THE PROPERTIES OF DIFFERENT AGGREGATE TYPES USED AS HIGHWAY CONSTRUCTION MATERIAL

MOHD SHAFIQ BIN SHAHRIN

CIVIL ENGINEERING
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By

MOHD SHAFIQ BIN SHAHRIN

Supervise by

AP IR DR. IBRAHIM KAMARUDDIN

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Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

Ibrahim Kamaruddin

Assoc. Prof. Ir. Dr. Ibrahim Kamaruddin

AP Ir Dr. Ibrahim Kamaruddin
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

Shafiq.

Mohd Shafiq Bin Shahrin

ABSTRACT

This research is to evaluate the properties of several aggregate types (limestone, granite and Recycled Concrete Aggregate) used in construction and also to determine the feasibility of RCA as highway construction material. Feasibility of RCA as highway construction material needs to be determined due to depletion of natural aggregate sources that becomes one of the big issues in construction field. The physical properties of selected aggregates were investigated in term of hardness, shape and specific gravity. The scope of studies involved would be on towards the various aggregate tests which include Los Angeles (LA) abrasion test, soundness test, sieve analysis, aggregate impact value test, aggregate crushing value test, flakiness and elongation test, 10% fines test and relative density test.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

RCA	Recycled Concrete Aggregate
AIV	Aggregate Impact Value
ACV	Aggregate Crushing Value
LA	Los Angeles
FI	Flakiness Index
EI	Elongation Index

1. INTRODUCTION

1.1 Background of study

Aggregates are granular mineral particles used as one of materials for construction of road bases, backfill, etc. Some typical uses of aggregates are Portland cement concrete, asphalt concrete, asphalt surfaces, road bases and sub-bases, railroad ballast, trench backfill, fill under floor slabs, concrete blocks, water filtration beds, drainage structures, riprap, and gabion material.

Properties required in an aggregate depend on its proposed use. However the types of aggregates, their basic properties, and tests used to evaluate these properties apply to most uses.
All properties of several types of aggregate will be discussed in this report. The aggregates are granite, limestone and recycled concrete aggregate (RCA).

1.1.1 Granite

Granite is categorized as one of intrusive igneous rocks, produced by magma. The textures of granite vary from medium to coarse. The granite color depends on their chemistry and mineralogy. It can be pink to dark grey. It can be in black color also.

1.1.2 Limestone

Limestone is a type of sedimentary rocks. It contained large amount of mineral calcite (calcium carbonate, $CaCO_3$). Limestone is an important stone for masonry and architecture, but granite and sandstone are more commonly used. It also can be processed to produce cement. Most of caves in Malaysia are made of limestone.

1.1.3 Recycled concrete aggregate (RCA)

Recycled concrete aggregates can be obtained from housing redevelopment site and concrete pavement rehabilitation project. RCA are come from common aggregates such as granite or basalt. The difference is presence of harden cement layer on the surface of the aggregates. So, it will reduce the permeability hence reduce the porosity of the aggregate.

1.2 Problem Statement

Without conducting any investigations, it is hard to predict the properties of an aggregate. The purpose of the investigation is to ensure the ability of the aggregate to resist any potential failure before it can be used in construction. If the investigations are not been carried out, the failures that may occur are:

- Cracking on surface of road
- Low skid resistance
- Short life span

For an example, before flexible pavement is constructed, sieve analysis need to be conducted to determine the gradation of the aggregate used. In construction of flexible pavement, well-graded gradation of aggregate must be obtained because the strength of the pavement is depends on interlock of the particles. If the aggregate is not well-graded gradation, it can't be used in the construction because it may cause failure to the pavement due to low strength, less friction between the particles. Some of the failures are alligator cracking due to weak base and sub-base and the other one is polished aggregate. Polished aggregate happened due to soft aggregate has been used in the construction of pavement. The pictures are shown in Appendix 2; Figure A9 and Figure A10.

Nowadays, depletion of natural aggregate sources becomes one of the big issues in construction field. To overcome this problem, many researchers try to discover and produce artificial aggregate.

Data of various aggregate types properties might already been discussed before. But, there still have some differences on results obtained by the researches. The differences might caused by the type of minerals consist in the aggregates.

1.3 Objective

The objectives of this study are:

- To investigate and evaluate the properties of several aggregate types (limestone, granite and RCA) used in construction.
- To determine the feasibility of RCA as highway construction material.

