GEOTECHNICAL AND CHEMICAL CHARACTERISTICS OF ETP AND WTP BIOSOLIDS

Aruna Ukwatta[1], Abbas Mohajerani[2]

[1]aruna.ukwatta@rmit.edu.au, [2]dr.abbas@rmit.edu.au

School of Civil, Environmental, and Chemical Engineering, RMIT University, Melbourne, VIC, Australia

ABSTRACT

Stricter regulations on the quality of wastewater treatment by-products are giving rise to an increasing volume of stockpiled biosolids. The annual production of biosolids in Australia is approximately 300,000 dry tonnes, which involves a biosolids management cost of about A$90 million. Biosolids are the end product and the main solid component collected from the wastewater treatment process. This paper presents some of the geotechnical and chemical properties of two samples of biosolids collected from Melbourne Water's Eastern Wastewater Treatment Plant (ETP) stockpile No. 22 and the Western Wastewater Treatment Plant (WTP) stockpile No. 10. Various geotechnical tests – liquid limit, plastic limit, particle density, particle size distribution, organic content, and linear shrinkage – were undertaken. In addition, chemical tests comprising leachate analysis for heavy metals and chemical composition were conducted on the samples of biosolids. From an environmental perspective, all the samples of biosolids were found to be safe in terms of leaching for use as a landfill application material. The experimental results showed that the ETP biosolids have about 7% of organic content with some of the geotechnical and chemical properties similar to a conventional soil with similar particle size distribution. In addition, empirical relationships were obtained for the compaction behaviour of the ETP biosolids and experimental soil used in this study. The results obtained in this study can be used as a guide for the use of ETP and WTP biosolids in different civil engineering applications.

Keywords: Biosolids; organic soil; geotechnical properties; recycling; Waste management

1 INTRODUCTION

Over the last two decades, the growth of implementing new wastewater treatment plants, continuous upgrading of wastewater treatment processes, and stringent controls concerning the quality of wastewater discharges have given rise to increasing the annual production of biosolids (Rulkens, 2007, Arulrajah et al., 2011, O'Kelly, 2004). Biosolids are the primary by-product of the wastewater sludge treatment process. Sludge is a sticky liquid, which, generally, contains up to 8% of dry solids and is collected from the wastewater treatment process, but, which has not undergone further treatment (AWA, 2012). In contrast, Melbourne Water biosolids contain between 50% and 96% of solids, and, have undergone further treatment to significantly reduce any volatile organic matter, thereby producing a stabilised product suitable for beneficial uses (ANZBP, 2012).

The annual production of biosolids in Australia is approximately 300,000 dry tonnes, from which over half (55%) is applied to agricultural land for beneficial use. In addition, just under a third (30%) is disposed of in land fill or stockpiled and the balance (15%) is used in composting, forestry, land rehabilitation or incinerated (AWA, 2012). Furthermore, in 2013, Melbourne Water produced around 78,650 m^3 of biosolids, and it is important to point out that 2,000,000 m^3 of biosolids are presently stock-piled at the Eastern Treatment Plant (ETP) and Western Treatment Plant (WTP) in Melbourne, which are suitable for forestry, farming, producing energy and structural fill (Melbourne Water, 2014). It is notable that, in Australia, the average cost for biosolids management is in the order of A$300 per dry tonne, which equates to about A$90 million per year. As a similar trend has been observed in recent years in several developed and developing countries, it is of great interest and widely accepted throughout the world that there is an urgent need for reusing biosolids in a sustainable way.

Although attempts have been made to address the geotechnical properties of biosolids, they are still limited, and need further investigation. The characteristics of sludge and biosolids have been studied in various countries including Australia, Hong Kong, the United States, Turkey, Singapore, and the United Kingdom (Puppala et al., 2007, Hundal et al., 2005, O'Kelly, 2004, Arulrajah et al., 2011)

Puppala et al. (2007) evaluated the physical and engineering properties of a control cohesive soil supplemented with two types of material, biosolids and dairy manure. This study concluded that the biosolids and the dairy manure compost could provide engineering benefits to control soil when used in moderate proportions, because the physical and engineering properties are directly related to the amount of organic matter present in the biosolids and dairy manure.

