LABORATORY SIMULATIVE CLOGGING BEHAVIOUR AND FRACTURE TOUGHNESS OF ONE AND TWO-LAYER POROUS ASPHALT

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by

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AL	Abrasion Loss
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Material
BS	British Standard
DBC	Design Binder Content
DRI	Danish Road Institute
DT	Discharge Time
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
HPU	Highway Planning Unit
ITS	Indirect Tensile Strength
JKR	Jabatan Kerja Raya
k	Coefficient of Permeability
OL	One-Layer
OPC	Ordinary Portland Cement
PA	Porous Asphalt
PWD	Public Works Department
R^2	Coefficient of Determination
TL	Two-Layer
TRL	Transportation Research Laboratory

SIMULASI TINGKAH LAKU PENYUMBATAN DAN KELIATAN PATAH ASFALT BERLIANG LAPISAN TUNGGAL DAN DWILAPISAN DI MAKMAL

ABSTRAK

Penyumbatan menyebabkan fungsi kebolehtelapan asfalt berliang menurun selepas beberapa tahun dalam perkhidmatan. Oleh yang demikian, asfalt berliang telah dibangunkan untuk meminimumkan masalah ini. Ujian simulasi terhadap fenomena penyumbatan telah dijalankan di makmal. Untuk mengkaji fenomena penyumbatan, asfalt berliang lapisan tunggal dan dwilapisan telah ditindaki enam kitaran penyumbatan dan pembersihan. Tingkah laku penyumbatan asfalt berliang dinilai menggunakan meter telap air turus menurun. Spesimen asfalt berliang dihasilkan menggunakan jenis pengikat, kandungan pengikat dan ketebalan lapisan atas spesimen dwilapisan yang berbeza. Spesimen terpilih disesuaikan pada suhu 10, 30 and 50 °C untuk mengkaji kesan suhu terhadap penyumbatan. Ujian lenturan separa-bulatan telah digunakan untuk menilai keliatan patah campuran asfalt berliang. Spesimen tunggal dan dwilapisan diuji pada suhu 0, 10 dan 20 °C. Kajian ini mendapati bahawa kebolehtelapan asfalt berliang menurun dengan lebih ketara pada beberapa kitaran awal ujian penyumbatan. Penambahan kitaran beban mempamerkan pola eksponen pada trend penyumbatan. Tahap kemampuan spesimen merintang penyumbatan boleh diukur melalui index penyumbatan dan index pemulihan. Kajian ini juga mendapati bahawa spesimen dwilapisan merintang penyumbatan dengan lebih baik berbanding spesimen tunggal manakala ketebalan lapisan atas spesimen dwilapisan tidak mempengaruhi penyumbatan. Jenis dan kandungan pengikat juga mempengaruhi penyumbatan asfalt berliang. Selain itu, suhu tinggi juga menyebabkan penyumbatan yang lebih ketara kepada campuran berbanding suhu rendah. Secara amnya, suhu ujian yang lebih rendah menyebabkan

keliatan patah yang lebih tinggi. Seterusnya, spesimen tunggal mempamerkan keliatan patah yang lebih tinggi berbanding dengan spesimen dwilapisan dan jenis pengikat juga mempengaruhi keliatan patah asfalt berliang.

LABORATORY SIMULATIVE CLOGGING BEHAVIOUR AND FRACTURE TOUGHNESS OF ONE AND TWO-LAYER POROUS ASPHALT

ABSTRACT

Clogging causes porous asphalt to lose its permeability function after a few years in service. Therefore, two-layer porous asphalt was developed to minimize this problem. This study presents a laboratory simulative test of clogging phenomenon occurred on porous pavements. To ascertain the clogging of porous asphalt, one and two-layer specimens were subjected to six clogging and cleansing cycles. The permeability loss was assessed using a falling head water permeameter. Porous asphalt specimens were tested incorporating conventional 60/70 and PG76 modified bitumen at four binder contents and three different top layer thicknesses of two-layer specimens. Selected specimens were subjected to temperature conditioning (10, 30 and 50 °C) to determine the effects of temperature to the severity of clogging. Semi-circular bending test was used to assess the fracture toughness of porous asphalt. One and two-layer specimens were tested at 0, 10 and 20 °C testing temperatures. The overall results showed that porous asphalt loses its permeability mainly in the first two to three clogging and cleansing cycles. The clogging trend exhibits an exponential pattern with addition of clogging material. The performance of porous asphalt in resisting clogging can be ranked from the clogging and clog-recovery index. It was also found that two-layer specimens were a better clog-resistant mix compared to one-layer specimens while top layer thicknesses of two-layer specimen have no significant effect on clogging. Binder type and content have significant effects on clogging of porous asphalt. Higher temperature caused severe clogging to the mix and lower temperature result in least clogged mix. Generally, lower testing temperature resulted in higher fracture toughness. Subsequently, one-layer specimen

exhibit higher fracture toughness compared to two-layer specimen and binder types also exhibit significant effect on the fracture toughness of porous asphalt.

