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Laboratory Performance of Recycled Concrete Aggregate as Base-course Material

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Abstract

This paper evaluates the application of RCAg as an unbound granular base course material for road construction in New Zealand. It investigates the physical properties of recycled concrete aggregate and their engineering performance (durability) through experimental laboratory based tests and compares the characteristics of tested RCAg with the specification of Basecourse materials (NZTA M4) in New Zealand and comments upon their appropriateness for pavement construction. According to tests results, tested RCAg has proven to meet a 'premium' grade product and it is expected that crushed recycled concrete if production is appropriately managed, could have high potential use as a base course material in road construction and in some cases perform better than common natural aggregates.

Keywords: recycled aggregate, recycled concrete, road construction, basecourse material, physical properties, engineering performance, durability.

1. Introduction

The sharp population increase and also high standards of living have caused a considerable demand for developing infrastructure and therefore a growth of construction activities. This demand leads to a considerable rise in the extraction and consumption of natural aggregate and caused meaningful environmental impacts. Moreover, the growing trend of generating waste material from demolished structures and the lack of landfills have raised governments and authorities' concern. Over the last decades and by increasing the environmental problems arising from explained issues, world's attention has been attracted to employ the waste products as a viable alternative in engineering applications. Different researches have been conducted into the various uses of recycled materials and thereby, road construction has known as a high potential area for applying Recycled Aggregate (RAg) with environmental and economic benefits (Chini, Kuo et al. 2001).

A pavement is a multi-layered structure comprising various layers such as the surface, base, subbase, and subgrade. The main role of the base layers is to provide a uniform support for pavement surface layers and adequate drainage during the lifetime of the pavement (Huang 1993). To have these qualifications, the materials used in unbound granular layers must meet specific engineering requirements such as particle size distributions with adequate stiffness, good durability, high permeability, and resistance to permanent deformation. So, in order to provide a viable option for use of Construction and Demolition (C&D) waste, there is a need to investigate the possibility of using RAg and specifically Recycled Concrete Aggregate RCAg as an unbound granular material in road base or subbase (Kim, Ceylan et al. 2011).

The essential need to preserve natural resources and increase landfill spaces have motivated governments and industrial organizations of different countries to make a concentrated effort to replace virgin aggregates with RAg. In 2002 a memorandum was released by the Federal Highway Administration (FHWA) agency within the U.S. Department of Transportation, which has accentuated the interest of FHWA in using recycled material products in the national highway system (Kim, Ceylan et al. 2011). Thereafter, in the United States, over 130×106 tons of construction and demolition (C&D) waste is produced each year which around 70% of RCA produced is used in pavement construction and particularly as a granular material in base and subbase layers (Gabr, Cameron et al. 2012). In the 1990s, Australian authorities started the technology of using RCA in lightly trafficked road construction. In 2004 and 2005, South Australia was generating around 1.5 million tons of C&D waste which 70% of this waste was recovered. In recent years, over 500 million kg of RCA have produced annually in South Australia mostly from building demolition waste, and a significant proportion of this is used in pavement construction (Gabr, Cameron 2012). In Europe, from 1945 to 2000, around 600×106 m3 of waste masonry was used in the rebuilding of Germany after World War II. Whereas, in 1998 about 350,000 tons of crushed concrete was used in base and subbase layers of Finland's road construction (Gabr, Cameron et al. 2012).

Despite the approval of different countries, the application of RAg as a viable alternative in road construction has not been widely accepted in New Zealand. It is estimated that Auckland city currently disposes of 550,000 tons per annum of construction and demolition waste in clean fill sites in the region and according to the study in the Waikato Region, if all waste concrete and glass were incorporated into aggregate, it would represent about 11% of the total road aggregate demand (Aggregate News, 2015). Due to the existence of C&D waste as a reusable material in New Zealand, it appears that the only restriction is the lack of technically proven documents and verifiable testing research which confirms the capability of recycled materials in pavement layers. This paper is a part of a research in the University of Auckland by the aim of understanding the characteristics of Recycled Concrete Aggregate thoroughly in the New Zealand context to enable their usage in basecourse layers. The following research investigates the physical properties and engineering performance of RCAg through experimental laboratory based tests and compares the results with the specification of Basecourse materials (NZTA M4) in New Zealand. RCAg used in this study is provided from one of the recycled aggregate suppliers in the Auckland region.

