Physical and Mechanical Properties of Recycled Concrete Aggregates for Road Construction in Malaysia

By

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MACELLUS HILAREY MARCUS

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ABSTRACT

The physical and mechanical aggregate are one of the important factors that determine the asphalt-aggregate bond. In Malaysia, the common types of aggregates used for road construction are granite and sandstone, but application of recycled concrete aggregates (RCA) are less. As the RCA made up from construction & demolition waste (CDW), and the waste are increasing by time. Thus, the re-use of RCA are one of the solutions. The purpose of this study was to determine the suitability of using RCA in road construction based on a better understanding of its physical and mechanical properties such as strength, stiffness and durability of the aggregates. The RCA was collected from difference construction site. Aggregates tests had been conducted to determine the properties and characteristic of the recycled concrete aggregates. The aggregates tests are specific gravity and water absorption test, flakiness and elongation test, LA abrasion test, and impact value test. It was determined that the RCA are suitable to be used for construction of road pavement structure.

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LIST OF ABBREVIATIONS

RCA	Recycled Concrete Aggregate
NA	Natural Aggregate
CDW	Construction and Demolition Waste

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Aggregates has play an important role in road construction. It form the major portion of the pavement structure to bear stresses occurring on the roads and have to resist wear due to abrasive action of traffic. Aggregates are used in flexible as well as in rigid pavements. Therefore the properties of aggregates are considerable importance to road construction. The typical aggregates used in road construction in Malaysia namely are granite and sandstone.

In this study, samples of difference recycled concrete aggregates (RCA) will be test with several difference test methods such as Aggregate Impact Value Test, Los Angeles Abrasion Test, Specific gravity and Water Absorption Test, Flakiness and Elongation Index, etc. From the test results, it will be compared to the aggregates tests result of Natural Aggregates which is Granite.

Granite are most commonly used in road construction in Malaysia because the aggregates are easily available in Malaysia and has the strongest properties among other types of aggregate. The aggregate properties of Granite and Sandstone will become a benchmark to compare the RCA properties as it will determine the suitability of using RCA in road constructions.

1.2 Problem Statement

In Malaysia, the application of recycled concrete aggregate (RCA) are limited to road construction, although RCA has been used as a construction materials worldwide for decades. RCA obtained after the demolition of reinforced or plain cement concrete infrastructure. Studies has shown that, 2-3 billion tons of construction and demolition waste are produced yearly worldwide of which Malaysia produces 10-20 million tons. These quantities are increasing with continued growth in population and economies. This situation has results many countries face the challenge of extending their landfill site areas, due to the “construction & demolition waste” forming a major portion. Many landfill site in Malaysia have reached their capacity and need to be extended, or new sites are to be claimed within reasonable distance for viable waste delivery and management. Extending the landfill further is impossible as it is surrounded by buildings. Thus, a way to mitigate this problem is to re-use the non-decomposing or non-combustible waste in road construction.

1.3 Objective

The purpose of this study is to determine the suitability of using Recycled Concrete Aggregate (RCA) in road construction (pavement design) based on a better understanding of its physical and mechanical properties such as strength, stiffness and durability of the aggregates. The focus objectives of this study are listed as follows:

- To determine the physical and mechanical properties of RCA from certain site construction in Perak.
- To compare the physical and mechanical properties in term of difference RCA from difference site construction with Natural Aggregates.

1.4 Scope of Study

The scope of study will be focus on the literature research and several methods of aggregates test to determine the properties of the aggregates. The RCA samples are collected from three difference site whereby sample A (RCA-A) was collected from Bungalow house construction site (Taman Victoria, Ipoh), sample B (RCA-B) from Village 2, UTP (Tronoh, Perak), and sample (RCA-C) from New Development of Office Building construction site (Taman Maju, Perak). These include the results from tests to determine the physical-mechanical properties of the Natural Aggregates, NA (granite).

Aggregate tests was conducted with difference sample of RCA collected from difference site, to determine the physical and mechanical properties of aggregates. All the results data will be compared to the aggregates tests result with the typical aggregate used in road construction road in Malaysia which is granite. By the comparison of RCA and Natural Aggregates of its properties, the suitability of RCA used for road con struction can be determine.

All the standards and schedules will be conducted based on the compliance with British Standard, and JKR Standard Specification for Road Work.

CHAPTER 2: LITERATURE REVIEW

2.1 Aggregate

Aggregates is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement). By volume, aggregate generally accounts for 92% - 96% of bituminous concrete and about 70% - 80% of Portland cement concrete [1]. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements [2]. Aggregates can either rick formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing.

The quality of an aggregate is determined by how well particles interlock to provide structural support for upper pavement layers and protection to lower subgrade soils, and how stable the aggregate is under freeze-thaw and wet-dry cycles [3]. These function in turn depend on the physical and mechanical properties of the aggregate.

The physical and mechanical characteristics of the aggregate are one of the significant factor in determine the strength of the asphalt-aggregate bond. Thus, understanding the properties of aggregate is important as the aggregate properties play a dominant role in asphalt-aggregate bonding or de-bonding. This also help to determine where and how these aggregates can be used most effectively in roads.

2.2 Recycled Concrete Aggregates (RCA)

Recycled concrete aggregate is defined as recycled aggregate principally comprising crushed concrete (BS 8500-1: 2006). The application of RCA in construction work started almost 70 years ago just after the Second World War, when many structures were demolished by bombing. During rebuilding, the demolished concrete was used as aggregate especially in the base or sub-base layers in new road construction. Today, RCA is used successfully in many countries in many fields such as road construction, protection against erosion, parking areas as well as structural concrete. A number of structures in Germany, Norway, United Kingdom, Finland, and Netherlands have been built with RCA as partial or full replacement of natural aggregate (NA) [4] . Sustainability drivers in the use of RCA include reduced landfill and natural resource requirement, and potentially lower energy requirement to produce than NA. Several countries face the challenge of extending their landfill site areas, with C&DW forming a major portion [5]. Through price structuring, governments are encouraging sustainable solutions to such waste problems. Sound re-uses in concrete presents a solution.