O'Kelly (2004) presented the geotechnical characteristics of the sludge from the Tullamore municipal wastewater treatment plant in the United Kingdom. The properties, including compaction, shear strength and consolidation, were determined to assess its suitability as a landfill (sludge-to-landfill) material. In this study, sludge was dewatered to the optimum moisture content [OMC] for compaction, placed in a landfill in layers and compacted to the maximum dry density (MDD), thereby maximising the operational life of the landfill site. The geometry of the landfill is of the utmost importance in terms of its stability, and, therefore, effective-stress strength properties were used to determine the factor of safety against the slope stability of the landfill.

Arulrajah et al. (2011) reviewed the research of Hundal et al. (2005) who studied the geotechnical characteristics of untreated biosolids including the compressibility, consolidation, and shear strength parameters. The samples of biosolids were obtained from a municipal wastewater treatment plant in Chicago, USA. Based on the experimental results, Hundal et al. (2005) concluded that the biosolids can be regarded as a potential alternative for embankment construction, and, moreover, the bearing capacity of biosolids can be enhanced by blending biosolids with topsoil or other residuals.

Disfani et al. (2009a), and Disfani et al. (2009b) assessed the geotechnical properties of biosolids, which were obtained from the existing biosolids stockpiles, WTP in Melbourne, Australia. Preliminary tests were conducted on samples made purely from recycled glass, and, also blended biosolids and recycled glass mixtures. The geotechnical properties including particle size distribution, compaction test, and direct shear test were performed for both, pure and blended mixtures. Disfani et al. (2009a), and Disfani et al. (2009b) concluded that the mixture of biosolids and recycled glass showed satisfactory shear strength characteristics, thereby indicating the excellent potential of these mixtures to be used as an embankment fill material for roads.

Asakura et al. (2009) investigated the geotechnical properties of sludge as well as sludge in blends with slag, and construction and demolition waste in order to determine the allowable ratio of sludge required to ensure an aerobic zone in landfills in Japan. The geotechnical properties of sludge including moisture content, loss on ignition, bulk density, particle density, particle size distribution, OMC, MDD were measured. Asakura et al. (2009) developed a method to improve sludge permeability, which involved blending sludge with slag and construction and demolition waste.

The end-use of biosolids heavily depends on the characteristics of the biosolids, which could vary around the world as the properties of biosolids significantly depend on factors, such as the quality and composition of the wastewater, method and extent of treatment process (primary, secondary, or tertiary treatment), method used for the stabilisation of biosolids, and the age of the biosolids. It is noteworthy that the properties of the biosolids can vary from time to time, even within the same treatment plant due to the variations in the incoming wastewater composition (NSW DPI, 2009, Suthagaran et al., 2010, Silveira et al., 2003, O'Kelly, 2004).

The primary objective of this paper is to present and discuss some of the results from an ongoing study on the use of ETP and WTP biosolids in construction materials, such as fired-clay bricks and road embankment material. From an economic point of view, use of biosolids in various civil engineering applications not only contributes to deceleration of the growth of biosolids in stockpiles but is also a viable solution for the scarcity of natural resources. Recently, biosolids have been used as a promising alternative raw material in manufacturing fired-clay bricks (Ukwatta et al., 2015).

2 MATERIALS AND METHODS

Samples of Biosolids were obtained from ETP stockpile No. 22 (ETP-SP22) and WTP stockpile No. 10 (WTP-SP10) in Melbourne, Australia (Figure 1). The age of the ETP and WTP biosolids was about 12 and 4 years, respectively. Since this paper presents some of the results of an ongoing study on the use of biosolids in fired-clay bricks, an experimental soil, which was provided by Boral Bricks Pty Ltd, was used as a blending material to address the compaction characteristics of the biosolids.

ETP SP-22 WTP Biosolids SP-10

Figure 1: Samples of biosolids used in the study.

The laboratory investigation was subsequently undertaken on samples of biosolids and geotechnical tests including liquid limit, plastic limit, particle size distribution, linear shrinkage, and compaction were conducted according to the Australian Standards (AS 1289.0, 2000), while the organic content test was conducted as per the British Standards (BS 1377-3, 1990). X-ray fluorescence (XRF) was used to quantify the chemical composition of the experimental soil and samples of biosolids. Leachate analysis was undertaken on the biosolids to examine the possibility of using biosolids as a landfill application according to the Australian Bottle Leaching Procedure (ABLP) (Australian Standard, 1997). All the geotechnical properties were tested in triplicate and the average values of the results are reported.

