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Research Paper

Laboratory evaluation of biosolids stabilized with demolition wastes as an embankment fill material

A. Arulrajah [1], F. Maghool [2], S. Horpibulsuk [3], M. W. Bo[4] and S. L. Shen[5]

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ABSTRACT

Biosolids (Bio) are air-dried sewage sludge from wastewater treatment plants. Stockpiles of Bio are rapidly increasing around the globe. The primary aim of this paper was to evaluate the potential for Bio stabilized with demolition wastes as an embankment fill material. This laboratory evaluation study was undertaken to evaluate the geotechnical properties of Bio when stabilized with various percentages of demolition wastes, being Crushed Brick (CB) and Crushed Concrete (CC). The standard compaction results indicated that the dry density of Bio increased with the addition of both demolition wastes. The optimum moisture content of Bio was found to consistently decrease with increasing amounts of demolition wastes. The gradation, pH value and specific gravity of Bio samples improved with the addition of demolition wastes. The California Bearing Ratio (CBR) value of Bio samples was increased with the addition of CB and CC, with the optimum value found to be achieved with 50% CC content (Bio50/CC50). The positive outcomes of this research project will potentially enable Bio to be used in combination with demolition wastes in embankment fill applications. This sustainable approach will reduce the demand for virgin materials and will potentially divert significant quantities of these waste materials from landfills and into a high value embankment fill material.

1. Introduction

Stockpiles of air-dried sludge from domestic and industrial wastes are increasing in all developed and developing countries worldwide, largely due to the rapid increase in the global population. The sustainable reuse of various forms of waste materials have been studied in the past decades in developed and developing countries alike. One of the main challenges is finding an innovative way to recycle and reuse various waste materials in all forms of civil engineering and road construction applications. In theory, this seems to be a simple solution, while in reality there are several obstacles associated with reusing waste materials instead of commonly used virgin materials. In

[1] Professor, Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn, Victoria 3122, AUSTRALIA, aarulrajah@swin.edu.au
[2] PhD Candidate, Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn, Victoria 3122, AUSTRALIA, fmaghool@swin.edu.au
[3] Professor and Chair of School of Civil Engineering and Director of Center of Excellence in Innovation for Sustainable Infrastructure Development, Suranaree University of Technology, Nakhon Ratchasima 30000, THAILAND, suksun@g.sut.ac.th
[4] President and COO, Sarafinchin Associates Ltd, Toronto, Ontario, CANADA, drmwbo@yahoo.co.uk
[5] Professor and department head, State Key Laboratory of Ocean Engineering, Department of Civil Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, CHINA, slshen@sjtu.edu.cn
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order for recycled materials to be reused in any civil engineering application, technical feasibility assessments using extensive laboratory testing, are required to meet the road authority requirements.

Biosolids (Bio) are a by-product from industrial and domestic sewage treatment processes in wastewater treatment plants (Asakura et al., 2009; O'Kelly, 2006). The Australian and New Zealand Biosolids Partnership (2013) stated that the annual production of air-dried Bio in Australia is approximately 330,000 tonnes. The average solids content of Bio is approximately 30%, which equates to about 1.3 million tonnes of Bio in the dewatered form. Nearly 30% of Bio (96,000 dry tonnes) is produced in the state of Victoria, Australia where most Bio are produced in the Western and Eastern wastewater treatment plants (ANZBP, 2013).

The engineering properties of pure untreated Bio are generally similar to organic soils (Disfani, 2011). Organic soils typically have a low shear strength and high compressibility, which is problematic for the construction of roads (Hampton and Edil, 1998). The key design parameters for road and highway embankments are typically obtained from the results of compaction, consolidation and shear strength tests (Arulrajah et al., 2011a). Maghoolpilehrood et al. (2013) reported that pure Bio have a soaked California Bearing Ratio (CBR) value of 1.0%, indicating poor load bearing characteristics. Pure Bio thus requires stabilization in order to be considered as an embankment fill material. Lim et al. (2002a) reported a CBR value of 2.74% for compacted sewage sludge and higher values for Bio stabilized with lime and fly ash.

Ciancio et al. (2014) reported on the interaction between lime and soil. This study implies that lime stabilization improves the stiffness, shear strength, workability and water absorption of the parent soil material. Ciancio et al. (2014) stated that the reaction between lime and soil is subject to a pozzolanic reaction, cation exchange or carbonation. Pozzolanic reaction is typically a temperature related reaction, while cation exchange occurs in the presence of water. Carbonation occurs when lime reacts with carbon dioxide present in the air (Ciancio et al., 2014).

