Asphalt mixture performance and testing

# Porous asphalt layers as noise reducing and drainable pavements

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## Abstract

The use of porous asphalt (PA) provides various advantages due to the high air voids content and the large permeability; however, PA can also pose some disadvantages, such as reduced performance, maintenance problems and limited structural contribution. Reduced performance of PA mixtures is associated with reduced durability and functionality (i.e., drainability and noise reduction effectiveness), due to raveling and clogging, respectively. In addition, for pavement structure design, PA mixtures are typically considered to have limited structural contribution. Three types of bitumen were used in this study to construct porous asphalt pavements to evaluate their long-term performance as follows: non-modified bitumen (NM), polymer-modified bitumen (PM), and highly-modified bitumen (HM). Test results indicated that a reduction in air voids inside the pavement resulted from clogging and densification. Decreases in air voids were primarily caused by traffic compaction for the NM section, while less in amount for the HM and PM sections. The reduction in noise levels was found to be positively related to the air voids inside PA. PA layers maintained adequate functional characteristics even after they were partially clogged and condensed. The long-term functionality of PA surfaces could be properly maintained. Satisfactory performance on drainability has been observed on the three test sections since they opened to traffic in 2009. PA pavements are shown to be a durable surface on high-speed, heavy-trafficked highways since they could reduce tire–pavement noise and avoid hydroplaning in the long run.

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## 1. INTRODUCTION

Reduction in noise and drainability are the main characteristics of porous asphalt (PA) mixtures. These functional properties are the primary reason for using PA mixtures around the world [1-3]. PA is an open-graded mixture placed at the surface of asphalt pavements to produce benefits in terms of safety, economy, and the environment. The air voids of PA are created by gap grading coarse aggregates and either eliminating or minimizing the volume of fine aggregates in the mixture to form a network of interconnected pores within the material. PA is an environmentally friendly road material using advanced technology in pavement construction. PA applied to the surface layers usually has an air void content of approximately 20 percent. Due to higher proportions of coarse aggregates and lower sand contents, interconnected air voids are created which, in wet weather, drain the moisture through a series of water channels inside PA. This drainage system prevents aquaplaning on the road surface and improves visibility. The high porosity of PA also reduces traffic induced noise emissions significantly [4, 5].

Although the use of PA mixtures provides various advantages due to the high air voids content and the large permeability, PA can also pose some disadvantages, such as reduced performance, high construction costs, maintenance problems, and limited structural contribution [6, 7]. Reduced performance of PA mixtures is associated with reduced durability and functionality (i.e., drainability and noise reduction effectiveness), due to raveling and clogging, respectively. In addition, for pavement structure design, PA mixtures are typically considered to have limited structural contribution [8, 9].

To maintain the benefits of a PA layer, a mix design system that produces mixtures that are both functional and durable is required. Drainability and noise reduction effectiveness are the main functional properties of PA mixtures that justify using PA mixtures as a surface layer in asphalt pavements [5, 10]. However, raveling is the distress most frequently reported as the cause of failure in PA mixtures [11, 12]. The engineering properties of PA mixtures could be lower than those of conventional dense-graded asphalt mixtures. High air voids created inside PA mixtures could lead to a potential loss of cohesion and less resistance to disintegration in the mix.

Using modified binders and adding additives are the common methods to improve the performance of porous asphalt. However, the effects of all these materials are two-sided: when they improve the mixture's performance in one aspect, they might decrease its performance in the other aspect. There is a need to investigate the effect of binder types on the noise level and durability of PA mixtures. The main objective of this study focuses on evaluating the functional properties of PA mixtures, and assessing PA performance according to field measurements.

## 2. MATERIALS, MIX DESIGN, AND TEST SECTIONS

### 2.1. Materials

The basic properties of limestone aggregate used in this study are listed in Table 1. Coarse aggregate for a PA mix must be strong to carry the imposed loads because coarse aggregate is primarily responsible for carrying the traffic loads in a PA mix. The LA abrasion value of coarse aggregate should be less than 30% to possess sufficient toughness. In addition, flat and elongated proportions must be limited to be a minimum value, and fracture faces are required to provide a coarse aggregate structure with high internal friction. Bitumen is one of the most important factors affecting the performance of porous asphalt. Three binders commonly used in Taiwan for PA pavements were included as follows: non-modified bitumen (NM), polymer-modified bitumen (PM), and highly-modified bitumen (HM). HM is a specially-designed asphalt binder which is characterized by extremely high absolute viscosity at 60℃. The viscosity and softening point of HM are much higher than those of NM and PM as listed in Table 1.

