ICSBE2016-195

EVALUATE THE STRENGTH OF CEMENT TREATED RECYCLED CONSTRUCTION AND DEMOLITION AGGREGATES AS A PAVEMENT MATERIAL

V. Gobieanandh[1*], S. Jayakody[2]

[1]Northshore College of Business and Technology, Colombo, Sri Lanka
[2]South Eastern University of Sri Lanka, Oluvil, Sri Lanka
**E-Mail: gobieanandh@gmail.com, TP: +94766466526*

Abstract: Generation of construction and demolition (C&D) waste is a part of urbanization and causes adverse effect on the environment. The most popular method of managing C&D waste is through disposal in landfills which is becoming an environmental hazard. Therefore, use of such waste as recycled aggregate in road construction will make more benefits in environmental and economic aspects. However, lack of research on properties and performances of recycled C&D has limited its use in pavement structures in many developing countries including Sri Lanka. This study discusses the possibility to partially replace conventional aggregates with recycled C&D aggregate in base or sub base road construction. Test samples were made by mixing C&D aggregates in different ratios with conventional aggregates. Tests were carried out for particle size distribution (PSD) and dry density - moisture content relationship. California bearing ratio (CBR) was conducted to better understand the bearing strength of recycled mixtures. The study further extended by adding cement to evaluate the improving range in strength. The resulted high strength properties of the C&D mixed samples revealed the potential use of recycled C&D aggregates as an alternative for conventional aggregates in road construction.

Keywords: California bearing ratio; pavement aggregates; recycled construction & demolition waste.

1. Introduction

Construction and Demolition (C&D) waste causes adverse effect on the environment. The use of such waste as recycled aggregate in road construction involves with sustainability as new buildings come up replacing old ones as the land space is limited. Using C&D would definitely cut down the cost compared to natural aggregates because it is easily obtainable and available abundantly and also would benefit environment drastically as we could reduce mining of quarries. Recycled C&D waste is generally produced by the crushing of demolished building waste, screening and then removal of contaminants such as reinforcement, paper, wood, plastics and gypsum.

Use of C&D started since the end of World War II by using a demolished concrete pavement as recycled aggregate in stabilizing the base course for road construction [1]. However, many developing countries including Sri Lanka have not started to practice the use of C&D yet. The current method of managing such waste is through disposal in landfills causing huge deposits of C&D waste and becoming an environmental hazard.

Western countries especially Netherland and Denmark have been successfully utilizing C&D waste in road construction and recorded the highest recycling rates above 94% [2]. Many studies in the extracted materials from recycled C&D have been conducted in recent years by Arul Rajah [3], Agrela et al. [4], Poon et al. [5] and they have shown the possibilities of reusing these materials in unbound road construction under different conditions. Ahmed Ebrahim et al. [6], Hilmi [7], Agrela et al. [8] have shown C&D material with a binding agent can be successfully used as bound pavement material. Though there is literature available on behaviour of road pavement using recycled C&D waste in temperate and arid climatic regions, very little research was found on the tropical climate similar to Sri Lanka [9].

Therefore, the performance of C&D materials has to be tested and establish the required specifications through research studies prior to the recommendation for pavement applications. As a long-term objective, the results of this research could be used to derive specification and design guidelines on the use of recycled C&D waste as road construction material, which are not widely available at present in Sri Lanka.

2. Materials

Recycled C&D materials were obtained from a leading recycling plant named COWAM centre in Galle. COWAM centre is the first location for sustainable construction waste management practice in Sri Lanka. Conventional Aggregates (CA) were acquired from quarry and crusher plant located in Nebada, Kalutara. Portland cement of strength class 42.5N is used as a treatment material.

(a) (b)

Fig 1: Sample of (a) C&D, (b) CA

3. Experimental program

This study presents a laboratory investigation aimed to characterize the behaviour of recycled C&D aggregate compared with natural aggregate for road applications. Four samples were prepared by mixing C&D and CA by weight as shown in Table 1. The objective of preparation of different samples is to determine the best mix ratio of recycled C&D and CA to be used as unbound pavement material. Prepared samples were tested in particle size distribution and proctor compaction test to examine their material gradation and moisture-density relationship respectively. Then the load bearing capacity of the samples were tested with California bearing capacity test. The first part of the research study was the strength characterization of the samples shown in Table 1 to determine the optimum mixing ratio. The second part is dedicated for the performance of cement treated C&D aggregate with CA to determine the optimum mixing ratio for a cement bound pavement which can bear heavy loads.

