British Journal of Applied Science & Technology
8(2): 148-161, 2015, Article no.BJAST.2015.193
ISSN: 2231-0843

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Waste Generation and Management in Lesotho and Waste to Clay Brick Recycling: A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Author IH designed the study, wrote the first draft of the manuscript and managed literature searches, particularly the literature on waste to clay brick recycling. Authors VN and BMT managed the literature searches on waste generation and waste management in Lesotho and proof read and edited the first draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/11224
Editor(s):
(1) Mark Vimalan, Department of Physics, Syed Ammal Arts and Science College, India.
Reviewers:
(1) Anonymous, Nigeria.
(2) Anonymous, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1070&id=5&aid=8587

Review Article

Received 5th May 2014
Accepted 10th June 2014
Published 25th March 2015

ABSTRACT

Waste management remains a matter of concern even in the most industrialized countries. The symbiotic relationship between industrialization and population growth on one hand and waste generation on the other hand, is undeniable. In developing counties the scourge of waste management has reached endemic levels; and only innovative and economic ways of waste management can serve as a sustainable solution. Municipalities and local authorities in developing countries spent in the order of 30% of their budgets on waste management, yet their efforts yield no salient fruits as random dumping, burning and illegal land filling remain dominant. The accompanying health and environmental hazards can never be over-emphasized. Research works, past and present, continue to reveal the possibility of turning waste into valuable raw material inputs to suitably identified products and processes. This paper focuses on reviewing the waste management situation in Lesotho, using Maseru city as base line, and results of research works on incorporation of waste materials in clay brick manufacture. Clay brick making is a key industry in

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Lesotho accompanying environmental issues notwithstanding. Suffice to say, a deliberate attempt has been made to streamline the attention towards those waste materials known to be available or generate in Lesotho in significantly large quantities.

Keywords: Waste generation; waste management; waste recycling; clay brick.

INTRODUCTION

Globally, rapid increase in waste generation, attributable to economic growth, urbanization and industrialization processes, is becoming a burgeoning problem for national and local governments to ensure effective and sustainable management of waste. Municipalities in developing countries spend as much as 20-50% of their total budgets on waste management. Notwithstanding that, 30-60% of their waste remains uncollected, while less than 50% of the population is serviced [1]. Consequently, there is widespread concern over deterioration environmental conditions and their long-term implications on local communities. Waste disposal is a major problem in Lesotho leading to indiscriminate dumping on roadsides, market and other public places. A concomitant increase in waste generation in the country's capital city, Maseru, has been widely reported [1-3]. The same trend is visibly obvious in all other urban and non-urban centres across the country since the overriding factors are replicated throughout the country, albeit at varying scales. In a 2002 study, Mvuma [4] estimated the total quantity of waste generated by Maseru city alone at 157552 tonnes per annum. About four years later, a waste survey for the city, by Lesotho National Development Corporation (LNDC), estimated the waste generation level at 244 832 ton/year [3,5]. In a recentreport [1], the UNEP depicted the waste management situation in Lesotho as characterized by absence of waste management system, insufficient informal collection system and widespread use of random and illegal dumpsites in both rural and urban areas. With specific, reference to Maseru, another report also noted that the prevailing waste management practices were unsustainable as they damage the city's natural resources (including its drinking water supply), threaten the health of residents, and also being wasteful with regard to potentially reusable and recyclable resources [3,6]. In 1999, Schoeman [7] observed that the wastewater and associated solid waste emanating from Maseru's textile industries posed a serious water resource management threat; that could potentially threaten the industry itself in the long run. Suffice to say, while water is a critical life-giving resource in general, for Lesotho water is a key income generator for the nation. Lesotho exports water to neighbouring Republic of South African with annually earnings of estimated at 3-5% of the country's GDP; concomitantly providing 9000 jobs to local communities [8]. The fact that, current waste management practices are unsustainable given the negative impacts on natural resources, possible negative health effects on local communities and wastage of potentially reusable and recyclable resources cannot be overemphasized. Notably, the key constraint towards sound waste management is the lack of sufficient financial resources, a common factor in developing countries [5]. Ultimate solution to this scenario rests in innovative ways and means of converting waste into economic and sustainable applications. The use of waste as partial and/or total substitute to conventional clay brick-making raw materials presents one of such sustainable solutions. Needless to say, such a solution would simultaneously address at least two key issues - namely waste management and resource conservation. Clay brick industry is one of Lesotho's major industries, also exporting some of its products neighboring Republic of South Africa and other regional countries like Botswana.

