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To cite this article: Saber Shah Saberi *et al* 2021 *J. Phys.: Conf. Ser.* **1973** 012236

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Mechanical And Physical Properties of Recycled Concrete Aggregates for Road Base Materials

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Abstract: The utilization of recycling recycled concrete aggregates (R-RCA) in road base construction is an option of value-added waste materials. The evaluation of R-RCA appropriateness as a road base material need to study. The use of massive amount of RCA in construction projects has acquired wide notoriety. The use of RCA is due to decrease- of amount natural rock as the original aggregate. The main objectives of this study are to characterize properties of R-RCA as road material, to determine mechanical and physical properties as a road base material, and to identify the R-RCA bearing capacity for road base comparison to natural aggregates. The mechanical and physical properties tests conducted according to standard, including particle size distribution Los Angeles Abrasion, Aggregate Crushing Value, Aggregate Impact Aggregate Density, Flakiness Index, Water Absorption, and California Bearing Ratio (CBR). The results show that the aggregates have an excellent distribution particle size, durability, and shapes as required by specifications R-RCA also produced appropriate CBR and strength for road base applications. These results stipulate exclusive information to utilize R-RCA as aggregates for road base construction. R-RCA can be used as road base construction materials, and its engineering properties transform from waste materials to value-added road base construction. Recycling of RCA not only can diminish the road base construction cost and decrease landfill space needed for disposal, but it engineering properties prone as road base construction, and considered a renewable resource.

Keywords: Recycling of RCA, Mechanical and Physical Properties, Road Base Materials

1.0 Introduction

1.1 Background of the Study

Nowadays, RCA that are the main components of old concrete is becoming broadly well known to be reused and recycled because of exhaustion of regular mineral assets, expanding the expense of waste removal, material usage, and demand. Conversely, with the end goal of development, providing ordinary totals have effects on asset deficiency, consumption of energy, and degradation of the environment [1]. Using aggregates in the road base not only increased the consumption of the aggregates from natural resources but also the volume of the recycled concrete aggregates RCA material produced when the service life of the structures comes down to the endpoint.



The unsustainable consumption and expanding the use of regular resources just as the excessive amount of the waste which are generated from building construction and demolition are economic and environmental challenges in the world because of most of these end up in landfills that have made their management a global problem. Indeed, as the rate of demolition waste is still becoming larger and the supply of appropriate natural aggregates is becoming lesser due to their over-exploitation, it is most essential to recycle and reuse the waste which is produced from demolished waste to save our natural resources. Besides, the deposition of RCA in landfills has caused more negative impacts on the environment for the long term, high transportation costs, and increased security issues. The use of recycled concrete aggregates is the only alternative way of environmental protection [2].

Recycling of RCA not only can diminish the transportation cost of waste material and decrease landfill space for disposal, but also it will lower road base construction, and the products in the urban areas can be considered a renewable resource [3]. To conserve natural resources, reduce the dependency on the use of natural aggregates, recycling of RAC as aggregates for road base could be a replacement material and this will pave the way to the preservation of the environment [2]. RCA was initially used as fill material and after many research works now we can use it as a road base material [4].

1.2 *Problem Statement*

Nowadays, recycled aggregates have achieved the attention of researchers to be used as an alternative aggregate. The depletion of natural rocks and unrecycled aggregates resulted in environmental and economic problems. Hence, several attempts were considered to exploit recycled aggregates as an alternative to natural aggregates in the construction industry. RCA is one of the possible options to be used as a replacement material. The recycled concrete aggregates RCA is the main component of old concrete and originates from various sources and compositions. Recycled, crushed concrete may be used as aggregate in many applications, including new Portland cement concrete (PCC) pavement, bituminous concrete, lean concrete, pavement subbases, roadway shoulder material, bulk fill for drainage layers, rip-rap for erosion control, and bedding for utility trenches. Besides, these recycle concrete are discarded as waste in a landfill after their service life. Some researchers have focused on the application of re-recycling aggregates as an alternative material in concrete, road base. But still, the RCA is discarded in landfills due to a lack of engineering properties and history of source recycled concrete aggregate. Limited literature is available on the utilization of re-recycled/reused concrete aggregate as a substitute material in the road base. Hence, this research focused on the mechanical and physical properties of R-RCA to investigate their suitability in a road base.

