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EVALUATING POTENTIAL OF DIATOMITE AS ANTI-CLOGGING AGENT FOR POROUS ASPHALT MIXTURE

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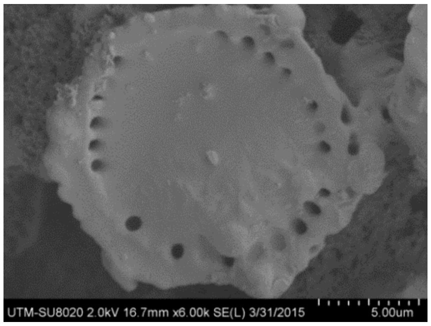
Graphical abstract



Abstract

Clogging is a major problem that occurs throughout the service life of porous asphalt due to the open nature of the mixture itself. Diatomite with characteristic of abrasiveness and porous structure seems to have potential in order to remove the clogging materials that mainly consists of soils. This study aims to investigate the effects of diatomite as anti-clogging agent on the permeability rate and strength of porous asphalt. The porous asphalt samples were prepared using Malaysia aggregate gradation and polymer modified bitumen of PG76 was used as the binder. This study focuses on clay as the clogging material at different concentration. A fixed amount of 0.5 g/L diatomite was applied to the porous asphalt samples as an anti-clogging agent prior to clogging cycles. The permeability test and resilient modulus were then conducted at different clogging concentrations (0.5, 1.0, 1.5 g/L) and cycles, with and without diatomite. It was found that samples with diatomite have a higher permeability rate compared to those without any application of diatomite after a few clogging cycles. As the clogging cycles increase, the clogging materials have trapped and filled up the voids in the porous asphalt samples and increase the resilient modulus result.

Keywords: Porous asphalt, anti-clogging, diatomite, clogging, permeability, concentration

1.0 INTRODUCTION

Porous asphalt is a paving material that aids in maintaining natural hydrological cycles on a developed property by allowing infiltration of rainwater into the subsurface while providing a structured surface [1]. By removing water from the road surface, porous asphalt provides benefits in terms of improving safety by reducing splashing and hydroplaning [2]. The air voids content in porous asphalt mixture generally not less than 15% and even as high as 25% shortly after construction unlike conventional asphalt typically provides 4% to 8% void volume. Porous asphalt is produced by eliminating the fine aggregate from the asphalt mixture and mixed with polymer modified binder. The presence of interconnected air voids in the wearing course layer allows water to penetrate from the surface to the bottom of the layer [3].

Porous asphalt mix has an open gradation with a coarse aggregate proportion that is greater than the fine aggregate make it more permeable compared to other types of asphalt mixes [4]. A typical infiltration rate of porous asphalt is 35 m/h [5]. Porous asphalt are designed to provide many advantages including storage and treatment of storm water runoff, improvement of water quality through the pollution removal and groundwater recharge [6-10]. On the other hand, porous asphalt provides advantages for road users by improved skid resistance and visibility, reduction of splash and spray, reduce headlight reflection and glare, and also reduce tire noise level. However, the main problem affecting the performance of porous asphalt is mainly on the permeability loss due to clogging problem. The large pore sizes, which allows for increased permeability, can also capture sediment in the voids and reduce the void interconnectivity.

Clogging is a major problem that occurred throughout the service life of porous asphalt due to the open nature of the mixture itself. Parts of the filtered particles remain trapped within the pores of porous pavement causing the pores to clog until the particles are pushed out and removed. Clogging pavement will reduce the rate of water infiltration through the porous media and will cause water ponding on the pavement surface. Suspended solid matter such as dirt, fine sand and debris contain in runoff can lead to a gradual reduction in the drainage capacity of permeable pavement [11]. Clogging of porous asphalt partly controls of sand coming from the porous asphalt mortar itself [12-14].

Porous asphalt has been properly designed to have good permeability properties and acts like a sieve, preventing silt from entering the pavement and facilitating the cleansing work. Concentration of runoff differs with location and traffic volume. Concentrations of selected constituents in highway runoff were affected by the number of vehicles passing the site during storm events [15]. The concentration of solids in storm water runoff varies among sites. The median concentration reported in a national survey was 99 mg/L for runoff from freeways and half that for residential and commercial drainage areas [16]. Other than that, the concentration of the runoff also can be based on the composition of the soil such as sand, silt and clay. The composition of each type of soil will be differed in the different local areas.

