

Possible Utilization of Cigarette Butts in Light-Weight Fired Clay Bricks

Aeslina Abdul Kadir, and Abbas Mohajerani

Abstract—Over a million tonnes of cigarette butts (CBs) are produced worldwide annually. These CBs accumulate in the environment due to the poor biodegradability of the cellulose acetate filters and pose a serious environmental risk. This paper presents some of the results from a continuing study on recycling CBs into fired clay bricks. Properties including compressive strength, flexural strength, density, water absorption and thermal conductivity of fired clay bricks are reported and discussed. Furthermore, leaching of heavy metals from the manufactured clay bricks was tested. The results show that the density of fired bricks was reduced by about 8–30 %, depending on the percentage of CBs incorporated into the raw materials. The compressive strength of bricks tested was 12.57, 5.22 and 3.00 MPa for 2.5, 5.0 and 10 % CB content respectively. Water absorption and initial rate of absorption values increased as density, and hence porosity, of bricks decreased with increasing CB volume. The leaching test results revealed trace amounts of heavy metals.

Keywords—Cigarette butts, Fired clay bricks, Light bricks, Recycling waste, Thermal conductivity.

I. INTRODUCTION

WORLDWIDE, cigarette butts (CBs) are the most common type of litter. The United States Department of Agriculture estimates that in 2004 over 5.5 trillion cigarettes were produced in the world [1]. This is equivalent to an estimated 1.2 million tonnes of cigarette butt waste per year. These figures are expected to increase by more than 50% by 2025, mainly due to an increase in world population [2]. In Australia alone, an estimated 25 to 30 billion filtered cigarettes [3] are smoked each year; of these, an estimated 7 billion are littered [4].

CBs accumulate in the environment mainly due to the poor biodegradability of the cellulose acetate filters. CB filters release a range of toxic chemicals as they deteriorate [5], [6]. CBs are carried by stormwater into watercourses and ultimately the ocean where the chemicals they contain pose a risk to the organisms of both freshwater and marine environments [3], [7].

Landfilling and incineration of CB waste are not, universally, environmentally sustainable nor economically feasible disposal methods. Even when correctly binned and sent to landfill far from natural waterways, CBs remain an environmental hazard [8]. Also, landfilling of waste with high organic content and toxic substances is in general becoming increasingly costly and difficult [9]–[11]. Incineration of CBs is also a seemingly unsustainable solution as emissions from the burning waste contain various hazardous substances [12].

Recycling CBs is problematic because there are no easy mechanisms or procedures to assure efficient and economical separation and recycling of the entrapped chemicals. An alternative could be to incorporate CBs in a sustainable composite building material such as fired bricks.

Brick is one of the most accommodating masonry units as a building material due to its properties. Attempts have been made to incorporate waste in the production of bricks; for instance, the use of rubber [13], limestone dust and wood sawdust [14], processed waste tea [15], fly ash [16], [17], polystyrene [18] and sludge [19]. Recycling of such wastes by incorporating them into building materials is a practical solution to the pollution problem. In addition, adding carbonaceous industrial wastes has also been demonstrated to be an efficient and environmentally advantageous way of reducing fuel use for brick-making. This paper describes some of the procedures and results from a study on incorporating CBs into fired clay bricks. Physical and mechanical properties of several brick samples with different CB contents are presented and discussed.

II. MATERIALS AND METHODS

The CBs (of different brands and sizes) used in this study (Fig. 1) were provided by Buttout Australia Pty Ltd. The butts had been collected from dry receptacles. Upon delivery, the CBs were disinfected at 105°C for 24 hours and then stored in sealed plastic bags. The soil used was brown silty clayey sand prepared for making fired clay and provided by Boral Bricks Pty Ltd, Australia. The classification tests including liquid limit, plastic limit, plasticity index and particle size distribution were carried out according to Australian Standard [20]. Chemical analyses were carried out to determine the main chemical components of the experimental soil. Chemical composition of the raw clay samples was determined using X-ray Fluorescence (XRF).