Stabilization increases the soil strength and stiffness through chemical reactions (Tastan et al., 2011). Lim et al. (2002b) stated that by adding cement to Bio, the compressibility and stiffness of the Bio improved to the extent that it could be used to support light structures. The short-term effect of chemical stabilization results in an improved workability and provides reduction in settlement, plasticity indices, shrinkage and the sell potential of the Bio. In the long-term, chemical reactions are accomplished over time, depending on the rate of chemical breakdown and hydration of the silicates and aluminates (Lim et al., 2002b). For cementation to occur and enhance over this long-term stabilization period, sufficient sources of pozzolans, either from the soil itself or from the chemical additive, is required (Lim et al., 2002b). Results of the existing research studies suggested that stabilized Bio had higher strength properties, improved permeability and lower secondary consolidation values as compared to untreated Bio (Maghoolpilehrood et al., 2013).

This research was conducted to determine the geotechnical properties of Bio as an embankment fill material when mixed with different percentages of CB and CC. Such an approach will enable Bio to be stabilized with demolition wastes instead of common high carbon additives such as cement or lime.

Geotechnical laboratory tests were undertaken in accordance with relevant Australian or ASTM testing methods on samples of Bio stabilized with CB and CC, in order to determine the optimum Bio-demolition waste mixtures. The suite of laboratory tests undertaken included specific gravity, particle size analysis, organic content, standard compaction, pH and California bearing ratio. Establishing the potential use of Bio as a road embankment fill materials in combination with demolition wastes was the main objective of this research.

2. Materials and methods

The Bio samples for this research were air-dried for almost eight years and collected from an old lagoon in a wastewater treatment plant in Melbourne, Australia. The samples were taken from several locations at depths of 0.2 to 1 m. The samples were then mixed to obtain representative Bio samples.

Crushed Brick (CB) is a by-product of demolition activities of buildings and other structures. CB from recycling sites typically contain 30% of other construction materials like rock and concrete aggregates (Arulrajah et al., 2011b). Crushed Concrete (CC) is also a by-product of demolition activities and constitutes the largest component of demolition wastes in Australia (Sustainability-Victoria, 2010). Samples of CC and CB were collected from a recycling site in the state of Victoria. 10%, 20%, 30%, 40% and 50% of CB and CB were mixed with Bio to improve the geotechnical and engineering properties of Bio in this research.

Organic content of all samples was measured using the loss of ignition technique according to the ASTM testing procedure (ASTM, 2007b). The pH value of the materials was determined using the electrometric method as outlined in Australian standards (AS, 1997). Particle size distribution tests were undertaken in accordance with Australian standards (AS, 1996). Three kilograms of representative sample of each blend was washed, dried and sieved on a sieve shaker as outlined in Australian standard. The apparent particle densities were determined in accordance with Australian standard (AS, 2000b) for fine fraction (passing 4.75 mm sieve) and according to Australian standard (AS, 2000a) for coarse aggregates (retained on 4.75 mm sieve).

Standard proctor compaction effort was undertaken to determine the optimum moisture content (OMC) and maximum dry density (MDD) of treated and untreated Bio samples following the Australian standard (AS, 2003). The samples were compacted in three layers, each layer by 25 blows with a 2.7 kg rammer falling freely from 300 mm in height (AS, 2003).

California Bearing Ratio (CBR) tests were conducted on samples compacted under standard Proctor compaction effort at OMC to reach the minimum MDD of 98% (ASTM, 2007a). All CBR samples were soaked after compaction with a surcharge of 4.5 kg on top for a period of 4 days. A dial gauge was placed on CBR mold to measure the amount of possible swell during the soaking period. Subsequently, the penetration test at a rate of 1 mm/min was undertaken at the end of the soaking period on all samples. The soaked CBR test is normally required to simulate the worst case scenario for a pavement (Arulrajah et al., 2014).

3. Results and discussion

Table 1 presents the results of particle density, pH and organic content tests for all samples. Organic content of Bio was determined by the loss on ignition method. Karlsson and Hansbo (1989) stated that soils having organic contents in the range of 6% to 20% were characterized as medium organic soils. The average organic content of the Bio was 28.3%, hence the Bio is classified as a high organic soil. The organic content value was found to decrease with the addition of both CB and CC.

Table 1. Geotechnical properties of Bio, CB and CC.

