EFFECTS OF PARTIAL REPLACEMENT OF NATURAL AGGREGATE BY RECYCLED AGGREGATE FROM ASPHALT PAVEMENT ON PROPERTIES OF CONCRETE

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EFFECTS OF PARTIAL REPLACEMENT OF COARSE AGGREGATE BY RECYCLED AGGREGATE FROM ASPHALT PAVEMENT ON PROPERTIES OF CONCRETE

By

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ABSTRAK

Turapan asfalt yang dikitar semula (RAP) boleh dirujuk sebagai bahan buangan yang ditebus dan diproses semula untuk memperoleh asfalt dan agregat. Kebanyakan penggunaan RAP akan dikitar semula ke dalam turapan dan oleh itu, kesesuaian agregat kitar semula dari turapan asfalt untuk digunakan dalam aplikasi lain seperti konkrit simen Portland masih belum dikenalpasti. Dalam kajian ini, kesan penggantian separa agregat kasar oleh agregat kitar semula dari turapan asfalt terhadap sifat-sifat konkrit telah dikaji. Agregat kitar semula yang digunakan berasal dari turapan asfalt atau agregat turapan asfalt dikitar semula (RAP). Agregat kasar RAP diperolehi dari JKR Pulau Pinang dan kemudiannya dihancurkan menjadi gumpalan agregat yang lebih kecil. Gumpalan agregat ini kemudiannya disaring dan digredkan kepada saiz yang sama seperti agregat granit semulajadi. Sebanyak enam campuran konkrit dengan peratusan penggantian yang berbeza terdiri daripada agregat RAP telah dihasilkan. Beberapa ujian telah dijalankan termasuk penilaian sifat fizikal dan mekanikal agregat RAP dan penilaian sifat fizikal dan mekanikal konkrit yang mengandungi agregat RAP yang kemudiannya dibanding dengan agregat normal dan campuran konkrit yang terdiri daripada aggregat normal. Untuk pencirian agregat RAP, bitumen yang terdapat pada permukaan agregat telah mempengaruhi prestasi fizikalnya manakala sifat mekanikalnya dipengaruhi oleh beban yang dikenakan ke atasnya semasa tempoh perkhidmatannya sebagai aggregat turapan asfalt. Untuk kesan agregat RAP terhadap sifat konkrit, dari segi sifat fizikal dan mekanikal, campuran konkrit dengan penggantian agregat RAP 30% telah dikenalpasti sebagai perkadaran campuran terbaik dalam semua aspek yang dikaji.

ABSTRACT

Recycled asphalt pavement (RAP) can be referred as waste materials that is reclaimed and reprocessed to acquire the asphalt and aggregate. Most of the application of RAP is to be recycled back into pavement and thus, the suitability of the recycled aggregate from asphalt pavement to be used in other possible applications such as Portland cement concrete is not yet being determined. In this study, the effects of partial replacement of coarse aggregate by recycled aggregate from asphalt pavement on properties of concrete has been investigated. The recycled aggregate used was originated from asphalt pavement or recycled asphalt pavement (RAP) aggregate. RAP coarse aggregate was being obtained from JKR Penang and later been crushed into rubbles. The aggregate rubbles sieved and graded to sizes similar as natural crushed granite aggregate. Six concrete mixes with different percentage replacement were made from RAP coarse aggregate. Several tests were conducted including the assessment of physical and mechanical properties of RAP aggregate, as well as physical and mechanical properties of concrete containing RAP aggregate. The results are compared with natural crushed granite aggregate and concrete containing 100% natural crushed granite aggregate as the control mix. For the characterization of the RAP aggregate, the bituminous contaminant found on the surface of the aggregate has greatly influence its physical performance while its mechanical properties are affected by axle loads subjected during its service period as asphalt pavement. For the effects of RAP aggregate on properties of concrete, in terms of physical and mechanical properties, concrete mix with 30% RAP aggregate replacement has been identified as the best mix proportion in all aspects studied.

