



Factors Impacting HMA Density

Prepared for
**WHRP Flexible Pavements
Technical Oversight Committee**

Prepared by
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WisDOT Research & Library Unit**

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Transportation Literature Searches are prepared for WisDOT staff and investigators to identify completed research and other authoritative information in an area of interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's [WorldCat](#) and [TLCat](#), U.S. DOT's [TRIS Online](#), the National Transportation Library ([NTL](#)), TRB's Research in Progress ([RiP](#)) database, and other academic, engineering and scientific databases as appropriate.

To request a literature search, contact the WisDOT Library at library@dot.state.wi.us or (608) 264-8142, or WisDOT Research at research@dot.state.wi.us or (608) 261-8198.

Topic/Problem Statement: Document relevant literature sources for a project relating density to construction and materials factors such as temperatures for mixing and compacting.

Keywords: density, permeability, temperature, compaction

Summary

We were asked to follow up a previous Transportation Literature Search (*Relationships Between HMA Permeability, Density and Performance*, June 13, 2007) with a more refined search of literature on factors in construction and mixtures relevant to as-built density of HMA pavements.

We weighed findings based on direct relationships to field density, and found citations focused on density and factors such as physical properties of aggregates, mat and compaction temperatures, and segregation, to name a few.

We found 19 finished documents. The citations were concentrated with seven in 2006, one each in 2004 and 2005, and two each in 2000, 2001, 2002, 2003, and 2007. Of these, two reports were sponsored by Washington State DOT, one by the Virginia Transportation Research Council, and one by Wisconsin DOT. Twelve of the 19 citations were of documents published by TRB.

We also found one study in progress. Mississippi DOT, the study's sponsor, expects the work to be completed September 2008.

Citations

Results are listed chronologically, the most recent citations shown first. Links to online copies of cited literature are provided when available. Contact the WisDOT Library to obtain hard copies of citations.

Title: Installation of Warm Mix Asphalt Projects in Virginia

Author(s): Stacey Diefenderfer, Kevin McGhee, Bridget Donaldson

Date: April 2007

Doc ID/URL: FHWA/VTRC 07-R25; VTRC 07-R25. http://www.virginiadot.org/vtrc/main/online_reports/pdf/07-r25.pdf.

Description: 34 pp.

Contents: Several processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt (HMA) without sacrificing the quality of the resulting pavement. The purpose of this study was to evaluate the installation of warm mix asphalt (WMA) to compile experiences and offer recommendations for future use. Three trial sections were installed using warm mix technologies between August and November of 2006. Two used the Sasobit technology, and the third employed the Evotherm technology. This report discusses the material makeup of these technologies and documents the production and placement of the three trial sections. The results of this study and further studies can serve as a basis for decision making by the Virginia Department of Transportation (VDOT) regarding the use of WMA technology. Trial sections were initiated through cooperative efforts by the Virginia Transportation Research Council; VDOT districts, residencies, and area headquarters; and participating contractors. Construction used typical mixture designs and practices so that performance under typical construction conditions could be evaluated. General experiences and processes used during construction were documented, and samples were taken for laboratory characterization. Density measurements and cores were taken at each site to determine the initial pavement properties. At the Evotherm installation, asphalt fume sampling was conducted by VDOT's Employee Safety and Health Division to evaluate differences in worker exposure between HMA and WMA pavement laydown operations. The study showed that WMA can be successfully placed using conventional HMA paving practices and procedures with only minor modifications to account for the reduction in temperature. The evaluated technologies affected mixture properties in slightly different ways such as changes in tensile strength ratios and variability in air voids. Additional monitoring of constructed sections was recommended to evaluate long-term performance. Inclusion of WMA technology as an option for paving operations provides potential benefits to VDOT and the contracting community. Theoretically, these technologies could extend the asphalt paving season into cooler weather, allowing for better optimization of paving resources. The technologies also allow the construction of asphalt pavements at lower temperatures, resulting in reduced cooling time before the pavement is opened to traffic. Lower production temperatures may also increase mixture durability by reducing production aging of the mix. Benefits to contractors may include the ability to increase hauling distances between the plant and project, reduced plant emissions resulting in improved air quality, and cost savings because of reduced energy costs. Because of the experimental nature of this study, no cost savings data are yet available to justify or refute the use of WMA technologies.