2. Literature Review

During the last years, different researches have been conducted by the aim of evaluating the sustainability of C&D waste in road construction. In 2001, Chini et al. studied the performances of RCAg in base layer by different ratiosof natural aggregates. According to the life expectancy analysis from circular accelerated test, it was concluded that after at least 3 years RCAg would perform equally to natural aggregate in an average daily traffic road. (Chini, Kuo et al. 2001)

In 2002, Molenaar and Niererk studied the physical properties of unbound basecourse materials made of reused concrete and masonry rubble. The results of this Hollander research showed that the level of compaction is a critical parameter which could strongly influence the mechanical characteristics of recycled material as a basecourse layer. (Molenaar, van Niekerk 2002)

In 2003, a research by the aim of investigating the properties of two samples of recycled concrete aggregate from different sources was conducted by Park. The first sample was sourced from a demolished vertical structure and the second one was obtained from a horizontal structure rehabilitation project. The initial test results proved a 20% reduction in the water absorption of first RCAg in comparison with the second one. In terms of dry density, results showed that by increasing the Optimum Moisture Content (OMC) from 9% to 12.8%, dry density dropped from 2.21 to 1.81 kg/m3 in the first and second samples respectively. It was observed that OMC was increased by the rising of water absorption whereas bulk specific gravity was equal for both aggregates. (Park 2003)

Poon and Chan in 2006 appraised the application of RCAg mixed with Crushed Clay Brick (CCB) in subbase pavement layer through experimental tests. The results confirmed a direct relationship between the percentage of RAg in samples and their OMC while the reduction of these two parameters raised the maximum dry density. They have also compared test results with the physical properties of natural aggregate in the same layer and concluded that the combination of RCAg and CCB could be a feasible alternative for subbase material in Hong Kong due to its potential to extend the service life of dumping facilities. (Poon, Chan 2006)

In Western Australia, Leek and Siripun (2010) investigated the characteristics of three types of RCAg and compared them with the natural aggregates during two years. Their results reflected that wherever high stress application is required, RCAg is a suitable material as a premium basecourse product. (Leek, Siripun 2010)

In 2011, a research in Spain focused on verifying the possibility of exploiting construction waste as a material for the subbase in road construction. Herrador et al. conducted a field study to assess the performance of mixed recycled aggregate consisting of 75% crushed concrete in subbase. They concluded that despite difficulties to provide a greater quantity of water and achieving desire level of compaction, the load bearing capacity of their mix was adequate to compete with natural quarry aggregate. (Herrador, Pérez et al. 2011)

The objective of following research is assessing the potential of RAg as an alternative in pavement construction. In this regard, Particle Size Distribution (PSD), Foreign Material Content (FMC) and Vibration Hammer Compaction (VHC) test methods have been followed for better understanding of the physical characteristics. Moreover, to study the compression strength and permanent deformation of RAg, Unconfined compression Strength (UCS) and Repeated Load Triaxial (RLT) tests has been chosen.

3. Methodology

The RCAg used in this research produced by a supplier in Auckland region and originated from vertical demolished structure sites. According to the recycling procedure, all of the C&D waste should be inspected before entering to the manufacturing plant to ensure that there is no hazardous material in the recycling operation. Crushing process is generally accompanied by removing steel from crumbled concretes thorough electromagnet, followed by sizing and screening based on the grading. Due to the generation of RCAg from old structures, it usually contains small parts of foreign materials such as crushed masonry, glass, wood, steel and asphalt which may affect the characteristics of RCAg. So it is necessary to determine the portions of foreign materials and study their influence on the performance of RAg. Moreover, an unbound granular material used in base layers must satisfy requirements related to the particle size distribution, stiffness, durability and also permeability. In this research, following tests were conducted by Australian and New Zealand’s standard to assess the application of RCAg in basecourse.