**Table 1. Material types and volumetric results**

| | PA mixes | | |
|---|---|---|---|
| Properties | NM | PM | HM |
| Bitumen | | | |
| Softening point (°C) | 54 | 62 | 91 |
| Viscosity (60°C, Pa.s) | 362 | 1,658 | 32,582 |
| Aggregate | | | |
| LA abrasion (%) | 17 | 17 | 17 |
| Flat & elongated (%) 3:1 | 5 | 5 | 5 |
| Flat & elongated (%) 5:1 | 1 | 1 | 1 |
| Asphalt Mix | | | |
| Binder content (%) | 5.1 | 5.1 | 5.1 |
| Air voids (%) | 20.1 | 20.2 | 20.2 |

### 2.2. Mix design

Based on the field test road selected, master aggregate gradation bands were determined. The 19-mm maximum aggregate size gradation was gapped on the 4.75-mm sieve to produce large size air voids. A nominal air-void content of 20 percent was decided for fabricating all PA specimens in this study. The job mix formula were decided using the Marshall mix design method. Specimens of 100mm diameter and 63.5mm height were prepared by applying 50 blows on each faces. As listed in Table 1, the in-situ air void content was 20.1, 20.2 and 20.2% for the NM, PM and HM mixes, respectively. Hydrated lime and cellulous fibers were added to the NM and PM mixes at the rate of 2.2 and 0.3% by mass of total mix, respectively. No additives were used for the HM mix. The asphalt content was determined to be 5.1, 5.1 and 5.0% by weight of total mix for NM, PM and HM, respectively.

### 2.3. Test sections

A test road was constructed in 2009 with a design speed of 100 km/h and has six lanes per direction. Three PA mixes were included in the test road as follows: NM, PM, and HM. For each mix, a 0.6-km section was constructed. This highway has an average traffic volume of 18,600 vehicles per day with about 6% truck traffic. The test sections are essentially straight and level, and there is limited background noise. The average annual precipitation is close to 2500 mm with rain day up to 90 days per year with relative humidity varying from 50 to 90%. The average maximum temperature in June, July and August exceeds 35°C. Under such difficult weather and heavy traffic, pavement alternatives were built to understand whether they could realize their designed durability and functionality while subjected to rigorous environmental and loading conditions. Distress surveys were conducted on a regular basis on each section during trafficking. The surveys including air voids, noise level and drainability were performed at a scheduled interval.

## 3. EXPERIMENTAL PLAN

### 3.1. Air voids

The potential for clogging of PA pavements might result from operational and construction problems. Dust, dirt and debris can fill the void structure of the porous asphalt layer, which may clog up the pavement and thus reduce its permeability. Densification is common phenomenon on highways because PA pavements are subjected to frequent passes of traffic and heavy loadings of vehicles. A slight consolidation of the porous asphalt layer will reduce air voids from the initial values.

When test sections are open to service, the initial air voids (Vi) inside PA mixes are reduced due to both dust clogging (Vd) and traffic densification (Vt). The air voids of in-situ PA pavements (Va) are then expressed as follows:

$$Va = Vi - Vd - Vt \tag{1}$$

Cores were taken periodically to determine changes in air voids in this study. Air voids in the following three locations were measured: the right wheel track, the left wheel track and the central part of a travel lane. Three samples were taken from each location for air void measurements. The initial air voids is represented by Vi that could be obtained from the field right after construction. During the service time, cores located on the wheel path are taken to measure the air void content in the field that is denoted by Va.