Title: Compaction and Tenderness of HMA Mixtures: A Laboratory Study

Author(s): Ahmed Fatin Faheem, Nabil Kamel, Hussain Bahia

Date: 2007

Doc ID/URL: *Transportation Research Board 86th Annual Meeting*, 2007. Report No. 07-1007.

Description: 19 pp.

Contents: This study evaluates the influence of binder viscosity, compaction temperature, compaction pressure, and binder content upon the densification of asphalt test mixtures produced using Process Modified Asphalt (PrMA) and Polymer Modified Asphalt (PMA). The effects upon densification are evaluated through a two stage laboratory study. The first stage is concerned with comparing the effort needed to compact each mix using two compaction levels and three compaction temperatures. One type of aggregate and one type of mix gradation are used in this evaluation. The second stage is concerned with the effect of the binder content on the mixtures' resistance to compaction and densification while varying the compaction temperatures, and pressure for mixtures made with the two types of binders tested. The results of the first stage showed that mixes vary in their sensitivity to the compaction level and the compaction temperature. It is observed that there is a high level of interaction between compaction pressure and temperature. Surprisingly, the conventional thinking of density always increases with temperature does not apply for all mixtures. There are clearly optimum temperature and pressure ranges within which densification can be achieved more efficiently. The second stage showed that the behavior of under asphalted mixtures depend mainly on the type of binder used. While for the over asphalted mixtures, their behavior is identical regardless of compaction temperature, pressure or binder type. While some studies have reported on what are known as "Tender Zones," very few could quantify this in the laboratory and report on what makes a mixture tender and how to give guidelines to contractors to avoid tender zones. The authors suggest that these zones could be asphalt binder specific and should be defined in a 3-domain chart showing pressure, temperature sensitivity, and asphalt binder type and content in the mixture.

Title: Factors Affecting Compaction of Asphalt Pavements.
Author(s): Transportation Research Board (corporate author)
Date: September 2006
Doc ID/URL: *Transportation Research E-Circular*, E-C105.
<http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf>.

Description: 190 pp.

Contents: An all-day workshop at the 84th Annual Meeting of the Transportation Research Board (TRB) addressed asphalt practitioners' concerns related to specifying and achieving density during hot-mix asphalt (HMA) pavement construction. The workshop was divided into four mini-sessions with the following themes: Optimizing HMA Construction Temperatures; Recent Advances in Compaction Equipment, Including "Intelligent Compaction"; Longitudinal Joint Density; and Incentives-Disincentives for Construction Quality. The papers in this document are invited papers for this workshop.

Title: Compaction of stiff and tender asphalt concrete mixes
Author(s): James Scherocman
Date: September 2006
Doc ID/URL: *Transportation Research E-Circular*, E-C105: 69-83.
<http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf>.

Description: 15 ppl.

Contents: Many of the asphalt concrete mixtures designed using the Superpave mix design system are relatively stiff and difficult to compact. In order to properly densify these types of mixtures, it is necessary to keep the rollers directly behind the paver in order to apply the compactive effort while the mix is hot. Several different roller patterns can be employed, but the most efficient roller pattern typically uses a pneumatic tire roller for initial compaction followed by a double drum vibratory roller for intermediate, and often finish, rolling. Some Superpave designed mixtures, however, are very tender and move under the compactive effort of the rollers. These tender mixes shove in both the longitudinal and transverse direction and often check or crack while being compacted. For tender mixtures, three temperature zones typically exist--both an upper and a lower temperature zone where density can be obtained and an intermediate temperature zone where de-compaction of the mix occurs during the rolling process. For tender mixes, it is necessary to alter the roller patterns in order to achieve the required level of density in the upper temperature zone--before the mix starts to move and shove. The use of two double-drum vibratory (DDV) rollers operated in echelon directly behind the paver is the most efficient and effective method to achieve the desired level of density in such mixtures. The purpose of this paper is to review some of the possible causes for both stiff and tender asphalt concrete mixtures and to discuss how to properly compact each type of mix. For mixtures which exhibit tender characteristics, the contractor must be aware of the three temperature zones which typically exist during the rolling process.

Title: Vibratory pneumatic tire roller
Author(s): Yukinori Nose
Date: September 2006
Doc ID/URL: *Transportation Research E-Circular*, E-C105: 54-68.
<http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf>.

Description: 15 pp.