Blends	Gs (kN/m3)	pH	Organic content (%)
Bio100	1.87	4.65	28.3
Bio90/CB10	1.94	5.85	25.71
Bio80/CB20	2.02	6.48	23.13
Bio70/CB30	2.1	6.88	20.55
Bio60/CB40	2.18	7.01	17.78
Bio50/CB50	2.26	7.14	15.38
CB100	2.65	9.3	2.5
Bio90/CC10	2	5.23	23.27
Bio80/CC20	2.03	6.57	21.06
Bio70/CC30	2.12	7.65	18.44
Bio60/CC40	2.2	8.01	17.16
Bio50/CC50	2.34	8.29	14.58
CC100	2.71	11.49	2.3

The specific gravity of the Bio was found to be 1.87 (kN/m^3), which is significantly lower than that of the inorganic soil and aggregates. The specific gravity of Bio was significantly improved with the addition of both demolition wastes. It is evident from **Table 1** that the G_s value of blends increases with the percentage of additives, with the highest value of 2.34 achieved in Bio50/CC50 blend. The pH value of Bio was found to consistently increase when increasing the content of demolition wastes.

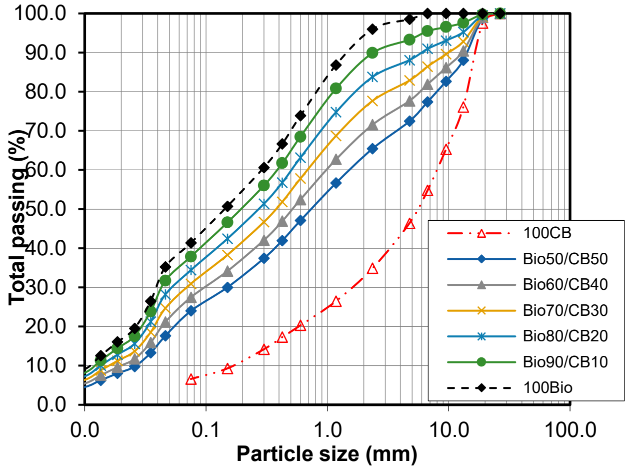

Fig. 1. Particle size distribution curve for Bio, CB and Bio/CB blends.

The particle size distribution curve of Bio treated with CB and CC are respectively shown in **Figures 1** and **2**. The curves show that all Bio blends contain more than 40% of sand sized particles and 20% clay sized particles. The particle sizes of Bio and Bio/demolition waste blends are within the range expected of a road subgrade material. The presence of a good mix of granular and cohesive materials ensures efficient compactability of the Bio/demolition wastes in the field.

Figures 2 and **3** respectively show the compaction curve for Bio blends with CB and CC. Results of standard

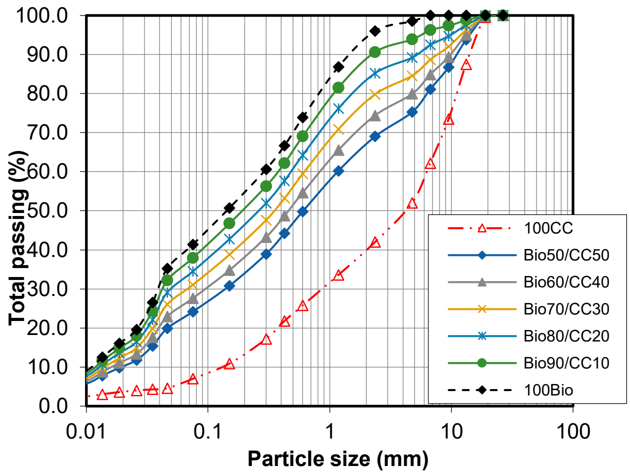

Fig. 2. Particle size distribution curve for Bio, CC and Bio/CC blends.

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compaction tests presented in **Table 2** indicate that with the addition of both additives there is a noticeable reduction in OMC of the Bio blends and subsequent increase in MDD. Disfani et al. (2014) also reported that the MDD of Bio increases with increasing percentage of additives, while OMC decreases. The maximum dry density of Bio/demolition waste blends was found to vary between 8.15 kN/m^3 and 11.57 kN/m^3 and the OMC ranged between 30% and 54%. These values are typical for Bio as reported earlier by other authors (Disfani et al., 2014; Maghoolpilehrood et al., 2013).

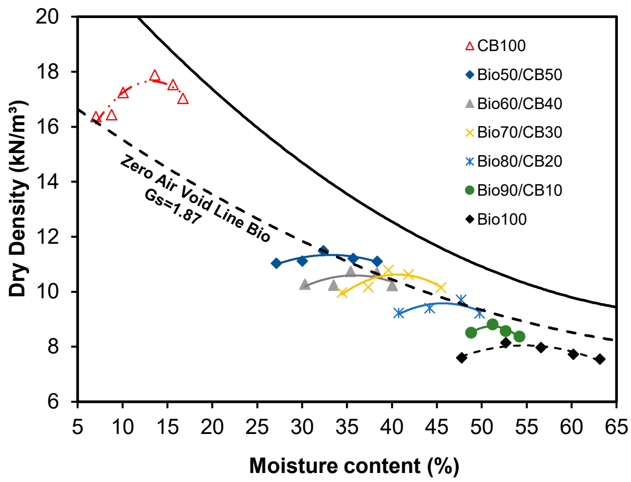

Fig. 3. Standard compaction curve for Bio, CB and Bio/CB blends.

