Adjusting design air void Levels in Superpave mixtures to enhance durability

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ABSTRACT

When developed in the early 1990s the Superpave method of asphalt design was structured similar to the Marshall method of asphalt design. In the Marshall method asphalt was designed with 3 to 5% air voids (typically 4%). Compaction specifications typically left the mixture with 8% air voids on the road. It was reasoned that traffic would compact the asphalt mixtures and achieve an ultimate density of 96%, the same as the design. Superpave calls for a design air void content of 4.0% (no range) and compaction specifications allow the mixture to have 7 to 8% air voids. Subsequent research in the early 2000s showed that after traffic densification air voids stabilize at about 6%.

This paper discusses proposed changes Superpave asphalt design method to design at 5% air voids. Target air voids after compaction would be the same, 5%. To achieve compaction of 95% (5% air voids) requires changes to the laboratory compactive effort in the Superpave design method.

The concept of designing and compacting asphalt at 5% air voids is inspired by the LCPC method of asphalt design used in France. The perceived benefit to Superpave is an improvement in mixture durability expected from lower air permeability leading to a reduced rate of oxidative hardening.

This paper discusses the concept of setting air void levels in asphalt design, research to identify changes to the Superpave method and recommendations for design compactive effort to be used.

Keywords: Asphalt, Durability, Gyratory, Permanent Deformation, Strategic Highway Research Program

1. INTRODUCTION

The design of bituminous pavements has evolved significantly since the origin of asphalt in the early 1800s. In earlier days, design was focused on the selection of an aggregate gradation and the “correct” amount of bitumen to add. Throughout the first part of the 20th century design methods continued to focus on gradation and bitumen content with simulative mechanical properties that were not measurements of engineering properties. In the latter part of the 20th century research including the Strategic Highway Research Program (SHRP) has focused on engineering properties of asphalt mixtures such as fatigue cracking and non-recoverable deformation as well as the effects of aging and moisture on those properties. The relationship of these properties and effects on actual performance of a pavement has been more tenuous. Complexity of these tests and an imperfect relationship to actual performance has been a significant barrier to implementation. Therefore, asphalt design of today remains grounded in the concept of selecting a gradation and determining the appropriate amount of bitumen to be added.

In North America Superpave is the predominant asphalt design method used. It is a product of SHRP. When developed in the 1990s, the method was envisioned to be based on engineering properties directly linked to in-service performance. Complexity of engineering property tests and lack of an implementable framework for estimating in-service performance prevented the performance-based Superpave method from becoming widely used. The fallback position was a preliminary version of Superpave based on updated volumetric properties (aggregate gradation and bitumen content). Today the performance-based version of Superpave has drifted into the mists of the past and is remembered predominantly by older members of the asphalt research community.

In Europe, as the Americans were developing and implementing Superpave, research was focused on cracking and permanent deformation tests which have become part of EU standards for asphalt mixture design. Criteria for these tests are based on empirical relationships between the tests and expected in-service performance.

Currently, mixture design in North America remains volumetric design. This paper provides an alternate approach to volumetric design in which asphalt mixture aging and durability can be enhanced with little or no cost increase.

2. History of Asphalt Volumetric Mix Design

The current criteria used in Superpave volumetric mix design can be traced back to early days of asphalt design in North America. In 1905 Clifford Richardson, owner of the New York Testing Company, described two types of asphalt mixes: surfacing mixtures and asphaltic concrete (used for lower courses).

Surfacing mixtures, which were high bitumen content sand mix mixtures, would resist the impact of horseshoes and was considered the best mixture for the surface of streets. Asphaltic concrete is more typical of current-day asphalt but was considered less suitable since the shoes of horses would ravel particles from its surface.

For design of asphaltic concrete Richardson calculated void space in the mineral aggregate, which he refers to it as Voids in the Mineral Aggregate (VMA). Richardson describes how the VMA must be adjusted to include the correct amount of bitumen [1].

In his method trial mixtures were made in the lab at different bitumen contents and placed on the road. The mixture was compacted with a heated hand tamp and the surface was inspected to see how much of the macro-texture was filled with mastic. There should be sufficient bitumen to fill voids inside the pavement but not so much as to fill the macro-texture to the surface. A minimum amount of bitumen was required and aggregate gradation was adjusted if macro-texture of the trial mixture was either too full, or not full enough.

In the mid-1920s Charles Hubbard and Frederick Field, both employees of the newly created Asphalt Association (later to become the Asphalt Institute), developed a new method of mix design called the Hubbard-Field Method of Design. The Hubbard-Field method was commonly used among state highway departments in the U.S. in the 1920s and 1930s.

Hubbard-Field design used 150 mm diameter specimens that were compacted with two different hand tamps. First 30 “heavy blows” were applied with a 50 mm diameter hand tamp followed by 30 blows with a 145 mm diameter hand tamp. The specimen was turned over and pushed to the opposite end of the mold. Again 30 blows of the 50-mm rammer were applied followed by 30 blows of the 145-mm diameter rammer. Note the similarity to the Marshall compaction method developed later in which the specimen is turned over and compacted on the opposite side.

