is normal practice to mix a minimum amount of release agent with the water in the roller drum to prevent the asphalt binder from sticking to the drum. Excessive amounts of water should not be used (2).

Pneumatic-tired rollers are not recommended for use on SMA or OGFC (5). The rubber tires tend to pick up the mortar causing surface defects.

One of the main differences between OGFC and SMA mixtures is that the goal for compaction is quite different. With SMA mixtures, compaction is necessary to make the mixture impermeable so that water does not infiltrate the layer through interconnected air voids. With the OGFC mixtures, compaction equipment is used only to seat the mixture in the tack coat to provide a good bond at the interface of layers. Otherwise, the mixture is intended to be highly permeable in order to transfer water through the layer onto the shoulder or edge of the pavement. Where air voids during construction are generally reduced to between 5 to 7 percent for SMA mixtures, OGFC should have above 15 percent air voids immediately after construction.

CHAPTER 6 - MIX SELECTION GUIDANCE

This section of the report provides recommended guidance for the selection of HMA mix type for various traffic and pavement type considerations. For the purposes of pavement layer characterization, this report will include four categories of HMA layers: surface courses, binder courses, base courses, and leveling courses. Surface courses generally contain the highest quality materials within the pavement structure. The surface course must be smooth, durable, rut resistant, and skid resistant (1). Binder courses help distribute the traffic loads from the pavement surface to the underlying layers. Binder courses also provide a construction platform for the surface course; therefore, binder courses can have a direct impact on smoothness (1). Base courses are generally placed upon the prepared subgrade, aggregate base, stabilized base or asphalt drainage course. Leveling courses, as the name suggests, is a layer of HMA that is used to correct small variations in the road profile either in the transverse or longitudinal direction.

When a pavement structure is designed, an important set of data required for the design is the estimated amount of traffic that the pavement will see during the design life. MDOT currently specifics HMA based upon three anticipated traffic volumes: standard, medium and high types. These categories are based upon anticipated equivalent single axle loads (ESALs) over a 10 year design life. These categories and associated ESAL levels are provided in Table 4.

Table 4: Traffic Categories for Specifying HMA

Category	10 yr. Design ESALs
Standard	< 1.0 million
Medium	1.0 to 3.0 million
High	> 3.0 million

According to the AASHTO design policy for streets and highways, traffic facilities can be classified for rural areas into: a) interstate, b) primary, c) secondary, and d) tertiary; and for urban areas into: a) freeway, b) arterial, c) collector, and d) local. Table 5 shows how these differ in their function.

Table 5: Differences in Traffic Facility Function

Function	Urban	Rural
Through movement exclusively	Freeway	Interstate
Through movement primarily, some land access	Arterial	Primary
Traffic movement to above facilities, access to abutting property	Collector	Secondary
Access to abutting land and local traffic movement	Local	Tertiary

Note that urban freeways can be part of the interstate system.

6.1   Determining Appropriate Mix Types (Mix Selection)

According to The National Asphalt Pavement Association (1), the following steps should normally be followed to determine appropriate mix types:

1. Determine total pavement thickness needed. For new construction this would include a structural design in accordance with MDOT's pavement design methodologies. For rehabilitation, a pavement and structural design evaluation should be performed.
2. Determine the type of HMA appropriate for the surface course based upon traffic and cost. Select a thickness and mix type for the surface course.
3. Subtract the thickness of the surface course from the total thickness and determine what mix or mixes are appropriate for the underlying layers.
4. Continue to subtract binder/base course mix thicknesses from the total thickness until the mixes and layer thicknesses have been selected for the required pavement structure.

An important component of selecting the appropriate mix for a given layer is the allowable lift thickness for the various HMA mixes that are available. Table 6 presents recommended thicknesses for various mixes along with current MDOT requirements. Recommended values shown in this table are slightly different than those contained within current MDOT specifications. Recommended values shown in Table 6 are based upon research conducted during National Cooperative Highway Research Program Project 9-27 (8), the current MDOT State Study 193 and experience. It is important to note that in-place density requirements are not applicable for any lift thickness below MDOT's current minimum requirements.