Aeslina Abdul Kadir (PhD candidate), School of Civil, Environmental and Chemical Engineering, RMIT University, 3001, Melbourne, Australia (e-mail: aeslina.abdulkadir@student.rmit.edu.au).

Abbas Mohajerani (PhD, Senior Lecturer), School of Civil, Environmental and Chemical Engineering, RMIT University, 3001, Melbourne, Australia. (corresponding author phone: +61 3 99253082; fax: +61 3 96390138; e-mail: dr.abbas@rmit.edu.au).



Fig. 1 Cigarette butts used in the study

Proctor standard compaction tests were conducted, according to Australian Standard [21], to determine optimum moisture contents (OMC) and maximum dry densities for the experimental soil (control sample) and the mixed soil-CBs samples.

Four different mixes were used for making fired brick samples (Table I). The CB content by volume depends on degree of disintegration of CBs during the mixing and compaction of samples. These values were estimated using the density of compacted mixes and the density of the compacted CBs alone in the compaction mould.

TABLE I
MIXES USED IN THIS STUDY

Mixture identification	Percentage of CBs by weight	Estimated percentage of CBs by volume (as compacted)
	(%)	(%)
CB (0.0)	0	0
CB (2.5)	2.5	10
CB (5.0)	5.0	20
CB (10.0)	10.0	30

The mixes were made using a Hobart mechanical mixer with a 10 litre capacity for 5 minutes. Potable water for the OMCs was used in order to make high density brick samples. The samples were compacted manually in appropriate moulds using predetermined masses corresponding to the maximum density (found from standard compaction tests). The samples were made in three sizes (Fig. 2), cube (100 x 100 x 100 mm), beam (225 x 110 x 75 mm) and brick (300 x 100 x 50 mm), for determining compressive strength, modulus of rupture, rate of water absorption, total water absorption and the density of the manufactured bricks.

The specimens were dried at 105°C for 24 hours, removed from the moulds and were fired in a (Barnstead/Thermolyne 30400) furnace at 1050°C. The fired samples were tested for compressive strength, flexural strength, density, water absorption and initial rate of absorption. All tests were carried out according to the Australian Standard [22] and the results reported are the mean of three values. Also, Australian Bottle

Leaching Procedure (ABLP), [23], was used for conducting a leachate analysis for the manufactured clay bricks. Leachate samples were prepared in triplicate and analyzed using Inductive Coupled Plasma Mass Spectrophotometer (ICPMS).



Fig. 2 Compacted bricks, beams and cubes (soil-CBs mix)

III. RESULTS AND DISCUSSION

Some of the physical and chemical properties of the soil used in making the experimental bricks are presented in Tables II and III.

TABLE II
PROPERTIES OF THE SOIL USED IN MAKING FIRED BRICKS

Soil Physical Properties	Test Results
Particles < 75 μm (%)	29
Liquid Limit (%)	31
Plastic Limit (%)	21
Plasticity index (%)	10
Maximum Dry Density (kg/m^3)	1807
Optimum moisture content (%)	17

TABLE III
CHEMICAL COMPOSITION OF THE SOIL USED IN MAKING FIRED BRICKS

Compound Formula	Atomic Weight	Average composition (wt.%)
SiO_2	14	58.73
Al_2O_3	13	18.75
Fe_2O_3	26	5.032
K_2O	19	3.446
MgO	12	1.639
TiO_2	22	0.5079
Na_2O	11	0.204
CaO	20	0.189
Loss on Ignition		9.60%

The density of the manufactured bricks decreased almost linearly from 2118 kg/m^3 for the control samples (0 % CBs) to 1482 kg/m^3 for bricks with 10 % CB content (Fig. 3). The density of bricks decreased by 8.3 %, 23.9 % and 30 % when 2.5 %, 5 % and 10 % CBs was incorporated into the raw materials (Table IV). The bricks became more porous as CB content increased (Figs. 4 and 5). Low-density or light-weight

bricks have great advantages in construction including, for example, lower structural dead load, easier handling, lower transport costs, lower thermal conductivity, and a higher number of bricks produced per tonne of raw materials. Light bricks can be substituted for standard bricks in most applications except when bricks of higher strength are needed or when a particular look or finish is desirable for architectural reasons. The light-weight bricks produced by incorporating 2.5 % to 10 % CBs by mass, equivalent to approximately 10 to 30 % by volume can be used in different applications according to the required strength.