The brick remains among the widely used and oldest man-made building materials. Some archaeological evidence confirms the use of clay bricks as far back as 14,000 BC in ancient Egypt and other regions [9-11]. The brick has endured the test of time among all cultures largely due to its outstanding physical and engineering properties, and other factors, such as ease of manufacture, low cost and availability of wide range of products with unlimited variety of patterns [12,13]. Clay bricks are good with respect to a wide range of aspects, *inter-alia* aesthetic appearance, durability, water absorption, compressive strength, fire resistance, sound and thermal insulation, moisture movement and low maintenance requirements [10,13,14]. Additionally, bricks do not cause indoor air quality problems; their thermal mass effect is also useful in terms of fuel-saving, effective natural heating and cooling such as solar heating and night-time cooling. Moderate insulating properties, make brick houses cooler in summer and warmer in winter compared to houses built with other construction materials [11,15].

Worldwide, the demand for building materials continues to increase due to population growth, industrialization and accompanying infrastructural demand. At the same time, quantities of waste from domestic and industrial activities continue to increase [11]. On the other hand, environmental regulations are becoming more and more stringent. Hence determination of alternative methods to sustainably manage and utilize wastes becomes imperative and fashionable [16]. It is no surprise that among the numerous research endeavours, investigation of the possibility of incorporating various wastes into fired clay bricks continues to be an area of intense interest. The potential of incorporating different types of wastes including rubber, limestone dust, wood sawdust, processed waste tea, fly ash, polystyrene and sludge have been subjects of investigation for quite sometime [11,16,17]. In many cases positive effects on some key brick properties have been reported. Among, the positive effects which have been reported are weight reduction, improved shrinkage, porosity, thermal properties and strength [17]. Light weight bricks offer obvious advantages such ase ase of handling and lower transportation costs; and mass reduction of the building improving its resistance to earthquake forces [18], an important aspect in earthquake prone regions. The use of high-calorific-value types of waste has also been reported to lower energy consumption during firing [11,19-21]. The development of lightweight bricks also allows brick manufacturers to reduce the total clay content. Brick is durable and has developed with time; and remains highly competitive, technically and economically, relative to other systems of structure and field. The main raw material for bricks isclay besides clayey soils, soft slate and shale, which are usually obtained from open pits with the attendance of disruption of drainage, vegetation and wildlife habitat [11,14]. Clays used for brick making vary broadly in their composition and are dependent on the locality from which the soil originates. Different proportions of clays are composed mainly of silica, alumina, lime, iron, manganese, sulphur and phosphates [11]. In Lesotho's case, brick-making clay extraction is so far concentrated in the lowlands competing for space with other economic activities, particularly agriculture, so lowering of clay content in bricks may be a very important factor. Being mountainous, suitable agricultural space is a key issue in Lesotho and is largely confined in the lowlands. Thus any innovative means leading to minimization of the use of fresh clay soils is a step in the right direction. Furthermore, the utilization of wastes would reduce the negative effects associated with their disposal. Recycling wastes by incorporating them into building materials presents a practical and innovative solution to a myriad of challenges associated with their disposal and management.