CHAPTER ONE

INTRODUCTION

1.1 General

Road network is an important indicator of economic growth and physical development of a nation such as Malaysia. The road design should be improved from time to time. Currently, porous asphalt (PA) is one type of road surfacing that is used pbeen identified as the greatest noise pollutant in the industrialized world with the tyre-road interaction being the major contributor at high vehicle speeds (Jongens, 1995). The noise reduction of PA is more prominent when it is new but all this may change as the pavements get older.

Malaysia started its PA field trial in 1991 (HPU, 1998). Subsequently, the material has been laid along the Federal Routes, toll expressways and several other locations. This effort was initiated to decrease the number of road accidents during wet weather conditions. The advantages of porous asphalt suit the Malaysian climate where rainfall is common throughout the year. Therefore the lifetime and advantages of this type of pavement should last a long time.

2.2 Problem Statement

Porous asphalt has been used mainly to mitigate ponding water hence reduce aquaplaning and subsequently reducing splash and spray. It also reduces traffic accident, road noise and improves skid resistance during wet weather conditions. It is well known for its excellent sound absorption properties. Traffic noise is becoming an escalating problem and is one of the major environmental issues in Europe. Many European countries have enforced policies or noise abatement program aimed at reducing traffic noise. Although road traffic noise may pose a threat to the environment in the developed world, it is not the main case in Malaysia. The main problem of PA in countries that receives heavy rain throughout the year such as Malaysia is water management during rainy condition. Water needs to be channelled and managed systematically to provide a safe and comfortable ride for road users.

Permeability of PA depends mainly on the effective air void space available for drainage. Effective voids are the interconnected voids that function as a water path that allows water to flow through it. A reduction in the effective air voids content occurs mainly due to clogging of voids and densification under heavy traffic. References have shown that air voids content in excess of 20 % may become partially filled with dust, reducing the effectiveness of the mixture in the long term. This is known as clogging and it is a common reported problem associated with PA. The air voids continuity of PA can be blocked very quickly with detritus such as tyre wear, leaves, dust, sand, soil, and other road debris. According to Van Blokland (1997), due to clogging and ageing of the surface, both the absorption and texture degraded and thus led to a significant loss of noise reduction capacity, sound absorption, and splash and spray.

The deterioration of the air voids continuity is also affected by temperature. In countries that experience tropical climates, the surface of asphalt pavement is particularly hot during daytime. The pavement surface will be heated and the asphalt softens. The sand and debris accumulated on top of the pavement penetrates into the high temperature asphalt. As day turns into night, the atmosphere cools and the binder hardens. The penetrated sand and debris will stick to the asphalt and become part of the pavement thus making it impossible to remove or cleanse from the pavement. It will fill up and close up the air voids of the pavement. This may be one of the major causes of clogging for PA. Severity of clogging of PA over time is one of the major concerns for the deterioration in the performance of PA (Dietz, 2007).

The problems addressed in this study were clogging and the effect of temperatures to the severity of clogging in porous asphalt especially in tropical countries such as Malaysia. In this study, evaluation of clogging behaviour was assessed through a laboratory simulative test. At present, there is still lacking of laboratory simulative tests on clogging of porous asphalt and the effect of temperatures has never been investigated. Therefore, this research simulates clogging that occurs on site and evaluate the effect of temperatures on clogging of porous asphalt.

1.3 Aim and Objectives

The aim of this research is to characterize the clogging behaviour of one and two-layer porous asphalt. The objectives are as follows:

1. To determine the effects of various top layer thicknesses, binder content, and binder type on the clogging behaviour of one and two-layer PA.
2. To assess the effects of temperature on the severity of clogging of one and two-layer porous asphalt.
3. To develop clogging and clog-recovery index to rank mixes according to their performances.

4. To evaluate the fracture toughness of fresh and clogged specimens of one and two-layer porous asphalt using the semi-circular bending test.

1.4 Significance of Study

Porous asphalt improves night visibility and skid resistance, while minimizing hydroplaning thus reducing splash and spray during rainy condition, and reducing traffic noise from vehicle tyres (Nicholls 1997, Huber 2000). The major problems that are associated with deterioration of the functionality of PA asphalts are ravelling and clogging of the air voids. This study focuses on clogging. PA is typically cleansed using vacuum techniques. Unfortunately, the technique has its own limitations. As a mitigation measure, the two-layer PA was invented. The material is named as Twinlay in the Netherlands and Double Draining Layer in Italy. This study focuses on assessing the clogging behaviour of one and two-layer PA. This study aims to prove that the two-layer PA can better resist clogging compared to one-layer PA. Currently, there are only a few laboratory simulative tests that has been carried out to assess the clogging behaviour of PA. It is essential to investigate the effects of various factors that may affect PA clogging. The effects of clogging and cleaning cycles on the hydraulic conductivity of porous asphalt are also evaluated. Temperature conditionings are carried out on selected specimens to ascertain the severity of clogging due to different temperature conditioning. Bitumen is susceptible to temperature, therefore temperature is found to have an effect on the severity of clogging.