The use of RCA in road design has to be controlled, and the composite behavior understood to ensure that required performance is achieved. Required measures include screening for contaminants and testing to ensure compliance with physical and durability requirements. As RCA has already been used in the construction industry internationally for number of decades, a large pool of information towards good practice and of mechanical and durability behavior is available. By applying good practice, it turns out that the mechanical properties of RCA are not that inferior, and meet the requirements of strength for certain application. There appears to be no or insignificant effect on road pavement strength at the replacement level of up to 30% of coarse aggregate by RCA, while a gradual reduction in strength may be found at increasing replacement percentages [6,7] . Less information is available on dimensional stability and durability, and indications are that the potential exists for increased shrinkage and creep, and reduced durability in terms of rates of ingress of deleterious matter into road pavement layers containing RCA in comparison with conventional road design. The results vary from country to country and also for different sources of RCA. Therefore there is a need for more and systematic research on the use of local RCA in road design subjected to mechanical and environmental actions.

2.3 Advantages of Recycled Concrete Aggregates

When any concrete structures are demolished or repaired, an international increasingly common method of utilizing the C&DW is concrete recycling. In the past, and to a large extent still today in South Africa, the routine disposal of C&DW was dumping it on the landfill sites but recycling provides an alternative feasible and attractive option in the present day because of greater environmental awareness, more environmental regulations and laws, and the desire to keep construction costs down. Recycling can be one of the best ways for us to have a positive impact on the world in which we live. Recycling helps in preserving the resources available for our future generations. If the current generation can utilize the natural resources more efficiently by converting them into new products, it means they are saving the natural resources for the following generations. Some reasons for recycled aggregates are as follows:-

i. It is accepted by several standards, including ASTM, AASHTO, JCI, Euro Code (EN206P as a source of aggregate for new concrete.
ii. RCA, if produced correctly and from properly selected waste materials, has a quality which meets and sometimes exceeds the requirements in specifications.
iii. RCA is usually of lighter weight per unit volume in comparison with natural aggregate and as a results, a reduction in structural self-weight may be achieved, leading to reduced costs.

iv. RCA is used in many developed and developing countries, and the structures are performing as well as those constructed using conventional aggregates (Cement Concrete & Aggregates, 2008).

v. RCA offers a way to reduce landfill waste streams.

2.4 Physical Properties

The physical properties of aggregates are those that refer to the physical structure of particles that make up the aggregate. The properties including:-

2.4.1 Absorption, Porosity, and Permeability

The inside pore characteristics are very important properties of aggregate particles. The size, the number, and the continuity of the pores through an aggregate particle may affect the strength of the aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action. Absorption relates to the particle's ability to absorb water into particles. Porosity is a ratio of the volume of the pores to the total volume of the particle. Permeability refers to the particle's ability to allow water to pass through. If the aggregates pores are not connected, it may have high porosity and low permeability.

2.4.2 Surface Texture of Aggregates

Surface texture is the pattern and the relative roughness or smoothness of the aggregate particle. Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger hot mix asphalt or Portland cement concrete. Surface texture also affects the workability of hot mix asphalt, the asphalt requirements of hot mix asphalt, and the water requirements of Portland cement concrete. Some aggregates may initially have good surface texture, but may polish smooth later under traffic. These aggregates are unacceptable for final wearing surfaces. Limestone usually falls into this category.

Dolomite does not, in general, when the magnesium content exceeds a minimum quantity of the material.

2.4.3 Strength and Elasticity

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces. Elasticity measures the "stretch" in a particle. High strength and elasticity are desirable in aggregate base and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material. The best results for Portland cement concrete may be obtained by compromising between high and low strength, and elasticity. This permits volumetric changes to take place more uniformly throughout the concrete.

2.4.4 Density and Specific Gravity

Density is the weight per unit of volume of a substance. Specific gravity is the ratio of the density of the substance to the density of water. The following chart illustrates these relationships for some common substances.

Typical Values		
Substance	Specific Gravity	Density (lb/ft^3)
Water	1.0 (73.4 °F)	62.4 (73.4 °F)
Limestone	2.6	165 to 170
Lead	11.0	680 to 690

The density and the specific gravity of an aggregate particle is dependent upon the density and specific gravity of the minerals making up the particle and upon the porosity of the particle. These may be defined as follows:

1) All of the pore space (bulk density or specific gravity)

2) Some of the pore space (effective density or specific gravity)

3) None of the pore space (apparent density or specific gravity)

Determining the porosity of aggregate is often necessary; however, measuring the volume of pore space is difficult. Correlations may be made between porosity and the bulk, apparent and effective specific gravities of the aggregate. As an example, specific gravity information about a particular aggregate helps in determining the amount of asphalt needed in the hot mix asphalt. If an aggregate is highly absorptive, the aggregate continues to absorb asphalt, after initial mixing at the plant, until the mix cools down completely. This process leaves less asphalt for bonding purposes; therefore, a more porous aggregate requires more asphalt than a less porous aggregate. The porosity of the aggregate may be taken into consideration in determining the amount of asphalt required by applying the three types of specific gravity measurements. In the example in Figure 3-1, the bulk specific gravity includes all the pores, the apparent specific gravity does not include any of the pores that would fill with water during a soaking, and the effective specific gravity excludes only those pores that would absorb asphalt. Correlation charts and tables provide guidance to asphalt quantities or acceptability of the aggregate.