3 RESULTS AND DISCUSSION

3.1 GEOTECHNICAL PROPERTIES OF THE BIOSOLIDS AND THE EXPERIMENTAL SOIL

The chemical compositions of the experimental soil and two biosolids samples, which were determined by XRF, are shown in Figure 2. The experimental soil presents a typical composition and mainly consists of Silica (SiO_2), Alumina (Al_2O_3), and ferric oxide (Fe_2O_3), with minor contents of MgO, P_2O_5, and TiO_2. Both the ETP and WTP biosolids samples are formed by silica, alumina, and ferric oxide, which are the major oxide components, with small amounts of MgO, K_2O, and TiO_2. It is important to note that the WTP biosolids contain a relatively higher percentage of CaO and P_2O_5 compared to the ETP biosolids and experimental soil.

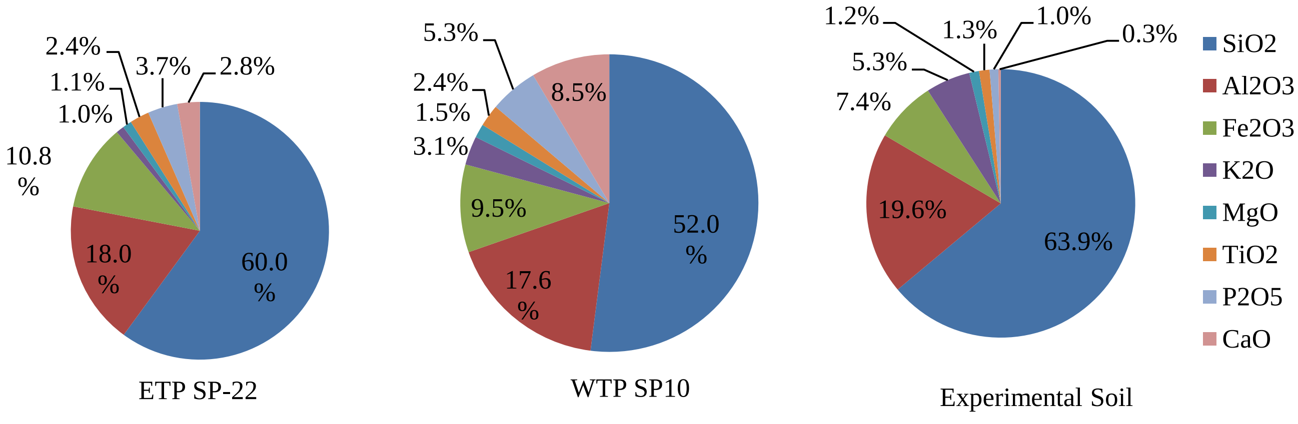

Figure 2 Chemical composition of the samples of and experimental soil

The geotechnical properties of the samples of ETP and WTP biosolids and experimental soil are presented in Table 1. The specific gravity of the samples of biosolids and the soil was determined using a density bottle for the fine fraction of the particles, and by weighing in water for particles retained on a 2.36 mm sieve in accordance with the Australian Standards (AS 1289.3.5.1, 2006). Kerosene was used as a density liquid instead of deionized or distilled water, to avoid the dissolving of the water-soluble salts that could be present in the biosolids. However, distilled water was used as a density liquid in measuring the specific gravity of the experimental soil. The specific gravity of the ETP and WTP biosolids samples was found to be 2.51 and 2.14, respectively, while the soil had the highest specific gravity of 2.69. Both samples of biosolids showed a relatively lower specific gravity compared to the soil, as expected, revealing that the samples of biosolids contained a higher amount of organic matter than the experimental soil (Tay et al., 2001).

The Atterberg limit test was performed on the biosolids and experimental soil samples to determine their plasticity characteristics. As presented in Table 1 and Figure 3, the liquid limit (LL) of the ETP and WTP biosolids ranged between 46% and 53%, while the plastic limit (PL) of the samples of ETP and WTP biosolids ranged between 27% and 41%. The plasticity index (PI) was found to be in the range of 19% and 12%, as shown in Figure 3. In addition, the LL, PL, and PI of the experimental soil were 32%, 29%, and 13%, respectively.