1.4 Scope of Study

The scopes of studies involved would be on towards the various aggregate tests which include Los Angeles (LA) abrasion test, soundness test, sieve analysis, aggregate impact value test, aggregate crushing value test, flakiness and elongation test, 10% fines test and relative density and absorption test. These tests are carried out in order to achieve the objective of project. The properties of aggregate that need to be investigated are gradation, relative density, hardness, fines content, durability, particle shape, particle surface, deleterious particle and chemical stability.

2. LITERATURE REVIEW

2.1 Literature review

John Keung (2008) stated density of RCA is estimated to be between 2100 to 2300 kg/m^3 but Taesoon Park (2003) stated the density of RCA is between 1810 to 2210 kg/m^3. The difference rise because the different type of aggregate and properties used in the concrete mixed. The amount of cement content also gives high affect to the density of RCA.

2.2 Theory

In this study, several types of aggregates properties will be discussed. In general, the properties are classified into three groups:

- Physical properties
- Chemical properties
- General field characteristics of these aggregates

Different types of aggregate have different properties. Aggregate particles have certain physical and chemical properties which make the aggregate acceptable or unacceptable for specific uses and conditions in construction.

2.2.1 Physical properties

2.2.1.1 Absorption, porosity and permeability

The internal pore characteristics are very important properties of aggregates which 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 property relates to the particle's ability to absorb liquid. 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 liquids to penetrate through. A rock may have high porosity and low permeability if the rock pores are not connected.

2.2.1.2 Surface texture

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.

2.2.1.3 Aggregate voids

There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of the aggregate materials.

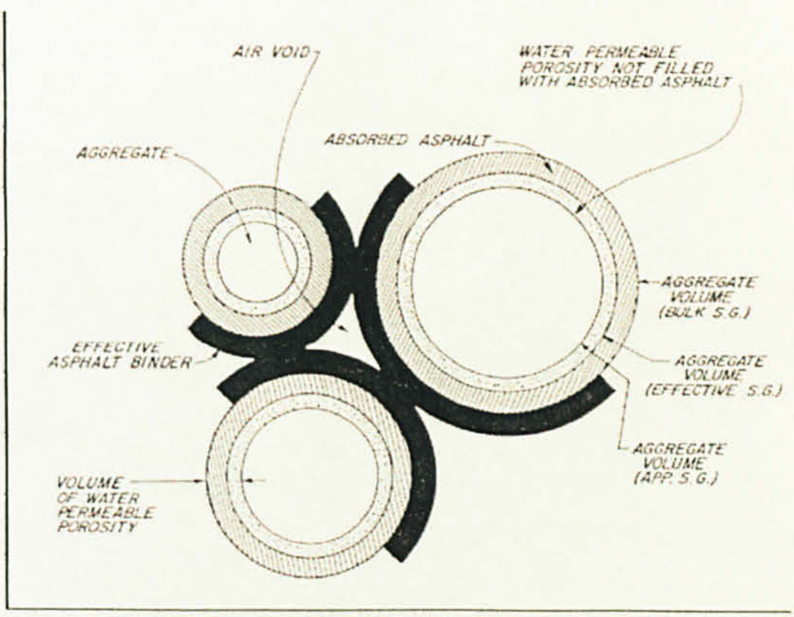

Figure 2.1: Aggregate Specific Gravities.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the design of hot mix asphalt or Portland cement concrete.

2.2.1.4 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 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:

- All of the pore space (bulk density or specific gravity)
- Some of the pore space (effective density or specific gravity)
- 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.

2.2.2 Chemical properties

2.2.2.1 Composition

The chemical composition of aggregate is significant in determining the difference between limestone and dolomite. Limestone is a rock consisting mainly or wholly of calcium carbonate and has a tendency to polish smooth under traffic. Therefore, limestone is limited to use in low traffic-volume HMA surface courses. Dolostone under traffic maintains a higher-friction, skid-resistant surface and is used on higher traffic volume locations. Dolostone is a carbonate rock which consists largely of calcium magnesium carbonate. The word dolomite is the mineral calcium magnesium carbonate Ca Mg (Co3)2. INDOT uses elemental magnesium (Mg) content test to determine if a rock source is dolomitic. Elemental magnesium content of 10.3 percent or above is required for dolomite aggregates.

Some aggregates have minerals that are subject to oxidation, hydration, and carbonation. These properties are not particularly harmful, except when the aggregates are used in Portland cement concrete. As might be expected, iron sulfides, ferric and ferrous oxides, free lime, and free magnesia in industrial products and wastes are some of the common substances. Any of these substances may cause distress in the Portland cement concrete and give the concrete an unsightly appearance.