3.1. Particle Size Distribution

Soils consist of particles with various shapes and sizes. Particle Size Distribution (PSD) test is used to separate particles into size ranges and to know quantitatively the mass of particles in each range. Gradation analysis is used to determine the uniformity coefficient (Cu) which reflect the empty spaces of material. According to NZS test method, a square opening sieve criterion was used to determine the gradation of soil between the 3-in. (75-mm) and No. 200 (75-µm) sieve.

3.2. Foreign Materials Content Test

Due to the existence of small portions of foreign materials in RCAg and their effects on the performance of base layers, Foreign Material test was done by following Australian standard. In this test, the materials retained on the sieve 4.75 mm were manually sorted out and the foreign contaminants were classified into three groups to determine their percentages as a mass of the test portion.

3.3. Compaction Test

Compaction test was carried out to determine the dry density of material based on different moisture contents. The outputs were plotted as a compaction test which specified maximum dry unit weight and corresponding water content for effective compaction of recycled concrete aggregate. Compaction procedure was done by using an electronic vibrating hammer in two layers and according to New Zealand test method.

3.4. Unconfined Compression Strength Test

Unconfined Compression Strength (UCS) test was conducted to evaluate the stiffness of pavement material used in mechanistic pavement design methods. In the UCS test, the axial vertical load is applied to a sample through loading plates and the UCS number was determined by using strain-control as the maximum unit stress obtained from load testing.

3.5. Repeated Load Triaxial Test

Triaxial testing is a research tool with the aim to simulate as closely as possible the range of conditions that will be experienced in a field pavement. The Repeated Load Triaxial (RLT) apparatus applies repetitive loading on cylindrical materials for a range of specified stress conditions, the output is deformation versus numbers of load cycles for a particular set of stress conditions and resilient modulus which reflects the stress-dependent stiffness of materials. In this research, RLT test was done on RCAg in small scale and by following New Zealand (NZTA T/15) method. This protocol has adopted 6 stages of permanent strain by 50,000 cycles per stage. (Arnold 2010).

4. Results

Table 1 presents the physical and engineering characteristics of the recycled concrete aggregate. Each type of test has been conducted at least three times to control the variability and approve the validity of the results In order to analyse the results and determine the merits of RCAg in the base layer, there is a need to compare the results with existent criteria. Many national and international specifications for the usage of RCAg as an unbound granular material in pavement layers have been codified around the world which are applicable to different classes of pavement based on the traffic road. In New Zealand, the appropriate specification for basecourse aggregate is NZTA M/4, which sets out requirements for basecourse aggregate for use on heavily trafficked roadways. M/4 was published by New Zealand Transportation Agency and used as a benchmark to assess the application of tested RCAg in basecourse layers. M4 not only specified criteria for Natural Aggregates (NAg) but also suggested some limits for applying Recycled Crushed Concrete (RCC) in basecourse.