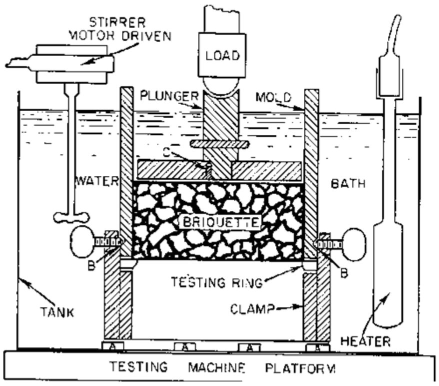

Figure 1: Hubbard Field stabilometer for asphalt design

The Hubbard-Field method of design built upon the process described by Richardson. An analytical method was developed to determine design bitumen content. Bulk specific gravity of the compacted asphalt was measured. Maximum theoretical specific gravity was calculated (not measured) using aggregate bulk specific gravity. Bitumen content was based on air voids and stability. Voids in the aggregate were evaluated to help adjust the mixture stability.

Note that bitumen absorption was not accounted for. Air voids were calculated, not measured, and the error from a measured value depended on the amount of bitumen absorbed into the aggregate. Voids in the aggregate skeleton, VMA by current terminology, was calculated in the same manner as done today. Hence, volumetric analysis as developed by Hubbard and Field is similar to today’s analysis.

In addition to volumetric analysis, Hubbard and Field developed a stability test. The compacted asphalt is squeezed through a ring slightly smaller than the specimen diameter at 60°C. The peak load sustained before the mix started flowing through the orifice was called Hubbard-Field stability. In concept, this is the similar to Marshall Stability where the specimen is loaded on its side and the peak load before it fails is defined as Marshall Stability.

Marshall design method was developed by Bruce Marshall of the Mississippi Department of Highways in the late 1930s [2]. The method is essentially an outgrowth of the Hubbard-Field mix design method. Marshall matched the compactor diameter to the diameter of the mold and tried to standardize the compaction energy by using a drop hammer. The drop hammer had a mass of 4.55 kg and was dropped a distance of 450 mm. Fifty or 75 blows of the drop hammer were applied to each side of a compacted specimen.

The Marshall mix design adopted volumetric analysis from the Hubbard-Field method including the calculation of maximum theoretical gravity ignoring bitumen absorption. Originally, the Marshall method did not include VMA. In 1956 James Rice of the National Crushed Stone Association (later with Bureau of Public Roads, now known as FHWA) developed a method of measuring the specific gravity of bitumen coated aggregates [3]. During the same time frame, Norman McLeod evaluated the measurement and specification of VMA [4][5]. In 1962 the Asphalt Institute changed the Marshall design method to include VMA as a mix design criteria and switched to measurement of maximum specific gravity for the calculation of air voids [6]. The Hubbard-Field stability test was replaced with the Marshall stability test.

Marshall asphalt design specified a range of design air voids of three to five percent; normally four percent is targeted. In concept, design specimens are considered to be the final density after the asphalt has been subjected to compaction during construction plus compaction by traffic during service. During construction the compacted mixture typically had 8 to 10 percent air voids. After being trafficked the air voids would decrease to three to five percent air voids in the pavement. This concept was a generally held belief, but is not well verified.

Superpave asphalt design was developed as part of the SHRP program that occurred from 1987 to 1993 [7]. Originally the Superpave method had three levels of design, each of increasing complexity. Performance-based asphalt tests were to be the basis of the design method. A performance-based test was defined as one measuring a basic engineering property test that could be used to predict stress and strain in the pavement to loads applied under specific environmental and traffic conditions.

During the SHRP program it was recognized that testing and analysis for the performance predictions was too complex for routine projects. As a result a simple, empirical design method was put forward as the base level of asphalt design. In the end the performance-based tests and models were never implemented and the base level of mix design became what is known as Superpave today.

The empirically-based Superpave asphalt design became an extension of the Marshall design. Important components of the Marshall method were carried over to Superpave [8]. Asphalt volumetric properties, that is, air voids, VMA and voids filled with bitumen (VFA), are empirical properties that control asphalt behavior.

A gyratory compactor was developed for Superpave that drew upon the Texas origins of gyratory compaction plus a gyratory compactor developed by the Laboratoire Central des Ponts et Chaussées (LCPC), today, known as Institut Français des Sciences et Technologies des Transports, de l'Amèngement et des Réseaux, (IFSTTAR), from the Texas principles. Superpave developmental studies focused on relating design compactive effort to the density of pavements at the end of their service lives. This underlying principle was carried over from the Marshall method.