Previous study has shown that sand clogging may reduce its overall permeability rate, but that the design goals for hydrological purposes can still be maintained [1]. There are also concerns about clogging with finer soil materials due to the infiltration of storm water with typical levels of solids. This paper focuses on the development of laboratory protocol which mimic five cycles of clogging event. The clogging material used is a clay type applied at three different concentrations. The anti-clogging agent can be one of the methods to reduce the clogging rate and increase the effective duration of the porous asphalt in service. Diatomite is also known as diatomaceous earth that has been identified to have potential to be used as a self-cleaning agent in losing the clogging materials that filled up the voids in porous asphalt such as clay.

Diatomite is a kind of silicate materials, a non-metal deposit that is produced from the remains of diatoms living in the ocean or lakes by action in natural circumstances [17]. The properties which make diatomite valuable include low density, high porosity and surface area, abrasiveness, insulation properties, inertness, absorptive capacity, brightness and high silica contents. Diatomite has a wide variety of uses, including as a filtration aid, mild abrasive, mechanical insecticide, absorbent for liquids and soil amendments. Its function as soil amendments has been considered to potentially be as anti-clogging agent in porous asphalt. Diatomite provides permanent porosity and absorbency for soils. When diatomite is incorporated into soil, it serves to reduce compaction and increase water and air permeation. Since clay has finer size and sticky properties, diatomite seems to have ability to remove clay when it's clogged into porous asphalt. Diatomite porosity increase drainage of the soil [18].

The main objective of this study is to evaluate the effect of using diatomite to drainage time of the porous asphalt mix at various cycles and concentrations of clogging material. The investigation of drainage time based on the permeability rate for five cycles of clogging. The effect of diatomite has been evaluated by comparing the permeability rate of samples with and without applying diatomite before the clogging cycles.

2.0 EXPERIMENTAL

2.1 Materials Properties

2.1.1 Aggregate and Bitumen

The aggregate gradation used for this study was adapted based on specifications from Public Works Department, Malaysia (2008). The granite used in this study was supplied by Hanson Quarry, Gunung Pulai, Johor. Hydrated lime was used as filler and anti-stripping agent. Table 1 and Figure 1 show the detailed distribution of aggregate particle size.

Table 1 Malaysian Aggregate Gradation for Porous Asphalt

Sieve size (mm)	Gradation limits (% passing)		Average passing (%)	Percentage Retained (%)	Mass for each sample (g)
	Upper	Lower			
20	100	100	100	0	0
14	100	85	92.5	7.5	54.4
10	75	55	65	27.5	199.4
5	25	10	17.5	47.5	344.4
2.36	10	5	7.5	10	72.5
0.075	4	2	3	4.5	32.6

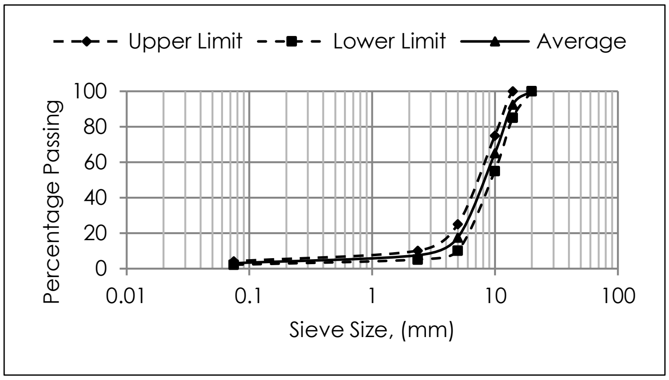


Figure 1 Plotted Gradation Limit for Malaysian Gradation

The specific gravity and water absorption of the coarse and fine aggregates used in this study was determined based on ASTM C127 and ASTM C128 specifications. Specific gravity is the main factor in identifying the optimum bitumen content required for the mixture design, voids in mineral aggregates and also the strength of the compacted mixture. The properties of coarse and fine aggregate used in this study as shown in Table 2. The aggregate impact value (AIV) test was conducted according to ASTM D5874-02 to evaluate the strength characteristic of the aggregates and the average result is 24%.