Fracture resistance has been one of the most important requirements for asphalt pavements and it significantly influences the service life of pavement consequently maintenance and management of the pavement network. Longitudinal cracking, thermal cracking, and reflective cracking are a few of pavement distresses that are related to the fracture properties of asphalt pavement. The Semi-Circular Bending (SCB) test was adopted to evaluate the fracture toughness of porous asphalt. The SCB test configuration has been adopted by many researchers in the asphalt pavement community due to the ease in sample preparation and set-up procedure (Huang and Zuo, 2004; Wu et al., 2005; Artamendi and Khalid, 2006). However, very limited material factors and testing conditions were included in previous studies especially on porous asphalt specimens. Hence, it is essential to characterize fracture toughness property of porous asphalt through the SCB test.

1.5 Scope of Work

The scope of work is limited to a study on one-layer and two-layer PA. The aggregate gradations were modifications of the Dutch Twinlay gradations using locally crushed granite and conventional 60/70 and PG76 binders. The property tests used for comparison include permeability, air voids and indirect tensile strength.

The crux of the study is on clogging. The parameters were one-layer (OL) and two-layer (TL) specimens prepared with two binder types at four binder contents and three different top layer thicknesses of TL specimens. Clogging test is conducted to assess the characteristic of the clogging behaviour of PA mixes. Clogging performance is evaluated via a falling head permeameter designed by Hamzah (1995) and available at the Highway Laboratory of Universiti Sains Malaysia. A number of specimens are allocated for the clogging test but subjected to temperature conditioning. This is to simulate the temperatures experienced by the mixes during its service life.

Mechanical properties of OL and TL porous asphalt were evaluated using the SCB test. The fracture toughness of OL and TL fresh specimens prepared with conventional 60/70 and PG76 binders at three different temperatures were assessed. The fracture toughness of selected clogged specimens was also evaluated.

1.6 Thesis Organization

The thesis begins with an introduction on clogging of PA as described briefly in Chapter 1. This chapter outlines the background, problem statement, objectives and the scope of work that need to be completed. Chapter 2 describes a much clearer overview of previous studies associated to PA and its problems related to clogging of the air voids.

Chapter 3 describes the materials and methods used in the laboratory tests. The properties of raw materials used such as aggregates, asphalt binders and fillers are assessed and reported in this chapter. The results and analysis of the mixture design are reported and discussed in Chapter 4. This chapter presents the results obtained from the evaluation of Dutch Twinlay PA mix properties, determination of the proposed gradation and the design binder content.

Chapter 5 presents the results recorded from the experimental studies. This chapter focuses on the deterioration of permeability due to clogging of the voids. The semi-circular bending test results are also evaluated and discussed in this chapter.

The experimental studies are concluded in Chapter 6. Conclusions of the research done and recommendations for future study are presented here.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Porous Asphalt (PA) is one type of road surfacing technology which has been used in many countries. Its continuous air voids conduct water into the asphalt mix and flows through it. It is used as a wearing course and laid on an impervious base course. It is applied to reduce traffic accidents especially in wet conditions on roads and highways. This porous surfacing is also effective in reducing traffic noise with its noise attenuation properties. Compared to dense mix, porous asphalt is susceptible to clogging and less durable.

Over the past years, many countries have been involved in the development of a low-noise pavement leading to the development of PA. This type of pavement offers excellent sound absorption properties and improves drainage abilities resulting in splash and spray reduction, and improved skid resistance. Two major concerns of PA deterioration are ravelling and clogging of the voids. The pores in PA are easily clogged by dirt, silt, clay and debris especially in wet conditions. When the pores are clogged, there will be permeability loss and when the extent of clogging is severe, the benefits associated with open mix will vanish.

Porous asphalt wearing courses have been used world-wide for more than 40 years. In the early years, PA was used to improve skid resistance. Initially, it was used to improve skid resistance on roads which has become too smooth. PA surfacing normally uses maximum aggregate size of 9 or 13 mm with an average void content of 15 percent (Visser et al., 1974). However, according to Horak et al. (1994), PA abilities were limited by its loss of permeability functions due to clogging of voids, low recycling potential, ravelling, and maintenance related problems such as pothole patching.

In European countries with a stricter environmental regulations related to traffic noise, PA surfacings offer a big potential to reduce traffic noise at source. Nonetheless, the noise absorbing capacity of PA is greater as the gradation becomes finer (Van Bochove, 1996). However, the finer graded PA, is more prone to clogging.