On the other hand, LCPC developed a gyratory compactor to simulate density at the end of construction (beginning of service life). The LCPC method of asphalt design is based on the principle that asphalt should be designed and, during construction, compacted to its ultimate density. LCPC has documented that there is little or no increase in density under traffic during the pavement in-service life [9].

In the LCPC method, the design bitumen content is fixed for each mixture type with adjustment factors for bitumen absorption, aggregate specific gravity and surface area. Since the effective bitumen volume is fixed, the design process becomes one of selecting an aggregate gradation to provide an air void content within the allowable range of four to eight percent. Generally designers target five percent air voids. In the field, the required density is 95 percent of maximum theoretical gravity.

LCPC established a laboratory compactive effort to match compaction that occurs during construction with a defined standard rolling train (16 passes of a defined pneumatic roller). Construction lift thickness was standardized at five to six times the maximum aggregate size. For example 0/14 asphalt with 14 mm maximum aggregate size would be constructed with 80 mm thickness, 5.7 times the maximum particle size. The combination of gyratory compactor characteristics, the design number of gyrations, the standardized roller train and the lift thickness combine to provide a harmonized design and construction system.

3. Objective

Superpave5 (Superpave with five percent design air voids) is inspired by the LCPC method but designed to meet American conditions. The LCPC design method cannot be directly used because of the difference in lift thickness used in America as compared to France. In Superpave5 asphalt is designed with five percent air voids and compacted on the roadway to five percent air voids.

As compared to regular Superpave (Superpave4), air voids are increased one percent from four percent to five percent. To maintain the same effective bitumen volume, Vbe, the VMA criteria must be increased by one percent as well. Aggregate consensus properties for different traffic levels and typical lift thickness remain unchanged from current American practice.

Superpave4 designed according to current AASHTO specifications cannot be consistently compacted to five percent air voids on the road. Using current rollers and lift thickness and with consistent asphalt production the achievable air voids after compaction are slightly less than seven percent.

The design compactive effort needs to be changed for Superpave5. The same Superpave gyratory compactor is proposed to be used but the number of design gyrations must be reduced. The objective of this paper is to determine the appropriate design compactive effort for Superpave5.

3.1 Role of Design Compactive Effort

In America, there is an incorrect belief that the amount of design compaction will influence the design bitumen content. The error of this thought process is that the higher the number of gyrations, the more tightly compacted the aggregates become, the less room is available for bitumen and, hence, bitumen content is reduced.

Table 1 shows the results of an experiment in which the same aggregates were designed using 125, 100 and 75 gyrations. The aggregate nominal maximum size is 9.5 mm that requires a minimum VMA of 15.0 percent. All three of these asphalt designs meet the criteria, each being slightly more than the minimum. Each asphalt is designed at four percent air voids; hence, the effective volume of bitumen is almost the same. Since the same aggregates are used in the three different asphalt designs, the amount of absorbed bitumen is relatively constant among the three designs and as shown in Table 1 the total bitumen content is the same for all three designs.

Table 1: Effect of design compaction effort on bitumen content

Design Compactive Effort, gyrations	Voids in Mineral Aggregate, %	Volume of Effective Bitumen, %	Bitumen Content, %
125	15.22	11.22	5.78
100	15.40	11.40	5.74
75	15.31	11.31	5.72

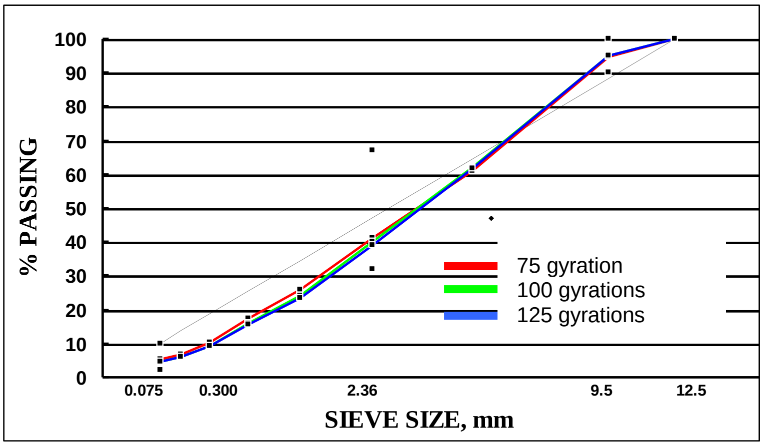

Figure 1: Design gradation for different design gyrations

Gradation changes among the three designs. The lower the design number of gyrations, the less resistive to compaction the aggregate blend must be in order not to have excess inter-granular space (VMA). Figure 1 shows the gradation for each of the three asphalt designs. All three designs are coarse-graded. Note that the gradations for 125, 100 and 75 gyrations are progressively closer to the maximum density line meaning that for the same compactive effort the gradation will compact together tighter. As the design compaction effort decreases, the gradation must compact to a tighter configuration more easily to offset the reduction in compactive effort. The net effect is that each gradation, with its own compactive effort will have the same degree of compaction. Hence, VMA and bitumen content remains the same.

