PERFORMANCE OF POROUS CONCRETE BLOCK WITH DIFFERENT SIZE OF COARSE AGGREGATE FOR PAVEMENT

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DEDICATION

Dedicated to my beloved father and mother,

Hj. Abd Halim Bin Hj. Shafie and Hajah Rohani Hj. Che Mat Noor,

my husband and son,

Muhammad Fadil Bin Sulaiman and Muhammad Uwais Al Qarni,

my sister and all my brothers

(Faridhatul Azna, Alfian Hady, Amir Al Mubarak and Hafiz Al Asad),

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ABSTRACT

Nowadays, concrete paving block (CPB) surfacing has become the preferred type of road in urban and residential areas due to its durability and aesthetical value. However, CPB has some disadvantages such as water ponding on the road surface and the generation of noise when vehicle tyre and road surface are in contact. In this study, porous concrete paving blocks (PCPB) has been developed to improve the functional performance of conventional concrete paving block (CPB) in skid resistance, permeability and sound absorption. There were two major phases in developing PCPB in this study. In Phase I, the material properties and characterization were determined through the physical test. Three different sizes of coarse aggregate were used in this study; passing 10 mm retains 5 mm sieve (5 – 10), passing 8 mm retains 5 mm sieve (5 – 8) and passing 10 mm retains 8 mm sieve (8 – 10). Open graded coarse aggregate has been used to allow voids to form inside the PCPB specimens. Phase I was continued with determining the physical, mechanical, microstructure and performance properties of CPB and PCPB. PCPB has been developed from the same CPB design mixture with three different sizes of coarse aggregate with no fine aggregate. All specimens were tested for density, porosity, water absorption, weight loss, compressive, tensile splitting, skid resistance, sound absorption and permeability. In addition, the relationships among these parameters were established. It was found that the single size of coarse aggregate had a slight effect on the strength of the specimens but increased the performance in skid resistance, sound absorption and permeability. However, all the PCPB specimens still achieve the minimum requirements with the porosity more than 15 % and compressive strength above 20 MPa for the individual block. Phase II focused on the functional performance of PCPB in permeability and sound absorption with presence of clogging agent. The specimens have been clogged with 1.0 g/l of road dust for 5 cycles and each cycle was tested. Results gained from the laboratory test show an excellent performance of PCPB (5 – 8) specimens in permeability and sound absorption from virgin stage until after 5 cycles of clogging. The acoustic parameter of specimens showed that PCPB has one peak of the sound absorption coefficient located at low frequency in the range of 500 to 700 Hz and this indicates that PCPB was suitable to be applied as traffic noise mitigation medium especially for low speed traffic. It can be said that PCPB can help in reducing the water ponding, improve driving safety and lowering the traffic noise impact to the surroundings.