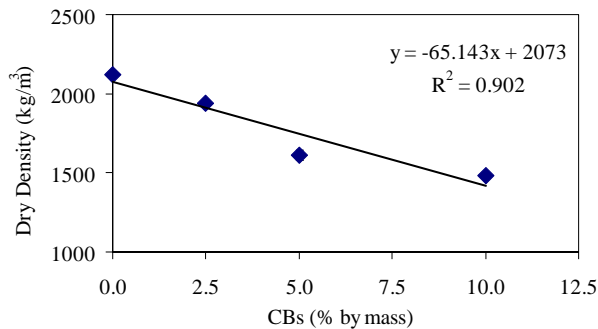


Fig. 3 Effect of CB content on density of fired bricks

TABLE IV
EXPERIMENTAL RESULTS* FOR THE CONTROL MIX AND OTHER TRIAL MIXES CONTAINING CBs

Mixture identification	Compressive Strength	Flexural Strength	Water Absorption	Initial Rate of Absorption (IRA)	Average Density
	(MPa)	(MPa)	(%)	(kg/m²/min)	(kg/m³)
CB (0.0)	25.65	2.79	5	0.2	2118
CB (2.5)	12.57	2.48	9	1.4	1941
CB (5.0)	5.22	2.40	15	2.3	1611
CB (10.0)	3.00	1.24	18	4.9	1482

*Average values of 3 test results

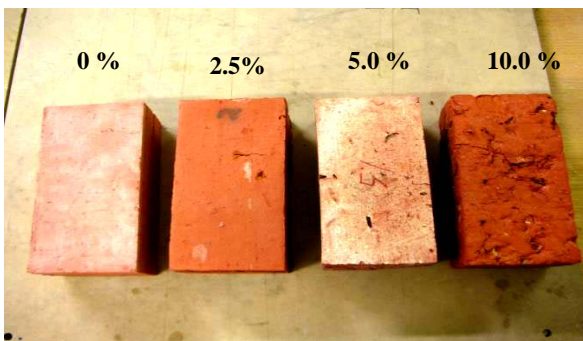


Fig. 4 Surface texture of bricks for mixes with 0 %, 2.5 %, 5 % and 10 % CBs



Fig. 5 Cross sections of bricks for mixes with 0 %, 2.5 %, 5 % and 10 % CBs

The compressive strength of bricks tested (Fig. 6) was reduced markedly from 25.65 MPa (for 0 % CBs) to 12.57, 5.22 and 3.00 MPa for 2.5, 5.0 and 10 % CB content respectively (Fig. 7). Compressive strength is important for determining the load bearing capability of the brick. Higher mixing speed and longer duration of mixing might lead to finer mixtures with higher compressive strength results; this is currently under investigation. Furthermore, different temperature regimes during firing might lead to higher compressive strength.



