Construction and Building Materials 48 (2013) 315–324

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# The effect of lift thickness on permeability and the time available for compaction of hot mix asphalt pavement under tropical climate condition

Mohd Rosli Hainin [a], Nur Izzi Md. Yusoff [b,*], Mohd. Khairul Idham Mohd Satar [a], E. Ray Brown [c]

[a] Faculty of Civil Engineering and Construction Research Alliance, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[b] Dept. of Civil & Structural Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[c] National Centre for Asphalt Technology, Auburn University, Auburn, AL 36849, United States

## HIGHLIGHTS

- We study the influence of lift thickness on time available for compaction of HMA.
- We examine the permeability of HMA pavements as related to lift thickness.
- HMA with a lift thickness of 30 mm and less is exposed to permeability problem.
- The thinner the mix layer, the faster the mix cools, thus reducing the TAC.

## ARTICLE INFO

*Article history:*
Received 3 October 2012
Received in revised form 8 April 2013
Accepted 22 June 2013
Available online 31 July 2013

*Keywords:*
Hot-mix asphalt
Lift thickness
Permeability
Time available for compaction
Cooling rate
Nominal maximum aggregate size and gradation

## ABSTRACT

This study investigates the effect of lift thickness on (i) permeability and (ii) the time available for compaction (TAC) of hot-mix asphalt (HMA) mixes under tropical climate condition. A total of 14 HMA mixes consisting of various types, gradations, and nominal maximum aggregate sizes (NMAS) were selected. The heights for thickness ($t$) to NMAS ratios of 2.0, 3.0, and 4.0 were determined with appropriate mass to produce 7.0 ± 1.0% air voids. The bulk specific gravity of the samples was determined using the vacuum sealing method. The laboratory permeability test and the relationships between permeability and lift thickness were evaluated. To achieve the second objective, seven field test sections with different HMA mixes were constructed; each was about 40 m long and 3.5 m wide. Each test section was paved with thickness ($t$) to a nominal maximum aggregate size (NMAS) ratio of 2.0 at the beginning of the section and gradually increased to a $t$/NMAS ratio of 5.0 at the end of the section with air temperatures during construction ranging from 26 to 35 °C. It was found that HMA mixes with a lift thickness of 30 mm and less with coarse gradation have a greater chance of having a permeability problem, even though they are compacted at the right density. In addition, the thinner the mix layer, the faster the mix cools, thus reducing the TAC. The results also suggest that the TAC for a 25 mm lift is 13 min, 23 min for 32 mm, 32 min for 38 mm, and is expected to be more than 50 min for 44 mm and above.


## 1. Introduction

Permeability can be defined as the ability of fluid, usually water, to infiltrate through the pavement. Many studies have proved that infiltration of water into pavement can affect its durability [1,2]. Density is the most significant factor affecting permeability. Low density is generally caused by inadequate compaction, which permits the entrance of water and air into the permeable pavement causing an increased potential for water damage, oxidation, travelling and cracking [3]. Permeability increases with decreasing density and the temperature of hot-mix asphalt (HMA) during compaction influences density. If the HMA temperature during compaction is lower than the desired temperature, the result is a low-density pavement with many air voids, while a high HMA temperature leads to a high-density pavement with few air voids [4].

Besides density, other factors that may influence permeability are the gradation of the mix, the nominal maximum aggregate size (NMAS) in the mix and the thickness of the compacted HMA layer [5–9]. The voids in the mixture, which are affected by compaction

* Corresponding author. Tel.: +60 3 8921 6447; fax: +60 3 8921 6147.
*E-mail addresses:* mrosli@utm.my (M.R. Hainin), izzi@eng.ukm.my (Nur Izzi Md. Yusoff).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.06.092

efforts, increase with increasing NMAS [10]. Several researchers have proved that the permeability value is higher with coarsely graded mixtures together with larger aggregate size [11]. Larger NMAS and coarser gradation, which means a lack of fine aggregates to fill the voids, lead to high permeability [12]. Cooley et al. [10] and Mallick et al. [13] found that the size of the individual air voids increased with increasing NMAS, resulting in a higher potential for interconnected air voids.