2.2.2.2 Reactions with asphalt and cement

There are several types of substances found in mineral aggregates which may have a negative effect on the cementing and overall performance qualities of asphalt and cement. Most are rarely significant but various organic substances may retard hardening, reduce strength development or cause excessive air entrainment in portland cement concrete. These organic substances include, but are not limited to, mica, iron oxide, lightweight chert, shale, coal, and lignite.

2.2.3 General characteristic

2.2.3.1 Compacted aggregates

Compacted aggregates without the addition of a cementing material may be used as a base or subbase for hot mix asphalt and Portland cement concrete pavements. Portland cement concrete pavements are rigid pavements. For these types of pavements, the purpose of the base may be to improve drainage, to prevent pumping, or to cover a material that is highly susceptible to frost. Consequently, gradation and soundness are the primary considerations in selecting or evaluating aggregates for bases under rigid pavements.

The load-carrying capacity is a primary factor in the selection of aggregates for hot mix asphalt pavements. A hot mix asphalt pavement does not carry the load; help from the underlying base courses is required. In addition of gradation requirements, the aggregates are required to also possess the strength to carry and transmit the applied loads.

Aggregates are sometimes used to make up the entire pavement structure. In this type of pavement, aggregates are placed on the natural soil to serve as a base course and surface course. Again, the primary requirement is the gradation.

In many instances, compacted aggregates are also used to construct roadway shoulders and berms. In these applications, gradation and stability are very important.

2.2.3.2 Aggregates for Hot Mix Asphalt

Hot mix asphalt is used in a number of different ways. In all cases the aggregates used should meet five requirements:

- Strong, tough and durable
- The ability to be crushed into bulky particles, without many flaky particles, slivers or pieces that are thin and elongated
- Low porosity
- Low permeability
- Correct particle size and gradation for the type of pavement

2.2.3.3 Aggregates for Portland cement concrete

There are many uses of Portland cement concrete in highway construction. Some of the major uses of aggregates are in rigid-pavement slabs, bridges, concrete barriers, sidewalks, curbs, slope walls, and other structures.

Aggregates in Portland cement concrete are required to always be physically and chemically stable. Other factors to be considered include:

- The size, distribution, and interconnection of voids within individual particles
- The surface character and texture of the particles
- The gradation of the coarse and fine aggregates
- The mineral composition of the particles
- The particle shape
- Soundness abrasion resistance
- Water absorption

3. METHODOLOGY

3.1 Research methodology

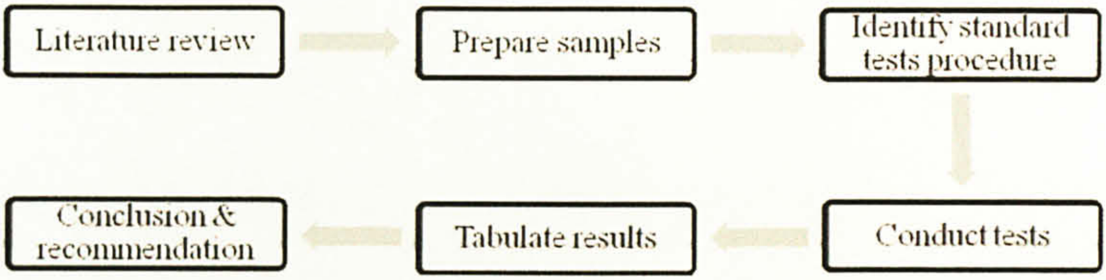

Figure 3.1: Research methodology

3.2 Procedure identification

In this study, various types of test need to be conducted in order to determine the properties of selected aggregates (basalt, limestone, granite and RCA). Several types of the tests will be discussed in this chapter. The tests are:

- Relative density and absorption (coarse aggregates)
- Los Angeles abrasion test (coarse aggregates)
- Soundness test
- Aggregate impact value test
- Aggregate crushing value test
- 10% fines value test
- Flakiness and elongation

3.2.1 Relative density (specific gravity) and absorption (coarse aggregates) test

The major objective of this test is to measure the relative density and absorption of the coarse aggregate samples. Most of aggregates are porous, not solid particles. Water is absorbed by the particle in the pore spaces, which may be relatively shallow or may extend well into the aggregate particle. The moisture condition of aggregate particles can be:

