

## CHARACTERIZATION OF THE CLOGGING BEHAVIOUR OF DOUBLE LAYER POROUS ASPHALT

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**Abstract:** Porous wearing courses improve traffic safety and can potentially reduce traffic noise. However, its service life is shorter compared to dense mix due to clogging and poor durability. This paper presents the characterization of the clogging behaviour of single and double layer porous asphalt (PA) mixtures. The double layer PA comprises of a finer upper layer and a coarser bottom layer and was historically developed to further reduce traffic noise. Two gradations comprising of 10 and 14 mm top layer maximum aggregate sizes were compacted to 30, 20 and 15 mm thickness, while the maximum aggregate size for the base layer is consistently maintained at 20 mm. The clogging behaviour of the double layer was compared to the single layer PA specimens. The laboratory experimental results showed that the double layer PA made with SBS exhibit drainage time 37% less upon cleansing as compared to similar single layer 10 mm maximum aggregate size porous asphalt.

**Key Words:** Double layer porous asphalt, Maximum aggregate size, Layer thickness, Clogging, Drainage time

### 1. INTRODUCTION

In many countries, porous surfacings are applied to reduce traffic accidents on roads and highways. In addition, these porous surfacings are also effective in reducing traffic noise. However, porous asphalt (PA) are susceptible to clogging and is less durable compared to dense mixes. The pores of a PA mix can be easily clogged by dirt and pollutants such as dust, detritus, tyre wear by-products and debris. Clogging is always accompanied by permeability loss and when the extent of clogging is severe, all benefits associated with an open mix will disappear.

Mallick et. al., (2000) reported significant loss in permeability of porous pavement after two to three years in service because of clogging of voids by deicing materials or other debris. In one field study in Europe, the initial drainage times of PA surfacings in the range of 25 to 75 s had increased to 80 to 100 s after 3 years and to 160 to 400 s after 9 years (Kraemer, 1990). In Singapore, local residual soils deposited from dirty wheels and vehicles carrying earth has been a major source of materials contributing to clogging of P A layers (Fwa et. al., 1999).

With stricter environmental regulations pertaining to traffic noise especially in Europe, the 'whispering' PA offers a big potential to reduce traffic noise at source. Nevertheless, the noise absorbing capacity of PA is greater as the gradation becomes finer (Van Bochove, 1996). On the other hand, the finer graded PA is more prone to clogging. Hence, the idea of

a double layer PA was conceived as schematically shown in Figure 1. The Dutch experience with double layer PA was presented to the 1<sup>st</sup> Eurasphalt and Eurobitume Congress held in Strasbourg (Van Bochove, 1996). In the Netherlands, double layer PA is termed as Twinlay while the Italians named it Double Draining Layer (Battiato et. al., 1996). Essentially the double layer PA consists of a finer thin porous mix as the top layer while overlying a much coarser but thicker porous base layer mix. Clogging is minimised through a 'sieve effect' when the finer upper layer prevents coarse dirt from entering lower layer while the higher water discharge capacity of the bottom layer reduces chances to trap dirt or pollutants. Hence, only the top layer is clogged up and can be easily removed by existing field cleansing techniques. In addition, field trials have shown the greater noise reduction potential of the double layer PA for all traffic speeds.

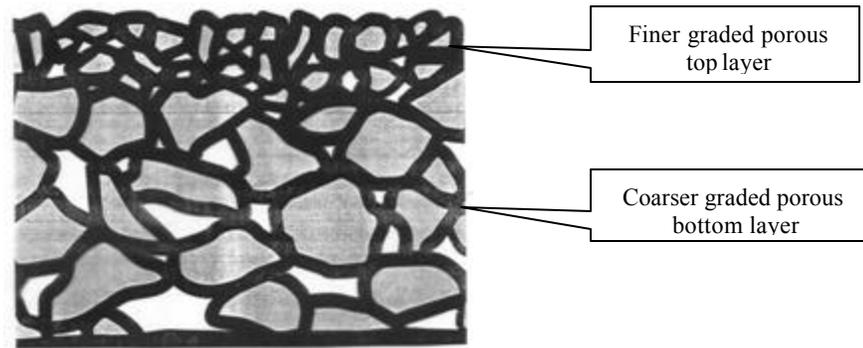


Figure 1. Schematic Diagram of a Double Layer PA (Van Bochove, 1996)

## 2. OBJECTIVE

The main objective of this paper is to investigate the effect of maximum aggregate sizes and top layer thickness on the clogging behaviour of double layer PA. Two gradations comprising of 10 and 14 mm top layer maximum aggregate size were compacted to 30, 20 and 15 mm thickness while the maximum aggregate size for the base layer is consistently maintained at 20 mm. Single layer PA specimens are also tested for comparative purposes. The clogging behaviour was assessed from a newly developed laboratory simulative test.