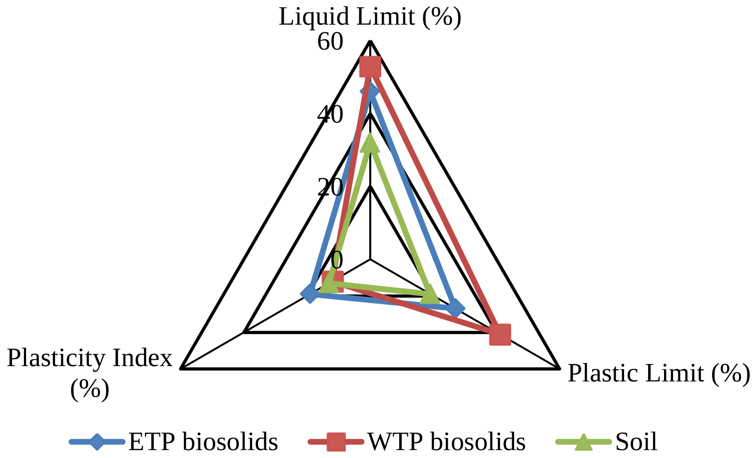

Figure 3: Atterberg limit test results of biosolids and soil.

Table 1: Geotechnical properties of the samples of biosolids and soil.

Test/ Property	ETP Biosolids	WTP Biosolids	Soil
Specific Gravity (%)	2.51	2.14	2.69
Liquid limit (%)	46	53	32
Plastic limit (%)	27	41	19
Plasticity index (%)	19	12	13
Linear Shrinkage	14.2	10	6.6
Organic Content	7.1	22.1	1.4
D_{10} (mm)	0.005	0.07	0.009
D_{30} (mm)	0.2	0.4	0.13
D_{60} (mm)	0.4	1.3	0.45
Grain size > 2.36 mm > (%)	0.4	13.4	1.2
Grain size between 0.075 - 2.36 mm (%)	87.5	76.0	74.6
Grain size between 0.002- 0.075 mm (%)	11.1	9.6	22.2
Grain sized < 0.002 mm) (%)	1.0	1.0	2.0
Coefficient of uniformity (C_u)	8.0	18.6	50.0
Coefficient of curvature (C_c)	2.0	1.8	4.2
Australian soil classification	SM	SW-SM	SM

The particle size distribution of all samples was achieved by means of sieve analysis. The test results of the particle size distribution are summarised in Table 1. According to the particle size distribution test results, the ETP and WTP biosolids contain 0.4% and 13.4% of gravel size particles, while the soil sample contains 1.2%. The ETP biosolids have the highest percentage of sand particles. In contrast, the soil and the WTP biosolids contain 74.6% and 76% of sand particles, respectively. The percentage of fine particles (< 0.075 mm) of the ETP and WTP biosolids slightly varied from 12.1% to 10.6%, while the soil had the highest percentage (24.2%) of fine particles. Based on the results of the particle size distribution and the Atterberg Limits, the WTP biosolids can be classified as well graded sand to silty sand (SW-SM) whereas both the ETP biosolids and experimental soil can be classified as silty sand (SM) according to the Australian Standards (AS 1726, 1993).

The linear shrinkage, which is an indirect method of estimating the swelling and shrinking capacity of soils, can be calculated as the percentage reduction in the length of the bars of the soil samples prepared in the liquid limit condition, after they have been air dried for 24 h followed by oven drying until no further length reduction is observed. The linear shrinkage of the ETP biosolids, WTP biosolids, and experimental soil was found to be 14.2%, 10% and 6.6 %, respectively.

The WTP biosolids have a significantly higher organic content of 22.2% compared to the ETP biosolids and experimental soil, which was 7.1% and 1.23%, respectively. It is important to point out that the organic content of the samples has a considerable influence on the plasticity index, strength, and compressibility characteristics (Puppala et al., 2007). Moreover, higher values of organic content in biosolids are not desirable to their usage as a fill material in civil engineering applications due to the decomposition settlement, as organic matter is subject to biodegradation. However, biosolids with higher organic content can still be used as a non-structural fill from the perspective of engineering applications.

3.2 COMPACTION CHARACTERISTICS OF BIOSOLIDS

The compaction curves of ETP and WTP biosolids are shown in Figure 4. The standard proctor compaction results indicated that the biosolids had a significantly higher MDD and lower OMC compared to that reported in previous studies. Several studies have reported much lower MDD values for organic materials, such as sludge with a MDD of 5.5 kN/m^3 (O'Kelly, 2006) and biosolids with a MDD of 8 kN/m^3 (Arulrajah et al., 2013). Both the ETP and WTP biosolids showed a much higher MDD of 15 kN/m^3 and 10.7 kN/m^3, respectively, which is believed to be the function of the organic content present in the biosolids. The OMC of WTP biosolids was found to be much higher (38%) than the OMC of ETP biosolids (23%). The shape of the compaction curves of the biosolids showed a typical convex nature similar to that of conventional soils, which is a positive sign for using biosolids as a replacement material for natural soil in civil engineering applications. The OMC and MDD of experimental soil were found to be 16% and 18 kN/m^3, respectively.