Contents: In order to improve the efficiency of the compaction process for both stiff and tender Superpave mixtures, a vibratory pneumatic tire (VPT) roller was developed by Sakai Heavy Industries, Limited, in 2002. The roller has been used on various types of paving projects in the United States since the first production unit was introduced in March 2003. For the evaluations conducted on normal paving operations, the VPT roller was used in the intermediate rolling position after breakdown rolling by a high-frequency double-drum vibratory (DDV) roller. Based on the evaluation of results obtained at San Francisco International Airport, King City, California, and Traverse City, Michigan, the following conclusions were reached. First, the minimum required density of the pavement was significantly exceeded with a combination of a high-frequency DDV roller and a VPT roller. Second, a vibratory pneumatic roller weighing only 9,350 kg (20,580 lb) and making six roller passes at medium amplitude achieved the same level of density as a conventional static pneumatic tire (SPT) roller weighing 27,270 kg (60,000 lb) and making 12 roller passes. It is obvious that the VPT roller is more versatile and efficient than a much heavier SPT roller. Third, the density distribution measured by cores cut from the pavement show that the density in middle or bottom portion is higher than that in the top portion. It is believed that the density in the top portion was lower due to excessive compactive effort applied during breakdown rolling when the pavement surface temperature was relatively low.

Title: Oscillatory compaction of hot-mix asphalt

Author(s): Edward Kearney

Date: September 2006

Doc ID/URL: *Transportation Research E-Circular*, E-C105: 49-53.

<http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf>.

Description: 5 pp.

Contents: Historically, compaction of hot-mix asphalt (HMA) pavements was done with steel wheel static rollers until vibratory rollers, introduced in the late 1950s, became the dominant compaction equipment. As difficulties in compacting Superpave mixes were encountered during the 1980s and 1990s, equipment manufacturers made their vibratory rollers bigger, heavier, and with higher vibration frequencies. In some cases, these rollers were so powerful that, during compaction, mix aggregates were fractured, the asphalt mat cracked, and damage to nearby buildings and underground utilities occurred. This latter problem had been evident earlier in European countries due to their narrower city streets and the proximity of many old, historic buildings. Thus oscillation technology was developed in Germany in 1983 and after years of testing and usage in Europe, the oscillatory asphalt roller was introduced in the United States in early 2003. The oscillatory system uses dual, opposed, eccentric weights rotating in the same direction around the roller drum axis to produce a rocking motion. This rocking motion produces horizontal and downward shear forces that achieve greater compaction by "massaging" the HMA--even at lower mix temperatures. Since the drum does not leave the pavement surface or bounce like a conventional vibratory roller drum, the compacted mat surface is smooth and flat and there is no damage to utilities, buildings, or bridges. Numerous tests have shown that oscillatory compaction can achieve higher densities with fewer passes when compared to a vibratory roller. Plus compaction is possible at lower temperatures (down to 150 deg F).

Title: State-of-the-practice for cold-weather compaction of hot-mix asphalt pavements

Author(s): Dale Decker

Date: September 2006

Doc ID/URL: *Transportation Research E-Circular*, E-C105: 27-33.

<http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf>.

Description: 7 pp.

Contents: Asphalt technologists around the world understand that achieving proper density of hot-mix asphalt (HMA) pavements in the field is the single most important factor in determining the performance of the pavement. There are literally hundreds of references in the technical literature on the subject. Compaction of the mix at the time of placement is the process whereby density is achieved. Many agencies have specification requirements which force the contractor to discontinue paving operations at some arbitrary temperature or calendar date. Yet pavements can be successfully placed at low temperatures. Done properly, pavements placed at low temperatures can perform well. Demands of construction scheduling, inclement weather and public safety often force the owner-agency and contractor into a position of needing to get the paving completed, regardless of the environmental circumstances. These are the issues to which this paper is addressed.

Title: How Temperature Impacts Compaction

Author(s): Dale Starry

Date: August 2006

Doc ID/URL: *Pavement*, Vol. 21 (6): 30-33.

Description: 4 pp.

Contents: This article discusses three factors that influence the ability of a paving train to achieve target density air void content on paving projects. These factors are mix design, mix placement, and the temperature of the hot mix asphalt during the compaction process. The temperature factor is the one contractors are most likely to miss on paving jobs. The case of a contractor's night paving job is highlighted to illustrate the importance of temperature, mix delivery and proper location of the compactors behind the paver.