Fig. 6 Compressive strength test

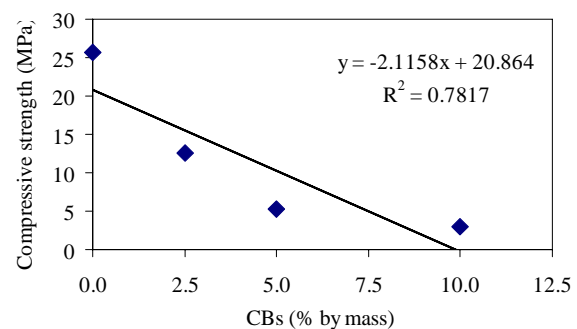


Fig. 7 Effect of CB content on compressive strength of fired bricks

TABLE V
LEACHING OF HEAVY METALS OF BRICK SAMPLES BY ABLP PROCEDURE USING ICPMS

Heavy metals	Concentration Level (mg/L)*	Concentration Level (mg/L)**	Percentage of CBs by weight			
			0 %	2.5 %	5 %	10 %
			Concentration (mg/L)			
Arsenic (As)	5	2.8	0.007	0.019	0.093	0.123
Selenium (Se)	1	4	-	-	-	-
Mercury (Hg)	0.2	0.4	-	-	-	-
Barium (Ba)	100	280	0.590	0.440	0.605	0.510
Cadmium (Cd)	1	0.8	-	-	-	-
Chromium (Cr)	5	20	0.033	0.005	0.028	0.009
Lead (Pb)	5	4	0.130	0.019	0.058	0.340
Silver (Ag)	5	40	-	-	-	-
Zinc (Zn)	500	1200	0.965	0.180	7.750	0.285
Copper (Cu)	100	800	0.190	0.320	0.680	1.090
Nickel (Ni)	1.34	8	0.007	0.006	0.016	0.009

* United States Environmental Protection Agency (USEPA) (1996)

** Environmental Protection Agency (EPA) Victoria (2005)

- not detected

Modulus of rupture (flexural strength, Fig. 8) values decreased from 2.48 to 1.24 MPa when 2.5 - 10 % CBs was incorporated into the raw materials (Fig. 9). The Australian Standard [24] recommendation for flexural strength of bricks is 1 to 2 MPa. High tensile strength indicates good quality bricks and reduces crack formation.

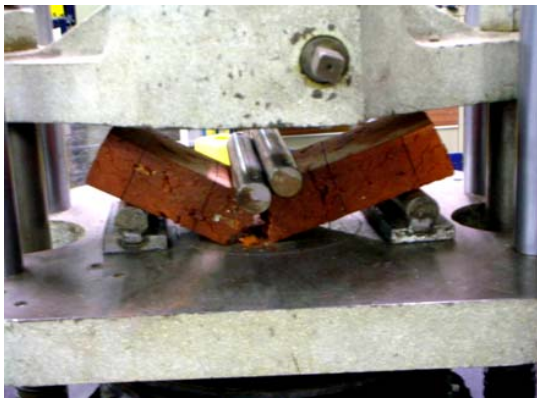


Fig. 8 Flexural test

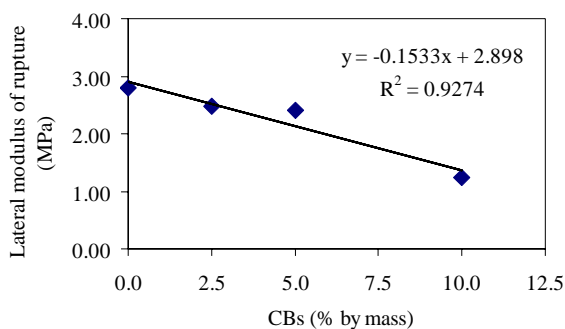


Fig. 9 Effect of CB content on lateral modulus of rupture of fired bricks

Water absorption and initial rate of absorption (IRA) increased almost linearly with increase in CB content (Figs. 10 and 11). The highest value of water absorption measured (18 %) occurred for 10 % CBs. This falls within the range of

the Australian Standard [24] of 5 to 20 %. The range of IRA values was found to be between 1.3 and 5.7 kg/m²/min for bricks made with 2.5 to 10 % CB content. According to the Australian Standard, IRA should be between 0.2 to 5 kg/m²/min. The IRA and the total water absorption capacity determine the ability and the potential performance of the brick in laying and durability. Unacceptably high values of IRA and water absorption can lead to volume changes that would result in cracking of the bricks or structural damage in building.