The lift thickness, which relates to density, also affects the permeability of HMA mixture [14,15]. The National Cooperative Highway Research Program (NCHRP) Project 9-27 has confirmed that lift thickness influences the density and consequently affects the permeability of HMA [16]. Hainin and Cooley [8] and Brown et al. [17] conclude that permeability decreases as the lift thickness increases. However, Cooley and Williams [4] found a different result in that the lift thickness had no influence on the permeability of the HMA mix. The thicker layer helped the mix to remain at the compaction temperature longer, so adequate density was easy to achieve [2]. Nevertheless, there has not been much research done into the specific impact of each factor, especially lift thickness. Therefore, the first part of this study looked at the influence of lift thickness on the permeability of HMA mixes.

In addition, research into the time available for compaction (TAC) of HMA pavement is also scarce. This is partly because the study involves many other significant variables such as lift thickness, mix temperature, solar flux, and wind speed. It also incurs a high cost and is tedious to perform. As Hughes [18] states, probably the single most important factor that affects the compaction of asphalt mix is the temperature at the time of compaction. One study of TAC discusses the cooling rate of asphalt pavements, and finds that the factors affecting the cooling rate include the initial temperature at the time of placement, the air temperature of the base, the thickness of the asphalt mix layer and environmental conditions. It is well known that the time required for HMA compaction decreases with increasing cooling rate. Thus, the ability to predict the cooling rate is more critical during adverse conditions, as the time available for mix compaction is limited [19].

Based on the previous study of TAC, Corlew and Dickenson [20] determined the time limits for compaction by specifying a minimum compaction temperature of 80 °C. At temperatures below 80 °C, the probability of significantly increasing density is very low and, in some cases, can result in the fracture of the aggregate in the mix and a decrease in density. In addition, inadequate compaction of HMA leads to a decrease in the fatigue life, reduces strength and stability, increases permanent deformation, accelerates oxidation or aging, increases moisture-related damage, and hence affects long-term pavement performance [21]. A study done by Tegelar and Dempsey [22] suggests that 10 min is the absolute minimum allowable compaction time needed with present-day equipment. They also developed cooling curves that predict the amount of TAC under different combinations of variables. Kari [23] proposes that increasing the lift thickness could allow the mix to retain heat longer, thus improve compactibility.

Jordan and Thomas [24] produced a computer program to predict the cooling curve for HMA materials. A new tool was developed by Chadbourn et al. [25] to simulate the cooling rate of HMA mat under adverse conditions. Most of the findings are based on work intended for cold climate conditions because of rapid decline in temperature of the mix. With the recent developments in asphalt technology, there has been wide use of a thin lift surface and PG grade asphalt, especially in tropical countries. Since the lift thickness is probably the single most important factor in the cooling rate of HMA mixes, there is a need to conduct a detailed study to investigate its effects on TAC under tropical climate conditions. Therefore, the second part of this study investigated the effects of lift thickness on the TAC of HMA mixes.

## 2. Experimental programs

### 2.1. Laboratory testing

To investigate the permeability characteristics of HMA at different thicknesses, 14 mixes were selected and gyratory and vibratory compactors were utilized. The test plan for this experimental study is shown in Fig. 1. Four Superpave mixes namely 9.5 mm NMAS Fine Graded (FG), 9.5 mm NMAS Coarse Graded (CG), 19.0 mm NMAS FG and 19.0 mm CG were used. Three others were Stone Mastic Asphalt (SMA) mixes with 9.5 mm, 12.5 mm and 19.0 mm NMAS. Two types of aggregates were utilized, namely limestone and granite. The asphalt cement was PG64-22 grade. The properties of the aggregates and asphalt cement are presented in Tables 1 and 2 respectively.