Proctor compaction test and CBR tests were conducted on another 4 samples which were prepared by adding 5% of Portland cement by weight as shown in Table 2. Samples used in test were divided into smaller convenient quantities using Cone & Quartering method and experiments were conducted following British Standard 1377 [10].

Table 01.Sample names and mix ratio

Sample Name	CA %	C&D %
CA-75/C&D-25	75	25
CA-50/C&D-50	50	50
CA-25/C&D-75	25	75
CA-0/C&D-100	0	100

Table 02.Cement treated mixture ratios

Sample Name	CA %	C&D %	cement %
CA-75/C&D-25	71.25	23.75	5
CA-50/C&D-50	47.5	47.5	5
CA-25/C&D-75	23.75	71.25	5
CA-0/C&D-100	0	95	5

This paper presents the results of classification test of different aggregate samples which were subjected to particle size distribution and proctor compaction test since C&D waste is highly heterogeneous and consists of different amount of impurities and their quantities are not consistent. California Bearing Ratio (CBR) was checked for relative measure of strength of aggregates for standard 4 day soaked condition. All results were compared with those of the ICTAD [11] road material used in Sri Lankan base layer. Further CBR test were done on cement treated CA-0/C&D-100 sample varying the curing period as 1 day, 4 days, 1 week & 2 weeks, to check initial strength gaining and strength behaviour with time in as a compacted unbound pavement material.

4. Results and Discussion

4.1 Physical Characteristics

4.1.1 Particle size distribution (PSD)

PSD of a particular pavement aggregate type affects its compressibility, permeability and density. Therefore, gradation of a pavement material has to be checked continuously to maintain the required particle size distribution according to the standard specification [12].

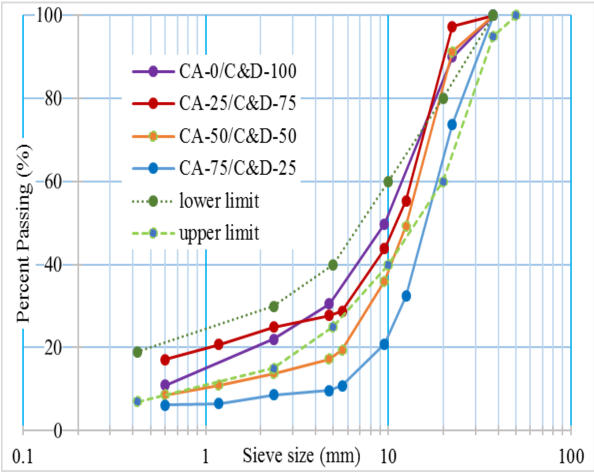

Fig 2: Particle size distribution of C&D and CA mixed samples

PSD of mix aggregate samples were plotted with upper and lower boundaries of standard specification of road base for graded crushed stone material specified by TRL Overseas Road Note 31 [13] and shown in Figure 2. The graphs depict higher coarse particles with increasing the portion of CA. Shapes of all the curves are close to well graded. However, with increasing the portion of C&D aggregates the curves are close to the lower limit which indicate higher finer fraction.

4.1.2 Proctor Compaction

The moisture and density curve which is obtained by conducting proctor compaction test on a soil is an indicator of the sensitivity of the density with respect to the variation of moisture content. Materials with flat curves can tolerate a greater amount of variations in the moisture content without compromising much of the achieved density from compaction. In contrast, materials with sharp curves are extremely sensitive to water (moisture) content during compaction [14]. The obtained OMC and MDD values of the four unbound material samples are shown in Table 3.

Table 03. OMC and MDD of samples

Sample Name	OMC (%)	MDD (g/cm³)
CA-75/C&D-25	8.9	2.022
CA-50/C&D-50	9.1	1.778
CA-25/C&D-75	10.1	1.755
CA-0/C&D-100	12.4	1.464

The values depict that increase in C&D material increases the optimum moisture content (OMC) while decreases the maximum dry density (MDD) when mixing with conventional aggregates. The difference in MDD was attributed to the physical properties of conventional aggregates which had higher density and were less porous compared to those of C&D aggregate. OMC values rise due to more fines content and higher absorption capacity of recycled C&D aggregates which has brick, cement mortar paste and residual cement within the aggregates [15].