2.4.5 Aggregate Shape and Surface Texture

Particle shape and surface texture are important for proper compaction, deformation resistance, HMA workability and PCC workability. However, the ideal shape for HMA and PCC is different because aggregates serve different purposes in each material. In HMA, since aggregates are relied upon to provide stiffness and strength by interlocking with one another, cubic angular-shaped particles with a rough surface texture are best. However, in PCC, where aggregates are used as an inexpensive high-strength material to occupy volume, workability is the major issue regarding particle shape. Therefore, in PCC rounded particles are better. Relevant particle shape/texture characteristics are:

i. Particle shape

Rounded particles create less particle-to-particle interlock than angular particles and thus provide better workability and easier compaction. However, in HMA less interlock is generally a disadvantage as rounded aggregate will continue to compact, shove and rut after construction. Thus angular particles are desirable for HMA (despite their poorer workability), while rounded particles are desirable for PCC because of their better workability (although particle smoothness will not appreciably affect strength) (PCA, 1988).

ii. Flat or elongated particles.

These particles tend to impede compaction or break during compaction and thus, may decrease strength.

iii. Smooth-surfaced particles.

These particles have a lower surface-to-volume ratio than rough-surfaced particles and thus may be easier to coat with binder. However, in HMA asphalt tends to bond more effectively with rough-surfaced particles, and in PCC rough-surfaced particles provide more area to which the cement paste can bond. Thus, rough-surface particles are desirable for both HMA and PCC.

2.5 Mechanical Properties

Mechanical properties of aggregates are important, especially when the aggregate is to be used in road construction where it is subjected to high wear. It is generally understood that the compressive strength of pavement layer cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. The required information about the aggregate particles has to be obtained from indirect tests, such as crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in road pavement layer. The aggregate crushing value (ACV) test is prescribed by different standards, and is a useful guide when dea1ing with aggregates of unknown performance. Toughness can be defined as the resistance of aggregate to fai1ure by impact, and it is usual to determine the aggregate impact value of bu1k aggregate based on BS standard [8,9]. Toughness determined in this manner is related to the crushing value, and can, in fact, be used as an alternative test. Hardness, or resistance to wear, is an important property of concrete used in roads and in floor surfaces subjected to heavy traffic. The aggregate abrasion value of the bulk aggregate is assessed using Los Angeles abrasion machine. The Los Angeles Abrasion test combines the processes of attrition and abrasion, and gives results which show a good correlation not only with the actual wear of the aggregate in concrete but also with the compressive and flexural strength of concrete when made with the same aggregate.

CHAPTHER 3: METHODOLOGY

3.1 Project Execution Flow Chart

In order to achieve the objectives that have been highlighted, a complete methodology has been set up in this project. This methodologies show the procedures and steps on how the project been conducted within the given timeframe. In this project, a series of experiments are used in order to come out with findings and solutions to the objectives as well as reflecting the title of the project. The project execution flow chart below shows the procedures involved in this project.

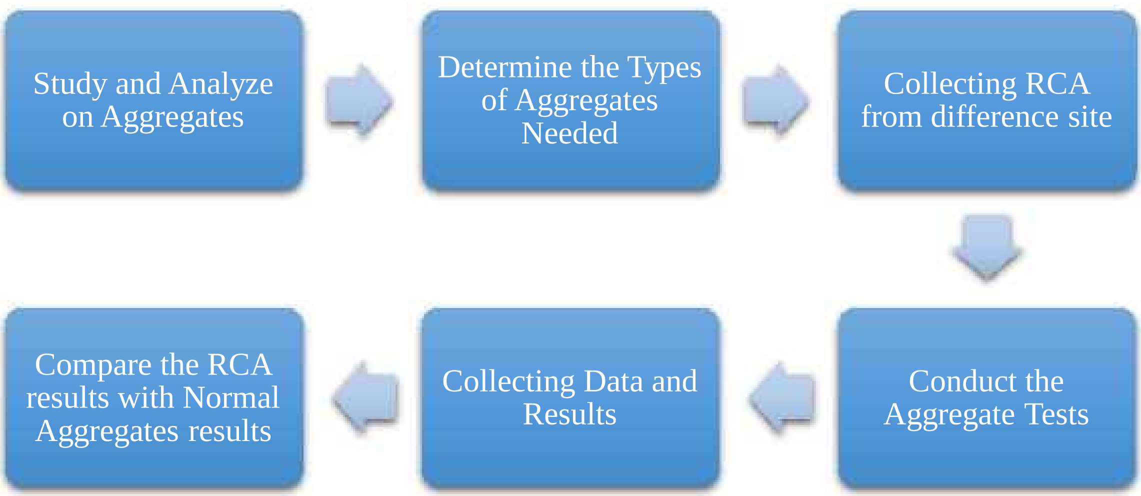


Figure 3.1: Methodology of Project

3.2 Aggregates Tests

The materials used in this research are recycled concrete aggregates and natural aggregates produced from crushing waste concrete. The recycled concrete aggregate was produced by crushing manually using a steel hammer. The size samples for recycled concrete aggregates and natural aggregates used for this study and 10mm – 20mm. The physical and mechanical properties of the recycled concrete aggregates and natural aggregates were determined by conducting standard tests on the specimens of the aggregates. The aggregate tests are:

i. Specific Gravity and Water Absorption Test
ii. Flakiness Index and Elongation Index
iii. Los Angeles Abrasion Test
iv. Impact Value Test

Figure 3.2.1: Sample Recycled Concrete Aggregates

3.2.1 Specific Gravity and Water Absorption Test

The main purpose of this test is to determine the bulk and apparent specific gravity and absorption of the aggregates particles after 24 hours soaking in the water.