The heights for *t*/NMAS ratios of 2.0, 3.0, and 4.0 were determined and samples were compacted with appropriate mass to produce 7.0 ± 1.0% air voids. The air void content was selected to simulate the density of pavement in the field after construction which typically between 92 and 96 percent of Theoretical Maximum Density (TMD). Since a constant density was used, the differences in permeability should be caused by the thickness of the sample, which influences the particle orientation of the aggregate during compaction. For gyratory samples, three replicates of 150 mm diameter for each mix were fabricated. Meanwhile for vibratory samples, two replicates of beams with 350 mm $\times$ 150 mm were prepared. Two 100 mm cores were cut from the beams produced from the vibratory compactor, because the laboratory permeameter requires cylindrical samples. The bulk specific gravity of samples was determined using the vacuum sealing method which should provide an accurate estimation for all gradation shapes [26]. The laboratory permeability test was performed on all samples and the relationships between permeability and lift thickness were evaluated.

In most cases, specimens compacted with the vibratory compactor had much lower permeability than specimens compacted with the gyratory compactor. This could possibly be explained by a study conducted by Cooley and Kandhal [6] comparing the compaction achieved by vibratory and gyratory compactors. Specimens compacted with the vibratory compactor had more compaction at the top, whereas the gyratory-compacted samples showed less compaction at the top, bottom, and outside edge and more compaction in the middle. This low compaction around the top, bottom, and outside edges for gyratory samples can increase the permeability significantly.

Laboratory permeability tests were conducted in accordance with ASTM PS 129-01 (Standard Provisional Test Method for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter). This method utilizes a falling head approach to measuring permeability. Each sample was vacuum-saturated with a pressure of 100 kPa for 5 min prior to testing. Water from a graduated standpipe was allowed to flow through the saturated sample and the time to reach a known change in head recorded. Saturation was considered sufficient when four consecutive time interval measurements did not differ by more than 10% of the mean. In this method, Darcy's Law is then applied to estimate the permeability of the sample.

The results from the gyratory compactor were very limited, but they did indicate that, in general, mixes with larger NMAS and a higher percentage of coarse aggregate had higher permeability. The effect of the *t*/NMAS ratio was not determined due to insufficient data. Of all the vibratory-compacted samples tested, only the 9.5 mm and 12.5 mm NMAS SMA mixes compacted at a *t*/NMAS ratio of 2.0 had permeability values greater than $125 \times 10^{-5}$ cm/s.

### 2.2. Field testing

The second reconstruction of the National Center for Asphalt Technology (NCAT) Test Track at Auburn, Alabama, USA provided the opportunity to build sections (off the track) with varying thicknesses from one end of each section to the other. The track was reconstructed in the summer season when the weather is very similar to a tropical climate. The test plan for this experimental study is shown in Fig. 2. Seven mixes were selected consisting of different NMASs, gradations, and mix types (Superpave and stone mastic asphalt, SMA). Six mixes which were 9.5 mm NMAS FG, 9.5 mm NMAS CG, 9.5 mm NMAS SMA, 12.5 mm NMAS SMA, 19.0 mm NMAS CG, used PG64-22 asphalt cement and one mix which was the other 19.0 mm NMAS CG used PG76-22 type of asphalt cement. The experiment was conducted during the trial mixing stage and included the construction of each section to different *t*/NMAS ratios ranging from approximately 2.0–5.0. The desired mat thickness was achieved by gradually adjusting the screed depth crank of the paver during the paving operation. The length of each section was about 40 m and the width was about 3.5 m. All mixes were paved on an existing HMA layer.

Since the cooling rate of the mat varied from one end of the section to the other due to the change of thickness, three locations were selected for temperature measurements on each section: one near the beginning of the section, one near the middle, and one near the end of the section. This was done to ensure that the mat was being compacted within the time available for compaction. At each location, two thermocouples were placed in the mat immediately after paving, as shown in Fig. 3. Surface temperatures were obtained with an infrared temperature gun. The average of the three temperature readings were taken to be the temperature of