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Density, Strength, Thermal Conductivity and Leachate Characteristics of Light-Weight Fired Clay Bricks Incorporating Cigarette Butts

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Abstract**—**Several trillion cigarettes produced worldwide annually lead to many thousands of kilograms of toxic waste. Cigarette butts (CBs) accumulate in the environment due to the poor biodegradability of the cellulose acetate filters. This paper presents some of the results from a continuing study on recycling CBs into fired clay bricks. Physico-mechanical properties of fired clay bricks manufactured with different percentages of CBs are reported and discussed. The results show that the density of fired bricks was reduced by up to 30 %, depending on the percentage of CBs incorporated into the raw materials. Similarly, the compressive strength of bricks tested decreased according to the percentage of CBs included in the mix. The thermal conductivity performance of bricks was improved by 51 and 58 % for 5 and 10 % CBs content respectively. Leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured clay-CB bricks. The results revealed trace amounts of heavy metals.

Keywords**—**Cigarette butts, Fired clay bricks, Light bricks, Recycling waste, Thermal conductivity, Leachates; Leaching test.

I. INTRODUCTION

CIGARETTE butts (CBs) are the most common type of litter in the world. In 2004, over 5.5 trillion cigarettes were produced worldwide [1], 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].

Most cigarette filters are made of cellulose acetate. Cellulose acetate filters are slow to biodegrade and can take up to 18 months or more to break down under normal litter conditions [5]-[6]. Filters have long term effects on the urban environment, especially in waterways and run-offs [7]. Toxic chemicals trapped in the CB filters can be leached and so cause serious damage to the environment [8]-[10]. There are up to 4000 chemical components in cigarette smoke, of which 3000 are in the gas phase and 1000 in the tar phase. Polycyclic aromatic hydrocarbons (PAHs), N-nitrosamines, aromatic amines, formaldehyde, acetaldehyde, benzene, and toxic metals such as cadmium and nickel combine to form more than 60 chemicals that are known to be carcinogenic [8]-[12].

Landfilling and incineration of CB waste are not universally sustainable nor economically feasible disposal methods. Even when correctly binned and sent to landfill far from natural waterways, CBs remain an environmental hazard [13]. Also, landfilling of waste with high organic content and toxic substances is becoming increasingly costly and difficult [14]-[16]. Incineration of CBs is also a seemingly unsustainable solution as emissions from the burning waste contain various hazardous substances [17]. Recycling CBs is difficult because there are no easy mechanisms or procedures to assure efficient and economical separation of the butts and appropriate treatment of the entrapped chemicals. An alternative could be to incorporate CBs in a building material such as fired bricks.

Brick is one of the most common masonry units as a building material due to its properties. Attempts have been made to incorporate waste in the production of bricks, for example, rubber [18], limestone dust and wood sawdust [19], processed waste tea [20], fly ash [21]-[22], polystyrene [23] and sludge [24]. Recycling of such wastes by incorporating them into building materials is a practical solution to a pollution problem. This paper presents and discusses some of the results from a study on recycling CBs into fired clay bricks. The 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 were provided by Buttout Australia Pty Ltd. The CBs were disinfected by heat 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 [25]. Chemical analyses were carried out, using X-ray

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Fluorescence (XRF), to determine the main chemical components of the experimental soil. Proctor standard compaction tests were conducted, according to Australian Standard [26], to determine optimum moisture contents (OMC) and maximum dry densities for the experimental soil (control sample) and the mixed soil-CBs samples. Some of the physical and chemical properties of the soil used in making the experimental bricks are shown in Tables 1 and 2.

TABLE I
PROPERTIES 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%

TABLE II
CHEMICAL COMPOSITION 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

Four different mixes were used for making fired brick samples. CBs (2.5, 5, and 10 % by weight, about 10 – 30 % by volume) were mixed with the experimental soil and fired to produce bricks. The mixes were made using a Hobart mechanical mixer with a 10 litre capacity for 5 minutes. The samples were compacted manually in appropriate moulds using predetermined masses corresponding to the maximum density using optimum moisture contents, found from standard compaction tests. The samples were made in three sizes: 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 [27]. 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 [28] and the results reported are the mean of three values.

It is known that heavy metals such as arsenic, chromium, nickel and cadmium can be trapped in the filters of cigarette butts [29]. Hence, leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured clay-CB bricks. Experimental bricks were crushed and representative samples finer than 9.5 mm were prepared for analysis using the Toxicity Characteristics Leaching Procedure (TCLP) [30]. Leaching tests were also carried out on whole solid brick samples (Fig. 1) to investigate the long-term leachate characteristics of bricks. This method was a modification of the static leachate test (SLT) [31] that is generally used to investigate the mechanism of leaching from solidified waste forms [32]-[33]. In the SLT method, the leachant (5.7 mL of glacial acetic acid per litre) was not renewed by a fresh solution in order to produce the maximum leachate concentrations, and leachates were collected over long durations of 25, 41, 71 and 134 days. Triplicate samples from all the leachates were used and analysed for heavy metals using Inductive Coupled Plasma Mass Spectrophotometer (ICPMS).

