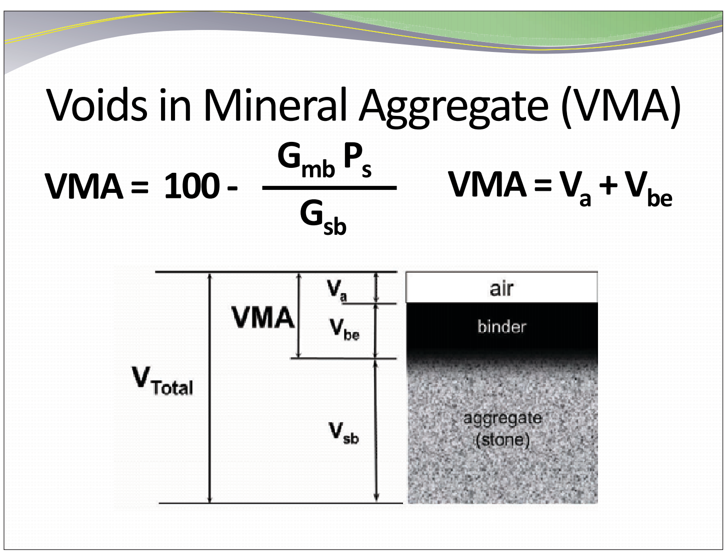
Don't Forget the Impact of Basic Principles on Asphalt Mix Durability

In a number of states, there has been increasing concern that many asphalt mixes are not as durable as they should be. Some cases of overlays deteriorating within a few years have been reported. The problems have been attributed to a range of causes such as the use of RAS, low asphalt contents, low in-place density, poor quality underlying layers, and freeze-thaw cycles of recent harsh winters. Typically, for any particular case there are a number of factors that play a part in durability problems. The root causes can often be traced back to failing to follow basic principles of mix design and quality assurance. The aim of this article is to refresh our attention to those basic principles.

Asphalt Content
In the past few years, many highway agencies have implemented specification changes to increase asphalt contents of mix designs. Some have reduced the target air void content or increased VMA limits in mix design. In general, reducing the target air void content by 0.5% or increasing the minimum VMA by 0.5% will add about 0.2% more asphalt to mixes. Increasing asphalt contents will generally improve durability and also make the mixes more compactible. However, there is another very basic element of mix design that has a big impact on the optimum asphalt of mixes - the aggregate blend bulk specific gravity (Gsb). Using a Gsb that is higher than its true value, either by error or intent, will result in a calculated VMA that is higher than it actually is, and the net effect will be a lower asphalt content for the mix. A small change in the blend's Gsb can have a significant impact on VMA; for example, increasing Gsb by 0.029 (a change that is within the repeatability of the tests) can increase the calculated VMA by 1.0%. Therefore, it is incumbent on agencies to check the Gsb of materials used in both mix designs and mix production. The frequency of checking Gsb should be based on historical data for how much the Gsb values change over time for aggregate and RAP components.



Voids in Mineral Aggregate (VMA) is the volume of intergranular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and effective volume of asphalt. It must be calculated using the Gsb of the aggregate blend.

It is also important to consider changes made to mixtures during production. In many quality assurance specifications, the air voids of lab compacted specimens have a greater impact on the contractor's pay per lot of mixture than asphalt content. This encourages a reduction of asphalt content in order to maintain air voids (and VMA), which essentially sacrifices durability in favor of rutting resistance. Agencies can discourage this practice by limiting the reduction of the target asphalt content during mix production, forcing contractors to make other adjustments in the mix to maintain volumetric properties. This will motivate mix designers to account for changes in gradation, particle shapes, and dust contents that often occur during plant production as they develop new mix designs.

Lower Ndesign
Reducing the laboratory compactive effort by itself will not necessarily increase the asphalt content of mixes, but it can help improve mixes in other ways such as enabling mix designers to use finer gradations. In general, fine-graded mixes are easier to compact than coarse-graded mixes both in the laboratory and in the field. When Superpave was introduced in many parts of the country, mix designers were encouraged to use coarse gradations in an effort to make mixes more rut resistant. A direct impact of using high-gyration, coarse-graded mixes was that achieving the minimum density specification in the field also became much tougher. NCHRP Project 9-9(1) found the SGC compactive effort table in AASHTO R35 to be too high. This study was published as NCHRP Report 573. Using data from numerous projects across the US, it showed that pavements were not densifying under traffic to the levels achieved in the SGC. The report recommended Ndesign levels 20 to 25% lower than in R35. A few states took a more radical step and set Ndesign to 60 or 65 gyrations for all mixes, regardless of the design traffic level, and have encountered no ill effects of that change. As long as Superpave aggregate criteria are met and the appropriate binder grade is used, those states found that lower gyration levels improved mix designs without causing rutting problems. The NCAT Test Track has also proven that 65 gyration mixes can hold up to very heavy traffic conditions.