Within a mix design and construction system the following parameters influence asphalt compaction achieved on the road: design compactive effort, lift thickness (in relation to aggregate size), roller characteristics and number of passes. Other mitigating parameters such as environmental conditions (temperature, wind), and out of specification asphalt (gradation, asphalt content) impact compactability regardless of the mix design system used and are not being discussed here.

Compare the LCPC and Superpave approaches. The LCPC method uses a lower degree of laboratory compaction. The gyratory angle is 1 degree (0.85 degrees internal angle) as compared to the Superpave compactor of 1.25 degrees (1.16 degrees internal angle). The number of gyrations for LCPC design is typically lower than Superpave. Lift thickness in the U.S. (Superpave) is typically thinner.

For example, lift thickness in France for a 0/14 mm mixture is 80 mm whereas the same asphalt would be placed 40 mm thick in the U.S. Heavy rollers (35 tonne) are typically used in France, much heavier than typical U.S. rollers. As a result, 0/14 mm asphalt in France, designed at five percent air voids and placed 80 mm thick can be compacted to five percent air voids on the road. In the U.S. 0/14 mm asphalt designed at four percent air voids and placed 40 mm thick can be compacted only to seven percent air voids.

3.2 Selecting Design Compactive Effort for Superpave5

Generally, as design compactive effort decreases, the asphalt becomes easier to compact on the roadway, has lower stiffness (E*) and has lower resistance to rutting. As the design compactive effort increases (design gyrations increase) the aggregate skeleton becomes stronger and the resistance to rutting increases.

Flow Number is a measure of rutting resistance. Flow Number is determined by applying a sinusoidal axial load to a cylindrical sample. Irrecoverable deformation is plotted versus the number of applications as shown in Figure 2. The rate of deformation is initially high, then stabilizes to a near constant rate. At some point, the specimen will start to fail and deformation will increase rapidly. Flow Number is defined as the number of applications at the point of inflection where the slope of the deformation begins to increase. The point where the slope of the line is a minimum is the Flow Number..

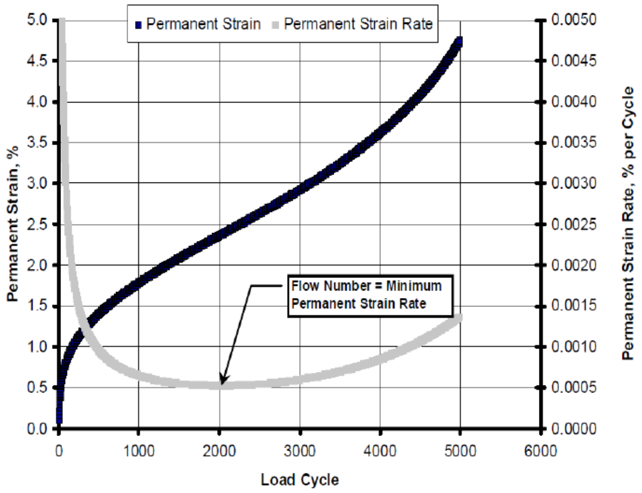

Figure 2: Typical Flow Number Test Result [10]

Table 2: Effect of design compaction effort on rutting resistance

Design Compactive Effort, gyrations	Stiffness, MPa, (37.7°C, 1 Hz)	Flow Number, (21°C, 200 kPa)
125	465	151
100	481	131
75	425	103

Flow Number was measured for the asphalt designs. These tests were done on specimens compacted in a gyratory compactor to 93 percent maximum theoretical density (plus or minus 0.5%) providing specimens with seven percent air voids. Flow Number results are shown in Table 2. As design compactive effort decreases from 125 to 100 to 75 gyrations the Flow Number decreases from 151 to 104. Also shown in Table 2 is the result of dynamic modulus testing. Although the data has variability, asphalt stiffness typically decreases as design compaction decreases.

3.3 Research Approach

The selection of design gyrations for Superpave5 is based on an evaluation of engineering properties of current Superpave4 mixtures. Since Superpave5 mixtures are envisioned to have the same bitumen content as Superpave4, no loss of durability or fatigue resistance is expected. Reducing design gyrations for Superpave5 will reduce rutting resistance unless the as-compacted density on the road increases.

Generally, it is observed that Superpave4 mixtures designed at four percent air voids and compacted to seven percent air voids are performing well against rutting. Hence, the target rut resistance for Superpave5 asphalt is the rut-resistance properties of current asphalt mixtures at the density compacted on roadways. So the question distills down to: At what design gyration level will Superpave5 mixtures designed at five percent air voids and compacted to five percent air voids match the rut resistance of Superpave4 mixtures designed at four percent air voids and compacted to seven percent air voids.

