National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

Relationship of Air Voids, Lift Thickness and Permeability in Hot-Mix Asphalt Pavements

RESEARCH SYNOPSIS–NCHRP REPORT 531

Problem Statement

For durability and long-term performance, hot-mix asphalt (HMA) pavements must be impermeable and have acceptable in-place air voids. While dense-graded HMA mixes are typically impermeable when in-place air voids are less than 8 percent, stone matrix asphalt (SMA) and some coarse-graded Superpave mixes have permeability issues at lower air void contents. The size and interconnectedness of air voids influences permeability.

Previous studies have found that lift thickness affects in-place density and, hence, permeability. While historical guidance recommends a minimum ratio of lift thickness to nominal maximum aggregate size (t/NMAS) of 3, some have suggested that t/NMAS equal to 4 is preferred. In order to achieve adequate density and avoid permeability issues, appropriate recommendations for t/NMAS should be determined based on gradation and mix type.

Objective

The objectives of the NCHRP 9-27 study were three-fold:

1. Determine the minimum t/NMAS necessary in order to achieve desirable pavement density levels and impermeable pavements
2. Evaluate the permeability characteristics of HMA compacted to different thicknesses
3. Evaluate factors that affect the relationship between in-place air voids, permeability and lift thickness

Description of Study

Since air void calculations are dependent on bulk specific gravity (G_{mb}) measurements, the study began by comparing four methods of measuring G_{mb} (AASHTO T 166, vacuum sealing, gamma ray and dimensional) to determine under what conditions the traditional T 166 method is accurate. The four methods were evaluated using both lab-compacted and field-compacted samples representing a variety of aggregate types, NMASs, gradation types and air void contents. The vacuum sealing method was found to provide more accurate results for coarse-graded mixes. For this reason, the vacuum sealing method was used to determine density for this study.

Next, the relationship between t/NMAS and density was evaluated within a controlled, statistically designed experiment. A Superpave gyratory compactor (SGC) and a laboratory vibratory compactor were used to compact a wide range of fine-graded, coarse-graded and SMA mixes at varying thicknesses (t/NMAS = 2, 3 and 4) to determine the effect of t/NMAS on density. However, the results did not clearly define what value of t/NMAS yielded optimum density. To better establish appropriate t/NMAS criteria, a field study was conducted during the reconstruction of the NCAT Test Track in 2003. Seven mixes were placed and compacted in 40-m sections on a paved surface adjacent to the track. Within each section, the layer thickness varied from 2 to 5 t/NMAS. Cores were taken to determine density at various layer thicknesses.

The relationship between t/NMAS and permeability was evaluated by testing specimens compacted using the SGC and laboratory vibratory compactor. Specimens were compacted to a target of 7.0 ± 1.0 percent air voids while thickness varied (t/NMAS = 2, 3 and 4). However, most of the thin SGC specimens did not reach the target air voids even after 300 gyrations. Field and lab permeability tests were also performed

