ENGINEERING PROPERTIES AND STRUCTURAL PERFOMANCE OF RUBBERIZED CONCRETE PAVING BLOCKS

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Dedicated to God and

to my beloved physical and spiritual family members.

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ABSTRACT

Waste tyres could be utilized as partial replacement in order to preserve natural resources such as sand and to prevent the environment from further damage due to improper disposal of the tyres. There also been considerable research and development in the use of high toughness recycled tyres in concrete mixture to improve some engineering properties. In response to these demands, series of investigations were conducted and divided into three major parts in this project. For Part I, the laboratory trials were conducted to study the correlation between rubberized concrete paving blocks (RCPB) mixtures at different percentages of crumb rubber, water-cement ratio and strength. The effects of crumb rubber size, cement content and dosage of styrene-butadiene rubber latex were also investigated. To promote a practical use and acceptance of using RCPB by potential end users, Part II was carried out to investigate the manufacturing processes and the feasibility of producing RCPB in a commercial plant setting. A total of 4,300 RCPB containing 10% (10-RCPB), 20% (20-RCPB) and 30% (30-RCPB) of rubber and control concrete paving blocks (CCPB) were produced and tested for voids, abrasion, sound absorption, skid resistance, scanning electron microscopy, and long-term strength development in compression, flexural and splitting-tensile. The effect of compressive strength under three curing conditions of RCPB was also assessed. A relationship for the strength development between compression, flexural and splitting-tensile was therefore established. In Part III of this study, Highway Accelerated Loading Instrument (HALI) was developed. The concept of HALI development, including design, fabrication, calibration and performance monitoring, is also presented. RCPB pavement was tested with HALI and subjected to 10,000 cycles of load repetition. Additional tests, including shear resistance, skid resistance, and impact resistance were also conducted in order to have a better understanding of the effects of RCPB on the pavement behaviour. Results obtained from three-dimensional models showed CCPB tend to yield slightly better than other types of RCPB. Despite better skid resistance and interlocking force of CCPB, the other types of RCPB containing crumb rubber showed a great improvement in toughness. The plant manufactured RCPB can be categorized as high strength and low toughness (CCPB); high strength and moderate toughness (10-RCPB); low strength and high toughness (20-RCPB and 30-RCPB). Therefore, all types of RCPB can be introduced to various types of pavement according to the traffic volume and the application of the pavement.

ABSTRAK

Tayar buruk boleh digunakan sebagai gantian separa untuk mengurangkan penggunaan sumber semulajadi seperti pasir dan melindungi alam sekitar daripada pembuangan tayar yang tidak teratur. Terdapat juga pertimbangan dalam penyelidikan dan pembangunan bagi mencampurkan tayar buruk yang mempunyai kekerasan yang tinggi dalam konkrit bagi meningkatkan sifat kejuruteraan konkrit. Untuk memenuhi keperluan tersebut, beberapa ujian yang telah dilaksanakan dibahagikan kepada tiga bahagian utama dalam projek ini. Untuk Bahagian I, ujian makmal dijalankan untuk mengkaji hubungan di antara peratusan getah, nisbah air-simen dan kekuatan mampatan bagi turapan blok konkrit bergetah (RCPB). Kesan daripada saiz getah, kandungan simen dan dos susu getah stirena butadiene juga dikaji. Untuk mempromosikan kegunaan dan kebolehterimaan penggunaan RCPB oleh pengguna yang berpotensi, Bahagian II telah dijalankan untuk mengkaji pemprosesan dan pratikaliti bagi menghasilkan RCPB di kilang secara komersil. Sebanyak 4300 RCBP yang mengandungi 10% (10-RCPB), 20% (20-RCPB) dan 30% (30-RCPB) getah termasuk turapan blok konkrit kawalan (CCPB) telah dihasilkan dan diuji untuk lompang udara, lelasan, serapan bunyi, rintangan pengeliciran, mikroskopi elektron pengimbasan, perkembangan jangka panjang bagi kekuatan mampatan, lenturan, tegangan pecah. Kesan daripada tiga jenis keadaan pengawetan terhadap kekuatan mampatan RCPB juga diperhatikan. Hubungan untuk perkembangan di antara kekuatan mampatan, lenturan dan tegangan pecah ditentukan. Dalam Bahagian III bagi kajian ini, alat *Highway Accelerated Loading Instrument* (HALI) telah cipta. Konsep pembangunan HALI termasuk rekabentuk, pembuatan, kalibrasi dan pengujian perlaksanaan, juga dibentangkan. Turapan RCPB diuji dengan HALI dan dikenakan 10000 kali beban berulangan. Pengujian tambahan, termasuk rintangan ricih, rintangan pengelinciran dan rintangan hentaman juga dijalankan untuk menambahkan pengetahuan kesan-kesan RCPB terhadap kelakuan turapan. Secara keseluruhan, keputusan yang diperolehi daripada model tiga dimensi, menunjukkan CCPB lebih baik daripada RCPB. Meskipun CCPB mempunyai lebih baik rintangan pengelinciran dan kekuatan penguncian, RCPB yang mengadungi getah menujukkan penambahan ketahanlaksakan yang tinggi. Penghasilan RCPB di kilang boleh dikategorikan kepada kekuatan tinggi dan ketahanlasakan rendah (CCPB); kekuatan tinggi dan ketahanlasakan sederhana (10-RCPB); kekuatan rendah dan ketahanlasakan tinggi (20-RCPB dan 30-RCPB). Oleh yang demikian, semua jenis RCPB berpotensi untuk diaplikasikan dalam pelbagai jenis turapan jalan berdasarkan bilangan trafik dan kegunaan bagi turapan berkenanan.