ABSTRAK

Pada masa kini, permukaan turapan blok konkrit telah menjadi pilihan untuk jalan raya di kawasan bandar dan perumahan kerana ketahanan dan nilai estetikanya. Namun, turapan blok konkrit mempunyai beberapa kelemahan seperti takungan air dipermukaan jalan dan penghasilan bunyi bising apabila tayar kenderaan dan permukaan jalan bersentuhan. Dalam kajian ini, turapan permukaan blok konkrit berliang telah dibangunkan untuk meningkatkan prestasi turapan blok konkrit konvensional dalam rintangan geseran, kebolehtelapan dan penyerapan bunyi. Terdapat dua fasa utama dalam membangunkan turapan blok konkrit berliang dalam kajian ini. Dalam Fasa I, sifat bahan dan pencirian ditentukan melalui ujian fizikal. Tiga saiz batu kasar yang berbeza digunakan dalam kajian ini; melepasi 10 mm tertahan di 5 mm pengayak (5 – 10), melepasi 8 mm tertahan di 5 mm pengayak (5 – 8) dan melepasi 10 mm tertahan di 8 mm pengayak (8 – 10). Batu kasar gred terbuka telah digunakan untuk membenarkan ruang udara terbentuk di dalam spesimen turapan blok konkrit berliang. Fasa I diteruskan dengan menentukan sifat fizikal, mekanikal, mikrostruktur dan prestasi turapan blok konkrit dan turapan blok konkrit berliang. Turapan blok konkrit berliang telah dihasilkan daripada campuran reka bentuk turapan blok konkrit yang sama dengan tiga saiz batu kasar yang berbeza tanpa batu halus. Semua spesimen telah diuji dengan ujian ketumpatan, keliangan, penyerapan air, pengurangan berat, kekuatan mampatan, pembelahan tegangan, rintangan geseran, penyerapan bunyi dan kebolehtelapan air. Disamping itu, hubungan antara parameter ini telah dihasilkan. Didapati bahawa saiz tunggal batu kasar memberi sedikit kesan ke atas kekuatan spesimen tetapi meningkatkan prestasi dalam rintangan geseran, penyerapan bunyi dan kebolehtelapan air. Walau bagaimanapun, semua spesimen turapan blok konkrit berliang masih mencapai syarat minimum dengan keliangan lebih daripada 15 % dan kekuatan mampatan melebihi 20 MPa untuk blok individu. Fasa II memberi tumpuan kepada prestasi fungsi turapan blok konkrit berliang dalam kebolehtelapan air dan penyerapan bunyi dengan kehadiran agen penyumbat. Spesimen telah disumbat dengan 1.0 g/l habuk jalan untuk 5 kitaran dan setiap kitaran telah diuji. Keputusan yang diperolehi daripada ujian makmal menunjukkan prestasi yang cemerlang bagi spesimen turapan blok konkrit berliang (5 – 8) dalam kebolehtelapan air dan penyerapan bunyi dari peringkat awal sehingga selepas 5 kitaran penyumbatan. Parameter akustik spesimen menunjukkan bahawa turapan blok konkrit berliang mempunyai satu puncak pekali serapan bunyi yang terletak pada frekuensi rendah dalam julat 500 hingga 700 Hz dan ini menunjukkan bahawa turapan blok konkrit berliang sesuai digunakan sebagai medium pengurangan bunyi trafik terutamanya untuk trafik berkelajuan rendah. Ianya boleh dikatakan bahawa turapan blok konkrit berliang boleh membantu dalam mengurangkan air bertakung, meningkatkan keselamatan pemanduan dan mengurangkan kesan bunyi lalu lintas kepada persekitaran.

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LIST OF ABBREVIATIONS

AIV	-	Aggregate Impact Value
Al	-	Aluminium
ASTM	-	American Society for Testing and Materials
BPN	-	British Pendulum Number
BPT	-	British Pendulum Tester
BRE	-	British Research Establishment
BS EN	-	British European Standard
C	-	Carbon
Ca	-	Calcium
CGP	-	Concrete Grid Pavers
Cl	-	Chlorine
CMA	-	Concrete Manufacturers Association
CMAA	-	Concrete Masonry Association of Australia
CPB	-	Concrete Paving Block
C-S-H	-	Calcium Silicate Hydrate
EDX	-	Energy-Dispersive X-ray
EI	-	Elongation Index
FESEM	-	Field Emission Scanning Electron Microscopy
FI	-	Flakiness Index
JKR	-	Jabatan Kerja Raya
K	-	Potassium
Mg	-	Magnesium
MHA	-	Malaysian Highway Authority
MMD	-	Malaysian Meteorological Department
Na	-	Sodium
NCAT		National Center for Asphalt Technology
OD	-	Oven-Dry
OPC	-	Ordinary Portland Cement
P	-	Porosity
PCPB	-	Porous Concrete Paving Block

PICP	-	Permeable Interlocking Concrete Pavers
S	-	Sulphur
SAC	-	Sound Absorption Coefficient
SEM	-	Scanning Electron Microscopy
SG	-	Specific Gravity
Si	-	Silicon
SO_4	-	Sulphate
SSD	-	Saturated Surface-Dry
Ti	-	Titanium
UTHM	-	Universiti Tun Hussien Onn
UTM	-	Universiti Teknologi Malaysia
w/c	-	Water-Cement
WA	-	Water Absorption
WL	-	Weight Loss
XRF	-	X-ray Fluorescence
Zn	-	Zinc