Title: Asphalt multi-integrated rollers and steel drum compactors: Evaluating effect of compaction on permeability of asphalt pavements

Author(s): Abd El Halim, Omar Abd El Halim, Abdelzاهر Mostafa

Date: 2006

Doc ID/URL: *Transportation Research Record No. 1967*, 2006: 173-180.

Description: 8 pp.

Contents: Theoretical analysis supported by laboratory investigations and verified by field studies and observations has shown that defects caused by rolling compaction are the main contributors to early deterioration of asphalt surfaces. The conventional and widely used steel drum roller induces hairline cracks, which permit moisture to infiltrate pavement structure, causing the phenomenon known as stripping. In addition to inducing cracks, steel

drums do not provide the desired uniformity in terms of density across the compacted width of the asphalt mat. Drummed rollers also produce poor compaction at unsupported edges of paved lanes. The asphalt multi-integrated roller (AMIR), an innovative compaction technology, offers a more effective alternative for overcoming problems of steel drum rollers by reducing permeability and, in turn, improving long-term performance of flexible pavements. A multistaged laboratory and field-testing program that measures permeability in terms of hydraulic conductivity was performed on pavement sections constructed using an AMIR side by side with a conventional steel roller. Asphalt concrete layers compacted by steel drum rollers were found, on average, to be up to 20 times more permeable than those compacted by the AMIR immediately after construction and as much as 10 times more permeable after 1 year. The major steps leading to the understanding of how rolling affects the permeability of asphalt layers and, consequently, the long-term performance of newly compacted pavements are discussed and presented.

Title: Rut resistance and volumetric composition of asphalt concrete mixtures (with discussion)

Author(s): Donald Christensen, Ramon Bonaquist

Date: 2005

Doc ID/URL: *Journal of the Association of Asphalt Paving Technologists*, Vol. 74, 2005: 485-518. (On CD-ROM, 2005 *Journal of the Association of Asphalt Paving Technologists: From the Proceedings of the Technical Sessions.*)

Description: 34 pp.

Contents: This paper describes a model for estimating mixture rut resistance using the concept of mixture resistivity, which is the inverse of the permeability of the mixture aggregate to the specific binder used in the mixture at the temperature of interest. Laboratory testing using the repeated shear at constant height test showed very good correlations between resistivity, compaction effort, and maximum permanent shear strain as determined using the repeated shear at constant height test. To verify the usefulness of the proposed model field rutting data from Mn/Road, WesTrack and the National Center for Asphalt Technology (NCAT) Test Track were modeled, using resistivity, N sub design, and relative field density as predictor variables. The resulting model predicted rutting rates for all three projects simultaneously with an r supra 2 value of 89%. This model was used to analyze the effects of changes in mixture composition, binder grade, and compaction on rut resistance, and also in a preliminary analysis of the current Superpave mix design system. The most important factor affecting rut resistance in Hot Mix Asphalt Concrete (HMAC) mixtures is binder grade, followed by aggregate fineness relative to voids in mineral aggregates (VMA). This suggests that both VMA and aggregate fineness should be tightly controlled to ensure that a given mixture exhibits the desired level of rut resistance.

Title: Elimination of temperature and density differentials: the cycle density specification

Author(s): Kim A. Willoughby

Date: April 2004

Doc ID/URL: Washington State Department of Transportation, 2004. OCLC 55688302.

Description: 1 pp.

Contents: CoreLock, which uses a controlled vacuum system to seal samples, should be used for testing coarse-graded and SMA mixes when the absorption exceeds 0.4 percent. AASHTO T-166 can be used for fine-graded mixes with less than 2.0 percent water absorption.

Title: Construction-related variability in pavement mat density due to temperature differences

Author(s): Kim A. Willoughby

Date: 2003

Doc ID/URL: *Transportation Research Record No. 1849*, 2003: 166-173.

Description: 8 pp.

Contents: The work reported on is an extension of work done in Washington State to examine the systematic occurrence and variability in pavement mat density. The focus will be on the extent of the pavement that is affected by variable density due to temperature differentials and the fact that randomly based testing does not identify the occurrence of cyclic density differentials. Temperature differentials 14 deg C (25 deg F) or greater generally cannot be compacted to the same level of density as the surrounding mat and therefore lead to significant density differentials (increase in air voids of 2% or more). A cyclic pattern typically occurs, matching each delivered truckload of mix, although temperature differentials can occur randomly or not at all, depending on the remixing device. The largest extent of pavement is affected when no remixing occurs and temperature differentials develop for every truckload of hot mix. These temperature differentials can cover the entire width and affect up to 50% of the mat. If the delivered hot mix is thoroughly remixed before placement, temperature differentials are minimal. Although density will vary in any paving operation, it was found that a uniform temperature mat greatly increases the ability to achieve a uniform density. Because of this cyclic pattern of variable density, random sampling for in-place density does not properly identify or quantify this problem. It is recommended that temperature differential areas be determined during construction and excluded from the random sampling used for acceptance testing. The

issue of variable densities due to temperature differences or aggregate segregation should be identified and eliminated at the start of the project.