1.3 *Objectives of the Study*

- (a) To characterize properties of R-RCA as a road base material.
- (b) To determine the R-RCA mechanical and physical properties as a road base material.
- (c) To identify the R-RCA bearing capacity for road base in comparison to natural aggregates

1.4 *Scopes and Limitations of the Study*

Determine the resistance of the crushing material, evaluate the level of degradation of the aggregates, investigate the density and water absorption of material, determine the bearing strength (CBR) of the material, determine the material particle shape, establish the moisture content range, and establishing the particle size of R-RCA.

1.5 Importance of the Study

Nowadays, in the world the concrete demolition (C&D) wastes are going up day by day, the rate of C&D waste, the increase is rapidly filling our future landfill sites, the disposal cost becomes higher. To tackle this trend, considerable efforts are performing in recycling waste, turning it into a re-useable by product. Unprocessed C&D wastes using in pavement causes a huge distress problem due to the difficulty in achieving better particle interaction, poor bearing strength, and dense uniform mass when loaded.

The outcome of this study could provide guidelines and an understanding of improving RCA processing and managing as a road base material. This not only for sustainable development but also can reduce hazardous waste generation, energy consumption, disposal cost, dependence on natural aggregates, and global warming potential. The utilization of RCA has proven as a base, sub-base, fill and drainage layers within the pavement construction, structure and performance have been excellent. RCA is generally considered equivalent to natural aggregates material for pavement design purposes.

2.0 Literature Review

2.1 Introduction

In the 21 century, the need for practical improvement is felt like never before despite unavoidable wonders, for example, a dangerous atmospheric deviation and environmental change [5]. The world's urge to protect the environment together with the preservation of natural raw material has created the necessity to use to manage the RCA through reprocessing various steps and use it as road base material. The proportion of the RCA in the strong waste sum is perceptibly higher contrasted with CB and RAP and subsequently, RCA is all the more normally executed in development undertakings and street layers [6]. RCA are mainly used as aggregates in granular base or sub-base applications, as well as for embankment and earth construction work. The reason is that the quality of RCA is usually lower than the quality of the natural aggregates. The aim is to have sustainable pavement construction, preserve the natural resources, and reduce the disposal cost of a huge amount of wastes in landfills hence lower the over-dependence extracted aggregates.

2.1.1 Recycled Concrete Aggregates (RCA)

The RCA is aggregated that are obtained from the crushing of concrete demolition. To create RCA, Portland concrete cement is separated and squashed. The major inherent material properties that limit the utilization of RCA are ingestion, explicit gravity, sufficiency (protection from ecological conditions, for example, physical and substance enduring), degree and regulation solvency, and the potential for groundwater tainting. The amount of fines in these aggregates reaches about 4.8% used as filling material, rocks, and demolished cement concrete can be utilized as coarse aggregate material or recycled aggregates in the road as a road base construction layer [7].

2.1.2 Material Properties Characterization

According to [8] observation is that RCA total properties tests are required to assess the nature of the RCA and find new data. The study focused on the kind of material to be characterized and on the parameters to be determined. RCA testing is made out of standardized tests proposed to give information about mechanical and physical qualities. The following characteristics of RCA can be identified, such as particle density and Water Absorption, particle size dispersion and measure of the fine particles, shape index, Aggregate Crushing Value, California Bearing Ratio (CBR), Los Angeles abrasion resistance, and Aggregate Impact Value test among others. All tests were carried

out basing on established standards like the American Society for Testing and Material (ASTM) or the American Association of State Highway and Transportation Officials (AASHTO).