Table 6: Appropriate Lift Thicknesses for Various HMA Types

Mixture	Recommended		MDOT Requirements	
	Minimum	Maximum	Minimum	Maximum
25mm	3	4	3	4
19mm	2 ½	3 ½	2 ¼	3
12.5mm	1 ½	3	1 ½	2
9.5mm	1	2	1	1 ½
4.75mm	½	1 ¼	½	¾
SMA, 19mm	3	4	2 ¼	3
SMA, 12.5mm	2	3	1 ½	2
SMA, 9.5mm	1 ½	2 ½	1 ⅛	1 ½
OGFC, 12.5	1	1 ½	1	1 ¼
OGFC, 9.5	¾	1 ¼	¾	1

Discussion on the recommended guidance is provided for the three pavement layer types discussed above: surface course, binder course, and base course. Figure 15 illustrates the relative appropriateness of the various mix types to be placed as surface courses based upon the traffic category. Dense-graded HMA is applicable for all three traffic categories. SMA mixes have applicability in both the medium type and high type

traffic categories. SMA should be considered for all pavements that will experience 20 percent or more trucks and interstate pavements. SMA can also be considered for troublesome intersections on state highways (medium type traffic). OGFCs have applicability within the medium type and high type categories. OGFCs should be considered on all limited access highways with posted speed limits above 45 mph. OGFCs should only be considered on medium type pavement surfaces that have a history of wet weather accidents. Again, posted speed limits should be above 45 mph. For high type pavements, dense-graded, SMA and OGFC should all be considered as viable options on the pavement surface.
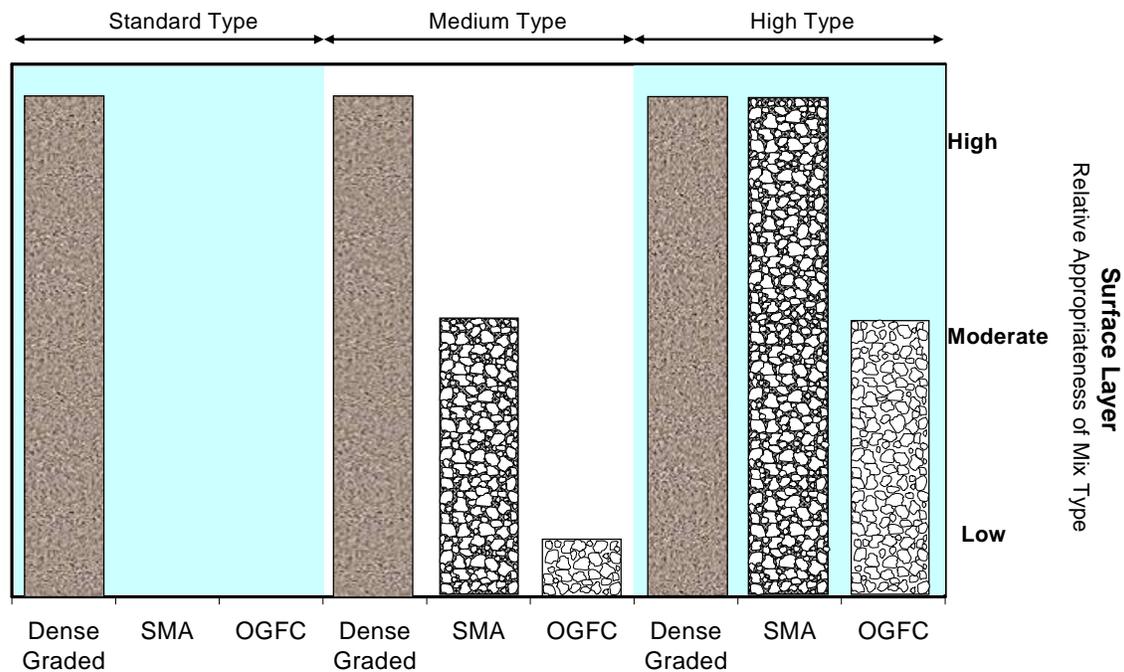
Figure 15: Relative Appropriateness of Mix Type - Surface Courses

