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Scholarship Research Report

Effects of Aggregate Blend Gradations on Hot Mix Asphalt Volumetrics

Prepared for the IAPA Scholarship Committee

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Abstract

Typical hot mix asphalt (HMA) in its compacted state comprises three things: air, asphalt binder (AB), and aggregate. Aggregate makes up the majority of the mix; typically, 90% by volume. Aggregate blends play a significant role in determining HMA mixes' characteristics, including mix stability, workability, skid resistance, durability, and volumetric properties. HMA technology is continuously evolving with new additives, placement methods, and materials introduced every year, but aggregate gradations are still fundamental in achieving the appropriate engineering properties. Aggregate gradations produce the volume of voids in the mineral aggregate (VMA). VMA provides the potential space for AB while AB's amount produces the volume of air voids. Everything begins with the aggregate. Aggregate particle shape has some influence on volumetrics but should be controlled using appropriate production methods for the available material and is mostly at the local geology's mercy. It is not practical or sustainable for Illinois HMA contractors to source and then transports large quantities of the perfect aggregate outside a certain distance. It is far more practical to utilize the locally available aggregate resources properly. Acceptable results can be achieved with non-optimal particle shapes, but not when combined with poorly conceived HMA mix gradations. Achieving the required volumetrics produces a more profitable and durable product, which meets the consumer and the producer's needs.

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Objectives and Scope of the Report

This report seeks to compare the aggregate blend gradations and compacted volumetrics of a typical 9.5 mm NMAS dense-graded N50 mix to a 9.5 mm NMAS N80 stone matrix asphalt (SMA). The relationships between aggregate blend gradations and volumetrics are fundamental for mix design and understanding the potential HMA performance after installation. This report seeks to clearly show the connection between compacted HMA mix volumetrics and HMA aggregate blend analysis.

For both mixes, the desired density is 96%, correlating to 4% design air voids. Asphalt binder (AB) content for both mixes was optimized during mix design and held constant throughout testing. This report's design volumetrics and gradation data are the average values for all testing on the individual mixes compiled during the 2020 work season at the UCM mix plant. For the data utilized in this paper, a Superpave gyratory compactor (SGC) and 6" (150mm) diameter molds were used to produce the HMA samples.

HMA Volumetrics and Definitions

Compacted HMA consists of aggregate, asphalt binder, and air. Asphalt binder is used to coat the aggregate and produce a monolithic material. In a compacted HMA mix, asphalt binder, which fills the aggregate's pores, is absorbed binder. The remaining binder in the HMA mix is known as effective binder. In a given volume, the remaining voids are known as air voids. The combined volume of air voids and effective binder is known as voids in mineral aggregate (VMA). Figure 1 shows the volumetric diagram of a compacted HMA sample.

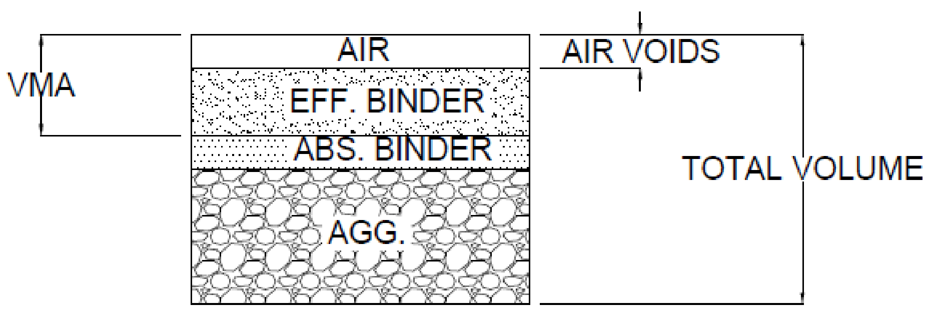

Figure 1. HMA Volumetric Diagram.

The HMA volumetric parameters are defined in the following paragraphs. Unless otherwise noted, Asphalt Design Methods 7th Edition was referenced.

Dense-Graded Mix – asphalt mix with a well-distributed aggregate gradation throughout the entire range of sieves used, most common type of mix

Stone Matrix Asphalt (SMA) – gap-graded asphalt mixture with the following characteristics: high-coarse aggregate content, high AB content, and high mineral-filler content resulting in a durable mixture with a high level of stone-on-stone contact and high resistance to rutting

Nominal maximum aggregate size (NMAS) - Sieve size larger than the first sieve to retain more than 15% by weight per Bailey Method principles [2]

G_{mb} - bulk specific gravity of compacted HMA blend

G_{mm} - maximum specific gravity of bulk uncompacted HMA blend

G_{sb} - bulk dry specific gravity for an aggregate blend

Voids – the volume of air voids in a compacted mixture, expressed as a percentage of the total mix volume [1]. Note that the calculation for air voids includes the G_{mm} of the entire HMA blend.

