Recycled concrete aggregate as a road base material

To cite this article: G. G. Giwangkara *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **527** 012061

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012061 doi:10.1088/1757-899X/527/1/012061

Recycled concrete aggregate as a road base material

G. G. Giwangkara[1], A. Mohamed*[1], N. H. A. Khalid[1], H. M. Nor[1], M. R. Hainin[1], R. P. Jaya[2], W. N. H. M. Sani[3], C. R. Ismail[1], and M. M. A. Aziz[1]

[1]School of Civil Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2]Department of Geotechnic and Infrastructure, Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia
[3]Civil Engineering Department, Politeknik Sultan Haji Ahmad Shah, 25350 Kuantan, Pahang, Malaysia

*Corresponding author e-mail: azmanmohamed.kl@utm.my

Abstract. Natural crushed aggregate (NCA) is the most common material for aggregate throughout the world. The consumption of the NCA itself is rising up through the years. Concrete structures and road construction are some of the most consuming aggregate material, especially NCA. Therefore, aggregate such as recycled concrete aggregate (RCA) has become an alternative material for some particular civil construction. The implementation of RCA as road construction material has been raised for a long time ago especially in road base layer. Road base layer as foundation for road pavement must provide an adequate strength to hold the working load on the pavement surface. RCA is more heterogeneous material compared to NCA as the RCA contain many substances, such as aggregate, cement, sand, and some additive substances. Hence, it effects the strength of the RCA as construction material. In this paper, the properties of the RCA are investigated to get the characteristic of the aggregate. Density, water absorption, aggregate crushing value (ACV), compaction, and penetration test (CBR) were conducted in this research. An improvement by using plastic strips as addition also proposed to strengthen the RCA as road base material.

1. Introduction

In the sustainable environment campaign, the waste management must have an essential contribution. Solid waste is one of the most troublesome to handle. Especially the solid waste generated from construction industry or what is commonly called as the Construction and Demolition Waste (CDW). Construction and demolition waste is a variety materials of waste which generated from construction, renovation, demolition, and natural disaster [1]. CDW has also becoming a burden for growing countries in South East Asia region. A study in 2005 indicated that Malaysia generated about 17,820 tons of concrete and aggregate waste from construction waste of 65.8% from total construction waste material [2]. In Thailand, the annually CDW from construction industry was estimated about 1.1 million tons in average from 2002 until 2005. The concrete waste itself contributes around 46% from total construction waste [3]. For some major cities in South East Asia such as Hanoi, the CDW is approximately 1,500 tons daily which is forecasted to be in 2,000 – 4,000 tons in 2020 [4]. The CDW data not always available in every country in South East Asia such as in Indonesia. But on the other hand, country such as Singapore always provides the data about construction waste annually. The National Environment Agency of Singapore stated that more than 1.6 million tons of construction debris were generated in

2017 [5]. CDW should be recognized as a valuable resource as it could be reused and recycled. The process of reuse and recycle is not always available in every country, especially in South East Asia. Lack of participation from national authorities and industries, lack of regulations, and inadequate of waste storage and recycling facilities are some of the restrains to achieve the ideal waste management [6]. The reuse and recycle programme must be considered as an important aspect as it will continue rising up and not every countries has an enough space for landfilling.

The volume of CDW is always rising up as more building to construct or demolish. The action of reduce, reuse, and recycle (3R) must be more optimized. According to the surveys, the cost for construction waste management is only makes up to 3% of overall project cost [7]. Most of it is used for landfilling cost as it is the easiest way to do. In reality, 67% of contractor already have issue of the limited landfilling area [7]. This situation pushes the government and the industrial sector to optimize the 3R actions. Recycle programme is one of the solution as solid waste from CDW keep rising up. In Hong Kong, over 20 million tons of CDW is generated each year [8]. Meanwhile in Malaysia as reported in 2012, 33,000 tons of solid waste had been generated daily [9]. The developed country such as United States also facing the same problem. The US Environmental Protection Agency reported that in 2014 there were more than 534 thousand tons of CDW which 70% of it is a concrete waste [1]. The large amount concrete waste and the lack of landfill area are the main backgrounds of this research to conduct an experiment on aggregate from concrete waste or used to be called as Recycled Concrete Aggregate (RCA). The concrete waste is not only acquired from construction or demolition sites, but also in some certain area that are using concrete for research, such as an R&D center or academic institutions. Universiti Teknologi Malaysia is one of the academic institutions that use concrete as one of the research topic. After many years, the concrete waste will accumulate as seen on Figure 1.