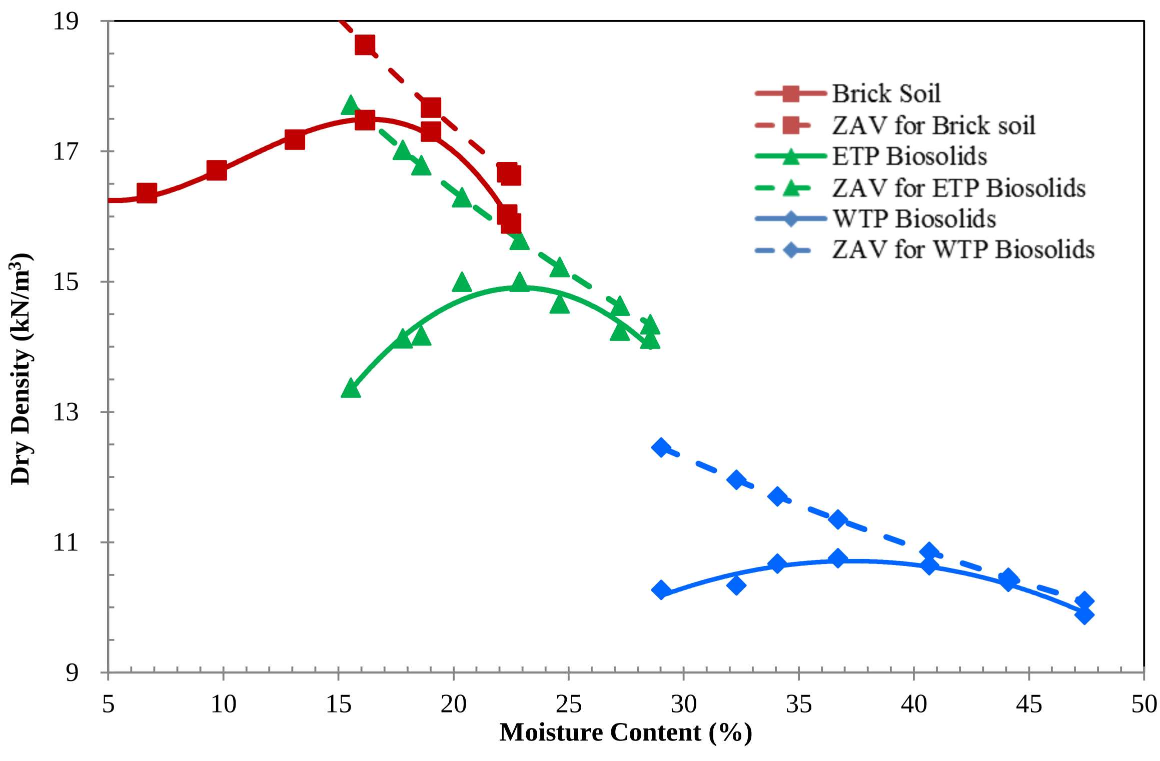

Figure 4: Standard proctor compaction curves for biosolids and experimental soil.

A series of compaction tests was conducted at different percentages (0% to 100%) of the ETP biosolids-soil mixtures. The test results showed that the MDD and OMC of different ETP biosolids-soil mixtures were functions of the percentage of the organic matter present in the mixture. The MDD and OMC varied linearly with the percentage of organic content present in the mixture, as shown in Figure 5. The R squared values indicated that there were strong correlations (R^2 = 0.95 and 0.97) between the MDD and OMC with the percentage of the organic content in the sample.