Title: Asphalt flow improvers – A new technology for reducing mixing temperature of asphalt concrete mixes with high-resistance against permanent deformation

Author(s): D. Klaus

Date: 2003

Doc ID/URL: *Proceedings of the XXIIInd PIARC World Road Congress*, October 2003.

Description: 7 pp.

Contents: This paper describes how asphalt flow improvers in the form of Fischer-Tropsch wax and Romontan wax have emerged successfully from an extensive program of laboratory testing and road trials to assess their suitability as modifiers for rolled asphalts and guss asphalt. They produce flow improvement effects in hot asphalt mixes that enable mixing temperatures to be reduced by 20-40 degrees Centigrade. Below the temperatures used in laying and compaction, these materials produce a stepwise increase in asphalt viscosity and stiffness. This results in a significant improvement in the stability (resistance to deformation) of the asphalt under operational conditions of high ambient temperatures and heavy traffic. The data gathered so far show that low temperature properties are not adversely affected. The higher density that is achieved on compaction greatly improves the life span of asphalts in service. Although these benefits can be realized by using flow improvers alone as bitumen additives, they are especially suitable as co-modifiers for polymer modified Bitumen PMB 45 and PMB 25 grades since they significantly improve handling and compatibility. Based on current experience, the recommended level of additivation with asphalt flow improvers is 3 % wt. of the binder quantity. Till the end of 2002 about 3 million m(2) of asphalt pavements would be laid successfully in Germany.

Title: Determining a Temperature-Density Relationship After Completed Rolling of HMA

Author(s): S.A. Hanna, H.U. Bahia, J.S. Russell, S. Schoenfelder, S-W. Loh

Date: January 2002

Doc ID/URL: WHRP Report No. 02-001, <http://www.dot.wisconsin.gov/library/research/docs/finalreports/00-06temperaturedensity-f.pdf>.

Description: 100 pp.

Contents: During the past few years, the implementation of the nuclear gauge method of testing hot mix asphalt for desired compaction has proven a nondestructive and timesaving option. However, discrepancies between contractors' and Wisconsin Department of Transportation readings have led to this research which serves to investigate the relationship between the temperature and density of newly placed hot mix asphalt. The theory states that as asphalt cools, it becomes denser. Hence, if a nuclear gauge is used to measure density after the asphalt has been allowed to cool, it should record a higher reading than when the asphalt was measured just after cold rolling the previous day. This research investigation has found a model that has not reinforced this theory. The research has shown that testing a road for density the morning following paving will not result in a significant difference in density than if it is tested the same day of paving.

Title: Construction-related asphalt concrete pavement temperature and density differentials

Author(s): K. A. Willoughby, J.P. Mahoney, L.M. Pierce, J.S. Uhlmeier, K.W. Anderson

Date: 2002

Doc ID/URL: *Transportation Research Record No. 1813*, 2002: 68-76.

Description: 9 pp.

Contents: The Washington State Department of Transportation (Washington State DOT) examined temperature differentials in hot-mix asphalt paving over four construction seasons. From those studies it was found that low-density areas can be caused by temperature differentials in the mat. The study summarized is based on an examination of 17 projects during the 2000 Washington State DOT paving season to determine density differentials in the mat with a "density profile." A density profile is a series of density readings taken in a longitudinal direction over a 15-m (50-ft) section through a low-temperature area. From this collection of density readings, the density range (the difference between the maximum and the minimum readings) and the density drop (the difference between the average and the minimum readings) are determined. The density range and drop are used to determine if low-temperature areas result in inadequate compaction. The criteria set forth by the Washington State DOT included temperature differentials greater than or equal to 14 deg C (25 deg F), a maximum density range of 96 kg/cu m (6.0 lb/cu ft), and a maximum density drop of 48 kg/cu m (3.0 lb/cu ft). Evaluation of the density profiles showed that when the temperature differential exceeded 14 deg C (25 deg F), 89% of the density profiles failed to meet the density criteria, but only 19% failed to meet the density criteria when the temperature differential was less than 14 deg C (25 deg F). It was found that pavements that experienced large temperature differentials during placement produced substantial density differentials.