Air voids = $1 - \frac{G_{mb}}{G_{mm}}$

Voids in Mineral Aggregate (VMA) – voids created by the aggregate structure of a compacted asphalt mixture, expressed as a percentage of the total mix volume. Note that the calculation for VMA involves the G_{sb} value for the aggregate blend.

VMA = $100 - \frac{G_{mb} * Percent\ Stone}{G_{sb}}$

The number of gyrations (N) – based on Equivalent Single Axle Loads (ESALs). Higher ESALs will correspond with a higher N(design) value. N(design) indicates the number of gyrations required to attain 96% density or 4 % air voids, i.e., N80 indicates 80 gyrations.

Maximum density line – used on a Power 0.45 Chart to indicate the maximum density possible for a given NMAS

Gradation Comparison

Table 1 shows the average percent passing values for the 9.5 NMAS used for the Dense-graded mix. Table 2 shows the same data for the 9.5 NMAS SMA. The highlighted sieve represents the primary control sieve (PCS) for the gradations and will be discussed later in the report.

Table 1: 9.5 mm NMAS N50 Gradation

Sieve Size		Percent Passing
(mm)	(inch or sieve no.)	%
19.0	¾	100
12.5	½	100.0
9.5	3/8	97.1
4.75	#4	66.1
2.36	#8	37.2
1.18	#16	25.8
0.600	#30	17.5
0.300	#50	8.6
0.150	#100	6.0
0.075	#200	4.9

Table 2: 9.5 mm NMAS N80 SMA Gradation.

Sieve Size		Percent Passing
(mm)	(inch or sieve no.)	%
19.0	¾	100
12.5	½	97.4
9.5	3/8	90.7
4.75	#4	42.3
2.36	#8	24.8
1.18	#16	18.1
0.600	#30	14.1
0.300	#50	11.8
0.150	#100	10.2
0.075	#200	8.4

Both mix gradations are plotted on the 0.45 power chart shown in Figure 2. The maximum density line represents the densest mix possible for the given NMAS. For both mixes, NMAS was determined using the Bailey Method principle mentioned in the Definition section. Mix gradations above the maximum density line are considered fine graded, while mix gradations below the line are considered coarse graded [1]. Both mixes shown on this chart are coarse-graded because the majority of both gradations lies below the maximum density line.

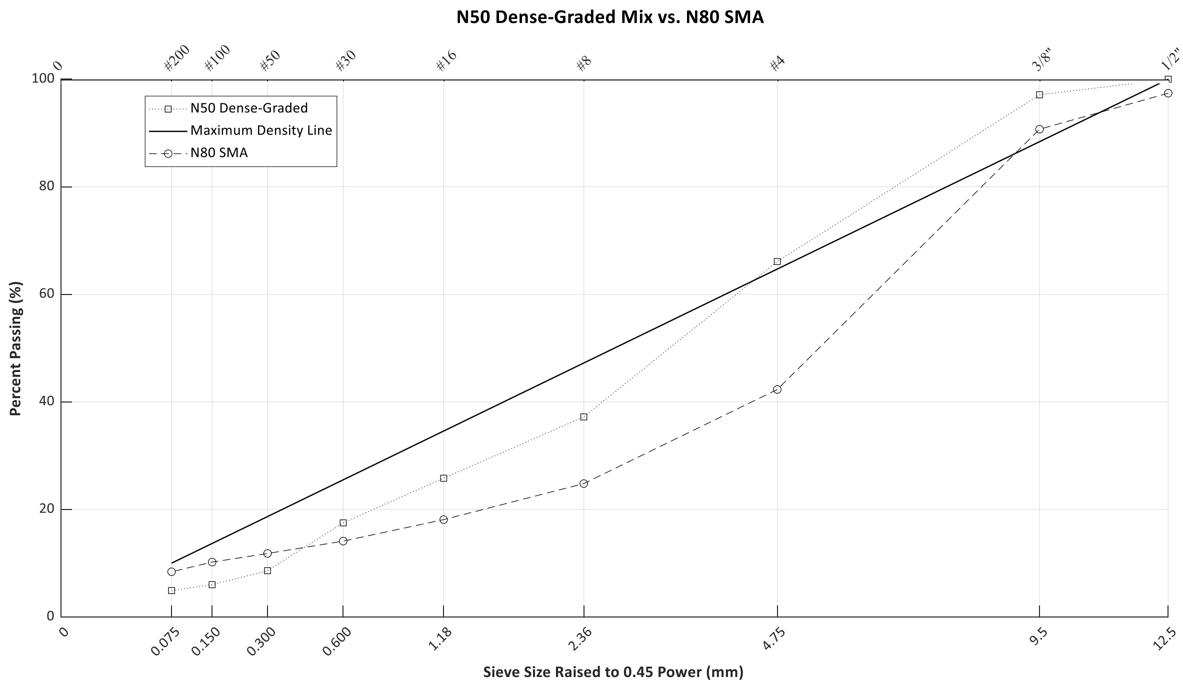

Figure 2: 0.45 Power Gradation Chart showing mix comparison.