Figure 16 illustrates the relative appropriateness of the HMA types as a binder course. Dense-graded mixes are applicable in all traffic categories. SMA would be appropriate on pavements that experience very high truck traffic or as an upper binder layer under an OGFC layer.
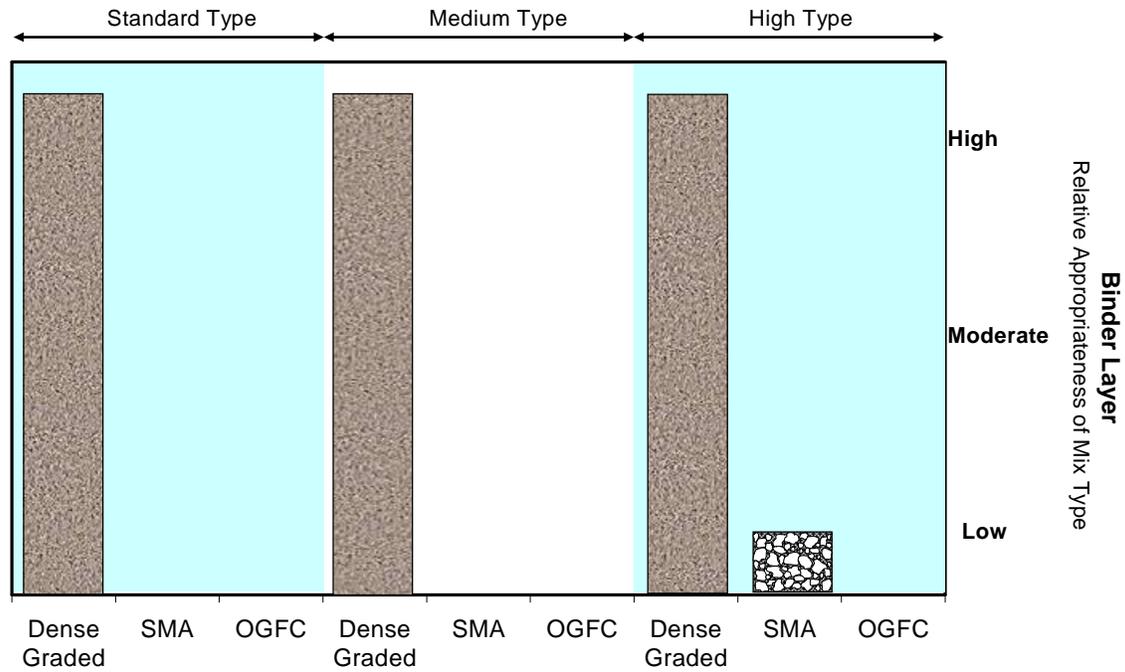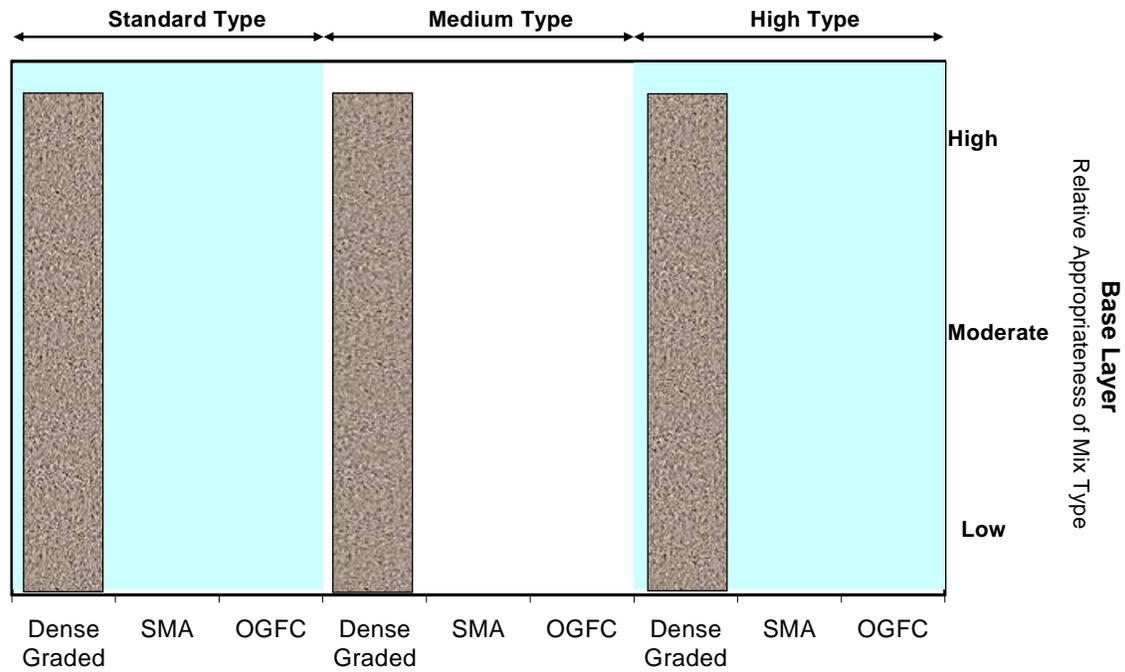
Figure 16: Relative Appropriateness of Mix Type - Binder Courses