## 3. MATERIALS USED

### 3.1 Materials for Bituminous Mixes

Crushed aggregates supplied by Kuad Quarry Sdn. Bhd. in Penang were used in this investigation. The aggregate gradations adopted were developed based on the theory of aggregate packing. The detailed procedure used was an extension to the method presented in an earlier literature (Hardiman and Hamzah, 2003). From this procedure, three gradations shown in Figure 2 that differs in terms of maximum aggregate sizes, were developed and tested. Each gradation incorporated a 2% hydrated lime filler.

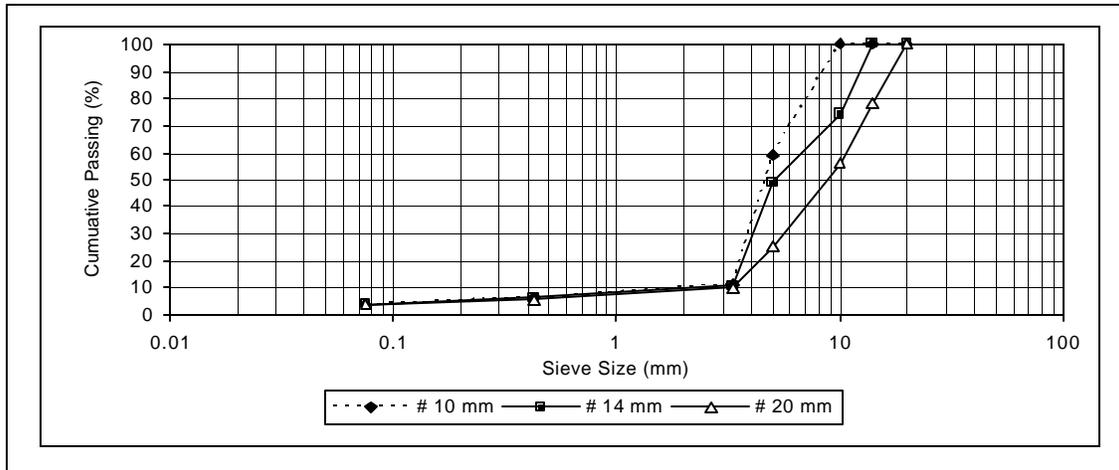


Figure 2. Aggregate Gradations Used in this Investigation

Binder used in this research was conventional binder (penetration grade 60/70) and an SBS polymer modified binder. The design binder content (DBC) used to prepare specimens was based on the Cantabrian and binder drainage tests. From these tests, the design binder contents corresponding to 10, 14 and 20 mm maximum aggregate size equal 5.4%, 5.0%, 4.5% and 5.7%, 5.2%, 4.6% respectively for conventional and SBS binders (Hamzah and Hardiman, 2004a).

### 3.2 Clogging Agent

The material for clogging agent used in this research was a clay silt soil combination, where more than 90% passed the 0.075 mm sieve. The soils were taken from Sungai Petani (designated as Soil A) and Sungai Kecil Hilir sites (designated as Soil B) in Kedah, Malaysia. The particle size distribution of each soil is shown in Table 1.

Table 1. Soil Particle Size Distribution Used in This Investigation

Sieve (mm)	Soil A % passing	Soil B % passing
2.36	100	100
1.18	99.5	94.2
0.6	99.2	84
0.3	98.8	67.4
0.15	98.2	52.4
0.075	97.7	46.9

#### 4. PREPARATION OF DOUBLE LAYER POROUS ASPHALT SPECIMENS AT THE DBC

##### 4.1 Specimen Preparation

Double layer PA comprises of top and base layers. The maximum aggregate size for the base layer was 20 mm while two maximum aggregate sizes 14 and 10 mm were used for the top layer. The relative thickness of top and bottom layers (T/B) in a specimen were 0/70(S); 30/40 (D1); 20/50 (D2) and 15/50 mm (D3) or schematically shown in Figure 3. The binder contents used for all mixes were based on their respective DBCs.

