UNIVERSITI PUTRA MALAYSIA

EVALUATION OF RECYCLED CRUSHED CONCRETE AS AGGREGATE SUBSTITUTE IN ASPHALT MIXTURES

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By

GAILAN ISMAT SAFA ELDEEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

December 2018

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DEDICATION

This thesis is especially dedicated to

My lovely Wife Hala Addnan Rasheed

My most lovely sons Abdullah and Abdulrahman

To My Parent

To My dear Sister Zainab Ismat safa Eldeen

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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December 2018

Chairman : Fauzan Mohd Jakarni, PhD
Faculty : Engineering

The amount of crushed cement concrete continues to increase daily as a result of the demolition of old structures, thereby increasing pollution. To cope with the pressure imposed by the rise in environmental awareness and the stringent disposal regulations set by environmental protection agencies, effective measures for handling and disposing of crushed concrete must be implemented. Instead of simply disposing of crushed concrete, alternative efforts should be considered to utilize it as a recyclable material. The objective of this study was to evaluate the use of recycled concrete aggregate (RCA) as an aggregate substitute in asphalt mixture for pavement construction. However, owing to the poor physical properties of crushed concrete in terms of absorption, abrasion and specific gravity, this study focused on recycled concrete aggregate (RCA) with a passing and retained sieve size of 5 mm and 1.18 mm, respectively. In order to take into considerate abrasion and absorption properties. The physical and chemical properties were evaluated for both RCA and natural aggregate, and the recommendation is to mix crushed concrete with conventional aggregates from natural sources. Then, suitable mixtures of crushed concrete and conventional aggregates were determined based on the combinations of five types of gradation (upper, lower, medium and two others) with six different proportions of recycled concrete aggregate (0%, 20%, 40%, 60%, 80% and 100%). The degradation that occurred in the aggregate after compaction was determined, and the feasibility of using RCA in asphalt mixtures was evaluated. Aggregate degradation analysis was performed using a newly developed testing method. Then, volumetric properties and Marshall Stability were determined for all the groups. Rutting performance was evaluated for all the mixtures via repeated load axial test at different temperatures. Three factors, namely, total permanent strain, intercept and slope, and creep rate, were used to evaluate the performance of the mixtures. Moisture damage resistance was assessed for all the mixtures using a modified Lottman test.

In this study, it was found that coarse RCA has a higher abrasion value a, whereas fine RCA has a higher absorption value. Absorption value increased with decreasing aggregate size. Therefore, balance should be achieved between absorption and abrasion values. In addition, RCA passed through a sieve size of 1.18 contained more cement than other fractions.

Aggregate gradation exerted greater effects on aggregate degradation, Marshall Stability, and resilient modulus (MR) than RCA proportion. RCA content had a negative effect on the rutting life of hot mix asphalt (HMA) mixtures and moisture damage.

The most important finding of this study is that median gradation is the best and most economical gradation for hot mix asphalt HMA that contained RCA. RCA can be used successfully up to 80%, 60%, and 40% for median, upper, and lower gradations, respectively. Moreover, the Resilient Modulus considerably affects moisture damage and rutting performance. Lastly, RCA can be used successfully in mixtures and satisfy requirements when the appropriate fraction of RCA, gradation, and traffic volume is selected.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN KONKRIT HANCUR YANG DIKITAR SEMULA SEBAGAI PENGGANTI AGREGAT DALAM CAMPURAN ASFALT