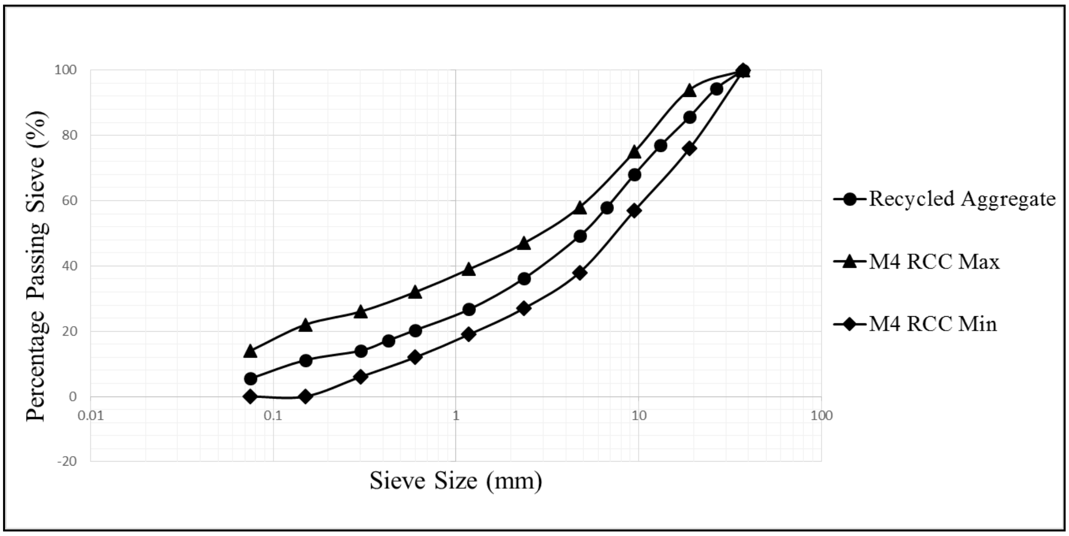
Table 1: Physical and engineering properties of RCAg

Engineering Properties	RCAg
Gravel Content (%)	50.8
Sand Content (%)	5.5
Fines Content (%)	43.7
Coefficient of Uniformity (C_u)	60.8
Coefficient of Curvature (C_c)	2.56
Maximum Dry Density (t/m^3)	0.0205
Optimum Moisture Content (%)	10.7
Unconfined Compression Strength (kPa)	650-700

The particle size distribution test on at least 3 samples of recycled concrete aggregate from same source indicates that these material can be classified as a well- graded gravel based on Unified Soil Classification System. The high amount of uniformity coefficient means there are no excessive empty spaces between small components of the material which could prevent particles to be broken (De Farias Pinto, De Sérgio Ricardo Honório et al. 2014).

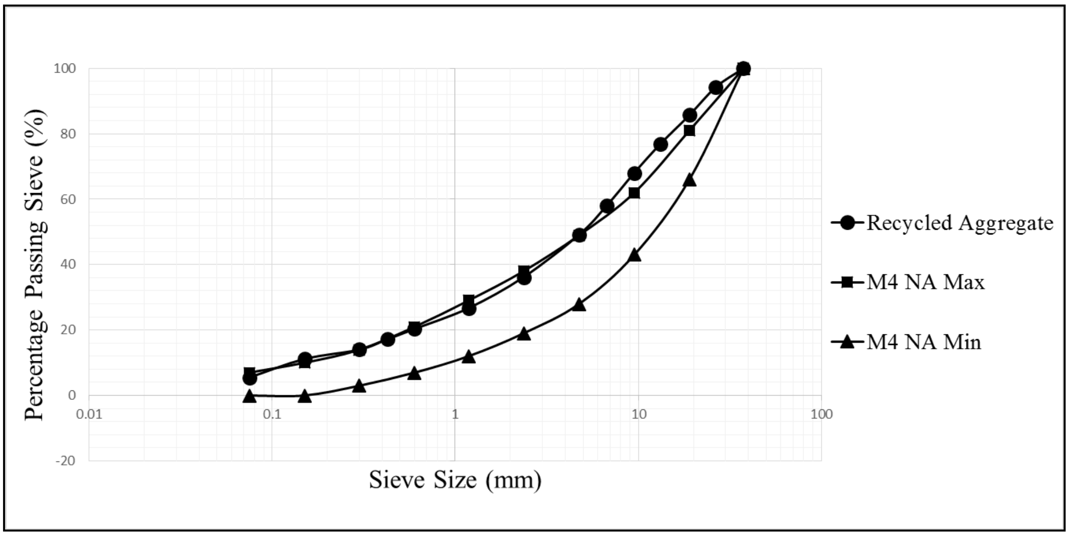
Figures 1 and 2 demonstrate the average particle size distribution of RCAg and compare the results to the NZTA M/4 criteria for Recycled Crushed Concrete (RCC) and Natural Aggregate (NA) respectively. According to the figure 1, particle sizes diagram of tested aggregate is within the M4 required limits for RCC aggregates specifications.