In-Place Density

Achieving a high relative density of each asphalt layer during construction is perhaps the most important factor that impacts long-term pavement performance. Therefore, most highway agencies use in-place density as a key pay factor in acceptance testing. The specified minimum density level is typically 92 to 93% of Gmm. It is generally understood that pavements with densities below that level tend to be permeable to water. However, the relationship between density and permeability is also greatly influenced by other simple gradation characteristics: nominal maximum aggregate size (NMAS) and the relative coarseness or fineness of the gradation. Figure 1 shows regressions between in-place air voids and permeability for different NMAS and coarse/fine gradations. From this graph it can be seen that 9.5 mm and 4.75 mm mixes are relatively impermeable at 8% air voids (92% of Gmm), whereas coarse-graded 12.5 mm mixes are on the cusp of a dramatic increase in permeability at 7% air voids, and 19.0 mm mixes are highly permeable to water at 7% air voids. This illustrates the advantage of smaller NMAS mixes for reduced permeability and the obvious need for higher density target levels when coarse mixes are used. When water is kept out of the pavement layers they will obviously be much more resistant to freeze-thaw, moisture damage, and age-hardening. Some asphalt experts have suggested that the industry should test in-place permeability rather than density. However, more work is needed to refine permeability testing before that can be seriously considered.

Thickness of the layer is a critical factor that affects a contractor's ability to adequately compact the material. NCHRP Report 531 recommends that fine-graded mixes be constructed at a minimum of three times the mixture's NMAS and course-graded mixes be constructed at least four times the NMAS. Trying to compact mixes below these thresholds is very challenging. This is a common problem for thin overlays on an existing pavement with a variable profile.

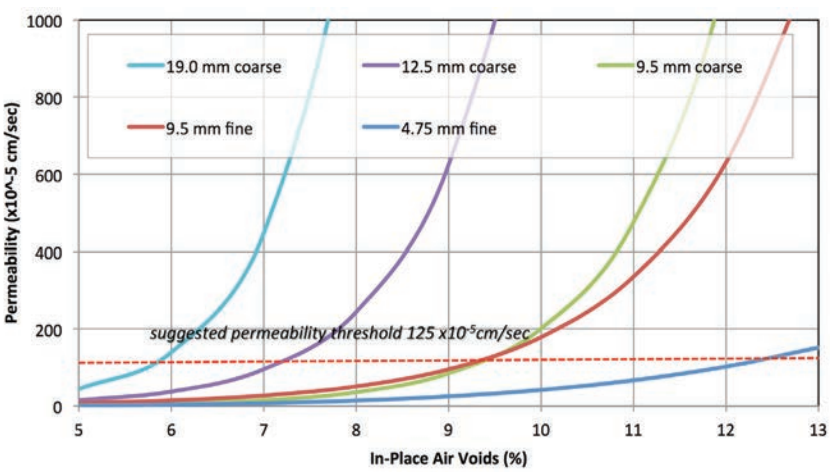


Figure 1: Relationship between air void content and permeability of various NMAS mixes (based on data from NCHRP Report 531 and NCAT Report 11-01).

Other important aspects of in-place density specifications deal with how density is measured and how frequent measurements are obtained to determine specification compliance. Some agencies use nuclear density gauges and others use roadway cores. Although there are advantages and disadvantages with both approaches, most asphalt experts consider cores to be the preferred method. If we consider that each core and nuclear density test represents areas of about 0.2 to 1.0 square feet, respectively and one test is taken every 1000 feet of pavement, then we are only sampling approximately 0.0016% to 0.0083% of the paved area. With this miniscule proportion of testing it is easy to miss areas of segregation and low density. It is in those missed areas where pavement performance problems likely begin. A greater frequency of in-place density testing should be considered in future specifications.

Another density measurement issue is the amount of water absorption of cores when using AASHTO T 166 or ASTM D2726. These methods use Archimedes' principle to determine the volume of a compacted asphalt sample, in this case a roadway core. The problem with this technique is that when cores with large voids are submerged, some of the water that enters those voids drains out of the core before the surface water is dried with a damp towel. This causes an error in the saturated surface dry (SSD) mass and the volume determination. The result is a higher calculated density (bulk specific gravity) than what the core actually has. In other words, AASHTO T166/ ASTM D2726 is not accurate for density determination of some coarse-graded mixtures, particularly when water permeable voids are interconnected. The current AASHTO and ASTM standards recommend a slightly different solution to this error by requiring that samples with greater than 2% water absorption be tested with different alternative methods. For T 166, the alternative method is the paraffin coating method, AASHTO T 275. The ASTM method allows either the parafilm method, ASTM D1188, or the vacuum sealing method, ASTM D6752.