Numerous specialists have concentrated in their work on the potential utilization of RCA and discovered it to be acceptably applied pavement road base and sub-base, discovered that RCA should be considered as an alternative to natural aggregates in road base layer construction [9].

[10] In their survey found that RCA is most commonly used as unbound granular material in the road base course. The most well-known test used to distinguish determination consistency for the reused material was a particle size analysis using the wet and dry sieve method followed by Atterberg Limits for consistency. The review shows that the most widely recognized tests for aggregates quality are the California Bearing Ratio test for aggregate bearing strength, the Los Angles Abrasion test (LAA) for aggregate for total strength, and the sulphate sufficiency test for total toughness.

Among other observations have made, RCA particles have more angular surface texture, having the higher scraped spot esteem, value and lesser scraped spot among other observations made, RCA particles have more angular surface texture, having higher abrasion value and lesser abrasion resistance with a decrease in aggregate size compared to natural aggregate. Also, the RCA requires about 10% more water than NA concrete for similar workability, 25% less compressive strength, and a 30% decrease in modulus of elasticity. The presence of a high amount of porosity in RCA increases water absorption significantly. Particle size distribution was genuinely changed by the compaction procedure.

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This explain the methodology and detail of the experimental procedure of this research project that is to investigate the mechanical and physical properties of R-RCA for road base material. The detail of the mixing, processing, and testing procedure were discussed in this section—the first step of the experiment to collect all the raw material needed in the experiment. The raw material was re-recycled concrete aggregates with 30 MPa strength, which were provided by Geo Scientific Gravity Material Testing Laboratories (GSMTL) in Kabul Afghanistan. Figure 1 shows R-RCA 30 MPa strength materials which are taken from old concrete according to standards in Kabul Afghanistan.



Figure 1. R-RCA after process

3.2.1 Processes and Material Samples

The material is building demolish concrete that is re-recycled and provided according to ASTM by GSMTL Afghanistan and brought to the laboratory for processing. Samples of R-RCA material of enough quantity for study work packed in unique bags. Visual inspection was done by expert persons to select samples to minimize pre-sorting and removal of none wanted waste materials.

A summary of tested properties, test methods, and standard specifications that have been followed in the study is given in Table 1

Table 1. Properties of CBD Aggregate, Test Method Standards, and Specifications.

Properties	Test Method	Standards	Specifications	Fraction
Physical				
Particle Size	Sieve analysis (washing)	ASTM C136-06	ASHTO	R-RCA & NA
Density – Oven Dry	Aggregates between 40 mm and 5 mm	ASTM C127-07	Not Applicable	R-RCA & NA
Water Absorption	Aggregates between 40 mm and 5 mm	ASTM C127-07	2% Max	R-RCA & NA
Particle Shape	Flakiness index	ASTM - D 4791	30% Max	R-RCA & NA
Elongation Value	Elongation Index	ASTM - D 4791	25% Max	R-RCA & NA
Mechanical				
Abrasion	Los Angeles abrasion machine	ASTM C 131	30% Max	R-RCA & NA
Crushing Strength	Aggregate crushing value	(ASTM - D 5821	30% Min	R-RCA & NA
Dry Density	Modified proctor using 4.5 kg hammer	ASTM- C 127-07	2.5g/cm ³ Min	R-RCA & NA
Bearing Strength	California bearing ratio (soaked condition)	ASTM D1883-07	80% Min	R-RCA & NA

4.0 Results and Discussions

4.1 Introduction

The classification of an aggregate used in a road pavement layer can be done by its physical and mechanical characteristics. This is done by analysing its geometry and performance while in service life. Laboratory tests on construction and building demolitions done in this study have yield varying results that are discussed in this chapter.

4.2 Physical Characteristic

4.2.1 Particle Size Distribution

The percentages of retained and passing were determined as showed in Test Report 1 and appendix A. It can be seen that the maximum size retained for R-RCA is in below graph.