2. OVERVIEW OF WASTE GENERATION IN LESOTHO

2.1 Textile Industry Waste

The textile industry remains the largest formal industry in the country employing over 50 000 workers and therefore immensely contributing to the country's economy. The industry produces both liquid (that is wastewater from dyeing and washing processes), and solid wastes. The solids are mainly sludge, blasting-sand pumice stones. Most of large-scale textile industries are situated in Maseru, they are said to be more than six of them, with a typical textile manufacturing plant generating approximately 960 m3of wastewater per day [7,22,23]. The single denim mill in the country produces about 1.4 tonnes of solid waste per day [22]. A waste survey by LNDC (2005)24, pegged the amount of solid waste generated by textile industry in Maseru alone at about 11673 tonnes per annum – with composition breakdown of 2 073 tonnes (17.8%) sludge, 3000 tonnes (25.7%) blasting sand, and 6600 tonnes (56.5%) pumice stones.The study also observed that the primary residual wastes produced by the textile industry, which include fabric and yarn scrap, off-spec yarn and fabric and packaging waste, are generally non-hazardous. It was further observed that while waste such as fabric off-cuts were being put to good uses, including acting as fire-boiler sources of energy for steam generation, most of the waste was disposed in dumpsites. A subsequent, 2006, study by the same institution estimated the annual waste generation by the industry at about 13200 ton/year [3,5,25]. This indicates an increase in annual waste generated by the industry of about 13%, which is in tandem with the observable growth of the industry in the city and the country in general.

2.2 Brewery and Soft-drink Industry Waste

Maluti Mountain Brewery (Pty) Ltd, whose biggest plant is located in Maseru, is a major play in this industry. According to company report [26], it controls 99% of the beer market and 97% of the soft-drink market, and the sole producer of all locally produced beers alongside a large assortment of soft-drinks, and also provides employment to a large number of people. Concomitantly, it is a major contributor to waste generation and a dominant contributor in this industrial sector of the country. According to the LNDC survey of 2006 [3,5,6,25], the industry generates seven different types of solid waste; with a total quantities estimated at 1677.8 ton/yr at the time for Maseru alone; and 99.7% (an equivalence of1 672.8 tonnes) of which are non-metallics. Table 1 shows the different types of non-metallic waste for the industry and their relative proportions by the year 2006 [3,5,5,6,25]. Notwithstanding this review's failure to unearth more recent waste quantification data, if any exists, it is manifestly evident that waste generation has maintained an upward trend. Hence current annual waste generation levels across the country can only be significantly higher, if not much higher, than the 2006 levels. Moreover, the overall national waste generation is obviously higher than these figures, which pertains to Maseru city alone.

2.3 Waste Generated by Commercial Industry

Lesotho, due to a combination of her limited endowment in natural resources and being surrounded by a relatively much more resource-rich and industrialized neighbor, the Republic of South Africa, is arguably more of a commercial-based economy than manufacturing-based economy. As such, the contribution of the commercial sector to the country's economy and waste generation dynamics cannot be over-looked. The LNDC 2006 estimated the waste generated by the sector at around 190000 tonnes annually, again in Maseru alone. Of the grand total amount, non-metallic waste constituted 92%, i.e. paper- 47%, plastic- 29%, garden and kitchen refuse - 9%, glass -5%, and others - 2%, the rest being metallic [3.5,6,25].

2.4 Waste from Residential Households and Other Institutions

The LNDC 2006 waste survey also estimated annual waste generation by households and educational and administrative institutions, again in the city of Maseru. The quantity of waste generated by education institutions was estimated at 900 ton/year, with non-metalllics constituting over 97%- i.e. paper - 43%, plastic - 21%, kitchen leftovers -19%, garden refuse - 9%, glass (2%); and other waste - 4%. Waste generations by administrative establishments and residential household were estimated at 5 323 ton/year32 900 ton/year respectively [3.5,6,25].

Overall the annual waste generated by various sectors in Maseru were estimated at 244 702 ton/year as of year 2006. Suffice to say, this figure excludes the waste from healthcare institutions (estimated at 130 ton/year) which are considered to be outside the scope of this discussion given the sensitivity required in their handling and the applicability interests of this review. Sewage sludge was also roughly estimated at 5000 ton/year though systematic studies did not include it [3.5,6,25].