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LIST OF ABBREVIATIONS

RAP	**R**ecycled **A**sphalt **P**avement
C&D	**C**onstruction and **D**emolition
RA	**R**ecycled **A**ggregate
RAC	**R**ecycled **A**ggregate **C**oncrete
RCA	**R**ecycled **C**oncrete **A**ggregate
ASTM	**A**merican **S**ociety for **T**esting **M**aterials
BS	**B**ritish **S**tandards
SSD	**S**aturated **S**urface **D**ried
OD	**O**ven **D**ried
ACV	**A**ggregate **C**rushing **V**alue
AIV	**A**ggregate **I**mpact **V**alue
TPFV	**T**en **P**ercent **F**ines **V**alue

NOMENCLATURES

γ	Specific gravity of aggregate
A	Mass of soaked (saturated surface-dried) sample
B	Mass of container filled with water
D	Mass of oven-dried sample
W	Weight of empty cylinder with base plate
W_1	Weight of compacted sample and cylinder with base plate
W_2	Weight of aggregate passing sieve opening
F	load required to produce 10% fine particles
f	Maximum force
m	Fines percentage passing sieve
γ_{fresh}	Density of fresh concrete
m_1	Mass of empty cylindrical container
m_2	Mass of compacted concrete in cylindrical container
V	Volume of cylindrical container
$\gamma_{hardened}$	Density of hardened concrete
m	Mass of hardened concrete sample

v	Volume of displaced water
w_2	Sample weight in SSD condition
w_3	Sample weight in water
w_4	Sample weight in OD condition
f_m	Compressive strength of concrete
P	Maximum load
A	Cross sectional area of concrete
T	Tensile splitting strength of concrete
l	Length of cylindrical concrete sample
d	Diameter of cylindrical concrete sample

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CHAPTER 1

INTRODUCTION

1.1 Background

Concrete currently has become the most widely used material by the construction industry. Aggregate is part of concrete materials that generally constitutes at least 60% to 75% by volume of the concrete and the material may be naturally available. The aggregate in concrete can be categorized into two distinct categories; fine aggregate and coarse aggregate. Fine aggregate generally comprises of natural sand or crushed stone passing through 950 µm sieve mesh. Coarse aggregate on the other hand comprises of any particles greater than 950 µm where gravel constitutes most of coarse aggregate while the rest are from crushed stone. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed and crushed aggregate usually being produced by crushing quarry rock, boulders, cobbles, or even large-size gravel. Nowadays, vast growth and demand from the construction industry will eventually deplete the natural resources of the concrete materials especially aggregate that constitutes as major part of the concrete.

In contrast, as much as the need of raw materials for the construction industry, there is a rising trend regarding the disposal of waste materials originated from construction and demolition (C&D) works worldwide. Generally, the major compositions of waste materials from C&D works include concrete, asphalt and masonry (Settari *et al.*, 2015). In Malaysia, previous study conducted shows that solid waste generated by construction industry accounted for approximately 41% from total waste generation (MHLG, 2012).

Under the current construction practices with minimum efforts for recycling, only 5% of C&D wastes are recycled back to their purposes while most of the remaining wastes will be dumped in the landfill (SWML, 2015). Due to the fact that Malaysia is still recognized as a developing nation, the environmental impacts by construction industry is unfortunately significant since the urbanization growth rate is peaking (Begum and Pereira, 2011) as well as the limitation of insufficient recycling facilities that results in landfilling as the only available option to manage the waste.

However, research and development to evaluate the applicability of materials that are recycled from the C&D wastes to be used as part of concrete materials is extensively being conducted and has positively changed the scenario over the time. It is reported that other than for landfilling purposes, C&D wastes can be reprocessed to produce recycled aggregate (RA) and can be used to partially replace the need of natural aggregate as major component in concrete (Imam *et al.*, 2015).

RA is referred as aggregate that is reprocessed and reclaimed from useful C&D wastes for example old concrete, palm kernel shell, palletized blast furnace slag and asphalt pavement to produce recycled aggregate concrete (RAC) (Okafor, 2010). By studying the physical properties of the recycled aggregate from various sources, the performance of the RAC can be identified whether it is applicable to be used in the construction industry. For instance, the performance of RAC is greatly influenced by the physical properties of recycled aggregate such as aggregate source, grade of recycling, aggregate water absorption rate, shape and size of aggregate, presence of contaminants and chemical compositions (Ullah and Rahman, 2015). Besides that, with the previous development of international standards for example BS-8500-2 (2002) and RILEM

(1994), the use of recycled products is encouraged to be implemented in the construction industry.