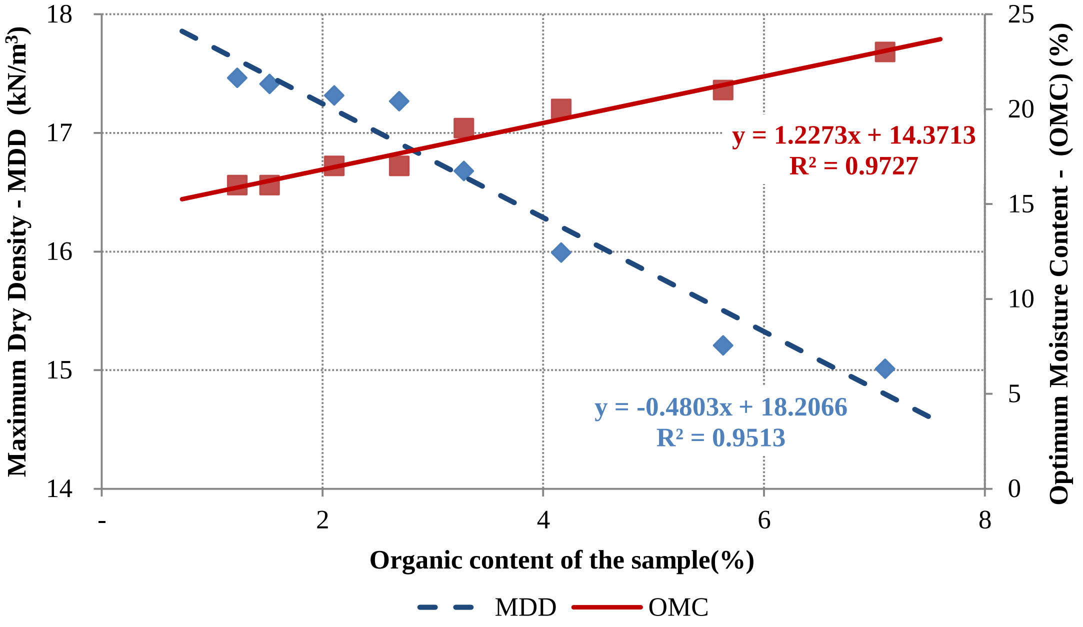

Figure 5: MDD and OMC of the ETP biosolids-soil mixtures as a function of organic content.

As shown in Figure 6, there was a linear relationship between the MDD values and the corresponding OMC of ETP biosolids-soil mixtures.

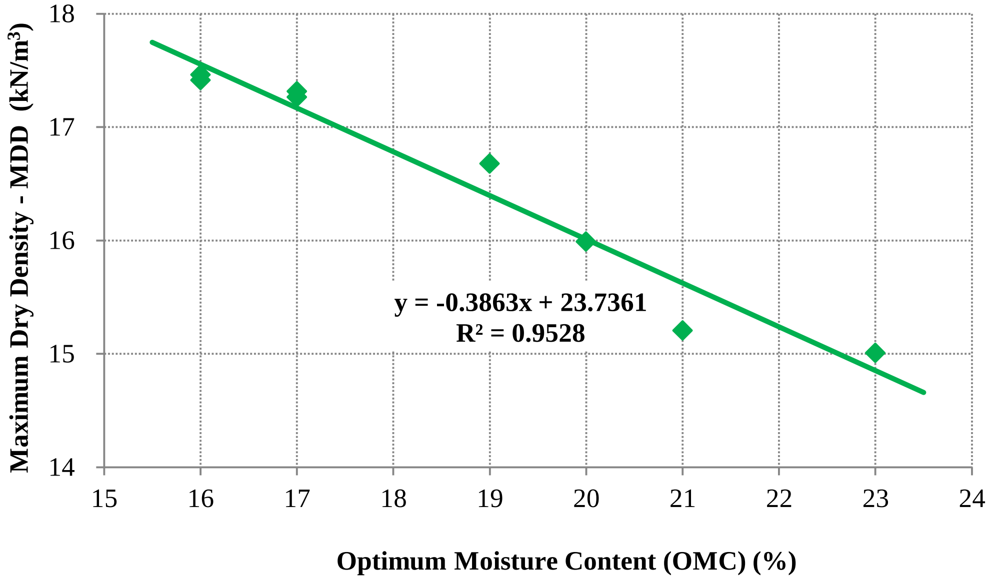

Figure 6: MDD vs. OMC for different soil-ETP biosolids mixtures.

The particle size distribution, shape of the soil grains, and the amount and type of clay minerals present in the sample have a considerable influence on its compaction behaviour. All the compaction curves were found to be bell shaped with a single-peak point; this type of curve is generally found in soils that have approximate liquid limit boundaries of 30 and 70 (Das, 2008, Lee and Suedkamp, 1972). It is noteworthy that the ETP biosolids resulted in an increase in the

OMC and a decrease in the MDD from the experimental soil. The variations are primarily attributed to both the percentage of the organic matter and the fine particles present in the respective biosolids-soil mixtures.