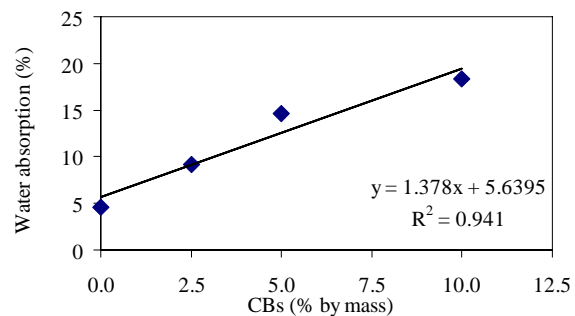


Fig. 10 Effect of CB content on water absorption

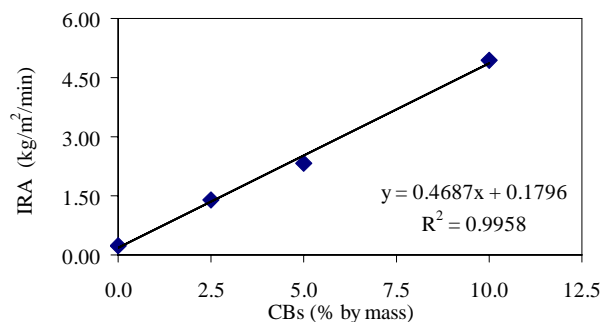


Fig. 11 Effect of CB content on initial rate of absorption of fired bricks

The results from the leachate analysis for heavy metals are presented in Table V. It can be seen that all concentrations

were insignificant and comply with trace concentration levels set by [25] and [26], and are far from exceeding the regulatory limits. As for Se, Hg, Ag and Cd metals, the concentrations were very low and were not detectable using ICPMS.

Adding CBs to the soil for manufacturing clay bricks assists firing due to its cellulose acetate content. It can be an effective and environmentally beneficial way of significantly reducing energy use for brick firing. By using the percentage of output power during firing, it was estimated that over 60 % of energy can be saved by adding 5 % of CBs to the raw clay soil. This is in line with [27] finding that five to six percent by weight of dispersed organic matter in Lower Oxford Clay saves two thirds of the energy required during firing. Detailed results from the firing energy consumption analysis will be reported in a future article.

IV. CONCLUSION

The study investigated the possibility of incorporating cigarette butts (CBs) into fired clay bricks. Four different clay-CB mixes with 0, 2.5, 5.0 and 10.0 % by weight CBs, corresponding to about 0, 10, 20 and 30 % by volume, were used for making fired brick samples.

The results show that the density of fired bricks decreased by 8.3 - 30 % when 2.5 - 10 % CBs was incorporated into the raw materials. The compressive strength of bricks tested was reduced from 25.65 MPa (control) to 12.57, 5.22 and 3.00 MPa for 2.5, 5.0 and 10 % CB content respectively. Lateral modulus of rupture test results show that the flexural or tensile strength of bricks does not decrease significantly with the incorporation of CBs up to 5 % CBs. The lowest value of flexural strength found was 1.24 MPa (for 10 % CBs). Water absorption values were increased from 5 to 18 % and the initial rate of absorption results increased from 0.2 to 4.9 kg/m²/min for the experimental mixes. The concentration values for all 11 metals measured in the leaching test on manufactured clay bricks (using the Australian Bottle Leaching Procedure and Inductive Coupled Plasma Mass Spectrophotometer) were insignificant and much lower than the acceptable regulatory limits. Also, it was estimated that over 60 % of firing energy can be saved by adding 5 % by weight CBs to the raw clay soil.

The results found so far show that cigarette butts can be regarded as a potential addition to raw materials used in the fabrication of light fired bricks.

ACKNOWLEDGMENT

The results presented in this paper are part of an ongoing postgraduate research, at RMIT University, on Recycling Cigarette Butts. The authors would like to thank Buttout Australia and Boral Bricks Pty Ltd for supplying the cigarette butts and soil, respectively, for this study.