Asphalt pavement is one of the most vastly generated C&D wastes other than concrete and masonry and the presence of the bituminous properties can be categorized as admissible in the category of inert waste (Settari *et. al.,* 2015). Generally, the main component of asphalt pavement is made up of natural aggregate and it contributes as one of the major consumption and demand for natural aggregate other than concrete. In asphalt pavement industry, demolished asphalt pavement can be reclaimed and reprocessed to produce asphalt and aggregate, and it is termed as recycled asphalt pavement (RAP) materials. Currently, most of the application of RAP materials is to be recycled back as pavement materials other than being used as embankment fill material with other low value purposes. Despite of its value that is purposely for recycled material in asphalt pavement industry, it is encouraged to optimize the use of RAP aggregate with other possible applications for example incorporation as material in Portland cement concrete.

However, there is a general lack of data determining the full potential of incorporation of the RAP aggregate in concrete. Only few studies had been conducted previously to explore the limitation of the RAP aggregate and hence, evaluating the suitability of the material as one of the components in Portland cement concrete. Therefore, this research is purposely to study the physical and mechanical properties of the RAP aggregate which later will influence the performance of RAC containing the RAP aggregate.

1.2 Problem statement

The problem statements of this research study are outlined as follow:

1. Vast growth and demand from construction industry nowadays will eventually deplete the natural resources of the aggregate as major part of concrete materials.
2. Recycling of waste materials is one of the modern days approach towards environmental sustainability.
3. Asphalt pavement is one of the major waste originated from C&D works in Malaysia.
4. Least studies have been conducted to evaluate the use of RAP aggregate in RAC and thus, lack of data pertaining its applicability to be used in Portland cement concrete.

1.3 Objectives

The objectives that need to be achieved for this study include:

1. To characterize the physical and mechanical properties of the RAP aggregate in comparison with natural crushed granite aggregate.
2. To assess the effects of partial replacement of natural granite aggregate by various percentages of RAP aggregate on properties of concrete.
3. To identify the potential applicability of the RAC comprising the RAP aggregate in construction industry.

1.4 Scope of works

This study will focus on assessing the potential of the RAP aggregate as a supplementary constituent of natural coarse granite aggregate in Portland cement concrete. There will be a total of six different concrete mixes comprising different percentages of aggregate replacement. The natural granite aggregate will be partially replaced with the RAP aggregate at 0%, 10%, 20%, 30%, 40%, and 50% while other parameters such as size of aggregate, water cement ratio as well as fine aggregate is kept constant for all mixes. There will be discussion and comparison in terms of physical and mechanical properties of the RAP aggregate with natural crushed granite aggregate, performance of each mix in terms physical and mechanical properties of concrete.

1.5 Layout of dissertation

This dissertation comprises of five different chapters. Chapter 1 introduces the background of this research, problem statements, objectives and scope of work. Chapter 2 reviews the literatures related to physical and mechanical properties of RAP aggregate as well as concrete containing RAP aggregate. Chapter 3 explains the research methodology adopted to achieve the research objectives. Chapter 4 presents the research results and discussion. Lastly, Chapter 5 outlines the research conclusions as well as recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Concrete industry is among the major consumer for naturally occurring materials namely sand as fine aggregate as well as gravel and granitic rock as source for coarse aggregate. Conversely, as much as the consumption of raw materials needed to produce concrete, the volume of waste generated from construction industry is increasing abruptly. Nowadays, both depletion of natural resources and disposal of construction and demolition (C&D) waste related problems are claimed as an environmental threat. Currently, the waste management related with the disposal of C&D waste is only focusing more to landfilling with least efforts for recycling the waste. Even though waste recycling is at minimum, it can be a promising solution to counter the environmental issues arise. Therefore, recycling of waste materials can be regarded as modern days approach towards the sustainability of the environment and as an effort to reduce the total volume of waste from C&D works (Ullah & Rahman, 2015).

Other than concrete industry, asphalt pavement industry is in the top list as major consumer for naturally occurring aggregate as part of pavement materials. At the same time, increasing volume of demolished asphalt pavement materials that are from road reconstruction projects are generated as C&D waste. The asphalt pavement waste usually will be repurposed back as sub-base material for the reconstruction process other than being used as embankment fill material. Recent studies reported that asphalt pavement waste can be valued as recycled waste materials namely recycled asphalt pavement

(RAP) aggregate which consist of asphalt and aggregate. The current practice of using RAP materials is to be used back in its closest area which is as pavement material. Other potential way to repurpose RAP materials is to incorporate the RAP aggregate with Portland cement to produce recycled aggregate concrete (RAC) (Okafor, 2010).