Figure 1- Comparison the PSD of RAg with M4 RCC



As it is shown in figure 2, the PSD results of RAg meets the minimum requirement of M4 NAg whereas the maximum criteria is not satisfied for the particles range coarser than 4.75mm. Although this difference in worst case is not more than 10%, it confirms that the established criteria for PSD of NAg is lower than the one stated for RCC in M4 specification.

Figure 2- Comparison the PSD of RAg with M4 NA



The reason for this difference might lie in the crushability property of aggregates which leads to the usage of different crushing machines and different scalping screens. During the process of crushing waste concrete, a definite amount of mortar and cement which was used as a binder in the original concrete remains attached to stone particles and forms sharp edges, whereas most particles of Natural Aggregates have smooth edges. Moreover, the presence of mortar in the recycled concrete increases the crushability and breaking RCAg into the smaller size leads to generating more fine and weak aggregates in comparison with NA.

Figure 3 shows the foreign materials content test results on 3 samples of RCAg that were appraised by the mass of materials retained on sieve #4. According to RTA T276, foreign materials existing in recycled concrete are divided into three types. Type I consists of high density materials whereas, Type II and III includes low density materials as follow:

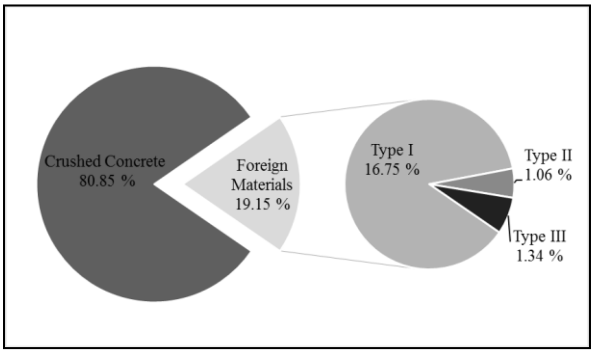
Type I: Metal, Glass Asphalt, Stone, Ceramic and Slag.

Type II: Plaster, Clay lumps and other Friable Materials.

Type III: Rubber, Plastic, Bitumen, Paper, Cloth, Paint, Wood and other Vegetable Matter.

According to the RTA test results, a significant part of the foreign material stones which are categorised in Type I and increased the portion of foreign material up to 19 %.

Figure 3- Foreign materials content of RCAg



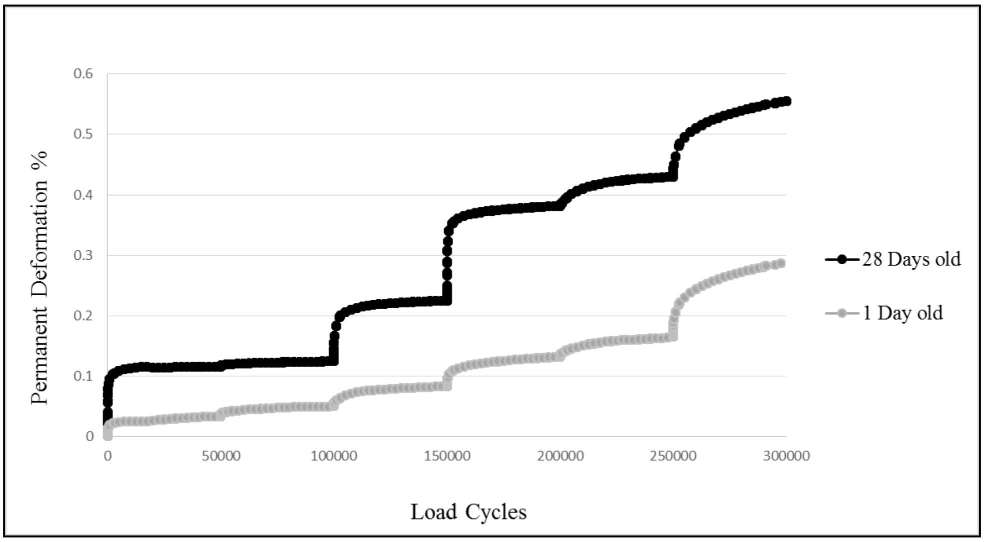
In this research, the strength of recycled aggregate was determined as the maximum unit stress by applying a monotonic load to the 3 compacted samples through platens. The material which passed the 19 mm sieve was compacted by following standard compaction procedure in 3 layers. Due to the existence of cement in the recycled aggregate, the specimens were cured for 28 days in a moist around 25°C. The UCS range of recycled aggregate is presented in table 1 and it is found to be higher than most of the UCS ranges which were reported by past researches on recycled crushed concrete. This difference could be referred to the curing period as self-cementing of recycled concrete increases the strength over the time.