The passing fraction percentage in the respective samples from sieve analysis is shown in Figure 2 The maximum size in both fractions is 37.5 mm and the minimum size for fraction R-RCA is 4.75mm. These values indicate the maximum and minimum size of aggregate.

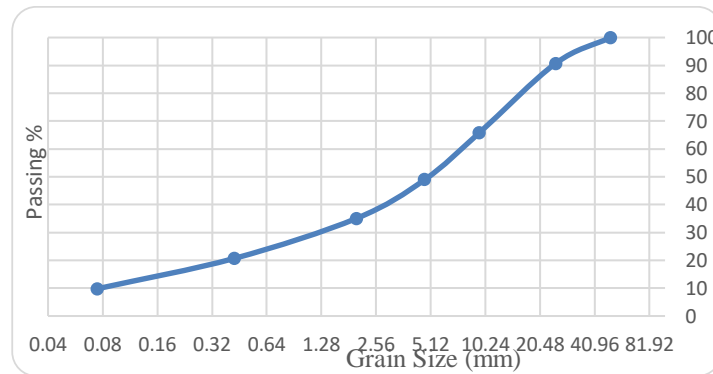


Figure 2 R-RCA Particle Size Distribution

4.2.2 *Fineness Modulus*

A fineness modulus is an index number that describes the coarseness or fines of the sample aggregates. It is obtained by adding the cumulative percentage retained in each sieve and dividing the sum by 100. The fines modulus values obtained are indicated in table 4.1, for respective samples. Higher values reflect a coarse material while lower values for finer material. The fines modulus for coarse aggregate ranges from 5.5 – 8.0.

Table 2 Shows R-RCA material fraction percentage which is pass from sieve 2", 1", 3/8 and No.4 is total 51.0% passing, in ASTM this size aggregate is called gravel, the aggregate which are passed from sieve No.10 and N0.40 is 39.2% it is called sand and the aggregate which are passed from sieve No.200 is 9.8% it is called silt or clay.

Table 2. R-RCA Fraction Passing Percentage

Sieve Size		Cum Retained Weight (gr)	Cum Retained (%)	Cum Passing (%)		Remarks
(in)	(mm)					
2"	50.0	0.0	0.0	100.0		Gravel 51.0%
1"	25.00	695.0	9.3	90.7		
3/8	9.50	2564.0	34.2	65.8		
No. 4	4.75	3829.0	51.0	49.0		
Dry weight of Sample Passing N0.4 Sieve in Grams			838.0			
No.10	2.00	238.0	28.40	71.6	35.1	Sand 39.2 %
No.40	0.425	484.0	57.76	42.2	20.7	
No.200	0.075	670.0	79.95	20.0	9.8	Silt & Clay 9.8 %
Total Dry weight of Sample in Grams			7503.00	Total Fraction Passing 100%		

4.2.3 Relative Density

The results for the two respective specimens R-RCA and NA tested are given in Table 4.2. It is seen oven-dry density (ODD) is 2.319 gr/cm³ when compared to natural aggregate dry density which is averagely 2.805 gr/cm³ the density values of R-RCA are relatively lower.

The results for the two respective specimens R-RCA and NA tested are given in Table 3. It is seen overall mean oven-dry density (ODD) is 2.319 gr/cm³ when compared to natural aggregate dry density which is averagely 2.805 gr/cm³ the density values of R-RCA are relatively lower.

Table 3. Results for Relative Density and Water absorption

Property	Sample R-RCA		Sample NA	
	R-RCA 1	R-RCA 2	NA 1	NA 2
Relative D-D gr/cm ³	2.325	2.314	2.802	2.808
Relative SSD gr/cm ³	2.399	2.399	2.809	2.817
Apparent gr/cm ³	2.512	2.528	2.882	2.834
Water Absorption %	3.209	3.649	0.244	0.318

4.2.4 Water absorption

The mean absorption for sample R-RCA is higher than NA. Higher water absorption of R-RCA sample is due to the presence of cement mortar coating on the aggregate which is more porous with a high absorption rate [11]. Table 4 and 5 shows R-RCA and NA water absorption percentage with details.

