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THERMAL CHARACTERISTICS OF EXPERIMENTAL POROUS PAVERS

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Graphical abstract

Abstract

Pavement covers quite high percentage of the urban fabric and contributes highly to the development of heat island. This research studies the usage of aggregates and epoxy binder (cement free binder) as the major materials for pervious pavements. Eight samples were produced using different sizes of aggregates by mixing with non-cement epoxy binder pervious pavements. The samples were then tested with thermal performance and infiltration test. The study indicated that the higher void structure in the pavers will cause faster infiltration but contributing to the higher thermal performance. However, the higher surface temperature is expected to promote more evaporation and consequently reduce the overall pavement and surrounding temperature.

Keywords: Pervious pavement, porous pavers, thermal characteristics

Abstrak

Dataran kejat diketahui meliputi kawasan perbandaran dalam peratusan yang agak tinggi. Hal ini menyumbang kepada tahap kesan pulau haba dalam bandar. Kajian ini telah menghasilkan blok turapan berliang yang dibina tanpa simen. Sebanyak lapan specimen telah dihasilkan menggunakan saiz batu baur yang berlainan. Sampel kemudiannya di kaji dan diuji ciri ciri haba dan salirannya. Keputusan kajian menunjukkan bahawa jumlah liang yang lebih tinggi menyebabkan kesan saliran yang lebih laju tetapi menyebabkan kesan suhu yang lebih tinggi. Walaupun begitu, suhu atau haba yang lebih tinggi di permukaan akan membantu lebih banyak penyejatan berlaku dan seterusnya mengurangkan haba secara keseluruhan untuk kawasan berkenaan.

Kata kunci: Dataran berliang, blok penurap berliang, ciri ciri haba

1.0 INTRODUCTION

In this recent decade, urbanization has brought negative effect to the environment. Majority of the area of pervious green area in the developing countries have been converted to the impervious area. More impervious road and roof surfaces have appeared, thus resulting in the increasing temperature in the urban area.

The need for pervious pavements has also grown, and nowadays the proper use of pervious concrete is among the recommended Best Management Practice (BMPs) of the US Environmental Protection Agency (EPA) in the United States [1]. Pervious pavements will helps in protecting the natural systems, improve the water quality, reducing the runoff volume and peak flow rates, integrated the storm water treatment in the landscape and add in to the sustainability of footpaths while help in minimizing the development costs.

Definition of permeable pavement by according to Wisconsin Department of Natural Resources Conservation Practise Standard (WIDNR) USA [2] is a pavement system that being designed to achieve water quality and quantity benefits by allowing the movement of storm water through the pavement surface and into a base or sub-base reservoir - including pervious concrete, porous asphalt and permeable paver/blocks.

Pervious paving systems are divided into three general types. Each type depends primarily upon the nature of the pervious paving surface course and the presence or absence of a runoff storage bed beneath the surface course. The types of pervious paving system that have been classified into three different types are including porous paving, permeable pavers with storage bed and permeable pavers without storage bed. Porous paving and permeable paver with storage bed systems treat the storm water quality design storm runoff through storage and infiltration.

While, in the other hand, heat island is refers to the development of higher urban temperature of an urban area compared to the temperatures of surrounding suburban and rural areas. This phenomenon is related to the positive thermal balance created in the urban environment because of the increased heat gains like the high absorption of solar radiation and the anthropogenic heat, and the decreased thermal losses [3]. It has an important impact on the energy consumption of buildings and increases their energy consumption for the cooling purposes. Various studies that been conducted all over the world have shown that the cooling energy consumption of buildings may be double because of the important increase of urban temperatures [4-5].

The role of pavements on the development of urban heat island is very important. Pavements cover a quite high percentage of the urban fabric and contribute highly to the development of heat island. Recent studies have shown that paving surfaces play a very determinant role on the overall urban thermal balance.

Numerous studies have been done in other country all over the world on the application of the permeable pavements. Most of the researches are focus on the properties of the permeable cement concrete pavements. The studies conducted are done on the innovative design materials based on the requirements within the aspect of economical, use, strength and recyclability. However, there is still less study and researches found on the properties and requirement for cement free permeable pavement. Based on the previous study [6] conducted on the preparing cement free pervious paver by using waste crushed concrete recycled aggregates, this project is basically continuing the study with the cement free binder, but with a different design and different focus which are to achieve a sustainable cooling permeable pavement and higher infiltration rate. The purpose of this study is to look for the thermal and hydraulic characteristics of the porous pavers.