Equipment and Apparatus:

i. Oven
ii. Soft Absorbent Cloths
iii. Airtight Container
iv. Electronic Balance
v. Pycnometer
vi. Hairdryer
vii. Sample Trays
viii. Glass Vessel

Procedure:

i. 1 kg of aggregate sample has been used. The sample is been thoroughly washed on the sieve to remove finer particles, particularly clay, slit and dust.
ii. The prepared sample is been immerse in water in the glass vessel at 20 ± 5°C for 24 ± 0.5 hours. After the immersion period, remove air entrapped on, or bubbles on the surface of the aggregate. Then the vessel

is overfilled by adding water and slide the plane ground glass disc over the mouth so as to ensure that no air is trapped in the vessel. The vessel then has been dry on the outside and weighed. (The weight is mass B)

iii. Then the vessel is emptied and allowed the aggregate to drain while the vessel is refilled with water, sliding the glass disc into position as before. The vessel is dried on the outside and been weighed (mass C).

iv. Next, the aggregate is placed on a dry cloth and gently surface-dry it with the cloth. The weigh is recorded (mass A).

v. The aggregate is placed in the shallow tray in the oven at a temperature of 105 ± 5°C for 24 ± 0.5 hours. Then it been cooled in the airtight container and weighed (mass D).

vi. Calculate particle densities as follows:

$$\text{Particle density on an oven-dried basis} = \frac{D}{A - (B - C)}$$

$$\text{Particle density on a saturated and surface-dried basis} = \frac{A}{A - (B - C)}$$

$$\text{Apparent particle density} = \frac{D}{D - (B - C)}$$

$$\text{Water absorption (\% of dry mass)} = \frac{100\,(A - D)}{D}$$

vii. The mean results shall ne reported for each form of particle density determined. The values of particle density shall be reported to the nearest 0.01 and those for water absorption to the nearest 0.1%.

Figure 3.2.1.1: Aggregates inside glass vessel

3.2.2 Flakiness Index and Elongation Index Test

To determine the flakiness and elongation of the aggregates

Equipment:

i. Riffle Box
ii. Ventilated Oven
iii. Test Sieves
iv. Electronic Balance
v. Metal Thickness Gauge
vi. Metal Length Gauge

Procedure: (Flakiness Index)

i. Take sufficient quantity of aggregates such that a minimum number of 280 pieces of any fraction can be tested.
ii. Sieve the aggregates first in IS sieve 63 mm and collect the aggregates passing through this sieve and retained on Is sieve 50 mm. Let it be w1 g.
iii. Pass the above aggregates though the 33.90 mm slot of thickness gauge.
iv. Collect the aggregates which are passing in the gauge in a separate tray.

v. Repeat the same procedure for the remaining sample of aggregate according to the table given below.

vi. Weigh the aggregate passing through the various slots of the thickness gauge and let it be W.

vii. Calculate the flakiness index which is taken as the total weight of material passing the various slots of the thickness gauge expressed as a percentage of the total weight of sample taken.

Procedure: (Elongation Index)

i. Take sufficient quantity of aggregate such that a minimum number of 200 pieces of any fraction can be tested.

ii. Sieve the aggregates through 80 mm IS sieve and collect the sample passing 890 mm and retained on 40 mm and weigh them accurately. Let it be w1 g.

iii. Pass each and every piece of aggregate from the above sample through the 81.0 mm slot of the length gauge.

iv. Collect the aggregates that are retained in a separate tray.

v. Repeat the same procedure for the remaining aggregate according to the table given below.

vi. Calculate the elongation index that is taken as the total weight of material retained on the various slots of the length gauge expressed as a percentage of total weight of material sample taken.

Flakiness Index Calculation

$$\text{Flakiness Index} = \frac{\text{Total Passing}}{\text{Total Passing + Total Retained}} \times 100$$

Elongation Index Calculation

$$\text{Elongation Index} = \frac{\text{Summation of fractions}}{\text{No of fractions}} \times 100$$

3.2.3 Los Angeles Abrasion Test

To determine the aggregates abrasion value in order to evaluate the difficulty with which aggregates particles are likely to wear under attribution from traffic.

Equipment:

i. Los Angeles Abrasion Machine
ii. Steel Ball Abrasion Charges (12 Steel Balls)
iii. 4.75mm and 1.18mm test sieves
iv. Electronic Balance

Procedure:

i. Approximately 5 kg of coarse aggregate retained is placed on the No.4 ASTM sieve (4.75 mm) into the Los Angeles abrasion machine.
ii. 12 steel balls of 44-48 cm in diameter and weight 390-445 g each was feed in as an abrasion charges.
iii. The machine is been turn on and let he drum rotate at 30-33 rpm for 500 revolutions.
iv. After 500 revolutions, the machine is stop automatically and all the steel balls is been taken out. All the aggregates in the drum were collected.

Pass the aggregate through No.12 ASTM sieve (1.18 mm) and weigh the material passing this sieve.

v. Determine Los Angeles abrasion value as follow:

$$\text{Los Angeles abrasion value} = \frac{M_2}{M_1} \times 100\%$$

vi. The result is reported to the nearest 0.1.