2.2 Recycled asphalt pavement (RAP) aggregate

Recycled asphalt pavement (RAP) materials refer to waste materials that are reclaimed and reprocessed from pavement reconstruction process. Materials that can be recycled from demolished pavement include asphalt and aggregate. As most of the application of RAP materials is to be recycled back as pavement materials, the use of RAP materials especially RAP aggregate to be incorporated with other possible applications is hardly can be quantified due to lacking data pertaining to its suitability to be used in other applications (Okafor, 2010). Thus, there is a need to assess the suitability of incorporating RAP aggregate with Portland cement to produce recycled aggregate concrete (RAC).

2.2.1 Contaminants

Generally, recycled aggregate from C&D waste comprises of contaminant substances for example ceramic particles, asphaltic particles as well as small amount of gypsum. The presence of contaminants in RAC can greatly influence its physical properties for example water absorption and carbonation (Ullah & Rahman, 2015). The same author also suggested that the volume of contaminants is greatly influenced by the source from which the waste materials is possessed as well as the process involved in the recycling plant. Therefore, it is important to evaluate the aggregate with bituminous contaminant in terms of physical and mechanical properties and to quantify its effects on properties of Portland cement concrete.

2.2.2 Percentage of aggregate replacement

RILEM (1992) proposed that the percentage of bituminous-coated aggregate in plain Portland concrete can be up to 35% for normal use concrete. However, Settari *et. al.* (2015) reported that for roller compacted concrete, it is possible to replace natural aggregate with RAP aggregate up to 50% replacement. Thus, it may be worthwhile to study the influence of the RAP aggregate replacement as substitute to normal granite aggregate on properties of concrete.

2.2.3 Size of aggregate

To acquire the RAP aggregate, demolished asphalt pavement must be milled and crushed into granulated particles before being sieved to various gradation. A proper and cost-effective recycling processes should be planned and implemented to achieve high quality and properly graded RAP aggregate. Similar to normal aggregate, the size distribution of RAP aggregate will influence the properties of the hardened RAC. Rahman *et. al.* (2009) suggested that aggregate size of 10 mm and 14 mm gives better compressive strength of hardened RAC than 20 mm aggregate size.

2.2.4 Specific gravity and absorption capacity

Specific gravity of recycled aggregate as well as its absorption capacity will be slightly different than that of natural aggregate. Kumar & Dhinakiran (2012) concluded that the presence of contaminants that has been discussed earlier will relatively lower the specific gravity while at the same time will increase the water absorption capacity of the recycled aggregate. The changes in specific gravity is due to the age of the source of aggregate, where older age of aggregate will inherit lower specific gravity value (Ullah & Rahman, 2015). The same author also suggested that source of the aggregate as well as the presence of contaminants will cause the water absorption capacity to be slightly higher than the natural aggregate. Based on this, it may be prudent to assess the effects of bituminous contaminant on the specific gravity and water absorption capacity of the recycled aggregate from RAP materials.

2.2.5 Crushing and impact values

Generally, crushing and impact values are greatly associated with the strength of aggregate. Stronger aggregate will relatively have higher resistance towards both crushing and impact and vice versa. According to Kumar & Dhinakaran (2012), crushing and impact values for recycled aggregate are comparatively higher than the natural aggregate together with the rising in age of source materials. Thus, evaluation of the mechanical properties of the recycled aggregate from RAP materials including crushing and impact values is rather to be carried out.

2.3 Recycled aggregate concrete (RAC)

Concrete made up from recycled aggregate is one of the innovative ways as cost saving initiative, to manage the total volume of waste generated from C&D works and to reduce the need of virgin aggregate to be used as concrete materials. The applicability of RAC to be used as in the case of normal concrete is not yet so popular and widely accepted by developers and contractors even though this is an alternative environmental friendly solution for sustainable concrete industry (Ullah & Rahman, 2015). For instance, there are abundance of wastes generated from pavement industry specifically in pavement reconstruction process and unfortunately, they ended up in landfill with minimum revalued purposes. Aggregate from RAP materials have great potential to be used as part of concrete materials as the gradation of the aggregate in asphalt pavement structure is closely related with that in normal plain concrete. But, limited study conducted previously causing general lack of data pertaining to the suitability and performance of RAP aggregate when utilized in Portland cement concrete. Thus, there is a need to assess the effects of the RAP aggregate in Portland cement concrete in terms of fresh and hardened properties of concrete.