2.2 Advantages of Porous Asphalt

Lefebvre (1993) had listed out the benefits of PA that were observed through years of practice in various countries. A lot of advantages were observed especially during rainy condition. Porous pavements can reduce and entirely eliminate surface runoff preventing the occurrence of aquaplaning. The absence of surface runoff will cause fewer splashes and spray of water thrown up on the sides and behind tires when driving through wet pavements. This increases the comfort of driving from the absence of spray and the noise reduction inside the vehicle. Drivers tend to slow down during the presence of water on traditional surface. The 'dry' aspect of porous pavements reduces the need to slow down and increase the capacity of the road, thus reducing traffic congestion which happens during rainy weather. A reduction in the presence of water on the surface of the pavement also increases adherence between tires and road surface. The absence of water causes porous pavement to reflect light in a diffused manner unlike traditional surfaces which can behave like mirrors reflecting light directly and more intensely to the driver. The strong discontinuity characterizing the aggregate gradation of porous asphalts makes them resistant to rutting. It is now well known that high void content of porous pavement can soften both moving and mechanical noises of the vehicle, enables it to absorb noise (Delanne, 1989, Descornet and Luminari, 2000).

2.3 Disadvantages of Porous Asphalt

Against these advantages, the disadvantages are also summarized by Lefebvre, (1993). The cost of preparing and laying as well as managing the porous pavement is very high. A good porous bituminous concrete depends on the use of high quality aggregates with excellent wear resistance. Moreover, the preservation of its functionality highly depends on frequent maintenance operations. Thus, having 50 % higher overall costs and up to 400 % depending on the availability on site of responding materials. During rain precipitations, the 'dry' look of porous pavements gives the drivers a sense of comfort and safety of driving thus inducing them to drive fast. This increases the capacity of the road, but on the other hand it increases the risks of road accidents. The available adherence coefficient in wet conditions is much less than it appears to drivers. Ravelling may also occur because of the discontinuous grading of the mix. A newly laid porous asphalt pavement has low skid resistance. This is due to the thick asphalt film that coats the aggregates thus reducing their microtexture. During emergency braking, the braking distance is 20-40 % longer than on traditional mixes. After a period of 3-6 months, this phenomenon disappears, due to the polishing effects, when pure bitumen is used and up to 18 months for modified bitumen. The main disadvantage is the clogging of the pores. The main characteristic of porous asphalt is the high percentage of voids.

2.4 Experiences on Porous Asphalt

2.4.1 Netherlands

In general, traffic noise is one of the major environmental issues in Europe especially in the Netherlands where the major highways are close to many urban areas. For this reason, the implementation of porous asphalt is required to reach more noise reduction.

Since the 1980's, porous asphalt had been used as a wearing course for pavement in urban roads in the Netherlands. The first trial was conducted in 1984. In 1990, Van Bochove from Heijmans Civil Engineering in the Netherland invented the two-layer porous asphalt and named it 'Twinlay'. Currently, about 70% of the major roads in the Netherlands are surfaced with Single Layer Porous Asphalt (SLPA) (Hagos et al., 2009). In comparison to the reference Dutch Dense Asphalt Concrete (DAC) surface layer, a noise reduction of 4 dB (A) with the SLPA and 6 dB (A) with the two-layer porous asphalt (TLPA) can be attained (IPG, 2002 and Hofman et al., 2005). TLPA is also being researched to further minimize noise (Hagos et al., 2009).

2.4.2 Denmark

According to Bendtsen (1996), porous asphalt has not much been used in Denmark in the past. In 1970s, some unsuccessful application has put a halt on the use of this type of surfacing. It was not until the early 1990s, two trials with porous asphalt in single layer surfacing were carried out in Denmark. One of the trials was carried out on an urban road in Copenhagen (Oesterbrogade), the capital city of Denmark. The noise measurements were taken on one of the trials immediately after paving. The noise reduction recorded was 3 dB, but after 2 years the noise reduction benefit of the pavement had vanished. Noise levels measurements achieved reductions of up to 6 dB with the “Micro Drain” method, which is a third-generation development of these two-layer porous asphalt surfacings used in the Netherlands. Therefore, the Danish study group decided to investigate and apply the Dutch technologies in practice, under Danish conditions.

2.4.3 Singapore

A few tests were conducted in the laboratory to simulate the clogging of air voids in porous asphalt. Using local soil as the clogging agent, the test samples of porous asphalt has the dimension of 500 x 500 mm and various thicknesses of approximately 50, 75 and 100 mm. A falling-head permeameter, developed at the National University of Singapore, was used to measure the permeability. The study tried to correlate the laboratory results obtained with a simple theoretical model which has been developed for the clogging of geotextiles, called the Giroud’s theory. It was then concluded that the evaluation of the test results was complicated by the different void contents in every specimen and there was a clear segregation of results according to the air voids ratios (Tan et al., 2000).