2.0 OVERVIEW ON POROUS PAVERS

Pervious paving systems are paved areas that produce less storm water runoff than the areas paved with conventional paving. The reduction of runoff is achieved primarily through the infiltration of a greater portion of the rain falling on the area than would occur with conventional paving. This causes increased infiltration that occurs either through the paving material itself or through void spaces between the individual paving blocks which also known as pavers [7].

A pervious pavement structure are includes a surface layer, a base and a sub-base which to allow a storm water to percolate into the sub-grade or to divert into the storm water drainage while retaining pollutants on the paver surface. Depending on the purpose of the pervious pavement and the sub-grade soil conditions, a geotextile will be placed between the sub-base layer and the sub-grade soil to avoid pollutants percolating into the groundwater [8].

Pervious pavements are classified based on the surface layout and the surface layer materials. Porous pavements and permeable pavements can be regarded as two different entities [9]. Porous pavements are a thick porous layer with a strong infiltration capacity. It contains a grass or gravel surface with a well compacted graded sand and gravel base. On the other hand, permeable pavement surfaces are normally constructed by impervious paver concrete blocks with infiltration voids between the blocks. Infiltration capacities of permeable pavements are high due to the coarse aggregate between concrete blocks. Whilst many of the principles obtained from the studies have a significant difference between porous and permeable pavements, the main function of it is still the same.

Permeable pavements are regarded in the recent years, as an effective tool in managing storm water. When compared to the conventional pavement systems such as impervious asphalt, permeable pavements can help in reducing the runoff quantity, lower the peak runoff rates, and delay the peak flows due to their high surface infiltration rates [10]. Even in the locations, where the underlying soil is not ideal for a complete infiltration, the installation of under drain pipes in the permeable pavement base has yielded the reductions in outflow volume and peak flow rate, and help in delayed the time to peak flow [11].

Storm water infiltrations using pervious pavements have been investigated by researchers as a method of managing storm water. Previous research on pervious pavements have included the configuration of pavement system structures, types of paver surfaces, sub-layer material selection, construction criteria, hydraulic performance of pavements and examines pollutant removal potential. Improvement to runoff quality and reduction in peak surface runoff are two major requirements of civil engineers when designing urban drainage systems [12]

Originally permeable paving systems were seen as a means of flood mitigation and control in Europe. This concept and principle remains a powerful argument for using permeable paving system in highly urbanised societies such as Australia where urban consolidation is placing increases demands on existing and often barely adequate stormwater infrastructure. The uptake of permeable paving has been a reaction to regulations for achieving sustainability and managing the environment. In reference, the UK concept of Sustainable Drainage Systems (SUDs) is equivalent with Australian, Water Sensitive Urban Design (WSUD). Both of the regulations are aim to manage stormwater and pollution at either the site level or on a regional basis [13-14].While, in the USA, the Environmental Protection Agency (USEPA) main priority is on controlling stormwater pollution. They have specifying Best Management Practices (BMP) for stormwater runoff management. Permeable paving are also included in the structural BMPs approved by the USEPA [15]. Permeable paving offers significant benefits compared to conventional pavements in terms of sustainability, environmental impact and project cost.

Numerous laboratory and in-situ tests [16-18] have carried out studies to assess the characteristics and requirement of pervious pavements including configuration of the pavement structure and design, hydraulic performance, pollutant retention efficiency and loading strength.

A study carried out by Dreelin *et al*. [19] is regarding the efficiency of porous pavements in controlling stormwater runoff on clay soils. This study compared the performance of an asphalt parking lot and a porous pavement parking lot of grass pavers in Athens, Georgia, USA over relatively small and low-intensity rain events. The porous pavement used are consists of a plastic matrix filled with sand and planted with grass over a base of open-graded gravel. Both of the parking lots were similar in age, size, slope and use. By using USEPA standard protocols for stormwater BMPs [20] the results indicate that the porous pavement parking lot produced almost 93% less surface runoff than the asphalt parking lot.

The high porosity of the concrete leads to good infiltration and air exchange rates. Filtered out pollutants can sometimes be removed by cleaning of the pavement [21]. Porous asphalt and porous concrete pavement systems are prone to clogging usually within three years after installation. Due to clogging of the voids, these systems can experience a loss of porosity.