Figure 1. Concrete waste at Structure and Materials Laboratory of Universiti Teknologi Malaysia.

2. Research objective

The research on this paper have two objectives. The first objective is to determine the properties of the aggregate by conducting some tests such as particle size distribution test, density test, water absorption test, aggregate crushing value test, compaction test, and penetration test. The second objective is the strength performance of the RCA compared to the NCA by using the California Bearing Ratio (CBR) method.

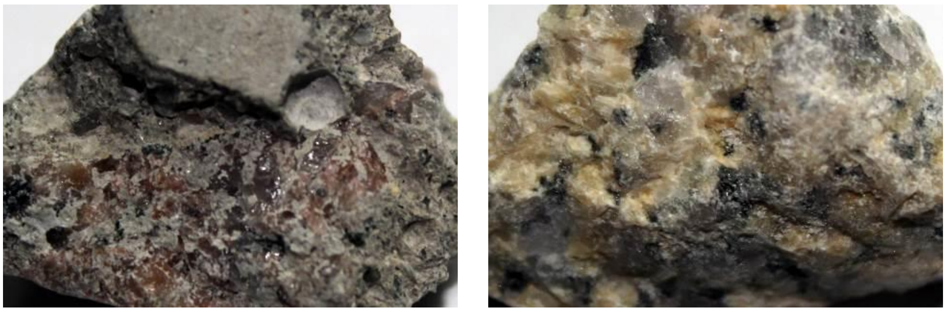
3. Road base

Road base is specific layer which acts as a foundation for road pavement. The working load on the surface of the road pavement will be directly supported by the road base layer. The simplest way to calculate the load distribution is by means of 2:1 method [10]. This method assumes that the distributed load over an area increases in width in proportion to the depth below the loaded area. Road base itself is a well graded material consisting of various size of coarse and fine aggregate [11]. Road base material must meet the requirements from the national authorities. In Malaysia, there are 7 (seven) requirements from the Road Works Department for road base material, such as plasticity index, aggregate crushing value (ACV), flakiness index, soundness, CBR value, sand equivalent value, and the aggregate gradation

[12]. Natural rock that is crushed with rock crushing machine usually used for road base construction. That material commonly called by Natural Crushed Aggregate (NCA). The use of the alternative material for NCA has been conducted for over the past decade. The RCA is the most popular among any other alternative materials.

4. Recycled concrete aggregate

Recycled concrete aggregate (RCA) is simply old concrete that has been crushed into aggregate. Although the RCA has a higher water absorption and lower specific gravity which is resulting in less strength compared to the natural crushed aggregate (NCA), it has been satisfactorily used for road pavement construction [13]. The lack of strength must be overcome as the load from the road pavement will directly go to the road base layer a main foundation. In concrete technology, a concrete which is made with RCA has 22-32% less strength than concrete made from NCA [14]. That fact may cause a further research or modification in road base construction. By using the RCA, it is expected that the use of NCA may be decreased as 61.7% of NCA is used for road construction [15]. The surface appearance between NCA and RCA also have a differences as seen on Figure 2. The RCA has a porous surface and sharp edge as it is a result for the cracking from the concrete crushing. Other than that, the mortar is often still attached on the surface of the RCA.



(a) (b)

Figure 2. (a)-RCA and (b)-NCA.

5. Material and methodology

5.1. Recycled concrete aggregate production

In general, the production of RCA has the same method to the NCA. This research use RCA from the waste of concrete construction in Universiti Teknologi Malaysia and produced by semi-manual process as seen on Figure 3.

(a) (b) (c) (d)

Figure 3. (a) Concrete waste breaking, (b) Demolished concrete, (c) Crushing the concrete, and (d) Recycled concrete aggregate.

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012061 doi:10.1088/1757-899X/527/1/012061

The concrete waste for the RCA material must have a minimum compressive strength of 30 MPa by rebound hammer test. The concrete waste then demolished into a smaller size that fit the crushing machine inlet. The crushing machine then crush the demolished concrete into aggregate.