A model has been set out to investigate the correlation between the hydraulic conductivity, the geometric road characteristics and the rainfall intensity. Based on the experimental data, this model has been tested in the laboratory and a chart for the design of porous asphalt was presented. It should be possible to improve the porous asphalt design with the use of this graph so that surface runoff could be avoided (Ranieri, 2002).

2.4.4 Norway

Road traffic noise has become one of the major environmental problems. In Norway, about 1.4 million people are exposed to road traffic noise levels exceeding the acceptable limit of 55 dB(A). This accounts for 79 % of the noise annoyance expressed in terms of noise annoyance index. Since the end of the project however, several developments took place in other countries; including the development of low noise thin pavements and twin layer porous asphalt. These pavements have been used successfully in a number of countries (Bendtsen et al., 2002). The current project therefore aims to evaluate the use of low noise pavements under Norwegian conditions and to come up with needed improvements to make them more suitable to prevailing road, traffic and climatic conditions in Norway (Aksnes et al., 2009).

2.5 The Use of Porous Asphalt in Malaysia

Porous asphalt was first tried on Malaysian roads along the Jalan Cheras-Beranang in 1994. Up to 1996, a total of 16 locations were resurfaced with porous asphalt along the Federal Routes and an additional of 25 more locations were identified for implementation in 1997. These efforts are to ensure the elimination of ponding water on the surface of the road; hence, improving the riding comfort of road users during wet condition. Other locations that use porous asphalt include the Federal Highway, the Kerinchi Link, Jalan Tebrau in Johor Bharu, and numerous patchy applications along the North-South Highway (HPU, 2002).

2.6 Clogging of Porous Asphalt

Significant loss in permeability of porous asphalt (PA) has been reported by Mallick et al. (2000), after two to three years in service due to clogging of the pores by dirt and pollutants such as dust, tyre wear by-product and debris. In one field study in Europe, the initial drainage times of PA pavements in the range of 25 to 75 seconds had increased to 80 to 100 seconds after 3 years and up to 160 to 400 seconds after 9 years in service (Kraemer, 1990). In Singapore, local residual soils deposits from dirty wheels and vehicles carrying earth has been a major source of materials contributing to clogging of PA layers (Fwa et al., 1999). Lane (2005) had also reported that the surface voids of PA start to become clogged with debris or dust after two or three years which reduced the pavement's ability to drain water. The effectiveness of PA reduced once this happen thus increasing vehicle spray, permeability reduction, a reduction in skid resistance and ultimately increasing accidents.

Porous asphalt is only used on high-speed roadways to prevent clogging problems. The high speed tires push water into the voids like a pumping effect and suck the water back out as they drive over the surface. Therefore, it is not recommended to use PA on low-volume or slow-traffic roadways (Van Heystraeten and Moraux, 1990). Less traffic will also result in more dirt and debris on roadways as the wind created by passing cars is not enough to keep the roadway clean (NCHRP, 2000).

Roadways with PA surface accumulate and trap particulate material and the associated pollutant within the pores of the porous structure and the solids are not blown to the sides of the road. In fact, air pressure in the vicinity of the tires may push the particle further down into the pores of the porous structure. This may cause the particles to clog the voids of the pavement (Barrett, 2008). Lane (2005) described the clogging materials as a build-up detritus which looks like cement from a stereoscopic photography. Oily material that accumulates in the voids comes to the surface during rain thus reducing the skid resistance in rainy weather as a further effect of clogging.

Van Blokland (1997) had also stated that the most important aspect in the wide spread use of PA surfaces is its expected performance after several years. It is known that the absorption and surface texture degrades due to clogging and ageing of the surface thus leading to a significant loss of reduction capacity. The main cause of not acting as a porous layer is clogging of the air voids. This primarily occurs in less trafficked parts of roads such as emergency lanes and hard shoulders. The clogging effect needs to be eliminated or at least retarded, by means of curative and preventative measures (Van Gorkum and Tolman, 1996).

A laboratory testing on PA specimens was done by Fwa et al., (1999), to evaluate the clogging potential of PA. The authors described the testing procedure which involved manually clogging the porous specimens with soil and recording the permeability throughout the clogging process. The coefficient of permeability (k) was calculated using an equation based on Darcy's Law. The reported results consistently showed the rapid decrement in coefficient of permeability in the beginning of the test and then asymptotically approaching a terminal value, as shown in Figure 2.1.