3.2.4 Impact Value Test

To determine the toughness of aggregate due to impact

Equipment:

i. Impact Testing Machine
ii. Cylinder Metal
iii. Tamping Rod
iv. Sieve 12.5mm, 10mm, 2.36mm
v. Electronic Balance
vi. Oven

Procedure:

The test sample consists of aggregates sized 10.0 mm 12.5 mm. Aggregates may be dried by heating at 100-110° C for a period of 4 hours and cooled.

i. Sieve the material through 12.5 mm and 10.0mm IS sieves. The aggregates passing through 12.5mm sieve and retained on 10.0mm sieve comprises the test material.
ii. Pour the aggregates to fill about just 1/3 rd depth of measuring cylinder.
iii. Compact the material by giving 25 gentle blows with the rounded end of the tamping rod.

iv. Add two more layers in similar manner, so that cylinder is full.

v. Strike off the surplus aggregates.

vi. Determine the net weight of the aggregates to the nearest gram (W).

vii. Bring the impact machine to rest without wedging or packing up on the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.

viii. Fix the cup firmly in position on the base of machine and place whole of the test sample in it and compact by giving 25 gentle strokes with tamping rod.

ix. Raise the hammer until its lower face is 380 mm above the surface of aggregate sample in the cup and allow it to fall freely on the aggregate sample. Give 15 such blows at an interval of not less than one second between successive falls.

x. Remove the crushed aggregate from the cup and sieve it through 2.36 mm IS sieves until no further significant amount passes in one minute. Weigh the fraction passing the sieve to an accuracy of 1 gm. Also, weigh the fraction retained in the sieve.

Compute the aggregate impact value. The mean of two observations, rounded to nearest whole number is reported as the Aggregate Impact Value.

Calculation

Total weight of dry sample (W1 gm)

Weight of portion passing 2.36 mm sieve (W2 gm)

Aggregate Impact Value (percent) = W2 / W1 X 100

Recommended Values

Classification of aggregates using Aggregates Impact Value is as given below:

Aggregate Impact Value	Classification

<20%	Exceptionally Strong
10-20%	Strong
20-30%	Satisfactory for road surfacing
>35%	Weak for road surfacing

Figure 3.2.4.1: Impact Testing Machine

3.3 Project Key Milestones

NO	ACTIVITIES	SEPT 2014				OCT 2014				NOV 2014				DEC 2014				
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1	Preparing Samples																	
2	Lab testing work for aggregates																	
3	Collecting and analysis data																	
4	FYP 2 progress report submission																	
5	Continue on lab work, and collecting and analyzing data																	
6	Pre-SEDEX & Presentation																	
7	Submission of Dissertation																	
8	Submission of Technical Paper																	
9	Oral Presentation 2 (VIVA)																	
10	Submission of Hard bound Report																	

Table 3.1: Grant Chart

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The results of aggregate tests performed on samples from each of three recycled concrete aggregates (RCA) sources are presented and discussed in this chapter. The RCA samples are collected from three difference site whereby sample A (RCA-1) was collected from Bungalow house construction site (Taman Victoria, Ipoh), sample B (RCA-B) from Village 2, Universiti Teknologi Petronas (Tronoh, Perak), and sample (RCA-C) from New Development of Office Building construction site (Taman Maju, Perak). These include the results from tests to determine the physical-mechanical properties of the Natural Aggregates, NA (granite).

4.2 Specific Gravity and Water Absorption Tests result

Specific gravity or density and water absorption of aggregates are the main properties that needed to design road pavement mixes in road construction. The density of an aggregates is the mass ratio equal to the volume of water that had been distilled at a certain temperature. The water-permeable voids may contain in the aggregates, therefore two measurements of density of aggregates are used: apparent specific gravity and bulk specific gravity.

- Apparent Specific Gravity, Gapp, is estimated on the base on the aggregates clear volume (i.e the volume excluding water permeable voids). Thus

$$\text{Gapp} = \frac{M\ /V}{W}$$

whereby, Md is the dry mass of the aggregate, Vn is the clear volume of the aggregate, and W is the water density.

- Bulk Specific Gravity, Gbulk, is calculate base on the total volume of aggregates (include the water permeable voids). Thus

$$\text{Gbulk} = \frac{M \ \ /V}{W}$$

where, VB is the total volume of the aggregates.

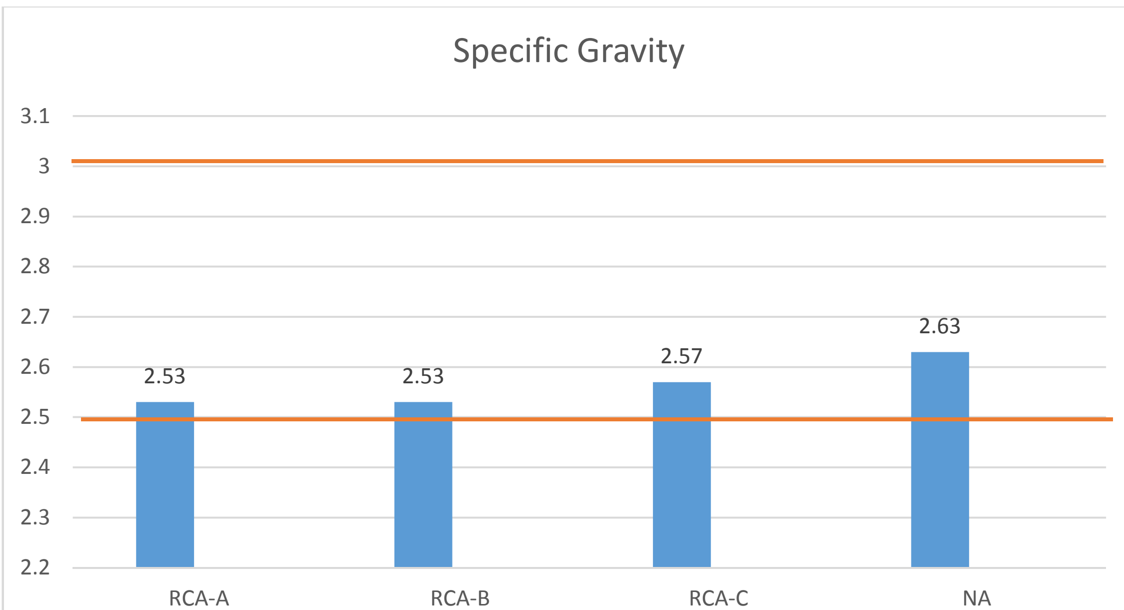
- Water absorption, the water permeable void of aggregates is the only difference between the bulk gravity and apparent specific gravity. The volume of such void can be determine by weighing the dry aggregates and the saturated aggregates. The value of Mw makes the different between dry and in saturated aggregates. Thus