5.2. Particle size distribution
The particle size distribution experiment procedure is according to the BS 1977-2:1990 [16]. The particle size distribution is an experiment to acquire the gradation of the aggregate. The gradation of the aggregate is specified on the road works standards, in this case, the Malaysian Road Works Standards [12]. The weight of the aggregate sample for this experiment is 2 (two) kg and oven dry. The sieve sizes to be used are 50.0 mm, 37.5 mm, 28.0 mm, 20.0 mm, 10.0 mm, 5.0 mm, 2.0 mm, 0.425 mm, and 0.075 mm. Pour the sample into the sieves on the mechanical shaker for five minutes. The sieves are weighted before and after the sieving. The passing percentage then calculated and presented in tabulation and logarithmic graphic.

5.3. Aggregate density and water absorption
In general, density can be describes as a compactness of a substance. It can be acquired from the proportion of the substance mass to its volume. When the density of a substance is being ratio with the reference substance, e.g. water, then it called the relative density or the specific gravity [17]. This test refers to ASTM C127-01 and AASHTO T85. Sample needed in each test are about 3 (three) kg in weight as the maximum samples size use in this study is 20 mm. There are 4 (four) samples for each aggregate type. Water absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential.

5.4. Aggregate Crushing Value (ACV)
The strength of coarse aggregates is assessed by aggregate crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. Generally, the smaller sized aggregates produce a higher strength value due to the packing nature and void characteristics of the particles in the test mould. The aggregates crushing value when tested shall be not more than 25%. This test refers to Malaysian Standard 30 Part 8 Section 1 1995 which also refers to BS 812-110:1990. The aggregates crushing value also known as ten percent fine value.

5.5. Aggregate compaction
The aggregate compaction test is conducted to determine the Optimum Dry Density (ODD) and the Optimum Moisture Content (OMC) for the aggregate. The sample must be oven dry before the test conducted. In this experiment, the method is according to the ASTM D1557 of the Modified Proctor test. The sample divided into 5 (five) layers in 6-in (152.4 mm) mold with 56 blows each layer of 10 lbs (4.5 kg) rammer. The water content added gradually every time a sample is done and weighted. The result is expressed in the graphic of ODD-OMC relationship.

5.6. Penetration test (California Bearing Ratio)
The California bearing ratio (CBR) is a penetration test used to evaluate the mechanical strength of subgrade and road base materials. It was developed by the California Department of Transportation before World War II [11]. A sample is compacted into a standard mold using the compaction values obtained from the ODD-OMC test. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The pressure required to achieve an equal penetration on a standard crushed rock material then divides the measured pressure. This test standard is referred to BS 1377-4:1990.

6. Results and analysis

6.1. Particle Size Distribution

The gradation of the RCA that newly crushed from the crusher machine in this research also did not meet the grading requirement as seen on Figure 4. Nevertheless, the NCA also facing the same problem. Hence, the aggregate for testing must be graded according to the grading requirement for road base construction. The road base layer must be constructed from a certain sizes of aggregate from crushed rock or NCA to gain the maximum density of the layer.

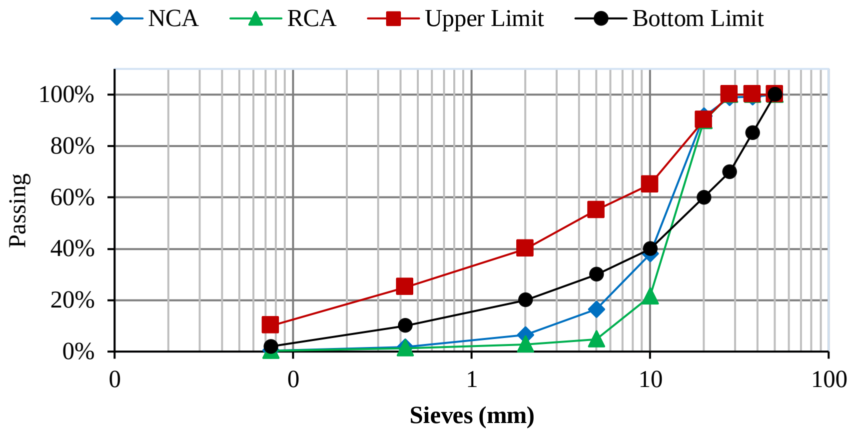


Figure 4. Particle size distribution of NCA and RCA.