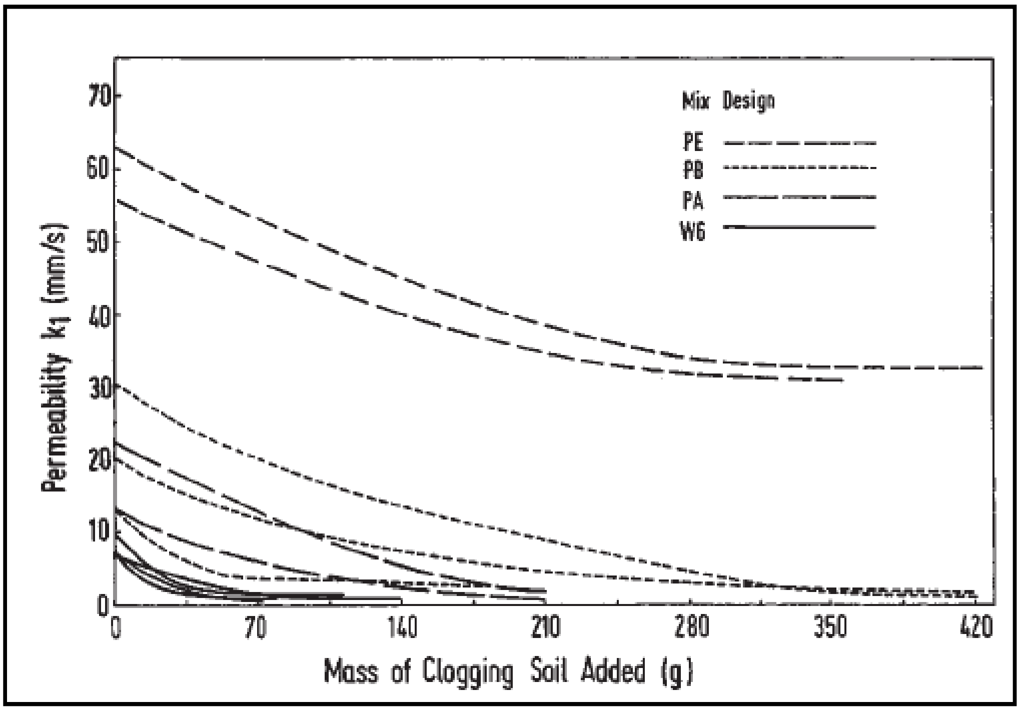

Figure 2.1: Deterioration of Coefficient of Permeability, k (Fwa et al., 1999)

The curves show the deterioration of k which can be comparable with an average of 33 mm/s of overall reduction from different initial permeability. This information can be used in design to establish the required initial permeability depending on the expected terminal value. Larger aggregate sizes are being specified by NCHRP (2000) because they create larger air voids that are less likely to clog. The pressure from traffic during rain events facilitate self-cleansing of the pavement.

According to Battiato et al. (1996), cleansing techniques by means of even a powerful cleansing machine turned out to contribute little to restore sufficient permeability conditions. An investigation was done on highways in Italy, which have been in service for more than three years. The study showed that with a 400 bar suction pressure, a restoration of only 60 % permeability values can be met compared to those measured after one month from the laying. The cleansing of air voids that exist in the pavement is only possible to a thickness of 1-2 cm from the surface of the pavement. All these assumptions have led to the development of the double draining layer pavement in Italy.

Pichon (1993) conducted a study to examine the clogging mechanism of PA. It was observed that the permeability loss of PA resulted from the densification of the particles retained on the surface of the pavement and not from the propagation of the clogging particles trapped within the pavement.

2.7 Effects of Porous Asphalt on Highway Runoff and Environment

Porous asphalt reduces splash and spray during wet weather. Spray generated by tires was assumed to wash pollutants from engine compartments and the bottoms of vehicles. It is reasonable to think that the amount of pollutants that was washed from vehicles reduces as porous asphalt reduces splash and spray (Barrett, 2008).

Legret and Colandini (1999) had reported in their study that metallic pollutants are mainly retained in the PA and that the soil underneath the structure do not show any significant contamination after an 8-year period during which the pavement has been in operation. It was also reported that the porous pavement was particularly efficient in the retention of heavy metals through the suspended solids in the PA.

2.8 Winter Conditions

A study was conducted by Backstrom and Bergstrom (2000) to investigate drainage through PA in freezing temperatures and snowmelt conditions. The laboratory experiments were performed in a climate room. The infiltration rates of porous asphalt specimens at cold temperatures were measured. The results indicated a significant decrease in infiltration rate at freezing temperatures and approaching zero at -5 °C. Periods of freezing temperatures were combined with rainfall to simulate snowmelt conditions. After a few days of these periods, a decrement of about 90 % of the initial infiltration rate was observed.

A model was developed by Shao et al. (1994) to predict the state of PA pavement surfaces. The thermal properties of PA depend on the porosity of the mixture. PA is an open structure and has high air voids. Higher porosity creates faster thermal response of asphalt to ambient air temperature. After rain events, the water is trapped in the pores of the structure and the heat from the sub-layer would have to be consumed first by evaporation of this trapped water. The air in the pores protects the mixture from heat coming from the road sub-layer ground. Therefore, the surface of the pavements reaches the freezing temperatures faster and stays below freezing longer than conventional pavements. Van de Zwan et al. (1990) also found similar result in their studies while FHWA (2005) found that porous pavements in France reached freezing temperatures about 30 minutes faster than conventional pavements.