Oleh

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Jumlah konkrit simen hancur semakin meningkat setiap hari daripada hasil perobohan bangunan lama yang mengakibatkan peningkatan pencemaran. Langkah-langkah yang lebih berkesan untuk pengendalian dan pelupusan konkrit hancur mesti dilaksanakan seiring dengan peningkatan kesedaran alam sekitar dan peraturan-peraturan ketat yang berkaitan dengan pelupusan seperti yang ditetapkan oleh agensi-agensi perlindungan alam sekitar. Daripada hanya melupuskan konkrit hancur, usaha alternatif yang berkesan harus dipertimbangkan untuk menggunakannya semula. Objektif kajian ini adalah untuk menilai penggunaan agregat konkrit kitar semula sebagai pengganti agregat dalam campuran asfalt bagi pembinaan kaki lima. Walau bagaimanapun, disebabkan oleh sifat fizikal konkrit hancur yang kurang dari segi penyerapan, lelasan dan graviti spesifik, kajian ini memberi tumpuan kepada agregat konkrit yang dikitar Semula (RCA) dengan saiz ayak 5 mm dan 1.18 mm. Dengan mengambil kira sifat lelasan dan penyerapan, ciri fizikal dan kimia dinilai pada RCA dan agregat semulajadi, dan cadangannya adalah untuk menggabungkan konkrit hancur dengan agregat konvensional daripada sumber semula jadi. Kemudian, campuran yang sesuai untuk konkrit hancur dan agregat konvensional ditentukan berdasarkan gabungan lima jenis penggredan (atas, bawah, sederhana dan dua yang lain) dengan enam penggredan agregat konkrit yang dikitar semula (0%, 20%, 40%, 60%, 80% dan 100%). Dalam kajian ini, degradasi yang berlaku dalam agregat selepas pemadatan ditentukan dan kesesuaian menggunakan RCA dalam campuran asfalt dinilai. Analisis degradasi agregat telah dilakukan menggunakan kaedah ujian baru. Kemudian, sifat volumetrik dan Marshall ditentukan untuk semua kumpulan. Prestasi pengeluman dinilai untuk semua campuran menggunakan ujian beban paksi pada suhu yang berbeza. Faktor-faktor yang digunakan untuk menilai prestasi campuran adalah jumlah ketegangan, pintasan dan kelerengan, serta kadar rayap. Rintangan kerosakan kelembapan dinilai untuk semua campuran menggunakan ujian Lottman terubah suai.

Dalam kajian ini, RCA kasar mencapai nilai lelasan yang lebih tinggi, sedangkan RCA halus mempunyai nilai penyerapan yang lebih tinggi. Nilai penyerapan meningkat dengan pengurangan saiz agregat. Oleh itu, keseimbangan perlu dicapai di antara nilai penyerapan dan lelasan. Di samping itu, RCA melepasi saiz ayak 1.18 yang mengandungi lebih banyak simen daripada pecahan lain. Penggredan agregat memberikan kesan yang lebih besar terhadap degradasi agregat, kestabilan Marshall, dan modulus bingkas (MR) daripada nisbah RCA.

Kandungan RCA mempunyai kesan negatif terhadap jangka hayat pengeluman asfalt campuran hangat (HMA) dan kerosakan kelembapan.

Penemuan yang terpenting dalam kajian ini ialah penggredan median merupakan penggredan yang terbaik dan paling jimat untuk asfalt campuran hangat yang mengandungi RCA. RCA boleh digunakan dengan jayanya sehingga 80%, 60%, dan 40% untuk penggredan median, atas dan bawah. Selain itu, Modulus Bingkas memberikan kesan besar kepada kerosakan kelembapan dan prestasi pengeluman. Akhir sekali, RCA boleh digunakan dengan jayanya dalam campuran dan memenuhi keperluan apabila pecahan RCA, penggredan, dan jumlah lalu lintas yang sesuai dipilih.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

P_{ba}	Absorbed Asphalt By Weight Of Aggregate
AASHTO	American Association Of State Highway And Transportation Officials
ANOVA	Analysis Of Variance
APA	Asphalt Pavement Analyser
ASTM	American Society for Testing and Material
BS	British Standard
CPP	Change In Passing Percentage
CPPG	Change In Passing Percentage For The Group
CPS	Cumulative Permanent Strain At 3600 Load Cycle
d	Maximum Particle Sieve Size Opening Diameter
D	Maximum Size of The Aggregate
DV	Dependent Variable
EAC	Effective Asphalt Content
g	Gram
GA	Granite
GA	Granite
G_b	Specific Gravity Of Asphalt
G_{mb}	Bulk Specific Gravity Of The Specimen
G_{mm}	Maximum Specific Gravity Mixture
G_{sb}	Bulk Specific Gravity Of The Aggregate
H_0	Null Hypothesis
H_1	Alternative Hypothesis
HMA	Hot Mix Asphalt
Hz	hertz