Mixing of C&D waste material increases the optimum moisture content (OMC) and this would be an issue in the regions where the water is scarce.

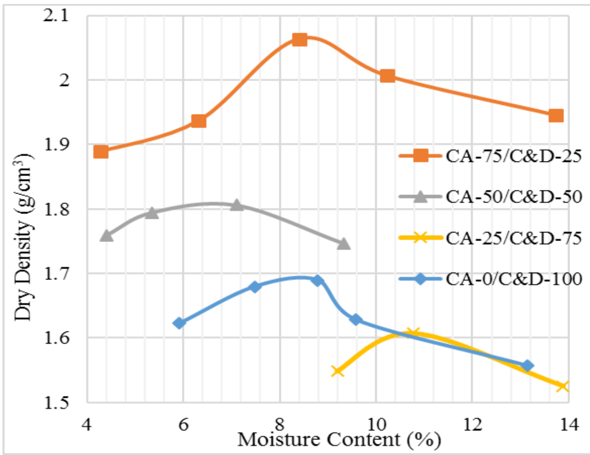

Fig 4: Proctor compaction curves of cement treated C&D and CA mixed samples

Figure 4 presents the compaction curves of the blended samples with 5% cement treated. It shows similar trend to un-bound pavement material in reducing MDD values when increasing the C&D content, however, OMC values varies a lot. The OMC has drastically dropped down to 6.9% - 10.8 %, this is mainly due to the hydration of cement content reacting with water and releasing more heat and stimulating water to rapidly evaporate.

Due to higher absorption and hydration loss of water, cement treated mixed recycled aggregates have a lower workability, and thus, it might be necessary to apply a setting retardant admixture such as plasticizer [9].

4.2 Strength Properties

CBR characterization is widely used in pavement industry to provide a relative measure of strength and elastic modulus across various road materials for structural design purposes of pavement. The mixed samples were tested under CBR after soaking 4 days and results are shown in Figure 5.

Soaking of aggregate sample specially unbound materials tend to loosen from their adhesion and compaction under fully saturated condition. Therefore, CBR values tend to reduce which is more significant. However, notable reduction of the CBR is observed when the C&D portion exceeds 50% in the CA samples. This is due to the increase of recycled C&D materials which have low strength.

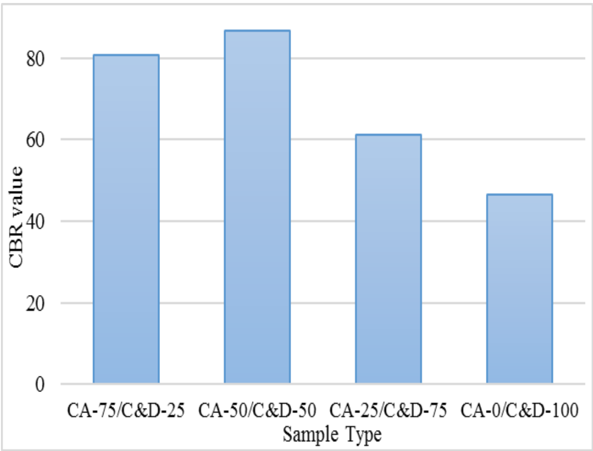

Fig 5: Comparison of CBR values for unbound C&D mixtures

According to ICTAD specification [11] RDA limits for the minimum CBR value for road sub-base is 30% and base layer requires 80%. Figure 5 show that CA-75/C&D-25 and CA-50/C&D-50 have CBR value higher than 80%.

It would be preferred to select CA-50/C&D-50 aggregate sample for road base and CA-0/C&D-100 aggregate sample for road subbase in terms of cost minimization and eco-friendliness to replace conventional aggregates for unbound road pavement construction.