In practice, the sample from between the wheel paths received much less traffic loading than the sample from within wheel path; therefore, its condition should be close to that of the newly placed mix. Reduction in air voids from the samples between the wheel paths was considered to be a minimum value. Clogging is the main reason to cause the decrease in air voids located in the middle area of a travel lane. Clogged voids due to dust could be obtained from cores taken in the middle part of a travel lane, and indicated by Vd. Reduction in air voids due to traffic densification can be expressed by Vi, Vd, and Va that can be determined from the previous procedures. Traffic-densified voids are derived by rearranging Equation (1) as follows:

$$Vt = Vi - Vd - Va \tag{2}$$

### 3.2. Noise level

The Statistical Pass-by (SPB) method was conducted to measure the maximum A-weighted sound levels in the field according to a statistically significant number of pass-by vehicles at a specified wayside location and a specific speed of 90 kph. In the SPB method, microphones are placed at a defined distance of 7.5 m from the center of the travel line and at a height of 1.2 m above the pavement surface. Measurements for automobiles, dual-axle heavy trucks, and multi-axle trucks were taken.

### 3.3. Drainability

Drainability is one of the main characteristics of PA mixtures and closely related to their advantages. A field drainability device made of a Plexiglas cylinder connected to a steel base was used for measuring drainability of the porous asphalt layer, as shown in Figure 1. The drainability is reported as the amount of water (ml) penetrating into the pavement structure within 15 seconds on average. In cases when the permeated water volume is more than 900 ml/15sec, the drainability of a porous asphalt layer is considered to be sufficient [13, 14].

**Figure 1: Measurement of drainability**

## 4. RESULTS AND DISCUSSION

### 4.1. Changes in air voids

PA has a coarse aggregate skeleton with stone-on-stone contact to minimize rutting. Because of the stone-on-stone contact in the aggregate structure of the mix, no rutting, raveling, cracking, or other failures are observed in any of the three monitored pavements to any significant extent eight years after construction. Porous asphalt is, however, subject to densification under traffic, which leads to a reduction in air voids. Figure 2 shows that traffic densification causes a reduction in the air voids of the PA structure over time, and the rate is asphalt dependent.