Figure 17 illustrates the relative appropriateness of the three mix types as a base course. This figure shows that only dense-graded mixes are applicable for base course layers.

Figure 17: Relative Appropriateness of Mix Type - Base Courses

Tables 7 through 16 provide specific recommendations for selection of for mix types in Mississippi. These tables are based upon the pavement layer being considered and the traffic category of the pavement.

Table 7:Mix Selection Recommendations for Standard Type-Surface Courses

Pavement Layer: Surface Course
Traffic Category: Standard Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using ST design compactive effort
Nominal Maximum Aggregate Size (Gradation Size)	4.75mm, 9.5mm, 12.5mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Limited Uncrushed Gravels, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban Local, Urban Collector, Rural-Tertiary, Rural-Secondary

Comments:
1. These mixes are ideal for most city streets, low volume state routes, low volume county highways and parking lots. If the percent trucks are greater than 5 percent consider going to Medium Type HMA.
2. If available, fine-graded mixes would be preferable as these mix types are generally more durable.
3. 4.75mm mixes should be considered for overlay projects on structurally sound pavements.

Table 8: Mix Selection Recommendations for Medium Type-Surface Courses

Pavement Layer: Surface Course
Traffic Category: Medium Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using MT design compactive effort. SMA OGFC
Nominal Maximum Aggregate Size (Gradation Size)	4.75mm, 9.5mm, 12.5mm
Asphalt Binder Type	PG 67-22 and PG 76-22
Aggregate Types	Crushed Gravel, Crushed Stone, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban Collector, Urban-Arterial, Rural-Primary

Comments:
1. The vast majority of these mixes will be dense-graded. SMA should be considered at troublesome intersections. OGFC should only be considered on pavement surfaces that have a history of wet weather accidents. OGFCs greatly improve wet weather frictional properties.
2. Polymer-modified binders (PG 76-22) can also be used at troublesome intersections and may be needed on some roadways that will experience truck volumes over 10 percent.
3. The MT dense-graded mixes are appropriate for state highways that only experience a moderate amount of truck traffic. These mixes are also applicable in some urban settings where moderate truck traffic is anticipated.
4. MT mixes should only be considered for parking lots within truck lanes.
5. 4.75mm mixes should only be used as overlays on structurally sound pavements.