Table 1. Non-metallic waste from brewery and soft-drink industry [3, 5,6, 25]

Type of waste	Weight [ton/annum]	Wt. % fraction
1. Boiler ash	936.0	55.9
2. Spent grain	504.0	30.1
3. Cullet (glass)	170.4	10.2
4. Labels & paper	39.6	2.4
5. Plastic	10.0	0.6
6. Malt dust	10.0	0.6
7. Kieselguhr	3.0.	0.2
Total	1672.8	100

3. REVIEW OF RECYCLING OF WASTES BY INCORPORATION IN CLAY BRICK

Many researchers have investigated potential incorporating different types of wastes (or residues) into fired clay bricks [10,11,19,20,21]. In many of the studies, the potential of many different types of waste has been successfully established. Among the commonly studied waste materials are various types of fly ash [16,27-31], various types of sludge [9,11,32,33-38] and other waste materials such as rubber [39], sawdust [40], polystyrene [18], brewery waste [41], glass [42], and cigarette butts [19,43,44]. Lesotho, possesses most of these wastes in reasonably large amounts, though some of them have not been systematically quantified by any published studies. It is envisaged that the exploitation of any of these waste would yield positive results both economically and environmentally. Under all circumstances, any innovative and sustainable utilization of wastes alleviates the negative effects of their disposal, while concomitantly conserves fresh raw materials and reduces environmental and ecological effects accompanying extraction of the fresh raw materials, such as clay, from their natural deposits.

Suffice to say, this review focuses on those wastes known to be present and/or generated in Lesotho in relatively large quantities. As such, the focal wastes include sludge from sewage treatment plant, used wastewater, textile industry, and tannery industry; fly ash from waste incineration processes; polystyrene; glass and cigarette butts. Furthermore, for simplification purposes, the review divides the wastes into three main categories, namely sludge, fly ash and other wastes. The resultant effects of incorporating the various wastes in clay bricks on physico-mechanical properties of incorporating of the bricks are also highlighted, being the key determinants for applicability of the waste.

3.1 Sludge

This category includes sludge from water treatment plant (WTP), sewage treatment plant (STP), used municipal wastewater (USMW), industry wastewater treatment plant (IWTP) and industry.

3.1.1 Water treatment plant sludge (WTPS)

Fresh water treatment plants generally generate significantly large amounts of waste in the form of sludge, mainly from the decantation and filtering operations, which are commonly discharged in hydric resources. This method of disposal, though economically attractive, is not a sustainable solution due to the possibility of undesirable formation of mud deposits and chemical contamination of those hydric resources [45,46]. An environmentally correct solution, which is currently being investigated is the incorporation of the sludge wastes in clayey bodies [46,47-52]. Coagulant sludge is generated by water treatment plants, that use metal salts such as aluminum sulfate (alum) or ferric chloride as coagulants to remove turbidity [9]. Lesotho's Water and Sewage Company (WASCO), responsible for urban water treatment and supply for the country's urban centres, produces coagulant sludge in significant quantities. The use of water treatment sludge in brick making is among the industrial applications that continue to be studied. In its favour, a number of researchers have reported close similarity in mineralogical composition between water treatment plant (WTP) and brick clay, and recommended it's use as partial or total substitute for clay in brick making. Tables 2 and 3 show some typical chemical compositions of WTP sludge and clay [9,53]. A study carried out by Feenstra and others in 1997 [38], successfully demonstrated the possibility of adding upto 5% WTP sludge to brick clay without unacceptably compromising of key properties of the brick. The studies culminated in industrial-scale application of the waste in Netherland. Another by Anderson and others in UK, in 2003, reported that incorporating of WTP sludge together with incinerated sewage sludge ash as partial replacements for traditional brick-making raw materials at a 5% proportion [35] also yielded positive results. In yet another study carried out in Taiwan, WTP sludge was blended with excavation waste soil to make bricks; and the results indicated that with addition of up to 15%sludge good quality bricks could be achieved [54. In Egypt, similar studies in which sludge completely and partial substituted for clay were also conducted -applying a firing temperature range of 950 to 1100°C. The physical properties of the bricks, determined and evaluated according to E.S.S, revealed the possibility of adding up 50% WTP to produce good bricks [9,32,33,53,55].