2.3.1 Workability

Slump test is widely accepted to measure the level of workability of fresh concrete. The workability of freshly mixed concrete is highly related with the water absorption capacity of the aggregate used. When incorporating recycled aggregate in concrete, it is crucial to know its water absorption capacity as it will influence the total volume of water available for the hydration process of cement and whether it is exceeding the needs or is insufficient and later will influence its workability. Ullah & Rahman (2015) reported that for recycled aggregate, the water absorption rate will be slightly higher than the normal aggregate due to the presence of the contaminants carried by the aggregate and thus, the high-water absorption attributes to difficulties in controlling the workability and other properties of fresh concrete. To overcome the high water absorption capacity, Ullah & Rahman (2015) suggested that soaking the aggregate before being used in the concrete mix will increase the fresh concrete workability. But, the use of aggregate in saturated surface dried (SSD) condition might end up in bleeding during casting due to high water content inside the soaked aggregate (Poon *et. al.*, 2004). The bleeding phenomena could possibly lead to production of lower concrete strength.

2.3.2 Porosity and density

Porosity refers to the air voids in the hardened concrete and the volume of air content inside the hardened concrete will influence its density. Ullah & Rahman (2015) reported that concrete incorporated with higher aggregate replacement will have higher air voids and thus, will contribute towards lower density of the hardened concrete.

2.3.3 Compressive strength

Compressive strength or compression strength is the ability of the concrete to withstand high compressive load. For the use of recycled aggregate in concrete, there are four common variables which are source of recycled aggregate, degree of replacement, water to cement ratio as well as the moisture state of the recycled aggregate that will influence the mechanical properties of the hardened concrete. According to Ullah & Rahman (2015), concrete that made up from recycled aggregate has lower compressive strength in comparison with concrete made with natural aggregate. The same author also mentioned the relationship of the four common variables which contributed to the reduction in the compressive strength of the concrete. For instance, the degree of replacement of normal aggregate by recycled aggregate will influence the free water content for the hydration of cement that later will affect its workability and strength of hardened concrete. Thus, studying specifically the influence of the percentage replacement as manipulating variable while the other variables are kept constant to assess the effects of different percentage replacement by RAP aggregate on properties of concrete with no other contributing factors is important to be pursued.

2.4 Summary

The literature review discusses the potential of using recycled aggregate to fulfill the demand for virgin aggregate in sustainable concrete industry. Recycled aggregate from recycled asphalt pavement (RAP) materials can be a promising alternative as recycled concrete aggregate (RCA) to be incorporated with Portland cement concrete. Even though RAP aggregate has quite similar gradation profile in comparison with natural aggregate used in normal concrete, the presence of bituminous contaminant covering the RAP aggregate will become the major factor influencing the physical properties of the aggregate and properties of the concrete. Limit studies that have been conducted previously to assess the applicability of incorporating RAP aggregate with Portland cement concrete in order to evaluate the true potential of the recycled waste material which is yet be discovered. Thus, this research study aims to explore the optimum potential of RAP aggregate as a supplementary component in concrete.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the methodology adopted to achieve all the prescribed objectives as stated in Chapter 1 for instance assessing the physical and mechanical properties of RAP aggregate as well as physical and mechanical properties of concrete comprising RAP aggregate will be explained. All testing methods adopted in this study are based on American Society for Testing and Materials (ASTM) as well as British Standard (BS) testing procedures.

3.2 Experimental design

Figure 3.1 below shows the overall stages involved in experimental works for the study:

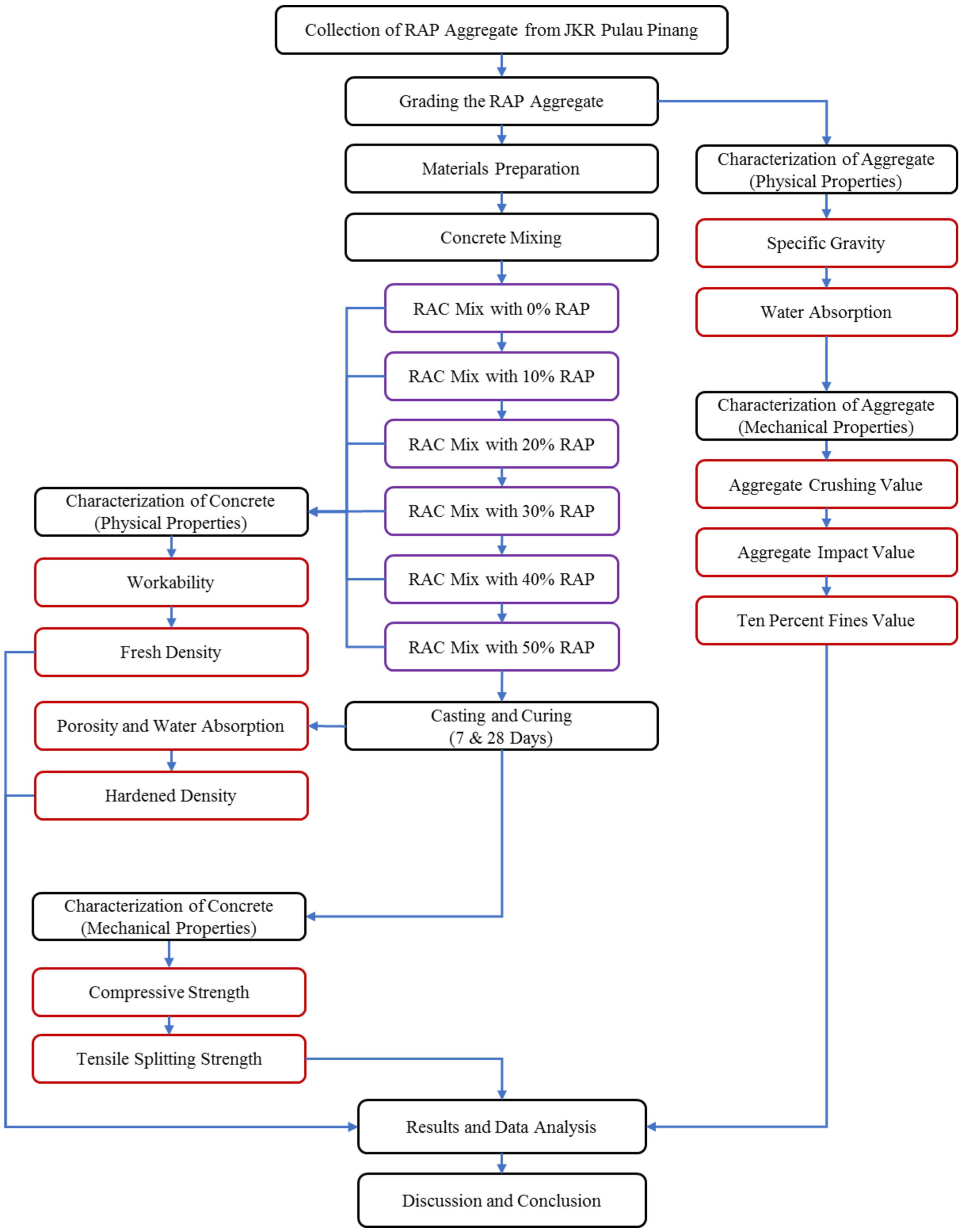

Figure 3.1: Overall stages of experimental works

3.3 Materials

The following materials were used to produce the RAC and conventional concrete in this study:

1. Portland cement Type I
2. River sand (as fine aggregate)
3. Crushed granite aggregate (as coarse aggregate)
4. RAP aggregate (as coarse aggregate replacement)
5. Water

3.3.1 Portland cement Type I

The cement that been used in this study was Portland cement Type I, which conformed with the requirements of BS EN 197-1. The Portland cement Type I was manufactured by Hume Cement Sdn Bhd (Figure 3.2). For the optimum use of the cement, the cement used in the concrete mixes did not exceed more than three months of storage period.

Figure 3.2: Portland cement Type I produced by Hume Cement Sdn Bhd

3.3.2 Sand

The fine aggregate that had been used was river sand (Figure 3.3). The grading of sand used was the sand passing sieve size of 2.36 µm and retained on 1.18 µm.

Figure 3.3: Rive sand in Concrete Laboratory

3.3.3 Crushed granite aggregate

The coarse aggregate used in this study was natural crushed granite aggregate as shown in Figure 3.4 and is obtained from a nearby quarry.