REFERENCES

- [1] U.S Department of Agriculture (USDA). (2004, September 31). *Production, Supply and Distribution*, [Online]. Available: <http://www.fas.usda.gov/psdonline/>.
- [2] Mackay, J., Eriksen, M. and Shafey, O., "*The Tobacco Atlas 2nd Edition*, American Cancer Society", 2000, pp. 32-33.
- [3] Micevskia, T., Warne, M. St. J., Pablo, F. and Patra, R., "Variation in, and causes of toxicity of cigarette butts to a cladoceran and microtox", *Arch. Environ. Contam. Toxicol.* vol. 50, pp. 205-212, 2006.
- [4] Butt Littering Trust. (2007, April, 10). *About Butt Litter* [Online]. Available: <http://www.buttlitteringtrust.org>.
- [5] Hoffmann, D. and Hoffmann, I., "The changing cigarette", *Journal Toxic Environ Health*, vol. 15, pp. 307-364, 1997.
- [6] Hoffmann, D., Hoffmann, I. and El-Bayoumy, K., "The less harmful cigarette: A controversial issue", A tribute to Ernst L. Wynder, *Chemical Research in Toxicology*, vol. 14, no. 7, pp. 767-790, 2001.
- [7] Register, K., "Cigarette butts as litter-toxic as well as ugly?", *Bull. Am. Litt. Soc.* vol. 254, pp. 23-29, 2000.
- [8] Yuan, Y., Lu, Z. X., Huang, L. J., Bie, X. M., Lu, F. X., and Li, Y., "Optimization of a medium for enhancing nicotine biodegradation by *Ochrobactrum intermedium* DN2", *Journal of Applied Microbiology*, vol. 101, pp. 691-697, 2006.
- [9] Ruan, A., Min, H., Peng, X. and Huang, Z., "Isolation and characterization of *Pseudomonas* sp. strain HF-1, capable of degrading nicotine", *Research in Microbiology*, vol.156, pp.700-706, 2005.
- [10] Hackendahl, N., Sereda, C. W. and Volmer, P. A., "The dangers of nicotine ingestion in dogs". *Veterinary Science*, vol. 99, no. 3, pp. 218-224, 2004.
- [11] Salomon, M. E., *Nicotine and tobacco preparations. Goldank's Toxicologic Emergencies, 6th Ed. (L.R. Goldfrank et al.ds.)*, Appleton and Lange, Stanford, Conn, 1998, pp. 1145-157.
- [12] Knox, A., "An overview of incineration and EFW technology as applied to the management of municipal solid waste (MSW)", *ONEIA Energy Subcommittee*. 2005.
- [13] Turgut, P. and Yesilata, B., "Physico-mechanical and thermal performances of newly developed rubber-added bricks", *Energy and Buildings*, vol. 40, pp. 679-688, 2008.
- [14] Turgut, P. and Algin, H. M., "Limestone dust and wood sawdust as brick material", *Building and Environment*, vol. 42, pp. 3399-3403, 2006.
- [15] Demir, I., "An investigation on the production of construction brick with processed waste tea", *Building and Environment*, vol. 41, pp. 1274-1278, 2005.
- [16] Kayali, O., "High performance bricks from fly ash", *Proceedings of the World of Coal Ash Conference, Lexington, Kentucky*, 2005.
- [17] Lin, K. L., "Feasibility study of using brick made from municipal solid waste incinerator fly ash slag". *Journal of Hazardous Materials* vol.137, pp.1810-1816, 2006.
- [18] Veisheh, S. and Yousefi, A. A., "The use of polystyrene in lightweight brick production", *Iranian Polymer Journal*, vol. 12, no. 4, pp. 324-329, 2003.
- [19] Basegio, T., Berutti, F., Bernades, A. and Bergmann, C. P., "Environmental and technical aspects of the utilization of tannery sludge as a raw material for clay products", *Journal of the European Ceramic Society*, vol.22, pp.2251-2259, 2002.
- [20] Australian/New Zealand Standard AS/NZS 1141.11:1996, Method 11, 1996.
- [21] Australian/New Zealand Standard AS/NZS 1289.5.1.1:2003, Method 5.1.1, 2003.
- [22] Australian/New Zealand Standard AS/NZS 4456.1:2003, Method 1, 2003.
- [23] Australian/New Zealand Standard AS/NZS 4439.3:1997, Method 3, 1997.
- [24] Australian/New Zealand Standard AS/NZS 3700, 2001.
- [25] USEPA, *Hazardous Waste Characteristics Scoping Study*, US Environmental Protection Agency, Office of Solid Waste, 1996.
- [26] EPAV, *Guidelines for Hazard Classification of Solid Prescribed Industrial Waste*, Publication 996, June 2005.
- [27] Jackson, N., Dhir, R. K., "*Civil Engineering Materials, 5th Edition*", Macmillan Press, London, 1997, pp. 496-497.