6.2. Aggregate density and water absorption

In terms of density of the aggregate, the dry density (oven dry) and SSD density are commonly used. The dry density (oven dry) is the ratio of aggregate weight in air (not including weight of water within the voids) to the mass of the same volume of water. While the SSD density is the ratio of aggregate weight in air (including weight of water within the voids) to the mass of the same volume of water. From Figure 5, the average values of NCA density are 2,557.7 kg/m^3 (oven dry) and 2,584.6 kg/m^3 (SSD), while the average values of RCA density are 2,293.6 kg/m^3 (oven dry) and 2,420.1 kg/m^3 (SSD).

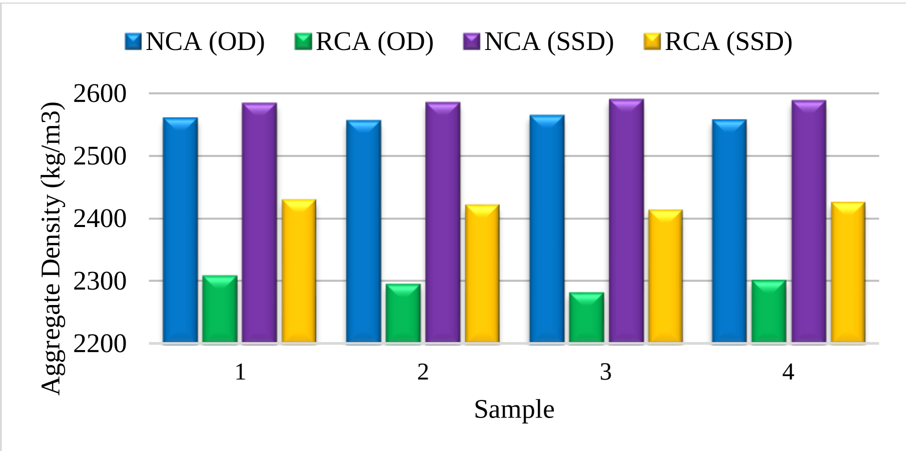


Figure 5. Aggregate density.

The difference of the density of the NCA between the oven dry and SSD is not too far compared to the RCA. This condition is affected by the water trapped in the voids of the aggregate. It is consistent to the result of the water absorption result which shows that RCA has a higher water absorption compared to the NCA. The average value of water absorption of RCA is 5.51% while NCA only 1.05% as seen on Figure 6 below.

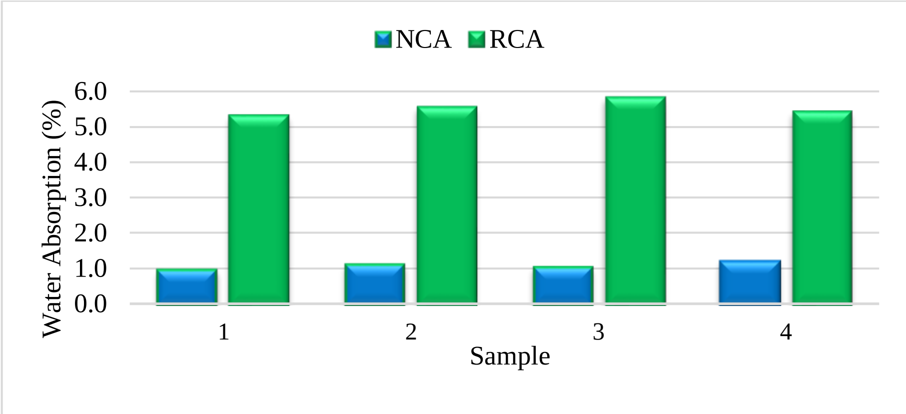


Figure 6. Aggregate water absorption.

6.3. Aggregate Crushing Value (ACV)

The aggregate crushing value (ACV) test also conducted in 4 (four) samples for each aggregate types. The average ACV for NCA is 25.6% while for RCA is 31.6%. According to the Malaysian Standard for Road Works, the ACV cannot exceed 25%. From the test result shown on Figure 7, both of the aggregate type are not qualified. The ACV represent the individual strength of the aggregate, then there must be an improvement, especially for RCA, to meet the requirement.