2.9 Cleansing of Porous Asphalt

Many methods and types of cleansing machines were developed over the years for cleansing roads and porous pavements. The most common type of cleansing machines that exist today operates by spraying high-pressure water into the overlay and vacuuming out the resulting sludge. This process is referred to as “captive hydrology”. In Europe, pressure cleansing is recommended on fine-graded PA surfaces once or twice a year (Newcomb and Scofield, 2004). Bäckström and

Bergstrom (2000) recommended cleansing the PA with this high-pressure water every 2 to 4 years.

The European countries have a lot of experience with porous asphalt pavements. Therefore, a study was conducted by the Federal Highway Administration (FHWA, 2005) to learn more about the European common practices with the noise-reducing pavements. Different general and winter maintenance methods were adopted based on the policy priorities and environment conditions. Most countries schedule cleansing of the porous pavement to maintain the noise reduction property of the pavement that deteriorates due to clogging.

Porous asphalt is cleansed with high-pressure water spray (125 psi) followed by vacuuming in Denmark. The cleansing schedule is performed 3 months after construction of the pavement and semi-annually beyond that. The Danish Road Institute (DRI) experienced that if cleansing is not performed regularly, the pavement can become too clogged to be cleansed effectively. In the Netherlands, the pavements are cleansed with a captive hydrology cleansing machine annually. The Dutch had found that the drainage and noise reduction benefits were reduced immediately after cleansing because the clogging materials which was brought up to the surface of the pavement. However, these properties improve to an unknown extent after a short time. Porous pavements are not used in urban areas due to the clogging problem and questioned effectiveness of cleansing (FHWA, 2005).

A report from the Public Work Research Institute (PWRI, 2005) gives some inspight on PA cleansing machines in Japan. The first types of machines that were developed were similar to the ones in Europe. The machine had to cleanse at very low speeds (1 km/hr) and attempted to fully recover the permeability of the pavement. The machines that were later developed can run at greater speeds of 10 to 20 km/hr and are designed so that the machine can be used more frequently to maintain the function of the pavement. A machine called the “Spec-Keeper” sprays water on the pavement and creates a high pressure vicinity where the water are forced back out of the pavement with the collected particles. The water and particles are first separated before the water can be reused. The schematic diagram of the “Spec-Keeper” cleansing process is shown in Figure 2.2 and a picture of the cleansing machine is shown in Plate 2.1.

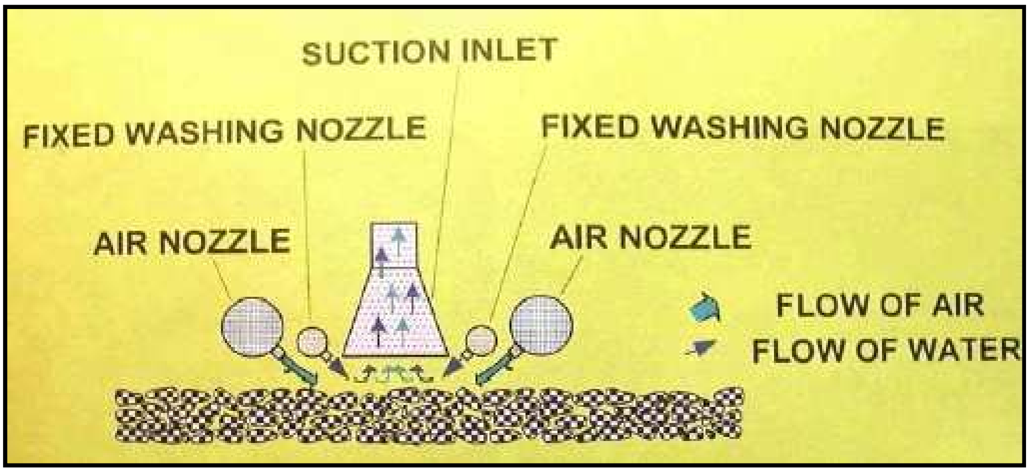

Figure 2.2: The Cleansing Process of the “Spec-Keeper” Cleansing Machine (PWRI, 2005)

Plate 2.1: The “Spec-Keeper” Cleansing Machine in Japan (PWRI, 2005)

PWRI (2005) had also described another machine that functions using a high-pressure air only to loosen the clogging particles and the particles are then vacuumed up. The machine has two air blowers attached on both sides of the pavement and a vacuum in the middle that collects dust and dirt from the pavement. This machine runs at an average speed of 20 km/hr. Frequent use of the machine suggests that cleansing should be done as often as possible to maintain the most effective function of the pavement. The picture of the machine is shown in Plate 2.2.

Plate 2.2: Cleansing Machine with High-Pressure Air (PWRI, 2005)

It was then concluded that the original slow-speed machine collected the most mass of particles per unit area compared to the other machine but it had to be used with the lowest frequency. However, the costs of cleansing were much greater. The high-pressure air and water machines were much more cost effective but had lower efficiencies.