Title: Construction-Related Asphalt Concrete Pavement Temperature Differentials and the Corresponding Density Differentials

Author(s): Kim A. Willoughby, J.P. Mahoney, L.M. Pierce, J.S. Uhlmeier, K.W. Anderson, S.A. Read, S.T. Muench, T.R. Thompson, R. Moore

Date: July 2001

Doc ID/URL: Report No. WA-RD 476.1, Washington State Department of Transportation;
<http://www.wsdot.wa.gov/research/reports/fullreports/476.1.pdf>.

Description: 163 pp.

Contents: The detrimental effects of low compaction temperatures or aggregate segregation have been documented for at least forty years. Lower compaction temperatures are directly related to an increase in air void content, which decreases the strength of the pavement. Even with a perfect mix design, if the mix is not properly compacted in the field, the final product will not last for its intended length of time. The goals of this study were to determine what kind of problem the Washington State Department of Transportation (WSDOT) experiences with hot-mix paving, whether temperature differentials or aggregate segregation or both, the possible causes of those problems, and what WSDOT can do to fix the problem. The study found that WSDOT experiences temperature differentials on many projects and to some extent aggregate segregation (typically in longitudinal streaks). The study also found that because many factors are involved with paving operations, no one single piece of equipment or operation will guarantee that temperature differentials will not occur, but that techniques can be utilized to offset the effects of the temperature differentials. The study utilized a density profile procedure that provides a method of determining the effect of the temperature differentials in the finished product. It can locate potential areas of low density, test those areas, and provide results (via a nuclear asphalt content gauge) to determine the extent of the problem. Density differentials are a primary concern in hot-mix paving. If temperature differentials exist, but the finished pavement has a uniform density of 93% or greater for dense-graded mixes, then the pavement should serve its intended purpose for its intended length of time. The density profile procedure does not guarantee a uniform mat density, but it can be used as a quality control tool to help attain a uniform density. This could be a major step in achieving a higher quality hot-mix product.

Title: Developing critical field permeability and pavement density values for coarse-graded Superpave pavements

Author(s): L. Allen Cooley, Jr., E. Ray Brown, Saeed Maghsoodloo

Date: 2001

Doc ID/URL: *Transportation Research Record No. 1761*, 2001: 41-49.

Description: 9 pp.

Contents: Within the hot mix asphalt (HMA) community, it is generally accepted that the proper compaction of al for a stable and durable pavement. Low in-place air voids have been shown to lead to rutting and shoving while high in-place air voids have been shown to reduce a pavement's durability through moisture damage and excessive oxidation of the asphalt binder. Recent research has suggested that coarse-graded Superpave designed mixes are more permeable than conventionally designed pavements at a given air void content. This higher permeability can lead to durability problems. The pavement density at which coarse-graded Superpave mixes become permeable was evaluated by using a field permeability device. On the basis of the data collected, 9.5- and 12.5-mm nominal maximum size (NMA) mixtures become excessively permeable at approximately 7.7 percent in-place air voids, which corresponded to a field permeability value of 100 x (10 to the -5th) cm/sec. Mixtures having a 19.0-mm NMA became permeable at an in-place air void content of 5.5 percent air voids which provided a field permeability value of 120 x (10 to the -5th) cm/sec. Coarse-graded mixes having an NMA of 25.0 became permeable at 4.4 percent air voids, which corresponded to a field permeability value of 150 x (10 to the -5th) cm/sec. (See also report of identical title, authorship, and contents: Report 01-03, National Center for Asphalt Technology, <http://www.eng.auburn.edu/center/ncat/reports/rep01-03.pdf>.)

Title: Construction-related temperature differentials in asphalt concrete pavement: identification and assessment

Author(s): J.P. Mahoney, S.T. Muench, L.M. Pierce, S.A. Read, H. Jakob, R. Moore

Date: 2000

Doc ID/URL: *Transportation Research Record No. 1712*, 2000: 93-100.

Description: 8 pp.