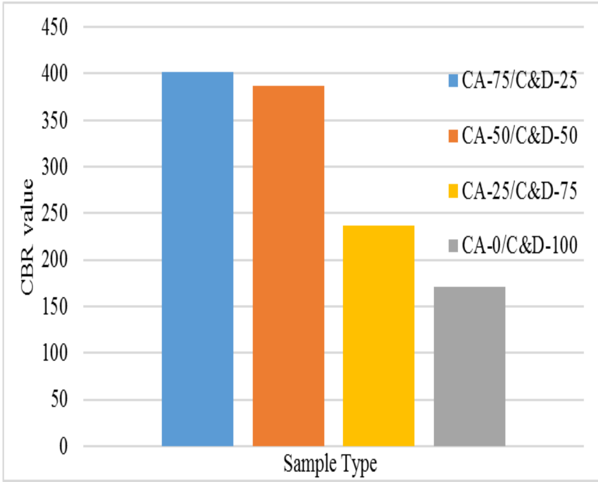

Fig 6: Comparison of CBR values for cement bound C&D mixtures

Figure 6 shows the result of cement treated samples and CBR values gradually decreases as the C&D content increases. This could be due to lower intrinsic particle strength of C&D which lead to a decrease in the overall bearing strength of the samples [16]. The attached cement mortar around the C&D aggregates caused weak inter particle bond even though cement fines are present as a binding agent. However, the result proves that the 4 days soaked CBR value for all C&D aggregates are very high and over 100% of CBR which depicts appreciable strength.

According to the results and focusing on greener environment, cement treated CA-0/C&D-100 was the best preferred sample to use in road replacing the conventional aggregates as it satisfies the minimum strength required for a road base. Therefore, demand on CA can be reduced and significantly effect on quarrying of natural rocks. For economical approach, determining the exact amount of cement as a binding agent can be done by unconfined compressive strength (UCS).

More CBR experiments were carried out in both soaked and unsoaked condition on cement treated CA-0/C&D-100 aggregate to examine the strength gaining with time and results are in Figure 7. Soaking the sample, stimulates the condition of water table increase during the rainy season and thus, it is significant to examine the strength variation with the soaked time period of the samples at the laboratory.

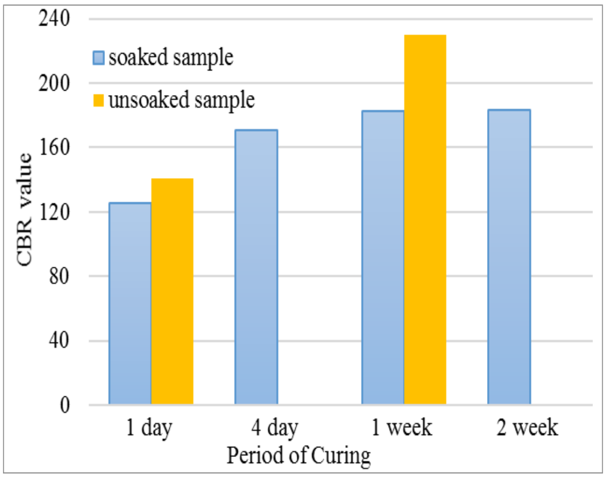

Fig 7: Comparison of CBR values of cement treated CA-0/C&D-100 aggregate sample for soaked and unsoaked condition

By increasing the number of curing days, samples are treating under high degree of saturated condition and makes weak condition. Figure 7 reveals that the strength of compacted samples increase with time with 7 days. The CBR values after 14 days soaking is not significantly increased and indicate the stabilization of cementation process of the samples and become stable with time. However, that inundated condition allows inter particle sliding and can increase the pore water pressure within the sample which reduces shear strength causing lower CBR value [17].

5. Conclusion

- Introduction of C&D particles which has more fines improves the PSD of the mixed samples to be well-graded within the TRL Road Note 31 specifications [13].
- Proctor compaction test gave relatively higher water absorption compared with conventional aggregates. C&D particles in the sample increases the OMC while decreases the MDD. This could be due to lesser fines content and higher absorption capacity of brick, residual cement and cement mortar paste within the C&D aggregates
- Blending the C&D over 50% with CA revealed strength properties which had CBR greater than 80%. Therefore, C&D aggregates can be mixed with CA up to 50% to use in base layers in unbound pavements.
- The strength properties of the C&D mixed materials can be dramatically increased by adding small amount of cement such that 5% by weight.
- Cement treated 'CA-0/C&D-100' which represent only C&D aggregate, revealed appreciable CBR over 100% for both soaked and unsoaked condition. Therefore, recycled C&D could be used with small amount of cement as bound pavement material without CA.
- Recycling of demolition debris into new construction offers a way to reduce waste disposal loads sent to the landfills and also extends the life of natural resources

Acknowledgment

The authors thank COWAM centre for providing recycled material and Northshore College of Business and Technology for giving the opportunity to conduct the research study.