3.4 Mix Designs Selected for Superpave5 Research

For the research it was decided to use reference Superpave4 asphalt designed with 100 gyrations. The same aggregates were used to design Superpave5 asphalt at five percent air voids and the test specimens will be compacted to five percent air voids. These will be compared to Superpave4 specimens designed at four percent air voids and compacted to seven percent air voids. All of the mixtures were produced using PG 64-22 bitumen. For ease of laboratory design, a recycled material (RAP) was not included in the design.

Three Superpave4 asphalt designs were selected for study:

- 9.5-mm nominal maximum size
    - 3 to 10 million ESAL (Category 3)
    - 100 gyrations
- 9.5-mm nominal maximum size
    - 10 to 30 million ESAL (Category 4)
    - 100 gyrations
- 19.0-mm nominal maximum size
    - 10 to 30 million ESAL (Category 4)
    - 100 gyrations

The Category 4 asphalt mixtures require a higher value of Fine Aggregate Angularity (FAA) meaning lesser amounts of natural sand can be used. The Category 4, 9.5-mm asphalt designed for surface wearing courses requires the use of a friction aggregate (for anti-polishing) whereas the Category 3 asphalt can be made with dolomitic limestone. The 19.0-mm asphalt was selected to explore if the Superpave5 concept can be applied to a larger size mixture.

3.5 Volumetric Mixture Designs for Research Asphalt

Superpave5 designs were done using the same materials as the Superpave4 design at three different design compaction levels. The design number of gyrations selected was

70, 50 and 30 gyrations. The target VMA for Superpave5 was one percent higher than for Superpave4.

Four asphalt designs for the Category 4, 19.0-mm asphalt are summarized in Table 3. N100 is the Superpave4 design with four percent design air voids. The other three designs are Superpave5 designs with a target air void content of five percent. Each of them ended up at 4.9 percent air voids.

Superpave design at four percent air voids has a VMA criterion of 13.0 percent minimum for 19.0-mm asphalt [11]. The Superpave4 design has a design VMA of 13.6 percent. The desired criterion for Superpave5 is one percent higher, which is 14.0 percent. For the sake of this research, the desire was to have the VMA not much more than one percent higher. The design VMA for the Superpave5 asphalt is close to the desired target.

The bitumen content for the Superpave4 design (N100) and the N70 design are both 4.7 percent. Note that the N50 and N30 designs each have bitumen content 0.4 percent higher. Aggregate absorption is the reason for this difference. Additional aggregates were sampled and found to have higher absorption than the first aggregates used in the research. Note that the effective bitumen content is 4.1 percent for the N100, N70 and N50 designs. The N30 design has an effective bitumen content of 4.3 percent, 0.2 percent higher than desired. It was difficult to reduce the VMA; as a result, the design VMA is 0.3 percent higher than desired and the bitumen content is 0.2 percent higher.

The gradation for each of the four mix designs is shown in Figure 3. In general, there are three ways to adjust gradation and change aggregate packing: change the relative proportion among the fine aggregates, change the relative proportion among the coarse aggregates and change the ratio of fine and coarse aggregate. In this particular design, there was only one fine aggregate (size less than 4.75 mm). As is apparent in Figure 3, gradation was changed by changing the relative proportion of the coarse aggregates.

In Figure 3 notice that gradation for the N100 (Superpave4) and N70 (Superpave5) asphalt designs are nearly identical. This can be explained according to the effect of gyrations on compaction. As a general rule of thumb, 25 less gyrations will cause the VMA to increase by one percent. Therefore if the gradation from the N100 design is compacted with 70 gyrations the air voids and VMA will increase by approximately one percent. In effect, the N100 design at four percent air voids is nearly the same as the N70 gradation at five percent.

Table 3: Asphalt design results of Category 4, 19.0-mm mixtures

	N100	N70	N50	N30
Air Voids, %	4.0	4.9	4.9	4.9
VMA, %	13.6	14.5	14.4	14.9
Bitumen Content, %	4.7	4.7	5.1	5.1
Effective Bitumen Content, %	4.1	4.1	4.1	4.3

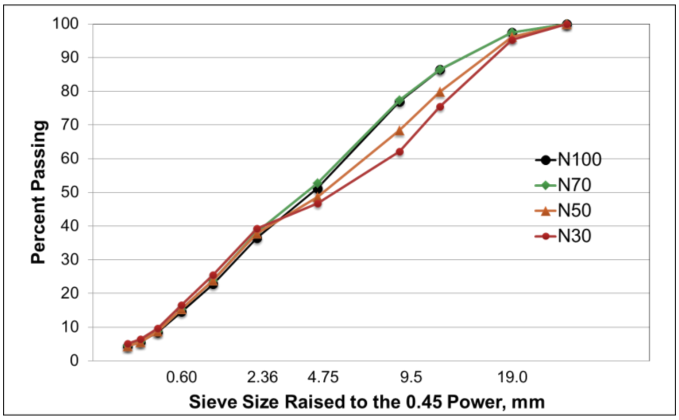

Figure 3: Gradation for 19.0-mm Nominal Maximum Particle Size Research Designs

Results of asphalt designs for the Category 3 and Category 4, 9.5-mm designs are listed in Table 4. Comments similar to those made for the 19.0-mm design can be made for each of the 9.5-mm designs. Note that a N70 design was not done for the Category 4 asphalt. This decision was made as a result of the N70 gradations having been the same as the N100 gradation for both the 19.0-mm and the Category 3 9.5-mm design.

