PHYSICO-MECHANICAL PROPERTIES AND LEACHATE ANALYSIS OF CLAY FIRED BRICKS INCORPORATED WITH CIGARETTE BUTTS

AESLINA ABDUL KADIR[1], ABBAS MOHAJERANI[2]

[1]Lecturer, University Technology Tun Hussein Onn (UTHM), Malaysia, currently a PhD candidate at the School of Civil, Environmental and Chemical Engineering, RMIT University.

[2]Senior Lecturer (PhD), School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia.

Email : dr. abbas@rmit.edu.au

ABSTRACT

Although small in size, indiscriminate littering of cigarette butts (CBs) can cause serious environmental impact. Several trillion cigarettes produced worldwide annually lead to thousands of kilograms of toxic waste. CBs accumulate in the environment due to the poor biodegradability of the cellulose acetate filters and, in doing so, they have become the most common litter item on our planet. 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 (2.5%, 5% and 10%) and also of control brick samples are reported and discussed. Furthermore, leaching of heavy metals from the fabricated clay bricks was tested to investigate whether the leachate values exceed the regulatory standards. The results show that the density of fired bricks decreased by up to 30 % when CBs were incorporated into the raw materials. The compressive strength of bricks tested were 12.57, 5.22 and 3.00 MPa for 2.5, 5.0 and 10 % CB content respectively. The leachate results revealed trace amounts of heavy metals.

Keywords: Cigarette butts; Recycling waste; Fired clay bricks; Light bricks; Leachate; Thermal conductivity.

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].

Most cigarette filters are made of cellulose acetate. Cellulose acetate filters in CBs 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 leach, thus causing serious damage to the environment [8,9,10]. 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 [8,9,11,12].

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 [13]. Also, landfilling of waste with high organic content and toxic substances is in general becoming increasingly costly and difficult [14,15,16]. 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 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 [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 as inert components 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. Physical and mechanical properties of several brick samples with different CB contents are presented and discussed.

MATERIALS AND METHODS

Preparation of clay brick samples incorporated with CBs. The CBs (of different brands and sizes) used in this study were provided by Buttout Australia Pty Ltd. The butts had been collected from dry receptacles. Upon delivery, the CBs were disinfected at 105^{o}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 to determine the main chemical components of the experimental soil. Chemical composition of the raw clay samples was determined using X-ray Fluorescence (XRF).

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. Four different mixes were used for making fired brick samples (Table 1). CBs (2.5, 5, and 10% by weight, about 10 – 40% 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 (found from standard compaction tests). The samples were made in three sizes (Fig. 1), 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.

Table 1 : Optimum Moisture Content for Different Percentage of CBs

Mixture identification	Optimum moisture content (%)
CB (0.0)	17
CB (2.5)	19
CB (5.0)	21
CB (10.0)	23

Figure 1 : Compacted Bricks, Beams and Cubes (Clay-CBs mix)

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 [27] and the results reported are the mean of three values.

Leachate analyses. It is known that heavy metals such as arsenic, chromium, nickel and cadmium can be trapped in the filters of cigarette butts [28]. Hence, leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured clay-CB bricks. Two different procedures were employed: In the Australian Bottle Leaching Procedure (ABLP) [29], the brick sample was crushed and a representative sample finer than 2.4 mm produced, while in the Toxicity Characteristics Leaching Procedure (TCLP) [30], a crushed sample finer than 9.5 mm was prepared for the analysis. Also, leaching tests were carried out on whole solid brick samples (Fig. 2) to investigate the long-term leachate characteristics of samples. 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 was not renewed by a fresh solution in order to produce the maximum leachate concentrations, and leachates were collected continuously over long durations of 25, 41, 71 and 134 days. Triplicate samples from all the leachates were produced and analysed for heavy metals using Inductive Coupled Plasma Mass Spectrophotometer (ICPMS).

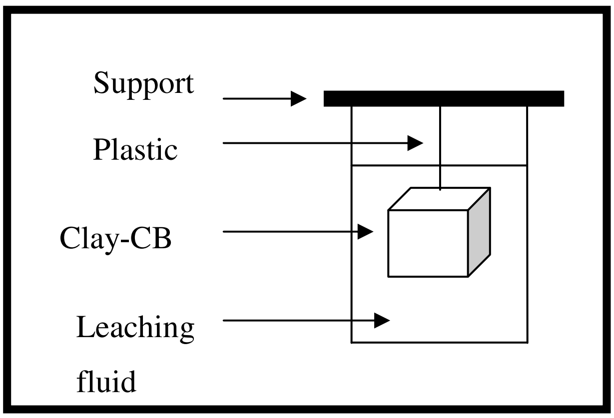

Figure 2 : Experimental Set up for Static Leachate Test

RESULTS AND DICUSSIONS

Physical and mechanical properties of experimental brick samples. Some of the physical and chemical properties of the soil used in making the experimental bricks are presented in Tables 2 and 3.