- Dry – oven-dry or no moisture content
- Air dry
- Saturated surface dry – all pores filled with water, but no moisture film on the surface
- Wet – pores saturated and surface moisture present

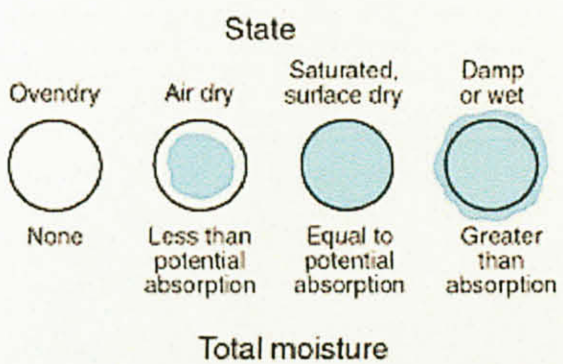

Figure 3.2: Type of moisture conditions

Either the mass in the dry condition or the mass is saturated surface dry condition can be used for relative density calculations. The volume can be the net (that is, the volume of the particle, excluding the volume of pore space that can be filled with water) or the bulk volume (the volume of the particle, including pores).

In this test, the particles are soaked, and then their mass is measured (1) in air, (2) when submerged, and (3) after drying in the oven. The difference between mass when dry and mass when submerged equals the volume of water displaced in cubic centimeter. Hence the net volume of the aggregate can be obtained.

Before the test can be carried out, several apparatus need to be prepared. The apparatus are:

- Wire basket
- Balance (accurate to 0.1 g)
- Oven

To make the calculation to determine relative density and absorption easier, the data obtained need to be arranged in following form:

Mass saturated surface dry : ___________ g (M_{SSD})
Mass submerged : ___________ g (M_{SUB})
Mass dry : ___________ g (M_D)
Calculations:
Mass of absorbed water ($M_{SSD} - M_D$): ___________ g (M_{WA})
Volume net ($M_D - M_{SUB}$) : ___________ g (V_N)
Volume bulk ($V_N + M_{WA}$/1 g/cm^3) : ___________ g (V_B)

Results:
RD_A = M_D/V_N = ___________
RDB = MD/VB = ___________
RD_{SSD} = MSSD/VB = ___________
Absorption = M_{WA}/M_D = ___________

3.2.2 Los Angeles abrasion test (coarse aggregates)

One of the major properties of aggregates that required in construction is hardness. To measure the hardness of aggregates, Los Angeles abrasion test need to be conducted. The sample will be placed in a drum with steel balls. The drum is rotated and the balls grind down the aggregate particles randomly. Hard aggregates lose little mass, while soft aggregates are quickly ground to dust.

The apparatus required to conduct the test are listed below:

- Los Angeles abrasion machine
- Sieves
- Balance (accurate to 0.01 g)

The aggregate sample that will be tested is approximately 5000 g including 2500 g ± 10 g of 19 mm to 12.5 mm (3/4 in. to 1/2 in.) size and 2500 g ± 10 g of 12.5 mm to 9.5 mm (1/2 in. to 3/8 in.) size.

From the experiment, data below need to be obtained in order to calculate the hardness of aggregates:

Mass of original sample : __________ g (A)
Mass of final sample : __________ g
Loss : __________ g (B)

% loss = B/A x 100 = ______________

3.2.3 Soundness test

This test is conducted to measure the resistance of aggregates to cycles of freezing and thawing. Certain aggregates tend to break up when subjected to cycles of freezing and thawing especially high porosity and weak aggregates. Water soaks into pores in the particles: freezes, expanding about 10%; and opens the pores even wider. On thawing process, more water can penetrate in, further widening the crack. After a number of cycles, the aggregate may break apart, or flakes may come off of it. This leads to disintegration of concrete and to weakening of base course layers.

In the soundness test, aggregates are soaked in a solution of magnesium sulfate ($MgSO_4$) or sodium sulfate ($NaSO_4$). The salt solution will seep into the pores of the aggregate. The sample is removed from the solution, drained, and then dried. During drying process, crystals form in the pores, just as ice crystals from in aggregates exposed to weathering. This soaking and drying operation is carried on for several times. At the end of the test, the amount of material that has broken down is found, and then the percentage loss can be calculated.