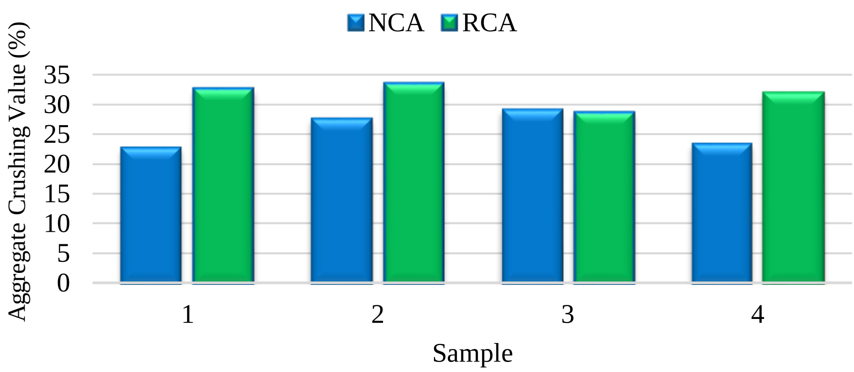


Figure 7. Aggregate Crushing Value (ACV) for NCA and RCA.

6.4. Aggregate compaction

The Optimum Dry Density (ODD) and Optimum Moisture Content (OMC) for the NCA and the RCA result can be seen on Figures 8 and 9. NCA has a higher density (2138 kg/m^3) as it is a pure crushed rock compared to RCA (1952 kg/m^3) which is made from mixture of cement, mortar, fine aggregate, and coarse aggregate. On the other hand, the RCA has a higher OMC (9.38%) compare to the NCA (8.56%). The result of the optimum moisture content also consistent to the result of the water absorption. The higher water absorption of the aggregate, the higher optimum moisture content will occur.

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012061 doi:10.1088/1757-899X/527/1/012061

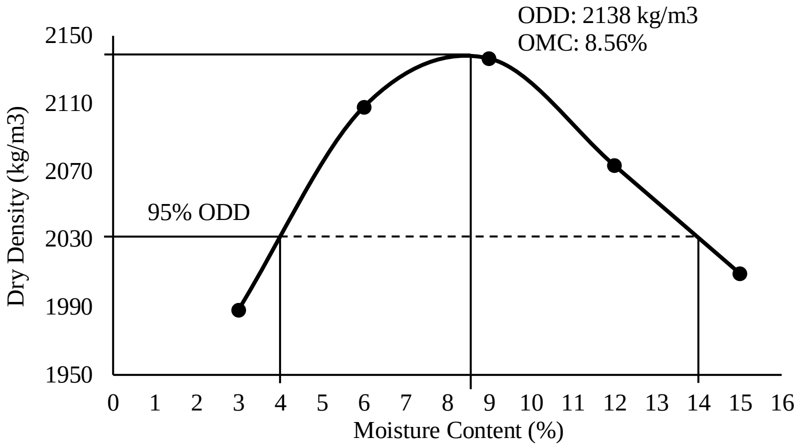


Figure 8. Relationship of ODD and OMC for NCA.

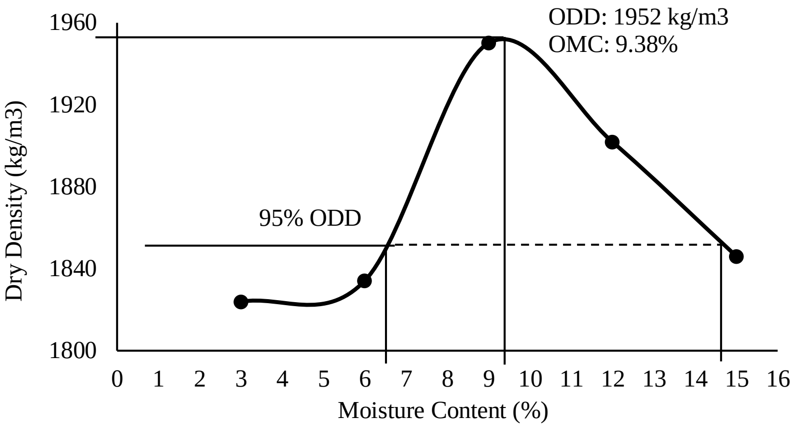


Figure 9. Relationship of ODD and OMC for RCA.

6.5. Penetration test (California Bearing Ratio)
California Bearing Ratio (CBR) test have been commonly used as a measurement for material quality, especially in terms of resistance to permanent deformation [18]. The CBR test of the NCA and RCA shows a very different result between this two types of aggregate. As seen on Figure 10, NCA has a CBR value of 97.0% from 19.40 kN for 5 mm penetration, while RCA only has a CBR value of 67.3% from 13.45 kN for 5 mm penetration. The CBR value of RCA is far below the requirement which is 80% at 95% compaction. As the indicator for material resistance of the working load, then an improvement is required for road base constructed from RCA.