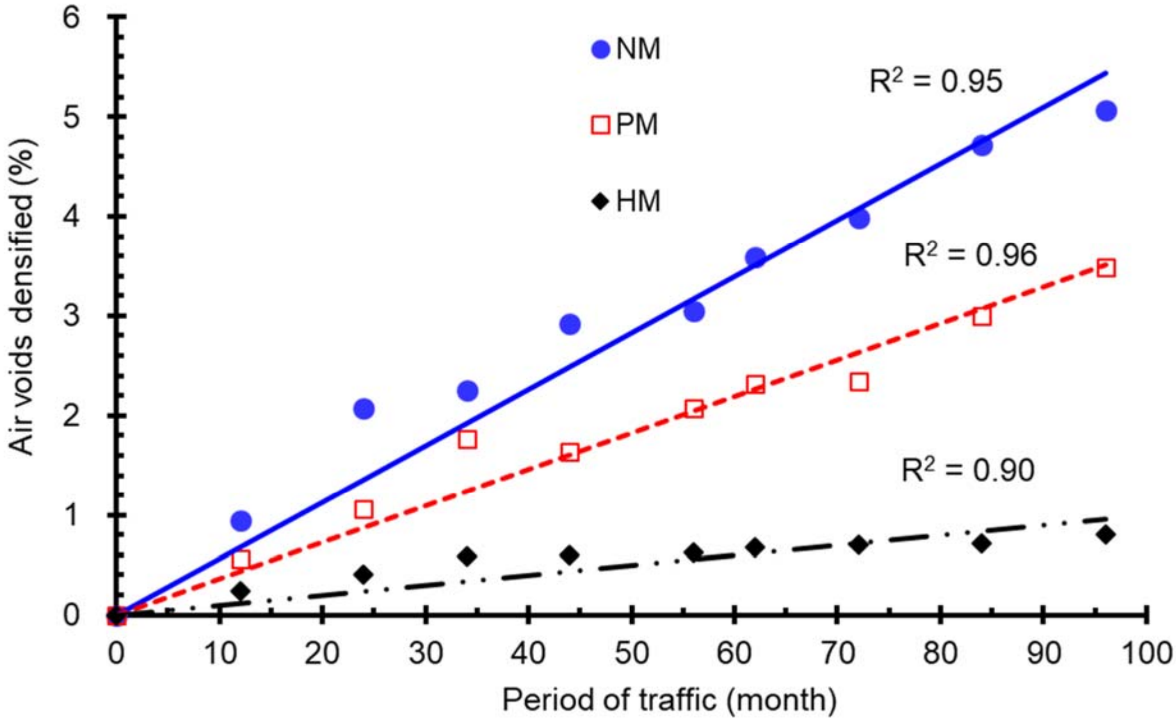


**Figure 2: Densification of air voids**

During the life of a porous asphalt layer, compaction efforts accumulate within the pavement structure and slowly close the voids. A reduction in air voids resulting from traffic compaction ranges from 0.8 to 5.1% depending on the binder type. A linear curve is used to describe the densification trend for PA surfaces with a $R^2$ value of at least 0.90. An increase in service time of 10 months could cause a decrease in air voids of 0.5%, 0.3% and 0.09% for the non-modified bitumen (NM), polymer-modified bitumen (PM), and highly-modified bitumen (HM) sections, respectively, as shown in Figure 2. The rate reduction of air voids is shown to be related to the binder type in this study. The use of polymeric bitumen in porous asphalt mixtures is shown to diminish the effect of post compaction by traffic.

In Figure 3, clogging and densification are shown to be the main reason to cause reduction in air voids of PA, but with different degrees of contribution to that decrease. Water that comes from the roadway is generally contaminated with dirt and debris, further reducing air voids. Through the infiltration of water into a porous asphalt layer, dirt and debris could clog the layer. The decrease in air voids primarily results from densification due to intense and heavy traffic.

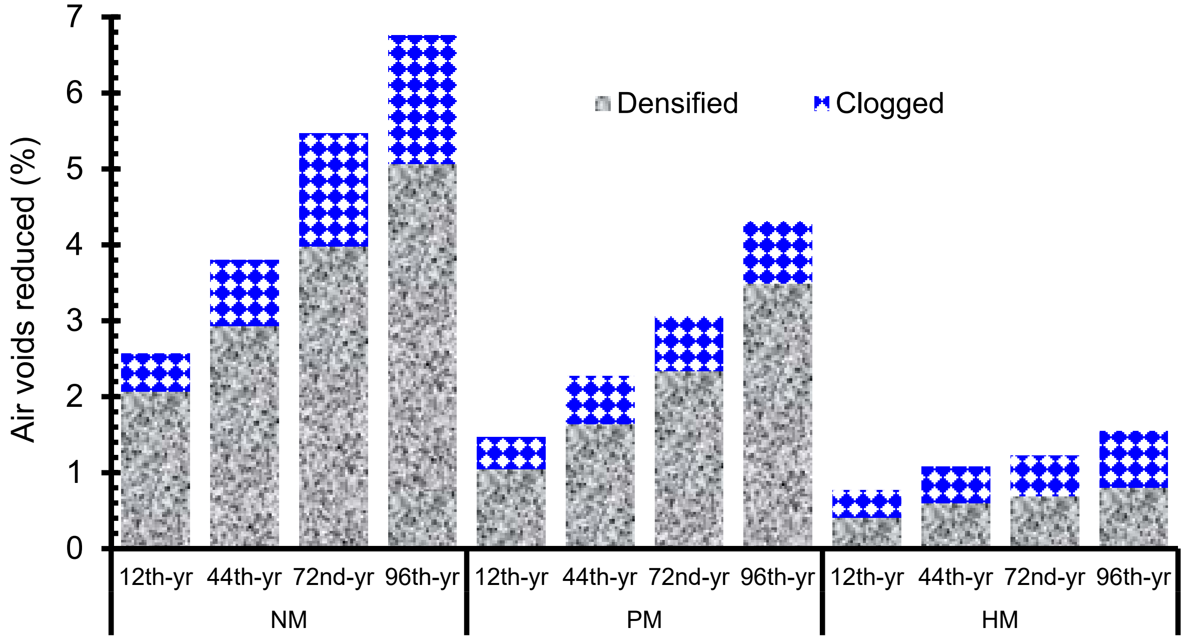


**Figure 3: Clogging and densification of air voids**

Figure 4 shows that the reduction rate of air voids is lower for the HM section than for the NM section over time. An increase in service time of 10 months could cause a total reduction in air voids of 0.7, 0.4 and 0.2% for the NM, PM and HM sections, respectively, as shown in Figure 4. The NM section becomes relatively clogged and consolidated. Nevertheless, the air voids in the porous asphalt were still higher than 13% after eight years in service. Air voids are important for maintaining noise reduction and water removal.