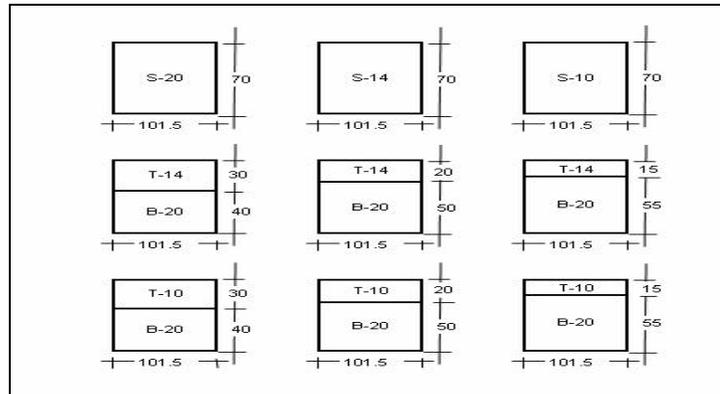


Figure 3. Schematic Diagram Showing the Relative Thickness of Double Layer PA

In principle, the preparation of 70 mm thick double layer porous Marshall specimen was similar with the preparation of Marshall specimen for single layer PA. However, the amount of aggregate for top and base layers were calculated based on the Marshall density of single layer PA. Knowing the density and volume, the actual amount of mix required was calculated. To do this, it is essential to know the relationship between density and binder content and is shown in Figure 4. By interpolation, the densities at DBC for maximum aggregate sizes 20, 14 and 10 mm are 2.0; 1.98; 1.97 g/cm<sup>3</sup> and 2.01; 1.98; 1.96 g/cm<sup>3</sup> respectively for conventional and SBS mixes (Hamzah and Hardiman, 2004a).

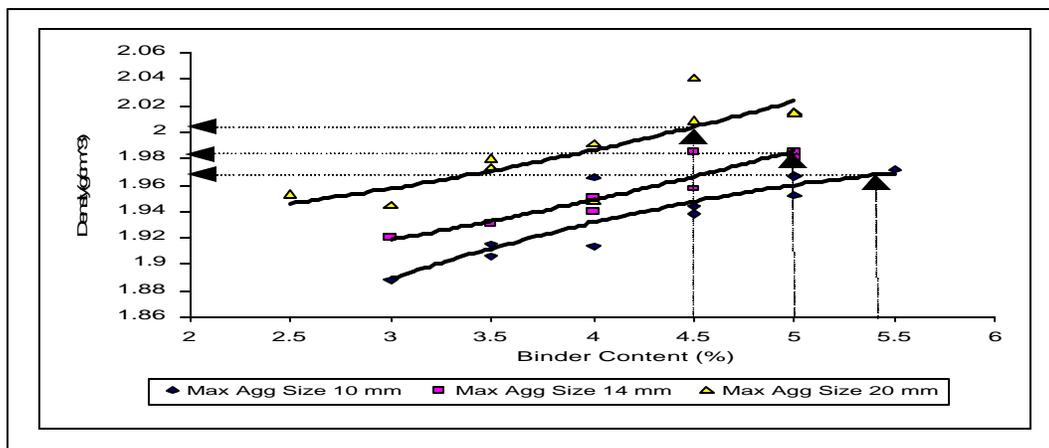


Figure 4. Relationship between Density and Binder Content of Single Layer PA

The impact mode of compaction was chosen to prepare cylindrical samples. This was necessary to take advantage of the strong bond between the sample and the cylinder walls to facilitate permeability test prior to extrusion. With the gyratory compactor, the strong bond persisted but the compacted un-extruded specimens cannot be tested for permeability. Cylindrical double layer PA samples were compacted in 2 steps involving 2x50 blows. The adopted compaction procedure was as follows:

- (i) The base layer mix ingredients were mixed at the DBC. The required quantity of mix was then placed inside the Marshall mould and the whole assembly was then transferred into the oven which was earlier set at the destined compaction temperature.
- (ii) For the next step, the porous mix for the top layer was prepared. The calculated amount of mix was then transferred into the Marshall mould and placed on top of the base layer mix.
- (iii) The mix was then compacted at 1x50 blows each face. Permeability or clogging tests were conducted prior to specimen extrusion.

The steps involved in the adopted compaction method are shown in Figure 5. A detailed discussion on other comparative compaction method and the reasons for its choice has been presented elsewhere (Hamzah and Hardiman, 2004b). However, the adopted compaction method was thought to result in uniform density of top and bottom layers. More importantly, the method eliminates the requirement for minimum top layer thickness in relation to maximum aggregate size.