Table 2. Chemical composition of WTP sludge [9,53]

Item	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl^-	L.I.O
Comp.[%]	43.12	5.26	15.97	5.56	0.95	0.05	0.52	0.26	0.012	26.79

Table 3. Chemical composition of clay [9,53]

Item	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	L.I.O
Comp.[%]	65.32	7.51	13.89	1.09	0.95	0.05	2.61	0.75	1.46	0.28	5.87

3.1.2 Used municipal wastewater sludge (UMWS)

Tay [56-58], investigated the potential of dried sludge from used municipal wastewater in fired clay bricks substituting the clay by proportions ranging 10 to 40% with 1080ºC as firing temperature. In very similar studies Tay [56] also utilized pulverized sludge ash derived from incinerated municipal sludge burnt at 600ºC, as an additive to clay in proportions ranging 10% to over 50 wt.%. The strengths obtained at 10% sludge ash were reportedly in the range of normalclay bricks; and better than that of the combination of clay and dried municipal sludge. Overall, Tay concluded that clay could be substituted by as much as 40% and 50% of dried municipal sludge and municipal sludge ash respectively and still meet minimum strength requirements for ordinary brick. In both cases, the studies showed an increase in water absorption of fired bricks with increasing levels of the additives. The shrinkage also increased with increasing amount of sludge. The products also exhibited uneven surface textures to the finished due to organic substances in the sludge. Leaching tests conducted on the clay-sludge products did not show any contamination problems.

3.1.3 Sewage treatment plant sludge

Large quantities of sewage sludge are generated in all urban settlements, particularly by WASCO which is also responsible for sewage treatment for all urban areas of Lesotho. Several studies have also been carried out on the use of sludge from sewage treatment plants in brick production [20,21,59-63]. Positive results have been reported at levels ranging from 2 to 30% sludge additions [60,61], including energy savings due to high organic content [63] of the sludge. Negative effects have also been reported at sludge proportions higher than 30% [59,62,63]. In their 2004 study, Liew et al. [59] concluded that the addition of not more than 30 wt.% sludge would result in bricks of acceptable properties and concomitantly recommended addition of up to 20 wt.% sludge to maintain functional characteristics of the brick. Notably, compressive strength decreased with increasing proportion of sludge, with a clay-sludge brick at 40% sludge showing strength of 2 N/mm2 against 15.8 N/mm2 for the control brick. The results also showed increase in water absorption and firing shrinkage and decrease in dry density. A number of researchers have also argued that sludge addition comes with significant energy savings along with environmentally friendly disposal the sludge waste [59,64,65]. Some researchers also note the increased plasticity due to fibrous nature of the waste as a key aspect in making brick-moulding easier [61,63].

3.1.4 Industry wastewater treatment plant sludge

The incorporation of sludge from industry wastewater treatment plant (IWTPS) in clay brick has also been investigated [34,66,67]. In China, 2003, Weng and colleagues [34] investigated the use of dried IWTPS as clay substitute in brick making. They found sludge proportion and firing temperature to be the key factors determining brick quality. Any inverse relationship was observed between sludge content and brick shrinkage, water absorption and compressive strength; while the converse was observed for temperature.

Bricks containing up to 20% sludge and fired at temperatures between 960 and 1000ºC met requirements of the Chinese National Standards with regard to strength. Overall the study recommended optimum conditions for manufacturing good quality clay-sludge brick to be10% sludge, 24% moisture content and firing temperature of 880 to 960ºC.

3.1.5 Industrial sludge

Various types of industrial sludges have also been investigated over the past three decades [36,37,66-68]. In 2001, Tay et al. [68]