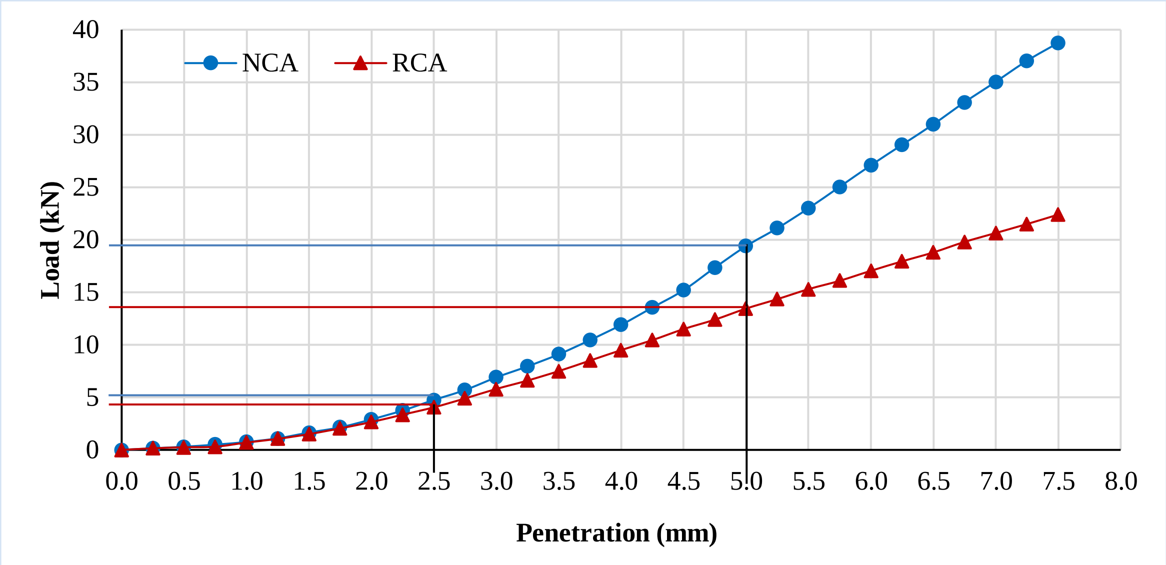


Figure 10. CBR value for NCA and RCA.

6.6. Road base improvement

Cement treated base (CTB) is one of the popular method for strengthening the road base layer. Compared to the normal CTB from NCA, the CTB that were made from RCA need more water to obtain the good workability since RCA has more porosity than NCA [19]. At present time the reliable performance of RCA for road base layer is ensured by the addition of the layer thickness than calculations. But it must considered the amount of the material used for the construction [20]. The use of additional material such as geosynthetics and geogrids have also conducted many times in road constructions. Geogrids may ensure additional strength for tensile and shear for cohesive soil and granular material such as aggregate. The structure principal of road base layer with geogrids is similar with the reinforced concrete. By using the geogrids system, the settlement may decreased around 13-30% compared to no geogrids [21]. The use of RCA for road base material itself has been proven more economical compared to the NCA. The Welshpool Road project in Australia is an example of the successful application of RCA for road base material in economic aspect [22].

The alternative material for replacing geogrids system is proposed to suppress the construction cost. The alternative material is by using the plastic strips from plastic bottle waste. Polyethylene terephthalate or PET is the type of plastic that is commonly used for plastic bottle, e.g. mineral water bottle, soda water bottle, etc. This type of plastic is considered as a thermoplastic [23]. Experimental results showed that a considerable improvement in flexural and tensile strength. Concrete with plastic strips addition may have flexural strength up to 84% [24] while the tensile strength may increase up to 20.3% [25] compared to a plain concrete.