Table 2 Aggregate Properties

Coarse Aggregate Properties	Value
Specific Gravity Bulk	2.690
Specific Gravity Saturated Surface Dry (SSD)	2.705
Specific Gravity Apparent	2.732
Water Absorption (%)	0.579
Fine Aggregate Properties	**Value**
Specific Gravity Bulk	2.427
Specific Gravity Saturated Surface Dry (SSD)	2.477
Specific Gravity Apparent	2.554
Water Absorption (%)	2.048

Polymer-modified bitumen, PG76 was used as a binder for the mix design and preparation of all the samples. Polymer modified bitumen, PG76 is a thick film of bituminous binder with improved resistance to age hardening. The performance grade of PG76 as shown in Table 3 is very suitable for porous asphalt mix performance since porous asphalt tends to age more rapidly because of the large interconnected air voids.

Table 3 Properties of performance grade bitumen, PG76

Properties	
Viscosity at 135°C	2.8 Pa.s
Penetration at 25°C	0.406 mm
Softening point	75°C
Specific gravity at 25°C	1.030g/cm³

The optimum bitumen content (OBC) was determined using Cantabro and Binder Draindown Tests. From these tests, the optimum bitumen content for PG76 was found at 5%. Using the binder draindown test, at the selected OBC value, it is expected that there is enough bitumen film thickness to coat the aggregate particles. Cantabro test evaluated the mixture's resistance against raveling or aggregate loss. The compacted sample was placed in the Los Angeles machine and determined the weight loss after 300 revolutions at ambient temperature.

2.1.2 Clogging Materials Properties

The clogging material used was a clay type, which is kaolin. Table 4 gives the properties of clogging material. Based on the Unified Soil Classification System (USCS) this soil is classified as fine-grained.

Table 4 Properties of clogging material

Soil type	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity Index, PI (%)
Kaolin clay	54.2	26.6	27.6

In order to determine the surface characteristics of the material used, Field Emission Scanning Microscopy (FESEM) was conducted on the clogging materials. Figure 2 shows the FESEM image of clay that was used as clogging material. The FESEM image shows that the particles of clay are platy, flaky and irregular shape.

Figure 2 FESEM images of clay

2.1.3 Properties of Diatomite

An anti-clogging agent used in this experiment was diatomite that was supplied by A&AT Filter-Aid Product Company from China. Diatomite used in this study has its application as a soil amendment that increases the porosity and drainage of the soil. The properties of anti-clogging agent are shown in Table 5. The FESEM images of diatomite particle are shown in Figure 3. Figure 3 (a) shows the FESEM image diatomite was measured at magnification of 5000 x that the particle of diatomite sample was at minimum with 10.0 µm while Figure 3 (b) is the image of diatomite particle with 6000x magnification and minimum particle size at 5.0 µm. Both images show that diatomite has high porosity texture and surface area.

Table 5 Properties of diatomite

Properties	
Color	White
Permeability	>12
Density (g/cm³)	≤0.35
Moisture (%)	≤0.3
Loss of ignition	≤2.0
PH	9.0-10.0
Water dissolvable (%)	≤0.2
Acid dissolvable (%)	≤3.0

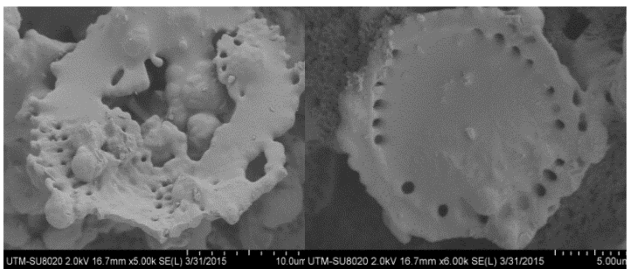


Figure 3 FESEM images of diatomite

2.2 Mixture Design and Sample Preparation

The target air void content is 20±1% for all the samples. The samples were prepared with design binder content of 5%. Samples were compacted with 20, 40, 60 and 80 number of gyration. From Figure 4, the optimum number of gyration to achieve the target of 20% air voids content is 58 gyrations.