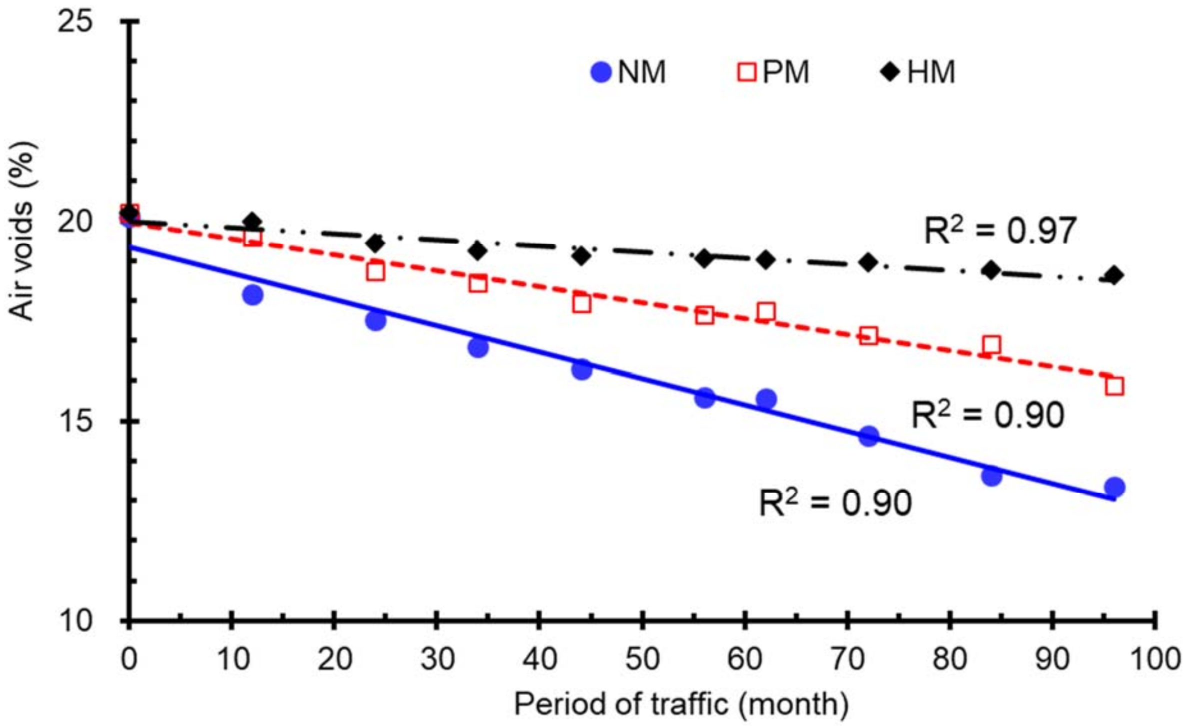


**Figure 4: Changes in air voids**

### 4.2. Changes in Noise Level

Figure 5 shows the noise reduction capabilities of porous asphalt diminished over time. The NM section has higher sound levels than other sections, and, in general, sound intensity levels increase with age. The average noise level of PA pavements were approximately 77 dBA after eight years in service, and the new pavements were 72 dBA. The noise level of PA mixtures increases with ages. PA increased the noise level by about 5 dBA in eight years.

Figure 5 indicates that the tire/pavement noise characteristics of PA depended on the air void content. The noise reduction effectiveness of PA mixtures is reduced in a few years due to clogging and densification of air voids and traffic compaction. Binder type appears to play an important role in the noise level reduction at the tire/pavement surface. Using a highly-modified modifier (HM) appears to be a good option for reducing traffic noise. This reduction in traffic noise for the HM section is due to the absorption of sound that occurs in the voids of the porous asphalt layer. Also, the void structure was maintained to eliminate the air pumping at the tire/pavement interface.

