PERFORMANCE OF RECYCLED PAPER MILL SLUDGE AS A MODIFIER IN ASPHALT MIXTURES THROUGH DRY PROCESS

CHEW J-WEI

UNIVERSITI SAINS MALAYSIA
2018

PERFORMANCE OF RECYCLED PAPER MILL SLUDGE AS A MODIFIER IN ASPHALT MIXTURES THROUGH DRY PROCESS

by

CHEW J-WEI

Thesis submitted in fulfilment of the

requirements for the Degree of

Master of Science

August 2018

There is nothing impossible
To him who will try

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor, Dr. Mohd Rosli Mohd Hasan for his continuous patience, motivation, expertise and constructive recommendations. My appreciation to the guidance and insight offered, which expedited my progress in completing this thesis on time. To respective staffs from School of Civil Engineering and School of Materials and Mineral Resources, my gratefulness to their supervision in facilitating this research effort.

I gratefully acknowledge the financial support from the Malaysian Ministry of Higher Education through Fundamental Research Grant Scheme under Grant No: 203.PAWAM.6071358 received as a graduate research assistant. This research is made possible with the support from Kuad Sdn.Bhd. and PENS Industries Sdn. Bhd for providing granite and limestone respectively. I express my gratitude also to the paper mill company which requested for confidentiality in providing raw recycled paper mill sludge which is crucial to this research initiative.

My deepest appreciation to my father, Assoc. Prof. Dr. Chew Cheng Meng, my mother, Pung Chen Choy, and my sister, Chew J-Yin, for their perpetual encouragement both morally and spiritually. Last but not least, my sense of gratitude to all whom had directly or indirectly lent their hand in this endeavor.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: **METHODOLOGY**

CHAPTER FOUR: RESULTS AND DISCUSSION

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
ABS-PC	Acrylonitrile Butadiene Styrene-Polycarbonate
ACV	Aggregate Crushing Value
ALVS	Accelerated Laboratory Vacuum Saturator
ASLP	Australian Standard Leaching Procedure
AV	Air Voids
CAM	Cold Asphalt Mixture
CEI	Compaction Energy Index
EPA Victoria	Environmental Protection Agency of Victoria
ESAL	Equivalent Single Axle Load
HIPS	High Impact Polystyrene
HMA	Hot Mix Asphalt
HOKLAS	Hong Kong Laboratory Accreditation Scheme
ICE	Initial Change Equilibrium
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometer
ITS	Indirect Tensile Strength
LAAV	Los Angeles Abrasion Value
LOI	Loss on Ignition
RAP	Recycled Asphalt Pavement
ROI	Return of Investment
RPMS	Recycled Paper Mill Sludge
SEM	Scanning Electron Microscope

SFE	Surface Free Energy
SGC	Servopac Gyratory Compactor
SMA	Stone Mastic Asphalt
SMA	Stone Matrix Asphalt
SSA	Specific Surface Area
SSD	Saturated Surface Dry
SST	Total Surface Area of Mix Design Combined Aggregates
TCLP	Toxicity characterization leaching procedure
USEPA	United State Environmental Protection Agency
UTM	Universal Testing Machine
VFA	Voids Filled by Asphalt
VMA	Voids in Mineral Aggregate
WI	Workability Index
WMA	Warm Mix Asphalt
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

LIST OF SYMBOLS

$Ca(Al_2Si_2O_8)$	Anorthite
$Al2O_3$	Aluminium Oxide
As	Arsenic
Ca	Calcium
$Ca(SO_4)$	Calcium Sulfate
$CaCO_3$	Calcium carbonate
$CaCO_3$	Calcite
CaO	Calcium Oxide
Cd	Cadmium
CO	Carbon monoxide
Cr	Chromium
Cu	Copper
CuO	Copper Oxide
$CaMg(CO_3)^2$	Dolomite
Fe	Iron
Fe_2O_3	Ferric Oxide
Ga_2O_3	Gallium Oxide
Hg	Mercury
K_2O	Potassium Oxide
Mg	Magnesium
MgO	Magnesium Oxide
Mn	Manganese