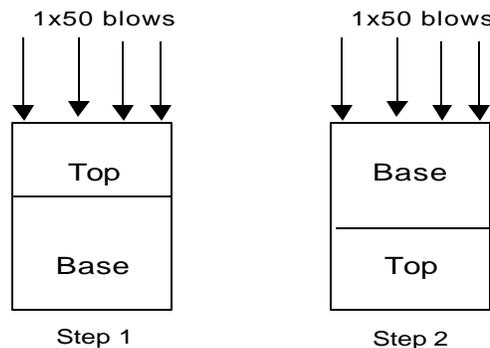


Figure 5. The Adopted Procedure to Compact Double Layer PA by Impact Mode

#### 4.2 The Proposed Clogging Test

The clogging test is a new test developed at the highway engineering laboratory of the University Sains Malaysia. The test intended to simulate progressive clogging taking place in the field and routine cleansing to unclog the pores. The preliminary clogging test involved the following steps:

- (i) Determination of particle size distribution of the soil which acted as the clogging agent.
- (ii) Determination of the amount of soil required to fill voids in the specimen.
- (iii) Determination of a method to remove part of soils trapped or soils that clogged or trapped inside the specimen.

To determine the particle size of soil distribution of the clogging agent, preliminary trials were conducted on different combinations of Soils A and B. The selection of the right combined quantity was based on the discharge time required to attain the minimum

permeability which reflects the amount of soil filling up the voids. The minimum coefficient of permeability stipulated in a TRL publication is 0.03 cm/sec (Colwill et al. 1993). Accordingly, when the permeability is less than 0.03 cm/sec, the mix ceased to function as a porous mixture. For the clogging test, permeability was indicated based on the time (second) taken for water to fall between two designated points on the permeameter tube. At 0.03 cm/sec, the discharge time approximately equals 240 sec and this value is termed the terminal discharge time.

In the initial trial, two permeant concentrations were prepared by dissolving 10 and 25 g in 1 liter of water. The amount of soil particle passing and retained by the specimens were also determined. Next, fresh water was used to determine the discharge time of the clogged specimen. To determine the method of removing trapped soils from porous asphalt specimens required tools such as a brush (k1), water sprayer (k2) and a vacuum cleaner (k3). The method that results in the smallest retained discharge time was selected. The discharge time of the clogged specimens begun after the sample has cooled overnight. This value was used as the reference point to indicate the lowest discharge time or highest permeability for unclogged or virgin specimens for comparative purposes. In this phase of the research, all specimens were prepared using conventional 60/70 binder.

Preliminary tests were carried out to determine a suitable permeant concentration. Soil concentrations ranging from 1.0 to 2.0 g/liter was used. Preliminary clogging tests were carried out only on single layer specimens made with maximum aggregate size 20 mm and conventional binder, which has the highest voids. This permeant was then allowed to clog the pores of the specimen. Then, discharge time was determined using plain water in the normal way. The clogging procedure was repeated until the terminal discharge time was surpassed. After the suitable permeant concentration was determined, similar procedure was used for all mixture types. The next step was to remove trapped soils in the voids. Initially, water was sprayed to loosen up the trapped soils. Then, the specimen was vacuumed using a conventional house vacuum cleaner. The duration of spraying and vacuuming for each specimen was approximately 15 seconds. The test attempted to simulate actual field cleansing of porous asphalt in developed nations. The specimen discharge time was then determined and the clogging procedure continued for another few cycles of clogging and cleansing.

The procedure of the newly developed clogging test can be summarized underneath:

- (i) Permeability test was conducted on virgin sample (without clogging agent) to determine discharge time.
- (ii) Soil and water, at 1.5 g/liter concentration, was mixed and stirred vigorously for several minutes.
- (iii) The soil-water mixture was poured into the permeameter tube to clog the specimen.
- (iv) The discharge time was determined using plain water. However, some soils remain trapped in the voids.
- (v) Steps 3 and 4 were repeated until the terminal discharge time, that is greater than 240 s, was exceeded. Steps 1 to 4 constitute one loading
- (vi) The specimen was left to dry overnight and the soil removed from specimen using a vacuum cleaner.
- (vii) The discharge time was determined using fresh water as permeant.
- (viii) Steps 3 to 4 were repeated until the terminal discharge time was exceeded. The number of loading cycles to attain the terminal discharge time constitute one cycle.

## 5. RESULTS AND DISCUSSION

### 5.1 Amount of Trapped Soil in Specimens.

The results of the sieve analysis for soils A and B are shown in Table 2. For Soil A, 100% passes the 2.36 mm sieve while 97.7% passes the 0.075 mm sieve. For Soil B, the corresponding values are 100% and 46.9%. Hence, Soil A is of the clayey fraction while Soil B is in the silty range. Preliminary investigation showed that the specimen clogged in a short time when only Soil B is used as the clogging agent. However, it takes very much longer to clog the specimen when Soil B is used because Soil B is much coarser compared to Soil A. It is for this reason that it is necessary to select suitable combinations of both soils so that the rate of clogging is acceptable. After numerous trials, the appropriate proportion of Soils A and B was 85:15 and the resultant particle size distribution is shown in Table 2.