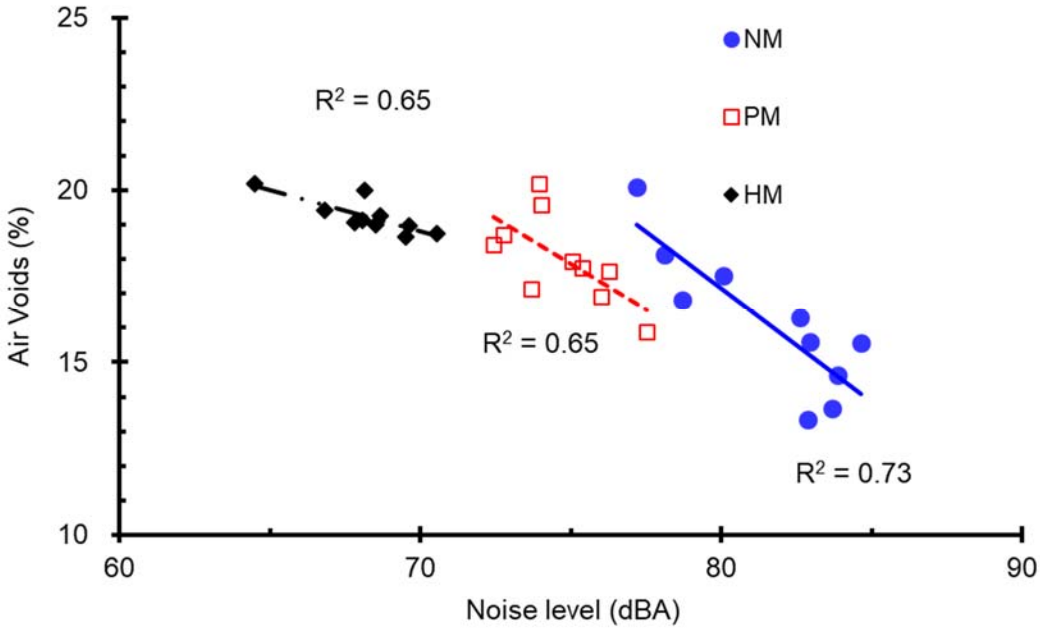


**Figure 5: Noise levels versus air voids**

### 4.3. Changes in drainability

Drainability of the porous asphalt wearing courses was almost the same in the beginning, with an average drainability of 1,380 ml/15sec, as shown Figures 6 and 7 for the wheelpaths and the central part of the driving lane, respectively. Drainability is included as part of the PA performance requirements after construction, which should be higher than 900 ml/15sec. All sections met the drainability requirement right after construction. The drainability conferred by an elevated, connected air void content in PA mixtures could contribute to improve safety under wet weather conditions. The drainability value for the middle portion of the driving lane is higher than that for the wheel tracks. Good drainability and low clogging are noted in the PM and HM sections having more than 20% air voids and using polymer-modified asphalt. Porous asphalt makes it possible for the tires on vehicles to stay in contact with the pavement surface during wet weather, thus avoiding hydroplaning.