MnO	Manganese (II) Oxide
Na_2O	Sodium Oxide
$NaCI$	Halite
Nb_2O_5	Niobium Oxide
Ni	Nickel
NiO	Nickel (II) Oxide
P_2O_5	Phosphorus pentoxide
Pb	Lead
PbO	Lead (II) Oxide
MgO	Periclase
$Ca(OH)^2$	Portlandite
SiO_2	Quartz
Rb_2O	Rubidium Oxide
Se	Selenium
SiO_2	Silicon Dioxide
SO_3	Sulphur Trioxide
Sr	Strontium
KCI	Sylvite
ThO_2	Thorium Dioxide
TiO_2	Titanium Oxide
Zn	Zinc
ZnO	Zinc Oxide
ZrO_2	Zirconium Dioxide

PRESTASI SISA KILANG KERTAS KITAR SEMULA SEBAGAI PENGUBAHSUAI DALAM CAMPURAN ASFALT MELALUI PROSES KERING

ABSTRAK

Pengumpulan sisa pepejal yang semakin meningkat memerlukan usaha global dalam pengurusan sisa yang efisien dan rawatan ekologi. Industri turapan asfalt yang menggunakan sumber semula jadi di samping menyumbang kepada gas rumah hijau, dilihat sebagai industri yang berpotensi tinggi bagi penggunaan sisa pepejal. Usaha penyelidikan ini memaparkan penggunaan sisa kilang kertas kitar semula (RPMS) sebagai bahan tambah baru ke dalam campuran asfalt. Rawatan pra-syarat RPMS memerlukan 6 jam oven kering, 10 pusingan penggilingan dan semburan retak 0.075mm manakala didapati tidak mudah terbakar. Lebih 60% RPMS digunakan, manakala baki 40% boleh digunakan sebagai pindaan tanah. RPMS dimasukkan ke dalam campuran aspal pada 0.5% dan 1% berat campuran asfalt. Bahan pengikat asfalt bergred penusukan 60/70 dan dua jenis agregat iaitu batu kapur dan granit digunakan. Campuran asfalt disediakan pada suhu 160°C, dan dipadatkan menggunakan pemadat legar pada suhu 150°C. Ciri-ciri perkhidmatan gabungan campuran RPMS asfalt menyebabkan indeks kebolehkerjaan (WI) yang lebih tinggi dan indeks tenaga pemadatan (CEI) yang lebih rendah berbanding kawalan. Campuran kering asfalt 0.5% RPMS menyebabkan kekuatan tegangan tidak langsung (ITS) yang setanding dengan kawalan, namun mempunyai rintangan kelembapan yang lemah dengan nisbah kekuatan tegangan tidak langsung (ITSR) yang rendah. RPMS mengakibatkan modulus kebingkasan & ricih Leutner yang lebih tinggi, sementara mempunyai prestasi rayapan dinamik berbanding kawalan campuran asfalt.

mikroskop elektron imbasan (SEM) menggambarkan morfologi permukaan berserat dan berliang RPMS. pembelauan sinar-X (XRD) menunjukkan komposisi mineralogik RPMS yang mengandungi kalsit, mempromosikan lekatan bitumen-agregat yang baik. Walau bagaimanapun, RPMS mengandungi sebatian kelarutan larut air yang tinggi iaitu anhydrite, halite, sylvine, quart dan periclase. Komposisi kimia ditentukan melalui pendarflour sinar-X (XRF) yang menunjukkan RPMS mengandungi komposit simen Portland yang sama iaitu SiO_2, Al_2O_3, K_2O dan CaO walaupun selepas kerugian penyalaan (LOI) sebanyak 52.52%. Prosedur larut lesap pencirian ketoksikan (TCLP) membuktikan hanya logam berat Arsenik dikesan jauh bawah had pengawalseliaan atas RPMS mentah. Sementara RPMS yang dimasukkan pengikat asfalt menunjukkan pengurangan Arsenik membuktikan integrasi pengikat asfalt yang baik. Unsur-unsur logam berat yang mempunyai aplikasi agronomik iaitu kalsium, besi & magnesium dikesan. Oleh itu membuktikan RPMS tidak berbahaya kepada alam sekitar. Kajian ini bertindak sebagai rangsangan untuk menggabungkan RPMS dalam penghasilan turapan asfalt eco di samping menyediakan industri kaedah pelupusan alternatif yang lebih hijau.