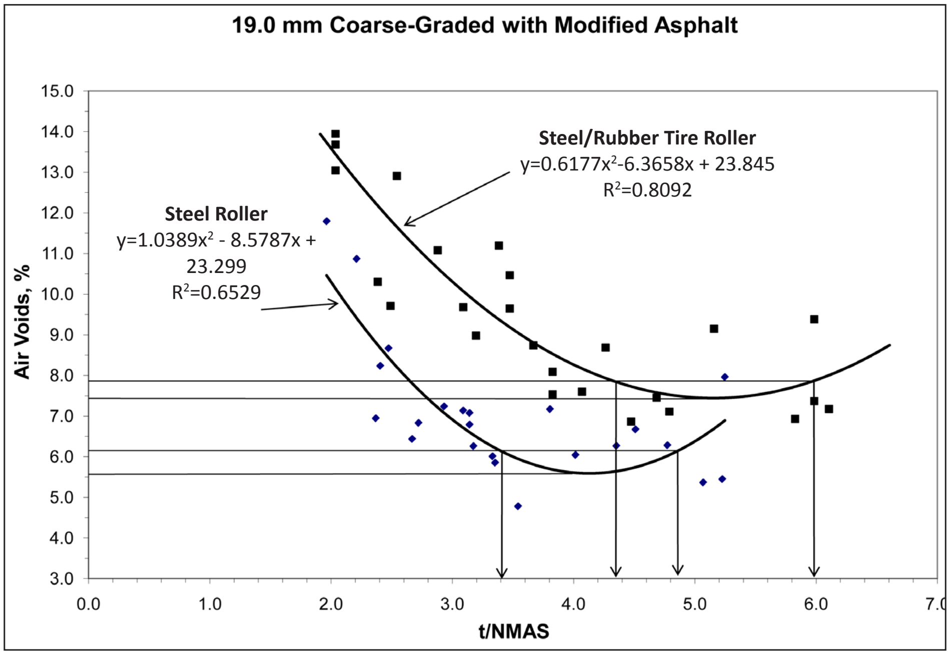

Figure 1 Relationship between air voids and t/NMAS for 19.0 mm coarse-graded mix, showing optimum t/NMAS ranges.

Figure 2 (Top) Removal of an SMA sample from water bath. (Bottom) Water draining from permeable voids of the specimen.

on the seven mixes placed adjacent to the test \track. Additionally, cores obtained from the NCHRP 9-9 study (including 40 sections with a range of aggregate types, NMASs, lift thicknesses and design gyrations) were used to help determine the level of air voids at which permeability reached a critical level.

Lastly, 20 construction projects were visited to verify the relationship between permeability, in-place density and lift thickness in the field. The projects represented wide ranges of NMAS, gradation type and t/NMAS. Field permeability tests were conducted, and plant-produced mix was used to compact samples for laboratory testing.

Key Findings

- The vacuum-sealing method is better than the water displacement method (AASHTO T 166) for determining the density of coarse-graded and SMA samples, because it is not possible to obtain an accurate saturated surface dry (SSD) mass measurement when water drains from permeable surface voids as the specimen is removed from the water bath.
- Data from the seven variable thickness sections at the track indicated that optimum t/NMAS was between 3 and 5. Optimum t/NMAS was considered the point at which additional thickness resulted in increased, rather than decreased, air voids. For fine-graded mixes, density changed very little when t/NMAS was reduced from optimum to 3, but for coarse-graded mixes, air voids significantly increased when t/NMAS was reduced from optimum to 3.
- In-place air voids were the most significant factor influencing permeability, followed by coarse aggregate ratio and VMA. Permeability increased as coarse aggregate ratio increased, while permeability decreased with increased VMA (for constant air voids).
- The field verification portion of the study showed that:
  - Higher t/NMAS typically resulted in lower air void levels
  - For a given air void content, coarse-graded mixes generally had higher permeability than fine-graded mixes
  - Although air voids were a key determining factor for permeability, permeability was often greater than the recommended maximum value of 125 x 10-5 cm/sec even at relatively low air void levels (5–7 percent)

Recommendations for Implementation

- The water absorption limit for AASHTO T 166 should be reduced to 1 percent. For water absorption levels greater than 1 percent, the vacuum-sealing method provides a more accurate measurement of G_{mb} and thus, a more accurate calculation of air voids.
- For best results, t/NMAS should be between 3 and 5. Recommendations for t/NMAS are at least 3 for fine-graded mixes and at least 4 for coarse-graded and SMA mixes. Ratios less than these recommended values will require greater compactive effort to achieve desired in-place density.
- In order to achieve density on thinner sections, rollers should stay close to the paver due to more rapid cooling of the mix for lower values of t/NMAS.
- In-place air voids should be approximately 7 percent or less, regardless of NMAS or gradation type, in order to avoid problems with permeability.

Acknowledgements and Disclaimer

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