LIST OF SYMBOLS

α	-	Sound absorption coefficient
α_{opt}	-	Optimum sound absorption coefficient
α_{600}	-	Sound absorption coefficient at 600 Hz frequency
α_{1000}	-	Sound absorption coefficient at 1000 Hz frequency
f	-	Frequency
k	-	Permeability coefficient
ρ	-	Density
kPa	-	Kilopascal
MPa	-	Mega pascal
R^2	-	Coefficient of determination
^oC	-	Degree Celsius
$\pm$	-	Plus minus
σ_c	-	Compressive strength
σ_T	-	Tensile splitting strength
C	-	Clogging cycles

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Roads are important in contributing to economic growth and social benefits. By providing access from the suburbs to urban areas, social facilities, health and educational services, the road network has become very important in daily life. The climate features of Malaysia, which include uniformity in temperature, high humidity and copious rainfall in monsoon season with average rainfall between 65 mm to 225 mm affects the environment such as increased water ponding on the road surface, increased surface runoff and increased risk of flooding (Malaysian Meteorological Department, 2019; Jabatan Pengairan dan Saliran, 2018 and Jabatan Pengairan dan Saliran, 2020). On the other hand, Malaysia has undergone tremendous change in development in many areas, including in the automobile industry. Substantial increase in production of automobiles has led to an increase in the use of vehicles on the road. Due to this issue, the demand for producing low noise pavements has increased. In urban areas, a higher noise reduction pavement is a main requirement in the society, as traffic noise is believed to be the biggest cause of disturbance in those areas.

Nowadays, Concrete Block Pavement has widely been applied as part from the main roads, for example at the roundabout, traffic lights and as main road in main city in sub urban area such as Kuala Kubu Baharu, compared to previous application of this type of pavement applied only as pedestrian path and parking area. Concrete Block Pavement has been known as one of the alternatives to reduce vehicle speed; it is due to the vehicle tending to vibrate because of interaction between vehicle tyre and uneven surface. However, physical conditions of conventional concrete paving block (CPB) are not adequate especially during raining season. The impermeable

surface and structure of CPB to rainwater lead to water ponding on the road surface, causing water splash and vehicle hydroplaning due to vehicles hitting the accumulated water on the road and damaging the paving. Water splash and vehicle hydroplaning are well known as one of the factors causing vehicle accidents during rainy season. In this case, permeable or Porous Concrete Paving Block (PCPB) has been utilized as a potential tool to manage surface runoff. Previous researchers have investigated the engineering properties of Conventional Concrete Paving Block (CPB), resulting in numerous findings and producing effective pavement practice guidelines. It has been traditionally proved that CPB provides durable road surfaces and can perform as permeable pavement (infiltrate between the blocks gap). However, conventional CPB produce noise due to tyre/road interaction and this causes noise disturbance to the surrounding. Due to filling the limitation of conventional CPB, CPB began to evolve in response to demand for a high permeability and low-noise concrete block for pavement.

Further development of a high permeability and low-noise porous concrete for pavement has led to the introduction of Porous Concrete Paving Block (PCPB). It is widely used for low-speed road and a variety of applications such as car park area, sidewalks, residential areas, around building, cycling track and footpath. PCPB contains little or no fine aggregate to allow voids inside the block structure. PCPB is a special type of concrete characterized by an interconnected pore structure, high void content and porosity typically in range 15 % to 25 % by volume (Tennis *et al.*, 2004; Li, 2015 and Buyung *et al.*, 2021). Previous finding show the range of infiltration rates of porous paver blocks is between 0.153 cm/s to 2.8 cm/s (Park *et al.*, 2020; Lee *et al.*, 2011 and Buyung *et al.*, 2021). On the other hand, Tanahashi (2000) found that sound level of porous concrete block is similar to the ordinary asphalt pavement. However, concerns remain about the long term functional performance of PCPB due to clogging phenomenon. It is well known that PCPB can easily become clogged by sediment and dust from water runoff that might reduce its high permeability and sound absorption ability. Therefore, this study investigated the engineering properties and functional performance properties of PCPB in term of permeability and acoustic performance subjected to clogging issue. It is important in this development process so that the finding from the PCPB can lead to the

development of a high permeability and low-noise for future application for interlocking concrete block pavement.