PERFORMANCE OF RECYCLED PAPER MILL SLUDGE AS A MODIFIER IN ASPHALT MIXTURES THROUGH DRY PROCESS

ABSTRACT

The escalating accretion of solid waste requires a global notion to strive for efficient waste management and ecological treatments. The asphalt pavement industry which consumes natural resources while contributing to greenhouse emissions, is viewed as a potential alternative for the incorporation of solid waste. This research effort incorporates Recycled Paper Mill Sludge (RPMS) as a solid waste addictive into asphalt mixture. Pre-requisite treatment of RPMS required 6 hours oven dried, 10 cycles milling and sieved retaining 0.075mm while found to be not combustible. Over 60% RPMS is utilized, while remaining 40% can be utilized as soil amendments. RPMS is incorporated into asphalt mixture at 0.5% and 1% asphalt mixture weight. Asphalt binder with penetration grade 60/70 and two types of aggregates namely limestone and granite is utilized. Asphalt mixture is mixed at temperature of 160°C and compacted at 150°C. Service characteristics of RPMS incorporated asphalt mixture resulted higher Workability Index (WI) and lower Compactability Energy Index (CEI) than control. Unconditional 0.5% RPMS asphalt mixture led to comparable Indirect Tensile Strength (ITS) with control, yet having poor moisture resistance with low Indirect Tensile Strength Ratio (ITSR). RPMS resulted in higher resilient modulus and Leutner shear, while having comparable dynamic creep performance than control asphalt mixture. Scanning Electron Microscope (SEM) illustrated the fibrous and porous surface morphology of RPMS. X-Ray Diffraction (XRD) shown RPMS mineralogical composition which contains calcite, promoting good bitumen-aggregate adhesion. However, RPMS contained high water solubility mineralogical compounds namely anhydrite, halite, sylvine, quart and periclase. Chemical composition are determined via X-Ray Fluorescence (XRF) indicating RPMS contained similar Portland cement composition namely SiO_2, Al_2O_3, K_2O and CaO even after Loss On Ignition (LOI) of 52.5%. Toxicity Characterization Leaching Procedure (TCLP) proved only Arsenic heavy metal is detected with levels far below regulatory limits on raw RPMS. While RPMS incorporated asphalt binder indicated a reduction in Arsenic proving good asphalt binder integration. Non heavy metal elements which have agronomic application namely calcium, iron & magnesium are detected. Thus proving RPMS is not harmful to the environment. This research acts as a stimulus to incorporate RPMS in eco and sustainable asphalt pavement development while providing industries with a greener disposal alternative.

CHAPTER ONE

INTRODUCTION

1.1 Background

Solid waste is accumulating on an escalating pace, snowballing into clusters of environmental and economic issues at an alarming rate [1-4]. Spanning over a decade from 2004 to 2014, the amount of household and industrial waste generated from the European Union (a collective of 28 countries), amounted to a staggering cumulative sum of approximately 12.5 billion tons [5]. In Malaysia, the generation of RPMS increased from 16,200 tons per day in 2001 to 19,100 tons in 2005 translating an average of 0.8 kilograms per capita per day, and the amount is escalating by about 4% annually [5]. Rapid population growth coupled with the increase in consumption rate are looming us towards a dire state of solid waste management which is dependent on landfilling as the main disposal method. As the amount of land available gets scarce for new landfill construction, illegal dumping or incineration alternatives are implemented despite the dominance of recyclable materials in the waste composition [3, 4]. The upsurge of a global movement consisting of diverse institutions including governments, universities and private sectors are facilitating solid waste recycling and reusing in a wide array of applications, to not jeopardize the resources of future generation [6, 7, 8].

Riding on this stimulus, the asphalt pavement industry which spans a production of more than 550 million tons of asphalt pavement annually in the United States alone [9] is viewed as a highly potential alternative for solid waste application. The emergence of asphalt pavement industry revolve around conventional Hot Mix