Apparatus need to be prepared are:

- Saturated solution of $MgSO_4$ or $NaSO_4$
- Containers for soaking samples
- Sieves
- Balance (accurate to 0.01 g)

Results:

Original mass : ____________ g (A)

Final mass : ____________ g

Loss : ____________ g (B)

Calculation:

% loss = B/A x 100 = __________

3.2.4 Aggregate impact value test

The aggregate impact value is a strength value of an aggregate that is determined by performing the Aggregate Impact Test on a sample of the aggregate. The sample used is the aggregate passing through 12.5 mm sieve and retained on 10.0 mm sieve. After it has been dried, the sample will be placed in the steel mould and compacted by using tamping road. Then, the sample is subjected to blows of dropping hammer. If less aggregate passing through 2.36 mm sieve, the aggregate is high strength.

The apparatus need to be used in order to conduct the test are:

- Steel mould
- Sieves
- Tamping rod
- Oven
- Impact testing machine
- Balance (accurate to 0.01g)

Calculation:

Initial mass = __________ g (A)

Mass of aggregate passing through 2.36 sieve = __________ g (B)

AIV = B/A x 100 = __________ %

3.2.5 Aggregate crushing value test

The aggregate crushing value is a value which indicates the ability of an aggregate to resist crushing. The sample used is the aggregate passing through 12.5 mm sieve and retained on 10.0 mm sieve. After it has been dried, the sample will be placed in the steel mould and compacted by using tamping road. Then, the sample is subjected to uniform rate of force for 10 minutes. If the ACV is low, the ability to resist crushing is great.

In the test, the apparatus needed are:

- Steel mould
- Compression testing machine
- Sieves
- Balance (accurate to 0.01g)

Calculation:

Original mass = __________ g (A)

Mass of aggregate passing through 2.36 sieve = __________ g (B)

ACV =B/A x 100 = __________ %

3.2.6 10% fines value test

This test is not is not too dissimilar from the test to determine the aggregate crushing value. But instead of using a standard force of 400kn, the force at which 10% of fines is produced is noted as the Ten Percent Fines Value (TFV).

Calculation:

Original mass	= _________	g (A)
Mass of aggregate passing through 2.36 sieve	= _________	g (B)

y = B/A x 100 = __________ %

TFV = 14x / (y + 4) = __________ kN

Where;

x = maximum force used (kN)

y = percentage fines from the test (%)

2 Flakiness and elongation

The objectives of the test are to determine flakiness index (FI) and elongation index (EI) of aggregates. The flakiness test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve, while the elongation test is not applicable to particles retained on a 50.0 mm BS test sieve and passing a 6.30 mm BS test sieve. The sieve size is shown in Table 4 (Appendix 1).

The apparatus required to conduct the test are:

- Flakiness index and Elongation index
- Balance (accurate to 0.1 g)

Calculation for flakiness and elongation test:

Initial mass = __________ g (M_1)

Remaining mass = M_1 – (fraction of which the mass is 5% or less of mass M_1)

= ___ g (M_2)

Mass of aggregate passing through the gauge = ________ g (M_3)

Flakiness = $M_3/M_2 \times 100$

Elongation = $M_3/M_2 \times 100$

4. RESULT AND DISCUSSION

In this study, the selected aggregate type that need to be investigated are limestone, granite and recycled concrete aggregate (RCA). The aggregates will undergo several types of tests in order to determine the properties of the aggregates.

Before the tests are done, the expected results can be made by doing some research from past investigation by other researchers. Even though the exact number cannot be shown for some of the properties, it can be put in range. The expected results such as hardness, density, specific gravity and absorption and also actual result are shown in tables below:

Table 1: Expected result

	Hardness, %	Density, kg/m^3	Specific gravity	Absorption
Basalt	10 – 17	1800 – 2200	1.8 – 2.2	0.6 – 24
Limestone	19 – 30	2100 – 2800	2.1 – 2.8	0.2 – 12
Granite	27 – 49	2700 – 2800	2.7 – 2.8	0.2 – 0.5
RCA	32 – 44	2400 – 2600	2.4 – 2.6	0.2 – 0.9

[Park (2003), Keung (2008), Muench & Mahoney (2005)]

Table 2: Result

	LA Abrasion, %	AIV, %	Specific gravity	Elongation index	Flakiness index
Granite	19.6	24.8	2.46	38.5	37.8
RCA	20.9	27.4	2.39	13.6	21.1
Limestone	20.8	26.1	2.62	23.9	32.5

Some of the properties cannot be considered as consistent for all similar type of aggregate. For example, the hardness of aggregate is depends on the type of minerals consist in the aggregate. The ranking of minerals hardness is shown in Table 5 in Appendix 1. Percentage of minerals consists in the aggregate also important in order to determine the hardness of the aggregate. For instance, the hardest mineral in granite (quartz) is harder than the hardest mineral in basalt (feldspar), but that's not enough to say that granite is conclusively harder than basalt.