Table 9: Mix Selection Recommendations for High Type-Surface Courses

Pavement Layer: Surface Course
Traffic Category: High Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using HT design compactive effort. SMA OGFC
Nominal Maximum Aggregate Size (Gradation Size)	9.5mm, 12.5mm
Asphalt Binder Type	PG 67-22, PG 76-22 and PG 82-22
Aggregate Types	Crushed Gravel, Crushed Stone, Limited Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Freeway, Rural-Interstate, Urban-Arterial, Rural-Primary

Comments:
1. High-type surface courses should be used on pavements that will experience high truck volumes.
2. SMA should be considered on all interstates that have very high truck volumes
3. OGFC should be considered for all limited access, high speed, roadways with posted speed limits greater than 45 mph.
4. 9.5 and 12.5mm mixes are ideal for inlays or overlays less than 2 inches in thickness.
5. PG 82-22 asphalt binders should only be used at troublesome intersections with very high truck traffic or near large industrial sites with significant truck traffic.

Table 10: Mix Selection Recommendations for Standard Type-Binder Courses

Pavement Layer: Binder Course

Traffic Category: Standard Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using ST design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm and 19.0mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Limited Uncrushed Gravel, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Local, Urban-Collector, Rural-Tertiary, Rural-Secondary

Comments:

1. These mixes are ideal for most city streets, low volume state routes, low volume county highways and parking lots.
2. These mixes are also ideal as the lowest HMA layer in full-depth asphalt pavements constructed for low volume city streets and parking lots.

Table 11: Mix Selection Recommendations for Medium Type-Binder Course

Pavement Layer: Binder Course	
Traffic Category: Medium Type	
Characteristic	**Recommendation**
Applicable Mix Type(s)	Dense-graded HMA designed using MT design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm, 19.0mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Collector, Urban-Arterial, Rural-Primary

Comments:
1. These mixes are appropriate for state highways that only experience a moderate amount of trucks. These mixes may also be appropriate in some urban settings where moderate truck traffic is anticipated.

Table 12: Mix Selection Recommendations for High Type-Binder Courses

Pavement Layer: Binder Course
Traffic Category: High Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using HT design compactive effort. Dense-graded HMA designed using MT design compactive effort. SMA
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm, 19.0mm
Asphalt Binder Type	PG 67-22 and PG 76-22
Aggregate Types	Crushed Gravel, Crushed Stone, Limited Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Freeway, Rural-Interstate, Urban-Arterial, Rural-Primary

Comments:
1. For interstate type pavements with very high truck volumes, SMA can be used as the upper binder layer. A number of agencies utilize SMA upper binder layers overlain with an OGFC to provide a rut-resistant and safe wearing surface.
2. On very high truck volume roadways, a polymer-modified asphalt binder (PG 76-22) should be used in binder layers located within 4 inches of the pavement surface.
3. For binder layers 4 inches or more below the pavement surface on roadways with moderate truck volumes, an MT mix can be used.

Table 13: Mix Selection Recommendations for Standard Type-Base Courses

Pavement Layer: Base Course
Traffic Category: Standard Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using ST design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm,19.0mm, 25.0mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Uncrushed Gravel, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Local, Urban-Collector, Rural-Tertiary, Rural-Secondary

Comments:
  1. These mixes are ideal for most city streets, low volume state routes, low volume county highways and parking lots.

Table 14: Mix Selection Recommendations for Medium Type-Base Courses

Pavement Layer: Base Course
Traffic Category: Medium Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using MT design compactive effort. Dense-graded HMA designed using ST design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm, 19.0mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Uncrushed Gravel Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Collector, Urban-Arterial, Rural-Primary

Comments:
1. ST mixes can be used as base courses under roadways that do not experience relatively high truck traffic or is the intended layer is more than 4 inches below the pavement surface.
2. For new construction of full depth asphalt pavements that involve four or more lifts, the base mix should be a ST mix.