Table 4. R-RCA water absorption percentage

Description		Determination		
		1	2	Average
A	Wt. of OD gr/cm ³	1997.3	1970.2	1983.75
B	Wt. of S.S.D gr/cm ³	2061.4	2042.1	2051.75
Absorption %	$(B-A/A) \times 100$	3.429 %		

Table 5. NA water absorption percentage

Description		Determination		
		1	2	Average
A	Wt. of OD Sample in Air (A) grams.	2946.3	2768.1	2857.2
B	Wt. of S.S.D grams.	2953.5	2776.9	2865.2
Absorption %	$(B-A/A) \times 100$	0.281%		

4.3 Mechanical Characteristic

Mechanical characteristic of material are those properties that involve a reaction to an applied load or are also used to help classify and identify material such as aggregate abrasion value, aggregate crush value and California bearing ratio.

4.3.1 Los Angeles Abrasion Value

Table 5 and Table 6 show the test result of degraded R-RCA and NA aggregate in the Los Angeles machine using 12 number steel spherical balls with 30-33 revolutions per minute. The aggregate size test fraction ranged from 37.5 mm – 10 mm. The percentage of R-RCA is 26.1% and the NA percentage is 23.8%. In ASTM international Maximum percentage is 30%, so R-RCA is in the normal range.

Table 6. R-RCA Los Angeles before the process

NUMBER OF TESTS		1
A	Total Weight of Sample grams	5000
B	Weight of Sample Retained On Sieve # 12 grams	3810
C	Weight of Sample Passed On Sieve # 12 grams	1190
D	Abrasion $((C) / A) * 100$ %	23.8
Average Loss %		23.8%

Table 7. R-RCA Los Angeles after the process

	NUMBER OF TESTS	1
A	Total Weight of Sample grams	5000
B	Weight of Sample Retained On Sieve # 12 grams	3693
C	Weight of Sample Passed On Sieve # 12 grams	1307
D	Abrasion ((C) / A)*100 %	26.1
	AVERAGE LOSS %	26.1%

4.3.2 Aggregate Crushing Value

This Part of BS 812 describes a method for the determination of the aggregate crushing value (ACV) which gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

All details and samples weights and results of ACV percentage is shown in table 9.

Table 8. Crush Value Result of R-RCA and NA

	Test Specimen	
	R-RCA	NA
Weight of Original Specimen (M1) by grams	4092	4230
Weight Passing 2.36 mm Sieve (M2) by grams	1103	995
Weight Retained on 2.36 mm Sieve (M3) by grams	2989	3235
Weight Passing + Retained (M2 + M3) by grams	4092	4230
Aggregate Crushing Value (%)	26.95%	23.52%

4.3.3 California Bering Ratio

This test method covers the determination of the CBR of pavement subgrade, subbase, and base course materials from laboratory compacted specimens and aggregate bearing strength is a key property considered when designing pavement layers. It can further be seen that the four-day soaked condition gave the aggregate dry density of 2088 kg/m³ and 2384.11 kg/m³ for the respective specimens. The moisture content in both tests is 10% and the aggregates had an insignificant swell.

Figures 3 and 4 CBR values for the respective test specimens at 2.5 mm and 5.0 mm penetration obtained after tangential curve correction Figure 1.3 R-RCA and NA in the corresponding specimens. This test was done for three types of blows which are 10, 25, and 56. The larger of these values is considered CBR for the material.