From Figure A6 in Appendix 2, it can be seen that the amount of cement particle is quiet high. The amount of cement on aggregate may contribute to big influence to the hardness and the specific gravity of the aggregate. Presence of too much cement may leads to increase number of LA abrasion test result, specific gravity and also aggregate impact value. Compare to aggregate, specific gravity of cement is higher than aggregate, approximately 3.15, and the strength is lower than aggregate.

As shown in Table 2, flakiness of RCA is less than granite. It means granite is flakier than RCA. RCA has lower flakiness index because during the demolition of concrete, flaky aggregate was crushed because it has low strength.

The relationship between density and porosity is an indirectly proportional. That is, the higher the density of a rock, the lower will be the porosity of that rock. When the porosity is high, the absorption ability is also increase.

Due to lack of apparatus, some of the tests can't be conducted. The tests are aggregate crushing value test, 10% fines test and soundness test. These tests will show the hardness of aggregate. The hardness of aggregate also can be determined from LA abrasion test and aggregate impact value test.

5. CONCLUSION & RECOMMENDATION

From the tests that have been conducted, the results show that RCA is feasible to be used as highway construction material. The properties of aggregates use in highway construction also can be determined but varied, depend on the mineral consist in the aggregate.

For further research, the feasibility of RCA as highway construction material can be tested in form of bituminous mixture. The tests should be conducted are beam fatigue test, indirect tensile stiffness modulus and indirect tensile fatigue test. So, the comparison can be done between bituminous mixture of RCA and bituminous mixture of granite.

6. ECONOMIC BENEFITS

The cost of the research is important to consider because it may determine the research feasibility that has been conducted. The total cost of the research is free because all of the samples and apparatus needed are provided by the university. The following are some of the samples and apparatus/machines that have been provided by the university:

- Granite
- Limestone
- Recycled Concrete Aggregate (RCA)
- LA abrasion machine
- Impact testing machine

But if the research is conducted outside, cost is needed to buy samples and to pay the charges to conduct the tests. Some of the costs are shown below:

Table 3: Cost of aggregates

Samples	Rate
Granite	RM 22.00 / metric ton
Limestone	RM 15.00 – 20.00 / metric ton
Recycled Concrete Aggregate (RCA)	-

There is no cost needed to get RCA because the aggregate can be obtained from demolition site of building. But the cost for preparing RCA is high because the process of separating cement and aggregate is so complicated and require a lot of manpower.

The tests required to determine the properties of the selected aggregates will be charge if the tests are carried out outside the university. Some of them are expensive because the test is hard to be conducted and require much time.

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APPENDIX

Appendix 1

Table 4: Dimensions of thickness and length Gauges

Aggregate Size-fraction BS Test Sieve Nominal Aperture Size		Thickness Gauge* Width of Slot	Length Gauge † Gap between Pins	Minimum Mass for Subdivision
100% passing	100% retained			
mm	mm	mm	mm	kg
63.0	50.0	33.9 ± 0.3	—	50
50.0	37.5	26.3 ± 0.3	78.7 ± 0.3	35
37.5	28.0	19.7 ± 0.3	59.0 ± 0.3	15
28.0	20.0	14.4 ± 0.15	43.2 ± 0.3	5
20.0	14.0	10.2 ± 0.15	30.6 ± 0.3	2
14.0	10.0	7.2 ± 0.1	21.6 ± 0.2	1
10.0	6.3	4.9 ± 0.1	14.7 ± 0.2	0.5

Table 5: Ranking of mineral hardness

Mineral	Hardness (Mohr's)
Quartz	7
Feldspar	6
Biotite	2.5 – 3
Pyroxene	5 – 6

Appendix 2

Figure A1: Recycled Concrete Aggregate

Figure A2: Limestone

Figure A3: Impact testing machine

Figure A4: Shaker

Figure A5: Elongation index &

Flakiness index

Figure A6: Crushed RCA

Figure A7: Hammer

Figure A8: Flaky aggregate

Figure A9: Alligator cracking

Figure A10: Polished aggregate