Table 2. Sieve Analysis of Soils as Clogging Material

Sieve (mm)	Soil A	Soil B	Soil Proportion (%)		Soils A+B
	% Passing	% Passing	85% A	15% B	(%)
2.36	100	100	85	15	100
1.18	99.5	94.2	84.6	14.1	98.7
0.6	99.2	84	84.3	12.6	96.9
0.3	98.8	67.4	84	10.1	94.1
0.15	98.2	52.4	83.5	7.9	91.4
0.075	97.7	46.9	83	7	90

The ability of PA specimens to conduct water depends on the amount of soils in voids of specimen. The amount of trapped soils for single and double layer PA mixes is shown in Figure 6. The results show different amount of soils retained or trapped in specimen voids. The single layer mixes made with maximum aggregate size 20 mm retained the least soil probably due to its high voids and permeability. The terminal drainage time 240 sec occurs when 10 g of soils were trapped inside the voids while the remaining 25 g were either trapped in the top layer or passed through the specimen. From Figure 6, the percentage of retained soil on the top layer of double PA decreases slightly as the top layer thickness decreases. The percentage of retained soil for double layer mixes made with top layer maximum aggregate sizes 10 mm is slightly higher compared with top layer maximum aggregate size 14 mm. Mix porosity plays a crucial role. However in general, the percentage of trapped soil in the double layer PA specimens is lower compared to single layer mixes, except for single layer mix made with maximum aggregate size 20 mm.

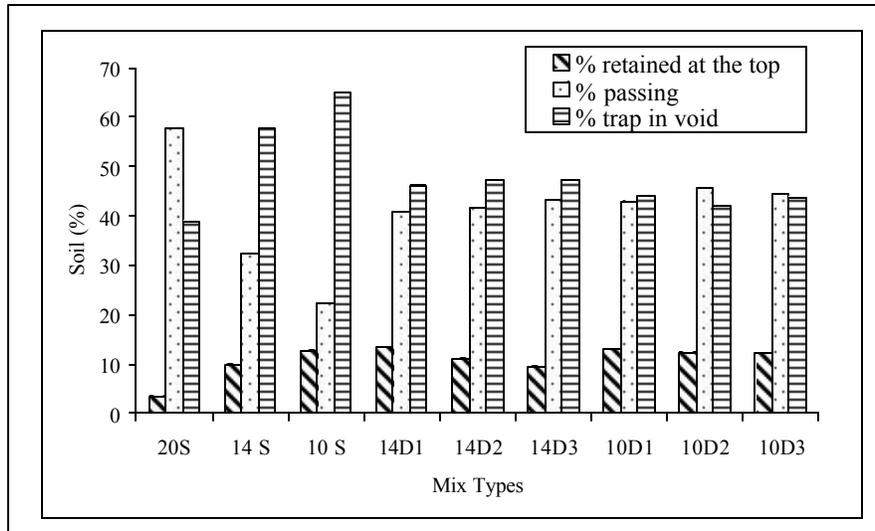


Figure 6. Percentage of Trapped Soil in Porous Asphalt Specimens

To determine an appropriate number of loadings to complete one cycle, preliminary trials were again conducted using 10 g of soil clogging agent. The soil was mixed in 5 liters of water which is the volume of permeameter tube used or 2.0 g/liter of concentration. The results are displayed in Table 3 which shows that the mixes made with maximum aggregate size 20 mm clogged after 2 loadings. The test was then continued with a lower 1.0 g/litre concentration and the specimen was not clogged after 7 loadings. For this reason, a permeant concentration of 1.5 g/liter water was adopted in future clogging tests.