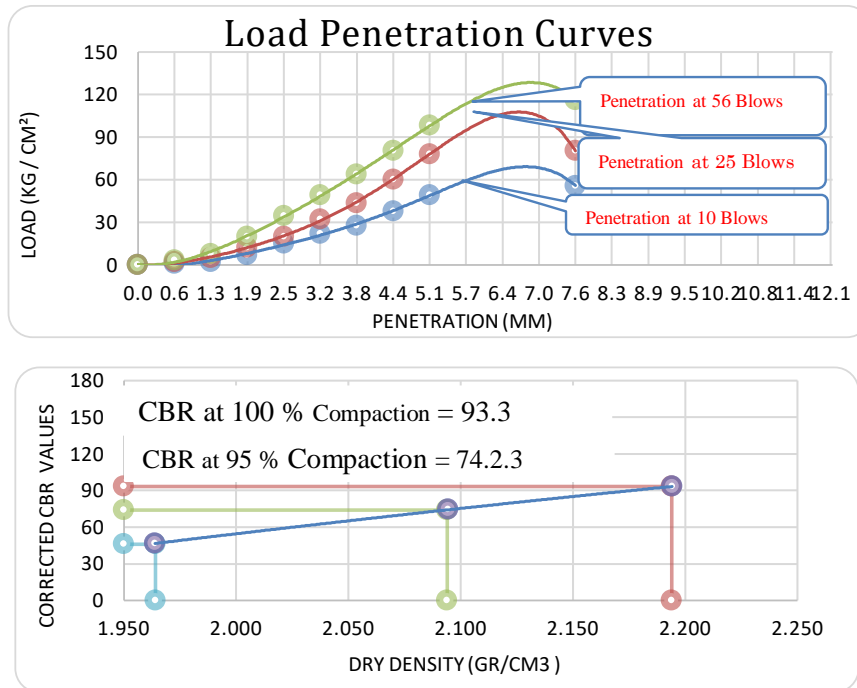
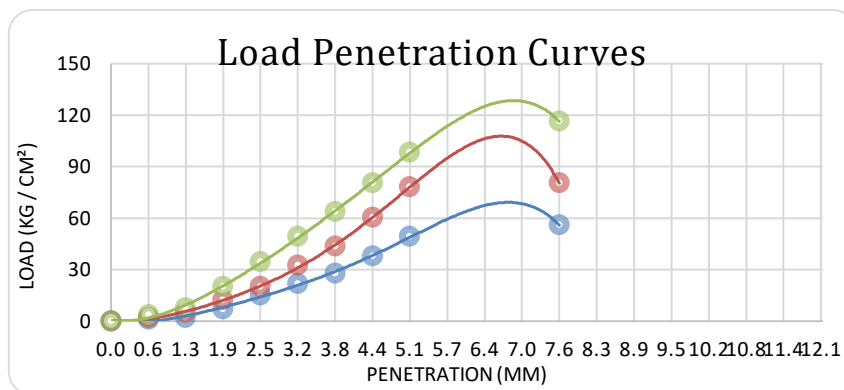


Figure 3. CBR final Curve with Dry Density



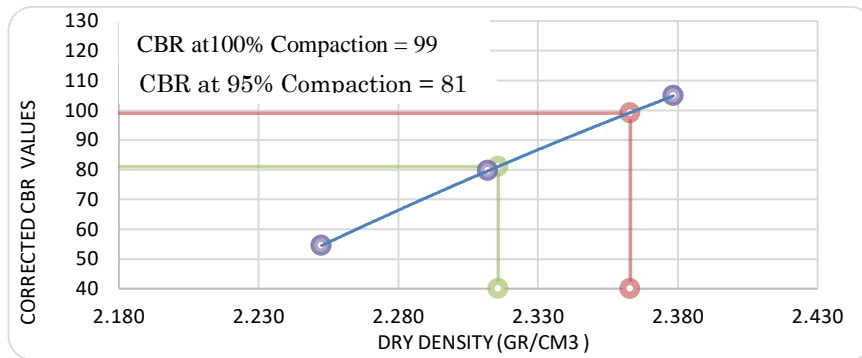


Figure 4. CBR final Curve with Dry Density

5.0 Conclusions and Recommendations

Material properties undergo degradation during the lifetime of structures. Nevertheless, there is measurable value in most instances that still exists in demolition that material that makes it reusable. Previous research work has qualified construction and demolition of buildings, a material good for construction of the base course layer. The studies based their finding on demolition and its components after carrying out different tests.