Yong *et al*. [22] conducted a study on to understand the main physical processes that govern physical clogging and develop a simple innovative black-box model that could be use to predict physical clogging. The researchers' use three common porous pavement types; monolithic porous asphalt, modular Hydrapave and monolithic Permapave as a study materials. After some time, Permapave did not clog even after 26 years of operation in simulated sub-tropical Brisbane (Australia) climate while porous asphalt and Hydrapave clogged after just 12 years, from surface clogging and geotextile clogging, respectively. Each systems was then tested again by using two different dosing patterns, which are continual wetting with no dry periods and variable inflow rates with drying periods. The results obtained from the latter dosing method approximately doubled the lifespan of all systems suggesting the influence of climate conditions on clogging. Clogging was found to be highly correlated with cumulative volume and flow rate. In addition, pavement design was also determined to hold an important role in clogging.

3.0 METHODOLOGY

3.1 Materials

In this study, aggregates are used as the main component in the pervious paver. The aggregates were obtained from local rock quary. The aggregate were gathered to be sieve into several groups of 5mm to 10mm sizes. Table 1 and Figure 1 and 2 describe the size of the sieve that the aggregate passed through and retained on as well as the dimensional characteristics of the aggregates.

Table 1 Size of the sieve that the aggregate passed through and retained on

Size of sieve (passes through)	Size of sieve (retained on)
12mm	10mm
10mm	5mm

Figure 1 5mm aggregate

Figure 2 10mm aggregate

3.2 Epoxy Binder

Epoxy was used as the binder in this study. It is made up from mixing two parts which are Part A and Part B.

Part A is epoxy resin while Part B is hardener. It is also known as two part liquid epoxy thermo setting resin system. Both epoxy and hardener are in a liquid form and have a transparent colour. Both of these liquid are group under synthetic resin and plastics. Manufactured by Oriental Option Sdn Bhd, the code number of epoxy resin is CP370A A, while the code number for hardener is CP370A B. The mixing ration of epoxy resin to hardener is 2 to 1 by weight. Figure 3 and 4 below shows Part A and Part B of epoxy binder.

Figure 3 Part A (Resin)

Figure 4 Part B (Hardener)

3.3 Mix Proportion

Based on the previous study [6], no bleeding was formed at the bottom of the samples of 5% by weight, while other samples with 8% and 10% a thick layer of bleeding formed at the bottom which could causing the water from passing through the samples. Thus, for this study volume of epoxy binder required to be used is 5% and the weight of aggregate have been fix by 5000g based on mix design table shown in Table 2.

Table 2 The Total Mix Proportions by Weight of the Epoxy Binder

weight of aggregate (g)	5%	epoxy binder	
		hardener	epoxy
		1	2
500	25	9	16
1000	50	18	32
2000	100	35	65
3000	150	53	97
4000	200	71	129
5000	250	89	161
6000	300	106	194
7000	350	124	226
8000	400	142	258
9000	450	160	290
10000	500	177	323

3.4 Experimental Setup

There are a total of 8 specimens. The epoxy binder used is 5% by weight. The sizes of aggregate used are from 5mm group for six specimens and from 10mm group for two specimens. All of the specimens were casted in the 300 x 300 x 30mm mould. All the mixing was load compacted. The aggregate and epoxy binder were mixed by hand and compacted by using a 10kg load. Each of the samples is left for 1 day at room temperature before being demoulded. Four specimens were tested with the thermal performance by placing them near two types of surrounding i.e. grass field and asphalt pavement as shown in Figure 5 and 6. Both of the surfaces are tested for 8 hours (8.00am to 5.00pm) by the specimens with the sizes of 5mm and 10mm each. Another four specimens were used for hydraulic testing as shown below in Figure 7 and 8 but will not be discussed in this paper.

Figure 5 Paver on grass field

Figure 6 Paver on asphalt pavement

Figure 7 Porous pavers

Figure 8 Double ring infiltrometer

4.0 RESULTS AND DISCUSSION

Result tabulated in Table 3 shows the average temperature with the time of the specimens by the aggregate sizes 5mm and 10mm that being placed on the grass surface. It can be found that, for the specimen with aggregate size of 5mm, the lowest temperature it can reached on the surface of grass is 32.64C which occur during early morning. While, the highest temperature is during afternoon when the sun is right above the head with the reading 55.66C.
As for the result on the specimen with aggregate size of 10mm has the highest temperature during the

peak hour at 1.00 pm with 59.32C. While, the lowest temperature 38.12C which also happen to be in the early morning.

It was clearly shown that specimen with aggregate of larger size has a higher temperature as compared to the specimen with a smaller size of aggregate. This is due to the larger surface area that being exposed to the sun and produces more heat than the smaller surface area.