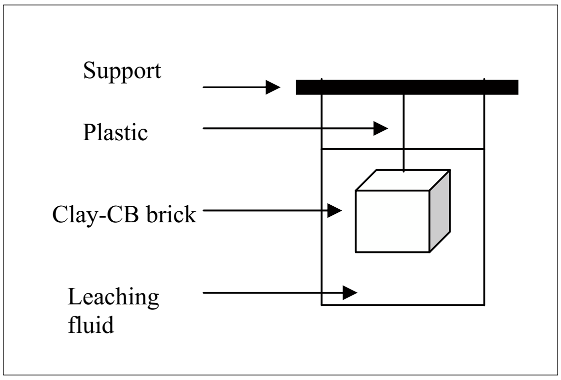

Fig. 1 Experimental set up for Static Leachate Test

III. RESULTS AND DISCUSSION

The density of the manufactured bricks decreased from 2118 kg/m^3 for the control samples (0 % CBs) to 1482 kg/m^3 for bricks with 10 % CB content (Table 3). The density of bricks decreased by 8.3 %, 23.9 % and 30 % when 2.5 %, 5 % and 10 % CBs was incorporated. The bricks became more porous as CB content increased (Figs. 2 and 3). 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 could be used in different applications according to the required strength.

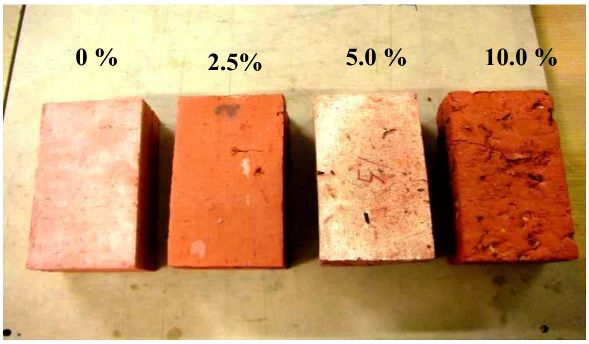

Fig. 2 Surface texture of bricks for mixes with 0 %, 2.5 %, 5 % and 10 % CBs

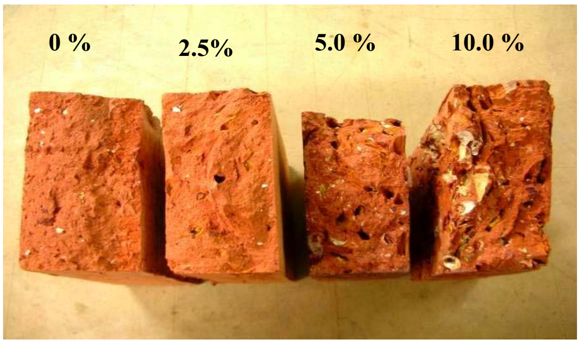

Fig. 3 Cross sections of bricks for mixes with 0 %, 2.5 %, 5 % and 10 % CBs

The compressive strength of bricks tested was reduced 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. Compressive strength is important for determining the load bearing capability of the brick. Common minimum values recommended for characteristic compressive strength for non-load-bearing and load-bearing solid fired clay bricks are 3 to 5 MPa and 5 to 10 MPa respectively [34]-[35]. Higher mixing speed and longer duration of mixing can lead to finer mixtures with higher compressive strength results.

Modulus of rupture (flexural strength) values decreased from 2.48 to 1.24 MPa when 2.5 – 10 % CBs was incorporated into the raw materials. The Australian Standard [36] recommendation for flexural strength of bricks is 1 to 2 MPa. High tensile strength indicates good quality bricks and reduces crack formation.

Water absorption and initial rate of absorption (IRA) increased almost linearly with increase in CB content. The highest value of water absorption measured (18 %) occurred for 10 % CBs and so was within the range of the Australian Standard of 5 to 20 %. The range of IRA values was found to be between 1.3 and 5.7 kg/m^2/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/m^2/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.

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

Mixture identification	Compressive Strength (MPa)	Flexural Strength (MPa)	Water Absorption (%)	Initial Rate of Absorption (IRA) (kg/m^2/min)	Average Density (kg/m^3)
CB (0.0)	25.65	1.97	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

Thermal conductivity performance is an important criterion of building materials, as the thermal conductivity influences the usage of the material in engineering applications. The thermal conductivity of a brick is the rate at which a brick conducts heat. Heat losses from buildings are dependent on the thermal conductivity of the materials in the walls and roof [18] and [37]. Building bricks have to minimize the heat flow from one side of the brick to the other side [38]. The thermal conductivity of bricks and other masonry materials depends on the density and therefore porosity of the material.