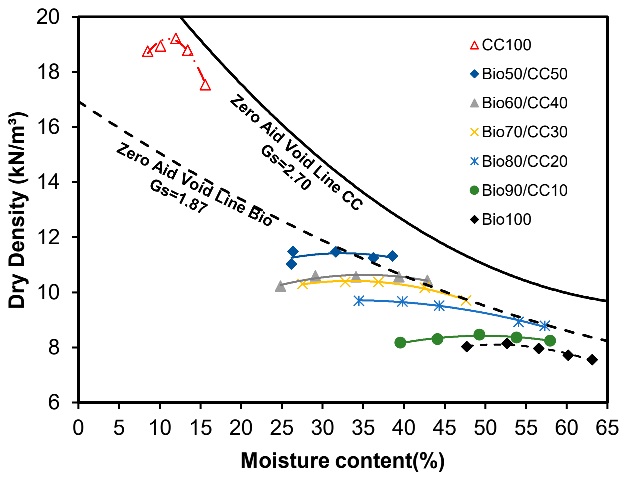

Fig. 4. Standard compaction curve for Bio, CC and Bio/CC blends.

CBR tests were conducted on three samples for each blend and the average values are reported in **Table 2**. From the results, it is clear that untreated and pure Bio does not meet the local road authority requirements for an embankment fill material, which requires CBR value of more than 2%.

The CBR value was found to increase by increasing the amount of demolition wastes. CBR values of treated Bio varied from 2% to 9%, which met the local road authority requirements. CC was found to enhance the CBR values of the Bio more than that of CB for all similar mix percentages. This would imply that CC was a more durable and robust pavement material, which was less susceptible to breakage than CB. The higher amount of high quality aggregates used in production of concrete would be the prime reason for this as compared to the usage of fired clay for brick making. The optimum CBR value was achieved at a mix of Bio50/CC50.

Table 2. Standard compaction and CBR test results.

Blends	OMC (%)	MDD (kN/m³)	CBR (%)
Bio100	54	8.15	1
Bio90/CB10	51	8.73	1
Bio80/CB20	47	9.41	2
Bio70/CB30	41.8	10.7	5
Bio60/CB40	37	11.08	6
Bio50/CB50	33.5	11.4	6
CB100	13.5	17.95	123
Bio90/CC10	50	8.44	5
Bio80/CC20	38	9.61	7
Bio70/CC30	35	10.4	8
Bio60/CC40	33	10.59	8
Bio50/CC50	30	11.57	9
CC100	12.5	19.12	139

4. Conclusion

Bio samples were collected from a wastewater treatment plant and were mixed with 10%, 20%, 30%, 40% and 50% of CB and CC obtained from a recycling facility in the state of Victoria, Australia. An extensive series of engineering tests were performed on untreated and treated Bio to evaluate their engineering and geotechnical properties.

The apparent density of Bio was found to be improved by up to 20% and 25% respectively, by increasing the amount of CB and CC. The organic content of Bio was found to decrease with increasing percentages of CB and CC. The pH test results indicate that the Bio characteristics were changed from acidic to an alkaline chemistry with the addition of demolition wastes. The results of standard compaction tests implied that the OMC decreased while the MDD of Bio increased with the addition of both demolition wastes.

The CBR value was found to increase by increasing the amount of demolition wastes. CBR values of treated Bio varied from 2% to 9%, which met the local road authority requirements. The optimum CBR value was achieved at a mix of Bio50/CC50. The CBR value of Bio was increased by 6 times in the Bio50/CB50 blend and by

9 times in the Bio50/CC50 blend. Both the CB and CC aggregates were found to improve the structure of the Bio/demolition waste samples and enhance its engineering properties.

CC was found to enhance the CBR values of the Bio more than that of CB for all similar mix percentages. This would imply that CC was a more durable and robust pavement material, which was less susceptible to breakage than CB. The higher amount of high quality aggregates used in production of concrete would be the prime reason for this as compared to the usage of fired clay for brick making.

The Bio stabilized with CB and CC satisfied the local road authority requirements for an embankment fill material. The laboratory testing results also indicated the potential for reuse of Bio/CB and Bio/CB blends as an embankment construction fill material.

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Symbols and abbreviations

CB	Crushed brick
CC	Crushed concrete
CBR	Internal cohesion of the ground
Bio	Biosolids
OMC	Optimum moisture content
MDD	Maximum dry density