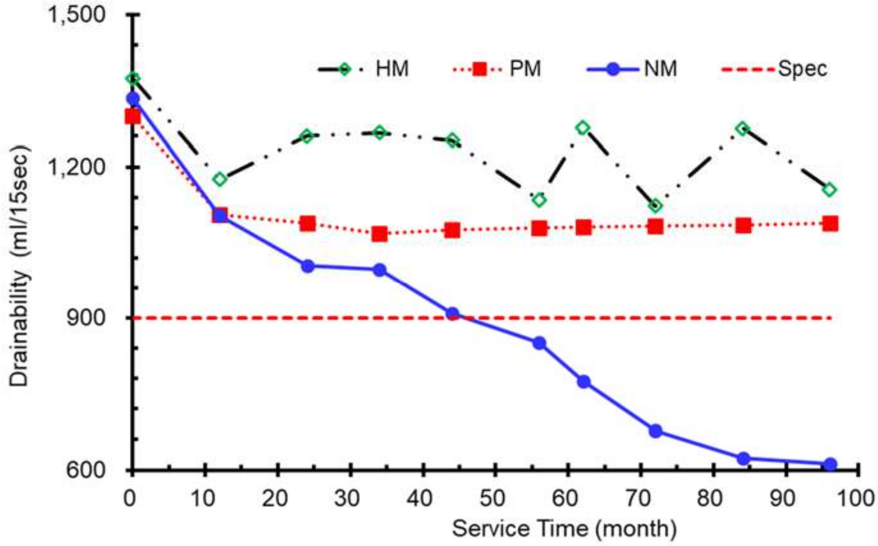


**Figure 6: Drainability on wheelpaths**

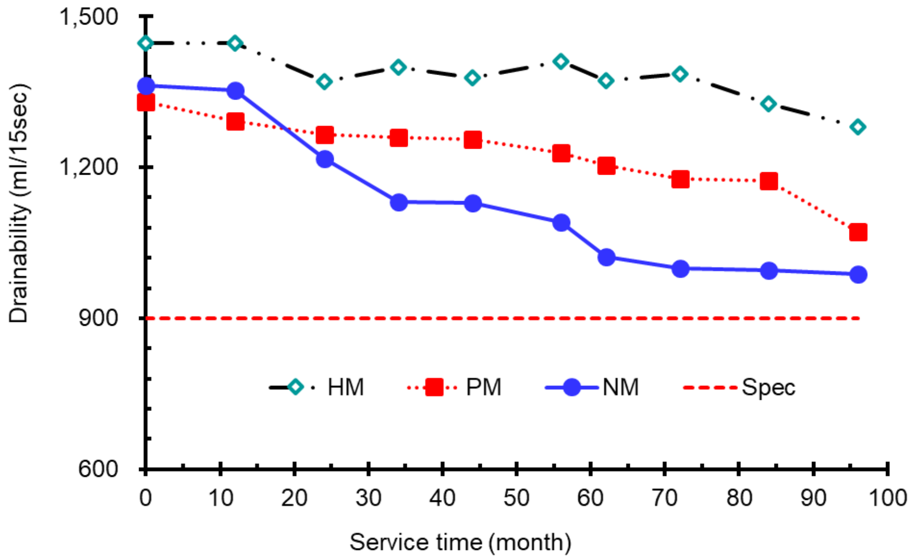


**Figure 7: Drainability on middle part of driving lane**

Figure 6 shows that drainability could be maintained within wheelpaths for the HM section. It is likely to result from cleaning pressure suction action caused by tires travelling over the PA layer, particularly at the 60th and the 84th months. The pumping and suction of the tires of numerous vehicles traveling higher than 90 kph could lead to clean and protect the pores from clogging at high vehicle speeds. Therefore, drainability was well maintained for the HM and PM sections. The mechanism of the self-cleaning is not well understood and more research is needed to look into this issue.

Figure 7 shows that the slight clogging in the middle part of a travel lane had no appreciable effect on the efficient of water draining. The clogging from debris and fines led to the slow reduction in the drainability of the PA surface over a period of time. With relatively high percentage of air voids, water would readily drain from the pavement surface into the voids of the PA layer. Partially clogged PA is shown to allow drainage through the pavement.

The decrease in drainability was due to densification and clogging. However, a gradual decrease in drainability is measured on the wheelpaths over time for the NM and PM sections as shown in Figure 6. An increase in service time results in a lowering of air void content, and thus caused a reduction in drainability. Since most reduction in air void content results from traffic compaction, operation to clean clogged surface layers does not appear to be effective to restore the drainability for the NM and PM sections.

## 5. CONCLUSIONS AND RECOMMENDATIONS

This paper is to evaluate the field performance of porous asphalt using three different types of asphalt (i.e., NM, PM and HM). Conclusions subsequently provided are based on the analysis of field testing results. Good drainability and low clogging were noted in the PM and HM mixes having more than 20% air voids and holding the void structure well. Binder type appears to play an important role in the noise level reduction at the tire/pavement surface. Using a HM modifier appears to be a good option for reducing traffic noise. At least 50% of reduction in air voids inside PA layers resulted from intense and heavy traffic. Densification of air voids is irreversible, and a PA surface cannot be restored to its original voids after traffic compaction. PA functionality could be properly maintained when suction forces produced by high speed traffic were likely to flush debris from the void structure for test sections. More research is needed to develop a better understanding of the self-cleaning effect in PA pavements.

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