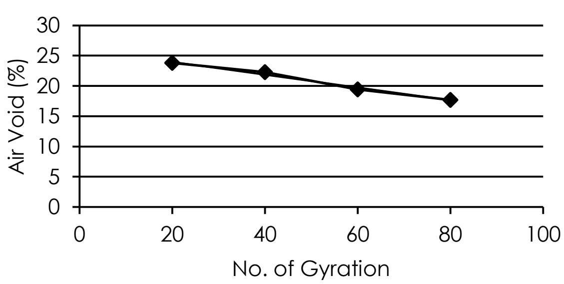


Figure 4 Determination number of gyration

2.3 Permeability Test and Clogging Simulation

A falling-head water permeameter was used to determine the permeability of the samples. The test was conducted according to ASTM D5084-10 at ambient room temperature. Permeability was measured in terms of its discharge time in seconds, which was the time taken for a specified volume of water to penetrate through the specimens. With the permeameter, this was measured in terms of the time taken for the water level to fall between two designated points from 60 to 20 on the permeameter tube. The coefficient of permeability, k was measured in terms of its discharge time for a specified volume of water to permeable through the samples. The permeability coefficient was calculated using Equation 1 following the Darcy's Law.

A total of 18 gyratory compacted samples were tested with three replicates for each concentration of clogging materials to identify the effectiveness of anti-clogging agent. Each sample has dimensions of 100 mm diameter and 50 mm height with approximately 20% of targeting air void content.

$$k = \frac{al}{At} ln \frac{h_1}{h_2} \qquad [1]$$

where,

k = Coefficient of water permeability, (cm/s)
a = Inside cross-sectional area of inlet standpipe, (cm²)
l = thickness of test sample, (cm)
A = cross-sectional area of test sample, (cm²)
t = average elapsed time of water flow between timing marks, (s)
h_1 = hydraulic head on sample at time t_1, (cm) and
h_2 = hydraulic head on sample at time t_2, (cm)

The permeability test was conducted for five cycles with tap water and contaminated water at different concentrations. The initial coefficient of permeability at which the porous asphalt functions effectively as an open mixture is average 0.25 cm/s. After that, 9 samples were applied with 0.5 g/L of diatomite by allowing it permeable through the samples. Next, the clogging materials were prepared by dissolving three different masses in 1 Liter of water to get different concentrations of clogging material i.e. 0.5, 1.0 and 1.5 g/L. These were then allowed to clog the pores of the sample. The samples were left to dry for 24 hours at a temperature of 35.0°C to complete one cycle. After that, the discharged time was determined using plain tap water. The clogging procedure was repeated for five cycles of clogging.

2.4 Resilient Modulus Test

The Resilient Modulus test was conducted using Universal Testing Machine (UTM), in accordance with the guideline practice of ASTM standard (ASTM D6931-12, 2013). It was conducted at a temperature of 25°C by applying repetitive applications of compressive loads in a haversine waveform on the sample. The compressive load was applied vertically along the curved plane of a cylindrical sample of asphalt mixture. The resulting horizontal and vertical deformations of the samples were measured. The resilient modulus was automatically calculated from the machine using recoverable vertical and horizontal deformations. The resilient modulus test was done to all 18 gyratory compacted samples for uncontaminated samples and also after each cycle of clogging in order to evaluate the strength of the sample through the clogging cycles.