1.2 Problem Statement

Conventional Concrete Paving Block (CPB) with flat surface and impermeable structure has caused low in skid resistance between vehicle tyre and the road surfaces especially when driving in the rain. Furthermore, interaction between vehicle tyre and dry road surfaces produce noise that cause discomfort to the driver. The traffic noise generated from tyre/road interaction, including the combination if all possible sources of noise on a vehicle; are one of the unwanted sounds that disturb the surrounding. According to Guski *et al*. (2016), people get annoyed about three times higher when attributed to noise pollution and environmental stressor among society. Coupled with the global climate changes have led lead to increased water ponding and water splash on the road surface and also flash flood.

However, PCPB is struggling with short service life due to clogging issues. According to previous study, the monolithic structure is more prone to clogging compared to modular structure (Ferguson, 2005 and Yong *et al.*, 2013). Monolithic structures consists of bond granular material such as concrete with the fine particles removed, while modular structures are constructed from individual paver with a gap between each paver (Ferguson, 2005). Although the structural performances of PCPB remain in good condition after few years in service, but the functional performance has sometimes reached its limits and has become dysfunctional. Clogging phenomenon does not only affect the permeability, but also the acoustic properties of the road surface. Therefore, the clogging issue is a great concern among researchers as clogged PCPB reduces the interconnected air voids and thus limits the water flow and sound absorption through the internal structure. Numerous researches have been performed to evaluate the functional performance of porous concrete paving block such as permeability and sound absorption. However, not much emphasis has been done previously on the no-fine concrete unit paver with the single size of coarse aggregate in correlating these properties with functional performance

under the repeated clogging problem. In this regard, the durability, skid resistance, porosity, permeability, sound absorption and effects of repeated clogging were investigated in this research.

1.3 Aim and Objectives

The main aim of this research is to improve the functional performance of conventional CPB by developing PCPB. This research was carried out and designed based on three main objectives. The detailed objectives as follows:

i. To investigate the physical, mechanical and performance properties of CPB and PCPB made with different sizes of coarse aggregate.
ii. To analyze the morphology and microstructure characteristics of hardened PCPB mixture.
iii. To evaluate the effects of clogging on the functional performance of PCPB in terms of permeability and sound absorption.

1.4 Scope of Study

In this research, developments of CPB and PCPB are mainly concentrating on experimental works in a laboratory. The selected material used and experimental works specifications refer to Concrete Masonry Association of Australia (CMA), British European Standard (BS EN), American Society for Testing and Materials (ASTM) and previous study.

In this study, CPB and PCPB in rectangular shape (blocks category type C) of dimension 200 mm (in length) x 100 mm (in width) x 80 mm (in thickness) were used for physical and mechanical experimental work and cylinder shape of 99.5 mm in diameter with 80 mm in thickness were used for function performance experimental works. Main materials for CPB and PCPB manufacturing are Ordinary

Portland cement, aggregates and water. The Ordinary Portland cement satisfying the requirement of Type 1 ASTM C150 (2012) was used as a major binder material in this study. The coarse aggregate categories as crushed granite with a maximum particle size of 10 mm sieve and for fine aggregate, maximum size of 5 mm sieve were used (ASTM C33, 2016). The PCPB concrete mixture contains no fine aggregate to allow voids inside the block. The target minimum strength is 20 MPa at 28 days for individual blocks and water to cement (w/c) ratio of 0.35. The contaminants used as clogging agent were collected in urban area during raining. The sizes of contaminants used are below 2.36 mm (ASTM C33, 2016). The clogging processes where repeated for 5 cycles and tested, where each cycle will clog with 1.0 g/l of contaminants concentrations.

The experimental program involved studying the characteristics of raw materials in terms of its physical properties, particle morphology and phase identification. Furthermore, the physical properties of CPB and PCPB investigated consist of density, porosity, water absorption, weight loss. The mechanical properties involved are the compressive strength and splitting tensile strength. The function performance properties such as skid resistance, permeability and sound absorption of CPB and PCPB were investigated. Effect of clogging also has been investigated in this research to evaluate the function performance of PCPB in terms of permeability and sound absorption.