According to Legret and Colandini (1999), a cleansing operation was carried out on roads in France with a road suction sweeper consisting of sweeping, then spraying water under pressure (120 bars) on the surface and finally sucking up the resulting sludge. The next cleansing operation followed in 1995 with a more powerful device specially designed for porous asphalt maintenance. The machine was a combination of high-pressure (400 bars) rotary spraying followed immediately by the suction of the resulting sludge. The infiltration capacity of the porous pavement was significantly improved after the cleansing operation. However, the French have found cleansing to be ineffective. Therefore, cleansing of pavements is not done in France. The mixes are designed to resist clogging and its expected service life lasts more than ten years (FHWA, 2005).

2.10 Design of Clog-Resistant Porous Asphalts

Earlier experience made by a contracting company in France has shown that when porous asphalt has been used on heavily trafficked roads, the permeability decreases to only 50 % in the first year. However, the permeability has nearly disappeared on roads with low traffic. The company has tried to develop porous asphalt which can retain the permeability for a longer period by increasing the air void to between 20 and 30 %. This had resulted in an initial permeability of 2 cm/s where the level traditionally was 1.2 cm/s (Michaut, 1997).

In Spain, recommendations are given on how to design and maintain permeability of pavements. A pavement is proposed to be designed with an air void content between 25 and 28 %. Cleansing of pavements must be done once a year, and in Spain it is recommended to do this just after the rainy season. Within a year after paving, the cleansing procedure must be started (Raz, 1997).

Experiences in the UK has described conflicts that meets the engineer concerning designing a porous pavement. They have to ensure a long lifetime porous pavement with the needed permeability. This means, the thick binder film must not drain from the surface of the aggregates during storage and transport. To secure the permeability of asphalt, the air void content should be greater than 20 %. The shape of aggregate should be cubic and the size should be greater than 11 mm. The traffic speed must not be low. No unpaved roads must lead the traffic up on porous asphalt. Surface of emergency lane on motorways should be sealed and the road must be cleansed. The observation has resulted in less clogging on areas which are trafficked than on areas which are less trafficked (Colwill et al., 1993).

2.11 Development of Two-Layer Porous Asphalt

According to Abbot and Nelson (1989) and Horak et al. (1994), road related noise has increasingly been identified as a major environmental pollution aspect which needs new and innovative measures to attenuate and control. A number of new environmental laws have been passed in the United Kingdom with the specific purpose of “putting people first”. Some of these regulations had stiffened to the extent that when a new road is built or substantially modified (addition of extra lane or carriageway), then it is mandatory for the highway authority to provide sound insulation treatment to the owner of the property whose traffic levels exceed 68 dBA. Immediate and corrective measures need to be taken to protect the environment and most importantly the people especially with the significant increase in traffic densities. The significant increase in traffic densities especially in urban areas are expected to increase noise pollution as well. Noise interferes with work, sleep, and recreation. High intensity noise may have cumulative effect on the human hearing mechanism causing temporary or permanent deafness. This makes the development of a low noise pavement imperative.

The Dutch experience with double layer PA was presented to the 1st Euroasphalt and Eurobitumen Congress held in Strasbourg (Van Bochove, 1996). In the Netherlands, double layer porous PA is termed as Twinlay while the Italians named it Double

Draining Layer (Battiato et. al., 1996). The double layer asphalt consists of two different mix gradations. The top layer consists of a finer thin porous mix while the bottom layer consists of a much coarser but thicker porous base layer mix. Kandhal (2004) defined the bottom layer aggregates ranging from 16 to 22 mm, while the upper layer ranges from 5 to 8 mm. This configuration helps to prevent the pavement from clogging during its service life. The top finer layer prevents dirt from entering the bottom layer, while the bottom layer, which has larger pores, reduces chances to trap dirt or pollutants. Therefore, only the top layer gets clogged and the dirt is easily removed by existing field cleansing techniques which involves vacuuming of the dirt (Van Bochove, 1996). This type of pavement offers solutions to the premature failures of the functional performance of PA (Kandhal, 2004).

According to Van Bochove (1996), ‘Twinlay’ PA offers the following advantages as compared to conventional asphalt mixes. The fine top layer offers acoustic advantage through the fine surface texture to reduce tire noise. The coarse bottom layer also provides the damping of sound in combination with the fine top layer. The top layer prevents coarse dirt and temporary store a large amount of dirt from entering into the structure. The dirt that is absorbed at the top of the thin top layer can be removed with less effort with existing cleansing techniques. The difference in flow resistance between the top and bottom layer has a positive effects on the self-cleansing of the pavement caused by traffic. The bottom layer has a higher discharge capacity compared to conventional porous asphalt through which the sideways discharge of water is considerably improved.