Contents: Numerous Washington State Department of Transportation (WSDOT) paving projects have experienced a cyclic occurrence of premature failure of open-textured asphalt concrete (AC) pavement sections by fatigue cracking, raveling, or both, generally called "cyclic segregation" or "end-of-load segregation." This resulted in an initial study in which mat temperature differentials were observed during laydown. In turn, this led to the current study and the reported results. Pavement temperature differentials result from placement of a cooler portion of the hot-mix mass into the mat. This cooler mass generally constitutes the crust, which can develop during hot-mix

transport from the mixing plant to the job site. Placement of this cooler hot mix can create pavement areas near cessation temperature that tend to resist proper compaction (they may also exhibit tearing or roughness or appear to be open textured). These areas were observed to have decreased densities and a higher percentage of air voids (higher air voids). Four 1998 WSDOT paving projects were examined to determine the existence and extent of mat temperature differentials and associated material characteristics. An infrared camera was used to identify cooler portions of the mat, which were then sampled along with normal-temperature pavement sections. Gradation and asphalt content analysis showed no significant aggregate segregation within the cooler areas. However, these cooler portions of the mat consistently showed higher air voids than the surrounding pavement. On the basis of numerous studies that have related AC deterioration and high air voids in a mix, it is known that the areas of a mat with higher air voids may experience premature failure compared with the time to failure of the mat as a whole.

Title: Study of compaction density in closed form

Author(s): J.D. Huh, Y.K. Nam

Date: 2000

Doc ID/URL: *Transportation Research Record No. 1712, 2000: 66-73.*

Description: 8 pp.

Contents: As a common description of the compaction process, density versus number of roller passes (coverage) is often found in the literature and is subsequently used in the field. The closed formula is introduced to quantify such a relationship. Variables considered are compaction density, mix viscosity, temperature, frequency, and amplitude, in addition to the number of roller passes. Their effects are included in the proposed formula. The experimental data found in the literature are used to verify the equation. Excellent prediction of the data confirms the success of the formulation. As the result of this mathematical modeling, the minimum number of passes required to finish a certain compaction job and the maximum compaction density achievable by a certain compaction operation are suggested. The equation and its features will be an effective tool for using rolling compaction in an effort to construct better roadway pavements.

Research in Progress

Results are listed chronologically, the most recent citations shown first. Links to research project Web sites or Research in Progress listings are provided when available.

Title: Evaluation of HMA Lift Thickness

Principal Investigator(s): L. Allen Cooley, Burns Cooley Dennis, Inc., <http://rip.trb.org/browse/www.bcdgeo.com>

Start Date: 10/1/2006

RIP URL: <http://rip.trb.org/browse/dproject.asp?n=12300>

Source Organization: Mississippi Department of Transportation

Contents: Proper compaction of hot mix asphalt (HMA) mixtures is vital to ensuring that a stable and durable pavement is constructed. There are many factors that can affect the compaction of HMA. One of these factors is lift thickness. Previous work by the Florida DOT and the National Center of Asphalt Technology showed that for a given compactive effort, an increase in lift thickness results in an increase in compacted density. MDOT's current lift thickness requirements for a single lift of HMA is based on nominal maximum aggregate size (NMAS), with maximum lift thickness limited to generally 4 times the NMAS. Most current gravel sources in Mississippi are producing particle sizes that are in the range of 1 ½ to 2 inches. Once crushed to provide the needed particle angularity for HMA, most of the aggregate particles are less than ½ inch in diameter. This means that the most rut resistant mixes (mixtures containing the most angular aggregates) have a relatively small NMAS. Under the current Mississippi aggregate requirements, the highest quality HMA mix used in Mississippi, a 9.5 mm NMAS, can not be used in 2 inch mill and fill overlay projects, and a high quality 12.5 mm NMAS mix cannot be utilized in a 2 ½ or 3 inch upper binder layer. The proposed research evaluates the use of 9.5 mm NMAS aggregate HMA in a 2-inch maximum lift thickness and a 12.5 mm NMAS aggregate HMA in a 3-inch maximum lift thickness in a total of 12 field projects. For each of these projects the compaction process will be monitored for roller types and pavement temperature and pavement density between roller passes. The collected data will be used to estimate the relative ability to compact the lift and provide information on whether the thicker lifts result in better density using a typical compactive effort. Uniformity of compaction throughout the depth of the compacted layer and the permeability of the layer will also be addressed. Based upon the research findings, MDOT would be provided with the requisite information to modify the current allowable lift thickness for HMA. Completion expected September 2008.