1.5 Significance of Study

The significance of this study is as follows:

i. To enhance the use of porous interlocking concrete paver in road application that is suitable to use as porous pavement to allow satisfactory infiltration capacity and sound absorption capacity.
ii. To provide basis design and database of PCPB for future interlocking porous pavement application.

iii. To provide useful information on the clogging behavior of PCPB after period of time and beneficial to be used to mitigate the clogging problem by improving the maintenance works.

1.6 Layout of Thesis

The thesis consists of five chapters:

Chapter 1 discusses the background of the study with a short overview of the past and present researches and problem statement. This chapter also provides the research objectives and briefly presents the scope and significance of the study.

Chapter 2 presents the background of the concrete materials, highlighting their performance in CPB and PCPB, such as physical properties, mechanical properties, skid resistance, permeability and acoustic absorbing properties. Previous and current ideas on the development of permeable and low-noise PCPB were also discussed in this chapter.

Chapter 3 represents an overview of the research program, discusses the selection and testing of constituent material and also the procedures for experimental investigation, test apparatus and mixture design.

Chapter 4 presents the physical and mechanical properties of CPB and PCPB with different size of coarse aggregate. This chapter also discusses the influence of coarse aggregate sizes and clogging agent on the permeable and acoustic absorbing performance of PCPB and the test results were highlighted.

Chapter 5 provides and discusses the summary of research finding, presents the contribution and offers several recommendations for future study.

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LIST OF PUBLICATIONS

Related Work Published in Journal and Proceedings

No.	Title	Year
1	**Properties of Porous Block Using Different Size of Coarse Aggregate for Pavement** *Nur Hidayah Abd Halim, Hasanan Md Nor. and Ramadhansyah Putra Jaya* **Journal of Advanced Research in Applied Mechanics (Non-index)**	2014
2	**Effect of Coarse Aggregate Sizes on Properties of Porous Concrete Paving Blocks** *Nur Hidayah Abd Halim, Hasanan Md Nor. and Ramadhansyah Putra Jaya* **Advanced Material Research (Scopus Index)** DOI: 10.4028/www.scientific.net/AMR911.433 Presented in The 4th International Conference on Key Engineering Materials **(ICKEM 2014)**, 22 – 23 March 2014, Bali, Indonesia.	2014
3	**Porous Concrete Paving Blocks Using Coarse Aggregate** *Nur Hidayah Abd Halim, Hasanan Md Nor. and Ramadhansyah Putra Jaya* **Applied Mechanics and Material (Scopus Index)** DOI: 10.4028/www.scientific.net/AMM554.111	2014
4	**Physical Properties of Porous Concrete Paving Blocks with Different Sizes of Coarse Aggregate** *Nur Hidayah Abd Halim, Hasanan Md Nor. and Ramadhansyah Putra Jaya* **Advanced Materials Research (Scopus Index)** DOI: 10.4028/www.scientific.net/AMR1113.86	2015
5	**Effect of Open-Graded Coarse Aggregate on Concrete Paving Block Properties for Pavement** *Nur Hidayah Abd Halim, Hasanan Md Nor. and Ramadhansyah Putra Jaya*	2016

ARPN Journal of Engineering and Applied Sciences

6 Permeability and Strength of Porous Concrete Paving Blocks at different Sizes Coarse Aggregate

Nur Hidayah Abd Halim, Hasanan Md Nor., Ramadhansyah Putra Jaya, Azman Mohamed, Mohd Haziman Wan Ibrahim, Noram Irwan Ramli and Fadzli Mohamed Nazri 2017

Journal of Physics (Scopus Index)
DOI: 10.1088/1742-6596/1049/1/012028

7 Sound Absorption and Morphology Characteristic of Porous Concrete Paving Blocks

Nur Hidayah Abd Halim, Hasanan Md Nor., Ramadhansyah Putra Jaya, Azman Mohamed, Norhidayah Abdul Hassan, Mohd Haziman Wan Ibrahim, Noram Irwan Ramli and Fadzli Mohamed Nazri 2017

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