The split between coarse and fine aggregates, known as the primary control sieve (PCS), will also be determined using Bailey Method principles. For 9.5 mm NMAS mixes, the PCS will be the 2.36 mm (#8) sieve. Aggregate retained above the PCS creates voids in mineral aggregate (VMA) while aggregate passing the PCS fills in these voids [2]. These voids are known as VMA, which is solely a property of the aggregate structure. The volumetric diagram in Figure 1 shows the relationship between VMA, air voids, and AB content. Mixes with higher levels of VMA will require a higher AB percentage by volume to achieve the targeted 4% air voids. The relationship between VMA, AB content, and air voids presented here is oversimplified and does not consider variable AB absorption rates for the different aggregates. Assuming equal absorption rates for both the dense-graded and SMA aggregates, the SMA will require a higher AB percentage by volume to achieve the desired 4% air voids.

While both mixes have roughly the same air voids, they differ in their VMA and AB content. Note the difference between the two mix gradations at the 2.36 mm (#8) sieve and the 4.75 mm (#4) sieve; the SMA is coarser at both sieves; much more so on the 4.75 mm (#4) sieve. The SMA builds most of its VMA with 4.75 mm (#4) aggregate and fills these voids in the aggregate with .300mm (#30) and smaller aggregate. This is expected for SMA mixes as this mix type's strength comes from the stone-on-stone contact of the coarse aggregate skeleton [1]. The gap in the gradation at the 2.36 (#8) to the 1.18 mm (#16) is necessary so that the larger 4.75 mm (#4) aggregate can be in contact with a similar-sized aggregate and achieve the stone-on-stone contact required.

The dense-graded mix has a more evenly distributed gradation with around 60% of the gradation coarser than the PCS, and a significant amount of this is retained on the PCS sieve itself. This uniform gradation builds a smaller volume of voids in the mineral aggregate. These aggregate voids are then filled in with a more even distribution of a smaller aggregate than the gap in the gradation used in the SMA. Some strength is derived from stone-on-stone contact, but the stone in contact is smaller than that of the SMA. The lower VMA values for this mix type also require less AB to achieve 4% air voids.

Figure 3 shows a compacted test sample of the SMA cut in half on the vertical plane. Figure 4 shows a compacted test sample of the dense-graded mix cut on the same plane.

Figure 3: 9.5 NMAS SMA Section.

Figure 4: 9.5 NMAS Dense-Graded Mix Section.

Figures 3 and 4 reiterate what the mix gradations and power .45 chart present. When comparing the two mixes, the SMA has a coarser aggregate structure while the dense-graded mix has a more even distribution of aggregate sizes. For the SMA sample, force normal to the top of the cut section will be distributed primarily amongst the aggregate coarser than the PCS. This contrasts with the dense-graded section where force normal to the top of the cut will be distributed primarily amongst aggregate finer than the PCS.

Volumetrics

The mix gradation analysis does not end there; volumetric characteristics can also be estimated using the relationship between the mix gradation line and the maximum density line. Distance from the maximum density line is directly related to the potential for VMA. Mix gradations closer to the maximum density line will have a lower potential for VMA along with a higher density. As expected for this comparison, the dense-graded mix gradation lies closer to the maximum density line, while the SMA has the greater potential for VMA.

Both mixes are designed to achieve the same 4% air voids at their respective N(design) values. The power .45 chart shows that the dense-graded mix should be denser, i.e., lower air voids, with lower VMA. Table 3 shows a comparison of the volumetric characteristics of the two mixes. The values shown in the table are the average values based on all quality control testing for the 2020 work year.

Table 3: Volumetric Comparison.

	N50 Dense-Graded Mix	N80 SMA
Air Voids	3.5%	3.8%
VMA	15.2%	18.0%
G_{mb}	2.375	2.305
G_{mm}	2.461	2.395

As expected, the G_{mm} values are higher for the dense-graded mix, and VMA is higher for the SMA. SMA mixes require a higher AB percentage, requiring a higher VMA to provide space for the AB to coat the aggregate particles at an acceptable thickness [3]. The power .45 chart and the mix gradations all coincide with the volumetric values shown in Table 3.

Conclusion

Comparing the two mix gradations with their differing volumetric values shows the relationship between aggregate blend gradations and volumetrics. While fundamental, the relationships are shown here are the building blocks for designing high-performance HMA.

References

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