investigated the effects of substituting 30 to 100% clay by sludge and fired their bricks at 1050ºC. Generally, acceptable results were reported, but bricks containing ≥ 90% were found to be prone to cracking during firing process. Tay et al. [69] also reported the successful manufacture of 'biobricks' from mixtures of clay and shale with sludge with a solid content ranging between 15 to 25%. In 1990 and 1982, Zani et al. [66] and Kutassy [67] respectively, investigated the use of sludge from paper-industry waste processing plants. Characteristically, the sludge was found to contain 20% organic matter, a correspondingly high calorific value (≈8,400kJ/kg), and capable of reducing the mass of the brick by more than 50%. They recommended an optimum sludge addition range of 3 to 8%. Increase in dry shrink age and moulding water content with increase sludge content were observed, and no significant problems during the moulding and drying process. Relatively low additions of the waste did not affect brick properties significantly. Fuel savings of up to about 18% [66,67] were reported. Among other conclusions, it was noted that the waste offered economic benefits while maintaining desirable properties of the bricks. On the basis of these studies, it is reported that sludge waste from the paper industry was successfully recycled by a number of Italian brick manufacturers [66]. In 2002, Basegio and colleagues [37] investigated the utilization of tannery sludge in clay products. They substituted tannery sludge for clay by proportions ranging between 9 and30%; fired the bricks at 1000, 1100 and 1180°C temperatures, and analyzed a number of physical properties. They reported increased strength with increasing firing temperature and lower sludge addition, with a maximum bending strength of 25 MPa at 0% sludge and 1000ºC, as well as at 10% sludge at 1180ºC. Water absorption increased with the increasing sludge content and decreased with firing temperature. Porosity also decreased with increased firing temperature. A combination of relatively high firing temperature and lower sludge content gave highest dry density. Samples containing 30% sludge showed the lowest dry density and highest linear shrinkage. Notably, the maximum firing shrinkage occurred between 1100ºC and 1180ºC. Porosity, which also influences mechanical properties, considerably decreased with increasing firing temperature. Overall, the bricks complied with the minimum requirements for the building industry and a maximum of10% tannery sludge was recommended with due consideration to environmental characteristics of the product. The use of other organic-laden industrial sludges such as those from textile and wool industry were examined and summarised by Dondi et al. [20] Considerable fuel savings (up to20% savings) during brick firing process were reported with the calorific values varying according to source and amount of the waste added.

3.2 Fly Ash

Use of various types of fly ash (FA) in clay bricks has also been extensively investigated. While earlier researchers have shown a more conservative approach to the proportions of FA additions, largely confining it to between 10 and 50wt.% [21] more recent ones have shown a propensity to push the boundaries, focusing more and more on the40 to 100%FA range [27-30]. Some of the studies noted accompanying energy savings as one of the key advantages of using FA; given the relatively high calorific values associated with typical FA, ranging about 1470 to11760 kJ/kg. Other reported positive attributes include reductions in density (up to 28% reduction) [29,30], improvements in plasticity, decreased drying and firing shrinkage and low crack formation[27,28,30,31,70,71]. These performance being dependent on the quantity and the nature of FA among other factors [27-31,72,73]. Particle size distribution of FA, one such factor and fine FA has proved better than coarse FA with regard to dry density, firing shrinkage and mechanical properties [27,30,31]. Addition of FA also reduced efflorescence [28,74]. In 1997, Dondi et al. [21] concluded addition of 10 wt.% FA as favourable in terms of energy saving. In 2006, Lin [27] recommended addition of up to 40% FA slag and a firing temperature of 800ºC for production good quality brick and concomitant savings in energy. From economic point of view, researchers noted that the results varied from very promising [27,29,30,71] to recommendable [31,70,74].

3.3 Other Wastes

3.3.1 Organic waste

Various industrial and agricultural organic residues have also been investigated including sawdusts, tobacco and brewery residue [40,41,75]. Brewery residues are largely from different branches of Maluti Brewary dotted across the country, with the largest plant in Maseru whose waste generation is in the order of 1 672.8 tonnes/year3. Agricultural and forestry residues are widely abundant in Lesotho although no quantitative study could be identified, if any. Sawdusts are also generated in significant amounts. In 2008, Demir [40] incorporated sawdust, tobacco residues and grass from industrial and agricultural waste in clay bricks in proportions varying from 0 to10% and fired the bricks at 900ºC. The addition of residues resulted in increased dry strength of unfired brick but the strength of fired brick decreased. Nevertheless, the compressive strength values complied with national Turkish Standards [40]. The studies also established that the organic materials acted as pore-forming agents in clay brick to increase porosity, and thus improve insulation properties of the brick. Addition of the organic residues resulted in increased shrinkage due to high presence of cellulose fibres. Ducman and Kopar [75] investigated influence of addition of sawdust to conventional clay brick mixes. Different proportions of sawdust up to 30 wt.% were added and the bricks were fired at a range of 850 to 920ºC. The addition of sawdust reduced the shrinkage after drying, a favourable effect for reducing crack formation during drying processes. The fired density was also reduced as sawdust acted as pore-forming agents thereby increasing the porosity. The compressive strength, at 30% sawdust was 10.7MP a compared to 23.9 MPa at 0% sawdust. Krebs and Mortel, in 1999 [41] investigated the use brewery waste (spent grains in particular) and produced light weight bricks of improved porosity and thermal conductivities without a significantly compromising mechanical strength. They also reported the subsequent industrial scale use of the waste. Banhidi and Gomze [76], investigated possibility of improving insulation properties of the conventional clay bricks by addition of sawdust and agricultural waste materials, rice peel and sunflower seed shell to the basic clay of the conventional brick mixture; and fired the bricks at 900ºC. They reported progressive reduction in thermal conductivities with increasing organic additions, thus improved the insulation properties. Further, energy savings were also realized during firing as the organics provided extra thermal energy. Pores were created during the firing process thus decreasing the thermal conductivity. The thermal conductivity values decreased by 10 to 31% compared to the control brick with 4% by weight of additives. The compressive strength decreased increase of additives respectively.