References

[1]. Olorunsogo, F. T., Early age properties of recycled aggregate concrete, in: Proceedings of the International Seminar on Exploiting Wastes in Concrete, University of Dundee, Scotland, UK, 1999, pp. 163–170.

[2]. Jiménez, J., Ayuso, J., Agrela, F., López, M. and Galvín, A., Utilisation of unbound recycled aggregates from selected CDW in unpaved rural roads. Resources, Conservation and Recycling, 58, 2012, pp. 88-97.

[3]. Arulrajah, A., Piratheepan, J., Bo, M. W., Ali, M., Geotechnical properties of recycled concrete aggregate in pavement sub-base applications. ASTM Geotech Test J 2012; 35(5):1–9.

[4]. Agrela, F., Sanchez de Juan, M., Ayuso, J., Geraldes, V. L., Jimenez, J. R. Limiting properties in the characterisation of mixed recycled

aggregates for use in the manufacture of concrete. Constr Build Mater 2011; 25:3950–5.

[5]. Ebrahim Abu El-Maaty Behiry, Ahmed. "Utilization of Cement Treated Recycled Concrete Aggregates as Base or Subbase Layer in Egypt". Ain Shams Engineering Journal 4.4, 2013, pp. 661-673.

[6]. Poon, C. and Chan, D. Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base. Construction and Building Materials, 20(8), 2006, pp. 578-585.

[7]. Hilmi A, Aysen M, Goktepe AB. Analysis and design of a stabilized fly ash as pavement base material. Fuel 2006; 85:2359–70.

[8]. Agrela, F., Barbudo, A., Ramı´rez, A., Ayuso, J., Carvajal M. D., Jime´nez J. R. Construction of road sections using mixed recycled aggregates treated with cement in Malaga, Spain. Resour Conserv Recycl 2012; 58:98–106.

[9]. Rameezdeen, R. Use of Recycled C&D Materials for Street Construction. Optimising the Sustainable Use and Management of Construction Waste in Sri Lanka, Vol. 05, March, 2009, pp. 6-7.

[10]. British Standard 1377: Methods of test for soils for civil engineering purposes, 1990.

[11]. ICTAD, Standard Specification for Construction and Maintenance of Road and Bridges, 2005.

[12]. Papagiannakis, A. T., Masad, E. A. Pavement design and materials. John Wiley & Sons Inc. Hoboken New jersey; 2008.

[13]. DOE, Road Research Laboratory Road Note 31, Fourth Edition, "A Guide to the Structural Design of Bitumen-surfaced roads in Tropical and Sub-Tropical Countries" 1993.

[14]. Poon, C., Qiao, X. C., Chan, D. The cause and influence of self-cementing properties of fine recycled concrete aggregates on the properties of unbound sub-base. Waste management 2005:1166-1172.

[15]. Jayakody, S., Gallage, C., & Kumar, A. Assessment of recycled concrete aggregate for road base and sub-base. In Hossain, Md. Zakaria & Huat, Bujang B.K. (Eds.) Proceedings of the Second International Conference on Geotechnique, Construction Materials and Environment, The GEOMATE International Society, Kuala Lumpur, Malaysia, 2012, pp. 575-579.

[16]. Boudlal, O., Melbouci, B. Study of the behavior of aggregates demolition by proctor and CBR tests. In: Material, design, construction, maintenance, and testing of pavement. Changsha, Hunan, China: 2009.

[17]. Gupta, Satish. "Pore Water Pressure Changes during Compression and Its Impact on Soil Strength". Department of Soil, Water, & Climate University of Minnesota St. Paul, MN, Presentation. St. Paul, MN