Gradations for the Category 3, 9.5-mm designs are shown in Figure 4. Figure 5 shows the gradations for the Category 4 designs. Note that changes to gradation to influence compactability of the aggregate were made in the fine aggregate for these designs. The main reason for this decision is that the packing characteristics of aggregate blends are more sensitive to fine aggregate gradation than to coarse aggregate gradation. Recall that in the 19.0-mm mixture contained only one fine aggregate and so it was not possible to adjust fine aggregate gradation. A visual comparison of Figure 3 to Figures 4 and 5 shows that larger deviations in gradation are needed in the coarse aggregate in Figure 3 to accomplish the necessary adjustment in VMA than in the fine aggregate in Figures 4 and 5.

Table 4: Asphalt design results of Category 3 and 4, 9.5-mm mixtures

	N100	**N70**	**N50**	**N30**
	Category 3 Asphalt Mixture			
Air Voids, %	4.1	5.1	4.9	5.3
VMA, %	15.0	16.0	15.8	16.3
Bitumen Content, %	5.9	5.9	6.0	6.0
Effective Bitumen Content, %	4.6	4.6	4.6	4.7
	Category 4 Asphalt Mixture			
Air Voids, %	3.8		4.9	5.0
VMA, %	15.0		16.4	16.4
Bitumen Content, %	6.5		6.5	6.4
Effective Bitumen Content, %	4.8		5.0	5.0

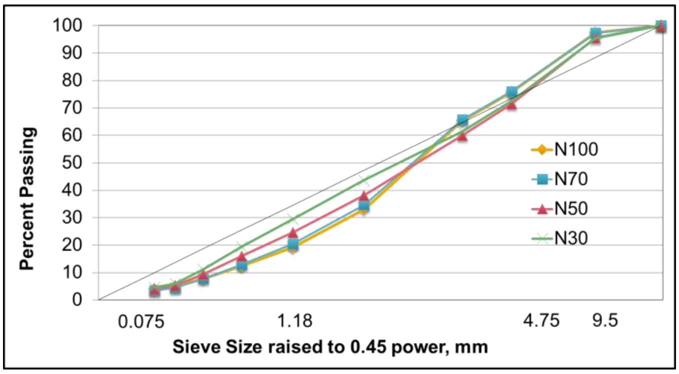

Figure 4: Gradation for Category 3, 9.5-mm Nominal Maximum Particle Size Research Designs

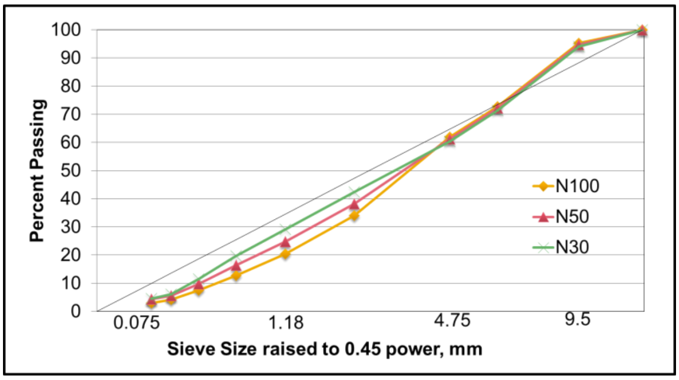

Figure 5: Gradation for Category 4, 9.5-mm Nominal Maximum Particle Size Research Designs

3.6 Engineering Properties of Research Asphalt

Dynamic Modulus and Flow Number were measured on each of the research asphalt designs using AASHTO TP-79 [12]. Figure 6 shows dynamic modulus master curves for each of the 19.0-mm designs. An arithmetic plot of selected frequencies is shown in Figure 7.

The N100 (Superpave4) design at seven percent air voids has the lowest stiffness. The highest stiffness asphalt is the N70 (Superpave5) design at five percent air voids. The N70, N50 and N30 asphalt are in decreasing order of stiffness. The N30 asphalt is approximately equal to the N100 asphalt.