Table 2 : 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 3 : 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 (Fig. 3) 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. 4). 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. The bricks became more porous as CB content increased. 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.

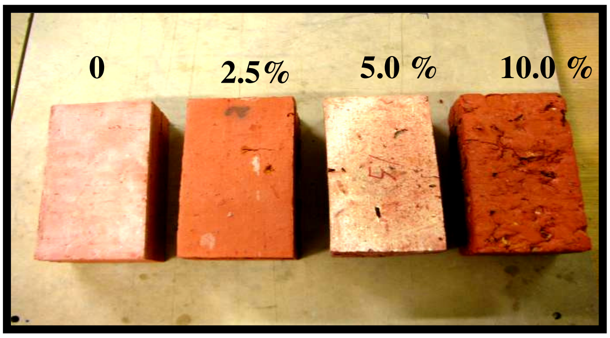

Figure 3 : Surface Texture of Bricks for Mixes with 0%, 2.5%, 5% and 10% CBs

The compressive strength of bricks tested (Fig. 5) 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. 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.

Modulus of rupture (flexural strength, Fig. 6) values decreased from 2.48 to 1.24 MPa when 2.5 - 10 % CBs was incorporated into the raw materials. The Australian Standard [34] 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 (Fig. 7 and 8). The highest value of water absorption measured (18%) occurred for 10% CBs. This falls within the range of the Australian Standard [34] 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.