3.3 LEACHATE ANALYSIS ON BIOSOLIDS SAMPLES

Two samples of biosolids were tested for different types of heavy metals and the results are shown in Table 2. The condition of filtered biosolids extracts after the ABLP extraction process was completed is shown in Figure 7. The heavy metal concentrations of ETP and WTP biosolids are assessed against the leachable concentration thresholds as specified in EPA Victoria (2009a) and EPA Victoria (2009b) for soils. The test results showed that heavy metal concentrations of ETP and WTP biosolids are much lower than the category C leachable concentration thresholds (EPA Victoria, 2009b).

ETP biosolids WTP biosolids

Figure 7: ABLP extracts of ETP and WTP biosolids.

Table 2: Leachable heavy metal concentrations of biosolids (all concentrations are in mg/L).

Heavy Metal	Category C upper limits	ETP Biosolids	WTP Biosolids
As	0.7	<0.009	<0.009
Cd	0.2	<0.018	<0.018
Cr	5.0	<0.004	<0.004
Cu	200.0	4.25	7.89
Pb	1.0	<0.01	<0.01
Se	1.0	<0.045	<0.046
Zn	300	34.87	74.94

4 CONCLUSION

This paper deals with the geotechnical properties of samples of biosolids, which were collected at ETP-SP22 and WTP-SP10 in Melbourne. In recent years, the use of biosolids in civil engineering applications has been of great interest and has become an innovative approach to the management of biosolids. Therefore, knowledge concerning the compaction behaviour and geotechnical properties of biosolids is the utmost importance when it comes to civil engineering applications.

Wastewater biosolids samples produced at ETP and WTP in Melbourne, Australia, were tested to investigate their geotechnical and chemical characteristics. It was found that the ETP and WTP biosolids can, respectively, be classified as silty sand (SM) and well-graded sand to silty sand (SW-SM), according to the Australian Standard. The organic contents of the ETP and WTP biosolids were 7% and 22.1%, respectively. Both the ETP and WTP biosolids samples as well as experimental soil are basically formed by silica, alumina, and ferric oxide. However, WTP biosolids contain a relatively higher percentage of CaO and P_2O_5 compared to the ETP biosolids and experimental soil.

The compaction behaviour of biosolids is important, when applying biosolids as a construction material. The results indicated that the OMC and MDD of the ETP biosolids were linearly proportional to the organic content present in the biosolids-soil mixture. The OMC increased and the MDD decreased, as the percentage of the organic content increased in the mixture. Therefore, it can be concluded that the organic content and particle size distribution of the tested biosolids-soil mixtures had a considerable influence on their compaction characteristics.

The leachate results of the two samples of biosolids were found to pose no environmental issues for use in landfill applications. In addition, some of the geotechnical and chemical properties of the ETP biosolids were similar to a conventional soil with similar particle size distribution.

5 ACKNOWLEDGEMENTS

The results presented in this paper are part of an ongoing postgraduate study on recycling biosolids in fired-clay bricks. The authors would like to thank Melbourne Water and the School of Civil, Environmental and Chemical Engineering, RMIT University, for their financial and in-kind support. In addition, the experimental soil provided by Boral Bricks Pty Ltd is gratefully acknowledged.

6 ABBREVIATIONS

ETP	Eastern Treatment Plant
WTP	Western Treatment Plant
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
ETP-SP22	ETP Stock Pill No.22
WTP-SP10	WTP Stock Pill No.10
XRF	X-ray fluorescence
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
ABLP	Australian Bottle Leaching Procedure
BCC	Biosolids Contaminant Concentration

REFERENCES

ANZBP 2012. Discussion Paper : Biosolids, Carbon and Climate Change. The Australian & New Zealand Biosolids Partnership.

ARULRAJAH, A., DISFANI, M. M., SUTHAGARAN, V. & BO, M. W. 2013. Laboratory Evaluation of the Geotechnical Characteristics of Wastewater Biosolids in Road Embankments. *Journal of Materials in Civil Engineering,* 25**,** 1682-1691.

ARULRAJAH, A., DISFANI, M. M., SUTHAGARAN, V. & IMTEAZ, M. 2011. Select chemical and engineering properties of wastewater biosolids. *Waste Management,* 31**,** 2522-2526.

AS 1289.0 2000. Method of testing soils for engineering purposes. *Part 0 : General requirements and list of methods.* NSW: Standards Australia International Ltd.

AS 1289.3.5.1 2006. Methods of testing soils for engineering purposes. *Determination of the soil particle density of a soil-Standard method.* Sydney, NSW: Standards Australia.

AS 1726 1993. Geotechnical site investigations. Standards Australia Ltd.