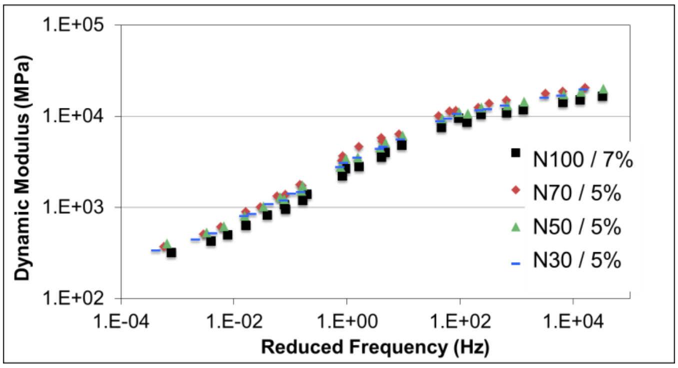

Figure 6: Dynamic Modulus for 19.0-mm Nominal Maximum Particle Size Research Designs

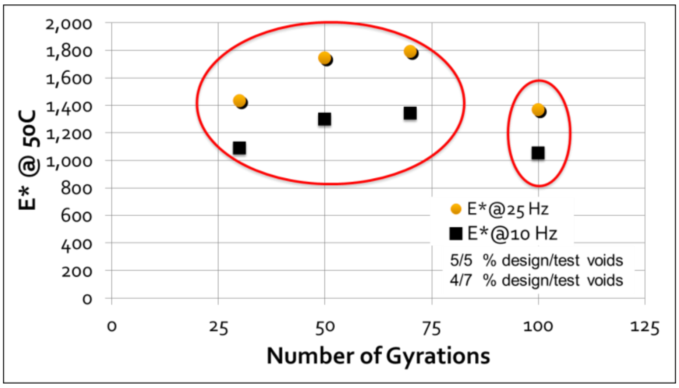

Figure 7: Selected Dynamic Modulus for 19.0-mm Nominal Maximum Particle Size Research Designs

Initially, it seems counter-intuitive that 100 gyrations should produce asphalt that is lower in stiffness than 30 or 50 gyrations. Two parameters are involved that counter each other. Lower design compaction will decrease asphalt stiffness. This effect can be observed among the N70, N50 and N30 mixtures. As lower design gyrations are used, asphalt stiffness decreases. The second effect is that of specimen density. The N100 asphalt specimens are compacted to seven percent air voids. The other asphalt designs are compacted to five percent air voids.

Now, consider that although the N100 and N70 asphalt are designed at different air voids the two are almost exactly the same. Each asphalt has the same bitumen content and nearly the same gradation. Since the N100 test specimens are compacted to seven percent air voids and the N70 test specimens are compacted to five percent air voids the comparison is of the “same” asphalt compacted to different void levels. The lower the voids, the higher the stiffness.

Dynamic modulus for the Category 3, 9.5-mm asphalt design is shown in Figure 8. In this group of designs a separate set of N100 samples was compacted to five percent air voids to independently evaluate the effect of density. Stiffness of the N100 design compacted to five percent air voids matched stiffness of the N70 design compacted to five percent air voids. Since the N70 and N100 designs are nearly the same gradation and are the same bitumen content this result is expected.

Comparing Figure 8 to Figure 6 shows there is less spread among the four asphalt designs. The N100 asphalt (compacted to seven percent air voids) has the lowest dynamic modulus. The N30 asphalt (compacted to five percent air voids) is about the same as the N100.

The Category 4 9.5-mm asphalt designs are shown in Figures 9. There are only three asphalts shown. The N70 mixture was not designed. The results for this group of asphalt designs is similar to the two sets of asphalts are similar to those for the 19.0-mm asphalt and the Category 3, 9.5-mm asphalt.

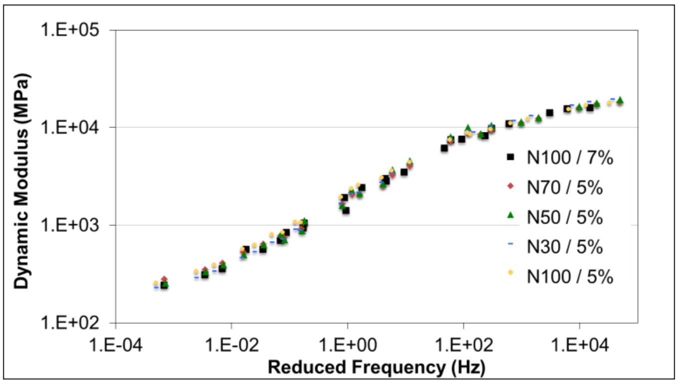

Figure 8: Dynamic Modulus for Category 3, 9.5-mm Nominal Maximum Particle Size Research Designs