3.0 RESULTS AND DISCUSSION

3.1 Analysis on Permeability

To better perceive the clogging phenomenon of the samples tested, the permeability coefficient was calculated using Equation 1 and plotted on permeability coefficient versus clogging cycles. Then, the results of each cycle were converted to permeability index by using Equation 2. This is to reduce the effect of different air void distribution between samples for comparison. Figure 5 shows the relationship between permeability coefficient index and clogging cycles for concentration of clogging material at 0.5 g/L, 1.0 g/L and 1.5 g/L. It also represents the comparison of permeability between the samples that have been applied with and without diatomite before the clogging cycles. An index of 1.0 indicates samples whose discharge times are not affected by clogging.

$$\text{Permeability index} = \frac{k^n}{k_0} \qquad [2]$$

where,

k^n = permeability coefficient after n, number of clogging cycles
k_0 = permeability coefficient before clogging cycles
n = number of clogging cycles

Figure 5 (a) and (b) indicate that the permeability rate reduced as the clogging cycles increase. It is clearly showed that the clogging material remains in the sample and filled up the voids in the porous asphalt samples. The clogging materials accumulate in the voids and remained trapped as the clogging cycles increase and clogged the samples. The clogging materials affected the air voids connectivity, causing the increase in discharge time and reduced the permeability coefficient.

Figure 5 (a) and (b) clearly show that samples with diatomite have a higher permeability coefficient after five clogging cycles compared to those without diatomite prior to clogging cycles. This indicates that diatomite has reduced the clogging rate of porous asphalt samples and effective as anti-clogging agent for clogging materials that have a concentration of 1.0 g/L and less. Diatomite provides porosity to clay by reducing its compactness and increases its drainage capacity. Furthermore, the clogging materials were then washed away during the clogging cycle and also permeability test.

Figure 5 (c) shows that the reduction in permeability rate for both samples, with and without diatomite are almost similar. This proves that 0.5 g/L of diatomite is not effective for 1. 5g/L concentration of clogging materials. The amount of diatomite may insufficient to improve the drainage capacity of the interconnected voids against clogging materials.

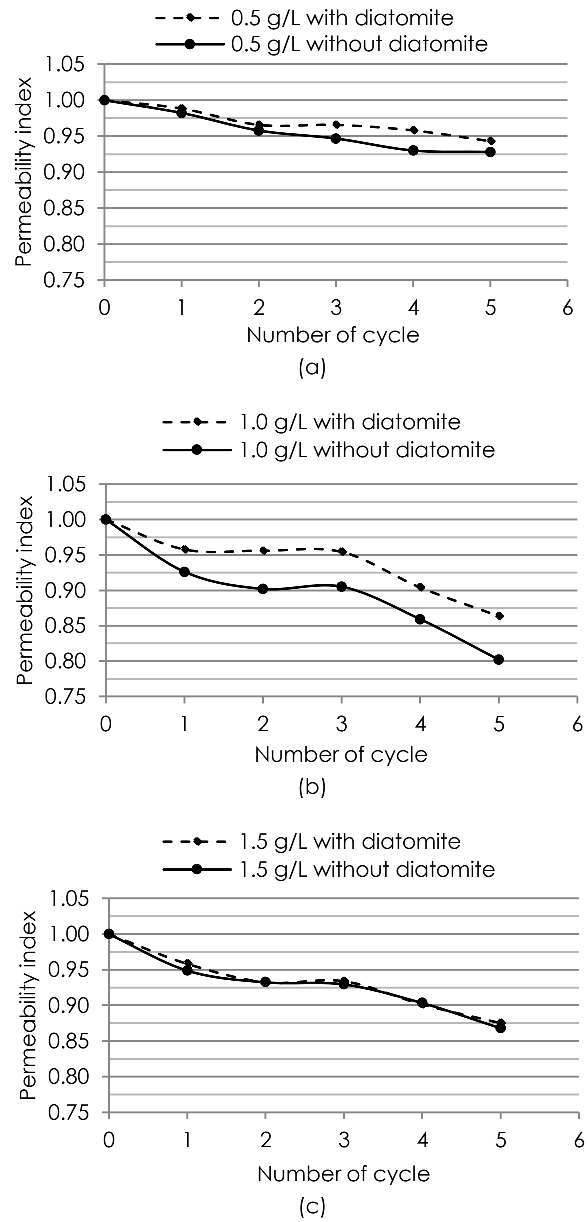
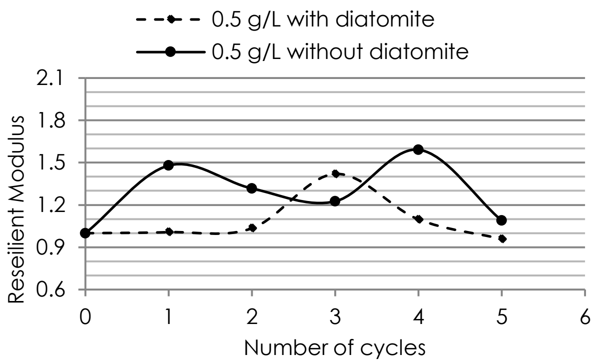