NCAT research has shown that the most accurate alternate method is the vacuum sealing method, and it should be used when water absorption exceeds 1.0% rather than the current limit of 2%. Data has shown that calculated in-place air voids are approximately 1.0% higher on average for coarse-graded mixtures when using the vacuum-sealing method in place of AASHTO T 166/ASTM D2726. Therefore, changing to the vacuum-sealing method for acceptance testing of in-place density results in lower density results than those typically obtained in current practice for coarse-graded mixes.

Contractors and highway departments should examine Gmb data for cores from recent projects to determine how often the cores absorb more than one percent water. Cores for longitudinal joint tests should especially be scrutinized. Even projects using nuclear density gauge tests should examine data for cores from test strips used to establish bias (correction) factors or equations. If more than 10% of cores have greater than 1.0% water absorption, then the highway agency should strongly consider adopting the vacuum sealing method when the 1.0% limit is exceeded. Greater attention to this detail could reveal that the adequate in-place density results that we think we have been getting on projects actually have a significant percentage of results below the target levels.

In effect, using the vacuum sealing method to determine core densities could mean that better field compaction methods are needed to reach appropriate in-place density targets. However, if other details described in this article are implemented at the same time, such as adjusting volumetric mix design criteria, correcting Gsb values, and lowering Ndesign, then achieving higher density levels should be attainable. There are also several other new tools and technologies available today that can help improve in-place densities: warm-mix asphalt (WMA), infrared mat temperature mapping, and intelligent compaction. Many contractors across the U.S. are using WMA because these technologies can help improve the compactibility of mixes. Infrared mat temperature systems are an excellent tool to help identify areas with temperature segregation, which can be challenging to achieve uniform densities and smoothness. Finally, intelligent compaction systems that map out roller passes are available to provide roller operators with a visual guide to compacting every part of the asphalt mat.

RAP and RAS

Using RAP and RAS can be an important part of the industry's effort to be more sustainable and cost-effective if good practices with these recycled materials are followed. Although a complete review of the best practices for handing these materials is beyond the scope of this article, there are a few key points to emphasize.

There is still considerable debate about exactly how much RAP and RAS binders are activated as effective asphalt, but most research indicates that we can assume that all of the RAP binder is effective. NCHRP Report 752 recommends that when the RAP binder exceeds 25% of the total binder in the mix, the virgin binder grade should be selected based on a blending equation. In effect, softer grades of virgin binder are often needed for high RAP content mixes, and several studies have shown that softer binders are effective in improving their cracking resistance.

Since RAS binders are much stiffer than RAP binders, all of the RAS binder may not be initially activated during mix design or mix production, particularly for post-consumer (tear-off) RAS. Therefore, the growing consensus is that the RAS binder availability factor be set in the range of 0.7 to 0.85, meaning that only 70 to 85% of the RAS binder should be considered effective. Currently, there is not a proven method on how to determine the availability factor; rather, most asphalt technologists with experience in production and placement of mixes containing RAS recognize that the effect of using a factor of 0.7 to 0.85 is to increase the virgin binder content by 0.3% to 0.15%, respectively, which helps improve placement, compaction, and durability of the mixes. There are several factors that are likely to affect how much RAS binder is effective in a given mix. Smaller grind size (essentially the nominal maximum particle size) of the recycled shingle material is generally considered to help improve blending of the RAS and virgin binder. Lower moisture contents of RAS being fed into a plant is also desired, since less energy is needed to drive off the moisture and more heat energy is available to raise the RAS binder to its melting point. Longer mixing times and silo storage times are also believed to be helpful in activating more RAS binder.

There are different views on how to make mixes containing RAS more resistant to cracking, partly because different studies have used different tests to evaluate cracking resistance. Presently, there are about a dozen different tests that have been used to evaluate the different modes of cracking for asphalt pavements: fatigue cracking, low-temperature cracking, reflection cracking, and top-down cracking. Many believe that the single greatest research need in the asphalt paving industry is to validate the cracking tests and their criteria using correlations to field performance. It will take a concerted effort and several more years to meet this need. In the meantime, we need to revive the basic principles of mix design, testing, and construction described above to help improve the durability of asphalt mixes in the field.

RELATED REPORTS & RESEARCH SYNOPSES

The following research is available at: ncat.us/info-pubs

NCAT Report 12-06: A Review of Aggregate and Asphalt Mixture Specific Gravity Requirements and Their Impacts on Asphalt Mix Design Properties and Mix Acceptance

NCHRP 531 Synopsis: Relationship of Air Voids, Lift Thickness and Permeability in Hot-Mix Asphalt Pavements

NCHRP 573 Synopsis: Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table

Research Synopsis: Relationships Between Laboratory-Measured Characteristics of HMA and Field Compactability

Research Synopsis 03-02: Factors Affecting Permeability of Superpave Mixes