Table 3. Time of Soil Loading of Specimen at Two Soil Concentrations

Soil Concentration (g/liter)	Initial Discharge Time (s)	Discharge Time For Each Loading (s)						
		t1	t2	t3	t4	t5	t6	t7
1.0	58.28	74.25	86.3	106.9	118.3	134.1	146.2	167
2.0	58.28	191.4	239.8					

### 5.2 Soil Removal Methods from Specimen

Figure 7 shows the permeability of double and single layer porous asphalt using various trapped soil removal methods. The methods tried out have been explained in Section 4.2. It appears that the discharge time after removing soil from specimen is only 2.17, 1.59, 1.51 times of the initial drainage time when a vacuum cleaner is used respectively for single layer, double layer top aggregate sizes 14 and 10 mm. Nevertheless, when water sprayer and brushing is used, the corresponding values are 3.72, 3.39, 3.74 and 3.5, 2.97, 3.0 times of initial discharge time respectively. Figure 7 shows that the double layer mixes are more readily cleansed compared to single layer mixes. The results indicate that the residual discharge time using vacuum cleaner is the lowest compared to the other methods. This indicates that the vacuum cleaner can remove trapped soil from specimen better compared to the rest and is adopted in future investigations. However, the double layer PA mixes made

with 10 mm top layer maximum aggregate size and 15 cm top layer thickness has the lowest discharge times for all methods used.

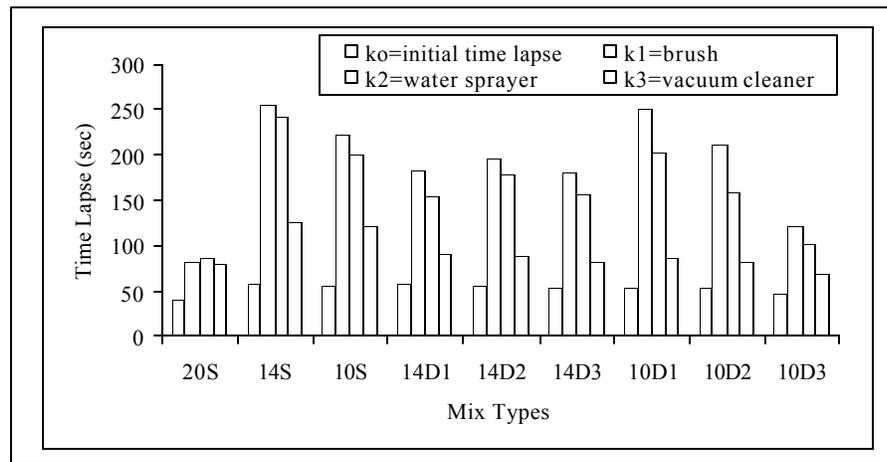


Figure 7. Discharge Time after Removal Soil by Using Various Methods

### 5.3 Clogging of Porous Asphalt Specimens

In the clogging test, the specimen ability to conduct water is measured in terms of discharge time rather than the actual coefficient of permeability value. The cycles of reduction and increase in drainage time upon clogging and vacuuming respectively is shown in Figures 8 through 13. For all maximum aggregate sizes, SBS mixes clogged faster compared to conventional mixes. For cycle 1 to complete, it requires an average of 4 and 5 loadings to exceed the terminal drainage time for SBS and conventional mixes respectively. In terms of the number of cycles, top layer made with maximum aggregate sizes 14 and 10 mm exceed the terminal discharge time after 4 cycles but for top layer thickness 15 cm the corresponding value is 5 and 4 respectively for conventional and SBS mixes. The figures also show that the number of cycles for double layer mixes made with the top layer thickness 30 mm and 20 mm are similar to single layer mixes made with maximum aggregate sizes 14 mm and 10 mm while double layer mixes made with top layer thickness 15 mm is similar to single layer mix made with maximum aggregate size 20 mm. Generally, drainage time for double layer mixes after cleansing trapped soils from specimen is better from single layer mixes, except single layer mixes made with maximum aggregate size 20 mm. The number of cycles and loadings are important indicators in the drainage ability of porous asphalt. The resultant discharge time just upon vacuuming differs significantly from the terminal drainage time. After cleansing, the discharge time measured in units of seconds of mixes made with conventional binder and SBS mixes is about 100s and 80s; 75s and 115s; 75s and 70s respectively for single layer maximum aggregate size 10, double layer maximum top aggregate 14 mm and 10 mm mixes at thickness top layer 15 cm. However, double layer specimen made of maximum aggregate size 10 mm at top layer thickness 15 cm exhibits the lowest discharge time of about 70 sec. The laboratory experimental results showed that the double layer PA made with conventional bitumen exhibit discharge time 22.5% less upon cleansing as compared to similar single layer 10 mm, while for double layer mix made with SBS is 37%. From the perspective of resistance to clogging, the two-layered porous asphalt construction has the potential to better resist clogging compared to conventional single layer porous asphalt.