Table 3 Porous paver on grass

	Temperature, Celcius	
TIME	**5 MM**	**10MM**
8:00 AM	35.82	40.34
9:00 AM	40.14	44.92
10:00 AM	44.98	48.42
11:00 AM	48.34	51.4
12:00 PM	54.66	56.8
1:00 PM	60.04	60.14
2:00 PM	53	53.38
3:00 PM	47.64	50.04
4:00 PM	44.26	44.06
5:00 PM	37.32	40.02

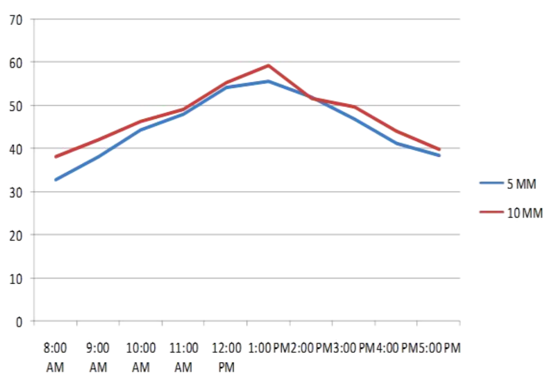

Figure 9 Temperature and time for paver on grass

Result tabulated in Table 4 shows the temperature with the time of the specimens by the aggregate sizes 5mm and 10mm that being placed on the asphalt surface. It can be found that, for the specimen with aggregate size of 10mm, the lowest temperature it can reached on the surface of asphalt is 40.02C which occur during the late evening. While, the highest temperature is during afternoon when the sun is right above the head with the reading 60.14C.

As for the result on the specimen with aggregate size of 5mm has the highest temperature during the peak hour at 1.00 pm with 60.04C. While, the lowest temperature is 35.82C which also happen to be in the early morning. Figure 2 shown that the specimen with aggregate of larger size has a higher temperature as compared to the specimen with a smaller size of aggregate.

Table 4 Paver on asphalt

	Temperature, Celcius	
TIME	**5 MM**	**10MM**
8:00 AM	32.64	38.12
9:00 AM	38.08	42.12
10:00 AM	44.24	46.36
11:00 AM	47.96	49.22
12:00 PM	54.38	55.46
1:00 PM	55.66	59.32
2:00 PM	52.04	51.66
3:00 PM	46.84	49.68
4:00 PM	41.1	43.94
5:00 PM	38.34	39.68

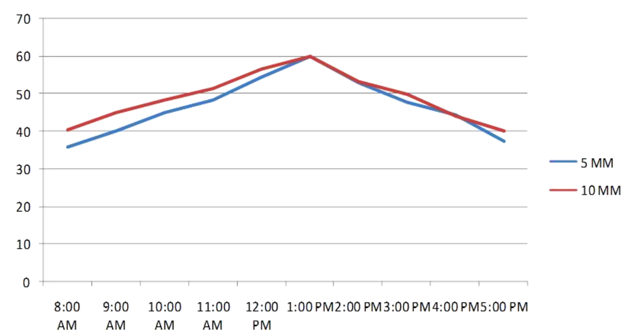

Figure 10 Temperature and time for paver on asphalt

Table 5 shows the comparison of asphalt and grass surface with the temperature for specimen with 5mm size of aggregate. On the surface of grass, the specimen has highest temperature with 55.66C and lowest temperature is 32.64C.

While, the specimen on the asphalt surface lowest temperature is 34.82C and the highest temperature is 60.04C. As shown in Figure 3, in overall, the temperature on the surface of asphalt is higher as compared to the temperature on the surface of grass.

Table 6 shows the result for the specimen with the size of 10mm aggregate on the two surfaces which are grass and asphalt. The overall temperature reading is quite high for both surfaces, only on the surface of grass the reading drop to about 30C. The highest reading for the surface of grass is 59.32C and the lowest reading is 38.12.

As for asphalt surface's, the lowest reading is 40.02C which occur during late afternoon. And highest reading is 60.14C on the afternoon at 1.00PM.