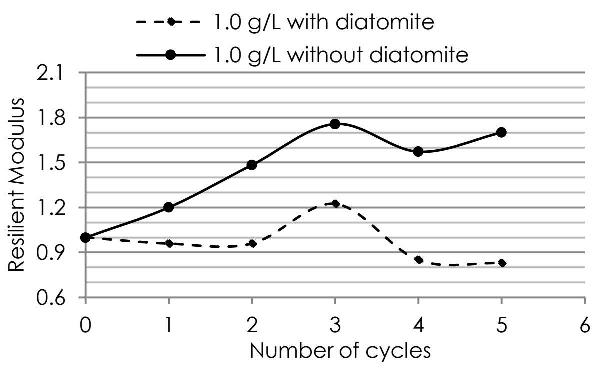
Figure 5 Effect of concentrations of clogging material (a)0.5g/L (b) 1.0 g/L and (c) 1.5g/L on permeability

3.2 Analysis on Resilient Modulus

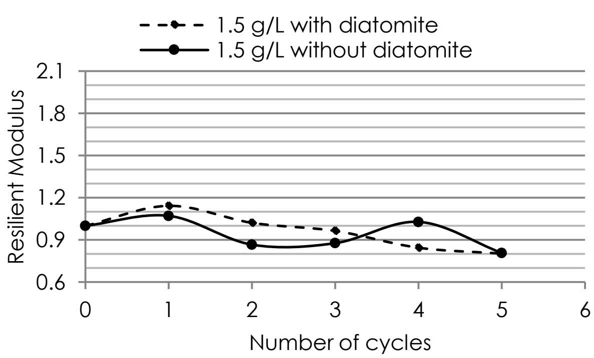
The resilient modulus test was conducted using Universal Testing Machine (UTM) at an ambient temperature of 25°C. The test was performed on samples that were applied with and without diatomite before clogging cycles. The results for the three concentrations of clogging materials are presented in Figure 6. For better comparison between the different samples, the ratio of resilient modulus for each cycle to the resilient modulus measured initially was calculated as resilient modulus index.



(a)



(b)



(c)

Figure 6 Effect of concentrations of clogging material (a)0.5 g/L (b) 1.0 g/L and (c) 1.5g/L on resilient modulus

Figure 6 shows that the average resilient moduli for samples with diatomite is almost consistent through the clogging cycles except during the third cycle. On the other hand, from Figure 6 (a) and (b), it can be seen that samples without diatomite have higher modulus which could be due to the accumulation of the clogging material that fill up the voids and increase the sample's density. This is also supported by the aforementioned permeability results with the reduction in the drainage capacity.

Besides that, the binder tends to get aged as it undergoes the clogging cycles. More oxidation process consequently reduces the strain and increase the resilient modulus. Binder hardens as a result of the oxidation process, thus increases the mixture stiffness. Figure 6 (c) shows the resilient moduli reduce after 5 cycles of clogging simulation for both samples. The reduction of resilient modulus are comparable for both samples with and without application of diatomite.

4.0 CONCLUSION

From the study, it can be concluded that, clogging reduces the ability of the porous mixture to drain water from the surface due to the deterioration of air voids conectivity. Diatomite with higher porosity surface texture, has ability to absorb impurities and increase drainage capacity of the porous asphalt by reducing the clay compactness. The clogging materials were then washed away as water permeable within the porous asphalt structure. However, in this study, a fixed diatomite concentration of 0.5 g/L was used and it seemed effective for unclogged pores with a clay concentration up to 1.0 g/L. This is supported by the consistent value of resilient modulus for samples that was initially conditioned with diatomite prior to clogging cycles.

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