The experiments for this research was conducted by using CBR test with 3 (three) different plastic strips content. Figure 11(a) show the plastic strips are made from plastic bottle waste which is shredded into the size of 2-4 mm width and 50-70 mm length. The optimum content of the plastic strips according to the similar study previously is 0.5% [25]. As a note, the 0.5% plastic strips content is for a well-mixed material between the aggregate and the plastic strips. In this research, the plastic strips will be laid and scattered on the aggregate surface. Therefore, the plastic strips content is based on the one of the commonly used geogrid product which is the Stratagrid 550. The Stratagrid 550 is made from PET and has a weight about 393.5 grams/m^2 Thus, the weight will be used as a reference for the plastic strips content. The mold has a diameter of 150 mm and surface area of 0.0177 m^2. Therefore, the plastic strips content is 6.95 grams. The other two samples use 3.48 grams (50%) and 1.74 gram (25%) of plastic strips content. The plastic strips layer is placed on the middle of the sample height as seen on Figure 11(b).

(a) (b)

Figure 11. (a) Plastic strip from plastic bottle and (b) Plastic strip from plastic bottle and its placement.

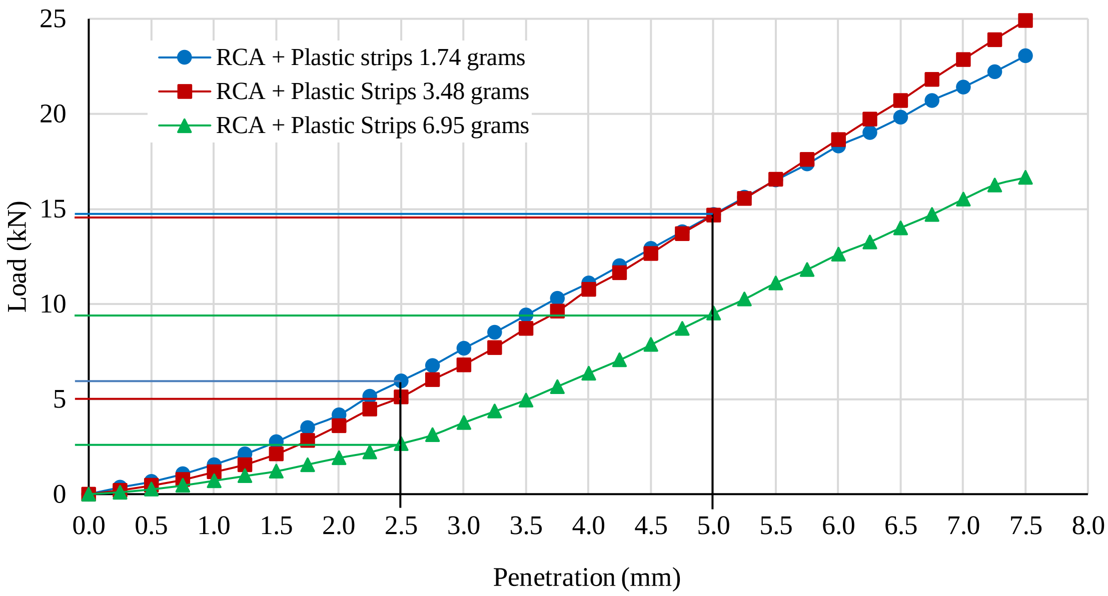


Figure 12. CBR result for RCA with various plastic strips content.

As shown in Figure 12, the optimum result is the RCA + 1.74 grams plastic strips with CBR value of 73.50% followed by RCA + 3.48 grams plastic strips with CBR value of 73.25%. The CBR value for RCA + 6.95 grams plastic strips fall to 47.50% which is worse than the RCA without any plastic strips content. The CBR result decreasing in line with the increment of the plastic strips content because when it too dense, then the plastic strips layer act like a plastic sheet and causing the aggregate separated. The aggregate must able to slip through between the plastic strips to make it as a one unit of road base layer, in this case, the sample in the CBR mould.

7. Conclusions

The conclusion from this research are:

i. The NCA and RCA gradation of the raw material were not fulfilled the requirement from the gradation limits. In order to use both materials as a road base layer, then it must be mixed in accordance of the grading requirement.

ii. The results in density test, water absorption test, ACV test, and aggregate compaction test show that the RCA has more porosity compare to the NCA. As a material made from several substances such as natural aggregate, fine aggregate (sand), binder (cement), and any other materials, it is can be accepted that the RCA is not as dense as the NCA. The nature of its porosity may cause as weakness for construction material as the strength is less than the NCA.

iii. The CBR result for RCA is far below the minimum requirement. Thus, an improvement is needed for RCA to equal the road base constructed from NCA. The proposed improvement by using plastic strips has shown a promising result. The RCA with 1.74 grams of plastic waste has a higher CBR result compared to RCA without plastic strips. To be considered, the CBR result also shows that the increasing plastic strips content may cause the CBR value decreasing.

iv. A further research is needed to obtain the optimum content of the plastic strips for RCA improvement.