3.3.2 Polystyrene waste

Due to its wide applications, which include disposable trays, plates, bowls and cups as well as cushioning of packaged fragile items, polystyrene constitutes a significant fraction of all the plastic waste generated in Lesotho. In 2003, Veiseh and Yousefi [18] investigated addition of polystyrene foam (PSF) to clay bricks aiming at reduction of dry density of the brick and improvement of thermal insulation properties. They used mixes containing 0.5 to 2%PSF and firing temperatures of 900 to1050ºC. Their results demonstrated that increasing the content of PSF in the clay brick reduces dry density and strength while it increases the water absorption properties of the brick. They concluded that mixtures containing≤ 2%PSFcould yield bricks usable for load-bearing purposes in accordance with the Iranian National Standard, which reportedly specify minimum strengths of 60 kg/cm2 for ordinary load-bearing and 40 kg/cm2 for non-load-bearing bricks. In particular, addition of 2.5%PSF gave compressive strength of 45 kg/cm2, which the limits for non-load bearing brick. The compressive strength increased with firing temperature and while water absorption decreased. Improvement in thermal performance was reported for bricks containing at least 1.5% PSF relative to ordinary bricks. The observed effects of temperature are shown in Table 4 for clay-PSF mixture containing 1.5% PSF [18].

Sohrab and Ali [77], also investigated production of light weight bricks of improved thermal insulation properties by addition of PSF to conventional raw materials of bricks, as a pore-

Table 4. Test results for light weight brick samples containing 1.5 wt.% recycled polystyrene foam fired at various temperatures [18]

Firing temp. [ºC]	Density [g/cm^3]	Water absorption[wt.%]	Compressive strength [kg/cm^2]
900	1.06	30.3	57
950	0.92	27.5	67
1000	0.98	25.5	97
1050	1.05	22.5	125

forming material. They studied the effects of PSF type and content and effect of firing temperature on density, water absorption and compressive strength. Krebs and Mortel [41] investigated addition of PVB-polymer from windshield glass, as a pore-forming agent in clay fired bricks and observed some positive results. These included savings in energy due to high calorific values of the additive. Further, crushed PVB-polymer additives conferred more positive results to the brick; while PVB-pellets improved drying shrinkage of the green brick tremendously and increased porosity of the bricks.

3.3.3 Glassy waste

The glassy wastes include all kinds of glass-containing scrap products or broken pieces such as bottles, lamps, bulbs, small flasks, window plates, mirrors, glass fibres and mats. Although a common soda-lime glass waste is non-hazardous and easily recyclable due to its low melting and processing temperatures, huge amounts are still discarded in dumps and landfills [46]. The incorporation of glassy residues to the clay brick, offers aviable alternative considering typical compatibility between clay and common soda lime glass structures. Since more than a century ago, research works have been dedicated to incorporation of glass to clayey ceramics [78-87]. In 1957, Everhart [78] reported addition of >2.5% of glass and accompanying improved strength and water absorption of clayey ceramics. Over a decade later (in 1972), Shutt and colleagues [79] developed bricks with varying glass content. In 1998, Youssef et al. [80] reported the addition of as much 33% soda-lime glass as a promising procedure for producing clayey floor tiles. Matteucci and colleagues, 1998 [81] also observed that the glass addition did not significantly alter processing and properties of clayey tiles. More recently, Morelli and Baldo [82] observed that the addition of a glassy waste decreases firing temperature required for clay body consolidation; while improving both strength and water absorption. In 2004, Bragança and Bergmann [83] replaced the traditional feldspar fluxing agent by conventional bottle glass in manufacturing of porcelain ceramic. They reported reduction in firing temperature and linear shrinkage of the bodies. Slightly less than a decade ago, Godinho and colleagues [84] also studied the incorporation of glassy waste into clay ceramics, and reported decrease in plasticity of the clay body and improved sintering conditions. They also reported reduced firing shrinkage and increased rupture stress and decrease in water absorption with increasing amount of glass added. In 2005, works by Pontikes and others [85,86] also reported improved water absorption and strength by addition of 30% glass in clayey roofing tile body mixtures.