RLT test was conducted on RCAg to study the variability of resilient modulus and permanent deformation by the impact of applied stress. Two same specimens were prepared by compacting the material at their Optimum Moisture Content (OMC) to a target of 95% of Maximum Dry Density (MDD) due to NZTA T15 method. The first specimen was tested in the RLT machine right after compaction and the second one was cured for 28 days before testing to demonstrate the influence of self-cementing properties of recycled concrete. The permanent deformation of specimens based on the number of cycles is presented in figures 4.

According to the figure 4, the permanent deformation of 28 days old specimen is higher than one-day old specimen and none of them failed during the 6 stages of test. Both of the tests were conducted under the dry/drained situation. Resilient module is another important criteria for designing flexible pavement which could be determined by RLT test and defines as a measure of material stiffness under repeated load (Gabr, Mills et al. 2013).

Table 2 summarizes the test results obtained from RLT tests using NZTA T15 protocol. One day old specimen achieved the lowest average permanent strain in comparison with 28 days old one whereas the resilient modulus of the second specimen is higher than the first one.

Figure 4- Comparison the permanent deformation of 1 day and 28 days old specimen



The higher resilient modulus indicates some cementations bonds have been formed. Regarding the permanent strain slope, NZTA M4 specification for basecourse aggregate determined some criteria for permanent strain slope of aggregates. According to this specification for the unbound aggregates used in high traffic state highways (>5 million ESA), the dry average permanent strain slope should be smaller than 0.55% while this amount was specified to be less than 1% per million for aggregates used in low traffic state highways (<1 million ESA). Based on the test results in table 2 for both specimens, permanent strain slopes in 5 stages are less than 0.55 at the tested density and MC.

Table 2: Permanent strain and resilient modulus results for 1day and 28 days old specimens

Stages	Resilient Modulus (MPa)		Permanent Axial Strain (µ€)		Permanent Strain Slope (%/1M)	
	1 Day old	28 Days old	1 Day old	28 Days old	1 Day old	28 Days old
Stage 1	507	617	423	2133	0.22	0.05
Stage 2	337	425	433	1963	0.11	0.07
Stage 3	477	581	878	3153	0.19	0.18
Stage 4	543	711	1479	4919	0.28	0.24
Stage 5	531	656	1749	5298	0.24	0.31
Stage 6	406	545	2826	6258	0.8	0.86

5. Discussion

Different researches have been conducted on the various usage of recycled materials and thereby, road construction was known as one of the best area with high potentials in applying Recycled Aggregate (RAg) and specifically Recycled Concrete Aggregate (RCAg) in pavement granular layers. Some of the physical properties of RCAg were evaluated by conducting relative tests and results were compared with New Zealand specification to assess their appropriateness as a basecourse material. PSD test was done to analysis the gradation of aggregates, then compaction test determined the optimum amount of moisture which leads to the maximum density, followed by measuring the strength of aggregates through UCS test and study the stiffness of RCAg by applying RLT test. The Foreign Material test was carried out to specify the range of existing contaminants in RCAg. The results approved that RCAg meets the requirements of New Zealand basecourse specification and the 28 days cured specimens reached higher strength and stiffness. On the other hand, the self-cementing property of RCAg affects the rutting of pavement.

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