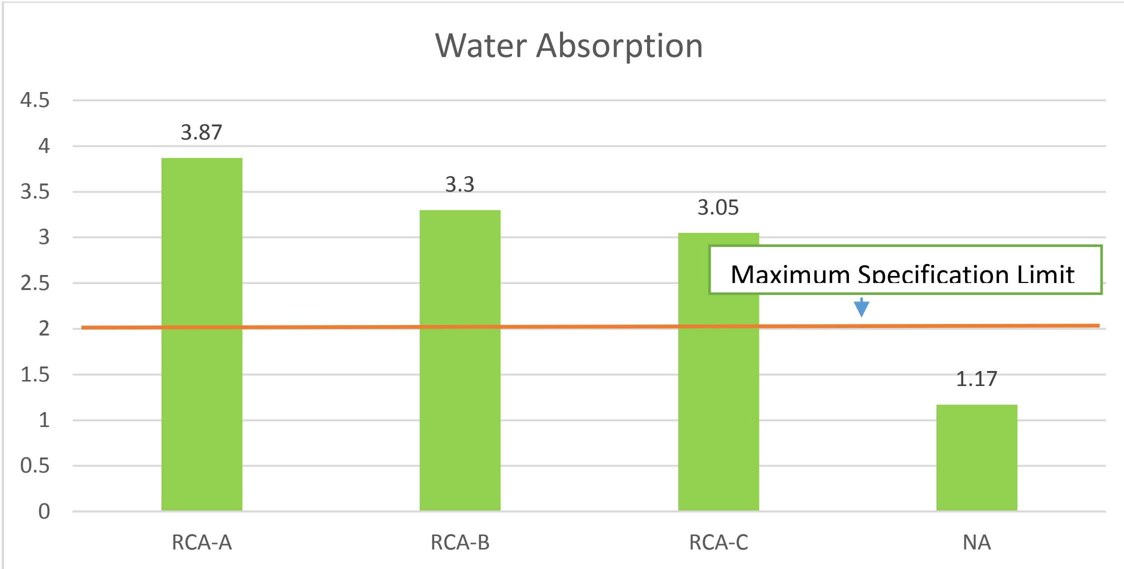
$$\text{water absorption} = \frac{M}{M} \text{ x } 100$$

The typical value specific gravity of aggregates used in road construction are fall in to the ranges between 2.5 to 3.0. Water absorption values ranges from 0.1 to about 2.0 percent for aggregates normally used in road surfacing. Table 4.2.1 below show that the result for water absorption and specific gravity of three RCA samples and NA samples for the mixtures. As can be seen, the specific gravity of samples for normal aggregate is almost the same compared to the recycled aggregates. For the absorption the absorption capacity of each RCA samples was higher than NA sample by 2%. This is indicated that the recycled concrete aggregates has a lower density than the natural aggregates and also has the higher porosity of the recycled concrete particles. Thus, all the samples have met the condition and suitable to be used for road construction.

Samples	Specific Gravity	Absorption Capacity, %
RCA-A	2.52	3.87
RCA-B	2.53	3.30
RCA-C	2.57	3.05
NA	2.63	1.17

Table 4.2.1: Specific gravity and water absorption





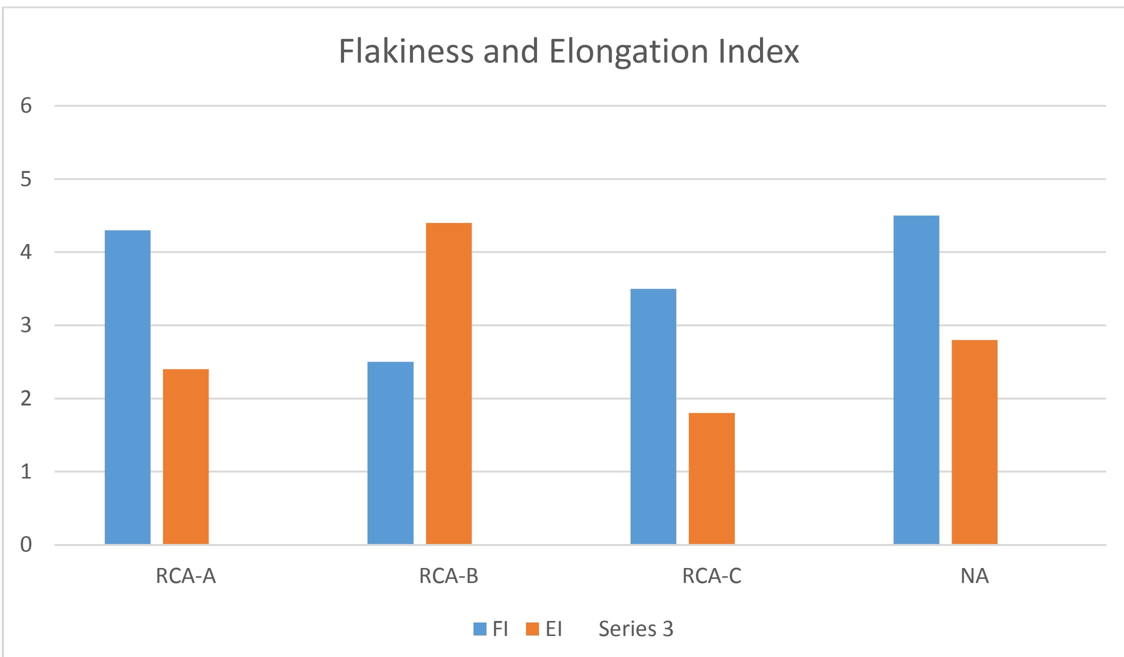
4.3 Flakiness Index and Elongation Index Test Results