3.3.4 Cigarette butts

Qualitative surveys by the authors indicate that cigarette-smoking is common in Lesotho, especially among men. Concomitantly, the cigarette butts generated constitute a sizeable fraction of national waste whose innovative exploitation may be worthwhile. The possibility of incorporating cigarette butts (CBs) in fired clay bricks has been investigated with very promising results [87-89]. In 2010, Kadir and colleagues [88] used four different clay-CBs mixes with CBs proportions ranging 0 to10%; and tested their fired brick samples for physico-mechanical properties according Australian/New Zealand Standard (AS/NZS) [90], and obtained results shown in Table 5. Given that commonly recommended minimum values for compressive strength for non-load-bearing and load-bearing fired clay bricks are 3 to 5 MPa and 5to 10 MPa, respectively [19,91], CBs additions of ≤ 5% met the strength requirements for both load-bearing and non-load-bearing brick. At beyond 5% and up to 10 % CBs the bricks only met the non-load-bearing requirements. On the other hand, modulus of rupture (flexural strength) values increased by 25% and 22% with addition 2.5% and 5% CBs, respectively, and decreased by 37% at 10% CBs level. In all cases the flexural strength values fell within the AS/NZS specifications [92], which recommend minimum values of 1 to 2MPa. High tensile strength indicates good quality bricks and reduces crack formation. Water absorption increased almost linearly with increase in CB content with a highest value of 18% at 10% CBs; which is reported within recommended range of the Australian Standard of 5 to 20%. The initial rate of absorption (IRA) ranging between 1.3 and 4.9 kg/m2/min for 2.5 to10% CB content are also within the recommended range of the Australian Standard, which specifies 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 lead to volume changes that result in cracking of the bricks or structural damage to building. The thermal conductivity performance of bricks was improved by 51% and 58% for 5%

Table 5. Experimental results for the control mix and trial mixes containing CBs [88]

CB content [wt%] of mix	Compressive strength [MPa]	Flexural strength [MPa]	% water absorption	Density [kg/m^3]	Initial water absorption rate [kg/m^2/min]
0.0	25.65	1.97	5	2118	0.2
2.5	12.57	2.48	9	1941	1.4
5.0	5.22	2.40	15	1611	2.3
10.0	3.00	1.24	18	1482	4.9

and 10% CBs content respectively. The leaching characteristics of the products were evaluated using the USEPA Toxic Characteristic Leaching Procedure [93] and revealed metal leaching levels to be generally low. Overall, the study demonstrated that CBs can used as additive raw materials in manufacturing of light-weight fired clay bricks with improved thermal performance and better energy efficiency. The incorporation of CBs into bricks can be a sustainable solution to one of the serious environmental pollution problems posed by disposal of these materials.

4. CONCLUSION

Based on the extensive literature review, there appears to be sufficient body of compelling evidence that the economic use of some of the currently troublesome waste in manufacture of bricks is a potentially sustainable solution to waste management for Lesotho. At the same time such a break from conventional methods of manufacturing would have many other benefits for the country, including reduced fresh material extraction and accompanying environmental degradation, maximum utility of raw materials, and realization of some improved brick performance attributes. The financial savings to government and local authorities would also be substantial, apart from potential boost to individual organization profits and in turn to the overall economy of the country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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