Table 15: Mix Selection Recommendations for High Type-Base Courses

Pavement Layer: Base Course
Traffic Category: High Type

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using ST design compactive effort. Dense-graded HMA designed using MT design compactive effort. Dense-graded HMA designed using HT design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	12.5mm, 19.0mm
Asphalt Binder Type	PG 67-22
Aggregate Types	Crushed Gravel, Crushed Stone, Coarse Sand and Manufactured Sand
Applicable Pavements	Urban-Freeway, Rural-Interstate, Urban-Arterial, Rural-Primary

Comments:
1. HT mixes should be used on all roadways with very high traffic.
2. MT mixes can be used deeper than 4 inches below the pavement surface on roadways with moderate truck traffic.
3. For new construction of full depth asphalt pavements that involve four or more lifts, the base mix should be a ST mix.

Table 16: Mix Selection Recommendations for Leveling Courses

Pavement Layer: Leveling Course

Traffic Category: Standard, Medium and High Types

Characteristic	Recommendation
Applicable Mix Type(s)	Dense-graded HMA designed using ST design compactive effort. Dense-graded HMA designed using MT design compactive effort. Dense-graded HMA designed using HT design compactive effort.
Nominal Maximum Aggregate Size (Gradation Size)	4.75mm, 9.5mm, 12.5mm
Asphalt Binder Type	PG 67-22 and PG 76-22
Aggregate Types	Crushed Gravel, Crushed Stone, Uncrushed Gravel Coarse Sand and Manufactured Sand
Applicable Pavements	All

Comments:

1. The leveling course should be selected based upon the traffic category.
2. Smaller nominal maximum aggregate size mixes are better for leveling courses.
3. Polymer modified asphalt binders (PG 76-22) may be required for some HT type projects which will experience very high truck traffic.

CHAPTER 7 – CONCLUSIONS

The objective of this report was to provide guidance for HMA mix selection in Mississippi. No specific laboratory or field research was conducted in order to develop the guidance contained herein; rather the experiences of the authors were utilized. MDOT pavement designers are encouraged to consider the guidance provided in Tables 7 through 16 when selecting appropriate HMA types for different applications.

REFERENCES

1. "HMA Pavement Mix Type Selection Guide." National Asphalt Pavement Association. Information Series 128. 2001.
2. Brown, E. R. and L. A. Cooley, Jr. "Designing Stone Matrix Asphalt Mixtures for Rut-Resistant Pavements." National Cooperative Highway Research Program. Report 425. Transportation Research Board. National Research Council. Washington, D.C. 1998.
3. Kandhal, P.S. and R. B. Mallick. "Open-Graded Friction Course: State of Practice." Transportation Research Board. Circular E-C005. Washington, D. C. 1998.
4. Huber, G. "Performance Survey on Open-Graded Friction Course Mixes." Synthesis of Highway Practice 284. National Cooperative Highway Research Program. Transportation Research Board. National Research Council. Washington, D.C. 2000.
5. Kandhal, P.S. "Design, Construction and Maintenance of Open-Graded Asphalt Friction Courses. National Asphalt Pavement Association. Information Series 115. May 2002.
6. Cooley, Jr., L. A. et al. "Performance and Maintenance of Permeable Friction Courses, Volume II: Guidelines on the Use of PFCs." Preliminary Draft Final Report. Submitted to National Cooperative Highway Research Program. Project 9-41. 2008.
7. Lefebvre, G. "Porous Asphalt." Permanent International Association of Road Congresses (PIARC). 1993.
8. Brown, E. R. and L. A. Cooley, Jr. "Relationships of Air Voids, Lift Thickness, and Permeability in Hot Mix Asphalt Pavements." National Cooperative Highway Research Program Report 531. Transportation Research Board. National Research Council. Washington, D.C. 2004.