ASAKURA, H., ENDO, K., YAMADA, M., INOUE, Y. & ONO, Y. 2009. Improvement of permeability of waste sludge by mixing with slag or construction and demolition waste. *Waste Management,* 29**,** 1877-1884.

AUSTRALIAN STANDARD 1997. AS 4439.3—1997 Wastes, sediments andcontaminated soils. *Part 3: Preparation of leachates-Bottle leaching procedure.* NSW: Standards Australia.

AWA 2012. The Management of Biosolids in Australia. NSW, Australia: Australian Water Association.

BS 1377-3 1990. Methods of test for soils for civil engineering purposes. *Chemical and electro-chemical tests.* British Standards Institution.

DAS, B. M. 2008. *Fundamentals of geotechnical engineering,* USA, Cengage Learning.

DISFANI, M., ARULRAJAH, A., SUTHAGARAN, V. & BO, M. 2009a. Shear strength behavior of recycled glass-biosolids mixtures. *62nd Canadian Geotechnical Conference and 10th Joint CGS/IAH-CNC Groundwater Conference.* Halifax, Canada: International Association of Hydrogeologists / Canadian Geotechnical Society.

DISFANI, M. M., ARULRAJAH, A., SUTHAGARAN, V. & BO, M. W. 2009b. Geotechnical characteristics of recycled glass-biosolid mixtures. *In:* HAMZA, M., SHAHIEN, M. & EL-MOSSALLAMY, Y. (eds.) *17th International Conference on Soil Mechanics and Geotechnical Engineering.* Alexandria, Egypt: IOS Press.

EPA VICTORIA 2009a. Guidelines for environmental management - 1288. *Use of biosolids as geotechnical fill.* Melbourne, VIC, Australia: EPA Victoria.

EPA VICTORIA 2009b. Industrial waste resource guidelines -341. *Soil hazard categorisation and management.* Melbourne, VIC, Australia: EPA Victoria.

HUNDAL, L., COX, A. & GRANTO, T. 2005. Promoting beneficial use of biosolids in Chicago: User needs and concerns. Rep. No. 03 ed. Chicargo, USA: Metropolitan Water Reclamation District of Greater Chicargo.

LEE, P. Y. & SUEDKAMP, R. 1972. Characteristics of irregularly shaped compaction curves of soils. Washington: National Academy of Sceinces.

MELBOURNE WATER. 2014. *Waste to resources* [Online]. Available: http://www.melbournewater.com.au/whatwedo/Liveability-and-environment/waste/Pages/Waste-to-resources.aspx [Accessed March 22 2014].

NSW DPI. 2009. *Use of Biosolids in Agriculture* [Online]. Cowra, NSW: NSW Department of Primary Industries. Available: http://www.dpi.nsw.gov.au/agriculture/farm/recycling-waste-mgt/recycled-organics/biosolids [Accessed November 05 2013].

O'KELLY, B. C. 2004. Geotechnical aspects of sewage sludge monofills. *Proceedings of the ICE-Municipal Engineer,* 157**,** 193-197.

O'KELLY, B. C. 2006. Geotechnical properties of municipal sewage sludge. *Geotechnical & Geological Engineering,* 24**,** 833-850.

PUPPALA, A., POKALA, S., INTHARASOMBAT, N. & WILLIAMMEE, R. 2007. Effects of Organic Matter on Physical, Strength, and Volume Change Properties of Compost Amended Expansive Clay. *Journal of Geotechnical and Geoenvironmental Engineering,* 133**,** 1449-1461.

RULKENS, W. 2007. Sewage Sludge as a Biomass Resource for the Production of Energy: Overview and Assessment of the Various Options†. *Energy & Fuels,* 22**,** 9-15.

SILVEIRA, M. L. A., ALLEONI, L. R. F. & GUILHERME, L. R. G. 2003. Biosolids and heavy metals in soils. *Scientia Agricola,* 60**,** 793-806.

SUTHAGARAN, V., ARULRAJAH, A. & BO, M. 2010. Geotechnical laboratory testing of biosolids. *International Journal of Geotechnical Engineering,* 4**,** 407-415.

TAY, J., SHOW, K. & HONG, S. 2001. The application of industrial sludge and marine clay in brick-making. *Journal of the Chinese Institute of Environmental Engineering,* 11**,** 203-208.

UKWATTA, A., MOHAJERANI, A., SETUNGE, S. & ESHTIAGHI, N. 2015. Possible use of biosolids in fired-clay bricks. *Construction and Building Materials,* 91**,** 86-93.