Thermal conductivity of samples was estimated using a model developed in this study based on some experimental results available in the literature [39]-[45]. This Model (1) was developed using 256 test results found for different types of bricks, concrete and aggregates. This equation, plotted in Fig. 4, gave the highest R^2 (coefficient of determination) value of 0.885 in a regression analysis.

$$T = 0.0559e^{(0.0014D_d)} \tag{1}$$

Where T = thermal conductivity
D_d = dry density

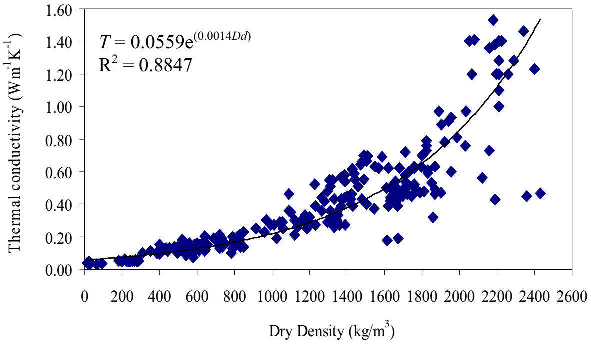

Fig. 4 Thermal conductivity vs. dry density of some different types of concrete, bricks and other masonry materials (adopted from Refs 39 to 45)

This relationship was used to estimate the thermal conductivity of the experimental bricks in this study (Table 4, Fig. 5). It can be seen that as the percentage of CBs increases, the dry density and therefore thermal conductivity of bricks decreases. For example, adding 5 % CBs reduces the thermal conductivity by approximately 51 %, which is a very significant amount in terms of energy saving.

TABLE IV
CALCULATED VALUES OF THERMAL CONDUCTIVITY OF CLAY BRICKS

Mixture identification	Density	Thermal conductivity	Reduction of thermal conductivity
	(kg/m^3)	(Wm^{-1}K^{-1})	(%)
CB (0.0)	2118	1.08	0
CB (2.5)	1941	0.85	21
CB (5.0)	1611	0.53	51
CB (10.0)	1482	0.45	58

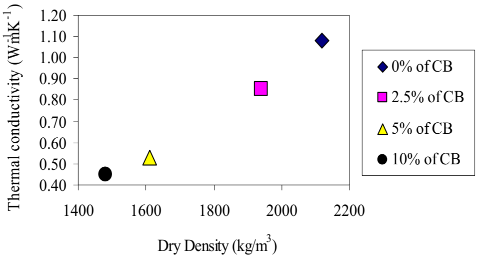

Fig. 5 Effect of CB content on dry density and thermal conductivity of clay bricks

Results for TCLP (Table 5) and SLT (Table 6) methods showed insignificant levels of heavy metals and comply with the concentration limits set by USEPA (1996) and EPAV (2005) [46]-[47]. No significant trend can be detected from the results obtained from the TCLP and SLT tests. However, due to the difference in the type of samples used, the TCLP tests (using crushed samples) produced slightly higher values than the SLT (solid samples) tests for most cases, even though SLT measurements were made after 134 days compared with short tem test that completed within 2 days for the TCLP test.

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 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 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

TABLE V
CONCENTRATIONS OF HEAVY METALS USING TCLP

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	0.025	0.012	0.045	0.035
Selenium (Se)	1	4	-	-	-	-
Mercury (Hg)	0.2	0.4	-	-	-	-
Barium (Ba)	100	280	0.270	0.280	0.295	0.275
Cadmium (Cd)	1	0.8	-	-	-	-
Chromium (Cr)	5	20	0.007	0.003	0.006	0.008
Lead (Pb)	5	4	1.941	0.044	0.037	0.032
Silver (Ag)	5	40	-	-	-	-
Zinc (Zn)	500	1200	0.255	0.115	0.670	1.145
Copper (Cu)	100	800	0.190	0.295	0.210	0.155
Nickel (Ni)	1.34	8	0.004	0.002	0.004	0.003

* United States Environmental Protection Agency (USEPA) (1996)
** Environmental Protection Agency (EPA) Victoria (2005)
- not detected

TABLE VI
CONCENTRATIONS OF HEAVY METALS USING SLT AFTER 134 DAYS

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	0.011	0.055	0.215	0.190
Selenium (Se)	1	4	-	-	-	-
Mercury (Hg)	0.2	0.4	-	-	-	-
Barium (Ba)	100	280	0.245	0.285	0.525	0.380
Cadmium (Cd)	1	0.8	-	-	-	-
Chromium (Cr)	5	20	0.005	0.006	0.010	0.010
Lead (Pb)	5	4	0.008	0.004	0.005	0.03
Silver (Ag)	5	40	-	-	-	-
Zinc (Zn)	500	1200	0.310	0.135	0.225	0.425
Copper (Cu)	100	800	0.069	0.074	0.082	0.090
Nickel (Ni)	1.34	8	0.005	0.006	0.007	0.010

* United States Environmental Protection Agency (USEPA) (1996)
** Environmental Protection Agency (EPA) Victoria (2005)
\- not detected

increased from 5 to 18 % and the initial rate of absorption results increased from 0.2 to 4.9 kg/m^2/min for the experimental mixes. Based on a model developed in this study, using some experimental data from several previous studies, thermal conductivity of the experimental bricks was estimated to reduce by 21, 51 and 58 % for CB contents of 2.5, 5 and 10% respectively. Leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured clay-CB bricks. Leachates were produced using the Toxicity Characteristics Leaching Procedure and the Static Leachate Test, and all heavy metal concentrations measured were insignificant and much lower than the acceptable regulatory limits.

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

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