IPC	Industrial Process Controls
JKR	Malaysian Standard Specification For Road Works
JMF	Job Mix Formula’
kN	Kilo Newton
kPa	kilo pascal
LVDT	Linear Variable Differential Transformers
mm	Millimeter
M_R	Resilient Modulus
N	Newton
OAC	Optimum Asphalt Content
P	Total Percent Passing The Particular Sieve
PVA	Polyvinyl Alcohol
RCA	Recycled Concrete Aggregate
RLAT	Repeated Load Axial Test
s	Second
SGC	Superpave Gyratory Compactor
TMD	Theoretical Maximum Density
TSR	Tensile Strength Ratio
UTM	Universal Testing Machine
UTS	Universal Testing System
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
VTM	Void in Total Mix
XRF	X-Ray Fluorescence
ε_e	Elastic Strain
ε_p	Plastic Strain

ε_T	Total Strain
ε_{Ve}	Viscoelastic Strain
ε_{Vp}	Viscoplastic Strain

CHAPTER 1

INTRODUCTION

1.1 Introduction

Environmental pollution occurs when waste materials cannot be destroyed or stored without causing harm or damage to the environment. These waste materials are typically generated by human activities. One example of these materials is demolition waste, which is produced by crushing old concrete structures. Concrete cement represents the majority of waste materials from demolition. The amount of waste concrete has increased and currently covers a large area because of earthquakes, wars, and the renovation of old structures. Similarly, the increasing price of land in recent years has led to high dumping costs at landfill sites. Table 1-1 provides examples of the amount of wastes produced during natural disasters. However, most waste concrete is derived from construction and demolition wastes. Figure 1-1 shows the amounts of construction and demolition wastes generated in Europe.

Table 1.1 : Examples of Waste Volume from Disasters (Brown & Milke, 2009)

Disaster	Date	Volume of waste (m^3)
Northridge Earthquake	January, 1994	5,351,884
Hurricane Iniki	September, 1992	3,822,774
Hurricane Andrew	August, 1992	32,875,859
Hurricane Hugo	September, 1989	1,529,110
Tsunami, Indonesia	December, 2004	10,000,000

Recycling crushed materials is the best solution for reducing waste and protecting the environment from pollution while simultaneously decreasing the amount of waste materials at landfill sites. One of the best methods for recycling crushed materials is to use them as aggregate in new concrete mixes. When crushed materials are used in mixes, they are called recycled concrete aggregate (RCA). RCA used in asphalt mixes is better RCA used in cement concrete because the former is coated with asphalt, which makes it durable. Moreover, using RCA as a granular material for base and sub base layers in road construction will affect vegetation within the vicinity of a road (Burns Cooley Dennis, 2007). Therefore, the use of RCA in asphalt mixes is the best solution.

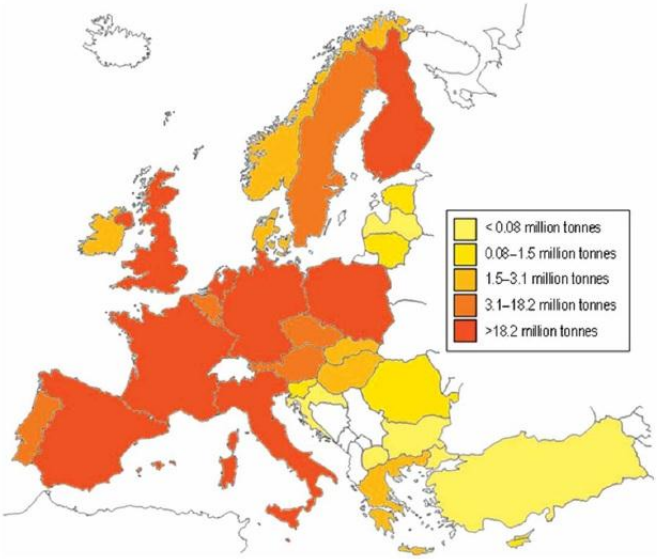

Figure 1.1 : Generation of Construction and Demolition Wastes in Europe (Rodríguez, 2015)