The aggregate mass it particles shape was determined by the percentage of elongation and flakiness particles in the aggregates. Aggregates which are flaky or elongated are tend to cause lower workability and stability mixture of pavement. The flakiness index can be determined as the percentage by the aggregates particles weight where the dimension is less than 0.6 times their original size. Test procedure had been standardized by BS812: Part 105.1: 1985. Meanwhile for the elongation index of an aggregate is determined as the percentage by the aggregates particles weight where the dimension is bigger as 1.8 times the original dimension. The test for flakiness index is applicable to aggregates that has more than 6.3 mm length. However for the elongation index test, it has no limits size.

The flakiness and elongation indexes tests on RCA and NA were conducted according to British Standard. The results are as shown in Table 4.3. The values of flakiness and elongation indexes of all the RCA samples are lower compared to the value of natural aggregate. Thus, the RCA is flakier than NA and this will reduce the workability of pavement mixture that use the RCA. The overall results of RCA flakiness index are lower than 25% where according to the JKR standard it is suitable to be used for construction of road pavement. This means that RCA is suitable to be used as coarse aggregate in road construction.

Samples	Flakiness Index (%)	Elongation Index (%)
RCA-A	19.40	11.30
RCA-B	18.70	11.80
RCA-C	21.50	13.40
NA	38.33	39.10

Table 4.3.1: Flakiness and Elongation Index value



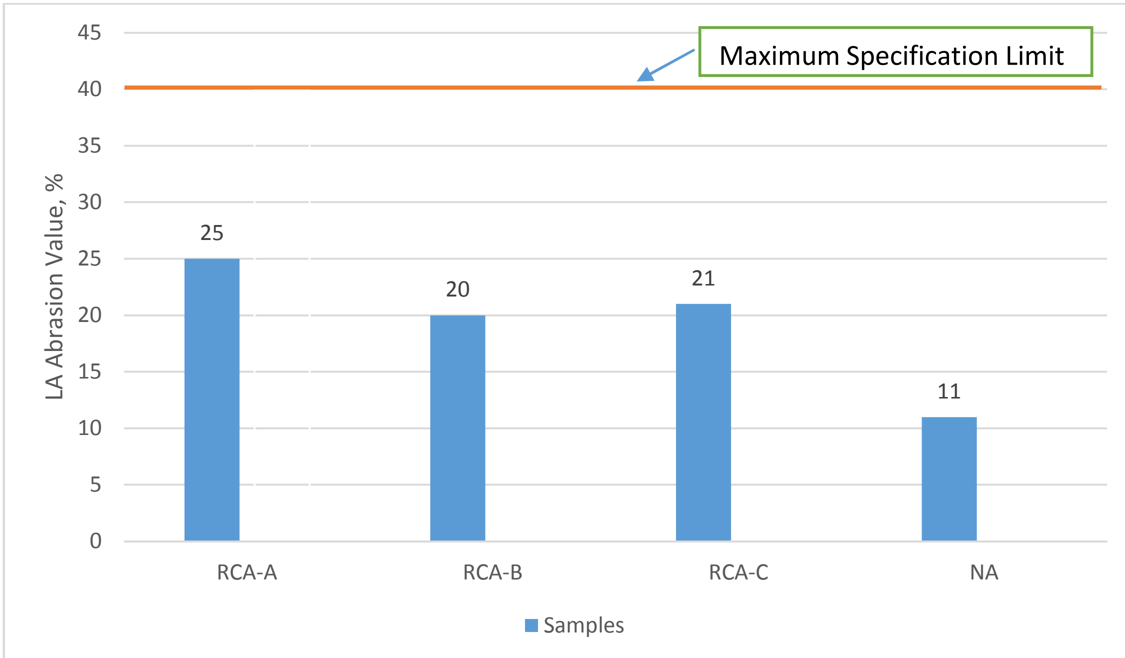
4.4 Los Angeles Abrasion Tests Results

The purpose of LA Abrasion test been carried out is to test the hardness of aggregates properties and to determine whether the aggregates are feasible to be used on construction of pavement layer. Los Angeles abrasion test is been standardized by BS812: Part 113:1990. The main focus of Los Angeles abrasion test is to find the percentage of wear due to relative rubbing action between the aggregate and steel balls used on this test. Los Angeles machine consists of circular barrel with the diameter of 700 mm and the length of 520 mm attached on horizontally to enable it to be rotated. An abrasive charge consist of steel round balls with a diameter of 48 mm and weighing 340-445 g was placed in the barrel along with the aggregates. The numbers of the abrasive steel balls used are difference depending on the grading of the sample. The quantity of aggregates to be used on this test depends on the gradation and normally it ranges between 5-10 kg. The barrel is then locked and rotated at the speed of 30 rpm for a total of 500 revolutions. After completed the 500 revolutions of rotation, the aggregate is sieved through 1.7 mm sieve and the weight of passing aggregates are taken. This value is called Los Angeles abrasion value. For bituminous concrete, a maximum value of 40 is specified.

This test was conducted according to ASTM C131 standard method. Figure 4.1 shows the results of the Los Angeles tests, where the L.A. abrasion loss value in percentage has been shown. As can be seen, the all the recycled concrete aggregates have a higher abrasion value compared to the normal aggregate. The RCA had a consistent results for Los Angeles Abrasion value which is 20% -25% greater than that for the NA which is only 11%.