8. References

[1] US Environmental Protection Agency 2016 Construction and demolition debris generation in the united states in 2014

[2] Begum R A, Siwar C, Pereira J J and Jaafar A H 2006 A benefit-cost analysis on the economic feasibility of construction waste minimisation: the case of malaysia *Resour. Conserv. Recycl.* **48(1)** 86–98

[3] Kofoworola O F and Gheewala S H 2010 Estimation of construction waste generation and management in thailand, *Waste Manag.* **29(2)** 731–738

[4] Lockrey S, Nguyen H, Crossin E, and Verghese K 2016 Recycling the construction and demolition waste in vietnam : opportunities and challenges in practice *J. Clean. Prod.* **133** 757–766

[5] NEA Singapore 2018 Waste management statistics and overall recycling measures *Waste Statistics and Overall Recycling* [Online] Available: https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling. [Accessed: 05-Sep-2018].

[6] Borongan G, Management U E, Luang K, Nitivattananon V, Management U E, and Luang K 2007 Current practices in selected south east asian countries on managing construction and demolition waste 5–7

[7] E Science 2018 Constraints to 3r construction waste reduction among contractors in penang

[8] Kou S, Poon C and Wan H 2012 Properties of concrete prepared with low-grade recycled aggregates c & d waste *Constr. Build. Mater.* **36** 881–889

[9] Wahi N, Joseph C, Tawie R and Ikau R 2016 Critical review on construction waste control practices : legislative and waste management perspective *Procedia - Soc. Behav. Sci.* **224**

[10] Fellenius B H 2009 *Basics of Foundation Design* April 2006 no March. Alberta: BiTech Richmond BC

[11] Cement Concrete & Aggregate 2017 Technical note 76 - introduction to roadbase products and testing australia 1–11

[12] JKR/SPJ/2008-S4 2008 Standard specification for road works - section 4: flexible pavement. malaysian road works department 1–187

[13] Brown B 1998 Aggregates for concrete *Design and Control of Conrete Mixtures* vol 32 no. 5 London, 1998 12–14.

[14] Sharma J and Singla S 2014 Study of recycled concrete aggregates *Int. J. Eng. Trends Technol.* **13(3)** 123–125

[15] Highley D, Harrison D, Cameron D and Lusty P 2013 British geological survey - construction aggregates

[16] BS 1377-2:1990 1990 Soils for civil engineering purposes - part 2: classification tests **3(1)** British Standard Institution

[17] ASTM C127-01 2001 Standard test method for density, relative density (specific gravity), and absorption of coarse aggregate *ASTM International*. American Society for Testing and Materials 1–6

[18] Christopher B R, Schwartz C and Boudreau R 2006 *Geotechnical Aspects of Pavements*

[19] Xuan D, Houben L J M, Molenaar and Shui Z 2010 Cement treated recycled demolition waste as

a road base material *J. Wuhan Univ. Technol. Sci. Ed.* **25(4)** 696–699
[20] Hill A R, Dawson A R and Mundy M 2001 Utilisation of aggregate materials in road construction and bulk fill *Resour. Conserv. Recycl.* **32(3-4)** 305–320
[21] Fischer S and Horvát F 2011 Investigation of the reinforcement and stabilisation effect of geogrid layers under railway ballast *Slovak J. Civ. Eng.* **XIX(3)** 22–30
[22] Leek C 2007 Use of recycled crushed demolition materials as base and sub-base in road construction City of Canning
[23] Mark J E 1999 *Polymer Data Handbook* Oxford Universiti Press
[24] Al-Tulaian B S, Al-Shannag M J and Al-Hozaimy A R 2016 Recycled plastic waste fibers for reinforcing portland cement mortar *Constr. Build. Mater.* **127** 102–110
[25] Kien N, Satomi T and Takahashi H 2018 Recycling woven plastic sack waste and pet bottle waste as fiber in recycled aggregate concrete : an experimental study *Waste Manag.* **78** 79–93

Acknowledgements
This study was conducted under the support from Research University Grant (GUP) Q.J130000.2522.13H03 and High Impact Research Grant (HIR) Q.J130000.2451.04G54.