Table 5 Paver grade 5mm in different environment

TIME	SAMPLE ON GRASS – 5MM	SAMPLE ON ASPHALT – 5MM
8:00 AM	32.64	34.82
9:00 AM	38.08	40.14
10:00 AM	44.24	44.98
11:00 AM	47.96	48.34
12:00 PM	54.38	54.66
1:00 PM	55.66	60.04
2:00 PM	52.04	53
3:00 PM	46.84	47.64
4:00 PM	41.1	44.26
5:00 PM	38.34	37.32

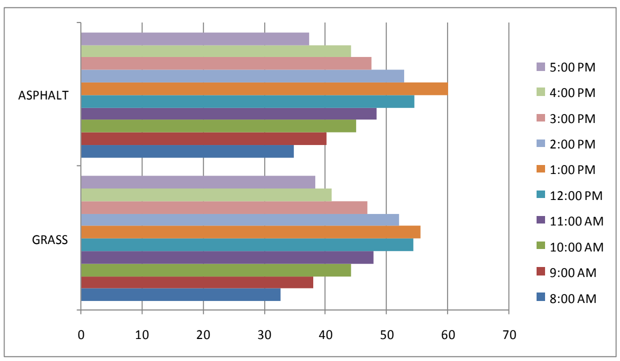

Figure 11 Surrounding effect on temperature characteristics of grade 5mm paver

Table 6 Paver grade 10mm in different environment

TIME	SAMPLE ON GRASS – 10MM	SAMPLE ON ASPHALT-10MM
8:00 AM	38.12	40.34
9:00 AM	42.12	44.92
10:00 AM	46.36	48.42
11:00 AM	49.22	51.4
12:00 PM	55.46	56.8
1:00 PM	59.32	60.14
2:00 PM	51.66	53.38
3:00 PM	49.68	50.04
4:00 PM	43.94	44.06
5:00 PM	39.68	40.02

The natural or existing ground service in the form of grass or pavement indicated that its temperatures are increasing from the early morning to the afternoon, where the weather are most hottest of the day and the reading started to decrease from 2.00 PM to the late evening where the sun will set down. The highest reading for the asphalt temperature is 58.18C while, the lowest reading is 33.62C. The highest reading for the grass temperature is 43.62C while, the lowest reading is 24.62C.

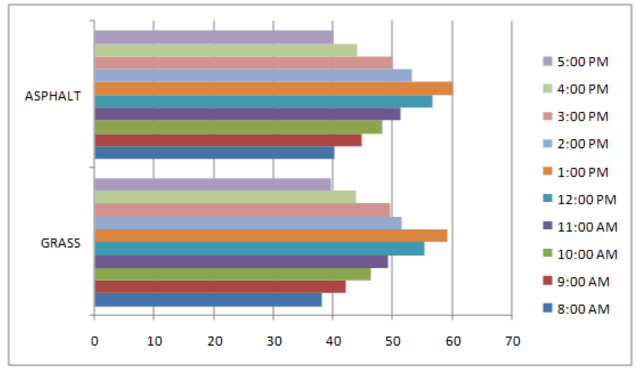

Figure 12 Surrounding effect on temperature characteristics of grade 10mm paver

The overall results that obtained from this study indicated that the existing surfaces affect the porous paver differently. It is identified that both on the surface of grass and the surface of asphalt, specimen with the size of aggregate 10mm have a higher temperature reading compared to the specimen with the smaller size aggregate of 5mm. This is probably due to the greater surface of the aggregate that being exposed to the sun. As permeable pavements, water passes through to the pavers through the void/pores. It evaporates when the temperature of the material increases, contributing towards a lower pavement surface temperature. Previous studies have shown that dry permeable pavements present a higher surface temperature than the non-permeable equivalents. Thus, the specimen with a higher void and a higher temperature which are specimen with size of aggregate 10mm are more suitable to use to improve the thermal performance of pavements in achieving sustainable environments.

The surrounding surfaces itself which are grass and asphalt have their own temperature but, when the specimens are placed on both of the surfaces, the specimen will absorb the temperature from those surfaces and give another reading which are more higher than the surface itself. This is due to the thermal conductivity and thermal capacitance that are affecting the thermal performance of the pavements. The increased thermal conductivity of paving surfaces, contributes to the transfer of the heat faster from the pavements to the ground and vice versa. During the daytime, the temperature of the pavements is higher than the temperature of the ground is causes by heat transferred to it, while during the night time the adverse flow is observed. Therefore, placing the specimen in the lower surrounding temperature is more acceptable. Placing it to the surrounding surface with higher temperature will cause the overall surrounding temperature to increase faster.

5.0 CONCLUSION

In conclusion, the ability of epoxy binder to bind aggregates together to be used as main material in pervious pavement is successful. Pervious pavements using mix proportions with 5% of epoxy binder by weight are suitable with no bleeding layer is formed. The pavers with 10mm size of aggregate shows higher surface temperature than the smaller 5mm aggregates. The higher surface temperature will help water to evaporates and reduce the overall pavement surface temperature.

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