The use of RCA in asphalt mixes will solve another global problem, namely, the shortage of materials. Road construction represents the largest consumer of aggregate worldwide, which affects the amount of available aggregate. Pourtahmasb and Karim (2014) reported that 12500 metric tons of aggregate are used for each kilometer of flexible pavement. Aggregate can be obtained by mining the earth, particularly by demolishing mountains and hills. This procedure will destroy the land, affect headwater rivers, and exert an impact on animal and plant life. Thus, the use of crushed concrete as aggregate in asphalt mixes is crucial.

Asphalt mixtures consist of aggregate and asphalt. The strength of a mixture is derived from aggregate, whereas the purpose of asphalt is to bind aggregate particles and protect aggregate from erosion. Asphalt is a binding agent that binds aggregate particles into a cohesive mass. Aggregate must provide a strong stone matrix to bear the applied repeated loads. The individual properties of asphalt and aggregate affect the overall performance of a mixture.

1.2 Background

Environmental pollution is worsening daily due to the increasing amounts of demolition waste materials while landfill space for these materials is decreasing. This type of pollution can be prevented by recycling these materials. Recycling waste concrete from the demolition of old structures as aggregate in hot mix asphalt (HMA) is an effective solution for decreasing pollution amount.

In recent years, several studies have examined the use of crushed concrete in asphalt mixes. Although these studies are encouraging, they present widely varying results. Cement mortar attached to aggregate surface in crushed concrete makes the performance of RCA different from that of natural aggregate. In particular, cement mortar causes RCA to have a lower specific gravity than natural aggregate. Pourtahmasb & Karim (2014), and Gul & Guler (2014) reported that the specific gravity of coarse RCA is lower than that of natural coarse aggregate by 16% and 14 %, respectively. In addition, the attached mortar makes the absorption value of RCA higher than that of natural aggregate. Rafi (2011) and Perez (2012) found that the absorption value of RCA is higher than that of natural aggregate by 319% and 2805%, respectively.

Moreover, cement mortar causes RCA particles to have a higher abrasion value than natural aggregate particles. Shen (2004) and Arabani & Azarhoosh (2012) indicated that the abrasion value of RCA is higher than that of natural fine aggregate by 102% and 13%, respectively.

1.3 Problem Statement

Demolition waste material is one of the major sources of global solid waste. It is one of the serious problems that will be increased by the time. The seriousness of this problem increases with the population growth and the economic development. In fact, there are many sources of this kind of the waste such as destruction and reconstruction as repairing of bridges, buildings, roads, dams and drainage systems. Natural disasters also have a significant role in spreading this waste. At the same time, the influence of the wars cannot be ignored in this field Demolition waste has covered large areas of land because of an inefficient waste management process. This type of pollution can be prevented by recycling these materials. Recycling waste concrete from the demolition of old structures as aggregate in hot mix asphalt is a good solution to decrease the amount of pollution.

Aggregate provides the structural framework of HMA, which bears stresses from traffic. Thus, the use of aggregate with low strength, which cannot bear applied stresses, is difficult. When aggregate particles are crushed due to applied stress, the pavement will crack and fail. In addition, the low specific gravity of aggregate is transferred to the mixture, which makes its specific gravity lower than the theoretical maximum.

Furthermore, an aggregate with a high absorption value absorbs a considerable amount of asphalt in the mix, which indicates that the mixture has higher optimum asphalt content than conventional mixes. Therefore, construction cost will increase. Moreover, if mixes with a high asphalt content cannot resist the applied load, then the mixture will have a permanent deformation problem, which will affect the durability of the pavement. The absorbed asphalt expands at high temperatures, which decreases

permanent deformation resistance due to increasing film thickness surrounding aggregate particles.