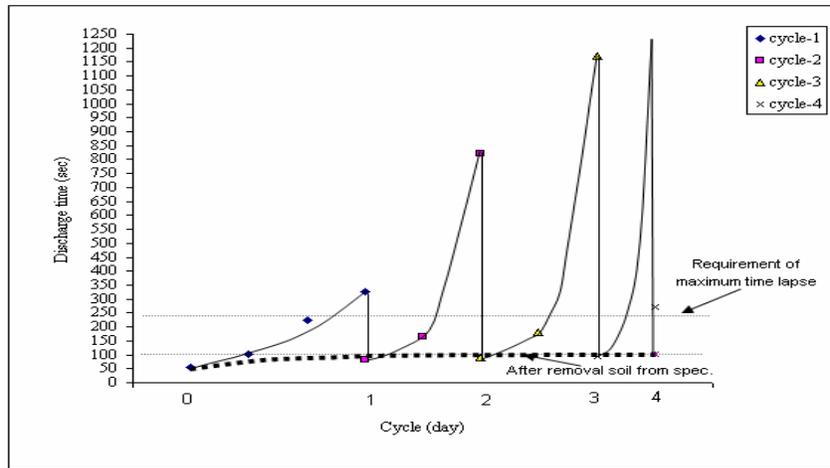


Figure 8. Cycle Time for Clogging of Single Layer PA (10S-60/70 Pen.)

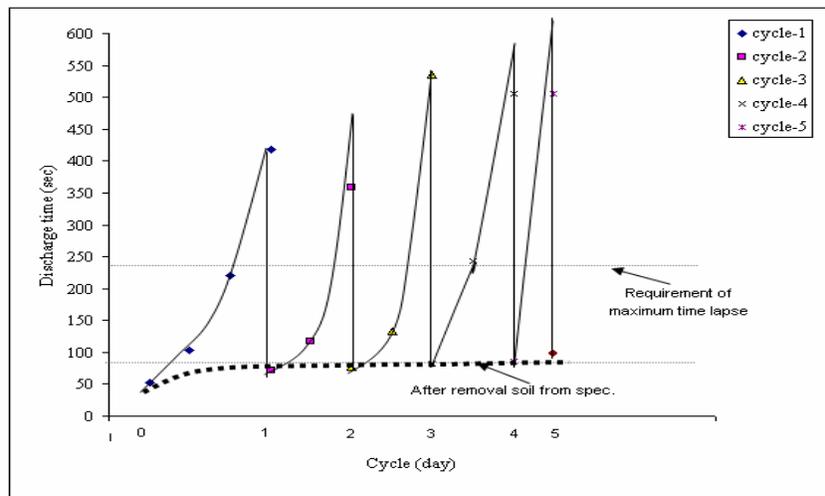


Figure 9. Cycle Time for Clogging of Double Layer PA (14D3-60/70 Pen.)

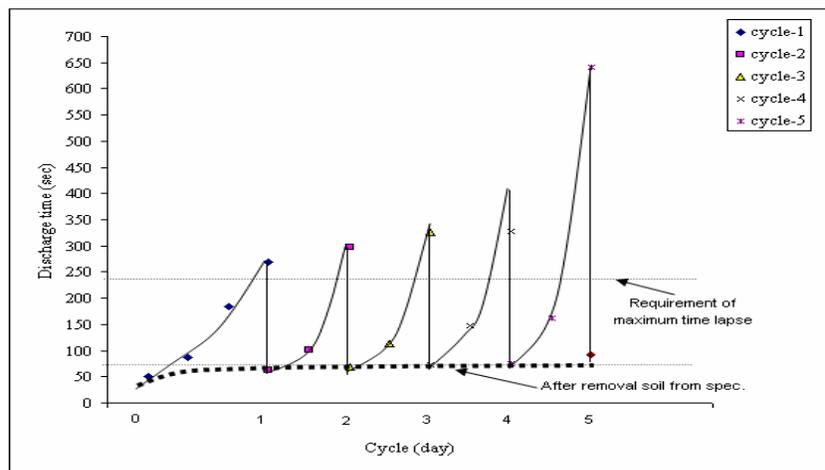


Figure 10. Cycle Time for Clogging of Double Layer PA (10D3-60/70 Pen.)