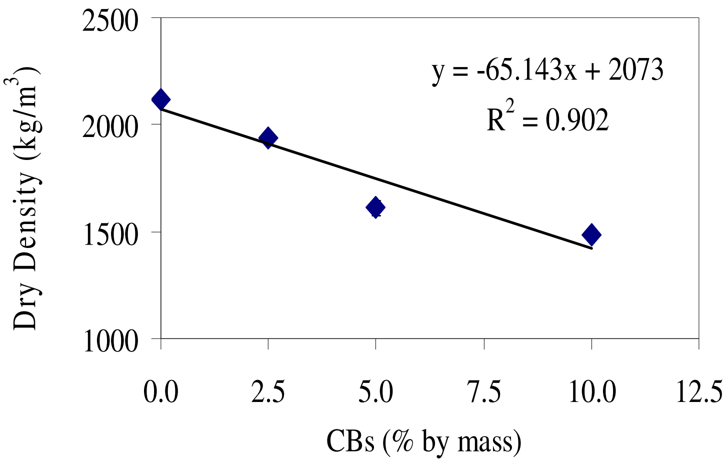

Figure 4: Effect of CBs Content on Dry Density of Bricks

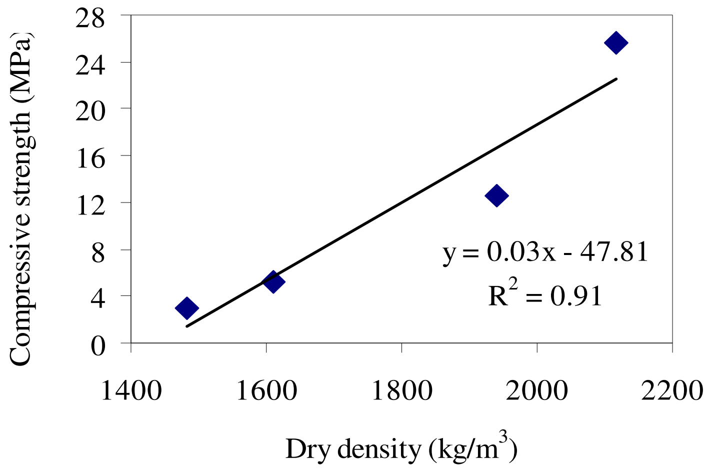

Figure 5 : Relationship between Compressive Strength and Dry Density of Bricks

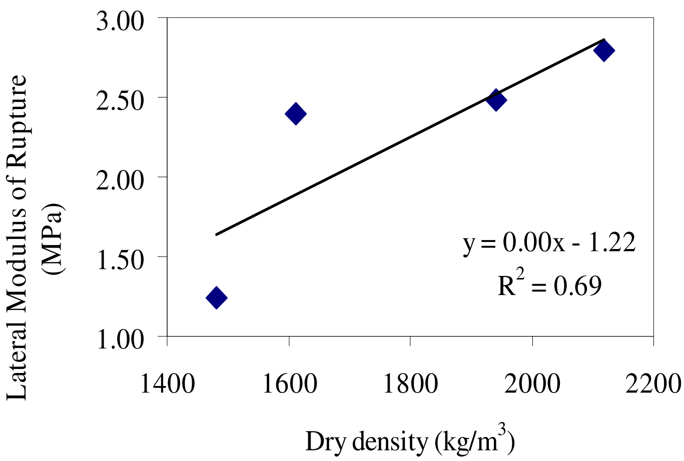

Figure 6 : Relationship between Flexural Strength and Dry Density of Bricks

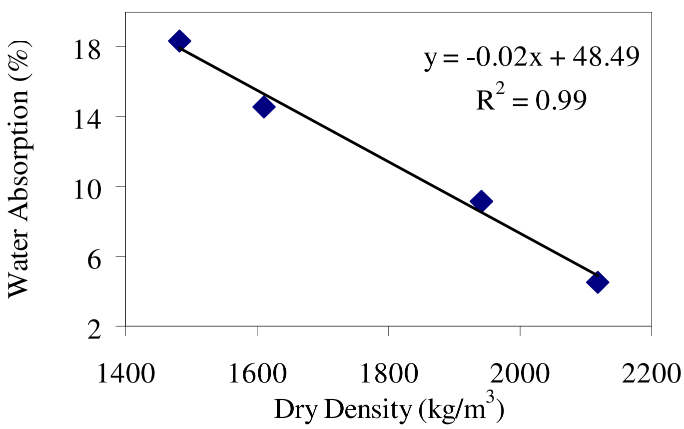

Figure 7 : Plot of Water Absorption in Relation to Dry Density of Bricks

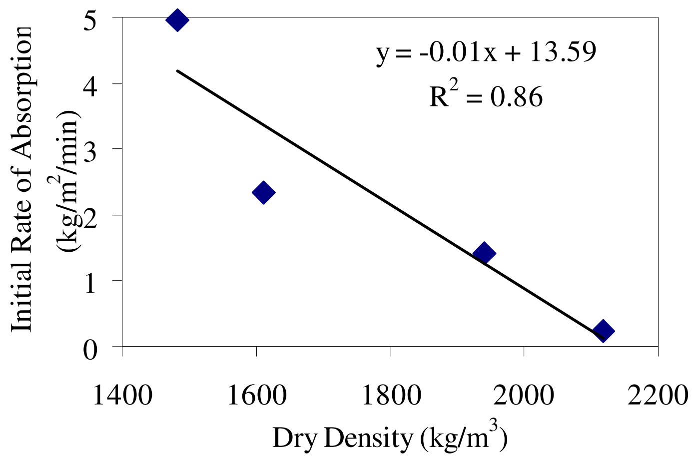

Figure 8: Plot of Initial Rate of Absorption in Relation to Dry Density of Bricks

ABLP, TCLP and SLT tests results. All heavy metal leachate values determined in ABLP, TCLP and SLT tests were insignificant and comply with the concentration limits set by USEPA (1996) and EPAV (2005) [35,36]. The ABLP and TCLP tests yielded similar leachate concentrations of target metals for clay bricks with 0 and 10% CBs (Table 4). However, due to the difference in crushed particle size, the ABLP test (using smaller particle size) produced slightly higher values than the TCLP test for most concentrations.

Table 4 : Concentrations of Heavy Metals using ABLP, TCLP and SLT tests

Heavy metals	Concentration Limit (mg/L)*	Concentration Limit (mg/L)**	ABLP		TCLP		SLT	
			0%	10%	0%	10%	0%	10%
			Concentration (mg/L)					
Arsenic (As)	5	2.8	0.007	0.123	0.025	0.035	0.011	0.190
Selenium (Se)	1	4	-	-	-	-	-	-
Mercury (Hg)	0.2	0.4	-	-	-	-	-	-
Barium (Ba)	100	280	0.590	0.510	0.270	0.275	0.245	0.380
Cadmium (Cd)	1	0.8	-	-	-	-	-	-
Chromium (Cr)	5	20	0.033	0.009	0.007	0.008	0.005	0.010
Lead (Pb)	5	4	0.130	0.340	1.941	0.032	0.008	0.003
Silver (Ag)	5	40	-	-	-	-	-	-
Zinc (Zn)	500	1200	0.965	0.285	0.255	1.145	0.330	0.425
Copper (Cu)	100	800	0.190	1.090	0.190	0.155	0.070	0.090
Nickel (Ni)	1.34	8	0.007	0.009	0.004	0.003	0.005	0.010

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

CONCLUSIONS

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/m^2/min for the experimental mixes. Heavy metal leachate testing was carried out using the Australian Bottle Leaching Procedure, Toxicity Characteristics Leaching Procedure and the Static Leachate Test, and samples analysed using Inductive Coupled Plasma Mass Spectrophotometer. All heavy metal concentrations 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.

ACKNOWLEDGEMENT

The results presented in this paper are part of an ongoing postgraduate research 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), Production, Supply and Distribution, electronic database updated 31 September 2004.