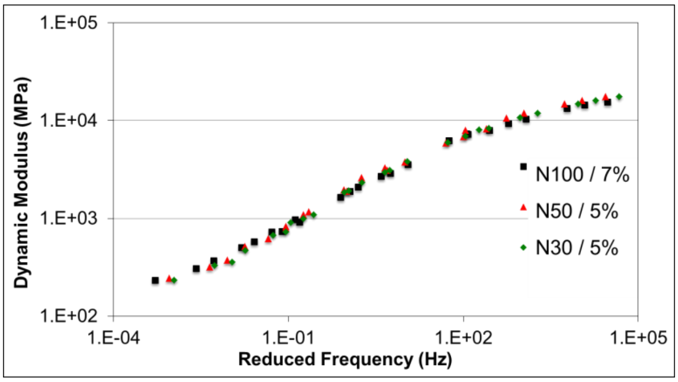

Figure 9: Dynamic Modulus for Category 4, 9.5-mm Nominal Maximum Particle Size Research Designs

Flow Number results for all the asphalt designs are listed in Table 5. In each case the Flow Number of all the Superpave5 asphalt is greater than the Superpave4 asphalt indicating that they are more resistant to rutting.

Table 5: Asphalt design results of Category 3 and 4, 9.5-mm mixtures

	N100	**N70**	**N50**	**N30**
	Category 4, 19.0-mm Asphalt			
Flow Number	162	386	348	185
Strain at Flow Number, µm	23,983	18,269	19,882	22,090
	Category 3, 9.5-mm Asphalt			
Flow Number	91	167	163	156
Strain at Flow Number, µm	18,114	17,704	20,300	19,204
	Category 4, 9.5-mm Asphalt			
Flow Number	100		253	211
Strain at Flow Number, µm	20,983		20,935	21,033

4. SUMMARY AND CONCLUSIONS

Asphalt can be designed using the Superpave gyratory compactor to have five percent air voids and the same bitumen content as regular Superpave asphalt designed according to AASHTO M323.

- Design air voids were increased to five percent. At the same time the design VMA was increased by one percent, thereby maintaining the same bitumen content.
- Asphalt designs were done at three different degrees of compaction: 30, 50 and 70 gyrations. The greatest challenge was experienced with the 30 gyration design compaction as it was difficult to reduce the VMA to the desired level
- The gradation was required to be changed in response the degree of laboratory compaction. The lower the design compaction, the closer the gradation comes to the maximum density line.
- The research did not investigate other changes to decrease VMA such as reducing aggregate particle shape and texture by substituting natural sand for manufactured sand. Reducing particle texture and shape will make the asphalt more susceptible to rutting. Changing particle shape and texture (fewer crushed faces and/or more natural sand) would violate the aggregate consensus properties in AASHTO M323 and is not desired.
- Asphalt designed at five percent air voids using 70 gyrations had the same gradation and bitumen content as asphalt designed at four percent air voids at 100 gyrations. In effect they are “exactly” the same asphalt (gradation and bitumen content).

Asphalt designed and compacted at five percent air voids can have equivalent dynamic modulus and flow number as asphalt designed at four percent air voids and compacted to seven percent air voids.

- For asphalt designed and compacted at five percent air voids dynamic modulus changed according to the design number of gyrations. The higher the number of gyrations the higher the dynamic modulus (stiffness) and the higher the Flow Number (rut resistance).
- Asphalt designed and compacted to five percent air voids at 30 gyrations had similar dynamic modulus to asphalt designed at four percent air voids at 100 gyrations and compacted to seven percent air voids.
- Asphalt designed and compacted to five percent air voids at 30 gyrations had a higher Flow Number than asphalt designed at four percent air voids at 100 gyrations and compacted to seven percent air voids.

The laboratory study discussed in this paper indicates that asphalt designed using 30 gyrations with five percent air voids and compacted to five percent air voids will perform as well or better than asphalt designed using 100 gyrations and compacted to seven percent air voids.

- Asphalt stiffness decreased and rutting susceptibility increases as the number of gyrations used in the design was decreased.
- Stiffness and rut resistance of asphalt compacted to five percent air voids as compared to asphalt compacted to seven percent air voids.
- The increase in stiffness and rut resistance from increased compaction more than offset the effect of reducing design gyrations.

Based on results of this laboratory study a design compactive effort of 30 gyrations was recommended.

4.1 Author’s Closure

Two trial sections of Superpave5 asphalt have been constructed. One was a Category 4, 9.5-mm surface asphalt. The other was a Category 4, 19.0-mm intermediate mixture. Asphalt designs were done using 30 gyrations and compacted on the roadway to a target air void level of five percent (95 percent maximum theoretical density, Gmm). In each case, using the same rollers and number of passes as the Superpave 4 (), the achieved density was approximately 96 percent Gmm, greater than 95 percent target. Before the trials there had been concern that the desired compaction would not be achieved. On the basis of the laboratory research documented in this paper and the results of the two trial sections the following recommendations are made by the researchers:

- 30 gyrations for asphalt with less than 3 million design Equivalent Single Axle Load (ESAL) over 20 years.
- 50 gyrations for asphalt with more than 3 million and less than 30 million ESAL
- 70 gyrations for asphalt with more than 30 million ESAL

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