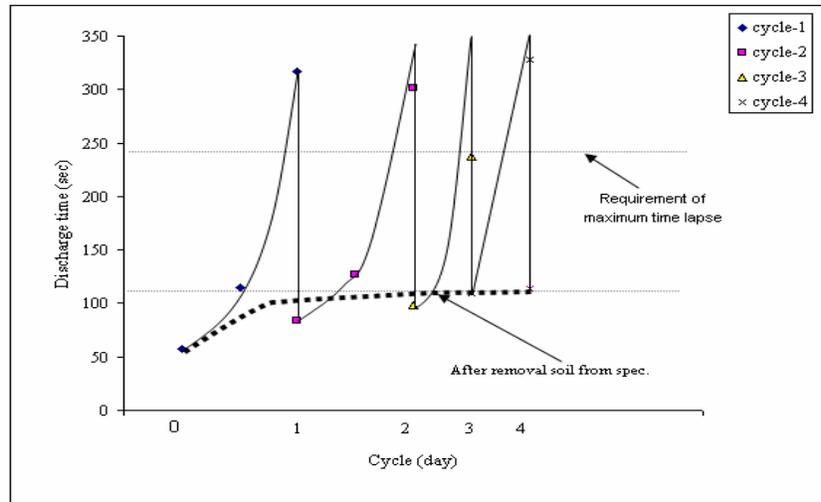


Figure 11. Cycle Time for Clogging of Single Layer PA (10S-SBS)

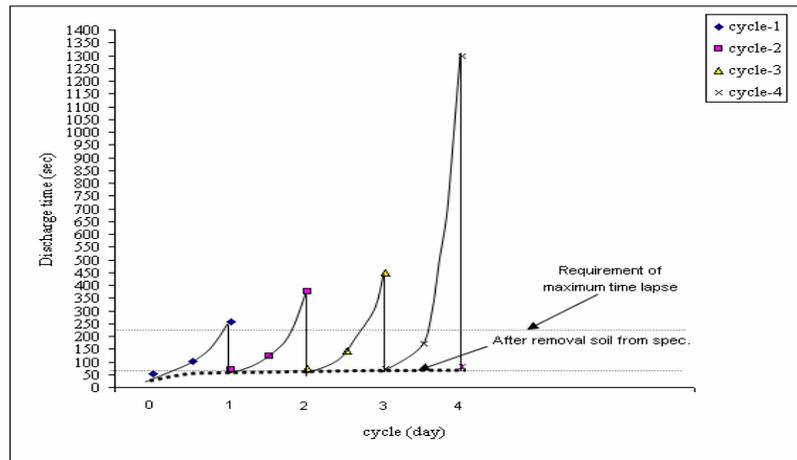


Figure 12. Cycle Time for Clogging of Double Layer PA (14D3-SBS)

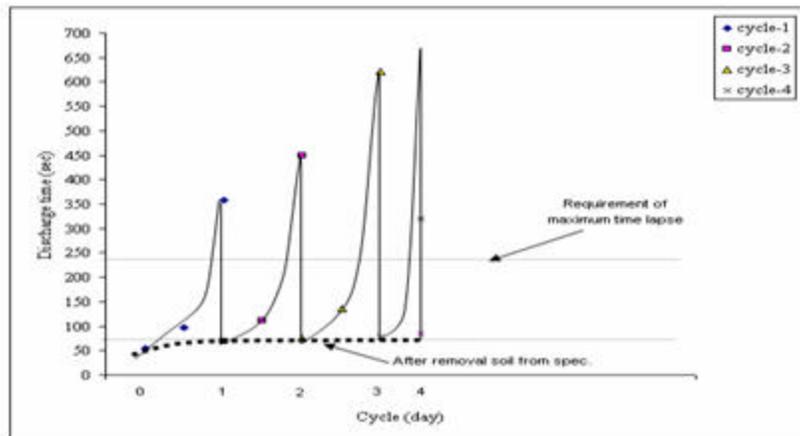


Figure 13. Cycle Time for Clogging of Double Layer PA (10D3-SBS)

## 6. CONCLUSIONS

1. Double layer PA was developed to mitigate clogging and to further enhance noise absorbing capacity of porous asphalt. It consists of a finer porous top layer mix and a coarser thicker bottom layer mix. The top layer functions to trap pollutants that can be easily unclogged by hydro vacuuming.
2. A newly developed clogging test was used to assess the clogging potential of the double layer compared to single layer PA. The method implicated determination of permeability in terms of time taken for water to fall between two designated points on the permeameter. The specimens were repeatedly clogged and unclogged until the terminal time lapse was attained. The clogging agent was a silty-clayey soil combination prepared at 1.5 g/l concentration to achieve progressive clogging.
3. As the maximum aggregate size increases and the top layer thickness reduces, the number of loadings to attain the terminal permeability or time lapse increases.
4. As the top layer thickness decreases, it takes a longer time to clog the specimen.
5. The double layer PA has the potential to better resist clogging compared to conventional single layer PA.

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