Abrasion resistance is one of the most important properties of aggregate because aggregate must resist crushing, degradation, and disintegration. RCA typically has a high abrasion value. The degradation of aggregate during compaction or throughout pavement life increases air void percentage in the pavement, which causes moisture damage. Moreover, aggregate degradation helps break the asphalt film around aggregate particles, which affect pavement durability.

This study attempts to produce a clear understanding of using recycled concrete aggregate as aggregate in asphalt mixtures and make boundaries for using RCA in asphalt mixtures without increasing in the construction cost.

1.4 Objective of Study

This study primarily aims to assess the potential of RCA as aggregate substitute in asphalt mixtures by considering balance between absorption and abrasion values. It intends to identify a suitable RCA fraction to be mixed with natural aggregate that will minimize absorption and abrasion problems. In addition, the most suitable applicable gradation is determined. The specific objectives that should be undertaken to achieve the primary objective are as follows:

i. To determine and analyse the mechanical and mineralogical properties of RCA.
ii. To determine the degradation of composite natural aggregate and RCA using newly developed procedures
iii. To analyse the mix design properties of asphalt mixtures with various percentages of RCA as aggregate substitute in the mixtures.
iv. To propose the performance of asphalt mixtures contain RCA as aggregate.

1.5 Hypothesis of the Study

On the basis of the literature review, prior experience, and preliminary examinations of aggregate and RCA, the hypothesis of this study is developed as follows: RCA can be used as aggregate in asphalt mixtures if a balance can be achieved between abrasion and absorption values. The coarse fraction of RCA typically has a higher abrasion value, whereas the fine fraction has a higher absorption value. Therefore, a medium fraction of RCA was used as aggregate in this research to balance the abrasion and absorption values. No treatment was applied to RCA to avoid increasing of the construction cost. The specific hypothesises that should be undertaken are as follows:

i. Asphalt mixtures contain RCA as aggregate has high degradation value due to the high abrasion values.
ii. Asphalt mixtures contain RCA as aggregate has high optimum asphalt content due to the high absorption values.
iii. These types of mixtures have higher permanent deformation than conventional mixtures due to asphalt content.
iv. The mixtures have high moisture damage value due to high absorption values.

1.6 Significance of the Study

The new knowledge gained from this study can be used to develop asphalt mixes with a partial replacement of RCA. In addition, this study can facilitate the acceptance of RCA use in asphalt mixtures. Moreover, the results obtained from this study can contribute to improving the understanding of the effect of RCA proportions on the performance properties of HMA mixtures. The results can help protect the environment from pollution and solve the problem of natural aggregate shortage worldwide. Furthermore, this research can provide a clear understanding of the importance of aggregate gradation and determine which gradation is suitable for asphalt mixtures with RCA. In addition, the study suggests a new technique for investigating aggregate degradation at different compaction levels. The results identify which gradation will suffer the least degradation and disintegration.

1.7 Thesis Layout

This study has five chapters. The first chapter provides a brief introduction to the importance of using RCA in asphalt mixes, explains the problem statement, describes the objective of the study, and states the hypothesis and significance of the study. The second chapter presents a literature review on using RCA in asphalt mixes, aggregate gradation, degradation, permanent deformation evaluation methods, and moisture damage test methods.

The third chapter provides information about the materials used, sample preparation, test procedures, and development of the experimental organization. The fourth chapter describes the details of the test results and statistical analysis, including the prediction models. It also includes an analytical discussion. The last chapter presents the conclusions drawn from the study and recommendations for future research. Finally, the raw data used in this work are provided in the appendices.

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LIST OF PUBLICATIONS

Publication

Jakarni, F. M., Eldeen, G. S., Muniandy, R., & Hassim, S. (2017, July). Effect of Compaction on the Degradation of Crushed Concrete Used as Partial Aggregate Substitute in Asphalt Mixtures. In Global Civil Engineering Conference (pp. 1333-1344). Springer, Singapore.

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Eldeen, G. S., Jakarni, F. M., Muniandy, R., & Hassim, S. EVALUATION OF MARSHALL COMPACTOR EFFECT ON THE DEGRADATION OF RECYCLED CONCRETE AGGREGATE. Submitted to Construction and Building Materials. Date of submission on 28/8/2018.

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