Figure 3.4: Natural crushed granite coarse aggregate

3.3.4 Recycled asphalt pavement (RAP) aggregate

The RAP aggregate that been used as partial coarse aggregate replacement for this study was acquired from JKR Pulau Pinang branch. The RAP aggregate was milled and recycled from the road throughout Pulau Pinang state. The RAP aggregate was screened using 20 mm, 14 mm, 10 mm and 5 mm sieve mesh and the RAP aggregate that passed 20 mm and retained on 14 mm and aggregate that passed 10 mm and retained on 5 mm sieve mesh has been used as coarse aggregate by partially replacing the crushed granite aggregate. The RAP aggregate used for the study was in oven-dried condition as can be referred in Figure 3.5 below.

Figure 3.5: RAP aggregate acquired from JKR Pulau Pinang

3.3.5 Water

Tap water was used as concrete mixing water throughout the study. The tap water was obtained from domestic water supply source available in the Concrete Laboratory, School of Civil Engineering, Universiti Sains Malaysia.

3.4 Characterization of aggregate (Physical properties)

This section will discuss the laboratory testing procedures conducted to characterize both natural crushed granite aggregate and RAP aggregate in terms of physical properties of aggregate. The testing procedures involved are based on the guidelines and standards from American Society for Testing and Materials (ASTM) and British Standards (BS).

3.4.1 Relative density (Specific gravity) of aggregate

Relative density or specific gravity is the characteristic that is generally used for calculating the volume occupied by the aggregate in concrete and is proportioned or analyzed on an absolute volume basis. For instance, relative density (specific gravity) in saturated surface-dried (SSD) condition (Figure 3.6) is used if the aggregate is wet and its water absorption has been satisfied. Conversely, the relative density (specific gravity) in oven-dried (OD) condition is used for computations when the aggregate is dry or assumed to be completely dry. The test conducted to determine the relative density (specific gravity) of natural crushed granite aggregate and RAP aggregate was in accordance with ASTM Designation: C 127-01. The specific gravity of the aggregate was calculated using Equation 3.1 as shown below:

$$\gamma = \frac{D}{D-(A-B)} \tag{3.1}$$

Where;

γ = Specific gravity

A = Mass of soaked (saturated) sample (g)

B = Mass of container filled with water (g)

D = Mass of oven-dried sample (g)

Figure 3.6: Saturated surface-dried aggregate

3.4.2 Water absorption of aggregate

Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for 24 hours period as in Figure 3.7. The test procedures used to determine the water absorption rate of coarse aggregate both natural granite aggregate and RAP aggregate were in accordance with ASTM Designation: C127-01. The percentage of water absorption capacity of aggregate can be calculated based on Equation 3.2:

$$\%\ Absorption = \frac{A - D}{D} \tag{3.2}$$

Where;

A = Mass of saturated surface-dried (SSD) sample (g)

D = Mass of oven-dried sample (g)

Figure 3.7: Soaked aggregate for saturated surface-dried condition

3.5 Characterization of aggregate (Mechanical properties)

This section will discuss the laboratory testing procedures conducted to characterize both natural crushed granite aggregate and RAP aggregate in terms of mechanical properties of aggregate. The testing procedures involved are based on the guidelines and standards from American Society for Testing and Materials (ASTM) and British Standards (BS).

3.5.1 Aggregate crushing value (ACV)

The aggregate crushing value (ACV) provides relative measures of the resistance of the aggregate to crushing under a gradually applied compressive load using compression testing equipment as shown in Figure 3.8. The test for determining the ACV value for both natural granite aggregate and RAP aggregate is in accordance with BS EN 812-110.

This method is applicable for testing aggregate passing 14 mm and retained on 10 mm sieve mesh. The following Equation 3.3 was used to calculate the ACV for both types of aggregate:

$$ACV\,\% = \frac{W_2}{W - W_1} \times 100\% \quad (3.3)$$

Where;

W = Weight of empty cylinder with base plate (g)

W_1 = Weight of compacted sample and cylinder with base plate (g)

W_2 = Weight of aggregate passing 2.36 mm sieve size (g)

Figure 3.8: Compression testing equipment

3.5.2 Aggregate impact value (AIV)

The aggregate impact value (AIV) provide relative measures of the resistance of aggregate when subjected to sudden shock or impact loads. Both natural crushed granite aggregate and the RAP aggregate were tested for resistance towards impact loads using