5.1 Conclusions

The RCA material in this study is gained from various demolished and wasted building concrete resources in Kabul Afghanistan. Specimen and all tests are prepared and done in Geo Scientific Material Testing Laboratories (GSMTL). Laboratories investigations and results have led to the following:

- (a) For the physical properties of RCA, flakiness and elongation index tests were conducted to determine the size and shape of aggregates. The results showed that the value of flakiness and elongation index of RCA were lower than Natural Aggregates, The RCA material relative density was lower when compared to natural aggregate value 2.319g/cm^3 and NA is 2.80g/cm^3 and therefore RCA considered light aggregate due to the surface of cement particles. The high water absorption of 3.429% of RCA determines porosity and the possibility of hydration of cement which is coated on the surface of aggregate lower than the NA. In conclusion, the physical properties of re-recycled concrete aggregate have met all ASTM standard specifications for aggregate to be used in road base layer construction.
- (b) The RCA material had various particles maximum and minimum size and classified as 51% coarse aggregate, 39.2% sand, and 9.8% silt and clay. The particle size distribution test of RCA had a close value of the results when compared to Natural Aggregate which is granite and sandstone. This indicates that re-recycled concrete aggregates can perform in-field quite similar to natural aggregates.
- (c) The shape of RCA in ASTM international specifications is satisfied and acceptable for the base course layer construction.
- (d) The mechanical properties of RCA had sufficient resistance when compared to Natural Aggregates because Los Anglos Abrasion value of RCA was 26.1% and NA was 23.8%, and the crushing value of RCA was 26.95% and NA was 23.52%. In conclusion, the

results showed that the mechanical properties of RCA had a close relation to Natural Aggregates. Therefore, RCA is very suitable to be used in the base course layer.

- (e) The bearing strength (CBR) of RCA as determined by the CBR test was 93.3% that is 5.7% lower than NA which is 99% and the strength of the NA is higher than RCA. Acceptable CBR in ASTM international specification is 80% min for base course construction and the swell amount percentage of RCA is negligible.

6. Recommendations

While two different materials mechanical and physical properties and comparison of RCA and NA are represented in this research, the properties of RCA were depended on its resource, type, and procedure. The RCA exhibits the strength and stiffness properties typical of materials commonly used in base course layer construction. The selection of RCA as a pavement base course materials ultimately depended on agency preference and RCA availability and cost. While this research provides engineers with the value of materials properties needed for the design of RCA base course layer construction, economic analyses must be conducted by the government agencies to optimize the overall pavement design. The above results are good indicators to a guide of processing and recycling of recycled concrete aggregate for the use of base course layer construction in the pavement in Kabul Afghanistan. Below are a few suggestions that may give some idea to continue the study on the physical and mechanical properties of recycled concrete aggregates use in road base construction. In order to boost degradation, processing and sorting the aggregate would help the crushing value and property of bearing strength.

- (a) The study should be conducted by using more various samples from different sites.
- (b) The RCA material is suitable for average traffic volume roads.
- (c) The most important test of RCA was the CBR test which result was very good for base course layer construction, so we can use RCA for average traffic volume roads.
- (d) Additives can be added to RCA aggregates to decrease the percentage of the porosity of particles.
- (e) The related machines and equipment in the laboratory have to be calibrated and maintained frequently to give effective results.

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Acknowledgments

Sincere thanks to Universiti Teknologi Malaysia for financial support from High Impact Research Grant (HIR) Q.J130000.2451.04G54 that enabled the conduct of this research.