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AASHTO	-	American Association of State Highway and Transportation Officials
AEA	-	Air-entraining agent
APTF	-	Accelerated Pavement Test Facility
ARRB	-	Australian Road Research Board
ASTM	-	American Society for Testing and Materials
BEI	-	Backscattered electrons imaging
BPN	-	British Pendulum Number
BS	-	British Standard
CBR	-	California Bearing Ratio
CCPB	-	Control concrete paving blocks
C&D	-	Construction and demolition
CPB	-	Concrete paving block
FWD	-	Falling weight deflectometer
HALI	-	Highway Accelerated Loading Instrument
HVS	-	Heavy Vehicle Simulator
ICT	-	Intensive compaction tester
MLS	-	Mobile Load Simulator
MOCRC	-	Magnesium oxychloride cement rubber concrete
MOE	-	Modulus of elasticity
MOR	-	Modulus of rupture
MW	-	Megawatt
NaOH	-	Sodium hydroxide
NUROLF	-	Newcastle University Rolling Load Facility
OPC	-	Ordinary Portland cement

PCRC	-	Portland cement rubber concrete
PVC	-	Poly(vinyl chloride)
RCPB	-	Rubberized concrete paving blocks
SBR	-	Styrene-butadiene rubber
SEI	-	Secondary electrons imaging
SEM	-	Scanning electron microscopy
TALC	-	Tyre-added latex concrete
UTM	-	Universiti Teknologi Malaysia
W/C	-	Water/cement ratios
A	-	Cross sectional area of the RCPB specimen
B	-	Average width of the sample
C	-	Average compressive strength
C_k	-	Characteristic compressive strength
C_p	-	Compressive strengths of plant-cast
C_m	-	Compressive strengths of manual-cast
D	-	Average thickness
E	-	Modulus of elasticity
F	-	Breaking load or maximum applied load
F_C	-	Flexural strengths of CCPB
F_R	-	Flexural strengths of RCPB
I_a	-	Abrasion index
k	-	Correction factor for the thickness
l ,L	-	Span length
$\Delta\ell$	-	Average length
N	-	No. of ball-race revolutions
p	-	Penetration
P	-	Maximum applied load or breaking load per unit length of the failure plane
R	-	Reduction factor
R^2	-	Correlation coefficient
s	-	Standard deviation of 5 paving units
S	-	Sample
S_c	-	Compressive strength of CCPB
S_r	-	Compressive strength of RCPB

T	-	Splitting tensile strength
V	-	Crumb rubber in volumetric ratio by total sand volume in the mix
σ	-	Modulus of rupture

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of small-element paving to create a hard surface for roads or pavements is an ancient tradition that can be traced back to the royal processional roads of ancient Babylon, continuing in Greek and Roman times (Lilley, 1991). Concrete paving block (CPB) continues this tradition and was first introduced in the Netherlands after the Second World War and spread quickly to countries in Europe. For the past 60 years, significant research activities for the development and refinement of CBP technique have been going on in many countries, including Australia, Canada, Germany, Israel, Japan, Netherlands, New Zealand, South Africa, the United Kingdom, and the United States.

The general worldwide trend towards beautification of certain city pavements, the rising cost of bitumen as a paving material, the rapid increase in construction and maintenance cost have encouraged designers to consider alternative paving material such as CPB. In addition, excellent engineering properties of CPB, ease of removal, reuse potential and ability to be utilized in all climate conditions are the main advantages of CPB to be used in a variety of commercial, municipal and industrial applications.