[2] Mackay, J., Eriksen, M. and Shafey, O., *The Tobacco Atlas 2nd Edition*, American Cancer Society, 2000.

[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, 2006, pp. 205-212.

[4] Butt Littering Trust, *About Butt Litter*, Article accessed 10 April 2007 from http://www.buttlitteringtrust.org.

[5] Ach, A Biodegradable plastics based on cellulose acetate, *J. Macromol Sci Pure Appl Chem* A30, 1993, pp. 733-40.

[6] Brodof, T. A., The mechanisms of cellulose acetate degradation and their relationships to environmental weathering, *Presented at the 50th Tobacco Chemists' Research Conference, Richmond, Virginia*, October, paper 19, 1996.

[7] Novotny T. E. and Zhao F., Consumption and production waste: another externality of tobacco use, *Tob. Control,* Vol. 8, No. 1, 1999, pp. 75-80.

[8] Hoffmann, D. and Hoffmann, I., The changing cigarette, *Journal Toxic Environ Health,* Vol. 15, 1997, pp. 307-364.

[9] Li, S., Banyasz, J. L., Parrish, M. E., Lyons-Hart, J. and Shafer, K. H., Formaldehyde in the gas phase of mainstream smoke, *Journal Analyt Appl Pyrol* 65, 2002, pp.137-145.

[10] Register, K., Cigarette butts as litter-toxic as well as ugly? *Bull. Am. Litt. Soc*. 254, 2000, pp. 23-29.

[11] 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, 2001, pp. 767-790.

[12] Hecht, S. S., Tobacco carcinogens, their biomarkers and tobacco-induced cancer. *Nature Reviews, Cancer*, No. 3, 2003, pp.733-744.

[13] 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, 2006, pp. 691-697.
[14] 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, 2005, pp.700–706.
[15] Hackendahl, N., Sereda, C. W. and Volmer, P. A., The dangers of nicotine ingestion in dogs. *Veterinary Science*, Vol.99, No. 3, 2004, pp. 218-224.
[16] 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.
[17] Knox, A., An overview of incineration and EFW technology as applied to the management of municipal solid waste (MSW). *ONEIA Energy Subcommitte.* 2005.
[18] Turgut, P. and Yesilata, B., Physico-mechanical and thermal performances of newly developed rubber-added bricks, *Energy and Buildings*, Vol. 40, 2008, pp. 679-688.
[19] Turgut, P. and Algin, H. M., Limestone dust and wood sawdust as brick material. *Building and Environment*, Vol. 42, 2006, pp. 3399-3403.
[20] Demir, I., An investigation on the production of construction brick with processed waste tea, *Building and Environment,* Vol. 41, 2005, pp. 1274-1278.
[21] Kayali, O., High performance bricks from fly ash. *Proceedings of the World of Coal Ash Conference, Lexinton, Kentucky,* 2005.
[22] Lin, K. L., Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. *Journal of Hazardous Materials* Vol.137, 2006, pp.1810-1816.
[23] Veiseh, S. and Yousefi, A. A., The use of polystyrene in lightweight brick production. *Iranian Polymer Journal,* Vol. 12, No. 4, 2003, pp. 324-329.
[24] 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, 2002, pp.2251-2259.
[25] Australian/New Zealand Standard AS/NZS 1141.11:1996, Method 11.
[26] Australian/New Zealand Standard AS/NZS 1289.5.1.1:2003, Methods 5.1.1.
[27] Australian/New Zealand Standard AS/NZS 4456.1:2003.
[28] International Agency for Research in Cancer. Overall evaluations of carcinogenic risk to humans: An updating of *IARC Monograph*s Vol. 1-42, 1987, pp. 440, Lyons, France.
[29] Australian/New Zealand Standard AS/NZS 4439.3:1997.
[30] USEPA, Toxicity characteristics leaching procedure (TCLP). Method 1311, Cincinnati. 1982.
[31] ANSI/ANS-16.1-2003 (American Nuclear Society), Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure, Illinois. 2003.
[32] V. Dutre and C. Vandecasteele, Solidification/Stabilisation of arsenic-containing waste: leach tests and behaviour of arsenic in the leachate. *Waste Manage.*, Vol.15, No.1, 1995, pp. 55-62.
[33] Singh, T.S., Pant and K. K. Pant, Solidification/stabilization of arsenic containing solid wastes using portland cement, fly ash and polymeric materials, *Journal of Hazardous Materials,* Vol.131, 2006, pp.29-36.
[34] Australian/New Zealand Standard AS/NZS 3700-2001.
[35] USEPA, Hazardous waste characteristics scoping study. US Environmental Protection Agency, Office of Solid Waste, 1996.
[36] EPAV, Guidelines for Hazard Classification of Solid Prescribed Industrial Waste, Publication 996, June 2005.