Samples	LA Abrasion Value, %
RCA-A	25
RCA-B	20
RCA-C	21
NA	11

Table 4.4.1: LA Abrasion Value



According to the requirement of JKR specification, the maximum percentage of abrasion value for bituminous road surfacing is limited to 40 which is satisfied for all mixtures for road mixtures. From the results, it is indicating that the use of recycled concrete aggregates in bituminous road surfacing will not cause any problem related to the resistance and abrasion, and suitable road mixtures.

4.5 Impact Value Test Results

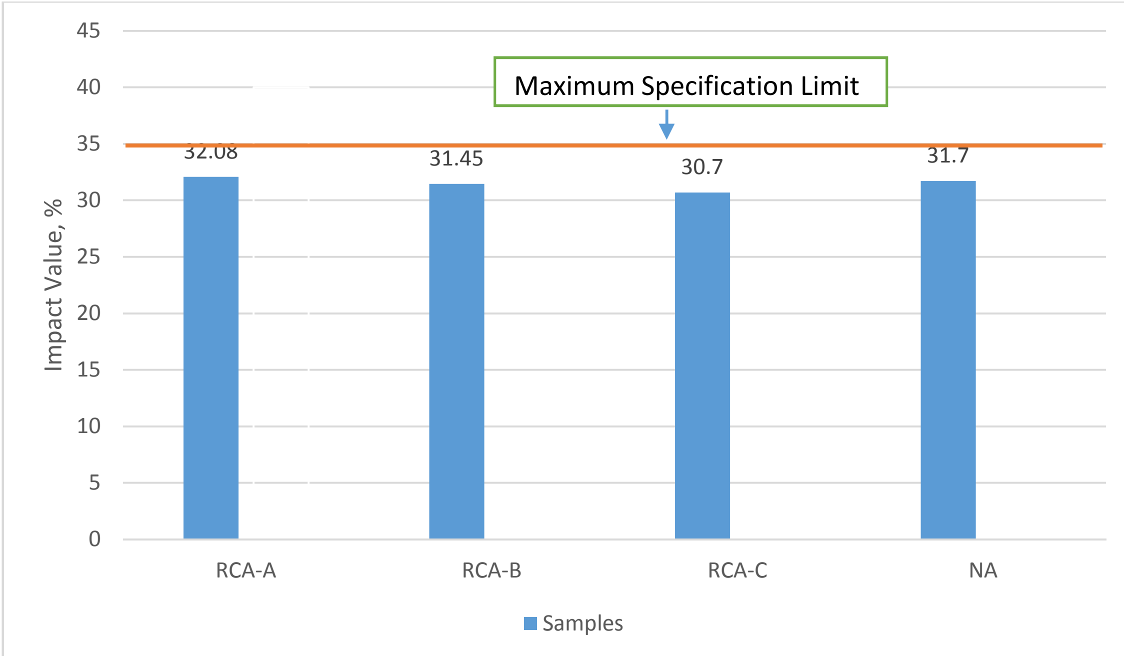
Aggregate impact value test is carried out to determine the resistance to impact of aggregates and the resistance of aggregates subjected to a sudden loading. Size of aggregates that passing 12.5 mm sieve and retained on 10 mm sieve are to be used. Then the aggregate is filled in a cylindrical steel cup with the diameter size of 10.2 mm and depth of 50 mm where it is attached to a base made up from metal of the impact testing machine. The aggregates are filled in 3 layers where each layer is hammered for 15 number of blows. Metal hammer with the weight of 13.5 to 14 Kg is drop with a free fall of 38.0 cm high. The crushed aggregate that pass through 2.36 mm IS sieve is weight as a impact value. And the impact value is measured as percentage of aggregates passing sieve (W2) to the total weight of the sample (W1).

$$\text{Aggregate impact value} = \frac{W1}{W2} \times 100$$

Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent.

Samples	Impact Value, %
RCA-A	32.08
RCA-B	31.45
RCA-C	30.70
NA	31.70

Table 4.5.1: Impact Value



The high value percentage denotes a low performance of aggregate in pavement or the strength of pavement layer in the field. In this study, as in table 5, shows that the impact values of recycled aggregate are similar compared to natural aggregate. The impact value for RCA range from 30.70% - 32.08% and NA have the value of 31.70%. From the test result, the all the RCA samples and NA samples fall below 35%, which means that recycled aggregate can perform in the field quite similar strength in concrete when compared to natural aggregate.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In order to determine the suitability of mechanical properties of RCA used in road pavement construction, it is necessary to determine their resistance to fragmentation and impact by the LA Abrasion Test and the Impact Value Test. The results of the LA abrasion and Impact Value test showed that the RC Aggregates had close value of results compared with the Natural Aggregate which is granite. This indicates that the recycled concrete aggregates can perform in field quite similar to natural aggregates. Meanwhile, for the physical properties of RCA, flakiness and elongation index, and particle density and water absorption test was conducted to determine the size, shape and absorption rate of water of the aggregates. From the result showed that the value of flakiness and elongation index for RCA and lower than the natural aggregates. For the specific gravity, the result value of RCA are almost the same as NA, and water absorption of RCA are more than 2% which indicate that the rate of water absorption for RCA are higher compared to NA. In conclusion, the properties of recycled concrete aggregate has meet all the JKR specification for the aggregates to be used in road pavement construction, and the RCA are suitable to be used as course aggregates in road pavement mixture.

5.1 Recommendation

Below are few suggestions that may give some idea to continue the study on the physical and mechanical properties of Recycled Concrete Aggregates use in road construction:-

i. Study should be conducted by using more samples of RCA from more than five difference construction site.

ii. Additives can be add into RC aggregates to decrease the percentage of porosity of particles.

iii. The equipment and machines in the laboratory has to be maintained and calibrated frequently to maintain the effectiveness.

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