CPB are fully engineered products manufactured in the factory to give consistency and accuracy. This advantage is offset, in part, by the need to use sophisticated special-purpose CPB making machines. Such equipment, however, tends to produce CPB of appreciably higher quality than conventional rigid pavements with respect to density, strength and durability. As a result, subject to the selection of an appropriate mix design, CPB surfaces can offer superior levels of performance in harsh environment compared to conventional concrete and asphalt pavements.

1.2 Research Background

In developing countries, utilization of CPB as a paving material is widespread. Cement and aggregate, which are the most important constituents used in manufacturing CPB, are also a vital material for the construction industry. This inevitably led to much quarrying of natural materials used for the production of concrete. The government has also indicated a growing concern for protecting the environment and preserving natural resources (example, aggregate) by using alternative materials (example, recycled or waste materials). On the other hand, wise disposal of waste materials all around the world is being encouraged due to the crucial environment issues. Recently, there have been suggestions and successful applications of using local waste materials as a partial replacement for cement or aggregate in manufacturing CPB in some Asian countries.

In Hong Kong, the construction industry generates very large amount of solid wastes such as crushed clay brick, crushed ceramic tile, crushed waste grass, wood chips, etc. Numerous studies on applications of construction and demolition (C&D) wastes as fine and coarse aggregates material are available in the literature (Poon and Chan (2006, 2007); Poon and Cheung, 2007; Poon *et al*., 2002; Lam *et al*., 2007), which demonstrated the possibility of utilizing huge amounts of C&D waste in CPB. The use of recycled aggregates in CPB production has been successfully implemented and is gaining wider acceptance.

In recent years in Japan, the amount of coal ash produced by power plant reached about 27,000 tons daily. Karasawa (2003) have reported that fly ash can be used as a substitute for fine aggregate in the production of CPB. However, utilization of fly ash can be accepted only when it meets the production target value with fly ash replacement ratio of 25%.

Phinyocheep (1988) and Nutalaya (1994) cited a large body of literature on the applications of fly ash in CPB. It is estimated that about 45,000 tons of Mae-Moh fly ash lignite is consumed daily for the generation of a 2,025 MW power plant in Thailand. Apart from fly ash, peanut shell ash and rice husk ash can be used as partial replacement of cement in CPB production. Due to the burden of waste disposal and environmental effect, the idea to utilize this fly ash is raised in the production of low-cost CPB. This created employment opportunities and benefited the people who live in the vicinity of the power plant.

Nevertheless, among the waste materials, pneumatic tyre is one of the most common environmental issues in the contemporary world, which is not readily biodegradable. Each year, approximately 800 million new tyres are produced in every region of the world, in various sizes and types (Ulrich, 1998). The lifetime of some tyres are prolonged, but ultimately they, too, will be discarded as waste materials. Majority of such tyres eventually end up in the already congested landfill or will become mosquito breeding places and gives the worst effects when it is burnt. Recent statistics in Malaysia indicated more than 100% increase in the number of registered vehicles within ten years. The current thirteen million of vehicles are producing large number of scrap tyres. Therefore, the Department of Environmental has put a stop to the open burning and burying of waste tyres as they cause air pollution and land instability, respectively. Even though several agencies and municipal councils are involved in waste management, they often have no clear functions in relation to waste management. Therefore, as an engineer and researcher, there is a need to seek economic and environmental friendly methods to manage these tyres in civil engineering applications, such as CPB products.

Existing CPB is characterized as a composite material with high compressive strength, moderate tensile strength and with a low toughness. It is anticipated that an ideal concrete block pavement should have high tensile strength and high toughness. Therefore, minimum required strength and improved toughness of modified CPB has to be developed for trafficked pavement application. For concrete, it is found that the higher the strength, the lower the toughness. Therefore it is impossible to develop high strength and high toughness concrete without modifications. Laboratory tests have shown that the addition of waste tyre rubber in concrete increase toughness, impact resistance, and plastic deformation considerably, offering a great potential for it to be used in sound/crash barriers, retaining structures and pavement structures (Eldin and Senouci, 1993; Khatib and Bayomy, 1999; Goulias and Ali, 1998). However, the strength of concrete containing crumb rubber or rubberized concrete is expected to be lower than those of the ordinary concrete (Toutanji, 1996; Siddique and Naik, 2004; Li *et al.*, 2004). The reason for the strength reduction could be attributed both to a reduction of quantity of the solid load carrying material and a lack of adhesion at the boundaries of the rubber aggregate, as soft rubber particles may behave as voids in the concrete matrix.

However, not much attention has been given to the potential use of rubber as concrete aggregate in pavement application, particularly for CPB. As previously mentioned, owing to the very high toughness of waste tyres, it is expected that adding crumb rubber into CPB mixture in this study can increase the toughness of CPB considerably. Furthermore, the environment benefits from the reduction of waste tyres disposal in landfills, in addition to natural materials in concrete being reserved. Therefore, this study aims at developing the potential of using crumb rubber as a partial sand replacement in manufacturing CPB. It is believe that by substituting sand with crumb rubber, concrete block pavement will be more durable, can absorb higher energy under impact and flexible, thus, providing softness to the surface.

1.3 Objectives

The overall objective of this study is to investigate the feasibility of incorporating crumb rubber into CPB as a partial replacement for natural sand in the concrete mix.

The specific objectives of this study are as follows:

(i) To look into the mechanical properties of CPB incorporating crumb rubber and styrene-butadiene rubber (SBR) latex;

(ii) To assess the feasibility of pilot plant manufacture of rubberized concrete paving blocks (RCPB) based on formulations developed in laboratory trials;

(iii) To study long-term engineering properties of pilot plant manufactured RCPB;

(iv) To develop a laboratory scale accelerated loading test equipment;

(v) To investigate structural performance of RCPB pavement subjected to accelerated loading test.

In addition to investigating the use of rubber aggregate in concrete mix design and the engineering properties of concrete mixes, an important consideration has been the development of RCPB products which are feasible in terms of production and good in service performance.

1.4 Scope of Investigation

The scopes of work undertaken are divided into three major parts:

Part I – Laboratory investigation of CPB incorporating crumb rubber and SBR latex

In order to develop information about the mechanical properties of CPB incorporating crumb rubber and SBR latex, the following aspects were considered:

(i) Mix design parameters:
- Cement content and water/cement (W/C) ratios
- Three different size of crumb rubber
- Eight different percentage of crumb rubber replacement at 0.45, 0.50 and 0.55 W/C ratios
- Four dosage of SBR latex admixture for 0%, 10%, 20% and 30% replacement of crumb rubber concrete mixtures

(ii) Mechanical properties:
- 7 and 28-day compressive strength
- Unit weight
- Skid resistance

Part II – Feasibility and engineering properties of pilot plant manufactured RCPB

Various tests were carried out to assess the feasibility of pilot plant production and to establish the long-term engineering properties of RCPB. The testing procedures are in accordance with BS 6717 (BSI, 2001), MA 20 (CMAA, 1996) and ASTM specifications to investigate the performance of RCPB against control blocks to look at:

(i) Fresh properties:
- Work dimensions
- Tolerances

(ii) Visual properties:
- Appearance
- Surface colour

(iii) Hardened, acoustic, mechanical and durability properties:
- Unit weight
- Water absorption
- Sound absorption
- Scanning electron microscopy (SEM)
- Long-term compressive strength under three curing conditions
- Long-term flexural strength
- Long-term splitting tensile strength
- Long-term abrasion resistance
- Impact resistance
- Skid resistance

To assess the long-term development and performance of abrasion resistance, compression; splitting tension and flexural strengths, samples were tested at 1, 7, 28, 91, 182 and 364 days of age.

Part III – Structural performance of RCPB pavement

To ensure that RCPB pavement is good in service performance, Highway Accelerated Loading Instrument (HALI) was developed and a series of accelerated trafficking tests were conducted:

(i) Development of HALI consists of

- Design
- Fabrication
- Calibration
- Monitoring of the equipment performance

(ii) Investigation of RCPB structural performance based on

- Longitudinal and transverse rutting profiles
- Three-dimensional surface deformation
- Open joint width
- Skid resistance
- Impact resistance
- Shear resistance

1.5 Significance of the Research

(i) Utilising waste material and reducing the use of natural material in CPB.

(ii) Developing an innovative RCPB product that has better engineering properties and comparable service performance in comparison with existing CPB.

(iii) Highlighting plant production technique to reuse recycled wastes in large quantities and in a fast manner. Therefore, this work would be a useful reference for future researchers on the possibility of incorporating other types of waste materials in CPB.

(iv) Contributing better understanding of long-term engineering properties of RCPB, which can be applied to other concrete applications in civil engineering.

(v) Providing low cost, operational guideline and simple accelerated loading facility for road authorities and highway research institutions.